AUGUST 29 - SEPTEMBER 3

Fel 2004 Trieste, Italy

26TH INTERNATIONAL FREE ELECTRON LASER CONFERENCE & 11TH FEL USERS WORKSHOP

STAZIONE MARITTIMA, TRIESTE, ITALY

CONFERENCE PROGRAMME AND ABSTRACTS

FEL2004

26th International Free-Electron Laser Conference and
11th FEL User-Workshop

CONFERENCE PROGRAMME AND ABSTRACTS

The Quay ("Il Molo")

For me there is no place on earth
more dear or devoted than this. Where else do I
feel no more alone
or in better company than at the San Carlo quay,*
and do the waves and shore please me more ?

-

Nor let it displease you, my friend, that I own
such love for the place where I was born.
You well know that there is no more varied,
busier port than this, save our heart.

Umberto Saba (1883-1957), born in Trieste

Il Molo

Per me al mondo
non v'ha un più caro e fido luogo di questo.
Dove mai più solo mi sento
e in buona compagnia che al molo San Carlo,*
e più mi piace l'onda e il lido ?

-

Né a te dispiaccia, amica mia,
se amore reco pur tanto al luogo ove son nato.
Sai che un più vario,
un più movimentato porto di questo è solo il nostro cuore.

* since 1918 known as the Molo Audace, a few minutes' walk from the Stazione Marittima and opposite to Piazza Unità

ORGANIZED BY

Sincrotrone Trieste (ELETTRA)
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ORGANIZING SECRETARIAT

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FEL2004

26th International Free-Electron Laser Conference and 11th FEL User-Workshop

August 29 to September 3, 2004
Stazione Marittima, Trieste, Italy

INSTITUTIONAL SPONSORS

Area Science Park
Consiglio Nazionale delle Ricerche (CNR)
Council for the Central Laboratory of the Research Councils (CCLRC)
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Ente per le Nuove tecnologie, l'Energia e l'Ambiente (ENEA)
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Instrumentation Technologies
Lecroy
MBE – Mediterranean Broadcasting Equipment
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RMP – Meccanica Progettazione Prototipi
Thales Electron Devices

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M. Trovò

[1] Organizing Secretariat "the office"

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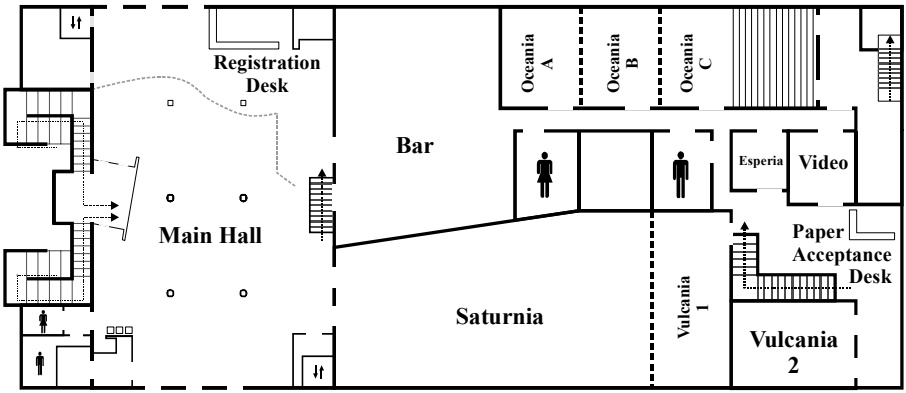
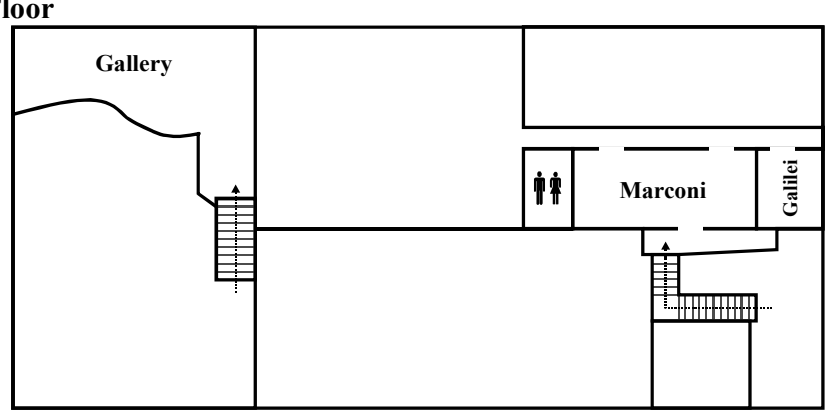
STAZIONE MARITTIMA FLOOR PLAN

1st Floor



2nd Floor



First Floor

Main Hall:	Registration, Scientific Secretariat, Industrial Exhibition, and Poster Session
Saturnia:	Main Lecture Hall
Oceanea C:	Secondary Lecture Hall
Vulcania 2:	Proceedings Office, Paper Acceptance Desk, and Video Presentation Office
🚻	Restrooms

Second Floor

Gallery:	Terminal Area and Internet Point

REGISTRATION

The Registration Desk is open on Sunday August 29 from 17:00 to 20:00, on Monday to Thursday from 8:00 to 18:00, and on Friday from 8:00 to 12:30. Participants, who have only registered for the Users Workshop and intend to join the excursion or conference dinner, must present themselves for registration prior to the events.

Payment upon registration at the conference must be made with Credit Card (VISA, Mastercard, or Eurocard) or in cash in Euros (€). ***No cheques will be accepted for registration.***

Important Notice: all FEL conference and Users Workshop attendees and accompanying persons must wear their identification badges at all times when inside the conference centre.

PAPER ACCEPTANCE

The Paper Acceptance Desk will be open on Sunday August 29 from 17:00 to 19:00, on Monday to Thursday from 8:00 to 18:00 and on Friday from 8:00 to 12:30. Authors are requested to hand in a paper copy of their paper on Sunday, August 29 or Monday, August 30.

LOCATION OF THE EVENTS

The conference takes place in the "Stazione Marittima":

Molo Bersaglieri 3, Trieste
Tel. +39-040-304988
Fax. +39-040-310856.

The centre is located directly on the waterfront in the centre of Trieste and a 15 minutes or 1.1 km (0.7 miles) walk South West of the railway station.

The floor plan of the conference centre is shown on the left. The main entrance hall on the first floor hosts the welcome cocktail, the poster sessions, the industrial exhibition, and serves for the coffee breaks. Oral sessions take place in the main lecture hall "Saturnia" or in the lecture hall "Oceania C". Computers for e-mail and paper modifications are located on the second floor on the Gallery.

Message board, tourist information, etc.

The Registration Desk also serves as message board for participants of the conference and for tourist and travel information. The Registration Desk is open on Sunday August 29 from 17:00 until 20:00, on Monday to Thursday from 8:00 to 18:00, and Friday from 8:00 to 12:30.

Paper Acceptance Desk

The Paper Acceptance Desk is located at the rear-end of the conference centre. It serves to accept the papers and for aid to speakers with electronic presentations. The Paper Acceptance Desk will be open on Sunday August 29 from 17:00 to 19:00, on Monday to Thursday from 8:00 to 18:00 and on Friday from 8:00 to 12:30.

Computer Connections

WiFi network with automatic DHCP will be available throughout the conference centre. Computers with fixed network connection for e-mail and paper modifications are located on the 2nd floor on the Gallery. This area also has spare tables for use with personal laptops and a limited amount of wired network access points for laptops without wireless network. Computer facilities are available throughout the conference from Sunday to Friday.

Conference Dinner

The conference dinner takes place on Wednesday September 1 from 20:30 to 23:00 in the Starhotel Savoia Excelsior, opposite to the conference centre.

SOCIAL PROGRAMME AND VISITS

Welcome Cocktail

- Sunday August 29: 18:00 – 20:00

A get-acquainted Welcome Cocktail with local dishes and wine is offered to all participants of the FEL conference and their accompanying persons. It takes place in the Main hall of the "Stazione Marittima".

Excursion to Aquileia, Grado and its surroundings

- Wednesday September 1: 13:30 – 19:00

All participants of the FEL conference and Users Workshop are invited for a tour to Aquileia and Grado. Accompanying persons can join for a fee of € 25. Those who did not register for the tour can still do so at the registration desk on Monday and Tuesday. The excursion departs from the conference centre at 13:30 and returns to the same location at 19:00.

Aquileia was founded in 181 BC by the Romans and became an important trading centre and capital of Istria and the region. Today it is a small town with an impressive 11th century basilica and Roman ruins.

Grado used to function as harbour town for Aquileia (gradus = harbour). During the Hapsburg's rule Emperor Franz Joseph appointed the town as Imperial Thermal Place (25 July 1892) and it became one of the favourite resorts of the end-of-century society. Today Grado features some of the nicest beaches of the area as well an historic centre.

Conference Dinner

- Wednesday September 1: 20:30 – 23:00.

The conference dinner takes place at Starhotel Savoia Excelsior, opposite to the conference centre. All participants of the FEL conference and Users Workshop are invited. Accompanying persons can join for a fee of € 50. Those who did not register can still do so at the registration desk from Sunday to Tuesday.

Visit to the ELETTRA Laboratory

- Friday September 3: 14:00 – 17:00

A tour the 3rd generation synchrotron light source ELETTRA, its storage-ring FEL EUFELE and the linac for the FERMI@ELETTRA project will be organized for all participants of the Conference and Users Workshop. Interested persons are kindly requested to register for the tour before Thursday 14:00. Buses leave from the conference centre at 14:00.

INDUSTRIAL EXHIBITION

The industrial exhibit takes place in the Main hall during the conference.

INFORMATION FOR AUTHORS

Paper Submission

Only electronic submission through conference web-interface will be accepted (**no floppies, CD's or memory stick**). The web-page for submission is identical as the one for abstract submission: http://fel2004.elettra.trieste.it/pls/fel2004. The final deadline for paper submission is prior to the conference on Wednesday August 25. **Authors must present a paper copy** of their contribution at the Paper Acceptance Desk **on Sunday, August 29 or Monday, August 30.**

Authors who failed to submit the electronic version of their paper before the conference can use the computers in the Gallery to submit their contributions electronically. Papers submitted during the conference will be accepted as long as they do not delay the final submission of the proceedings. Questions may be addressed to the Paper Acceptance Desk.

Note that only papers for which a corresponding oral or poster presentation has been made will be eligible for publication in the conference proceedings.

Visual Aids for Speakers

Visual presentations can be made electronically using the projector equipment provided by the conference, or with transparencies. ***Use of private computers for oral presentations will not be possible.*** Electronic presentations must be uploaded to the presentation server (http://fel2004.elettra.trieste.it/pls/fel2004) in advance. Only PowerPoint, OpenOffice or PDF format can be accepted. Note that the computer system connected to the projector is running under Windows XP. Special precautions should be taken for .ppt files to beware of unusual fonts, and for .pdf files to be sure to include all fonts when preparing the .ps and .pdf files. A speaker preparation office is located in the Vulcania-2 room to check presentations on the electronic platform provided by the conference centre. Please check with the Paper Acceptance Desk for availability.

For presentations with transparencies, one overhead projector will be available.

No slide projector will be available.

Oral Presentations

All speakers have received information on the duration of their presentation. Please respect those time slots, taking into account the period should also be used to address questions. Speakers are requested to present themselves to the chair person of the session in the coffee break prior to the session.

Speakers with an electronic presentation are advised to check their presentation one day in advance in the Vulcania-2 room. Please check with the Paper Acceptance Desk for availability.

Poster Sessions

The three poster sessions are scheduled to take place in the Main Hall on:

- Monday (MOPOS) from 14:00 to 17:45,
- Tuesday (TUPOS) from 10:45 to 17:45, and
- Thursday (THPOS) from 10:45 to 17:45.

Presenting authors must be at their poster between 14:00 and 16:00. Presenting authors for the Thursday poster session are encouraged to mount their poster Wednesday morning and to dismount them on Thursday afternoon.

Each poster will be displayed on a panel 1.10 m (43.3″) wide and 1.30 m (51.2″) high. Posters should be mounted before 14:00 on Monday and before 10:45 on Tuesday and Thursday. Posters should be dismounted after 17:45.

Programme Overview

	Monday August 30	Tuesday August 31	Wednesday September 1	Thursday September 2	Friday September 3
8:00 - 8:30	Coffee				
8:30 - 10:15	Opening Session	FEL Technology I	FEL Experiments	Joint Session FEL / Workshop	Biological and Medical Sciences
10:15 - 10:45	Coffee				
10:45 - 12:30	Single Pass FELs	FEL Technology II | Poster	New Concepts and Ideas	Gun Injector Tech-nology; Physical and Chemical Sciences | Poster	Closing Session
12:30 - 14:00	Lunch				Lunch
14:00 - 16:00	Poster Session and Coffee	Poster Session and Coffee	Excursion 13:30 - 19:00	Poster Session and Coffee	Visit ELETTRA until 17:00
16:00 - 17:45	FEL Theory | Poster	FEL Oscillators | Poster		Short-wavelength FEL applications | Poster	
			Conference Dinner 20:30 - 23:00		

Registration* and Welcome Cocktail Sunday, August 29, 18:00 - 20:00

* registration on Sunday from 17:00 to 20:00

Legenda:
- FEL Conference
- Users Workshop

Monday August 30 08:30-10:15

Location: Saturnia

Opening Session

Chair: Richard Walker (DIAMOND)

08:30-08:45 **MOAIS01** 15 min **Opening**
René Johan Bakker (Elettra, Basovizza, Trieste)

08:45-09:00 **MOAIS02** 15 min **Welcome Addresses**

09:00-09:45 **MOAIS03** 45 min **FEL Prize Talk: R&D Experiments at BNL to Address the Associated Issues in the Cascading HGHG Scheme**
Li-Hua Yu (BNL, Upton, Long Island, New York)

09:45-10:00 **MOAIS04** 15 min **First Lasing at the ELBE mid-IR FEL (invited)**
Peter Michel (Forschungszentrum Rossendorf, Dresden - Sachsen)

10:00-10:15 **MOAIS05** 15 min **Information on the Programme and Proceedings**
Luca Giannessi (ENEA C.R. Frascati, Frascati - Roma)

Monday August 30 10:45-12:30

Location: Saturnia

Single Pass FELs

Chair: John Galayda (SLAC)

10:45-11:20 **MOBIS01** 35 min **Overview of Single Pass FEL Designs (invited)**
Tsumoru Shintake (RIKEN Spring-8 Harima, Hyogo)

11:20-11:40 **MOBOS02** 20 min **Scheme for Generation of Single 100 GW 300-as Pulse in the X-ray SASE FEL with the Use of a Few Cycles Optical Pulse from Ti:Sapphire Laser System**
Evgeny Saldin (DESY, Hamburg)

11:40-12:00 **MOBOS03** 20 min **An Experimental Study of the Beam-Steering Effect on the FEL Gain at LEUTL's Segmented Undulators**
Yong-Chul Chae (ANL/APS, Argonne, Illinois)

12:00-12:15 **MOBOS04** 15 min **Suppression of Microbunching Instability in the Linac Coherent Light Source**
Zhirong Huang (SLAC, Menlo Park, California)

12:15-12:30 **MOBOS05** 15 min **Generation of Narrow Linewidth X-rays by a Harmonic Cascade FEL**
William S Graves (MIT/BLAC, Middleton, Massachusetts)

Monday August 30 16:00-17:45

Location: Saturnia

FEL Theory

Chair: Li-Hua Yu (BNL)

16:00-16:35 **MOCIS01** 35 min **Bunching, non Linear Harmonic Generation, Exotic Undulators and Cascade Undulator FELs (invited)**
Giuseppe Dattoli (ENEA C.R. Frascati, Frascati - Roma)

16:35-17:00 **MOCOS02** 25 min **Spectral Properties of FEL Oscillators: New Theoretical and Experimental Results on the Super-ACO FEL**
Serge Bielawski (PhLAM, Villeneuve d'Ascq)

17:00-17:15 **MOCOS03** 15 min **Backward Wave Excitation and Generation of Oscillations in Distributed Gain Media and Free-Electron Lasers in the Absence of Feedback**
Yosef Pinhasi (The College of Judea and Samaria, Ariel)

17:15-17:30 **MOCOS04** 15 min **Nonlinear Harmonic Generation in Free-Electron Lasers with Helical Wigglers**
Henry Freund (SAIC McLean, McLean)

17:30-17:45 **MOCOS05** 15 min **CSRtrack: Faster Calculations of 3D CSR Effects**
Torsten Limberg (DESY, Hamburg)

Location: Main Hall

Poster Session

10:45-17:45 **MOPOS** **Single Pass FELs, FEL Theory**

Tuesday August 31 08:30-10:15

Location: Saturnia

FEL Technology I

Chair: Dirk Noelle (DESY)

08:30-09:05 **TUAIS01** 35 min **Sub-Picosecond Electron Bunch Length Measurements at SLAC (invited)**
Patrick Krejcik (SLAC/LCLS, Menlo Park, California)

09:05-09:30 **TUAOS02** 25 min **Bunch Compressors for XFELs against Microbunching Instability and CSR**
Yujong Kim (DESY, Hamburg)

09:30-09:45 **TUAOS03** 15 min **Large-Scale Timing Distribution and RF-Synchronization for FEL-Facilities**
Jung-Won Kim (MIT, Cambridge, Massachusetts)

09:45-10:00 **TUAOS04** 15 min **Real-Time, Non-Destructive, Single-Shot Longitudinal Profile Measurements of Sub-Picosecond Electron Bunches**
Giel Berden (FOM Rijnhuizen, Nieuwegein)

10:00-10:15 **TUAOS05** 15 min **Gas-Monitor Detector for FEL Online Photon Beam Diagnostics**
Andrei Alekseevich Sorokin (PTB, Braunschweig; IOFFE, St. Petersburg)

Tuesday August 31 — 10:45-12:30

Location: Saturnia

FEL Technology II

Chair: Ryoichi Hajima (JAERI/FEL)

10:45-11:20 **TUBIS01** 35 min **Attosecond Pulses in the LCLS using the Slotted Foil Method (invited)**
Paul J Emma (SLAC, Menlo Park, California)

11:20-11:40 **TUBOS02** 20 min **Longitudinal Space Charge Effects in the JLAB IR FEL SRF Linac**
Carlos Hernandez-Garcia (Jefferson Lab, Newport News, Virginia)

11:40-12:00 **TUBOS03** 20 min **High Average Power Operation of a Scraper-Outcoupled Free Electron Laser**
Michelle D. Shinn (Jefferson Lab, Newport News, Virginia)

12:00-12:15 **TUBOS04** 15 min **LCLS Undulator Design Development***
Isaac Vasserman (ANL/APS, Argonne, Illinois)

12:15-12:30 **TUBOS05** 15 min **Commissioning of the TTF Linac Injector at the DESY VUV-FEL**
Katja Honkavaara (DESY, Hamburg)

Tuesday August 31 16:00-17:45

Location: Saturnia

FEL Oscillators

Chair: Marie-Emmanuelle Couprie (LURE)

16:00-16:25 **TUCOS01** 25 min **Status of the Novosibirsk Terahertz FEL**
Nikolai Aleksandrovich Vinokurov (BINP, Novosibirsk)

16:25-16:45 **TUCOS02** 20 min **High Power Lasing in the IR Upgrade FEL at Jefferson Lab**
Stephen Vincent Benson (Jefferson Lab, Newport News, Virginia)

16:45-17:05 **TUCOS03** 20 min **VUV Optics Development for the Elettra Storage Ring FEL**
Stefan Guenster (LZH, Hannover)

17:05-17:25 **TUCOS04** 20 min **Coherent Harmonic Generation using the ELETTRA Optical Klystron**
Giovanni De Ninno (Elettra, Basovizza, Trieste)

17:25-17:45 **TUCOS05** 20 min **Short Rayleigh Length Free Electron Lasers**
William Colson (NPS, Monterey, CA)

Location: Main Hall

Poster Session

10:45-17:45 **TUPOS** **FEL Technology**

Wednesday September 1 — 08:30-10:15

Location: Saturnia

FEL Experiments

Chair: Michelle Shinn (Jefferson Lab)

08:30-09:05 **WEAIS01** 35 min **Experiments on the HGHG Wavelength Tuning at the DUV FEL (invited)**
Timur Shaftan (BNL/NSLS, Upton, Long Island, New York)

09:05-09:30 **WEAOS02** 25 min **Spectral Phase Modulation and chirped pulse amplification in HGHG**
Brian Sheehy (BNL/NSLS, Upton, Long Island, New York)

09:30-09:45 **WEAOS03** 15 min **Dynamical Analysis of Chaos Generated on a Storage Ring Free Electron Laser**
Christelle Bruni (LURE, Orsay)

09:45-10:00 **WEAOS04** 15 min **Study of Coherence Limits and Chirp Control in Long Pulse FEL Oscillator**
Avraham Gover (University of Tel-Aviv, Tel-Aviv)

10:00-10:15 **WEAOS05** 15 min **Measuring the Double-Differential Spectrum of Ultra-Short SASE Radiation Pulses at VISA FEL**
Murokh Alex (UCLA/DPA, Los Angeles - California)

Wednesday September 1 — 10:45-12:30

Location: Saturnia

New Concepts and Ideas

Chair: Nikolai Vinokurov (BINP)

10:45-11:05 **WEBOS01** 20 min **Current-Enhanced SASE Using an Optical Laser and its Application to the LCLS**
William M Fawley (LBNL/CBP, Berkeley, California)

11:05-11:25 **WEBOS02** 20 min **Generation of Terahertz Radiation by Modulating the Electron Beam at the Cathode**
Jonathan Neumann (IREAP, College Park, Maryland)

11:25-11:45 **WEBOS03** 20 min **Suppression of Multipass, Multibunch Beam Breakup in Two Pass Recirculating Accelerators**
Todd I. Smith (Stanford University, Stanford, California)

11:45-12:05 **WEBOS04** 20 min **Potential Use of eRHIC's 10 GeV ERL for FELs and Light Source**
Vladimir Litvinenko (BNL, Upton, Long Island, New York)

12:05-12:25 **WEBOS05** 20 min **The Harmonically Coupled 2-Beam FEL**
Brian McNeil (Strathclyde University, Glasgow)

Thursday September 2 08:30-10:15

Location: Saturnia

Joint Session

Chair: Ingolf Lindau (Lund University)

08:30-09:05 **THAIS01** 35 min **Coherent XUV Radiation with Conventional Lasers (invited)**
Philippe Zeitoun (LOA, Palaiseau)

09:05-09:40 **THAIS02** 35 min **SPPS: New Science on the Way to LCLS (invited)**
Aaron M. Lindenberg (SLAC/SSRL, Menlo Park, California)

09:40-10:15 **THAIS03** 35 min **Advancing Terahertz Science and Technology with the UCSB Free-electron Lasers (invited)**
S. James Allen (UCSB, Santa Barbara)

Thursday September 2 — 10:45-12:30

Location: Oceania C

Gun/Injector Technology

Chair: Tsumoru Shintake (RIKEN Spring-8 Harima)

10:45-11:20 **THBIC01** 35 min **Technologies for e-Beam Generation (invited)**
James Rosenzweig (UCLA, Los Angeles, California)

11:20-11:40 **THBOC02** 20 min **Recent Results and Perspectives of the Low Emittance Photo Injector at PITZ**
Frank Stephan (DESY Zeuthen, Zeuthen)

11:40-12:00 **THBOC03** 20 min **Emittance Measurement on the CeB6 Electron Gun for the SPring-8 Compact SASE Source**
Kazuaki Togawa (RIKEN Spring-8 Harima, Hyogo)

12:00-12:15 **THBOC04** 15 min **Ampere Average Current Photoinjector and Energy Recovery Linac**
Ilan Ben-Zvi (BNL, Upton, Long Island, New York)

12:15-12:30 **THBOC05** 15 min **Development of a Superconducting RF Gun in Rossendorf**
Dietmar Janssen (FZR, Dresden)

Thursday September 2 — 10:45-12:30

Location: Saturnia

Physical and Chemical Sciences

Chair: Norman Tolk (Vanderbilt/DPA)

10:45-11:10 **THBOS01** 25 min **Generation of Surface Electromagnetic Waves by Free-Electron Laser Terahertz Radiation and their Refractive Index Determination**
Guerman N. Zhizhin (RAS/STC UI, Moscow)

11:10-11:35 **THBOS02** 25 min **Femtosecond Laser Prevention for the Cold-Worked Stress Corrosion Crackings on Reactor Grade Low Carbon Stainless Steel**
Eisuke John Minehara (JAERI/FEL, Ibaraki-ken)

11:35-12:00 **THBOS03** 25 min **THz Imaging by a Wide-band Compact FEL**
Young Uk Jeong (KAERI, Daejon)

12:00-12:25 **THBOS04** 25 min **Present Applications of IR FEL at Peking University**
Limin Yang (PKU/IHIP, Beijing)

Thursday September 2 — 16:00-17:45

Location: Saturnia

Short wavelength FEL applications

Chair: Joseph Feldhaus (DESY)

16:00-16:35 **THCIS01** 35 min **Pump-Probe Experiments in the Gas Phase using the TTF2-FEL (invited)**
Michael Meyer (LURE, Orsay)

16:35-17:00 **THCOS02** 25 min **Interaction of Intense Ultrashort VUV Pulses with Different Solids – Results from the Tesla Test Facility FEL Phase I**
Jacek Krzywinski (IP PAS, Warsaw)

17:00-17:25 **THCOS03** 25 min **Short X-Ray Pulses Diffraction on 'Frozen' Crystals**
Souren Grigorian (RAS/CRYS, Moscow)

17:25-17:45 **THCOS04** 20 min **Soft X-Ray Study of Free Clusters Produced by a Pulsed Microplasma Cluster Source**
Cristina Lenardi (Università di Milano, Milano)

Location: Main Hall

Poster Session

10:15-17:45 **THPOS** **FEL Oscillators, FEL Experiments, New Concepts and Ideas, Users Workshop**

Friday September 3 08:30-10:15

Location: Saturnia

Biological and Medical Sciences

Chair: Charles Brau (Vanderbilt/DPA)

08:30-09:05 **FRAIS01** 35 min **Advances in the Physical Understanding of Laser Surgery at 6.45 microns (invited)**
Michael Shane Hutson (Vanderbilt/DPA, Nashville - Tennessee)

09:05-09:30 **FRAOS02** 25 min **Two-Color Mid-IR Pump-Probe Spectroscopy of Myoglobin and Corneal Stroma**
George A. Marcus (HEPL-FEL, Stanford)

09:30-09:55 **FRAOS03** 25 min **Picked FEL-Micro Pulse for Nano-Second Interaction with Bio-Molecules**
Sachiko Suzuki (OU-iFEL, Hirakata, Osaka)

09:55-10:15 **FRAOS04** 20 min **A Giant, Narrow Resonance in the Amide I Band in Proteins**
Robert Austin (PU, Princeton, New Jersey)

Friday September 3 — 10:45-12:15

Location: Saturnia

Closing Session

Chair: Luca Giannessi (ENEA C.R. Frascati)

10:45-11:15 **FRBIS01** 30 min **The European X-ray Free Electron Laser Project at DESY (invited)**
Andreas Schwarz (DESY, Hamburg)

11:15-11:45 **FRBIS02** 30 min **Overview of THz Radiation Sources (invited)**
Gian Piero Gallerano (ENEA C.R. Frascati, Frascati - Roma)

11:45-12:05 **FRBIS03** 20 min **FEL Developments and Trends: A Personal Observation of FEL2004**
Mike Poole (CCLRC/DL/ASTeC, Daresbury, Warrington, Cheshire)

12:05-12:15 **FRBIS04** 10 min **Closing Remarks**
Richard Peter Walker (DIAMOND, Chilton, Didcot, Oxon)

Opening Session

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MOAIS

FEL Prize Talk: R&D Experiments at BNL to Address the Associated Issues in the Cascading HGHG Scheme

MOAIS03

Li-Hua Yu (*BNL, Upton, Long Island, New York*)

We discuss several experiments that can be carried out at BNL's DUVFEL to address several issues associated with cascaded HGHG FELs. These include: Chirped Pulse Amplification (CPA); HGHG with seed shorter than electron bunch length; 8^{th} harmonic HGHG (from 800nm to 100nm); Regenerative synchronization of seed pulse and electron bunch; Tuning of HGHG without changing seed, proposed by Timur Shaftan; Cascading using NISUS and VISA: from 400nm to 100nm to 50nm. These experiments may have important impact on the development of multi-stage cascaded HGHG FELs.

First Lasing at the ELBE mid-IR FEL

MOAIS04

Peter Michel (*Forschungszentrum Rossendorf, Dresden - Sachsen*), Thomas Dekorsy, Pavel Evtushenko, Frank Gabriel, Eckart Grosse, Manfred Helm, Marcel Krenz, Ulf Lehnert, Wolfgang Seidel, Dietrich Wohlfarth, Andreas Wolf, Rudi Wuensch (*FZR, Dresden*)

First lasing of the mid infrared FEL at ELBE was achieved on May 7, 2004. The Radiation Source ELBE at the Forschungszentrum Rossendorf in Dresden is currently under transition from commissioning to regular user operation. Presently the electron linac produces an up to 18 MeV, 1 mA (cw) electron beam which is alotted to generate various kinds of secondary radiation. After the successful commissioning of the bremsstrahlung and channeling-X-ray facilities during 2003 stable lasing has now been observed in the IR range (15 to 22 μm). The oscillator FEL is equipped with two planar undulator units, both consisting of 34 hybrid permanent magnet periods of 27.3 mm (K_{rms} = 0.3 - 0.8). The distance between the two parts is variable and the gaps can be adjusted and tapered independently. At 19.6 ţm an optical power of 3W was out-coupled in a macro pulse of 0.6 ms duration using an electron beam energy of 16.1 MeV and an energy spread of less than 100 keV; the micropulse charge was 50 pC and its width slightly above 1ps. With the installation of a second acceleration module for additional 20 MeV smaller wavelengths will become available in the near future.

Single Pass FELs

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MOBxS

Overview of Single Pass FEL Designs MOBIS01

Tsumoru Shintake (*RIKEN Spring-8 Harima, Hyogo*)

The talk will review recent achievement of technology development for SASE-FELs, such as the low emittance electron sources. The talk also gives some suggestion on "Background technology requirement for Single Pass FELs before or behind the "low emittance" story. Question is what do we need to prepare before starting the construction of a large scale machine?

Scheme for Generation of Single 100 GW 300-as Pulse in the X-ray SASE FEL with the Use of a Few Cycles Optical Pulse from Ti:sapphire Laser System MOBOS02

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

Femtosecond optical pulse interacts with the electron beam in the two-period undulator and produces energy modulation within a slice of the electron bunch. Then the electron beam enters the first part of the X-ray undulator and produces SASE radiation with 100 MW-level power. Due to energy modulation the frequency is correlated to the longitudinal position, and the largest frequency offset corresponds to a single-spike pulse in the time domain which is confined to one half-oscillation period near the central peak electron energy. After the first undulator the electron beam is guided through a magnetic delay which we use to position the X-ray spike with the largest frequency offset at the "fresh" part of the electron bunch. After the chicane the electron beam and the radiation enter the second undulator which is resonant with the offset frequency where only a single (300 as duration) spike grows rapidly. The final part of the undulator is a tapered section allowing to achieve maximum output power 100-150 GW in 0.15 nm wavelength range.

An Experimental Study of the Beam-Steering Effect on the FEL Gain at LEUTL's Segmented Undulators MOBOS03

Yong-Chul Chae, Roger Dejus, Mark Erdmann, John Lewellen, Alex Lumpkin, Stephen Milton (*ANL/APS, Argonne, Illinois*)

The electron trajectories at the LEUTL, a SASE FEL facility at Argonne, were routinely corrected during the user run in order to deliver maximum radiation power to the user. Even though we knew

from experience that SASE gain at the segmented undulators was dependent on the trajectory, the quantitative understanding of steering effects associated with the specific trajectory was lacking. Recently Tanaka et al. proposed an analytical model for the single-kick error (SKE) effect. Since LEUTL has eight segmented undulators, we performed the first measurement of SKE on the FEL gain. In the experiments we varied the corrector strength up to the critical angle, and the gain over the undulator was measured for each corrector setting. The results were compared with the analytical model and GENESIS simulations. We also measured the e-beam positions and SASE intensities over the undulators. The experimental data were analyzed and their results were reproduced by GENESIS simulation. The simulation condition, including the measured not-so-ideal trajectory, was used to predict performance enhancements that could be achieved by upgrading e-beam current, e-beam emittance, or trajectory control.

MOBOS04 **Suppression of Microbunching Instability in the Linac Coherent Light Source**

Zhirong Huang, Paul J Emma, C. Limborg, Gennady Stupakov, Jim Welch, Juhao Wu (*SLAC, Menlo Park, California*), Michael Borland (*ANL/APS, Argonne, Illinois*)

A microbunching instability driven by longitudinal space charge, coherent synchrotron radiation, and linac wakefields is studied for the linac coherent light source (LCLS) accelerator system. Since the uncorrelated (local) energy spread of electron beams generated from a photocathode rf gun is very small, the microbunching gain may be large enough to significantly amplify rf-gun generated modulations or even shot-noise fluctuations of the electron beam. The uncorrelated energy spread can be increased by an order of magnitude to provide strong Landau damping against the instability without degrading the free-electron laser performance. We study different damping options in the LCLS and discuss an effective laser heater to minimize the impact of the instability on the quality of the electron beam.

Generation of Narrow Linewidth X-rays by a Harmonic Cascade FEL

MOBOS05

William S Graves, David Moncton (*MIT/BLAC, Middleton, Massachusetts*),
William M Fawley (*LBNL/CBP, Berkeley, California*)

The transform-limited bandwidth of a 1 ps laser pulse is 2 meV regardless of wavelength. For 1 Angstrom x-rays this corresponds to a relative bandwidth of less than 2.0e-7. While this bandwidth is similar to the best x-ray crystal monochromators, the peak brilliance of the beams would be over ten orders of magnitude higher than current third-generation synchrotron sources, offering unprecedented science opportunities. This long-pulse, narrow-bandwidth regime approaches the limit where all photons are in the same quantum state. We present time-dependent simulations of the evolution of a long coherent pulse in a harmonic cascade FEL, approaching the transform limit.

FEL Theory
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MOCOS

Spectral Properties of FEL Oscillators: New Theoretical and Experimental Results on the Super-ACO FEL

MOCOS02

Serge Bielawski, Christophe Szwaj (*PhLAM, Villeneuve d'Ascq*), Christelle Bruni, Marie-Emmanuelle Couprie, David Garzella, Gian Luca Orlandi (*LURE, Orsay*)

Spectral properties of FELs can be modeled using several ways. Particularly complete approaches consists to integrate the full quantum or classical equations for the beam and optical field, at each pass, and/or using statistical descriptions. Here we propose an alternate approach leading to the derivation of a simple model that is able to take the spectral as well as the other usual properties (pulse durations, etc.) into account. The simplification stems from the peculiar properties of usual FEL oscillators, but can be used either in the storage ring and LINAC cases. We will see that the relative simplicity of the model allows to perform easily deep investigations, and thus leads naturally to the prediction of new surprising dynamics. In particular the model predicts the existence of spectro-temporal defects, that are characterized by amplitude "holes", and phase singularities. Then we will show that all these predictions are verified experimentally, using new experimental investigations of the super-ACO FEL. These behaviors are generic and should be observable on other SR-FELs, and the modeling strategy can be potentially extended to LINAC-based FEL oscillators.

Backward Wave Excitation and Generation of Oscillations in Distributed Gain Media and Free-Electron Lasers in the Absence of Feedback

MOCOS03

Yosef Pinhasi, Yuri Lurie, Gad A. Pinhasi, Asher Yahalom (*The College of Judea and Samaria, Ariel*)

Quantum and free-electron lasers (FELs) are based on distributed interactions between electromagnetic radiation and gain media. In an amplifier configuration, a forward wave is amplified while propagating in a polarized medium. Formulating a coupled mode theory for excitation of both forward and backward waves, we identify conditions for phase matching, leading to efficient excitation of backward wave without any mechanism of feedback or resonator assembly. The excitations of incident and reflected waves are de-

scribed by a set of coupled differential equations expressed in the frequency domain. The induced polarization is given in terms of an electronic susceptibility tensor. In quantum lasers the interaction is described by two first order differential equations, while in high-gain free-electron lasers, the differential equations are of the third order each. Analytical solutions of reflectance and transmittance for both quantum lasers and FELs are presented. It is found that when the solutions become infinite, the device operates as an oscillator, producing radiation at the output with no field at its input, entirely without any localized or distributed feedback.

MOCOS04

Nonlinear Harmonic Generation in Free-Electron Lasers with Helical Wigglers

Henry Freund (*SAIC McLean, McLean*), Sandra G. Biedron (*ANL, Argonne, Illinois*), Patrick Gerard O'Shea (*IREAP, College Park, Maryland*)

It is widely believed that harmonic generation is suppressed in helical wigglers. However, harmonic generation can occur in both planar and helical wigglers albeit by different mechanisms. Linear harmonic generation (LHG) in planar wigglers is due to harmonics in the axial velocity that excite linearly polarized, on-axis modes. In contrast, LHG in helical wigglers is due to an azimuthal resonance that excites circularly polarized, off-axis waves where the hth harmonic varies as exp(ihq). Nonlinear harmonic generation (NHG) is driven by nonlinear bunching at the fundamental and has different properties from LHG. While NHG has been studied in planar wigglers, there has been no analysis heretofore of NHG in helical wigglers. To this end, the 3-D simulation code MEDUSA has been modified to describe NHG in helical wigglers. A comparative analysis of NHG in planar and helical wigglers is presented. It is shown that NHG in helical wigglers excites on-axis modes with comparable intensities in the even and odd harmonics.

NAVSEA and JTO

CSRtrack: Faster Calculations of 3D CSR Effects MOCOS05

Martin Dohlus, Torsten Limberg (*DESY, Hamburg*)

CSRtrack is a new code for the simulation of Coherent Synchrotron radiation effects on the beam dynamics of linear accelerators. It incorporates the physics of our previous code, TraFiC4, and adds new algorithms for the calculation of the CSR fields. A one-dimensional projected method allows quick estimates and a greens function method allows 3D calculations about ten times faster than with the 'direct' method. The tracking code is written in standard FORTRAN77 and has its own parser for comfortable input of calculation parameters and geometry. Phase space input and the analysis of the traced particle distribution is done with MATLAB interface programs.

Single Pass FELs and FEL Theory
—
MOPOS

Simulation of VFEL (Volume Free Electron Laser) Oscillator

MOPOS01

Konstantin Batrakov, Svetlana Sytova (*Belarussian State University, Minsk*)

The main feature of VFEL is volume distributed feedback. This feedback mechanism is provided by several Bragg coupled waves. In general case wave vectors of these waves are not aligned with direction of electron beam velocity. Volume feedback gives possibility to reduce generation threshold, to tune frequency, to regulate resonator Q-factor [2,3]. Linear stage and nonlinear amplifier regime of VFEL were discussed in our previous considerations. In present work the nonlinear saturation stage is studied in oscillation and regenerative amplifier regimes. Threshold conditions, VFEL output power and their dependencies on distributed feedback parameters are obtained. Additional influence of external Bragg mirrors on generation at nonlinear stage is discussed.

1. Baryshevsky V.G., Feranchuk I.D. Parametric beam instability of relativistic charged particles in a crystal, Phys. Lett. 1984. Vol. A102. P. 141.
2. Baryshevsky V.G., Batrakov K.G., Dubovskaya I.Ya. Parametric (Quasi-Cherenkov) X-ray Free Electron Laser, J. of Physics: D. 1991. Vol. 24. P. 1250-1257.
3. Baryshevsky V.G. Volume Free Electron Lasers, Nucl. Instr. and Meth. in Phys.Res. 2000. Vol. A445. P. 281.

Different Regimes of VFEL (Volume Free Electron Laser) Operation at Nonlinear Generation Stage

MOPOS02

Konstantin Batrakov, Svetlana Sytova (*Belarussian State University, Minsk*)

VFELs with multiwave distributed feedback were proposed in [1]. Linear regime of VFEL was actively studied. It was shown that VFELs are capable to generate in wide spectral range from X-ray to microwaves. Surface optical VFEL amplifier was simulated in [2]. Present work studies oscillator regime and regenerative amplifier regime of VFEL generation. Equations describing nonstationary dynamics of system "electromagnetic radiation + electron beam + periodical structure" are derived and simulated. Bifurcation points

corresponding to transition between different generation regimes at nonlinear stage are obtained. It is shown that stationary saturation regime can transform to non-stationary regimes in these points. Dependence of bifurcation points positions on distributed feedback geometry and other VFEL parameters is studied.

1. Baryshevsky V.G., Feranchuk I.D. - Parametric beam instability of relativistic charged particles in a crystal, Phys. Lett. 1984. Vol. A102. P. 141.
2. Baryshevsky V.G., Batrakov K.G., Dubovskaya I.Ya., Sytova S.N. - Visible Surface Quasi-Cherenkov FEL, Nucl. Instr. And Meth. in Phys. Res. 1995. Vol. A358. P. 508-511.

MOPOS03 Start-To-End Tolerance Studies for the BESSY FEL*

Michael Abo-Bakr, Bettina Kuske, Atoosa Meseck (*BESSY GmbH, Berlin*)

BESSY is proposing a Soft X-ray FEL user facility in Berlin, delivering short and stabile photon pulses in the wavelength range of 62 nm $< \lambda <$ 1.2 nm by applying up to four cascaded High Gain Harmonic Generation (HGHG) stages. For optimization of the FEL performance of the cascaded HGHG stages extensive Start-to-End (S2E) simulations have been carried out. In order to test the quality of the chosen configuration with respect to the sensitivity against various error sources tolerance studies from the injector to the linac end have been performed. Procedures and results of these studies will be presented.

* Funded by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, the Land Berlin and the Zukunftsfonds des Landes Berlin.

MOPOS04 A Multistage HGHG-Scheme for the BESSY Soft X-ray Multi User FEL Facility

Dieter Krämer (*BESSY GmbH, Berlin*)

BESSY recently finalized the Technical Design Report for a multi-user FEL-facility in the VUV to soft X-ray spectral range. A cascaded

HGHG-approach has been adopted, allowing to generate stable, reproducible multi-GW pulses at selectable pulse duration down to <20 fs. Three independent FEL-lines with three beamlines each are proposed. The FELs are driven by a most flexible superconducting CW linac based on the TESLA 9-cell cavities[1]. 18 modules of 8 cavities are needed to accelerate the beam to a final energy of 2.3 GeV at a modest field of < 16 MV/m. A 1 kHz repetition frequency rf-photoinjector, similar to the PITZ-gun [2], will be used in the beginning, to be replaced later on by a CW-photoinjector to produce arbitrary pulse patterns as needed by the experimenters. A summary of the project plans and present activities will be given.

[1] TESLA Technical Design Report, Part II - The Accelerator, DESY-2001-011
[2] F. Stephan et al., Characterization of the PITZ Electron Source for the VUV-FEL and Further Advances, these proceedings

Funded by the Bundesministerium für Bildung und Forschung, the Land Berlin and the Zukunftsfonds des Landes Berlin

Tolerance Studies for the BESSY HGHG FEL

MOPOS05

Bettina Kuske, Michael Abo-Bakr, Atoosa Meseck (*BESSY GmbH, Berlin*)

BESSY is proposing a linac-based High Gain Harmonic Generation FEL multi user facility covering the VUV to soft X-ray spectral range. A photoinjector and a superconducting 2.3 GeV CW linac will feed three independent multi-stage HGHG lines consisting of APPLE II type undulators. Tolerance studies have been performed for the FEL process, including variations in the electron beam parameters like current, emittance, and energy spread. The influence of undulator field errors has been investigated and start to end calculations, taking varying conditions for each slice into account, have been performed. The investigations show, that the behaviour in the presence of errors is quite different from the SASE case, and depends heavily on the specific design and optimization of the different stages.

Funded by the Bundesministerium für Bildung, Wissenschaft, Forschnung and Technologie (BMBF), the Land Berlin and the Zukunftsfonds des Landes Berlin.

MOPOS06 **The Influence of the Seed Pulse Shape on the Output Performance of the BESSY Multi-stage HGHG-FEL**

Atoosa Meseck, Michael Abo-Bakr, Bettina Kuske (*BESSY GmbH, Berlin*)

The BESSY soft X-ray FEL is planned as a High Gain Harmonic Generation (HGHG) FEL multi-user facility covering the VUV to soft X-ray spectral range. In the HGHG scheme, the properties of the radiation output are dominated by the characteristics of the laser seed. In this connection, the influence of the laser pulse shape on the output, in particular on the output spectrum is of interest. Simulation studies for the BESSY-HGHG-FELs are presented and the output performance for different shapes of the laser pulse is discussed.

Funded by the Bundesministerium für Bildung, Wissenschaft, Forschnung und Technologie (BMBF), the Land Berlin and the Zukunftsfonds des Landes Berlin.

MOPOS07 **Velocity Bunching at TTF2**

Jean-Paul Carneiro, Bart Faatz, Klaus Floettmann (*DESY, Hamburg*)

The TESLA Test Facility FEL is currently being upgraded to reach in its final stage a SASE radiation wavelength of 6 nm. After a brief description of layout and status of the TTF-FEL, the paper will present start-to-end simulations studying velocity bunching as a scenario for first operations of the accelerator.

MOPOS08 **A 3D Self-Consistent, Analytical Model for Longitudinal Plasma Oscillation in a Relativistic Electron Beam**

Gianluca Geloni, Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

Longitudinal plasma oscillations are becoming a subject of great interest for XFEL physics in connection with LSC microbunching instability [1] and certain pump-probe synchronization schemes [2]. In

the present paper we developed the first exact analytical treatment for longitudinal oscillations within an axis-symmetric, (relativistic) electron beam, which can be used as a primary standard for benchmarking space-charge simulation codes. Also, this result is per se of obvious theoretical relevance as it constitutes one of the few exact solutions for the evolution of charged particles under the action of self-interactions.

[1] E. Saldin et al. Longitudinal Spacs Charge Driven Michrobunching instability in TTF linac, TESLA-FEL-2003-02, May 2003
[2] J. Feldhaus et al. Two-color FEL amplifier for femtosecond-resolution pump-probe experiments with GW-scale X-ray and optical pulses DESY 03-091, July 2003

Benchmark of Astra with Analytical Solution for the Longitudinal Plasma Oscillation Problem

MOPOS09

Gianluca Geloni, Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov
(*DESY, Hamburg*)

During the design of X-FELs, space-charge codes are required to simulate the evolution of longitudinal plasma oscillation within an electron beam in connection with LSC microbunching instability [1] and certain pump-probe synchronization schemes [2]. In the paper [3] we presented an analytical solution to the initial value problem for longitudinal plasma oscillation in an electron beam. Such a result, besides its theoretical importance, allows one to benchmark space-charge simulation programs against a self-consistent solution of the evolution problem. In this paper we present a comparison between our results [3] and the outcomes of the simulation code ASTRA.

[1] E. Saldin et al., Longitudinal Space Charge Driven Michrobunching instability in TTF linac, TESLA-FEL-2003-02, May 2003
[2] J. Feldhaus et al., Two-color FEL amplifier for femtosecond-resolution pump-probe experiments with GW-scale X-ray and optical pulses, DESY 03-091, July 2003
[3] G. Geloni et al., A 3D self-consistent, analytical model

for longitudinal plasma oscillation in a relativistic electron beam, this conference

MOPOS10 The Potential for the Development of the X-ray Free Electron Laser: Generation of SASE Radiation

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

We present a concept of a universal FEL beamline covering continuously wavelength range from 0.1 to 1.6 nm at a fixed energy of the electron beam. FEL beamline accommodates three undulators (SASE1-3) installed one after another. The first undulator, SASE1, is optimized for operation at the wavelength range 0.1-0.15 nm. Our study shows that such tunability range almost does not affect operation at the shortest wavelength of 0.1 nm. Operation of two other FELs (SASE2 and SASE3) is not so critical, and nominal tunability range is chosen to be by a factor of two (2-4 nm, and 8-16 nm, respectively). The length of the undulators is chosen such that continuous wavelength tunability can be provided by means of extra opening the undulator gaps, or by tuning to the frequency doubler mode of operation. Changing of undulator gaps in different parts of SASE2 and SASE3 undulators allows one to tune the modes with high output power (sub-TW level), or for effective generation of the second harmonic. The latter feature might be important for future pump-probe experiments. Also, recently proposed attosecond SASE FEL scheme is foreseen for implementation.

MOPOS11 Attosecond X-ray Source for Light-Triggered Time-Resolved Experiments Associated with the X-ray SASE FEL

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

We propose a technique for the production of attosecond X-ray pulses which is based on the use of X-ray SASE FEL combined with a femtosecond laser system. A few-cycle optical pulse from a Ti:sapphire laser interacts with the electron beam in a two-period undulator resonant to 800 nm wavelength and produces energy modulation within a slice of the electron bunch. Following the energy

modulator the electron beam enters the X-ray undulator and produces SASE radiation. Due to energy modulation the frequency is correlated to the longitudinal position within the few-cycle-driven slice of SASE radiation pulse. The largest frequency offset corresponds to a single-spike pulse in the time domain which is confined to one half-oscillation period near the central peak electron energy. The selection of single-spike pulses is achieved by using a crystal monochromator after the X-ray undulator. Our studies show that the proposed technique is capable to produce 300 attoseconds long single pulses with GW-level output power in the 0.1 m wavelength range, and is applicable to the European X-Ray Laser Project XFEL and the Linac Coherent Light Source at SLAC.

The Potential for the Development of the X-ray Free Electron Laser: Multi-User Photon Distribution System for XFEL Laboratory MOPOS12

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

X-ray photon beam from a SASE FEL undulator is in principle a single user tool, just like an optical laser. Therefore, the operation and amortization cost cannot be easily spread over many simultaneous experiments. To avoid prohibitive cost for each experiment, a new XFEL laboratory scheme is proposed. A photon beam distribution system based on movable multilayer X-ray mirrors can provide an efficient way to generate a multi-user facility. Distribution of photons is achieved on the basis of pulse trains and it is possible to partition the photon beam among a few tens independent beamlines thereby obtaining many users working in parallel. The second way to increase the number of simultaneous experiments is based on the working with a series of perfect crystals in transmission (Laue) geometry. The later concept is the basic idea of the Troika beamline at ESRF. In principle, a hundred of photon beamlines with different experiments can be served by a single XFEL source.

Influence of an energy chirp on SASE FEL operation MOPOS13

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

Influence of a linear energy chirp, imposed on the electron beam, on SASE process is studied numerically. Universal dependencies of

a saturation length and FEL efficiency on the energy chirp parameter are presented.

MOPOS14 Sub-Terawatt Mode of Operation of X-ray SASE FEL

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

Application of dispersion section in combination with undulator tapering is an effective tool for achieving extremely high output power of XFEL. In the first part of the undulator the gap is fixed, and amplification process is developed as in usual SASE FEL. When energy modulation of the electron beam becomes to be comparable with local energy spread, the electron bunch passes via dispersion section resulting in an effective compression of the electron bunch. Then bunched electron beam enters the second half of the undulator where the gap is tapered for effective extraction of the energy from the electron bunch. Our studies shows that output radiation power can reach a sub-TW level in Angstrom wavelength range.

MOPOS15 Design Formulas for VUV and X-Ray FELs

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

Simple formulas for optimization of VUV and X-ray SASE FELs are presented. The FEL gain length and the optimal beta-function are explicitly expressed in terms of the electron beam and undulator parameters. The FEL saturation length is estimated taking into account energy diffusion due to quantum fluctuations of the undulator radiation. Examples of the FEL optimization are given. Parameters of a SASE FEL, operating at the Compton wavelength, are suggested.

MOPOS16 The Free Electron Laser Klystron Amplifier Concept

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

We consider optical klystron with a high gain per cascade pass. In order to achieve high gain at short wavelengths, conventional FEL amplifier require electron beam peak current of a few kA. This is achieved by applying longitudinal compression using a magnetic chicane. In the case of klystron things are quite different and gain of klystron does not depend on the bunch compression in the injector linac. A distinguishing feature of the klystron amplifier is that maximum of gain per cascade pass at high beam peak current is the same

as at low beam peak current without compression. Second important feature of the klystron configuration is that there are no requirements on the alignment of the cascade undulators and dispersion sections. This is related to the fact that the cascades, in our (high gain) case, do not need the radiation phase matching. There are applications, like XFELs, where unique properties of high gain klystron FEL amplifier are very desirable. Such a scheme allows one to decrease the total length of magnetic system. On the other hand, the saturation efficiency of the klystron is the same that of conventional XFEL.

The Potential for Extending the Spectral Range Accessible to the European X-ray Free Electron Laser in the Direction of Longer Wavelengths MOPOS17

Evgeny Saldin, Evgeny Schneidmiller, Mikhail V. Yurkov (*DESY, Hamburg*)

The baseline specifications of European XFEL give a range of wavelengths between 0.1 nm and 2 nm. This wavelength range at fixed electron beam energy 17.5 GeV can be covered by operating the SASE FEL with three undulators which have different period and tunable gap. A study of the potential for the extending the spectral range accessible to the XFEL in the direction of longer wavelengths is presented. The extension of the wavelength range to 6 nm would be cover the water window in the VUV region, opening the facility to a new class of experiments. There are at least two possible sources of VUV radiation associated with the X-ray FEL; the "low (2.5 GeV) energy electron beam dedicated" and the " 17.5 GeV spent beam parasitic" (or "after-burner") source modes. The second alternative, "after-burner undulator" is the one we regard as most favorable. It is possible to place an undulator as long as 80 meters after 2 nm undulator. Ultimately, VUV undulator would be able to deliver output power approaching 100 GW. A beam from this device could be run in pump-probe mode with X-ray FEL.

Start-To-End Simulations for the PAL XFEL Project MOPOS18

Yujong Kim (*DESY, Hamburg*), Dongchul Son (*KNU, Daegu*), In-Soo Ko, Jong-Seok Oh (*PAL, Pohang*), Won Namkung (*POSTECH, Pohang, Kyungbuk*)

At the Pohang Accelerator Laboratory (PAL), there is a 2.5 GeV S-band linac which is under operating as a full energy injector for

the Pohang Light Source (PLS) storage ring. By installing a new electron gun, a new 0.5 GeV linac, and two new bunch compressors, the PLS linac can be used as an FEL driver for the PAL XFEL project. To saturate 0.3 nm wavelength PAL XFEL SASE source, we should supply high quality electron beams to a 60 m long undulator. In this paper, we describe a new linac layout for the PAL XFEL project and its various start-to-end simulations from the cathode to the end of the linac.

MOPOS19 **Optimization of TTF2 Linac for the First Lasing**

Yujong Kim, Bart Faatz, Klaus Floettmann (*DESY, Hamburg*), Dongchul Son (*KNU, Daegu*)

To saturate 30 nm wavelength SASE source at TESLA Test Facility Phase 2 (TTF2), we should supply high quality electron beams to about 30 m length undulator. In this paper, we describe TTF2 linac optimization and various start-to-end simulations for its first lasing.

MOPOS20 **Start-to-end Simulations on Jitter and Error Tolerances in the European XFEL Project**

Yujong Kim, Bart Faatz, Klaus Floettmann, Torsten Limberg (*DESY, Hamburg*), Dongchul Son (*KNU, Daegu*)

In order to generate stable 0.1 nm wavelength SASE source at the European X-ray laser project XFEL, we should supply high quality electron beams with constant beam characteristics to a 200 m long undulator. Generally, beam parameters such as peak current and energy spread are significantly dependent on jitter or error in RF phase and RF amplitude of superconducting accelerating modules, and magnetic field error of bunch compressors. In this paper, we describe the start-to-end simulations from the cathode to the end of linac to determine the jitter and error tolerances for the European XFEL project.

Seeding High Gain Harmonic Generation with Laser Harmonics Produced in Gases MOPOS21

Guillaume Lambert, Bertrand Carre (*CEA/Saclay, Gif-sur-Yvette*), Luca Giannessi (*ENEA C.R. Frascati, Frascati - Roma*), Marie-Emmanuelle Couprie, David Garzella (*LURE, Orsay*), Hideo Kitamura, Tsumoru Shintake, Hara Toru (*RIKEN Spring-8, Hyogo*)

Free electron Lasers employing High Gain Harmonic generation (HGHG) schemes are very promising coherent ligth sources for the soft X-ray regime. They offer both transverse and longitudinal coherence, while Self Amplified Spontaneous Emission schemes have a longitudinal coherence limited. We propose here to seed HGHG with high harmonics produced by a Ti:Sa femtosecond laser focused on a gas jet, tuneable in the 100-10 nm spectral region. Specifities concerning the implementation of this particular laser source as a seed for HGHG are investigated. Semi analytical , numerical 1D and 3D calculations are given, for the cases of the SCSS, SPARC and ARC-EN-CIEL projects.

Off-Axis Orbits in Realistic Helical Wigglers: Fixed Points and Time Averaged Dynamical Variables MOPOS22

John Thomas Donohue (*CENBG, Gradignan*), Jean-Luc Rullier (*CESTA, Le Barp*)

Many years ago Fajans, Kirkpatrick and Bekefi studied off-axis orbits in a realistic helical wiggler, both experimentally and theoretically. They found that as the distance from the axis of symmetry to the guiding center increased, both the mean axial velocity and the precession frequency of the guiding center varied. . They proposed a clever semi-empirical model which yielded an excellent description of both these variations. We point out that a approximate model proposed by us several years ago can be made to predict these delicate effects correctly, provided we extend our truncated quadratic Hamiltonian to include appropriate cubic terms. We develop an argument similar to the virial theorem to compare time averaged and fixed-point values of dynamical variables. Illustrative comparisons of our model with numerical calculation are presented.

MOPOS23

Analytic Electron Trajectories in an Extremely Relativistic Helical Wiggler: an Application to the Proposed SLAC E166 Experiment.

John Thomas Donohue (*CENBG, Gradignan*)

The proposed experiment SLAC E166 intends to generate circularly polarized gamma rays of energy 10 MeV by passing a 15 GeV electron beam through a meter long wiggler with approximately 400 periods. Using an analytic model formulated by Rullier and me, I present calculations of electron trajectories. At this extremely high energy the trajectories are described quite well by the model, and an extremely simple picture emerges, even for trajectories that that fail to encircle the axis of the wiggler. Our calculations are successfully compared with standard numerical integration of the Lorentz force equations of motion. In addition, the calculation of the spectrum and angular distribution of the radiated photons is easily carried out.

MOPOS24

FERMI@ELETTRA: Status Report

Rene Johan Bakker, Carlo Joseph Bocchetta, Paolo Craievich, Mitcho Danailov, Gerardo D'Auria, Giovanni De Ninno, Simone Di Mitri, Bruno Diviacco, Gianpiero Pangon, Luca Rumiz, Lidia Tosi, Victor Verzilov (*Elettra, Basovizza, Trieste*)

The FERMI@ELETTRA project is an initiative from ELETTRA, INFM and other Italian institutes, to construct a single-pass FEL user-facility for the wavelength range from 100 nm (12 eV) to 10 nm (124 eV), to be located next to the third-generation synchrotron radiation facility ELETTRA in Trieste, Italy. The project is concentrated around the existing 1.2-GeV S-band linac. At this moment the FEL project evolves from a conceptional design stage towards a technical design and the actual implementation. Key issues are: incorporation of the free-electron laser in the infrastructure of the Sincrotrone Trieste, adjustments of the linac to facilitate FEL operation, required additional civil engineering, undulator design, FEL seeding options, and beamline design. This paper serves as an overview of the project in combination with a discussion of the critical issues involved.

Start-to-end simulations for the FERMI project at ELETTRA MOPOS25

Simone Di Mitri, Rene Johan Bakker, Paolo Craievich, Gerardo D'Auria, Giovanni De Ninno, Bruno Diviacco, Lidia Tosi, Victor Verzilov (*Elettra, Basovizza, Trieste*)

FERMI at ELETTRA is a project aims at the construction of a single-pass user facility for the spectral range from 100 nm to 10 nm. Starting point is the existing 1.2 GeV, 3-GHz linac. Downstream of the linac two undulator beamlines will serve the wavelength range from 100 nm to 40 nm, and 40 nm to 10 nm, respectively. The former beamline will be based on a single-stage HGHG scheme while for the latter a double stage HGHG scheme is foreseen. This paper discusses results from start-to-end simulations for the former beamline, including the option of HGHG. Care has been taken to include realistic models for the injector, accelerating structures, and undulator beamline.

Harmonic Generation and Linewidth Narrowing in Seeded FELs MOPOS26

Luca Giannessi (*ENEA C.R. Frascati, Frascati - Roma*)

The process of harmonic generation in a seeded single pass Free Electron Laser are studied in the time/frequency domain. The linewidth narrowing of the fundamental harmonic is correlated to the amplitude of the input seed. The spectral evolution of the harmonics is studied within a self consistent time dependent model.

MOPOS27

Status Report on SPARC Project

Alberto Renieri, Franco Ciocci, Giuseppe Dattoli, Antonio Di Pace, Andrea Doria, Francesco Flora, Gian Piero Gallerano, Luca Giannessi, Emilio Giovenale, Giovanni Messina, Luca Mezi, Pier Luigi Ottaviani, Simonetta Pagnutti, Giovanni Parisi, Luigi Picardi, Marcello Quattromini, Giuseppe Ronci, Concetta Ronsivalle, Elio Sabia, Mauro Sassi, Alberto Zucchini (*ENEA C.R. Frascati, Frascati - Roma*), Carlo Joseph Bocchetta, Mitcho Danailov, Gerardo D'Auria (*Elettra, Basovizza, Trieste*), F. Alessandria, A. Bacci, Ilario Boscolo, F. Broggi, S. Cialdi, C. De Martinis, D. Giove, C. Maroli, V. Petrillo, M. Romè, Luca Serafini (*INFN Milano, Milano*), D. Levi, Mario Mattioli, G. Medici (*INFN Roma, Roma*), L. Catani, E. Chiadroni, Sergio Tazzari (*INFN, Roma*), Ahmed Al-Shamma'a, Sergio Bertolucci, M.E. Biagini, Caterina Biscari, R. Boni, Manuela Boscolo, Michele Castellano, A. Clozza, G. Di Pirro, A. Drago, A. Esposito, Massimo Ferrario, V. Fusco, A. Gallo, A. Ghigo, Susanna Guiducci, M. Incurvati, C. Ligi, F. Marcellini, Mauro Migliorati, C. Milardi, Luigi Palumbo, L. Pellegrino, Miro Preger, P. Raimondi, R. Ricci, C. Sanelli, Mario Serio, F. Sgamma, Bruno Spataro, A. Stecchi, A. Stella, Franco Tazzioli, Cristina Vaccarezza, Mario Vescovi, C. Vicario, M. Zobov (*INFN/LNF, Frascati (Roma)*), A. Cianchi, A. D'Angelo, R. Di Salvo, A. Fantini, D. Moricciani, Carlo Schaerf (*Rome University Tor Vergata, Roma*), D. Dowell, Paul J Emma, C. Limborg, D. T. Palmer (*SLAC, Menlo Park, California*), James Rosenzweig, Gil Travish (*UCLA, Los Angeles, California*), Sven Reiche (*UCLA/DPA, Los Angeles - California*)

We review the status of FEL source activity of the on going SPARC FEL experiment, developed within the framework of a collaboration among ENEA, CNR, INFN, INFM, Sincrotrone Trieste and University of Rome Tor Vergata. The project is aimed at realising a SASE FEL source, operating in the visible (around 500 nm), with an extended range of tunability down to the VUV (100nm) by the use of the mechanism of non-linear harmonic generation. The development of the relevant activities foresees the realisation of an advanced 150 MeV photo-injector source, aimed at producing a high brightness electron beams, needed to drive a SASE-FEL experiment and a 12 m long undulator. We present the status of the design and construction of the injector, of the undulator and of the e-beam transport line. In particular we discuss the choice of the project parameters, their optimisation and the sensitivity of the SPARC performance to any parameter variation. We will show, using start to-end simulations, what is the impact of the e-beam and of the undulator parameters on the characteristics of the output laser field and in particular on the amount of the non linearly generated power at higher harmonics.

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Superradiance and Stimulated Superradiance at Zero-Slippage Conditions

MOPOS28

Yuri Lurie, Yosef Pinhasi, Zakir F. Seidov, Asher Yahalom (*The College of Judea and Samaria, Ariel*), Egor Dyunin, Avraham Gover (*University of Tel-Aviv, Tel-Aviv*)

When the electron beam bunch duration is shorter than an optical period, all electrons emit in the wiggler coherent synchrotron radiation wavepackets that are in phase with each other. The resultant superradiant radiation power is then proportional to the number of electrons in the bunch squared. With present state of the art photocathode e-gun injectors, ftSec-pSec duration e-beam bunches enable generation of intense superradiant radiation pulses in the mm-wave and THz spectral regimes. In free space, the optical pulse duration is determined by the slippage effect. It is possible, though, to attain ultra-short coherent radiation pulses of high instantaneous power, if the interaction takes place in a dispersive waveguide at the "zero-slippage" (grazing intersection) condition: v_z=v_g. An interesting situation is encountered, when the superradiant emission takes place in an optical resonator, and the e-beam bunch repetition rate is matched to the round trip time of the generated optical pulses. This specific FEL regime of oscillations at the zero-slippage condition is analyzed theoretically and numerically in the framework of our space-frequency 3D approach.

Analytical Solution of Phase Space Evolution of Electrons in a SASE FEL

MOPOS29

Nobuyuki Nishimori (*JAERI/FEL, Ibaraki-ken*)

The phase space evolution of electrons in a self-amplified spontaneous emission (SASE) FEL operating in the linear regime before saturation is solved analytically from the one dimensional (1D) FEL equaiton. The analytical solution agrees well with a time-dependent numerical simulation which solves the 1D FEL equation in an exact manner and includes a shot-noise effect. The radiation field reaches saturation when the optimum bunching of the electrons is formed on the scale of the resonant wavelength. The optimum bunching leads to the well known saturation condition ρ N_w 1.

MOPOS30 Analysis of Intensity Fluctuations of SASE using the AR Model

Ryukou Kato, Goro Isoyama, Shigeru Kashiwagi (*ISIR, Osaka*), Hironao Sakaki (*J-PARC, Ibaraki-ken*)

We are conducting experimental study on Self-Amplified Spontaneous Emission (SASE) in the far-infrared region using the L-band linac at the Institute of Scientific and Industrial Research (ISIR), Osaka University. The intensity of SASE fluctuates intrinsically because the number of coherent optical pulses generated in an electron bunch is limited. In the actual system, however, another factor producing intensity fluctuations also shows up, which is instability of the linac. Generally speaking, it is difficult to distinguish contributions of these two factors in measured intensity fluctuations. We have applied the autoregressive (AR) model, which is one of the techniques of statistical analysis, to exclude contributions of linac instability from measured data. In the AR model, the present data can be expressed with a linear combination of the past data plus white noise. In the analysis, contributions of the linac instability are identified with the AR model and can be subtracted from the measured data of SASE, so that white noise remains, which is due to intrinsic fluctuations of SASE. In this paper, we will report results of analysis of intensity fluctuations of SASE measured at ISIR, Osaka University, using the AR model.

MOPOS31 The Design of a Free Electron Laser System Using a System Dynamics Model

Eiichi Nishimura (*METI, Tokyo*), Kousuke Nishimura (*HU, Hiraoka-cho*)

We have designed a free electron laser system using a system dynamics model based on the STELLA software. System dynamics has been developed by Jay W, Forrester at MIT in 1956. This is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems. The system dynamic software for a modern personal computer provides a simple icon-based language that enables us easily to construct our understanding of complex phenomena. So, we tried to apply the software to designing a free electron laser system containing many parameters which are related each other complexly. An upstream flow icon

in the system dynamics model, for example, denotes the single pass gain in an optical cavity. Then, the stock icon corresponding to the flow icon gives the intensities of the free electron lasers in the optical cavity. The information provided from the computation was compared with that obtained experimentally in lasing experiments. We will discuss these results in detail at the meeting.

The METI has no concern in this work which has been done privately for a poster session at the meeting.

Behaviour of Electron Beam in Combined a Self-Generated Field and a Reversed Guide Field in the Helical Wiggler

MOPOS32

Soon-Kwon Nam, Ki-Bum Kim (*Kangwon National University, Kangwon-Do*)

We have studied behaviour of electron beam in combined a self-generated field and a reversed axial-guide field in the tapered helical wiggler. The divergence of electron beam is caused by a three-dimensional effect on the off-axis electrons and self-generated fields. In order to reduce the electron beam loss, we employ a tapered and reversed axial-guide magnetic field. Evolution of energy spread and emittance of electron beam are investigated using three dimensional simulation. Beam cross-section, transverse momentum variation and cross-section view of electron beam are calculated along the z axis. The electron beam loss is reduced by optimizing the magnetic field strength and tapering parameter of reversed axial guide field.

Evolution of Electron Beam in the Tapered Planar Wiggler

MOPOS33

Soon-Kwon Nam, Ki-Bum Kim (*Kangwon National University, Kangwon-Do*)

We have investigated the evolution of electron beam in the tapered planar wiggler field with a axial-guide field, self-electric fields, and self-magnetic fields. In order to suppress the divergence of emittance and energy spread of the electron beam by the three-dimensional effects on the off-axis electrons and a self-generated field effect,the wiggler field was tapered and the reversed axial-guide magnetic field was applied. We calculate the emittance, transverse trajectories

and Fourier transfomation of electron beam using three dimensional simulation by optimizing the magnetic field strength, a tapering parameter and self-field parameters. This method could be expected to enhance the gain and efficiency compared to those of a uniform axial-guide field and a untapered wiggler in a free-electron laser.

MOPOS34 Linac Lattice and Beam Dynamics for X-ray FEL at PAL

Eun-San Kim (*PAL, Pohang*), Moohyun Yoon (*POSTECH, Pohang, Kyungbuk*)

Lattice optimization of 3 GeV linac and studies on the beam dynamics for X-ray FEL at PAL are presented. Investigation of microbunching instability due to coherent synchrotron radiation and wake fields in the PAL linac is also given.

MOPOS35 Investigation on Machine Tolerances in FEL Performance of PAL-XFEL

Eun-San Kim, Sanghoon Nam, Jong-Seok Oh (*PAL, Pohang*), Moohyun Yoon (*POSTECH, Pohang, Kyungbuk*)

We present simulation results on investigation of the emittance dilution in the 3 GeV linac and undulators for PAL-XFEL. For this investigation, rf phase errors, misalignment, wakefields and magnetic field errors are considered. Dependencies of FEL performance on these tolerances are estimated.

MOPOS36 Design Study on 0.3-nm PAL-XFEL

Jong-Seok Oh (*PAL, Pohang*), Yujong Kim (*DESY, Hamburg*), In-Soo Ko, Won Namkung (*POSTECH, Pohang, Kyungbuk*)

PAL is operating a 2.5-GeV electron linac as a full-energy injector to the PLS storage ring. The PAL linac can be converted to a SASE-XFEL facility (PAL-XFEL) that supplies coherent X-rays down to 0.3-nm wavelength. It requires a 3-GeV driver linac and a 60-m long in-vacuum undulator with a 3-mm gap and a 12.5-mm period to realize a hard X-ray SASE-FEL. The linac should supply highly bright beams with emittance of 1.5 mm-mrad, a peak current of 4 kA, and a low energy spread of 0.02%. FEL performance is very sensitive to electron beam parameters. The beam quality is degraded along the undulator trajectory due to the energy loss and the wake field. Also the FEL gain is reduced by errors in the undulator fields and

beam trajectories. The preliminary design details for the 0.3-nm PAL-XFEL are presented with parametric analysis.

Design Study of Low-Emittance Injector for SASE-XFEL at PAL

MOPOS37

Sungju Park, Sunggi Baik, Jung Yun Huang, In-Soo Ko, Sanghoon Nam, Jong-Seok Oh (*PAL, Pohang*), Jangho Park, Kiwan Park, Moohyun Yoon (*POSTECH, Pohang, Kyungbuk*)

We report on the design study of the low-emittance injector for the SASE-XFEL that is being considered as a possible choice for the next-generation light sources at the Pohang Accelerator Laboratory, POSTECH. Using the PARMELA code, beam dynamics simulations were performed aiming to achieve the invariant-envelope matching at booster entrance, and to insure beam emittance < 1 mm.mrad (at 1-nC bunch charge) at the injector end. We also utilized the MAGIC code for analyzing beam dynamics inside the RF-gun cavities and to confirm the part of PARMELA simulations. Hardware design was done with possible implementation of high-Q.E. photocathode, which could reduce burdens imposed on laser system, thus improving overall system stability and reliability.

Work supported by the MOST and POSCO, Korea

Optimization of a Soft X-Ray SASE-FEL Parameters at Pohang Accelerator Laboratory

MOPOS38

Moohyun Yoon (*POSTECH, Pohang, Kyungbuk*), Eun-San Kim (*PAL, Pohang*)

A free-electron laser (FEL) based on self-amplified spontaneous emission has been designed. This FEL is utilizing the existing 2.5 GeV electron linear accelerator at Pohang Accelerator Laboratory (PAL). The radiation wavelength was chosen to be in the water-window region 3-4 nm which can be used for biological imaging. In this paper, it is shown that the PAL is particularly suited for this wavelength if the existing linear accelerator is employed without having major modification. For 4 nm wavelength, the saturated power is shown to be 12 GW with a saturation length of about 25 m.

MOPOS39 The Effect of Liner Errors on the Gain of a Cerenkov FEL

Isabel de la Fuente, Peter van der Slot (*UTWENTE, Enschede*)

It is well known that wiggler errors can degrade the gain of a FEL. A similar process takes places in a Cerenkov FEL where the phase velocity of the amplified EM wave is determined by parameters of the dielectric liner. Thus deviations in the inner radius (R_d) of the liner will result in fluctuations of the phase velocity of the EM wave. E.g., for a quartz liner (ϵ_r=4.4) with R_d = 1.5 mm and outer radius of 4 mm, the derivative of the longitudinal wavenumber with respect to R_d is about 10^5 m^{-2} for a frequency of 50 GHz. Thus fluctuations in the R_d induce phase fluctuations that may degrade the gain of a Cerenkov FEL. In contrast to the undulator FEL, where the relative phase fluctuations are a result from deviations in the electron trajectories, the phase fluctuations are a result of pertubations in the radiation field for a Cerenkov FEL. As an example of the influence of pertubations in the inner radius of the liner on the gain we will present results of an analysis for a 100 kV Cerenkov FEL operating at a frequency of 50 GHz.

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MOPOS40 Simulation Investigation of the Detuning Curve

Xiaojian Shu, Yuhuan Dou, Yuanzhang Wang (*IAP, Beijing*)

The detuning curves of free-electron laser oscillators are calculated with the help of our three-dimensional code, which are compared with those from one-dimensional simulations and supermode theory, and the experiments. The influence of the optical guiding and other three-dimensional effects on the detuning curve is studied. It is found that the length of the detuning curve from three-dimemsional simulations is shorter than that from one-dimensional simulations and supermode theroy.

Optical Klystron Amplifier Free Electron Laser MOPOS41

Qika Jia (*USTC/NSRL, Hefei, Anhui*)

The evolution of the optical field for an optical klystron(OK) free electron laser is described analytically for both low gain case and high gain case. The harmonic optical klystron (HOK) in which the second undulator is resonant on the higher harmonic of the first undulator is analysed as a harmonic amplifier. The optical field evolution equation of the HOK is derived analytically for both CHG mode (Coherent Harmonic Generation, the quadratic gain regime) and HGHG mode (High Gain Harmonic Generation, the exponential gain regime), the effects of energy spread, energy modulation and dispersion in the whole process are considered. For the quadratic gain regime, the analytical formula of CHG mode is given and compared with that of OK case. For the exponential gain regime, the linear theory of HGHG mode is given and discussed.

Parameter Analysis For A High-Gain Harmonic Generation FEL By Numerical Calculation Based On 1D Theory MOPOS42

Yuhui Li, Qika Jia, Shancai Zhang (*USTC/NSRL, Hefei, Anhui*)

The high-gain harmonic generation (HGHG) free-electron laser (FEL) is an important candidate for a fourth-generation light source. Lots of theoretical work has been performed. Recently a further 1D theory about HGHG FEL has been developed. It considers the effects of different parameters for the whole process. An initial program based on this theory has been made. In this paper, a brief comparison of the results from this 1D program and from TDA (3D code) is discussed. It also analyses the parameters for Shanghai deep ultra violate free-electron laser source (SDUV-FEL), including electron beam energy spread, seed laser power, strength of dispersion section etc.

Harmonic Operation of the SDUV HGHG-FEL MOPOS43

Zhimin Dai, Dongguo Li, Yi Xu, Xiaofeng Zhao, Zhentang Zhao (*SINAP, Jiading, Shanghai*)

In this paper, we study the harmonic operation of the SDUV HGHG-FEL (Phase-I), which consists of 160MeV linac, and two un-

dulators separated by a dispersion section. A laser light at 352nm is injected into the first undulator to modulate the energy of the electron beam. This is followed by a dispersion section to produce spatial bunching at 352nm, and a second undulator which fundamental is resonant to 264nm and 3rd harmonic is resonant to 88nm. Upon passing through the second undulator, the prebunched electron beam first radiates coherently at 88nm (i.e., the 3rd harmonic of the second undulator which is integer times of the seeding laser), and then this radiation is exponentially amplified, while the fundamental of the second undulator is allowed to grow from noise. Under proper condition, the output power of the 3rd harmonic may be much higher than that of the fundamental.

MOPOS44 Numerical Simulation of HGHG Operation for Shanghai DUV FEL

Dongguo Li, Zhimin Dai, Xiaofeng Zhao, Zhentang Zhao (*SINAP, Jiading, Shanghai*), Qika Jia, Shancai Zhang (*USTC/NSRL, Hefei, Anhui*)

In present paper, we briefly introduce the numerical simulation for HGHG operation of the Shanghai deep ultra-violet free electron laser source (SDUV-FEL). In this operation, a 264nm seed laser interacts with a 277MeV, 400A, normalized emittance 4mmŒmrad and local energy spread 0.01% electron beam in the first undulator(modulator) with period λ_u=5cm, length 0.8m and K=2.03, where the energy of the electron beam is modulated. Then through a dispersion section with dy/dg 3.47, the energy modulation is converted to spatial bunching. In the second undulator(radiator) with period λ_u=2.5cm, length 10m and K=1.45, the 88nm coherent radiation is generated in the first two gain lengths and then its radiation power is exponentially amplified. The simulation indicates that about several hundred MW 88nm and about 10MW 29.3nm radiation can be produced.

MOPOS45 Start-to-End simulation for the SDUV FEL

Yi Xu, Zhimin Dai, Q. Gu, Dongguo Li, L. Sun, Zhentang Zhao (*SINAP, Jiading, Shanghai*), Jianping Dai (*IHEP Beijing, Beijing*), Qika Jia, Shancai Zhang (*USTC/NSRL, Hefei, Anhui*)

Based upon three codes PARMELA, ELEGANT and GENESIS, the start-to-end simulation of Shanghai DUV FEL is performed. In this

study, the codes PARMELA and ELEGANT are used to track particle distribution from the cathode to the undulator entrance，and the code GENESIS is used to simulate SASE and HGHG FEL process. The study shows, at the entrance of undulator, with more than 300A peak current the electron beam has less than 3um-rad emittance and 0.05% energy spread. In the 260nm SASE FEL simulation, the saturation length is about 9 meters and more than 100MW laser is produced. As in the 88nm HGHG FEL simulation, shorter radiator is needed to reach radiation saturation. These simulation results are well in agreement with the theoretical anticipation.

Design Optimization of the SDUV-FEL Facility MOPOS46

Zhentang Zhao, Zhimin Dai, Q. Gu, D.K. Liu, Xiaofeng Zhao, Qiaogen Zhou (*SINAP, Jiading, Shanghai*), S.Y. Chen, Jianping Dai (*IHEP Beijing, Beijing*), Duohui He, Qika Jia (*USTC/NSRL, Hefei, Anhui*)

The design optimization and R&D for the Shanghai deep ultraviolet free electron laser source (SDUV-FEL) are being carried out under the collaboration among Shanghai Institute of Applied Physics, National Synchrotron Radiation Laboratory and Institute of High Energy Physics. The SDUV-FEL based a 300MeV S-band normal conducting Linac has been designed as an HGHG type high gain FEL facility, since this July its first 100MeV Linac section, constructed in a new building dedicated for this FEL facility, has been being commissioned with a 100kV thermionic gun. The 40MeV photo cathode injector is under integration, and the FEL required beam diagnostics, the magnetic bunch compressor and an undulator section including a modulator undulator, a dispersive section and a radiator undulator, are all under design and development. In this paper, we present the design optimization on the SDUV-FEL facility and report the progress of the facility component developments.

Simulation of FEM Amplifiers: Features in Various Regimes MOPOS47

Artem Elzhov, Elkuno Perelstein, Sergey Sedykh, Anatoly Sergeev (*JINR, Dubna, Moscow Region*), Alim Kaminsky (*JINR/PPL, Dubna, Moscow Region*)

The results of previous experiments with free electron maser amplifiers in high-gain Compton and Raman regimes are analyzed by numerical simulation. Compact quasi-one-dimensional models in

a helical trajectory approximation were employed. A tare on the stationary trajectories due to radiation was inserted. Reasonable agreement between simulation and experimental results get in the regimes with reversed guide magnetic field. A handy means for determination of the basic amplification parameters for possible future experiment is available.

MOPOS48 Modeling of the 200 GHz Superradiance in the Long Electron Pulse Regime

Naum Samuilovich Ginzburg, Roman Markovich Rozental, Alexander Sergeevich Sergeev (*IAP RAS, Nizhny Novgorod*)

By now serious experimental progress was achieved in production of single ultrashort e.m. pulses at centimeter and long millimeter wave bands based on Cherenkov mechanism of superradaince (SR) [1]. The present paper is devoted to study of generation of powerful e.m. pulses at short mm and sub-mm wavebands based on undulator mechanism of SR from intense electron bunches. We studied 200-400 GHz SR in a planar waveguide system in the long electron pulse regime. The simulations are carried out based on averaged self-consistent system of equations which is valid for strong variation of electron energy and transverse momentum [2]. The average equations as well PIC-simulations demonstrated that the 1 MV, 100 A, 600 ps electron bunch in the 2 m long undulator could produce single 10-20 ps SR pulses with power exceeding 35 MW. In accordance with [3] in the long pulse regime the SR pulse peak power increased without saturation with increasing the length of undulator.

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[3] R.Bonifacio, et al. // Phys.Rev.A, 1989, 40(8), 4467.

Improving Selectivity of 1D Bragg Resonator Based on Coupling of Propagating and Locked Waves MOPOS49

Naum Samuilovich Ginzburg, Andrey Malkin, Nikolay Peskov, Alexander Sergeevich Sergeev (*IAP RAS, Nizhny Novgorod*), Artem Elzhov (*JINR, Dubna, Moscow Region*), Alim Kaminsky, Sergey Sedykh (*JINR/PPL, Dubna, Moscow Region*)

A novel 1D Bragg resonator based on coupling propagated and locked (quasi cut-off) modes should be tested in a JINR- IAP FEM-oscillator to improve selectivity over the transverse mode index. In this scheme the electron beam interacts with only propagating wave, and the latter is coupled with a quasi cut-off mode. This coupling can be realized by either helical or azimuthally-symmetric corrugation. The quasi cut-off mode provides the feedback in the system leading to the absolute instability and the self-excitation of the whole system while efficiency in the steady-state regime of generation is almost completely determined by the propagating mode, synchronous to the beam. Analytical consideration and numerical simulation show that the efficiency of such an FEM can be rather high. The main advantage of this scheme is provision of higher selectivity over the transverse mode index than traditional scheme of Bragg FEL that encourage increasing operating frequency for fixed transverse size of the interaction space.

Dynamics of a FEM with a Broadband Feedback and the Twystron-like Interaction Region MOPOS50

Andrey Savilov, Nikolay Peskov (*IAP RAS, Nizhny Novgorod*)

We study the dynamics of a free-electron maser with a feedback system having an infinitely broad frequency band (which could be useful for realization of a frequency-tunable oscillator). In such systems, a lot longitudinal modes compete during the excitation process. If the electron current exceeds some threshold and, therefore, the radiated RF power becomes too high, then the build-up regime of the FEM operation represents a co-generation of several modes*. Thus, the electron efficiency is limited by the danger of losing stability of the single-frequency operation. In this work we study a twystron-like FEM. Similar to the optical klystron**, its interaction region consists of three parts, namely, a short section of the input electron-wave interaction, a quite long bunching section (where the

electron-wave interaction is absent), and an output interaction section (where the bunched electron beam passes the energy to the RF wave). Such modification improves electron-wave interaction and, simultaneously, decreases the number of competing modes. As a result, a significant efficiency enhancement in the stable single-frequency regimes is provided.

* N.S.Ginzburg,A.S.Sergeev.
*N.A.Vinokurov,A.N.Skrinsky.

MOPOS51 Design considerations for the coherent radiator, FEL, in the MAX IV proposal

Sverker Werin, Åke Andersson, Mathias Brandin, Mikael Eriksson, Jörgen Larsson, Lars-Johan Lindgren, Hamed Tarawneh (*MAX-lab, Lund*)

The MAX IV proposal is a project for the next Swedish synchrotron radiation source. Currently a design study is produced with funding from the Swedish research council (VR). One half of the project will be a double storage ring (at 3 and 1.5 GeV respectively) but the other half will be a coherent radiator, FEL, based on the 3 GeV injector. The basic FEL solution will consist of a normal conducting linac at 3 GeV which feeds three seeded cascaded optical klystrons and a radiator undulator to produce radiation down to 1.5-3 nm at GW powers. To assure synchronisation the gun laser and the seed laser share initial laser and amplifier. This basic system can be enhanced in various ways which will be discussed .

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Swedish research council (VR)

MOPOS52 The Landau Equation for a Single-Pass Steady-State Free-Electron Laser: an Analytical Derivation

Duccio Fanelli (*MTC, Stockholm*), Thierry Dauxois (*ENS-Lyon, Lyon*), Giovanni De Ninno (*Elettra, Basovizza, Trieste*), Julien Barre' (*LANL, Los Alamos, New Mexico*), Stefano Ruffo (*Unifi-DI, Firenze*)

The non-linear dynamics of a single-pass, high-gain free-electron laser is analytically studied in the framework of the Vlasov-wave

picture. A multiple time scale method allows us to obtain the well known non-linear Landau equation for the complex amplitude of the unstable mode, which hence exhibits limit cycle behaviour. The coefficients of the equation are analytically determined under the hypothesis of a bump-on-tail profile of the initial electron-beam distribution. Possible extensions of this approach are also discussed

Stimulated X-radiation of Relativistic Electrons in the Field of Plane Light Wave MOPOS53

Andrey Yurij Zelinsky, Illya Drebot, Yurij Grigor'ev, Olga Zvonarjova
(*NSC/KIPT, Kharkov*)

In the work the equation of electron motion in the summarized fields of initial plane light wave and produced X-radiation was integrated approximately. Stimulated radiation is initiated due to interaction of electrons with the X-radiation produced by scattering of a light wave with relativistic electrons (Compton scattering).In the work the expressions for frequency and total power of stimulated radiation has been calculated. A possibility of electrons grouping is investigated.

Theoretical Investigations of the Attenuation in Cerenkov FEM Oscillators MOPOS54

Ahmed Al-Shamma'a, James Lucas, Robert Stuart (*UoL-EEE, Liverpool*)

The possibility of using the cylindrical Cherenkov structure as an industrial microwave source has been considered recently. Such a structure would be simple to construct, consisting only of a metal tube fitted with a dielectric liner, as compared with the relative complexity of the helix of a travelling wave tube for example. However, such a device should be driven by an electron beam accelerated by a voltage (<100kV); this then limits operation to frequencies well above the point where the dispersion curve and vacuum light line intersect. In this region, the TM01 mode field pattern is such that the longitudinal electric and the tangential magnetic fields are concentrated near the inner surface of the metal tube. This reduces the strength of the interaction between the electromagnetic wave and a solid electron beam, but possibly more of a problem is the much greater attenuation in the Cherenkov structure than in an unloaded

guide. This leads to important practical difficulties such as the reduction in efficiency, the removal of heat from the dielectric and the increase in the electron beam current necessary for oscillation. An example of such calculation will be presented.

MOPOS55 **An FEL Project at CAMD**

Yanshan Wang (*LSU/CAMD, Baton Rouge, Louisiana*)

Based on 200 MeV linac, an injector of Center of Advanced Microstructures and Devices (CAMD) 1.3 GeV accelerator at Louisiana State University*, an FEL project will be proposed and designed. In the paper, we discuss the design and output radiation parameters for the DUV-FEL at CAMD, which will generate coherent light using SASE. The result of FEL calculation and the design of the major components are presented.

* Y. Wang et al., Proc. of the Particle Accelerator Conference, 2003,p2892-2894.

Supported by State of Louisiana, USA

MOPOS56 **Noise and Temporal Coherence Evolution through a Multi-Stage Harmonic Cascade FEL**

William M Fawley (*LBNL/CBP, Berkeley, California*), William S Graves (*MIT/BLAC, Middleton, Massachusetts*)

Generation of fully coherent x-ray pulses from a seeded harmonic cascade FEL offers many benefits, including improved power and wavelength stability. Longitudinal coherence also enables the generation of either very short pulses (< 1 fs) or narrow spectral widths (few meV). The output coherence is most sensitive to noise in the long wavelength stages due to the high harmonic number required to reach x-ray wavelengths. The primary noise sources are seed laser imperfections and amplified spontaneous emission. Temporal variations in electron beam properties can also broaden the output spectrum, producing time-correlated phase and amplitude variations. We present analysis and time-dependent FEL simulations that explore the noise evolution in configurations of interest. We

find that slippage effects in the early cascade stages can delay noise growth. Also, the growth rates of amplitude and phase noise can differ significantly. By operating the early harmonic stages as frequency multipliers without gain, we find it possible to generate nearly transform-limited x-ray pulses starting from a UV seed pulse.

Work supported in part by U.S. Dept. of Energy under Contract DE-AC03-76SF0098

Analytic Model of Harmonic Generation in the Low-Gain FEL Regime

MOPOS57

Gregory Penn (*LBNL/CBP, Berkeley, California*), Jonathan Wurtele (*LBNL, Berkeley, California*), Matthias Reinsch (*UC Berkeley, Berkeley*)

Harmonic generation using free electron lasers (FELs) requires two undulators: the first generates energy modulation through the inverse FEL effect; the second undulator uses the subsequently bunched beam to radiate at a higher harmonic. These processes are currently evaluated using extensive calculations or simulation codes which can be slow to evaluate and difficult to set up. We describe a simple algorithm to predict the output of a harmonic generation beamline in the low-gain FEL regime based on trial functions for the output radiation. Full three-dimensional effects are included. This method has been implemented as a Mathematica script which runs rapidly and can be generalized to include effects such as asymmetric beams and misalignments. This method is compared with simulation results using the FEL code GENESIS, both for single stages of harmonic generation and to model the design of LUX, a proposed facility for ultra-short X-ray pulses, where multiple stages upshift the input laser frequency by factors of up to 200.

Work supported by the Director, Office of Science, U.S. Dept. of Energy under Contract DE-AC03-76SF0098.

MOPOS58 Simulations of Giant Pulses in Storage Ring FELs

Samadrita Roychowdhury (*Duke University, Durham, North Carolina*), Vladimir Litvinenko (*BNL, Upton, Long Island, New York*)

We present the results of simulation of giant pulses in two storage ring FEL: the OK-4/Duke FEL and ELETTRA FEL using self-consistent cosed #fel3D and #uvfel. We use the range of the e-beam parameters used in recent experiments for coherent harmonic generation. We compare some selected experimental results with simulations.

MOPOS59 Coherent Radiation Effects in the LCLS Undulator

Sven Reiche (*UCLA/DPA, Los Angeles - California*), Zhirong Huang (*SLAC, Menlo Park, California*)

For X-ray Free-Electron Lasers, a change in the electron energy while amplifying the FEL radiation can shift the resonance condition out of the bandwidth of the FEL. The largest sources of energy loss is incoherent undulator radiation. Because the loss per electron depends only on the undulator parameters and the beam energy, which are fixed for a given resonant wavelength, the average energy loss can be compensated for by a fixed taper of the undulator. Coherent radiation has a strong enhancement proportional to the number of electrons in the bunch for wavelengths comparable to or longer than the bunch dimension or bunch sub-structures. If the coherent loss is comparable to that of the incoherent the required taper depends on the bunch charge and the applied compression scheme and a change of these parameters would require a change of the taper. This imposes a limitation on the operation of FELs, where the taper can only be adjusted manually. In this presentation we analyze the coherent emission of undulator radiation and transition undulator radiation for LCLS, and estimate the effect of the energy spread by the coherent synchrotron radiation within the undulator.

MOPOS60 Spontaneous Radiation Background Calculation for LCLS

Sven Reiche (*UCLA/DPA, Los Angeles - California*)

The intensity of undulator radiation, not amplified by the FEL interaction, can be larger than the maximum FEL signal in the case

of an X-ray FEL. In the commissioning of a SASE FEL it is essential to extract an amplified signal early to diagnose eventual misalignment of undulator modules or errors in the undulator field strength. We developed a numerical code to calculate the radiation pattern at any position behind a multi-segmented undulator with arbitrary spacing and field profiles. The output can be run through numerical spatial and frequency filters to model the radiation beam transport and diagnostic. In this presentation we estimate the expected background signal for the FEL diagnostic and at what point along the undulator the FEL signal can be separated from the background. We also discusses how much information on the undulator field and alignment can be obtained from the incoherent radiation signal itself.

The VISA II and Chicane Compression Experiments at BNL ATF

MOPOS61

James Rosenzweig, Ronald Barkley Agustsson, Pedro Frigola, Alex Murokh, Claudio Pellegrini, Gil Travish (*UCLA, Los Angeles, California*), Marcus Babzien, Ilan Ben-Zvi, Vladimir Litvinenko, Vitaly Yakimenko (*BNL, Upton, Long Island, New York*), Massimo Ferrario, Luigi Palumbo, C. Vicario (*INFN/LNF, Frascati (Roma)*), Gerard Andonian, Sven Reiche (*UCLA/DPA, Los Angeles - California*)

A joint program in ultra-short electron beam and FEL physics is now underway in the VISA II and UCLA Chicane Compressor projects at BNL ATF. The goals of these experiments are to explore new physical regimes relevant to creation of ultra-short pulse SASE FELs. The VISA II experiment entails use of a chirped beam to drive a high gain SASE FEL, which is diagnosed using an advanced FROG technique. Implemenation of sextupole correction of the longitudinal aberrations affecting the high energy spread chirped beam during transport to the VISA undulator are discussed. In the compressor experiments, the effects of compression of the electron beam to 20 microns rms on the beam's transverse phase space and longitudinal phase space are examined. Detailed studies of the coherent edge radiation produced inside of the compressor chicane are now being implemented. Start-to-end simulations, including radiation diagnostics, as well as initial experimental results, are reported.

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MOPOS62 Phase Matching Segmented Wigglers In Free-Electron Lasers

Henry Freund (*SAIC McLean, McLean*)

Since many free-electron lasers use a segmented undulator, it is important to understand the requirements on phase matching between the undulators. A simulation that self-consistently determines the phase slippage between the light and the electrons is used to study these effects. The simulation is found to be in agreement with an analytic formulation of the phase slippage. A seeded x-ray free-electron laser is studied which makes use of a segmented undulator with quadrupoles in the gaps to provide strong focusing. Optimal performance is found for gap lengths corresponding to a phase slippage within about 20% of a wavelength through a unit cell consisting of an undulator and gap.

Joint Technology Office, ONR, NAVSEA

MOPOS63 Generation of GW-level, sub-Angstrom Radiation in the LCLS using a Second-Stage Harmonic Radiator

Zhirong Huang (*SLAC, Menlo Park, California*), Sven Reiche (*UCLA/DPA, Los Angeles - California*)

Electron beams are strongly microbunched near the high-gain FEL saturation with a rich harmonic content in the beam current. While the coherent harmonic emission is possible in a planar undulator, the third harmonic radiation typically dominates with about 1% of the fundamental power at saturation. In this paper, we discuss the second harmonic emission in the main undulator induced by effects of finite beam size and angular spread. We show that by a suitable design of an second-stage undulator with its fundamental wavelength tuned to the second harmonic of the main undulator, coherent second harmonic radiation much more intense than the third harmonic is emitted. Numerical simulations and applications to the LCLS project aiming at generating GW-level and sub-Angstrom x-ray pulses are presented.

Emittance Measurements from a 1.6 cell S-band Photocathode RF Gun with a Mg Cathode

MOPOS64

John Schmerge, John Castro, D. Dowell, Steve Gierman (*SLAC/LCLS, Menlo Park, California*), Jym Clendenin (*SLAC/AD, Menlo Park, California*)

Previously we had shown transverse slice and longitudinal emittance measurements using a 1.6 cell S-band rf gun with a Cu cathode [1]. Slice emittances at low charge (15 pC) set an upper limit of 0.6 microns per mm radius. Previous measurements were limited to a maximum of 600 pC total charge due to the relatively low quantum efficiency (5 10-5) of the copper cathodes. In order to increase the available charge to the nC level, we have installed a Mg cathode. The lower work function of Mg compared to Cu increases the quantum efficiency for a fixed laser wavelength but also potentially increases the thermal emittance. Emittance measurements with the Mg cathode will be presented and compared with previous Cu cathode measurements.

[1] D. H. Dowell, P. R. Bolton, J.E. Clendenin, P. Emma, S.M. Gierman, W.S. Graves, C.G. Limborg, B.F. Murphy, J.F. Schmerge, "Slice emittance measurements at the SLAC Gun Test Facility", NIM A507(2003)327-330.

Work supported by Department of Energy contract DE-AC03-76SF00515.

Short Rayleigh Length Free Electron Laser Simulations in Expanding Coordinates

MOPOS65

Robert Armstead, Joseph Blau, William Colson (*NPS, Monterey, CA*)

For compact short-Rayleigh length FELs, the area of the optical beam can be thousands of times greater at the mirrors than at the beam waist. A fixed numerical grid of sufficient resolution to represent the narrow mode at the waist and the broad mode at the mirrors would be prohibitively large. To accommodate this extreme change of scale with no loss of information, we employ a coordinate system that expands with the diffracting optical mode. The simulation

using the new expanding coordinates has been validated by comparison to analytical cold-cavity theory, and is now used to simulate short-Rayleigh length FELs.

MOPOS66 Optical Mode Distortion in a Short Rayleigh Length Free Electron Laser

Joseph Blau, William Colson, Robb Mansfield, Sean Niles, Brett Williams (*NPS, Monterey, CA*)

A short-Rayleigh length FEL will operate primarily in the fundamental mode with a Gaussian profile that is narrow at the waist and broad at the mirrors. The gain medium will distort the optical mode profile and produce higher-order modes that will expand more rapidly than the fundamental. Wavefront propagation simulations are used to study the higher-order modes, as the cavity length, Rayleigh length, electron beam current and radius, undulator taper, and the focus positions of the optical mode and electron beam are varied.

MOPOS67 The Upgrade of the DUV-FEL Facility at the BNL

Xijie Wang, Henrik Loos, James Murphy, George Rakowsky, James Rose, Timur Shaftan, Brian Sheehy, Yuzhen Shen, John Skaritka, Zilu Wu, Li-Hua Yu (*BNL/NSLS, Upton, Long Island, New York*)

The DUV-FEL at BNL, is the world's only facility dedicated to laser-seeded FEL R&D and its applications. The HGHG at the DUV-FEL reached saturation at 266 nm with 800 nm seeding [1] in 2002. Since then, the first chemical science experiment - ion pair imaging, was successfully completed [2].The DUV-FEL linac is being upgraded from 200 to 300 MeV to enable the HGHG FEL to produce 100 μJ pulses of 100 nm light. This will establish the DUV FEL as a premier user facility for XUV radiation. The upgraded facility will also enable several critical R&Ds for a future X-ray FEL based on HGHG, such as cascaded HGHG and higher harmonic HGHG (n>5). The upgraded HGHG will operate at the 4th harmonic with the seed laser at 400nm. The increase of the electron beam energy will be accomplished by installing a 5th linac cavity and two 45 MW klystrons. New modulator and dispersion sections vacuum chambers will be manufactured to accommodate new matching optics and

8th harmonic HGHG. The status of the DUV-FEL upgrade and other FEL R&D opportunities will be discussed.

[1] L. H. Yu et al, Phy. Rev. Lett. 91, 074801-1 (2003).
[2] W. Li et al, Phy. Rev. Lett. 92, 083002-1(2004).

Design of a Compact, Optically-Guided, Pinched, Megawatt Class FEL MOPOS68

Phillip Sprangle (*NRL/PPD, Washington, DC*), Bahman Hafizi (*Icarus, Bethesda, MD*)

A conceptual design for a compact, megawatt class FEL operating at 1 micron is presented. The proposed FEL consists of an optically guided, pinched amplifier configuration driven by an RF linac. The gain length, efficiency, electron pulse slippage and the distance between the wiggler and first relay mirror are determined for a megawatt class design. Of particular concern in the design is the overall length of the optical system, i.e., wiggler length and distance to the first relay mirror. In the present design the wiggler length is 1 meter and the distance between the first relay mirror and the wiggler is determined by the average intensity damage threshold on the mirror. By focusing the electron beam, the optical beam can be pinched upon exiting the wiggler. The pinched optical beam has a reduced Rayleigh range which permits the first relay mirror to be relatively close to the wiggler. By pinching the optical beam and employing grazing incidence the first relay mirror can be located within 3 meters of the wiggler.

Work supported by ONR

Self-field and Wiggler Effects on the Growth Rate of a Raman Free-electron Laser MOPOS69

Behrouz Maraghechi (*IPM, Tehran ; AUT, Tehran*), Hossein Aghahosseini (*AUT, Tehran*), Amir Kordbacheh (*AUT, Tehran ; IPM, Tehran*)

A relativistic theory for Raman backscattering in the beam frame of electrons is presented and is used to find the growth rate of a free-electron laser (FEL), in the Raman regime. A one dimensional

helical wiggler and an axial magnetic field are considered. The effects of static self-electric and self-magnetic fields, induced by the steady-state charge density and currents of the non-neutral electron beam, are taken into account to find the steady-state trajectories. The wiggler effects on the linear dispersion relations of the space-charge wave and radiation are included in the analysis. A numerical computation is conducted to compare the growth rate of the excited waves with nonrelativistic treatment. It was found that self-field effects increase the growth rate in the group II orbits and decrease it in the group I orbits. However, the wiggler effects on growth rate are stronger and increase the growth rate on both group I and group II orbits. The discontinuity, due to the cyclotron resonance with the radiation, is removed by including the self-fields or wiggler effects.

MOPOS70 **Quantum Signatures in X-ray Compton Laser***

Hamlet Karo Avetissian, Garnik Felix Mkrtchian (*YSU, Yerevan*)

In contrast with the conventional lasers FEL is usually reckoned as a classical device. However this is not the universal property of FEL. Particularly for X-ray FEL if amplifying photon energy is larger or comparable to resonance widths due to the beam spreads or the finite interaction length, then the quantum effects may play a significant role [1]. The recent advancement of high brightness particle and laser beams technology makes achievable the fulfillment of this condition in the scheme of X-ray Backscatter Compton laser. Hence, it is necessary to have the entire quantum theory of FEL. In this work we derive the self consistent set of equations for X-ray quantum FEL arising from the Wigner function formalism, which is reduced to Maxwell-Vlasov equations in the quasiclassical limit. As the most effective case the hydrodynamic instability of a cold electron beam is considered and the criteria is obtained, which shows either High Gain or quantum regime of generation takes place depending on the beam parameters and amplifying photon energy.

[1] H.K. Avetissian, G.F. Mkrtchian, Phys. Rev. E 65, 046505 (2002).

*This work was supported by NFSAT Grant No. PH 082-02/CRDF 12023.

Chaotic Particle Dynamic in Free-Electron Lasers With Coaxial Wiggler

MOPOS71

Bizhan Farokhi (*BASU Physics, Hamadan*)

The motion of a relativistic test electron in FEL can be altered significantly by the equilibrium self-field effects produced by the beam space charge and current and by the transvers an ideal coaxial-wiggler field and uniform axial-guide field. We have investigated the group II orbits and finally have found that orbits become chaotic at sufficiently high beam density. We have changed beam radii, density, intensity of magnetic field as a parameter for finding chaotic area. An analytical estimate of the threshold value of the self-field parameter for the onset of chaos is obtaied and found to be in good agreement with computer simulations. The threshold value of the wiggler amplitude for the onset of chaos is estimated analytically and confirmed by computer simulations for spatial case where self-field effects are negligibly small. It is shown that the particle motion becomes chaotic on a time scale comparable with the beam transit time through a few wiggler periods.

References

1- C.Chen, and R.C. Davidson, phys. Fluids B 2,171,(1990)
2- C.Chen , and R.C. Davidson,phys Rev.A,43,5541,(1991).
3- B. Maraghechi, B. Farokhi,J.E.Willett, Physical Review E, Vol. 61, 7046, (2000).

Short Pulse Amplification in FEL

MOPOS72

Sergei Georgii Oganesyan (*OSG, Yerevan*)

We have considered the problem of amplification of a pulse of arbitrary duration in an undulator FEL. We have studied the case when the undulator is long and electron beams have small density. It is shown that the system gain is determined by a total width, which includes the e-beam energy spread width and the pulse frequency spread width. The theory made it possible to introduce a conception

of a pulse characteristic duration. A pulse is long if its duration is more than the quantity. The gain of long pulses is determined, as usually, by the electron energy width. Pulses are short in the opposite case. It was obtained their gains depending only on the frequency width (i.e., on the pulse duration).

MOPOS73 Cherenkov Oscillator Based on Stimulated Spin-Flip Effect

Sergei Georgii Oganesyan (*OSG, Yerevan*)

An analysis performed in Ref. [1] showed that in according to the angular momentum conservation law, an electron beam, which is fully polarized along a suitable direction, could only radiate photons due to the Cherenkov spin phenomenon. We have employed the effect for developing a theory of a spin-flip oscillator. The latter includes a plane Fabry-Perot resonator filled with a dielectric and an electron beam that falls at the right angle to the resonator walls. Basing on a quantum electrodynamics approach [2] we have written an equation that describes the formation of a radiation from a spontaneous noise. In general case the oscillator output depends on the electron beam polarization degree. The obtained result demonstrates that the free electron oscillator could be employed for such fine experiment as detection and measuring of the electron beam polarization.

[1] S.G. Oganesyan, N.H. Sargsyan, Phys. Lett. A 140,249 (1989).
[2] S.G. Oganesyan, Phys. Rev. E 56, 4683 (1997).

FEL Technology I

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TUAxS

Sub-Picosecond Electron Bunch Length Measurements at SLAC

TUAIS01

Patrick Krejcik, Ron Akre (*SLAC/LCLS, Menlo Park, California*), Rasmus Ischebeck, Holger Schlarb (*DESY, Hamburg*), Paul J Emma, Mark J. Hogan (*SLAC, Menlo Park, California*), Jerry Hastings (*SLAC/SSRL, Menlo Park, California*)

The Sub-Picosecond Pulse Source (SPPS) built at SLAC uses a magnetic chicane to compress electron bunches to extremely short bunch lengths. The 28.5-GeV bunches of 3 nC charge transported to the test beam line can be as short as 80 fs fwhm, which poses a considerable instrumentation challenge for measuring the bunch length. This paper reviews the results obtained measuring such short bunches. Several techniques are compared in terms of their degree of invasiveness to the beam, single pulse versus average measurement of many bunches, capability to determine absolute bunch length versus relative measurement, and limits to achieving fs resolution. The techniques developed at SLAC range from a transverse RF deflecting cavity to electro-optic modulation of a fs laser pulse. Coherent radiation from the bunch is also used as a diagnostic of the bunch length. The power spectrum of THz coherent transition radiation is used to control the bunch length on pulse-by-pulse basis. Autocorrelation measurements of the coherent radiation to measure the average bunch length have also given much insight into the issues of propagating the THz radiation through windows and apertures.

Work supported by the U.S. Department of Energy under contract DE-AC03-76SF00515

Bunch Compressors for XFELs against Microbunching Instability and CSR

TUAOS02

Yujong Kim, Martin Dohlus, Klaus Floettmann, Torsten Limberg (*DESY, Hamburg*), Dongchul Son (*KNU, Daegu*)

Recently, we have found that slice beam parameters such as slice emittance and slice energy spread become significantly deteriorated if the microbunching instability is generated by coherent synchrotron radiation in bunch compressors and longitudinal space charge force in the linac and drift. In this paper, we describe a noble bunch

compressor optimization method for XFEL projects to control the possible microbunching instability in the linac.

TUAOS03

Large-Scale Timing Distribution and RF-Synchronization for FEL-Facilities

Jung-Won Kim, Fatih Oemer Ilday, Franz Kaertner, Oliver Muecke, Michael Perrott (*MIT, Cambridge, Massachusetts*), William S Graves, David Moncton, Townsend Zwart (*MIT/BLAC, Middleton, Massachusetts*)

For future advances in accelerator physics in general and seeding of FELs in particular, precise synchronization between seed radiation, low-level RF-systems and photo-injector laser is required. Typical synchronization methods based on direct photodetection are limited by the detector nonlinearities, which lead to amplitude-to-phase conversion and introduce timing jitter. A new synchronization scheme for extraction of low jitter RF-signals from optical pulse trains distributed by mode-locked lasers is proposed. It is robust against photodetector nonlinearities. The scheme is based on a transfer of timing information into an intensity imbalance between the two output beams from a Sagnac-loop interferometer. As a first experimental demonstration, sub-100 fs timing jitter between the extracted 2 GHz RF-signal and the 100 MHz optical pulse train from a mode-locked Ti:sapphire laser is demonstrated. Numerical simulations show that scaling to sub-femtosecond precision is possible. Together with mode-locked fiber lasers and timing stabilized fiber-link, this scheme can be applied for the large-scale precise timing distribution and synchronization of free-electron laser facilities.

ONR, AFOSR, NSF

Real-Time, Non-Destructive, Single-Shot Longitudinal Profile Measurements of Sub-Picosecond Electron Bunches TUAOS04

Giel Berden, Britta Redlich, Lex van der Meer (*FOM Rijnhuizen, Nieuwegein*), Steven Jamison (*Strathclyde University, Glasgow*), Allan Gillespie, Allan MacLeod (*UAD, Dundee*)

A new technique, combining electro-optic detection of the Coulomb field of an electron bunch with single-shot cross-correlation of optical pulses is used to enable single-shot measurements of the electric field profile of sub-picosecond electron bunches. As in our previous "spectral decoding" technique (I. Wilke et al., Phys. Rev. Lett. 88(12) 2002), the electric field of the electron bunch is encoded electro-optically on an optical pulse. However, the new "temporal decoding" method offers a much better time resolution since it overcomes a fundamental time-resolution limit of the spectral decoding method, which arises from the inseparability of time and frequency properties of the probing optical pulse. The temporal decoding technique has been applied to the measurement of 50 MeV electron bunches in the FELIX free electron laser, showing the longitudinal profile of single bunches of around 650 fs FWHM. The method is non-destructive and real-time, and therefore ideal for online monitoring of the longitudinal shape of single electron bunches. At FELIX we have used it for real-time optimization of sub-picosecond electron bunches.

Gas-Monitor Detector for FEL Online Photon Beam Diagnostics TUAOS05

Andrei Alekseevich Sorokin (*PTB, Braunschweig ; IOFFE, St. Petersburg*), Joseph Feldhaus, Ulrich Hahn, Kai Tiedtke (*DESY, Hamburg*), Sergei Bobashev (*IOFFE, St. Petersburg*), Alexander Gottwald, Mathias Richter (*PTB, Braunschweig*)

A gas-monitor detector based on the photoionization of rare gases was developed and successfully used for the non-destructive characterization of highly intense and extremely pulsed VUV free electron laser (FEL) radiation at the TESLA test facility (phase 1) in Hamburg. By first pulse resolved measurements, a peak power of more than 100 MW at a wavelength of 87 nm was detected. In order to provide online photon beam diagnostics of VUV-FEL radiation during phase 2 of the TTF project, a set of four new detectors has been

constructed which are based on the prototype. The new detectors will not be used for intensity measurements only, but also for monitoring of the photon beam position. Each detector has been tested and calibrated in the Radiometry Laboratory of the Physikalisch-Technische Bundesanstalt at the electron storage ring BESSY II using spectrally dispersed synchrotron radiation at low intensities and a semiconductor photodiode as transfer standard. A conception for future gas-monitor detectors to characterize FEL radiation in the X-ray regime is also discussed.

FEL Technology II

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TUBxS

Attosecond Pulses in the LCLS using the Slotted Foil Method TUBIS01

Paul J Emma, Zhirong Huang (*SLAC, Menlo Park, California*), Michael Borland (*ANL/APS, Argonne, Illinois*)

A proposal has been made to generate femtosecond and sub-femtosecond x-ray pulses in the Linac Coherent Light Source (LCLS) SASE FEL by using a slotted spoiler foil located at the center of the second bunch compressor chicane. This previous study highlighted a simple case, using the nominal LCLS parameters, to produce a 2-fsec fwhm, 8-keV x-ray pulse. The study also pointed out the possibility of attaining sub-femtosecond pulses by somewhat modifying the LCLS compression parameters, but did not undertake a full tracking simulation for this more aggressive case. We take the opportunity here to study this 'attosecond' case in detail, including a full tracking simulation, pushing the limit of the technique.

Work supported by US Depertment of Energy contract DE-AC03-76SF00515.

Longitudinal Space Charge Effects in the JLAB IR FEL SRF Linac TUBOS02

Carlos Hernandez-Garcia, Kevin Beard, Chris Behre, Stephen Vincent Benson, George Herman Biallas, James Boyce, David Douglas, Fred Dylla, Richard Evans, Al Grippo, Joe Gubeli, David Hardy, Kevin Jordan, Lia Merminga, George Neil, Joe Preble, Michelle D. Shinn, Tim Siggins, Richard Walker, Byung Yunn, Shukui Zhang (*Jefferson Lab, Newport News, Virginia*)

Observations of energy spread asymmetry when operating the Linac on either side of crest and longitudinal emittance growth have been confirmed by extending PARMELA simulations from the injector to the end of the first SRF Linac module. The asymmetry can be explained by the interaction of the accelerating electric field with that from longitudinal space charge effects within the electron bunch. This can be a major limitation to performance in FEL accelerators.

This work supported by The Office of Naval Research under contract to the Dept. of Energy, the Air Force Research Lab, and the Commonwealth of Virginia.

TUBOS03

High Average Power Operation of a Scraper-Outcoupled Free Electron Laser

Michelle D. Shinn, Chris Behre, Stephen Vincent Benson, Michael Bevins, Don Bullard (*Jefferson Lab, Newport News, Virginia*)

We describe the design, construction, and operation of a high average power free electron laser using scraper outcoupling. Using the FEL in this all-reflective configuration, we achieved approximately 2 kW of stable output at 10 um. Measurements of gain, loss, and output mode will be compared with our models.

This work supported by the Office of Naval Research, the Joint Technology Office, the Commonwealth of Virginia, the Air Force Research Laboratory, and by DOE Contract DE-AC05-84ER40150.

TUBOS04

LCLS Undulator Design Development*

Isaac Vasserman, Roger Dejus, Patric Den Hartog, Elizabeth Moog, Shigemi Sasaki, Emil Trakhtenberg, Marion White (*ANL/APS, Argonne, Illinois*)

The fractional variation in deflection parameter K between segments of the 130.4-m-long undulator line for the Linac Coherent Light Source (LCLS) must be < 1.5 x 10-4. Mechanical shims were used to set the undulator gap to control K in the prototype, but this is too tedious a procedure to be used for all 33 undulator segments. Although the prototype undulator met all of the LCLS specifications, development continued in order to simplify the system. Various other alternatives for adjusting the field were considered. A canted-pole geometry was adopted that allows the K value to be changed by lateral translation of the entire undulator segment. This scheme also facilitates tapering the undulator line to accommodate energy loss in the electron beam. The prototype undulator was subsequently modified to test the canted-pole concept. Magnetic measurements demonstrated that the undulator with canted poles meets all LCLS specifications, and is more cost-effective to implement.

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Commissioning of the TTF Linac Injector at the DESY VUV-FEL

TUBOS05

Katja Honkavaara (*DESY, Hamburg*)

The upgrade of the TESLA Test Facility (TTF) Linac at DESY is almost completed. With electron beam energies up to 1 GeV, it will be able to drive a new SASE FEL user facility (VUV-FEL) in the wavelength range from VUV to soft X-rays. The first phase of the redesigned photoinjector is finished. We report on its commissioning during spring 2004, including the first measurements of electron beam parameters. Since this injector is also a prototype for the XFEL injector, the results obtained are important for future SASE XFEL drive linacs.

FEL Oscillators
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TUCOS

Status of the Novosibirsk Terahertz FEL TUCOS01

Nikolai Aleksandrovich Vinokurov, Vladimir Petrovich Bolotin, Aleksey Vladimirovich Davydov, Dmitriy Aleksandrovich Kayran, Boris Aleksandrovich Knyazev, Evgeniy Ivanovich Kolobanov, Vitaliy Vladimirovich Kubarev, Gennadiy Nikolaevich Kulipanov, Alexander Nikolaevich Matveenko, Lev Eduardovich Medvedev, Sergey Vladimirovich Miginsky, Leontiy Alekseevich Mironenko, Aleksandr Danilovich Oreshkov, Vladimir Kirillovich Ovchar, Vasiliy Mikhailovich Popik, Tatyana Vladimirovna Salikova, Mikhail Alekseevich Scheglov, Stanislav Sergeevich Serednyakov, Oleg Alexandrovich Shevchenko, Aleksandr Nikolayevich Skrinsky (*BINP, Novosibirsk*)

The first stage of Novosibirsk high power free electron laser (FEL) was commissioned in 2003. It is based on normal conducting CW energy recovery linac. Now the FEL provides electromagnetic radiation in the wavelength range 120 - 180 micron. The average power is 100 W. The measured linewidth is 0.3%, which is close to the Fourier-transform limit. The assembly of user beamline is in progress. Plans of future developments are discussed.

High Power Lasing in the IR Upgrade FEL at Jefferson Lab TUCOS02

Stephen Vincent Benson, Kevin Beard, Chris Behre, George Herman Biallas, James Boyce, David Douglas, Fred Dylla, Richard Evans, Al Grippo, Joe Gubeli, David Hardy, Carlos Hernandez-Garcia, Kevin Jordan, Lia Merminga, George Neil, Joe Preble, Michelle D. Shinn, Tim Siggins, Richard Walker, Byung Yunn, Shukui Zhang (*Jefferson Lab, Newport News, Virginia*), Hiroyuki Toyokawa (*KEK, Ibaraki*)

We report on progress in commissioning the IR Upgrade facility at Jefferson Lab. Operation at high power has been demonstrated at 5.7 microns with over 4 kW of continuous power output and a recirculated electron beam power of up to 800 kW. We report on the features and limitations of the present design and on efforts to increase the power to over 10 kW.

This work supported by the Office of Naval Research, the Joint Technology Office, the Commonwealth of Virginia, the Air Force Research Laboratory, and by DOE Contract DE-AC05-84ER40150.

TUCOS03 VUV Optics Development for the Elettra Storage Ring FEL

Stefan Guenster, Detlev Ristau (*LZH, Hannover*), Francesca Sarto (*ENEA, Roma*), Mitcho Danailov, Mauro Trovò (*Elettra, Basovizza, Trieste*), Alexandre Gatto, Norbert Kaiser (*IOF, Jena*)

Vacuum ultraviolet optical components for the storage ring FEL at Elettra are under continuous development in the European research consortium EUFELE. Target of the project is the progress to shorter lasing wavelengths in the VUV spectral range. The current status allows lasing with oxide mirror systems down to 190 nm. The main obstacles for the development of optical coatings for shorter wavelengths is the high energetic background of the synchrotron radiation impinging onto the front mirror in the laser cavity. Investigations in single layer systems and multilayer stacks of oxide or fluoride materials demonstrate that fluoride mirrors reach highest reflectivity values down to 140 nm, and oxide coatings possess a satisfactory resistance against the high energetic background irradiation. However, pure oxide multilayer stacks exhibit significant absorption below 190 nm and pure fluoride stacks suffer from strong degradation effects under synchrotron radiation. A solution could be hybrid systems, combining fluoride stacks with oxide protection layers to provide high reflectivity and a robust behaviour under synchrotron radiation load. Results of hybrid systems will be presented.

TUCOS04 Coherent Harmonic Generation using the ELETTRA Optical Klystron

Giovanni De Ninno, Mitcho Danailov, Bruno Diviacco, Mauro Trovò (*Elettra, Basovizza, Trieste*), Giuseppe Dattoli, Luca Giannessi (*ENEA C.R. Frascati, Frascati - Roma*)

The standard process leading to CHG using single-pass devices or storage rings is based on the up-frequency conversion of a high-power laser focused into the first undulator of an optical klystron. The seeding signal, which is necessary to produce the modulation of the electron density and hence to induce the coherent emission, may be provided by an external laser or, in the case of storage-ring oscillators, by the FEL itself. The latter configuration has been recently implemented at ELETTRA allowing to generate the third harmonic of an intra-cavity signal at 660 nm. In the first part of this paper,

we report about the set of measurements that have been performed, for different experimental set-ups, with the aim of characterizing the power as well as the spectral and temporal characteristics of the obtained radiation. As for seeding using an external laser, a detailed campaign of simulations, reported in the second part of the paper, shows that the ELETTRA optical klystron is also well suited for the investigation of this configuration. These results make the ELETTRA FEL an ideal test-facility in view of CHG experiments planned on dedicated next-generation devices.

Short Rayleigh Length Free Electron Lasers TUCOS05

William Colson (*NPS, Monterey, CA*)

Conventional free electron laser (FEL) oscillators minimize the optical mode volume around the electron beam in the undulator by making the resonator Rayleigh length about one third of the undulator length. This maximizes gain and beam-mode coupling. In compact configurations of high-power infrared FELs or moderate power UV FELs, the resulting optical intensity can damage the resonator mirrors. To increase the spot size and thereby reduce the optical intensity at the mirrors below the damage threshold, a shorter Rayleigh length can be used, but the FEL interaction is significantly altered. A new FEL interaction is described and analyzed with a Rayleigh length that is only one tenth the undulator length, or less. The effect of mirror vibration and positioning are more critical in the short Rayleigh length design, but we find that they are still within normal design tolerances.

FEL Technology
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TUPOS

Industrial Production of Superconducting 1.3 GHz Accelerator Modules and components for FEL application TUPOS01

Michael Pekeler, Hanspeter Vogel, Peter vom Stein (*ACCEL, Bergisch Gladbach*)

Daresbury Laboratory contracted ACCEL in April for the delivery of two superconducting 1.3 GHz modules for the R&D phase of their 4GLS project. The modules are delivered with guaranteed performance on cavity voltage and cryogenic losses. The modules contain 2 TESLA type cavities each and are of the design developed at Forschungszentrum Rossendorf. To investigate the capabilities of our cavity treatment and preparation techniques, our infrastructure was further upgraded to allow chemical treatment and high pressure rinsing of TESLA cavities. First test results on TESLA cavities produced for BESSY are very encouraging. 23 MV/m accelerating gradient were achieved in the cold vertical test. In addition 12 power couplers of the TTF III type were produced for DESY and BESSY. The conditioning of those couplers was performed at DESY in a very short time of approximately 50 hours demonstrating our high quality surface treatment capabilities.

Collimation System for the BESSY FEL TUPOS02

Thorsten Kamps (*BESSY GmbH, Berlin*)

Beam collimation is an essential element for the successful running of a linear accelerator based free electron laser. The task of the collimation system is to protect the undulator modules against mis-steered beam and dark-current. This is achieved by a set of apertures limiting the succeeding transverse phase space volume and a magnetic dogleg structure for longitudinal phase space filtering. In the following the design of the BESSY FEL collimation section is described together with detailed simulation studies.

TUPOS03 High Power RF Conditioning and Measurement of Longitudinal Emittance at PITZ

Dieter Richter, Michael v. Hartrott (*BESSY GmbH, Berlin*), Juergen Baehr, Hans-Juergen Grabosch, Jang Hui Han, Mikhail Krasilnikov, Dirk Lipka, Velizar Miltchev, Anne Oppelt, Bagrat Petrosyan, Dietrich Pose, Sabine Riemann, Lazar Staykov, Frank Stephan (*DESY Zeuthen, Zeuthen*), Galina Asova, Gancho Dimitrov (*DESY Zeuthen, Zeuthen ; INRNE, Sofia*), Karen Abrahamyan (*DESY Zeuthen, Zeuthen ; YerPhI, Yerevan*), Ilja Bohnet, Jean-Paul Carneiro, Klaus Floettmann, Siegfried Schreiber (*DESY, Hamburg*), Paolo Michelato, Laura Monaco, Daniele Sertore (*INFN/LASA, Segrate (MI)*)

In 2003 the PITZ RF-gun at DESY Zeuthen has been fully characterized. After RF conditioning 3.2MW input power at 10Hz and a RF-pulse length of 0.9ms has been reached. This correponds to a gradient of 42MV/m at the cathode. The goal is to increase the accelerating gradient of the gun and the duty cycle significantly. The motivation is based on the expectation of a remarkable increase in beam quality at higher gradients. A high duty cycle is of advantage for FEL users. The conditioning procedure was started in spring 2004. The paper will report about procedure and results of this program. The preparation of an experimental setup for the measurement of the complete longitudinal phase space at about 5 MeV using a streak camera will be finished in summer 2004. Cherenkov light created by Silica aerogel radiators in the dispersive arm of PITZ is transmitted to a streak camera by an optical transmission line. The light distribution of the momentum spectrum is projected onto the entrance slit of the streak camera. The setup and first results will be presented.

TUPOS04 A Far-Infrared FEL at the Radiation Source ELBE

Rudi Wuensch, Thomas Dekorsy, Karim Fahmy, Eckart Grosse, Wolfgang Seidel, Andreas Wolf (*FZR, Dresden*)

The first lasing in the mid IR at the ELBE FEL allows us to specify the parameters of a new undulator for longer wavelengths to complement the U27 undulator which is useful up to about 25 microns. In the longer wavelength region FELs constitute a unique radiation source with appealing properties. Radiation quanta in this range (2 - 10 THz) are appropriate for the low-energy spectroscopy of various interesting modes in solid state quantum structures as well as in complex biological systems. Their study establishes the basis for

understanding phenomena in semiconductors and elucidating biological processes of interest for medical innovations. We envisage an electromagnetic undulator with a period of 90 - 100 mm. Using the ELBE beam IR light from 20 to 150 microns and beyond can be produced. To keep the transverse beam extension small the IR beam is to be guided by a partial waveguide inside the undulator. Appropriate bifocal resonator mirrors minimize the mode coupling losses at the exits of the waveguide. Detailed calculations and computer simulations predict an outcoupled laser power of roughly 50 W at 150 microns which will be transported to experimental stations.

Layout and Photon Beam Diagnostics for the VUV-FEL User Facility at DESY

TUPOS05

Elke Ploenjes, Stefan Duesterer, Joseph Feldhaus, Ulrich Hahn, Fini Jastrow, Teresa Nunez, Kai Tiedtke, Rolf Treusch (*DESY, Hamburg*)

The VUV-FEL at the Tesla Test Facility at DESY is currently developed into a full user facility with five experimental stations using the laser beam alternating. Online diagnostics for photon beam parameters such as wavelength, pulse energy, and beam position, which operate in parallel to user experiments in a parasitic non-destructive way, will be integrated permanently into the user facility. These diagnostics have to be capable of covering the full spectral range from 6 - 100 nm as well as an extended dynamic range of intensities from spontaneous undulator emission to SASE in saturation. A pulse duration of typically 100 fs or shorter is one of the most attractive features of linear accelerator based FELs. Online, single-pulse measurements of FEL pulse duration and timing with respect to a synchronized femtosecond optical laser are developed to exploit the ultrafast FEL pulses in two-color pump-probe experiments. Alternatively, a delay-line setup will allow single-color pump-probe experiments or, using suitable filters, a combination of first and third harmonic with ultimate time resolution independent of pulse timing.

TUPOS06 Electro-Optical Bunch Length Measurements at the SLS Linac

Bernd Steffen, Sara Casalbuoni, Stefan Simrock (*DESY, Hamburg*), Timo Korhonen, Thomas Schilcher, Volker Schlott, Hans Sigg, Daniel Suetterlin (*PSI, Villigen*), Manfred Tonutti, Axel Winter (*RWTH, Aachen*), Peter Schmüser (*Uni HH, Hamburg*)

The temporal profile of the electron bunches in the SLS Linac was determined by means of electro-optical techniques. In a first experiment a mode locked Ti:Sa Laser with 15 fs pulse width (FWHM) was used for coincidence and sampling measurements between the laser pulse and the coherent transition radiation (CTR) generated by short electron bunches. A synchronization accuracy of 70 fs rms between the 3 GHz Linac RF and the 81 MHz repetition frequency of the laser was achieved, which is important for the optimum time resolution of the applied electro-optical sampling technique. In a second experiment a mode locked Nd:YAG laser with 400 ps long pulses will be used for electro-optical autocorrelation measurements between the CTR and the laser pulses. This alternative technique promises single shot capability and requires much relaxed synchronization stability between laser and electron beam.

TUPOS07 Longitudinal Bunch Shape Diagnostics

Oliver Grimm (*DESY, Hamburg*)

The VUV-FEL at DESY, Hamburg, will require novel techniques to characterize the longitudinal charge distribution of the electron bunches that drive the free-electron laser. Two reasons are the short bunch lengths that will be obtained by the bunch compression schemes and the high sensitivity of the lasing process to spikes in the charge distribution. This contribution will give an overview of the different measurement techniques to access bunch lengths on the order of 50 μ m. Approaches to reconstruct the bunch shape by Fourier analysis of the coherent part of the infrared spectrum of synchrotron, transition, diffraction and undulator radiation will be presented. Furthermore, methods working in the time domain, like the use of transverse mode cavities or the principle of electro-optical sampling, will be discussed. Examples from TTF2 will be used to show possible technical implementations of the corresponding techniques.

Timing and Synchronisation for the X-Ray FEL Project TUPOS08

Holger Schlarb (*DESY, Hamburg*)

High gain FELs operating in the Angstrom regime require high peak current(kA) and ultra-low emittance (μm) to achieve saturation within reasonable undulator length (100-300 m). The high peak current is produced by compressing the bunch longitudinally in magnetic chicanes from typically millimetres at the exit of the injector down to few ten's of microns. The compression process puts stringent demands on the RF acceleration phase in order to stabilise the electron bunch length and the arrival time variations at the entrance of the undulator. The major sources for bunch timing jitter and the proposed concepts for ultra-high precision synchronisation of the critical subsystems for the VUV-FEL at DESY and the proposed European XFEL are presented.

Transverse Emittance Measurements at the Photo Injector Test Facility at DESY Zeuthen TUPOS09

Velizar Miltchev, Juergen Baehr, Hans-Juergen Grabosch, Jang Hui Han, Mikhail Krasilnikov, Dirk Lipka, Anne Oppelt, Bagrat Petrosyan, Dietrich Pose, Sabine Riemann, Lazar Staykov, Frank Stephan (*DESY Zeuthen, Zeuthen*), Michael von Hartrott, Dieter Richter (*BESSY GmbH, Berlin*), Galina Asova, Gancho Dimitrov (*DESY Zeuthen, Zeuthen ; INRNE, Sofia*), Karen Abrahamyan (*DESY Zeuthen, Zeuthen ; YerPhI, Yerevan*), Jean-Paul Carneiro, Klaus Floettmann, Siegfried Schreiber (*DESY, Hamburg*), Paolo Michelato, Laura Monaco, Daniele Sertore (*INFN/LASA, Segrate (MI)*), Ivan Tsakov (*INRNE, Sofia*), Ingo Will (*MBI, Berlin*), Wolfgang Ackermann, Stefan Setzer (*TU Darmstadt, Darmstadt*)

The main goal of the Photo Injector Test Facility at DESY Zeuthen (PITZ) is the development of electron sources for Free Electron Lasers. The presented contribution summarizes the transverse emittance studies done for producing an electron beam that meets the requirements of the TTF2 VUV-FEL. Systematic measurements of the beam emittance in a wide range of parameters (e.g. bunch charge, RF phase, solenoid fields) will be presented and compared with simulations. The impact of the laser pulse longitudinal and transverse profile on the beam emittance will be demonstrated. Results of thermal emittance measurements will be discussed.

TUPOS10 The Short-Range Wakefields in the BTW Accelerating Structure of the Elettra Linac

Paolo Craievich (*Elettra, Basovizza, Trieste*), Thomas Weiland, Igor Zagorodnov (*TU Darmstadt, Darmstadt*)

Future FEL operations in the ELETTRA LINAC require a high quality beam with an ultra short bunch. The knowledge of the short-range wakefields in the backward traveling wave (BTW) accelerating structure is needed to predict the beam quality in term of the single bunch energy spread and emittance. To calculate the effect of the longitudinal and transverse wakefileds we have used the time domain numerical approch with a new implicit scheme for calculation of wake potential of short bunches in long structure [1,2]. The wake potentials of the BTW structure are calculated numerically for very short bunches and analytical approximations for wake functions in short and long ranges are obtained by fitting procedures based on analytical estimations.

[1] A. Novokhatski, M.timm, T. Weiland, Transition Dynamics of the Wake Fields of Ultra Short Bunches, Proceeding of the ICAP 1998,Monterey, California, USA.
[2] I. Zagorodnov, T. Weiland, Calculation of Transverse Wake Potential for Short Bunches, ICAP 2002.

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The SPARX Project : R&D Activity towards X-rays FEL Sources

TUPOS11

Massimo Ferrario, David Alesini, Sergio Bertolucci, M.E. Biagini, Caterina Biscari, R. Boni, Manuela Boscolo, Michele Castellano, A. Clozza, G. Di Pirro, A. Drago, A. Esposito, V. Fusco, A. Gallo, A. Ghigo, Susanna Guiducci, M. Incurvati, C. Ligi, F. Marcellini, Mauro Migliorati, C. Milardi, Andrea Mostacci, Luigi Palumbo, L. Pellegrino, Miro Preger, P. Raimondi, R. Ricci, C. Sanelli, Mario Serio, F. Sgamma, Bruno Spataro, A. Stecchi, A. Stella, Franco Tazzioli, Cristina Vaccarezza, Mario Vescovi, C. Vicario, M. Zobov (*INFN/LNF, Frascati (Roma)*), L. Avaldi, R. Camilloni, C. Carbone, S. Colonna, A. Cricenti, I. De Padova, S. Lagomarsino, C. Ottaviani, B. Paci, Paolo Perfetti, A. Pifferi, T. Prosperi, C. Quaresima, V. Rossi Albertini, N. Zema (*CNR-ISM, Roma*), Franco Ciocci, Giuseppe Dattoli, Antonio Di Pace, Andrea Doria, Francesco Flora, Gian Piero Gallerano, Luca Giannessi, Emilio Giovenale, Giovanni Messina, Luca Mezi, Pier Luigi Ottaviani, Simonetta Pagnutti, Giovanni Parisi, Luigi Picardi, Marcello Quattromini, Alberto Renieri, Concetta Ronsivalle, Elio Sabia, A. Torre, Alberto Zucchini (*ENEA C.R. Frascati, Frascati - Roma*), F. Alessandria, A. Bacci, Ilario Boscolo, F. Broggi, S. Cialdi, C. De Martinis, D. Giove, C. Maroli, V. Petrillo, M. Romè, Luca Serafini (*INFN Milano, Milano*), D. Levi, Mario Mattioli, G. Medici (*INFN Roma, Roma*), L. Catani, E. Chiadroni (*INFN, Roma*), S. De Silvestri, M. Nisoli, S. Stagira (*Politecnico di Milano, Milano*), A. Cianchi, Carlo Schaerf (*Rome University Tor Vergata, Roma*), D. Dowell, Paul J Emma, C. Limborg, D. T. Palmer (*SLAC, Menlo Park, California*), Pietro Musumeci, James Rosenzweig, Gil Travish (*UCLA, Los Angeles, California*), Sven Reiche (*UCLA/DPA, Los Angeles - California*)

SPARX is an evolutionary project proposed by a collaboration among ENEA-INFN-CNR-Università di Roma Tor Vergata aiming at the construction of a FEL-SASE X-ray source in the Tor Vergata Campus. The first phase of the SPARX project, funded by Government Agencies, will be focused on the R&D activity on critical components and techniques for future X-ray facilities. The R&D plans for the FEL source will be developped along two lines: (a) use of the SPARC high brightness photo-injector to develop experimental test on RF compression techniques and other beam physics issues, like emittance degradation in magnetic compressors due to CSR; (b) development of new undulator design concepts and up-grading of the FEL SPARC source to enhance the non linear harmonic generation mechanism, design and test of e-beam conditioning, prebunching and seeding. A parallel program will be aimed at the development of high repetition rate S-band gun, high Quantum Efficiency cathodes, high gradient X-band RF accelerating structures and harmonic generation in gas. In a second phase we plan to explore produc-

tion of X-rays in a SASE-FEL with harmonic generation, upgrading existing facilities.

TUPOS12 Spectral Analysys of Charge Emission Spatial Inhomogeneities and Emittance Diluition in RF Guns

Marcello Quattromini, Luca Giannessi, Concetta Ronsivalle (*ENEA C.R. Frascati, Frascati - Roma*)

The effects of fluctuations in cathode's quantum efficiency and other sources of dishomogeneities in the performances of a typical RF photoinjector have been investigated with TREDI numerical simulations. The RF gun layout includes a focusing solenoid in a configuration aimed at minimizing the emittance growth due to space charge effects.

TUPOS13 EUV Spectrometer for the Monitoring of the FEL Radiation at DESY

Piergiorgio Nicolosi, Maria-Guglielmina Pelizzo, Luca Poletto (*INFM-LUXOR, Padova*), Joseph Feldhaus, Fini Jastrow, Elke Ploenjes, Kai Tiedtke, Rolf Treusch (*DESY, Hamburg*)

A grazing-incidence flat-field spectrometer has been designed. The optical design is based on a Kirkpatrick-Baez configuration in which one of the optical elements is a spherical mirror and the other is a spherical grating [1]. This configuration gives high spectral and spatial resolution even for a large field-of-view. The grating is a variable-line-spaced one, in which the groove spacing changes along the surface following a polynomial law in order to obtain a flat-field focal surface nearly parallel to the grating normal. The detector can be both an EUV-enhanced CCD and a MCP-based detector. The spectrometer was tested in the 5-45 nm spectral region with spectra emitted both by a laser-produced-plasma and by a hollow-cathode lamp. Spectral resolution of about 2000 was measured at 20 nm, in good agreement with the theoretical predictions. Spatial resolution better than 0.1 mm over 2 mm field-of-view has been measured. At present, the instrument is installed at DESY (Hamburg, Germany) on the TESLA-Test-Facility and will be used for the monitoring of

the spectral emission of the FEL radiation in the 25-45 nm spectral region.

[1] Poletto, Nicolosi and Tondello, Appl. Opt. 41, 172 (2002)

ABCD Matrix Method: a Case Study TUPOS14

Zakir F. Seidov, Yosef Pinhasi, Asher Yahalom (*The College of Judea and Samaria, Ariel*)

In the Israeli Electrostatic Accelerator FEL, the distance between the accelerator's end and the wiggler's entrance is about 2.1 m, and 1.4 MeV electron beam is transported through this space using four similar quadrupoles (FODO-channel). The transfer matrix method (ABCD matrix method) was used for simulating the beam transport, a set of programs is written in the several programming languages (MATHEMATICA, MATLAB, MATCAD, MAPLE) and reasonable agreement is demonstrated between experimental results and simulations. Comparison of ABCD matrix method with the direct "numerical experiments" using EGUN, ELOP, and GPT programs with and without taking into account the space-charge effects showed the agreement to be good enough as well. Also the inverse problem of finding emittance of the electron beam at the S1 screen position (before FODO-channel), by using the spot image at S2 screen position (after FODO-channel) as function of quad currents, is considered. Spot and beam at both screens are described as tilted eellipses with diameters and orientation angle of which being found by STB (Spot-to-Beam) procedure, and trace-ellipse transformation is used to found emittance at S1 position.

Spot-to-Beam Procedure TUPOS15

Zakir F. Seidov, Yosef Pinhasi, Asher Yahalom (*The College of Judea and Samaria, Ariel*)

We describe the interactive "STB" (spot_to_beam) MATHEMATICA procedure for a) approximating the spot image at the screen as ellipse, b) getting five parameters of the elliptic beam (two diameters, center coordinates, and orientation angle). The basic idea is to "map" the reference holes at screen onto the X-Y plane normal to the beam direction (Z-axis). All distortions of the image, e.g.,

due to camera-screen disposition can be, in principle, taken into account,assuming that the hole positions at screen and the orientation of the screen are known. With the non-linear LMS fitting, the "curved-coordinate-system" of the holes at image is transferred to the Cartesian coordinate system at XY-plane. Then the fitting ellipse is found in this latter system, by solving the system of N linear equations for 5 unknown parameters of beam ellipse, where N>5 is a number of reference points on edge of spot image. The examples of the real measurements at various screens will be demonstrated. The accuracy of beam diameters is about .1 mm depending on quality of picture and the perator's experience. The procedure is to be used in the routine measurements in the Israeli FEL.

TUPOS16 **Status of IR FEL of Tokyo University of Science**

Takayuki Imai, Akira Iwata, Tetsuhito Kadowaki, Haruo Kuroda, Kozi Nakai (*FEL-SUT, Chiba*), Masayuki Kawai (*Tohoku/LNS, Taihaku-Ku Sendai - Miyagi Prefecture*)

In order to develop high performance IR FEL and new photo science by use of it, the IR FEL Research Center of Tokyo University of Science (FEL-SUT) was established in 1999 and has been operating as a user facility for application experiments [1]. The center has two FEL devices. One is mid-infrared FEL (MIR FEL) for the wavelength range of 5-16 μ m and the other is far-infrared FEL (FIR FEL) at 300-1000 μ m wavelengths. MIR FEL consists of an RF gun with a thermionic cathode, an alpha magnet, an S-band linac and a permanent magnet undulator combined with an optical resonance cavity of hole-coupling mode. It has been operated providing FEL light for various researches. FIR FEL is also using S-band linac, but optical resonator is composed of waveguide and two cylindrical mirrors to improve slippage problem and reduce diffraction losses [2]. The commissioning of FIR FEL is under way. In this paper, we present the status of those IR FELs at FEL-SUT.

[1] Haruo Kuroda, "Status of the FEL-SUT Project", Jpn. J. Appl. Phys., 41, Suppl-1, 1 (2002). [2] H. Koike et al., "Design and study of FIR FEL device using S-band linac at FEL-SUT", Nuclear Inst. & Meth. Phys. Res., A507, 242 (2003).

Guiding Optics System for LEBRA FEL User Facility TUPOS17

Toshinari Tanaka, Ken Hayakawa, Yasushi Hayakawa, Isamu Sato (*LEBRA, Funabashi*)

A guiding optics system for LEBRA FEL facility was completed in 2003. The optical beam extracted from the Infrared FEL resonator is guided through a long vacuum system to user's experimental rooms, where maximum 17 aluminum-coated mirrors are used in the guiding optics. The maximum length of the optical line is approximately 50 m. Therefore, the FEL extracted through a coupling hole in a resonator mirror has to be converted to a parallel beam. The conversion optics consists of an elliptic mirror and a parabolic mirror aligned to form a confocal configuration. The diffraction profiles of a guide laser extracted through the coupling hole have shown approximately identical patterns at output ports of the experimental facility. The guiding optics has two monitoring ports consisting of fluorite beam splitters, which is useful for simultaneous measurement of the power and the spectrum of the FEL during user experiments.

Upgrade of a Photocathode RF Gun at SPring-8 TUPOS18

Tsutomu Taniuchi, Takao Asaka, Hideki Dewa, Hirofumi Hanaki, Toshiaki Kobayashi, Akihiko Mizuno, Shinsuke Suzuki, Hiromitsu Tomizawa, Kenichi Yanagida (*JASRI-SPring-8, Hyogo*)

The test bench of a photocathode RF gun at SPring-8 has been upgraded. The radiation shielded area was expanded about 3 times larger and the maximum beam energy was increased from up to 30 MeV including a 3-m long accelerating tube. The clean room for the drive laser system was newly built and the performance and reliability of the laser was improved. After the construction of the shielded room and set up of the components, the RF conditioning of the waveguides, the gun cavity and the accelerating tube was successfully performed and the beam characteristics such as the emittance and bunch length were measured. In this presentation, further plans for the improvement of the beam quality will also be presented.

TUPOS19 Development of an FEL Simulation Code to Test the Undulator Performance

Takashi Tanaka (*RIKEN Spring-8 Harima, Hyogo*)

In an FEL project based on the principle of SASE, a long undulator with a good field quality should be installed to ensure saturation. The performance of the undulator as a (spontaneous) synchrotron light source is represented by phase errors as well as the trajectory straightness. In addition, the synchrotron radiation from an undulator is easily calculated by Fourier transforming the electric field generated by an electron passing through the undulator field. On the other hand, an FEL simulation should be carried out with the actual magnetic field taken into account in order to estimate the undulator performance as an FEL driver. We have recently developed an FEL simulation code for such a purpose, the details of which will be presented in this paper.

TUPOS20 Electron Beam Simulations on the SCSS Accelerator

Hara Toru, Hideo Kitamura, Tsumoru Shintake (*RIKEN Spring-8 Harima, Hyogo*)

The SPring-8 Compact SASE Source (SCSS) is a SASE-FEL project aiming at soft X-ray radiation at its first stage using 1 GeV electron beams. One of the unique features of the SCSS is the use of a pulsed high-voltage electron gun with a thermionic cathode. Main reason for this choice is its high stability and the well developed technology relating to the gun. Meanwhile, the electron bunch should be compressed properly at the injector in order to obtain sufficient peak currents. In this presentation, the results of the electron beam simulations along the accelerator and the expected parameters of the electron beam will be given.

TUPOS21 Reducing Back-Bombardment Effect Using Thermionic Cathode in IAE-RF Gun

Toshiteru Kii, Kazushi Hayakawa, Kai Masuda, Shio Murakami, Hideaki Ohgaki, Tetsuo Yamazaki, Kiyoshi Yoshikawa, Heishun Zen (*Kyoto University, Kyoto*)

We have numerically studied on improvement of electron beam macro-pulse properties from thermionic RF gun [1,2]. Beam properties, such as energy spectrum, macro-pulse duration and emittance

were measured with a 2 mm diameter slim thermionic dispenser cathode. Effect of the transverse magnetic field to reduce back-streaming electrons to these properties was studied experimentally. Comparison with measured and numerical results will be discussed. Effect of a non-flat RF input to compensate a decreasing beam energy during macropulse due to a back-bombardment effect will be also presented.

[1] T. Kii, et al. , NIM A in press
[2] K. Masuda, et al., NIM A483, 315-320, 2002

Renewal of KU-FEL Facility

TUPOS22

Toshiteru Kii, Kazushi Hayakawa, Kai Masuda, Shio Murakami, Hideaki Ohgaki, Tetsuo Yamazaki, Kiyoshi Yoshikawa, Heishun Zen (*Kyoto University, Kyoto*)

Users demands to a high power tunable IR laser are increasing in Japan in energy-related science, such as basic study of high-efficiency solar cells, generation of new energy source of alcohol and/or H_2 from polluted gas, and separation of DNA and/or RNA. To satisfy these demands, we decided to renew our FEL facility more user friendly and to operate more flexibly. Construction and fundamental studies on the KU-FEL have been carried out at a building of Institute of Chemical Research where few other accelerators are operating. Therefore, available machine time for our experiments is quite limited. We are now modifying the room by adding concrete walls of 2-m thickness and some space for users will be available. The present FEL system will be moved to the room A photocathode RF-gun system will be nearly added to the system and the present thermionic RF-gun will be used ternatively according to the demands of users. The photocathode material will be Cs_2Te. The room with the shielding will be completed in June, 2004, and we will moved the machine shortly. We hope to resume the operation of the linac in fall of 2004. The FEL is expected lasing in the next year.

TUPOS23 Beam Property Measurements on the KU-FEL Linac

Kai Masuda, Kazushi Hayakawa, Toshiteru Kii, Shio Murakami, Hideaki Ohgaki, Tetsuo Yamazaki, Kiyoshi Yoshikawa, Heishun Zen (*Kyoto University, Kyoto*)

An infrared FEL facility is under construction for advanced energy researches [1]. Electron beams of around 30 MeV have been obtained by an S-band 4.5-cell rf gun with a thermionic cathode, and a recently installed 3-m accelerating tube. A 180 degree arc consisting of three bending magnets have been also set up for bunch compression, and beam property measurements are under way. Transverse phase space distributions and resultant emittances have been obtained through the tomographic technique [2] by use of a quadrupole magnet, an alumina phosphor screen and a CCD camera. An OTR screen is being prepared for a higher spatial resolution as well as for longitudinal bunch shape measurements by use of a streak camera of 0.2 psec resolution. Comparison with the start-to-end simulation results [3] will be also presented.

[1] T. Yamazaki, et al., Proc. of FEL 2001 (2002) II-13.
[2] C.B. McKee, et al., NIM A 358 (1995) 264.
[3] H. Ohgaki, et al., NIM A 507 (2003) 150.

TUPOS24 Upgrade Design of KU-FEL Driver Linac Using Photo-Cathode RF-GUN

Hideaki Ohgaki, Kazushi Hayakawa, Toshiteru Kii, Kai Masuda, Shio Murakami, Tetsuo Yamazaki, Kiyoshi Yoshikawa, Heishun Zen (*Kyoto University, Kyoto*)

An infrared FEL facility is under construction at Institute of Advanced Energy, Kyoto University[1]. The electron beam of 30 MeV has been successfully accelerated by the S-band linac consisted of thermionic RF-gun[2]. To reduce the back-bombardment effect in the 4.5-cell RF gun, several attempts have been done and the macro-pulse duration of 3 μs has been achieved[3]. However, there still needs several efforts to obtain enough macro-pulse duration[4]. Upgrade from the thermionic RF-gun to a photo-cathode RF-gun is a short-cut solution. So a design work for the system upgrade has

been performed. The system will use not only a 1.5-cell photocathode RF-gun, but also use the existing thermionic RF-gun. A Gun-to-Linac beam transport system was designed for two different injectors. Numerical calculation of the beam property has been performed by PARMELA to compare the existing one. We will discuss on the expected FEL gain with the upgraded driver system.

[1] T. Yamazaki et al., Free Electron Laser 2001, (2002) II-13.
[2] K. Masuda et al., presented in FEL2004.
[3] T. Kii et al., presented in FEL2004.
[4] H. Ohgaki, et al., NIM A 507 (2003) 150.

First Model of the Edge-Focusing Wiggler for SASE TUPOS25

Shigeru Kashiwagi, Goro Isoyama, Ryukou Kato, Takanori Noda (*ISIR, Osaka*), Kimichika Tsuchiya, Shigeru Yamamoto (*KEK, Ibaraki*)

We are developing a new type of wiggler named the edge-focusing (EF) wiggler, which produces the strong transverse focusing field incorporated with the normal wiggler field. The idea of the EF wiggler* and development of permanent magnet blocks with small magnetization errors for the wiggler** were reported at the two preceding FEL conferences. We have fabricated the first model of the EF wiggler to evaluate its performance. It is a five-period planar wiggler with an edge angle of 2 degrees and a period length of 60 mm. The magnetic field in the wiggler is measured with a Hole probe at a magnet gap of 30 mm. It is experimentally confirmed that a high field gradient of 1.0 T /m is realized along the beam axis in the EF wiggler. In this paper, we will report results of the magnetic field measurement and its analysis for the first mode of the EF wiggler.

* G. Isoyama et al., Nucl. Instr. and Meth. A 507 (2003) 234
* S. Kashiwagi et., Nucl. Instr. and Meth. A, in press

Upgrade of the L-Band Linac at ISIR, Osaka University for a Far-Infrared FEL TUPOS26

Ryukou Kato, Goro Isoyama, Shigeru Kashiwagi, Shoji Suemine, Tamotsu Yamamoto (*ISIR, Osaka*)

We are developing the far-infrared free-electron laser (FEL) using the L-band electron linac at the Institute of Scientific and Industrial

Research (ISIR), Osaka University. The first lasing of the FEL was obtained at wavelengths from 32 to 40 μm in 1994, and the wavelength region has been extended up to 150 μm. The linac was designed and constructed for producing the high-intensity single-bunch beam for pulse radiolysis, so that the filling time of the accelerating structure is 1.8 μs long and the maximum macropulse length of the electron beam is limited to 2 μs, though the duration of the RF pulse can be extended to 4 μs. As a result, the FEL could not reach power saturation because the number of amplification times was limited. Recently, the linac has been extensively remodeled to realize high operational stability and reproducibility for advanced studies in beam science and technology. Almost all the peripheral components are replaced with new ones. At this opportunity, the linac is also made suitable for FEL so that the macropule can be extended up to 6 μs in duration for power saturation of the FEL. The modification of the linac has been completed and commissioning is now in progress. In this paper, we will report performance and characteristics of the linac after modification.

TUPOS27 Development of Compact Soft X-ray Source Based on Laser Undulator

Ryunosuke Kuroda, Masakazu Washio (*RISE, Tokyo*), Shigeru Kashiwagi (*ISIR, Osaka*), Hitoshi Hayano, Junji Urakawa (*KEK, Ibaraki*)

A compact soft X-ray source is required in various research fields such as material and biological science. The laser undulator based on backward Compton scattering has been developed as a compact soft X-ray source for the biological observation at Waseda University. It is performed in a water window region (250eV - 500 eV) using the interaction between 1047 nm Nd:YLF laser and 4 MeV high quality electron beam generated from rf gun system. The range of energy in the water window region has K-shell absorption edges of Oxygen, Carbon and Nitrogen, which mainly constitute of living body. Since the absorption coefficient of water is much smaller than the protein's coefficient in this range, a dehydration of the specimens is not necessary. As a preliminary experiment, about 300 eV X-ray generation was carried out. As next step, soft X-ray optics with zone

plate was proposed for Soft X-ray microscopy. In this conference, we will report details and results of the experiment.

Design of a Laser Thomson Scattering Facility for Femtosecond Hard X-ray Pulse Generation at PNU TUPOS28

Jung Keun Ahn (*PNU/NuRI, Busan*), Eun-San Kim (*PAL, Pohang*)

We present a proposed 100 femtosecond X-ray beam facility at Pusan National University through Thomson scattering of short laser pulse with femtosecond electron beam. A electron beam with 100 femtosecond duration will be generated by a photocathode rf gun and bunch compressors in the 50 MeV electron linac. We show simulation results on beam dynamics in the designed accelerator, and on the interaction between the high intensity laser and the electron beam. The proposed experimental setup and research programs are also presented.

KRF-2003-015-C00130

Repetitive Bunches from RF Photocathode Radiate Coherently TUPOS29

Kees van der Geer (*PP, Soest*), Dino Jaroszynski, Albert Reitsma (*Strathclyde University, Glasgow*)

We consider to feed the laser wake field accelerator of the alpha-X project by a train of low charge pancake electron bunches to reduce undesired expansion due to space-charge forces. To this purpose the photo excitation laser of the rf-injector is split into a train of sub-pulses, such that each of the produced electron bunches falls into a successive ponderomotive well of the plasma accelerator. This way the total accelerated charge is not reduced. The repetitive photo gun can be tested, at low energy, by connecting it directly to the undulator and monitoring the radiation. The assertions are based on the results of new GPT simulations.

Wavelength Stabilization in the Beijing Free Electron Laser TUPOS30

YaoHui Fan (*IHEP BFEL, Beijing*), Yonggui Li (*IHEP Beijing, Beijing*)

The wavelength fluctuation of FEL will reduce the experimental

precision and limit the research fields for application work. Several methods for FEL output wavelength stabilization have been put forward. One of them is based upon controlling the microwave power which is injected into the linac structure to change the output energy of accelerator, and finally correct the output wavelength of the FEL facility. This paper presents a method through controlling alpha-magnet exciting current, further change the inject-phase of the electron bunch out of the injector, to control the output energy of accelerator and correct the output wavelength of the FEL facility. Several main factors resulting in the fluctuation of FEL wavelength are analyzed. Based on such analysis, a negative feedback system to auto-stabilize the output wavelength has been successfully developed at BFEL. The experiment results showed that the output wavelength could be stably controlled within a precision of 1% for a long period stabilization.

Fan Yaohui, Li Yonggui, Wang Mingkai, Zhu Junbiao, Yang Xueping

Institute of High Energy Physics, CAS

TUPOS31

On the Theory and Simulation of BNL-Type Photocathode RF Gun

Jianping Dai (*IHEP Beijing, Beijing*)

Photocathode RF guns are now widely used to produce very bright electron beams, and for RF gun theories, simulation tools and cavity designs, one can find three corresponding peaks, which are Kim's theory, PARMELA and the so-called BNL type RF gun. In this paper, we present and discuss the characteristics of the BNL-type RF gun, such as the energy, energy spread, bunch length and emittance, etc., got by Kim's theory, PARMELA and J. Gao's improved model respectively.

Development of the Undulator Used for PKU-FEL TUPOS32

Jianping Dai, Wan Chen, Caitu Shi (*IHEP Beijing, Beijing*), Yanan Li, Huihua Lu, Yufeng Yang, Jiejia Zhuang (*IHEP BFEL, Beijing*)

A 5m-long combined function undulator used for the Peking University Infrared SASE FEL facility (PKU-FEL) is currently under construction at IHEP, and a 10 period prototype has already been developed. This paper describes the design study of the undulator, which is a hybrid planar magnet structure with extra focusing. The results of magnetic measurements performed on the prototype are also reported and discussed, and it demonstrates that the proposed combined function magnet structure is very promising for the use in the SASE FEL at Peking University.

Study on the Planar Undulator Scheme with Focusing Properties for PKU-FEL TUPOS33

Yuantao Ding, Jia'er Chen, Senlin Huang, Yugang Wang, Kui Zhao, Jiejia Zhuang (*PKU/IHIP, Beijing*)

An IR range SASE FEL test facility will be built at Peking University. The project is designed to get the SASE FEL at 7 micron driven by a superconducting accelerator. A hybrid planar Nd-Fe-B undulator is employed and the optimization of the external focus system for the undulator is studied. In the PKU-FEL facility, the electron energy is about 30-40 MeV. The combined function undulator with FODO lattice imposes quite stringent tolerances on the strength of the quads. To solve this problem, the weak natural focusing of the undulator in the vertical plane together with horizontally focusing quads, is proposed to supply the focusing in the facility. The combined function undulator of FOFO lattice and FF lattice in the horizontal plane are studied. Compared with the FODO lattice, the FOFO and FF lattice make the saturation a bit longer and the requirements of the field accuracy for the focusing system are much reduced.

Work supported by Chinese department of Science and Technology under the National Basic Research Projects. (No. 2002CB713604)

TUPOS34 **Beam Loading Tests on DC-SC Photoinjector at Peking University**

Senlin Huang, Jia'er Chen, Xiangqiang Chu, Yuantao Ding, Jiankui Hao, Fei Jiao, Lin Lin, Xiangyang Lu, Shengwen Quan, Guimei Wang, Lifang Wang, Rong Xiang, Binping Xiao, Baocheng Zhang, Kui Zhao (*PKU/IHIP, Beijing*)

Since the beginning of commissioning in February 2003, lots of tests on the DC-SC photoinjector test facility have been performed. At present, Q0 of the 1+1/2-cell cavity has reached 1E8 (at 4.2K) and the average gradient was about 4MeV/m. The DC photogun can provide stable electron beams. When the power of output laser went up to 100mW (266nm), the average beam current reached 400μA. Beam loading tests have been carried out, and SC acceleration was achieved. Average current of electron beams is about 100μA after acceleration.Further investigations are in progress to improve diagnostics system and to measure the emittance, energy spread and pulse length of electron beams.

Supported by Chinese department of Science and Technology under the National Basic Research Projects. (No. 2002CB713602)

TUPOS35 **The Drive Laser System for DC-SC Injector**

Xiangyang Lu, Lin Lin, Shengwen Quan, Fang Wang, Kui Zhao (*PKU/IHIP, Beijing*)

PKU-SCAF has developed a photoinjector which adopt a 1+1/2 cell super conducting cavity and DC electron gun. We also developed a low cost drive laser system for the photocathode DC gun to provide high average beam current. This laser system include a commercial high repetition rate, ps, all solid-state laser, the home made SHG and FHG, Fourier relay optics and the uniform illumination optics. The test results shows the output power at 266 nm of the laser system is more than 1.2W and got more than 500 A beam current from CsTe cathode from the DC gun.

The Spectral Ratio Gauging for CHG-FEL Experiment in NSRL TUPOS36

Nian Chen, Duohui He, Qika Jia, Ge Li, Yuhui Li, Jinying Liu, Hongliang Xu, Pengfei Zhang, Shancai Zhang (*USTC/NSRL, Hefei, Anhui*)

The goal of the coherent harmonic generation free-electron laser (CHG-FEL) experiment in NSRL is to gain a 266nm coherent radiation and a large spectral ratio which is defined as the ratio of coherent intensity to incoherent intensity in infinitesimal bandwidth and solid angle aperture. The intensity measurements are made through a spectrometer whose spectral and angular aperture is much larger than the actual apertures of coherent radiation and smaller than those of incoherent radiation. So the measured ratio is integral ratio integrated over the actual apertures of the measurement system. This paper is mainly on giving a formula and designing a computer program to calculate the spectral ratio according to the bandwidth and solid angle aperture of the measurement system, taking into account the measured magnetic field of optical klystron and the energy spread of the electron beam. The code will soon be employed in our next turn experiment.

This work is supported by Foundation of National Key Program for Basic Research of China (2001CCB01000), National Natural Science Foundation of China (20173055), Natural Science Foundation of Anhui Province(01046202).

Multi-Objective Optimization for Pure Permanent-Magnet Undulator Magnets Ordering Using Modified Simulated Annealing TUPOS37

Nian Chen, Duohui He, Ge Li (*USTC/NSRL, Hefei, Anhui*)

Undulator field errors influence the electron beam trajectories and lower the radiation quality. Angular deflection of electron beam is determined by first field integral, orbital displacement of electron beam is determined by second field integral and radiation quality can be evaluated by rms field error or phase error. Appropriate ordering of magnets can greatly reduce the errors. We apply a modified simulated annealing algorithm to this multi-objective optimization

problem, taking first field integral, second field integral and rms field error as objective functions. Undulator with small field errors can be designed by this method within a reasonable calculation time even for the case of hundreds of magnets (first field integral reduced to 10^{-6}Tům, second integral to 10^{-6}Tům^2 and rms field error to 0.01%). Thus, the field correction after assembling of undulator will be greatly simplified. This paper gives the optimizing process in detail and puts forward a new method to quickly calculate the rms field error and field integrals.

Foundation of National Key Program for Basic Research of China(2001CCB01000),National Natural Science Foundation of China(20173055).

TUPOS38 Design of Undulator for the Shanghai DUV-FEL

Qika Jia, Duohui He, Shengkuan Lu, Shancai Zhang (*USTC/NSRL, Hefei, Anhui*), Yun Cao, Zhimin Dai, Zhentang Zhao, Qiaogen Zhou (*SINAP, Jiading, Shanghai*)

The design study of the undu1ator for Shanghai deep ultra violate free electron laser source (SDUV-FEL) is presented. The optimum undulator parameters for the FEL performance have been studied. The scheme of focusing and segmentation is discussed. The requirements of undulator magnet field and main technical demand are given.

TUPOS39 Study of Grid Control RF Gun

Jin Xiao (*CAEP/IAP, Mianyang, Sichuan*)

In this paper, the beam loading effect of RF Gun was analyzed. To minimize the energy spread, the grid control RF Gun was introduced. The result shows that the grid congrol RF Gun can increase electron beam within 1% energy spread.

TUPOS40 In-Vacuo Superconducting Undulator with Switching Polarized Light

Ching-Shiang Hwang (*NSRRC, Hsinchu*)

This study investigates planar in-vacuo superconducting undulators with periodic length of 5 cm (IVSU5) producing linearly and

circularly polarized infrared rays or xrays source. The vertically wound racetrack coil is selected for the coil and pole fabrication of the IVSU5. When the up and down magnetic pole arrays with alternative directions rotated wires in the horizontal plane, a helical field radiates circularly polarized light in the electron storage ring, the free electron laser (FEL), and the energy recovery linac (ERL) facilities. Meanwhile, an un-rotated wire is constructed together with the rotated wire on the same undulator is used to switch the linear horizontal and vertical, the right- and left-circular polarization radiation. Given a periodic length of 5 cm and a gap of 23 mm, the maximum magnetic flux density in the helical undulator are B_z = 1.5 T and B_x = 0.5 T when the wires rotated by 20°. This article describes the main factors of the planar and helical undulator design for FEL and the concepts concerning the magnet array structures of the superconducting undulators. The photon flux and the mechanism of the switching polarization radiation are discussed.

Correction Elements for Providing Effective Non-adiabatic Injection into Helical Undulators TUPOS41

Vitaly Arkadievich Papadichev (*LPI, Moscow*)

During recent years, many options for non-adiabatic injection into helical undulators have been proposed and checked experimentally. They have many advantages over still almost exclusively used so-called adiabatic injection: 1) much shorter undulator, 2) minimal betatron oscillations because injection is matched in angle and displacement in both transverse coordinates (in contradistinction to adiabatic injection) and 3) a possibility of much easier phasing of electron beam bunches and radiation in multi-sectional undulators. Characteristic features of the elements for angle and orbit-displacement correction are described and analyzed. Various combinations of elements are examined, including some with no intersection of windings of elements and undulator since they are placed on different radii and/or axial positions. Optimization of parameters of the elements allows constructing a nearly "ideal" magnetic field for non-adiabatic injection. The second field integral curve versus axial coordinate, i.e., beam orbit, consists in this case of an integral number of sinusoidal

half-periods, except for about a quarter-period-long part at the beginning and end of the undulator.

TUPOS42 Saturation of Iron Poles in Hybrid Undulators Influencing the Search for the Minima of the First and Second Field Integrals

Vitaly Arkadievich Papadichev, G. V. Rybalchenko (*LPI, Moscow*)

Hybrid undulators are widely used in many FELs. For example, in an XFEL project, dozens of undulator sections are to be used. Changing the radiation wavelength is performed often by varying the undulator gap. Matching the beam injection angle and beam displacement is performed by correction elements, usually one-period long, placed at both undulator ends. Saturation in iron poles of a hybrid undulator strongly affects matching of the first and second field integrals, especially at small undulator gaps. Since correction periods at both ends of the undulator have lower field amplitudes, the most pronounced effect is in the regular part of an undulator. Various methods of reducing such influence or adjusting it to the required dependence on the undulator gap were analyzed. Chamfers of various shapes were studied and a set of complementary parameters of poles and magnets of the correction part were found using iterations. Numerical calculations of an undulator model show that it is possible to minimize the deviation of the average values of the first and second field integrals for a large range of gaps to an acceptable level of less than 0.02 T·mm.

TUPOS43 Commissioning of Strong Tapered Undulator Developed for IFEL Accelerator

Alexander Varfolomeev, Sergey Tolmachev, Alexander Varfolomeev Jr., Timofey Yarovoi (*RRC Kurchatov Institute, Moscow*), Pietro Musumeci, Claudio Pellegrini, James Rosenzweig (*UCLA, Los Angeles, California*)

Description is presented of the KIAE-2p planar undulator device manufactured for the UCLA - Kurchatov Institute IFEL project (see PAC2001 Proceedings, p.p. 4008-4010 and PAC2003 Proceedings). Physical requirements for the undulator and simulations results on the design were given earlier (Nucl. Instr. and Meth. A483 (2002)

372-382). Here we describe main technological aspects enabled to fabricate the installation responding to the stringent requirements on mechanical construction accuracy and magnetic field strong tapering. Main parameters of the tuned undulator including last results of the magnetic field measurements by different methods are given. The obtained magnetic fields were used for final simulations of the acceleration process. It is shown that capture of 30% of electrons is provided in the acceleration process with energy gain from initial 14 MeV up to 50 MeV for nominal electron beam and laser beam parameters. Special analysis of the undulator acceptances for these parameters was made. It is shown that the acceleration takes place up to energies > 30 MeV for rather wide deviations from nominal ones in laser pulse energy, Rayleigh length and e.b. emittance.

Mesh Fabry-Perot Interferometers for FEL Applications

TUPOS44

Vitaliy Vladimirovich Kubarev (*BINP, Novosibirsk*)

Mesh Fabry-Perot interferometers are simplest and most adequate devices for spectral measurements of FEL radiation in wavelength range 20-500 microns. Main principles of calculation and design of optimal Fabry-Perot interferometers are described. Universal singemode gas-discharge laser was used for creation and calibration of the interferometers. Instrumental functions of the interferometers was measured by this laser. Measured spectra of the powerful FEL of Siberian Center for Photochemical Research and compact KAERI FEL are presented.

Free Electron Lasers and Libera both Push Performance into New Frontiers

TUPOS45

Rok Ursic (*Instrumentation Technologies, Solkan*)

Free Electron Lasers and Libera electron beam position processor share a common vocation - they both push performance into new frontiers. Advances in electron accelerator technology that enabled FELs to fulfill their earliest days promises have also been due to the recent developments in the beam instrumentation. Libera that has till know been successfully employed in the light sources projects promises to become an indispensable tool also in the FEL

field. The three main advantages of Libera are: all-in-one, customization and connectivity. All-in-one is the concept of unification of various building blocks and thus various functionalities in one product. The customization is enabled by the product's reconfigurability that allows it to grow and support new requirements and application without changing hardware. The consequence of the two is the capacity of the single instrument to perform a variety of tasks that before were split among different devices. Connectivity improves the communication between controls and beam diagnostics, brings out-of-the crate-freedom and opens unforeseen possibilities for inter-accelerator cooperation and remote technical support.

TUPOS46 Control and Pulse Synchronization Systems of Linear Electron Accelerator for FEL

Andrey Styervoyedov (*SCPT, Kharkiv*), Yana Shashel, Mykola Styervoyedov (*KhNU, Kharkov*)

The succesful usage of linear accelerators for FEL is determined by quantity and quality of information about basic parameters of charged particles beams. Effective work of FEL is possible in case of high and stable characteristics of electron beam parameters. These characteristics depend mainly on informational possibilities of accelerator control system and correct time sequence of systems and accelerator units, which the system of pulse synchronization provides. New realizations of accelerator control system based on radiation-acoustic effects and system of synchronization for pulse formation of starting of electron source, SHF-generators, scientific and technological equipment are presented in the report. The tasks of stabilization of current and energy of accelerated beam, regulation and stabilization of accelerated charge of beam in every separate cycle of acceleration, organization of multibeam regime, adjustment of energetical spectrum by time delay method are solved with the help of developed systems. Block diagram of systems, schematic diagram of main system units and the results of their test are presented in the report.

Optical Systems for the Fourth Generation Light Source, 4GLS TUPOS47

Frances Quinn, Marion Bowler, Mike MacDonald, Mark Roper (*CCLRC/DL/SRD, Warrington*)

4GLS is a multi-user, multi-source facility proposed for construction at Daresbury Laboratory in the UK. By exploiting superconducting linac technology with energy recovery, it will combine three free electron lasers and a range of conventional synchrotron radiation sources covering the THz to SXR region. The facility will provide femtosecond pulses at high repetition rate, with the FELs delivering GW power in the VUV and XUV region. This paper discusses the options and challenges for the optical systems associated with the suite of photon sources. The beamlines will need to operate both independently and in flexible, synchronised combinations. Together with the requirements for preserving the ultra-bright, fast pulse properties, this places unique demands on the design, layout and operational modes. The paper summarises current technical achievements and identifies the research and development necessary before detailed design of the 4GLS optical systems.

A Concept for z-Dependent Microbunching Measurements with Coherent X-ray Transition Radiation in a SASE FEL* TUPOS48

Alex Lumpkin (*ANL/APS, Argonne, Illinois*), William M Fawley (*LBNL/CBP, Berkeley, California*), Don W. Rule (*NSWC-CD, West Bethesda*)

Previously, measurements in the visible to VUV regimes of z-dependent microbunching in a self-amplified spontaneous emission (SASE) free-electron laser (FEL) have provided important information about the fundamental mechanisms. In those experiments a thin metal foil was used to block the more intense SASE radiation and to generate coherent optical transition radiation (COTR) as one source in a two-foil interferometer. However, for the proposed Linac Coherent Light Source (LCLS), the intense SASE emission is either too strongly transmitted at 1.5 angstroms or the needed foil thickness for blocking scatters the electron beam too much. Since coherent x-ray transition radiation (CXTR) is emitted in an annulus with opening angle 1/γ = 36 ţrad for 14.09-GeV electrons, one could use a

thin foil or foil stack to generate the XTR and CXTR and an annular crystal to wavelength sort the radiation. The combined selectivity will favor the CXTR over SASE by about eight orders of magnitude. Time-dependent GINGER simulations support the z-dependent gain evaluation plan.

* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract Nos. W-31-109-ENG-38 and DE-AC03-76SF00098.

TUPOS49 First Direct Comparisons of a COTRI Analytical Model to Data from a SASE FEL at 540, 265, and 157 nm*

Alex Lumpkin, Roger Dejus (*ANL/APS, Argonne, Illinois*), Don W. Rule (*NSWC-CD, West Bethesda*)

We have been addressing fundamental aspects of the microbunching that is induced by the self-amplified spontaneous emission (SASE) free-electron laser (FEL) process using coherent optical transition radiation interferometry (COTRI) techniques. Over the last several years we have extended operations from the visible to the VUV regime at the Advanced Photon Source (APS) low-energy undulator test line (LEUTL) project. We have now performed our first direct comparisons of the results of an analytical model to COTRI experimental data at 540, 265, and 157 nm. The direct comparisons illustrate a number of details in the images that are not matched by the simplifying assumption of a single Gaussian transverse beam profile of the size consistent with the incoherent OTR measurements. This result indicates there are localized transverse portions of the beam distribution with a higher bunching fraction than the mean. The different beam energies used result in different overlaps of relevant functions,and this aspect probed the model's applicability and sensitivities.

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Use of VUV Imaging to Evaluate COTR and Beam-Steering Effects in a SASE FEL at 130 nm* TUPOS50

Alex Lumpkin, Yong-Chul Chae, Roger Dejus, Mark Erdmann, John Lewellen, Yuelin Li, Stephen Milton (*ANL/APS, Argonne, Illinois*)

We have continued to explore VUV operations on the Advanced Photon Source (APS) self-amplified spontaneous emission (SASE) free-electron laser (FEL). With the installation of a fifth VUV imaging station located after undulator 7 of an eight-undulator series, we have performed our most complete SASE gain curve measurements at 130 nm as well as obtaining beam profile, position, and divergence information. This is the shortest wavelength to date for our complementary coherent optical transition radiation (COTR) measurements. We have also done the first experimental test of Tanaka et al.'s analytical model for the effects of a single-kick error of the e-beam on gain and microbunching in a SASE FEL. In addition, we compared the e-beam image centroid positions with those of the alignment laser at the available cameras and the local rf BPM readings to sort out the effective trajectory and its effect on overall gain. The FEL performance was consistent with GENESIS simulations of the experiment described in detail in a companion paper.

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

Test of Horizontal Magnetic Field Measurements in the Presence of Strong Vertical Field TUPOS51

Isaac Vasserman (*ANL/APS, Argonne, Illinois*)

Trajectory straightness is an important parameter defining the performance of free-electron laser (FEL) devices. The first test of horizontal field measurements using Hall probes was done in 1998 as a preparation to the tuning of undulators for the FEL project at the Advanced Photon Source. This work continues the 1998 work, now associated with Linac Coherent Light Source (LCLS) project. Tolerances for the LCLS FEL undulator specify 2 um trajectory excursion in both (horizontal and vertical) planes for a particle energy of 14.1 GeV, which means that measurements of a small horizontal field

in presence of strong (up to 1.5 T) vertical field are required. Hall probe measurements under such conditions are complicated due to a planar Hall probe effect. Previous tests done in 1998 showed that a 2- axis Sentron probe is a possible choice. The high sensitivity of horizontal field integrals to the vertical position of the sensor was observed. It was shown that this probe could be used for fast measurements and tuning of the device. The Sentron probe was recently used for LCLS prototype measurements and tuning. Rather good agreement with reference moving coil measurements was obtained.

TUPOS52 Development and Measurement of Strain Free RF Photoinjector Vacuum Windows

Sandra G. Biedron (*ANL, Argonne, Illinois*), Lahsen Assoufid, Yuelin Li, Jun Qiun (*ANL/APS, Argonne, Illinois*), Marcus Babzien (*BNL, Upton, Long Island, New York*), Gregory Gill (*ISI, Sarasota Florida*)

RF photoinjectors produce the highest brightness electron bunches only under nearly ideal illumination by a drive laser. The vacuum window used to introduce the laser beam is an essential element that may potentially degrade any distribution, making it difficult or impossible to know the actual uniformity achieved at the cathode. Because of the necessity to obtain ultrahigh vacuum near the photoinjector, some restrictions are imposed on the fabrication technology available to manufacture distortion-free windows. At the UV wavelengths commonly used for photoinjectors, it is challenging to measure and eliminate degradation caused by vacuum windows. Here, we discuss the initial laser-based measurements of a strain-free, coated, UHV window manufactured by Insulator Seal in collaboration with members of Brookhaven and Argonne National Laboratories.

This work is supported by the US Department of Energy, Office of Basic Energy Sciences under Contract No. W-31-109-ENG-38.

Normal-Conducting RF Cavity of High Current Photoinjector for High Power CW FEL TUPOS53

Sergey S Kurennoy, Dale Schrage, Richard Wood, Lloyd M Young (*LANL/LANSCE, Los Alamos, New Mexico*), John Rathke, Thomas John Schultheiss (*AES, Medford, NY*)

An RF photoinjector capable of producing high continuous average current with low emittance and energy spread is a key enabling technology for high power CW FEL. The design of a 2.5-cell, pi-mode, 700-MHz normal-conducting RF photoinjector cavity with magnetic emittance compensation is completed. With the electric field gradients of 7, 7, and 5 MV/m in the three subsequent cells, the photoinjector will produce a 2.5-MeV electron beam with 3-nC charge per bunch and the transverse rms emittance 7 mm-mrad. Electromagnetic modeling was used extensively to optimize ridge-loaded tapered waveguides and RF couplers, which led to a new, improved coupler iris design. The results, combined with a thermal and stress analysis, show that the challenging problem of cavity cooling can be successfully solved. The manufacturing of a demo 100-mA (at 35 MHz bunch repetition rate) photoinjector is underway. The design is scalable to higher power levels by increasing the electron bunch repetition rate, and provides a path to a MW-class amplifier FEL. This paper presents the cavity design and details of RF coupler modeling.

Comparison of Parmela and MAFIA Simulations of Beam Dynamics in High Current Photoinjector TUPOS54

Sergey S Kurennoy (*LANL/LANSCE, Los Alamos, New Mexico*)

A high-current RF photoinjector producing low-emittance electron beam is an important technology for high-power CW FEL. LANL-AES team designed a 2.5-cell, pi-mode, 700-MHz normal-conducting RF photoinjector with magnetic emittance compensation. With the electric field gradients of 7, 7, and 5 MV/m in the three subsequent cells, the photoinjector will produce a 2.5-MeV electron beam with 3-nC charge per bunch and the transverse rms emittance 7 mm-mrad. Beam dynamics in the photoinjector has been modeled in details. In addition to the usual approach, with fields calculated by Superfish-Poisson and beam simulations performed by Parmela,

we also used MAFIA group of codes, both to calculate cavity fields and to model beam dynamics with its particle-in-cell module TS. The second way naturally includes wake-field effects into consideration. The simulation results and comparison between two approaches will be presented.

TUPOS55 Progress of a High-Average-Current RF Photoinjector for 100 kW FEL

Thomas John Schultheiss, Vincent Christina, John Rathke (*AES, Medford, NY*), Patrick Colestock, Sergey S Kurennoy, Dinh Nguyen, Dale Schrage, Richard Wood (*LANL/LANSCE, Los Alamos, New Mexico*), Lloyd M Young (*TechSource, Santa Fe*)

A high current RF photoinjector capable of producing continuous average current on the order of 100 mA is a key enabling technology for high-power Free Electron Lasers. A 2.5 cell normal-conducting photocathode gun is described here. It will be operated at 700 MHz with a mean electric field along the beam axis of 7.0 MV/m in the first cell 7.0 MV/m in the second cell and 5.0 MV/m in the third cell, and capable of 3 nC bunch charge and less than 10 mm-mrad emittance at the wiggler. Los Alamos and TechSource developed the RF/Physics design. AES developed the mechanical and thermal management details of the gun. The RF design, tuning concept, and fabrication process are described. Thermal, structural and RF analysis details including the ridge loaded waveguide region have been completed and are presented. RF heat loads, temperature distribution, and the resulting surface displacements are weakly coupled in an axisymmetric analysis and are used to determine frequency shift and cell-to-cell field distribution effects for nominal and off-nominal flow rates. AES is presently fabricating the gun, which will subsequently be tested at the LANL LEDA facility.

TUPOS56 RF Design for the Linac Coherent Light Source (LCLS) Injector

D. Dowell, C. Limborg (*SLAC, Menlo Park, California*), John Schmerge (*SLAC/LCLS, Menlo Park, California*)

The Linac Coherent Light Source (LCLS) will be the world's first free electron laser, and the successful operation of this very short-wavelength FEL will require excellent beam quality from its electron

source. Therefore a critical component is the RF photocathode injector. This paper describes the design issues of the LCLS RF gun and accelerator structures. The injector consists of a 1.6 cell s-band gun followed by two 3-meter SLAC sections. The gun and the first RF section will have dual RF feeds both to eliminate transverse RF kicks and to reduce the pulsed heating of the coupling ports. In addition, the input coupler cavity of the first accelerator section will be specially shaped to greatly reduce the RF quadrupole fields. The design for the accelerator section is now complete, and the RF design of the gun's dual coupler and the full cell shape is in progress. These and other aspects of the gun and structure designs will be discussed.

Optimal RF systems for Lightly Loaded Superconducting Structures

TUPOS57

Townsend Zwart, William S Graves, William North, Abbi Zolfaghari (*MIT/BLAC, Middleton, Massachusetts*)

Recent developments in the field of RF accelerators have created a demand for power amplifiers that can support very high accelerating gradients, 15-25 MV/m, in superconducting structures with extremely low losses. Free electron lasers (FEL's) with modest beam current, I< 10 uA, or based on energy recovery linacs (ERL's) may have intrinsic power demands of less than 1 kW/m. We present the design of an amplifier and external tuner system that will efficiently meet this requirement. The RF amplifier, an Inductive Output Tube (IOT), offers high AC/RF efficiency, flexible power output and switching capability without the need for external modulation. The tuner circuit makes use of low loss ferrite phase shifters to create a moderate quality standing wave (Q 100-1000) between the amplifier and the superconducting cavity. An alternative design based on a shorter cavity structure and employing solid state amplifiers is also presented. The expected performance characteristics of both systems are described.

TUPOS58 Electron Beam Diagnostics Using Diffraction Radiation

Bibo Feng, Steven E. Csorna, William E. Gabella (*Vanderbilt/DPA, Nashville - Tennessee*)

Diffraction radiation, emitted from ralativistic electron bunches, has the potential applications of non-intercepting electron beam diagnostics. The electron longitudinal distribution in a bunch can be obtained from the coherent diffraction radiation spectrum; the beam transverse properties, such as beam size, divergence and emittance, can be measured through the analysis of the angular distribution of the diffraction radiation. The design study and initial experimental results at the Vanderbilt FEL facility will be presented.

This work is supported by the Department of Defense through the MFEL program under award No. F49620-01-1-0429.

TUPOS59 Simulation of Phase Instability of NJIT/Rutgers FIR FEL Operation

Jianjun Zheng, Ken Chin (*NJIT, Newark*), John Madey, Eric Szarmes (*UHM-Physics, Honolulu, Hawaii*)

The operation of the NJIT/Rutgers FIR FEL is simulated for the first time sing the slightly modified UH code. The lasering behavior is explored for a wide range of parameters. Particularly, we studied the effects on the operation of the microtron based FEL due to the electron beam pulse phase instability which is possibly caused by the microtron cathode back heating. The study shows that for a small phase slew, systematic or random, there is little effect on the normal operation of the FEL. However, a dramatic phase slew of the e-pulse lasting for 1μs kills the operation of the FEL. We estimated the tolerance of the phase instability and discussed the proper operation condition of the device.

TUPOS60 Making an Inexpensive Electromagnetic Wiggler Using Sheet Materials for the Coils

George Herman Biallas, Stephen Vincent Benson, Thomas Hiatt, George Neil, Michael Snyder (*Jefferson Lab, Newport News, Virginia*)

An inexpensive electromagnetic wiggler, made with twenty-eight,

4 cm periods with a K of 1 and gap of 2.6 cm was made within 10 weeks after receipt of order by an industrial machine shop. The coil design used sheet and plate materials cut to shapes using water jet cutting and was assembled in a simple stack design. The coil design extends the serpentine conductor design of the Duke OK4 to more and smaller conductors. The coils are conduction cooled to imbedded cooling plates. The wiggler features graded end pole fields, trim coil compensation for end field errors and mirror plates on the ends to avoid three dimensional end field effects. Details of the methods used in construction and the wiggler performance are presented.

* This work supported by DOE Contract DE-AC05-84ER40150, the Office of Naval Research, Air Force Research Laboratory, the Commonwealth of Virginia and the Laser Processing Consortium

Performance and Modeling of the JLab IR FEL Upgrade Injector

TUPOS61

Carlos Hernandez-Garcia, Kevin Beard, Stephen Vincent Benson, George Herman Biallas, Don Bullard, David Douglas, Fred Dylla, Richard Evans, Al Grippo, Joe Gubeli, Kevin Jordan, George Neil, Michelle D. Shinn, Tim Siggins, Richard Walker, Byung Yunn, Shukui Zhang (*Jefferson Lab, Newport News, Virginia*)

The JLab IR Upgrade Injector has delivered up to 9.1 mA CW of electron beam current at 9 MeV. The injector is driven by a 350 kV DC Photocathode Gun. Injector behavior and beam-based measurements are in very good agreement with PARMELA simulations. The injected beam envelopes were established by measuring beam spot sizes and comparing them with those predicted by a transport matrix based model. The emittances were measured by fitting an initial trial beam matrix to the measured data. The injected bunch length was established by measuring the energy spread downstream of the Linac while operating at either side of crest.

This work supported by The Office of Naval Research under contract to the Dept. of Energy, the Air Force Research Lab, and the Commonwealth of Virginia.

TUPOS62 Short Electron Beam Bunch Characterization Through Measurements of THz Radiation

Shukui Zhang, Stephen Vincent Benson, David Douglas, George Neil, Michelle D. Shinn, Gwyn Williams (*Jefferson Lab, Newport News, Virginia*)

Characterization of the electron beam bunch length of the upgrade FEL at Jefferson Lab was performed by analyzing the FTIR spectra of the coherent terahertz pulses. The results are compared with autocorrelation from a scanning polarization autocorrelator that measures the optical transition radiation. The limitations of the different methods to such a characterization are presented in this paper.

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TUPOS63 RF Sources for 3rd & 4th Generation Light Sources

Stephan Lenci, Heinz Bohlen (*CPI/MPP, Palo Alto, CA*)

The growing number of third and fourth generation light sources has resulted in an increase of the available rf sources to power them. Single beam klystrons are the traditional power source, but the development of IOT's and multiple-beam klystrons (MBK's) in L-Band have increased the options for these machines. The Eimac division of CPI has recently built and tested a prototype L-Band IOT, which delivered 30 kW CW at 1.3 GHz. Future work includes the building of an IOT at 1.5 GHz. Meanwhile the MPP division of CPI is currently testing the prototype 10 MW peak, 1.3 GHz MBK for the TESLA x-ray free-electron laser (XFEL). Test results for these new products as well as information on all CPI products at 500 MHz, 1.3 GHz, and 1.5 GHz will be presented.

* CPI MPP Division
* CPI Eimac Division

High Current Energy Recovery Linac at BNL TUPOS64

Vladimir Litvinenko, Ilan Ben-Zvi (*BNL, Upton, Long Island, New York*)

We present the design, the parameters of a small test Energy Recovery Linac (ERL) facility, which is under construction at Collider-Accelerator Department, BNL. This R&D facility has goals to demonstrate CW operation of ERL with average beam current in the range of 0.1 - 1 ampere, combined with very high efficiency of energy recovery. A possibility for future up-grade to a two-pass ERL is considered. The heart of the facility is a 5-cell 700 MHz super-conducting RF linac with HOM damping. Flexible lattice of ERL provides a test-bed for testing issues of transverse and longitudinal instabilities and diagnostics of intense CW e-beam. ERL is also perfectly suited for a far-IR FEL. We present the status and our plans for construction and commissioning of this facility.

Thermal and Field Enhanced Photoemission: Comparison of Theory to Experiment TUPOS65

Kevin Lynn Jensen (*NRL/ESTD, Washington*), David L. Demske, Donald W. Feldman, Nate Moody, Patrick Gerard O'Shea (*IREAP, College Park, Maryland*)

Photocathodes are a critical component of high-gain FEL's and the analysis of their emission is complex. Relating their performance under laboratory conditions to conditions of an rf photoinjector is difficult. Useful models must account for cathode surface conditions and material properties, as well as drive laser parameters. We have developed a time-dependent model accounting for the effects of laser heating and thermal propagation on photoemission. It accounts for surface conditions (coating, field enhancement, reflectivity), laser parameters (duration, intensity, wavelength), and material characteristics (reflectivity, laser penetration depth, scattering rates) to predict current distribution and quantum efficiency. The applicatIon will focus on photoemission from metals and, in particular, dispenser photocathodes: the later introduces complications such as coverage non-uniformity and field enhancement. The performance of experimentally characterized photocathodes will be extrapolated to 0.1 - 1 nC bunches in 10 ps pulses under fields of 10 - 50 MV/cm and other conditions typical of high gain FELs.

Supported by Joint Technology Office and Office of Naval Research.

TUPOS66 Coherent Resonant Diffraction Radiation for Charged Particle Beams Diagnostics*

Hamlet Karo Avetissian, Samvel Samvel Israelyan, Garnik Felix Mkrtchian (*YSU, Yerevan*)

As is known the energy of Resonant Diffraction Radiation (RDR) exceeds by several orders the ordinary diffraction radiation energy because of the coherent factor being proportional to the square of the number of metallic screens. Besides, if the radiation wavelengths are larger or comparable with the transverse or longitudinal size of a particle beam bunch the Coherent RDR (CRDR) will be produced with intensity much higher than incoherent RDR due to the superradiation. So, CRDR may serve as an effective tool for the non-destructive beam diagnostics. In this paper we concern with the analysis of CRDR. The exact solution of the Maxwell equation for RDR by Wiener-Hopf method for a charged particle moving above periodically spaced semi-infinite ideally conducting screens has been obtained. We have derived the spectral-angular distribution of the CRDR by the obtained exact solution. To emphasize main principles of charged particle beam diagnostic method, based on the CRDR, we present the special case of RDR, when the charged particles move perpendicular to the screens plane, which is referred as Smith-Purcell radiation.

*This work was supported by NFSAT Grant No. PH 082-02/CRDF 12023.

TUPOS67 A Mode Locked UV-FEL

Parviz Parvin (*AUT, Tehran ; AEOI-RCLA, Tehran*), A. Basam (*AU, Vanak, Tehran*), B. Sajad (*AU, Vanak, Tehran ; IHU, Tehran*), G. R. Davoud-Abadi, F. Ebadpoor (*AUT, Tehran*)

An appropriate resonator has been designed to generate femtosecond mode locked pulses in a UV FEL with the modulator performance based on the gain switching. The gain broadening due

to electron energy spread affects on the gain parameters, small signal gain (γ_0) and saturation intensity (I_s), to determine the optimum output coupling as small.

The Resistive Impedance of the Small-Gap Undulator Vacuum Chamber TUPOS68

Mikhael Ivanyan, Vassili Tsakanov (*CANDLE, Yerevan*)

The small gap undulator vacuum chamber resistive impedance is studied. The vacuum chamber is considered as a two-layer cylindrical tube with finite wall thickness. An analytical form of longitudinal impedance is obtained. The study includes both the thin and thick layer cases.

FEL Experiments
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WEAxS

Experiments on the HGHG Wavelength Tuning at the DUV FEL

WEAIS01

Timur Shaftan, Sam Krinsky, Henrik Loos, James Murphy, James Rose, Brian Sheehy, John Skaritka, Xijie Wang, Zilu Wu, Li-Hua Yu (*BNL/NSLS, Upton, Long Island, New York*)

We present experimental results on tuning of the HGHG FEL output wavelength while holding the input seed wavelength constant. Using compression of the initially chirped beam in the HGHG dispersion section we have measured the wavelength shift of about 1% around the nominal value of 266 nm. The tuning range is expected to reach 3 % after the dispersive section upgrade at the DUV FEL. An optimized design based on this principle, using additional linac sections, would have the capability of providing full tunability.

Spectral Phase Modulation and chirped pulse amplification in HGHG

WEAOS02

Zilu Wu, Erik Johnson, Sam Krinsky, Henrik Loos, James Murphy, Timur Shaftan, Brian Sheehy, Yuzhen Shen, Xijie Wang, Li-Hua Yu (*BNL/NSLS, Upton, Long Island, New York*)

High Gain Harmonic Generation (HGHG), because it produces longitudinally coherent pulses derived from a coherent seed, presents remarkable possibilities for manipulating FEL pulses. If spectral phase modulation imposed on the seed modulates the spectral phase of the HGHG in a deterministic fashion, then chirped pulse amplification, pulse shaping, and coherent control experiments at short wavelengths become possible. In addition, the details of the "transfer function" will likely depend on electron beam and radiator dynamics and so prove to be a useful tool for studying these. Using the DUVFEL at the National Synchrotron Light Source at Brookhaven National Laboratory, we present spectral phase analyses of both coherent HGHG and incoherent SASE ultraviolet FEL radiation, applying Spectral Interferometry for Direct Electric Field Reconstruction (SPIDER), and assess the potential for employing compression and shaping techniques.

U.S. Department of Energy, Office of Basic Energy Sciences, under contract DE-AC02-98CH10886, and Office of Naval Research Grant N00014-97-1-0845.

WEAOS03 Dynamical Analysis of Chaos Generated on a Storage Ring Free Electron Laser

Christelle Bruni, Marie-Emmanuelle Couprie, David Garzella, Gian Luca Orlandi (*LURE, Orsay*), Dalila Amroun, Christophe Letellier (*Université de Rouen, Saint Etienne du Rouvray*)

Chaos could be generated on a FEL by applying a modulation on the gain, which frequency is near the resonance one of the system. Systematic studies of the macro-temporal structures show that windows of chaos appear according to the frequency and the amplitude of the modulation. The evolution of the system is reproduced by a numerical code based on a system of differential equations. It describes pass to pass in the optical klystron, the laser intensity and the energy spread evolution. The dynamical analysis is realised by underlying the topology of the phase-space portrait built from the laser intensity time series. The experimental dynamics is compared to the dynamics of the model.

WEAOS04 Study of Coherence Limits and Chirp Control in Long Pulse FEL Oscillator

Avraham Gover, Alon Eliran, Yehoshua Socol, Mark Volshonok (*University of Tel-Aviv, Tel-Aviv*), Moshe Einat, Miki Kanter, Boris Yu Kapilevich, Yuri Lurie, Yosef Pinhasi, Asher Yahalom (*The College of Judea and Samaria, Ariel*)

Electrostatic Accelerator FELs have the capacity to generate long pulses of tens microseconds and more, that in principle can be elongated indefinitely (CW operation). This allows the generation of very coherent radiation. The fundamental linewidth is extremely narrow [1], and in practice the spectral width is limited by the pulse duration (Fourier transform limit) and e-beam stability. Practical problems such as the accelerator terminal voltage drop due to a non-ideal electron beam transport may reduce the length of the radiation pulse and hence create a limiting factor for coherence measurement. The current status of the Israeli Tandem Electrostatic Accelerator FEL allows the generation of pulses of tens microseconds duration. It has been operated recently past saturation, and produces single mode coherent radiation of relative linewidth Δf/f=10-5 at frequencies near 100GHz. A clear frequency chirp is observed during pulses of tens of microseconds (0.1-1 MHz/mS), and is directly proportional to the voltage drop rate of the High-Voltage terminal. We

will report experimental studies of the spectral linewidth and chirp characteristics of the radiation, along with theory and numerical simulations, carried out using space-frequency model [2], matching the experimental data.

Measuring the Double-Differential Spectrum of Ultra-Short SASE Radiation Pulses at VISA FEL

WEAOS05

Murokh Alex, Gerard Andonian, Sven Reiche (*UCLA/DPA, Los Angeles - California*), Yakimenko Vitaly (*BNL, Upton, Long Island, New York*), C. Vicario (*INFN/LNF, Frascati (Roma)*), James Rosenzweig, Gil Travish (*UCLA, Los Angeles, California*)

In recent years, there have been numerous publications related to the generation of femtosecond radiation pulses with SASE FEL. In VISA II experiment at BNL, experimental studies were undertaken to characterize the emission properties of the short pulses generated by strongly compressed single spike electron beam. Strong deviation from a continuous beam model was found in angular, spectral and gain evolution properties of such radiation. Simultaneous measurements of angular and spectral distributions was performed and results are compare to theoretical and simulation models.

New Concepts and Ideas

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WEBOS

Current-Enhanced SASE Using an Optical Laser and its Application to the LCLS

WEBOS01

Alexander A Zholents, William M Fawley (*LBNL/CBP, Berkeley, California*), Paul J Emma, Zhirong Huang (*SLAC, Menlo Park, California*), Sven Reiche (*UCLA/DPA, Los Angeles - California*)

We propose a significant enhancement of the electron peak current entering a SASE undulator by inducing an energy modulation in an upstream wiggler magnet via resonant interaction with an optical laser, followed by micro-bunching of the energy-modulated electrons at the accelerator exit. This current enhancement allows a considerable reduction of the FEL gain length. The x-ray output consists of a series of uniformly spaced spikes, each spike being temporally coherent. The duration of this series is controlled by the laser pulse and in principle can be narrowed down to just a single, 100-attosecond spike. Given potentially absolute temporal synchronization of the x-ray spikes to the energy-modulating laser pulse, this scheme naturally makes pump-probe experiments available to SASE FEL's. We also study various detrimental effects related to the high electron peak current and discuss potential cures. We suggest a possible operational scenario for the LCLS optimized with respect to the choice of the modulating laser beam and electron beam parameters. Numerical simulations are provided.

Work supported by the U.S. Dept. of Energy under Contracts DE-AC03-76SF0098 and DE-AC03-76SF0015.

Generation of Terahertz Radiation by Modulating the Electron Beam at the Cathode

WEBOS02

Jonathan Neumann, Ralph Fiorito, Patrick Gerard O'Shea (*IREAP, College Park, Maryland*), Henrik Loos, Brian Sheehy (*BNL/NSLS, Upton, Long Island, New York*)

A bunched electron beam can be used to generate coherent radiation in a particle accelerator. This experiment, a collaboration between the University of Maryland and the Source Development Laboratory at Brookhaven National Laboratory, uses a drive laser modulated at terahertz frequencies in an RF-photoinjecting electron accelerator to produce a bunched beam at the cathode. The experiment is designed to determine if such a scheme could be used to

develop a compact, high power terahertz emitter. After acceleration to approximately 72 MeV, a mirror intercepts the beam. The backwards transition radiation from the mirror is measured with a bolometer. The experiment was conducted at various modulation frequencies and levels of charge.

WEBOS03 Suppression of Multipass, Multibunch Beam Breakup in Two Pass Recirculating Accelerators

Todd I. Smith (*Stanford University, Stanford, California*), Lia Merminga, Eduard Pozdeyev, Chris Tennant (*Jefferson Lab, Newport News, Virginia*)

Beam Breakup (BBU) occurs in all accelerators at sufficiently high currents. In recirculating accelerators, such as the energy recovery linacs used for high power FELs, the maximum current has historically been limited by multipass, multibunch BBU, a form that occurs when the electron beam interacts with the high order modes (HOMs) of an accelerating cavity on one pass and then again on the second pass. This effect is of particular concern in the designs of modern high average current energy recovery accelerators utilizing superconducting technology. In such two pass machines rotation of the betatron planes by 90◦, first proposed by Smith and Rand in 1980 [1], should significantly increase the threshold current of the multibunch BBU. Using a newly developed 4-dimensional tracking code, we study the effect of rotation on the threshold current of the JLAB FEL Upgrade. We examine several optical rotator schemes based on quadrupoles and solenoids and evaluate their performance in terms of the instability threshold current increase and their effect on the FEL optics.

[1] R.E. Rand and T.I. Smith, Beam Optical Control of Beam Breakup in a Recirculating Electron Accelerator, Particle Accelerators 1980, Vol. II, pp. 1-13.

WEBOS04 Potential Use of eRHIC's 10 GeV ERL for FELs and Light Source

Vladimir Litvinenko, Ilan Ben-Zvi (*BNL, Upton, Long Island, New York*)

One of the design of future electron-hadron collider eRHIC* is based on a 5-10 GeV high current energy-recovery linac (ERL) with

possible extension of its energy to 20 GeV. This ERL will operate with high brightness electron beams, which do naturally match requirements for X-ray FELs and other next generation light sources. In this paper we present a number of possible scenarios which use eRHIC ERL in parasitic and dedicated mode for SASE, HGHG and oscillator X-ray FELs. We explore a possibility of optic-free X-ray oscillator in detail.

*http://www.agsrhichome.bnl.gov/eRHIC/, Appendix A: Linac-Ring Option

The Harmonically Coupled 2-Beam FEL

WEBOS05

Brian McNeil, Gordon Robb (*Strathclyde University, Glasgow*), Mike Poole (*CCLRC/DL/ASTeC, Daresbury, Warrington, Cheshire*)

A 1-D model of a 2-beam Free Electron Laser amplifier is presented. The two co-propagating electron beams have different energies, chosen so that the fundamental resonant FEL interaction of the higher energy beam is at an harmonic of the lower energy beam. In this way, a coupling between the FEL interactions of the two beams occurs via the harmonic components of the electron bunching and radiation emission of the lower energy interaction. Such resonantly coupled FEL interactions may offer potential benefits over existing single beam FEL schemes. A simple example is presented where the lower energy FEL interaction only is seeded with radiation at its fundamental resonant wavelength. It is predicted that the coherence properties of this seed field are transfered via the resonantly coupled FEL interaction to the un-seeded higher energy FEL interaction, thereby improving its coherence properties over that of a SASE interaction alone. This method may offer an alternative seeding scheme for FELs operating in the XUV and x-ray regions of the spectrum.

Joint Session
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THAIS

Coherent XUV Radiation with Conventional Lasers THAIS01

Philippe Zeitoun, Philippe Balcou, Frederique Burgy, Denis Douillet, Gregory Faivre, Abdesselem Hallou, Thierry Lefrou, Pascal Mercère, Tomas Mocek, Anne-Sophie Morlens, Jean-Philippe Rousseau, Stéphane Sebban, Constance Valentin (*LOA, Palaiseau*), Damien Aubert, Gaetan de Lachèze-Murel (*CEA/DIF, Bruyères-le-Châtel*), Marta Fajardo, H. Merdji (*IST-FP, Lisboa*), Sophie Kazamias (*LSAI, Orsay*), Sebastien le Pape (*Laboratoire pour l'Utilisation des Lasers Intenses, Palaiseau*)

For about thirty years, lasers have been used to produce laser-like emission in the XUV spectral range (typically 4-60 nm). During the late 90's, independantely High harmonics generation (HHG) and soft x-ray lasers (SXRL) have reached the level of stability and reproducibility for being run on applications experiment. The first source inherits from very short pulse duration as short as 100 attosecond, good optical beam quality but with a low energy per pulse. Soft x-ray lasers demonstrated pulse energy as high as 10 mJ at 21.2 nm but with lower optical quality and longer pulse duration (from 2 to 80 ps FWHM). A very recent experiment as demonstrated that seeding a soft x-ray laser with HHG generates high energy pulse while keeping the HHG beam quality. Numerical modelling shows that seeded soft x-ray lasers may reach the mJ level with pulse duration around 100 fs. These sources (HHG, SXRL and seeded SXRL) are complementary from VUV-FEL for many experiments.

SPPS: New Science on the Way to LCLS THAIS02

Aaron M. Lindenberg (*SLAC/SSRL, Menlo Park, California*)

We report new results from the Subpicosecond Pulse Source (SPPS) demonstrating the ability of accelerator-based x-ray sources to resolve atomic-scale motion with femtosecond temporal resolution. It is shown that the short-time-scale dynamics associated with ultrafast melting of solids is inertial in character, pointing to analogies with the intrinsic dynamics of equilibrium liquids.

THAIS03 Advancing Terahertz Science and Technology with the UCSB Free-electron Lasers

S. James Allen (*UCSB, Santa Barbara*)

The UCSB free-electron lasers deliver kilowatts of coherent terahertz radiation that can be tuned from 140 GHz to 4.8 THz with pulse widths that can be controlled and varied from 10's of microsconds to several picoseconds. This unique source has made possible a wide variety of experiments on terahertz electro-optics, coherent quantum control, photon assisted transport, terahertz device physics, terahertz material properties, non-equilibrium dynamics, and nonlinear dynamics. A compilation of the work at UCSB documented through 2001 can be found at

http://www.iquest.ucsb.edu/sites/sjallen/pubs/final_report_organized.pdf.

Here we will focus on recent efforts on terahertz coherent quantum control, terahertz electro optics and device physics.

Gun/Injector Technology

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THBOC

Recent Results and Perspectives of the Low Emittance Photo Injector at PITZ THBOC02

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The Photo Injector Test Facility at DESY Zeuthen (PITZ) was built to study the production of minimum transverse emittance electron beams for Free Electron Lasers. In November 2003 the electron beam from the RF gun was fully characterized at PITZ. For a bunch charge of 1 nC a minimum normalized projected beam emittance of 1.5 π mm mrad in the vertical plane and a minimum geometrical average of both transverse planes of 1.7 π mm mrad have been achieved. This fulfils the requirements of the VUV-FEL at DESY Hamburg. In this contribution an overview on the measured electron beam and high duty cycle RF parameters including transverse emittance, thermal emittance, bunch length, momentum and momentum spread will be given. In addition, planned major upgrades and first results towards fulfilling the even more challenging requirements for the European XFEL will be discussed. This includes the increase of the accelerating gradient on the photo-cathode and the improvement of the transverse and longitudinal laser beam parameters.

Emittance Measurement on the CeB6 Electron Gun for the SPring-8 Compact SASE Source THBOC03

Kazuaki Togawa, Hitoshi Baba, Takahiro Inagaki, Kazuyuki Onoe, Tsumoru Shintake, Takashi Tanaka (*RIKEN Spring-8 Harima, Hyogo*), Hiroshi Matsumoto (*KEK, Ibaraki*)

A high-volatage pulsed electron gun has been constructed for the injector system of the soft X-ray FEL project at SPring-8 (SCSS project). A CeB6 single crystal was chosen as a thermionic cathode, because of its excellent emission properties. The gun voltage of -500

kV was chosen to reduce emittance growth due to space charge. We have succeeded in generating a 500 keV beam with 1 A peak current and 3 micro-sec FWHM. The beam was very stable with low jitter. The beam emittance has been measured by means of double-slits method, and the normalized rms emittance of 1.1 pi-mm-mrad has been obtained. We report on the experimental result on the emittance measurement of the CeB6 electron gun.

THBOC04 Ampere Average Current Photoinjector and Energy Recovery Linac

Ilan Ben-Zvi (*BNL, Upton, Long Island, New York*)

High-power Free-Electron Lasers were made possible by advances in superconducting linac operated in an energy-recovery mode, as demonstrated by the spectacular success of the Jefferson Laboratory IR-Demo. In order to get to much higher power levels, say a fraction of a megawatt average power, many technological barriers are yet to be broken. BNL's Collider-Accelerator Department is pursuing some of these technologies for a different application, that of electron cooling of high-energy hadron beams. I will describe work on CW, high-current and high-brightness electron beams. This will include a description of a superconducting, laser-photocathode RF gun employing a new secondary-emission multiplying cathode and an accelerator cavity, both capable of producing of the order of one ampere average current.

Work performed under the auspices of the US Department of Energy, contract number DE-AC02-98CH10886.

THBOC05 Development of a Superconducting RF Gun in Rossendorf

Dietmar Janssen, Hartmut Buettig, Pavel Evtushenko, Ulf Lehnert, Peter Michel, Christof Schneider, Juergen Stephan, Jochen Teichert (*FZR, Dresden*), Slava Kruchkov, Oleg Myskin, Vladimir Volkov (*BINP, Novosibirsk*), Ingo Will (*MBI, Berlin*)

In Rossendorf it was shown for the first time that a RF electron gun where a photo cathode is inside a superconducting cavity, works stable over a period of seven weeks. At 4.2K no change of the quality

factor Q = 2.5 10^8 has been observed [1]. The experimental results were the basis for the design of a new 3.4 cell superconducting RF photo electron gun [2]. The paper presents details of different components of this gun, explains the status of manufacturing and gives results of first test measurements. Furthermore, the idea is discussed to use for emittance compensation instead of a static magnetic field which is inside the cavity of a normal conducting RF gun in the superconducting gun cavity an additional magnetic RF field (TE_{011} mode) . By computer simulation the attraction of this idea is demonstrated.

[1] First operation of a superconducting RF gun, D.Janssen et al., NIM A507 (2003)314-317
[2] Superconducting RF guns for FELs, D.Janssen et al., NIM(2004) in print

Physical and Chemical Sciences
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THBOS

Generation of Surface Electromagnetic Waves by Free-Electron Laser Terahertz Radiation and their Refractive Index Determination

THBOS01

Guerman N. Zhizhin (*RAS/STC UI, Moscow*), Grigori M. Kazakevitch (*BINP, Novosibirsk*), Guenrikh D. Bogomolov, Vitaliy V. Zavyalov (*IPP, Moscow*), Young Uk Jeong, Byung Cheol Lee (*KAERI, Daejon*)

In this paper we discuss the perspective of combined use of plane waves along with the surface electromagnetic waves (SEW) for interferometric studies of metals' optical properties. Recently we succeeded in the experiments on the SEW generation and on use of them for interferometric determination of light phase velocity in the wavelength range of λ=110-150 μm by using a wide-band THz FEL in KAERI. The interference technique employing SEW propagation in the part of one shoulder of asymmetric phase interferometer was applied. From the interference pattern the real part of SEW' effective refraction index was determined for laser emission wavelengths: for λ=150 μm -it is $1+5\cdot10^{-5}$, for λ=110 μm -it is $1+8\cdot10^{-4}$. The high sensitivity of interference pattern to overlayers of Ge and of Si having thickness 100 nm was demonstrated as well. The interference pattern was recorded by a liquid helium cooled Ge:Ga detector. FEL radiation arrived the input of experimental set-up in the form of macropulses with duration of 3 μs (10 W at λ=110 μm) and repetition period of 1-10 Hz, while registered radiation intensity(normalized on independently measured beam intensity) was averaged over 8 sequential pulses.

Femtosecond Laser Prevention for the Cold-Worked Stress Corrosion Crackings on Reactor Grade Low Carbon Stainless Steel

THBOS02

Eisuke John Minehara, Akihiko Nisimura (*JAERI/FEL, Ibaraki-ken*), Takashi Tsukada (*JAERI, Ibaraki-ken*)

We report here that the femtosecond lasers like low average power Ti:Sapphire lasers, the JAERI high average power free-electron laser and others could peel off and remove two stress corrosion cracking (SCC) origins of the cold-worked and the cracking susceptible material, and residual tensile stress in hardened and stretched surface of low-carbon stainless steel cubic samples for nuclear reactor internals

as a proof of principle experiment except for the third origin of corrosive environment. Because a 143 ∘C and 43% $MgCl_2$ hot solution SCC test was performed for the samples to simulate the cold-worked SCC phenomena of the internals to show no crack at the laser-peered off strip on the cold-worked side and ten-thousands of cracks at the non-peeled off on the same side, it has been successfully demonstrated that the femtosecond lasers could clearly remove the two SCC origins and could resultantly prevent the cold-worked SCC.

THBOS03 THz Imaging by a Wide-band Compact FEL

Young Uk Jeong, Hyuk Jin Cha, Byung Cheol Lee, Seong Hee Park (*KAERI, Daejon*), Grigori M. Kazakevitch (*BINP, Novosibirsk*)

We have developed a laboratory-scale users facility with a compact THz FEL. The FEL operates in the wide wavelength range of 100-1200 μm, which corresponds to 0.3-3 THz. THz radiation from the FEL shows well collimated Gaussian spatial distribution and narrow spectral width of 0.3 μm, which is Fourier transform limited by the estimated pulse duration of 20 ps. The main application of the FEL is THz imaging for bio-medical researches. We are developing THz imaging techniques by 2-D scanning, single pulse capturing with the electro-optic method, and 3-D holography. High power, coherent, and pulsed feature of the FEL radiation is expected to show much better performance in advanced THz imaging of 3-D tomography by comparing with incoherent and weak THz sources. By controlling the optical delay between reference beam and scattered light from an object, we can get its 3-D tomography by the holograms. The coherent and pulse length of the FEL beam is measured to be 3-6 mm. In this paper we will show and discuss the main results of THz imaging with the different methods by using the KAERI compact FEL.

This work was supported by Korea Research Foundation Grant (KRF-2003-042-D00195).

THBOS04 Present Applications of IR FEL at Peking University

Limin Yang (*PKU/IHIP, Beijing*)

In this study the sections of human tissues were treated under 9.5 μm FEL in the BFEL based on the vibrational spectroscopic in-

vestigation that significant differences occur between normal and malignant tissues. Under the defocus condition, the burning of tissue section at some part while other part remains unchanged, suggesting that the FEL can selectively destroy some part of tissue. Vibrational spectroscopic and microscopic methods have shown that the FEL can induce decomposition of malignant tissues. The application of FEL whose wavelength is on the characteristic bands of malignant tissues may provide a new method to kill cancer cells with higher selectivity. For understanding the interactions between FEL and biological tissues, structure changes of substances under irradiation by FEL of 9.414 μm and 6.228 μm were measured using FTIR spectroscopy. The samples include ATP, ADP, AMP, and D-ribose, etc. The FTIR spectra of the molecules before and after irradiation of FEL indicate molecular structure variations of the samples after irradiation of FEL, especially the rearrangement of their hydrogen bond networks, which may be caused by multiple photons process induced by FEL.

Short Wavelength FEL Applications

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THCxS

Pump-Probe Experiments in the Gas Phase using the TTF2-FEL THCIS01

Michael Meyer (*LURE, Orsay*)

Many processes induced by the interaction of XUV light with atoms and molecules take place on a very short time scale. The temporal width of the soft X-Ray FEL pulses (100-300 fs) and of the synchronized, tunable optical laser (150 fs) will therefore be ideally suited to gain an insight into the dynamics of these processes. A first series of proposed experiments will serve to characterize the FEL pulses themselves, in particular the intensity, frequency and time structure of the individual pulses by using a cross correlation technique between the XUV photons and a strong infrared pulse. Depending on the final characteristics of the FEL with respect to photon energy range and tunability, these two-photon pump-probe experiments will be extended to further studies, like the investigation of resonances, which are only accessible by a two-photon excitation, the coupling of autoionization states by a strong laser field, which induces drastic changes in the resonance profiles, the wavepacket formation of higher Rydberg states, and the coherent population of excited states by fast dissociation, which will result in the observation of quantum beats on the decay curve of excited fragments.

Interaction of Intense Ultrashort VUV Pulses with Different Solids - Results from the Tesla Test Facility FEL Phase I THCOS02

Jacek Krzywinski, Marek Jurek, Dorota Klinger, Jerzy Pelka, Andrzej Wawro (*IP PAS, Warsaw*), Marcin Sikora (*AGH University of Science and Technology, Krakow*), Evgeny Saldin, Evgeny Schneidmiller, Barbara Steeg, Rolf Treusch, Mikhail V. Yurkov (*DESY, Hamburg*), Dagmar Chwostowa, Libor Juha, Vit Letal (*FZU, Prague*), Andrzej Andrejczuk, Henryk Reniewicz (*University of Bialystok, Bialystok*), Ryszard Sobierajski (*Warsaw University of Technology, Warsaw*), Anna Kauch (*Warsaw University, Warsaw*)

Desorption, ablation, and plasma formation have been studied for a large variety of materials (insulators, semiconductors, and metals). Damaged surfaces have been investigated using light, electron, and atomic force microscopy. Short-wavelength ablation was very efficient and clean when proper irradiation conditions were chosen. The edges of craters were sharp, and the area around the craters was

clean. A distinct difference in the behavior of conducting materials and insulators was observed. In the case of insulators the morphology of the irradiated surface and the crater depth hardly depended on the beam intensity. In contrast, the irradiated silicon surface becomes very rough when the intensity exceeds the damage threshold. At high intensities multiple charged ions were registered. Kinetic energy of the ions increases with charge state and reaches keV range for highly-charged ions. Again, a clear difference between insulators and conducting material was observed. High charge states and energetic ions were typical for conductors and semiconductors. Only single ions states and low energetic ions (50 eV) were detected for insulators for all irradiation conditions.

THCOS03 Short X-Ray Pulses Diffraction on 'Frozen' Crystals

Souren Grigorian (*RAS/CRYS, Moscow*), Ullrich Pietsch (*University of Potsdam, Potsdam*)

The problem of reflection and diffraction of x-ray FEL beam has been recently studied in the number of works [1,2]. The response of the crystal reflection to a delta-like incident pulse was analyzed with respect to a possible tailoring of the time duration after diffraction at a perfect crystal. Till now it is not clear whether one can use perfect crystals as monochromators considering the high-intense x-ray beam. Here one expects a destruction of the crystal perfection or a change in the shape of diffraction curve due to head load. In this work we present a time-dependent x-ray diffraction theory based on a "frozen" atomic lattice approach. Because the phonon inverse lifetime is few order of magnitude longer than the x-ray FEL pulse one can assume that a single FEL pulse will probe one or several "frozen phonon modes". Simultaneous the FEL pulse may excite or annihilate other phonon modes which will influence the diffraction curve for the next pulses. Based on this approach the short pulse scattering signals will be simulated and discussed in terms of consequences for a use as crystal monochromator.

[1] Chukovski, F. N. and Foerster, E. (1995). Acta Cryst. A51, 668-672.
[2] Wark, J. S. and Lee, R. W. (1999). J. Appl. Cryst. 32, 692-703.

Soft X-Ray Study of Free Clusters Produced by a Pulsed Microplasma Cluster Source

THCOS04

Cristina Lenardi, Gero Bongiorno, Paolo Milani, Paolo Piseri, Luca Ravagnan (*Università di Milano, Milano*), Marcello Coreno, Monica De Simone (*CNR-IMIP, Basovizza (TS)*)

At LAMINA Laboratory in Milano, a high intensity cluster source has been developed. This source (the Pulsed Microplasma Cluster Source - PMCS) is able to deliver collimated and stable supersonic cluster beams suitable for nanostructured film deposition. Recently an UHV compatible system (CESYRA - Cluster Experiment with SYnchrotron RAdiation), equipped with a PMCS and a linear TOF/MS has been interfaced to the Gas-Phase beamline to perform XAS measurements on both free clusters by mass resolved ion yield and on cluster assembled carbon and titanium films deposited in-situ. This experience led us to design a new apparatus with improved detection efficiency, compactness and portability. The new geometry permits to fully exploit the photon flux, since the experiment can be run as a photo-electron/photo-ion coincidence experiment. The foreseen brilliance of Fermi XFEL will strongly improve the feasibility of UPS and XAS spectroscopic measurements on targets showing low densities as in the case of flying clusters. The study of size related effects will enable us to get unique insight into the electronic properties of free clusters of refractory or metal based materials.

FEL Oscillators, FEL Experiments, New Concepts and Ideas, Users Workshop

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THPOS

Low Emittance Gun based on Field Emission THPOS01

Romain Ganter, Micha Dehler, Jens Gobrecht, Chris Gough, Gerhard Ingold, Simon Leemann, Martin Paraliev, Marco Pedrozzi, Jean-Yves Raguin, Leonid Rivkin, Volker Schlott, Andreas Streun, Albin Wrulich (*PSI, Villigen*), Arno Candel, Kevin Shing Bruce Li (*ETH, Zürich*)

The design of an electron gun capable of producing beam emittance one order of magnitude lower than current technology would reduce considerably the cost and size of a free electron laser emitting at 0.1nm. Field emitter arrays (FEAs) including a gate and a focusing layer are an attractive technology for such high brightness sources. Electrons are extracted from micrometric tips thanks to voltage pulses between gate and tips. The focusing layer should then reduce the initial divergence of each emitted beamlets. This FEA will be inserted in a high gradient diode configuration coupled with a radiofrequency structure. In the diode part very high electric field pulses (several hundreds of MV/m) will limit the degradation of emittance due to space charge effect. This first acceleration will be obtained with high voltage pulses (typically a megavolt in a few hundred of nanoseconds) synchronized with the low voltage pulses applied to the FEA (typically one hundred of volts in one nanosecond at frequency below kilohertz). This diode part will then be followed by an RF accelerating structure in order to bring the electrons to relativistic energies.

Field Emitter Arrays for a Free Electron Laser Application. THPOS02

Kevin Shing Bruce Li (*ETH, Zürich*), Micha Dehler, Romain Ganter, Jens Gobrecht, Leonid Rivkin, Albin Wrulich (*PSI, Villigen*)

The development of a new electron gun with the lowest possible emittance would help reducing the total length and cost of a free electron laser. Field emitter arrays (FEAs) are an attractive technology for electron sources of ultra high brightness. Indeed, several thousands of microscopic tips can be deposited on a 1 mm diameter area. Electrons are then extracted by applying voltage to a first grid layer close to the tip apexes, the so called gate layer, and focused by a second grid layer one micrometer above the tips. The typical aperture diameter of the gate and the focusing layer is in the range of one micrometer. One challenge for such cathodes is to pro-

duce peak currents in the ampere range since the usual applications of FEAs require less than milliampere. Encouraging peak current performances have been obtained by applying voltage pulses at low frequency between gate and tips. In this paper we report on different tip materials available on the market: diamond FEAs from Extreme Devices Inc., ZrC single tips from Applied Physics Technologies Inc. and Mo FEAs from SRI International.

THPOS03 Undulators for the BESSY Soft-X-Ray FEL

Johannes Bahrdt, Winfried Frentrup, Andreas Gaupp, Bettina Kuske, Atoosa Meseck, Michael Scheer (*BESSY GmbH, Berlin*)

BESSY plans a linac based high gain harmonic generation FEL user facility with three FEL lines [1]. The modulators and most of the radiators are planar pure permanent magnet undulators. The last radiator and the final amplifier produce radiation of linear polarization with arbitrary orientation as well as elliptically or helically polarized light. They will have a modified APPLE II design which provides higher fields compared to a conventional APPLE II [2]. Detailed calculations for this design will be presented. FEL 3D-calculations provide information about the radiation field distribution at the end of the undulator. A beamline designer needs the information about the effective source size at the waist and the location of the waist. The electric fields calculated by GENESIS have been propagated and the source characteristics have been derived for various FEL parameters. The FEL process requires tight gap tolerances within and between modules. We present a new gap measurement system with a gap positioning accuracy of 1.5 microns.

[1] D. Krämer et al., these proceedings.
[2] J. Bahrdt et al., 8th Int. Conf. on Syncrotron Radiation Instrumentation, San Francisco, 2003.

THPOS04 Characterization of Laser-Electron Interaction in the BESSY Femtoslicing Facility

Shaukat Khan (*BESSY GmbH, Berlin*)

A "femtoslicing" facility to generate ultrashort x-ray pulses by laser-electron interaction [1] is being commissioned at the BESSY II

storage ring. The energy modulation of electrons by femtosecond laser pulses of several mJ in an undulator is a good test case for FEL seeding schemes. The dependence of the interaction efficiency on various parameters is measured and compared to simulations and analytical results.

* S. Khan for the BESSY femtoslicing project team.
[1] A. Zholents, M. Zoloterev, PRL 76 (1996) p. 912.

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Exploring the Spatial Resolution of the Photothermal Beam Deflection Technique in the Infrared Region THPOS05

Wolfgang Seidel, Harald Foerstendorf (*FZR, Dresden*), François Glotin, Jean Michel Ortega, Rui Prazeres (*LURE, Orsay*)

In photothermal beam deflection spectroscopy (PTBD) generating and detection of thermal waves occur generally in the sub-millimeter length scale. Therefore, PTBD provides spatial information about the surface of the sample and permits imaging and/or microspectrometry. Recent results of PTBD experiments are presented with a high spatial resolution which is near the diffraction limit of the infrared pump beam (CLIO-FEL). We investigated germanium substrates showing restricted O+-doped regions with an infrared absorption line at a wavelength around 11.6 microns. The spatial resolution was obtained by strongly focusing the probe beam (i.e. a HeNe laser) on a sufficiently small spot. The strong divergence makes it necessary to refocus the probe beam in front of the position detector. The influence of the focusing elements on spatial resolution and signal-to-noise ratio is discussed. In future studies we expect an enhanced spatial resolution due to an extreme focusing of the probe beam leading to a highly sensitive technique for detection of sorbed species on surfaces in the far infrared region.

THPOS06 **The 'CLIO' Infrared FEL at Long Wavelength**

Rui Prazeres, François Glotin, Jean Michel Ortega (*LURE, Orsay*)

This paper describe recent measurements which have been performed with the CLIO FEL in the wavelength range 40 to 120ţm. The FEL electron efficiency, η, is deduced from the electron energy loss. It gives an absolute measurement of the optical power produced by the electron beam, which is then compared to the extracted power of the FEL measured optically. The ratio is compared to numerical simulation taking into account the diffraction of the optical mode in the optical cavity and in the beam line.

THPOS07 **Derivative Control of the ELETTRA Storage-Ring Free-Electron Laser**

Giovanni De Ninno, Bruno Diviacco, Mauro Trovò (*Elettra, Basovizza, Trieste*), Luca Giannessi (*ENEA C.R. Frascati, Frascati - Roma*), Riccardo Meucci (*INOA, Firenze*), Christelle Bruni, Marie-Emmanuelle Couprie (*LURE, Orsay*), Duccio Fanelli (*MTC, Stockholm*), Serge Bielawski (*PhLAM, Villeneuve d'Ascq*)

The "natural" dynamics of a Storage-Ring Free-Electron Laser (SRFEL) on a millisecond temporal scale strongly depends on the temporal photon-electron beam synchronism, i.e. the difference between the electron beam revolution period and the round trip of the photons in the cavity. For a small detuning, the laser intensity displays a "continuous wave" ("cw") behaviour, while regular oscillations are found for larger detuning amounts. Recently, a new model for the longitudinal dynamics of a SRFEL has been proposed and shown to be particularly suitable for analytic calculations. Within this framework the transition between stable and unstable regimes is characterized as a Hopf bifurcation and an explicit expression for the critical detuning is given. These findings open up the perspective of introducing a derivative self-controlled feedback to enlarge the region of stable signal. A feedback of this type has been implemented on the Super-ACO and ELETTRA SRFELs and fully confirmed the theoretical predictions. In this paper we review these results and present new experiments carried out at ELETTRA.

Experiments on the Synchronization of an Ultrafast Cr:LiSAF Laser with the Elettra Storage Ring and FEL pulses THPOS08

Mario Ferianis, Mitcho Danailov, Giovanni De Ninno, Bruno Diviacco, Mauro Trovò (*Elettra, Basovizza, Trieste*), Marcello Coreno (*CNR-IMIP, Basovizza (TS)*), Gamal Elsayed Afifi (*NILES, Cairo*)

The techniques for synchronizing ultrafast lasers to external radio frequency reference sources are well established and characterized in the literature. However, data lack on the minimum light-to-light jitter which can be achieved in different synchrotron operation modes when an external laser is locked to the storage ring master clock. Here we present first results for the synchronization of an ultrafast Cr:LiSAF laser with electromagnetic radiation coming from the Elettra storage ring in four bunch and multi-bunch mode. In addition, data on the synchronization of the same laser with the Elettra FEL pulses, both in free running and Q-switching regime, are reported. In our experiments, laser-to-RF locking was continuously monitored using a built-in phase detection. The laser light to storage ring light locking was characterized by simultaneous acquisition of two/three pulse trains by a streak camera. In addition, pulse jitter was determined by processing of the signal of fast photodiodes monitoring the different light beams.

Electron-Beam Stabilization for the European Storage-Ring Free-Electron Laser at Elettra THPOS09

Mauro Trovò, Daniele Bulfone, Mitcho Danailov, Giovanni De Ninno, Bruno Diviacco, Vincenzo Frochì, Marco Lonza (*Elettra, Basovizza, Trieste*), Luca Giannessi (*ENEA C.R. Frascati, Frascati - Roma*)

The temporal structure of the storage-ring free-electron laser at Elettra shows high sensitivity to electron-beam instabilities. In fact, even small beam orbit oscillations (of the order of few microns) may perturb the FEL dynamics and periodically switch off the laser. In order to improve the FEL operation and performance, a longitudinal multi-bunch feedback and a local orbit feedback have been activated. This paper reports on the beneficial effect of these feedback systems. Plans for a future "slow" longitudinal feedback are also briefly described.

THPOS10 Compact Terahertz Free Electron Lasers and Free Electron-Like Coherent Radiators

Gian Piero Gallerano, Andrea Doria, Emilio Giovenale, Giovanni Messina, Ivan Panov Spassovsky (*ENEA C.R. Frascati, Frascati - Roma*), Sandra G. Biedron (*ANL, Argonne, Illinois*), John Lewellen, Stephen Milton (*ANL/APS, Argonne, Illinois*)

Free Electron coherent radiation sources operating in spectral regions where conventional laser sources are not easily available (e.g. VUV, FIR, mm-wave) have been realized in different laboratories all over the world. In most cases these sources are built at large facilities to provide users with coherent radiation in wide spectral ranges. In the far-infrared and mm-wave (100 GHz to 10 THz) spectral regions, however, small size, low cost systems can be built, providing wide tunability, short pulses and high peak brightness. Good performance in terms of output power and bandwidth can be achieved at moderate electron energies (< 10 MeV) with a short length of the interaction region (< 50 cm) and with different schemes of energy transfer from the electron beam to the radiation field. Compact THz sources can be easily tailored to meet the requirements of specific experiments.In this paper we review the development of compact and table-top THz photon sources with a glance to their applications.

THPOS11 Resonant Two Photon Ionitation (R2PI) Studies of Asymmetric Microsolvation Effects in the Bond Cleavage of Chiral Radical Cations

Susanna Piccirillo (*Università degli Studi di Roma "Tor Vergata", Rome*), Marcello Coreno (*CNR-IMIP, Basovizza (TS)*), Mauro Satta (*CNR-IMIP, Tito scalo (Pz)*), Debora Scuderi, Maurizio Speranza (*SCTSBA, Rome*), Daniele Catone, Anna Giardini, Alessandra Paladini, Flaminia Rondino (*Università degli Studi di Roma 'La Sapienza', Rome*)

Oxidative bond breaking and forming involving radical ions take place in many organic reactions and in biological processes, such as asymmetric enzyme cavities. In this work we report on the effects of micro-solvation on the photofragmentation of R-1-phenyl-1-propanol cation. The energy thresholds of the homolytic C(alpha)-C(beta) bond cleavage of R-1-phenyl-1-propanol. Radical cation, its mono-hydrated cluster, and its clusters with R,R and S,S 2,3-butanediol have been determined by laser Photoionization. The experimental results, combined with computational methodologies

show that the activation energy of the C(alpha)-C(beta) bond cleavage in the bare ion is remarkably higher than that in the solvated form. The availability of free electron laser light, would allow to investigate clusters by single ionization technique of different species than those studied in 2C-R2PI experiments and shed light in both the structure and the dynamics of solvated transition states. Photoexcitation of clusters with circularly polarized light would also be achievable and light it self may be used as a chiral selector for investigation of asymmetric photofragmentation in gas phase.

Optical Emission Spectroscopy of Plasma Plume Induced by Ultra-Short Pulsed Laser Ablation of Aluminum Nitride Target THPOS12

Stefano Orlando, Rosanna Larciprete, Veronica Marotta, Antonio Santagata (*CNR-IMIP, Tito scalo (Pz)*), Marcello Coreno (*CNR-IMIP, Basovizza (TS)*), Roberto Teghil, Marilisa Zaccagnino (*Università degli Studi della Basilicata, Potenza*), Anna Giardini (*Università degli Studi di Roma 'La Sapienza', Rome*)

The plasma plume expansion process of an AlN target ablated by an ultra-short Nd:Glass pulsed laser (200 fs, 1.2 ps) has been surveyed by emission spectroscopy and fast imaging. The data have been collected with spatial and temporal resolution in order to find out the species speed and their angular distribution. Furthermore, it has been possible to discriminate different regimes involved during the plasma expansion by comparing the data so obtained with previous studies performed with ns laser sources. These results could also justify the cluster formation, detected by a quadrupole mass spectrometer, observed during the ultra-short laser ablation regime, but not for the ns one.

Study on Laser-Driven Acceleration with Bessel Beam THPOS13

Dazhi Li, Kazo Imasaki (*ILT, 2-6 Yamada-oka, Suita, Osaka*)

A possible approach of realizing multi-stage laser-driven acceleration with Bessel beam is explored. With using a set of annular slits, Bessel beam is truncated and structured into several separate sections during its transportation, leading to the possibility of accelerating electrons stage by stage. Bessel beam is regarded as diffraction-free beam, allowing a very long acceleration distance in contrast to the

Gaussian beam. In this paper, the transportation characteristics of the structured Bessel beam is analyzed based on scalar diffraction theory, as well as the acceleration mechanism is demonstrated numerically.

THPOS14 Research on Efficiency of Nuclear Transmutation Induced by Gamma Ray

Dazhi Li, Kazo Imasaki (*ILT, 2-6 Yamada-oka, Suita, Osaka*)

High brightness beams of gamma rays produced with laser Compton scattering have the potential to realize photo-transmutation through (γ,n) reaction, implying an efficient method to dispose long-lived fission products. Preliminary investigations have been carried out in understanding the feasibility of development of a transmutation facility to repose nuclear waste. A laser Compton scattering experimental setup based on a storage ring started to generate gamma-ray beams for studying the coupling of gamma photons and nuclear giant resonance. This paper demonstrates the dependency of nuclear transmutation efficiency on target dimensions and gamma ray features. ^{197}Au sample was adopted in our experiment, and experimental results correspond to the theoretical estimations.

THPOS15 Tunability and Power Characteristics of the LEBRA Infrared FEL

Toshinari Tanaka, Ken Hayakawa, Yasushi Hayakawa, Ken-ichiro Ishiwata, Koichi Kanno, Akira Mori, Keisuke Nakao, Kyoko Nogami, Takeshi Sakai, Isamu Sato, Kazue Yokoyama (*LEBRA, Funabashi*)

Application of the infrared (IR) Free-Electron Laser (FEL) was started in October 2003 at the Laboratory for Electron Beam Research and Application (LEBRA) of Nihon University. The FEL system consisted of silver-coated copper mirrors has demonstrated wavelength tunability ranged from 940 to 6100 nm as a function of the electron energy and the undulator K-value. Wavelength dependence of the FEL output power has been measured in term of different electron beam currents, electron energies and the undulator K-values. Approximate 25 mJ/macropulse has been obtained in the range 2 to 3 microns, which corresponds to peak power of 2 MW, provided that

the FEL pulse length is 0.4 ps as resulted from the measurement by an interferometric method. The power decrease observed in the longer wavelength range is due to a large diffraction loss in the FEL guiding optics and the vacuum ducts.

Amplification of Short-Pulse Radiation from the Electron Undergoing Half-Cyclotron Rotation THPOS16

Makoto R Asakawa (*OU-iFEL, Hirakata, Osaka*)

Electrons undergoing half-cyclotron rotation emitts a half-cycle electromagnetic wave. A novel light source based on such short-pulse radiation is under developing at Institute of Free Electron Laser Osaka university. In this presentation, the experiments to amplify the radiation in the optical resonator will be discussed.

Status of Institute of Free Electron Laser, Osaka university THPOS17

Hiroshi Horiike (*OU-iFEL, Hirakata, Osaka*)

Research activities at iFEL Osaka, including development of FEL systems and application programs, will be reviewed.

Development of a Pump-Probe Irradiation System Using a Non-Coating ZnSe Beam Splitter Cube for an MIR-FEL THPOS18

Heya Manabu, Ishii Katsunori, Awazu Kunio (*OU-iFEL, Hirakata, Osaka*)

A pump-probe technique is essential for a proper understanding of laser interaction with tissue and material. Our pump-probe system divides the incident mid-infrared Free Electron Laser (MIR-FEL) into two beams with equal intensity, and crosses simultaneously the two incoming beams at the same position. One is for a pump beam, another is for a probe beam. Time-resolved absorption spectroscopy involving this technique gives us information on the vibrational dynamics of molecules. We have developed this system for an MIR-FEL using a non-coating ZnSe beam splitter cube. The beam splitter cube is composed of two ZnSe prisms in the shape like a trapezoid. The two pulses with equal intensity are generated due to Fresnel reflection and transmission at the boundary between two prisms, then

are reflected due to total reflection at other side boundaries between each prism and air, and illuminate simultaneously the same spot. We have conducted a proof-of-concept of experiment of this system using an MIR-FEL. We showed that this system is applicable for a broad waveband (6-11 μm). Thus, we proved that this system without complicated optical alignment is useful for absorption spectroscopy.

THPOS19 MIR-FEL Delivery by Hollow Optical Fiber for Bio-Medical Applications

Sachiko Suzuki (*OU-iFEL, Hirakata, Osaka*)

Mid-infrared Free Electron Laser (FEL) is expected as new application for biomedical surgery. However, delivery of MIR-FEL into the body is difficult because the common glass optical fibers have strong absorption at MIR region. A good operational and flexible line for FEL is required at medical field. A Hollow optical fiber is developed for IR laser and high-power laser delivery. We evaluated the fiber for FEL transmission line. This fiber is coated with cyclic olefin polymer (COP) and silver thin film on the inside of glass capillary tube. It is 700 μm-bore and 1m in lengths. The fiber transmission loss of the measured wavelength region of 5.5 μm to 12 μm is less than 1dB/m when the fiber is straight and 1.2 dB/m when bent to radius of 20 cm. Additionally, the output beam profile and the pulse structure is not so different form incidence beam. In conclusion, the fiber is suitable for delivery of the FEL energy for applications in medical and laser surgery.

THPOS20 Design of a THz Beam Line for the JAERI FEL

Ryoichi Hajima, Nobuhiro Kikuzawa, Eisuke John Minehara, Ryoji Nagai, Nobuyuki Nishimori, Tomohiro Nishitani, Masaru Sawamura (*JAERI/FEL, Ibaraki-ken*)

The 2.5-MeV injector of JAERI-FEL has been improved to generate an electron beam of 20mA (0.5nC x 40MHz), which is quadruple of the original configuration. We propose to construct a THz beam line, which is a right-angled branch of the injector followed by a short undulator to produce coherent spontaneous radiation in the THz region. We present the results of design study: electron beam dynamics, optimization of an undulator and an optical elements.

Recent Results of the JAERI Energy-Recovery Linac FEL THPOS21

Ryoichi Hajima, Nobuhiro Kikuzawa, Eisuke John Minehara, Ryoji Nagai, Nobuyuki Nishimori, Tomohiro Nishitani, Masaru Sawamura (*JAERI/FEL, Ibaraki-ken*)

A research program towards a high-power FEL utilizing an energy-recovery linac is carried forward at Japan Atomic Energy Research Institute (JAERI). In this paper, we summarize recent results of the research activity at the JAERI ERL-FEL, which include the reinforcement of the injector, replacement of the RF control system and so on.

Misalingment Tolerance of a Hole-Coupling Optical Resonator for JAERI ERL-FEL THPOS22

Ryoji Nagai, Ryoichi Hajima, Nobuhiro Kikuzawa, Eisuke John Minehara, Nobuyuki Nishimori, Tomohiro Nishitani, Masaru Sawamura (*JAERI/FEL, Ibaraki-ken*)

The misalignment tolerance of a hole-coupling optical resonator for the JAERI ERL-FEL is estimated with a wavelength of 22 μm by a Fox-Li procedure simulation code. The output power stability depends on the misalignment tolerance. It is found that the misalignment tolerance of the hole-coupling mirror is less than the non-coupling mirror and the offset of the non-coupling mirror is compensable tilting the mirror.

The Development of the JAERI 200 keV Electron Gun with an NEA-GaAs Photocathode THPOS23

Tomohiro Nishitani (*JAERI/FEL, Ibaraki-ken*)

The GaAs photocathode with negative electron affinity surface (NEA-GaAs) has been expected to be low emittance (<0.5 πmm・mrad) electron beam source. In order to generate low emittance electron beam required from ERL-FEL, we have started the developmental program of a 200keV electron gun with the NEA-GaAs photocathode for the first time in JAERI. An NEA surface has the problem that lifetime is limited by gun vacuum condition and by ion back bombardment between anode- and cathode-electrode. In order to long an NEA surface lifetime, the

JAERI 200keV electron gun system consists of a 200kV DC-gun chamber on extreme high vacuum condition and an NEA activation chamber with load-lock system.

T. Nishitani, E. J. Minehara, R. Hajima, R. Nagai, M. Sawamura, N. Nishimori, N. Kikuzawa, T. Yamauchi

THPOS24 Present Status of the UVSOR-II Storage Ring FEL

Masahito Hosaka, Kenji Hayashi, Masahiro Katoh, Akira Mochihashi, Jun-ichiro Yamazaki (*IMS, Okazaki*), Yoshifumi Takashima (*NU-GSE, Nagoya*)

At the UVSOR facility, upgrade of the storage ring to UVSOR-II was successfully done in 2003. Owing to the upgrade, the performance of the electron beam has been much improved. Especially the beam emittance is reduced by factor 6. The first FEL lasing with the UVSOR-II storage ring was achieved on November 2003. The measured FEL gain was enhanced by factor 2 comparing the previous value. We are proceeding to a user's experiment of the FEL in the UV region around 250 nm. The latest performance of the FEL, especially for the user's experiment will be reported.

THPOS25 Modification of HAp Crystal using IR Laser

Saburoh Satoh (*Saga University, Saga*)

The first application of laser technology to dentistry was for the removal of caries. However, reports of laser application on improvement of dental surface were emerged, much attention has been focused on the laser's potential to enhance enamel's hardness and resistance to acid. Most of the previous reports concentrated on the photo issue interaction. Few research has pursued the photochemical phenomenon occurred during laser irradiation on biological tissues. In order to find a creative method to remineralize the dissociating enamel and exposed coronal of dentine, the authors developed a novel procedure during laser irradiation. Slice of sound molar and artificial HAp pellet were irradiated separately, with CO_2 laser under different laser parameters. Tow series of samples covered with saturation calcium ion solution were irradiated separately. To investigate the crystal morphology, XRD pattern were surveyed. The comparison of each cases show that the chemical coating affected the ablation

process evidently though distinct XRD results were observed. After CO_2 laser irradiation, the (002) reflection was increased significantly that indicates the crystal growth in c-axis.

Vibrational Excitation of Ammonia Molecules by FEL-SUT

THPOS26

Yoshihiro Ogi, Koichi Tsukiyama (*TUS-Kagurazaka, Shinjuku, Tokyo*)

Free Electron Laser at Tokyo University of Science (FEL-SUT) was employed for exciting single vibrational modes of ammonia molecules. FEL is tuned to 10.5 μm, corresponding to the X^1A_1' $(\nu_2 = 1) \leftarrow (\nu_2 = 0)$ transition of NH_3. The population of the vibrationally excited states is probed by the (2 + 1) resonance enhanced multiphoton ionization (REMPI) technique via the B ^{1}E" Rydberg state. Maximum excitation efficiency of $\nu_2 = 1 \leftarrow \nu_2 = 0$ transition was about 50 %, which was estimated by taking account of Franck-Condon factors and the rotational line strengths. Rotational analyses of the spectra revealed that vibrational ladder climbing up to $\nu_2 = 2$ in NH_3 was realized for the first time. Experimental results on ν_4 vibrational excitation of NH_3 and ND_3 will be also reported.

Optimization of the NIJI-IV FEL System for the Coherent Harmonic Generation in a Q-switched Regime

THPOS27

Hiroshi Ogawa, Norihiro Sei, Kawakatsu Yamada, Masato Yasumoto (*AIST-PRI, Tsukuba, Ibaraki*)

The Coherent Harmonic Generation (CHG) in the VUV region at the storage ring NIJI-IV has been numerically investigated. The harmonic radiation is produced in an FEL oscillator with a hole-coupled resonator including a 6.3-m optical klystron ETLOK-II. The evolution of light pulses through Q-switched FEL process is simulated using the code GENESIS1.3 and its extended code. The parameters of the NIJI-IV FEL system will be optimized for different electron-beam energy of 310-450MeV and optical cavity configurations.

THPOS28 Performance of the Optical Klystron ETLOK-III for Developing Infrared Storage Ring Free Electron Lasers

Norihiro Sei, Hiroshi Ogawa, Kawakatsu Yamada, Masato Yasumoto (*AIST-PRI, Tsukuba, Ibaraki*)

Oscillations of free electron lasers (FELs) with the compact storage ring NIJI-IV in a wade wavelength region of 1-12 micron are planned in the AIST. The optical klystron ETLOK-III for developing infrared FELs has been installed in a long straight section of the NIJI-IV. The ETLOK-III has two undulator sections of 7 periods of 20 cm and one 75 cm dispersive section. The maximum K value is about 10. Electron injection to the NIJI-IV with the ETLOK-III is now in progress. Fundamental and higher harmonics of spontaneous emission from the ETLOK-III will be observed in detail. The electron-beam qualities will be also evaluated by using the measurements of the spontaneous emission. In the presentation, we will report the experimental results and discuss the performance of the ETLOK-III.

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THPOS29 Improved Performance of the NIJI-IV Compact VUV/IR FEL and its Application to the Surface Observation

Kawakatsu Yamada, Hiroshi Ogawa, Norihiro Sei, Kazutoshi yagi Watanabe, Masato Yasumoto (*AIST-PRI, Tsukuba, Ibaraki*)

At AIST, efforts to increase the FEL power as well as to shorten the lasing wavelength below 190 nm are being made, to use the NIJI-IV FEL as an intense light source for real-time surface observation using the photoelectron emission microscopy (PEEM). By irradiating a transition-metal surface with the 200-nm FEL, fine structure of one-micron scale was successfully observed with spatial and temporal resolutions of a few hundreds nm and 33 ms, respectively. In addition, a 3.6-m optical klystron for lasing in the infrared was recently installed into the north straight section of the NIJI-IV to extend the lasing wavelength range up to 10 microns. One of our interests in the infrared-FEL application is to utilize it for a Raman spectroscopy

which can examine adsorbed molecules and their bonding conditions on the metal surface. Establishment of a total surface analysis system using NIJI-IV compact VUV/IR FEL combined with characteristic surface analysis techniques is one of our goals in the near future. Improved performance of the NIJI-IV FEL obtained this year will be reported. Typical results of the PEEM measurement will be discussed.

Photo-Acoustic Spectroscopy with Infrared FEL THPOS30

Masato Yasumoto, Hiroshi Ogawa, Norihiro Sei, Kawakatsu Yamada (*AIST-PRI, Tsukuba, Ibaraki*)

Photo-acoustic spectroscopy (PAS) is a sensitive technique for measuring small absorptions of samples. In an ordinary PAS a pulse laser is used as a light source for inducing photo-acoustic signals. In our novel PAS an infrared FEL is used as the light source. The infrared FEL is continuously tunable in the wavelength with a high repetition rate. Thus, the PAS with the infrared FEL can be applied in various samples compared with the ordinary PAS. We will show the feasibility of the novel PAS.

Behavior of Power Spectrum of the Compact FIR FEL at KAERI THPOS31

Seong Hee Park, Hyuk Jin Cha, Young Uk Jeong, Byung Cheol Lee (*KAERI, Daejon*), Grigori M. Kazakevitch (*BINP, Novosibirsk*)

The KAERI FIR FEL, driven by a magnetron-based microtron, is operated in the wavelength of 100 μ m - 300 μ m by varying the electron beam energy from 6.5 MeV to 4.3 MeV. The optical cavity is a partial waveguide, horizontally free and vertically waveguide, to reduce the diffraction loss. The power spectra are measured at the different fundamental wavelength as changing the cavity detuning length, using Fabry-Perot interferometer. We present and discuss the behavior of power spectrum of the compact FIR FEL at KAERI.

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THPOS32 Coherent Far-Infrared Radiation Generation from Bunched Electron Beam by Using PAL Test Linac

Jung Yun Huang, Heung-Sik Kang (*PAL, Pohang*)

The Pohang Accelerator Laboratory (PAL) Test Linac which consists of a half-cell thermionic RF-gun, an alpha magnet, and two S-band accelerating columns can provide a bunched electron beam with a beam energy of up to 85 MeV, a pulse length of 3 μs, and a pulse current of 100 mA. The bunch length measured with a streak camera is 4 ps. Test Linac can be used to produce a femtosecond electron beam and radiation pulses. With the addition of a chicane to the linac, we will be able to produce sub-picosecond ultrashort electron pulses. Such electron pulses can be converted into coherent, broadband far-infrared (FIR) radiation with a brightness exceeding that of a storage ring by many orders of magnitude. In this paper, the mechanism of bunch compression in a chicane magnet and generation of femtosecond far-infrared radiation in the PAL Test Linac is presented.

work supported by MOST

THPOS33 A mm-Wave Table Top Cerenkov Free-Electron Laser

Isabel de la Fuente, Peter van der Slot (*UTWENTE, Enschede*)

We have designed and constructed a compact (0.5 x 1.5 m), 100 kV Cerenkov FEL operating at a frequency of 50 GHz. The electron beam is produced by a gridded thermionic electron gun with a beam current of 800 mA. Simulations shows that 800 mA is sufficient to produce an output power of 1 kW peak at 50 GHz using a total cavity reflectivity of about 10 to 20 %. The average power approaches 1 kW when the electron pulse length is extended to CW. A depressed collector will be used to increase the overall efficiency of this device. Special attention has been given to the outcoupler that has to combine multiple functions. First it has to separate the radiation field from the electron beam. Second it has to be transparent for the electron beam and acts as a partial reflector for radiation. Finally it has to convert the generated TM_{01} mode in the interaction region into the fundamental TE_{01} mode of the standard rectangular output port. We will present

the overall design and experimental set-up, first experimental results and discuss possible applications for this table-top Cerenkov FEL.

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Chemical Composition Image and Spectral Analysis by Using SNIM Technology THPOS34

Yonggui Li (*IHEP Beijing, Beijing*), LiYuan Zhang (*IHEP BFEL, Beijing*)

By using SNIM (scan near-field infrared microscopy) technology with FEL as light source, the chemical composition and spectrum in a micro-scale of samples have been measured. Because the most "fingerprint" of the substances are located at the Mid-IR region, using Mid-IR FEL as light source of the SNIM will be very useful to study the constitute of matters by testing its IR absorption or reflection spectrum and taking the image of its chemical composition. In this paper, the experiment apparatus, fabrication of the infrared probe, sample preparation and experimental results were described. The Mid-IR near-field image of the chemical composition of the film which consists of the mixed polyethylene and polypropylene was shown. And the near-field reflection spectrum of the GaN samples was presented.

Li Yonggui，Zhang Liyuan，Wang Qian，Xu Jinqiang，Fan Yaohui

Institute of High Energy Physics (IHEP), CAS，China

Development of Pulsed X-Ray Source at Tsinghua University THPOS35

Wenhui Huang, Taibin Du (*Tsinghua University, Beijing*)

The bright and tunable short pulse X-ray sources are being widely used in various research fields including materials, chemistry, biology and solid physics. Thomson scattering source is one of the most promising approaches to short pulsed X-ray sources. Researches on

Thomson scattering x-ray sources are being carried out in Tsinghua University. Some theoretical results and the preliminary experiment on the Thomson scattering between electron beams and laser pulses are described in this paper.

THPOS36 Preliminary Design of a Synchronized High Power FEL Facility at NSRRC

Wai Keung Lau, Cheng Wei Chen, Huan Yang Chen, June Rong Chen, Tai Ching Fan, Feng Zone Hsiao, Kuo Tung Hsu, Ching-Shiang Hwang, Chin Cheng Kuo, Chih Ching Liu, Guo Huei Luo, Duan Jen Wang, Jau Ping Wang, Min Huey Wang (*NSRRC, Hsinchu*)

Design study of a narrow line-width, high power IR-FEL facility has been carried out at NSRRC. This machine is designed to synchronize with the U9 undulator radiation of Taiwan Light Source and therefore provide new opportunity for chemical dynamics and condensed matter research. It has been proposed to use a superconducting linac to provide a 60 MeV high quality electron beam to drive a 2.5-10 microns FEL oscillator with U5 undulator. Operating this linac in energy recovery mode will also be considered as an option to improve overall system effeciency and reduce heat loss and radiation dosage at the beam dump. Performance requirements and outcomes from this preliminary design study will be reported.

THPOS37 Present Status of 30 HGz Facility for Experimental Investigation

Alim Kaminsky, Sergey Sedykh (*JINR/PPL, Dubna, Moscow Region*), Naum Samuilovich Ginzburg, Sergey Kuzikov, Nikolay Peskov, Mikhail Petelin, Alexander Sergeevich Sergeev, Nikolay Zaitsev (*IAP RAS, Nizhny Novgorod*), Artem Elzhov, Eugene Gorbachev, Vitaly Kosukhin, Elkuno Perelstein, Nikolay Pilyar, Tatiana Rukoyatkina, Anatoly Sergeev, Alexey Sidorov, Vladimir Tarasov (*JINR, Dubna, Moscow Region*)

Facility for experimental investigation of a copper cavity lifetime under multiple action of 30 GHz power pulses is now created by the collaboration of CLIC team (CERN) [1], FEM groups of JINR (Dubna) and IAP RAS (Nizhny Novgorod). Design of the test cavity, estimation of the operating parameters of the FEM oscillator and the RF power transmission line was already reported at FEL'03 [2]. Last year was devoted to the achievement of the design parameters of

all the elements of the facility. We have developed the equipment and the procedure of RF transmission line adjustment, improved the stability of the linac power supplies, created the new system of data acquisition. Start of the full-scale experiments is planned to the end of 2004.

[1] J.-P.Delahaye et al., "CLIC, a 0.5 to 5 TeV eś Compact Linear Collider", Proc. of EPAC'98, Stockholm, June 1998, p. 58-62.
[2] A.V.Elzhov, N.S.Ginzburg, A.K.Kaminsky, et al.- Test facility for investigation of heating of 30 GHz accelerating structure imitator for CLIC project.- Presented to 25-th Free Electron Laser Conference (FEL'2003), Tsukuba (September 8-12, 2003), report Tu-P-16.

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The Coherent Synchrotron Radiation Influence on the Storage Ring Longitudinal Beam Dynamics THPOS38

Evgueni Bessonov, Rouslan Mikhailovich Feschenko (*LPI, Moscow*), Vasily Ivanovich Shvedunov (*MSU, Moscow*)

We investigate influence on the storage ring beam dynamics of the coherent Synchrotron Radiation (SR) self fields produced by an electron bunch. We show that the maximum energy gain in the RF cavity must far exceed the energy loss of electrons due to the coherent SR.

Electron Beam Bunching on High Harmonics of a Laser Field THPOS39

Alexander Varfolomeev, Denis Ovchinnikov, Timofey Yarovoi (*RRC Kurchatov Institute, Moscow*)

Prebunching of electron beam on short wave-length would be very useful for SASE FELs as well as for production of alternative

short wave length sources. Conventional FEL schemes were usually used for velocity modulation of electron beams. We present a new type of electron beam bunching scheme which can more effectively provide higher harmonic bunching. In our scheme transverse velocity components are modulating (transverse bunching). Strong laser field acting on electrons as a transverse field undulator induces oscillating trajectories depending on electron phases with respect to the laser field. A special quadrupole defocusing line resonant to the electron energies amplifies these deflection. The transverse velocity modulation induced by magnetic field is accompanying by longitudinal space modulation. Numerical simulation results on odd harmonics are presented. It is shown that for CO2 laser power 2 GW coherent spontaneous radiation enhancement induced by a beam bunching for 6 harmonic is equal 1.6E7 what is comparable with enhancement for the 2-nd harmonic bunching found by the BNL group in the traditional bunching system of FEL type (Nucl. Instr. and Meth. A445 (2000) 301)

THPOS40 Design of Bragg FEM-Oscillator Experiment in the Regime of Non-Resonant Trapping

Ilya Vladimirovich Bandurkin, Nikolay Peskov, Andrey Savilov (*IAP RAS, Nizhny Novgorod*), Alim Kaminsky, Elkuno Perelstein, Sergey Sedykh, Alexander Sergeev (*JINR/PPL, Dubna, Moscow Region*)

The regime of non-resonant trapping was proposed for FEMs [1]. The main idea is to give up the requirement of the initial synchronism between electrons and the operating RF wave and to provide gradual involving of different fractions of the electron beam into the interaction with the wave. It is shown that the possibility of achieving a high efficiency and a very weak sensitivity to the beam quality occures in this regime. Project for demonstration of such novel regime of operation is under development in JINR-IAP FEM-oscillator based. The key elements of the design are (a) a two-mirror Bragg resonator, which is responsible for the selective feedback at 30 GHz and for the longitudinal RF structure needed for realization of a trap for the electrons, and (b) tapered wiggler, which would lead for moving this trap over all the beam fractions. Modeling predicts an efficiency of over 40% for the FEM even when driven by the beam with extremely low quality.*

[1] A.V. Savilov, Phys. Rev.E (2001); I.V. Bandurkin, A.V. Savilov, N.Yu. Peskov., NIMA (2004).

* This work is supported by the Russian Foundation for Basic Research, Project 02-02-17205, and by the Russian Science Support Foundation.

Bragg FEM Operating at a High-Q Resonant Load THPOS41

Nikolay Peskov, Naum Samuilovich Ginzburg, Sergey Kuzikov, Mikhail Petelin, Alexander Sergeevich Sergeev (*IAP RAS, Nizhny Novgorod*), Elkuno Perelstein, Anatoly Sergeev (*JINR, Dubna, Moscow Region*), Alim Kaminsky, Sergey Sedykh (*JINR/PPL, Dubna, Moscow Region*)

Based on JINR-IAP 30-GHz Bragg FEM the experimental facility to study heating stress of metals in the multiple RF-pulses is under development. This FEM produces 20 MW / 200 ns pulses with repletion rate 0.5 - 1 Hz and stability of single-mode operation suitable to drive testing high-Q resonator. Enhancement of the field amplitude inside the resonator should provide necessary temperature rise at the resonator surface. The key question for conducted experiments is ability of an FEM to operate with a high-Q load when taking into account parasitic reflections. In the present paper modeling was done in the frame of 1D time-domain approach. It was found that if the eigenfrequency of the load-resonator coincides with the FEM operating frequency the load-resonator becomes transparent and accumulation of the e.m. energy inside the resonator occurs. Detuning of the load-resonator frequency leads to strong reflections from this resonator what results in suppression of the FEM oscillations. Influence of time delay of the reflected RF-pulse and RF-pulse losses on stability of FEM operation was studied. Results of preliminary experiments at 30-GHz FEM test facility are discussed.

A New Method for Generation of Short Powerful RF Pulses THPOS42

Andrey Savilov, Mikhail Dorf (*IAP RAS, Nizhny Novgorod*)

We propose an new scheme for generation of short powerful mm-wavelength RF pulses, which is based on interaction of an electron

pulse with a wave stored in a cavity. In this scheme, a short electron pulse enters into a Bragg-type cavity, which has been "pumped" by a long low-power input RF pulse. The forward component of the standing wave, which is stored in the cavity, interacts with electrons, if some electron-wave resonance condition (namely, either cyclotron or undulator combination one) is provided. It is shown that if the electron velocity is close to the group velocity of the forward wave, then a short RF pulse is formed close to the electron pulse front and is "pressed out" from the cavity. The energy of this output RF pulse is small as compared to the energy stored inside the cavity. However, its peak power can be very high and significantly exceed both the input RF power and the electron beam power. It is important that the output pulse length is independent on the electron current and determined by parameters of the Bragg cavity.*

* This work was supported by the Russian Foundation for Basic Research, Project No. 02-02-17205, and by the Russian Science Support Foundation.

THPOS43 Electron Bunching at a Multiplied Frequency of the Signal Wave and the Use of this Effect in Electrom Masers with Frequency Multiplication

Andrey Savilov, Ilya Vladimirovich Bandurkin (*IAP RAS, Nizhny Novgorod*)

Electron masers with frequency multiplication seem to be attractive as sources of high-power radiation in the short-millimeter and sub-millimeter ranges of wavelengths, which are based on selective spontaneous coherent emission from pre-bunched weakly/moderately relativistic electron beams at high harmonics of the frequency of electron oscillations. In this work we describe a new scheme of such a maser, which is based on interaction between electrons and a low-frequency signal wave at a multiplied frequency of this wave. Such interaction appears when electrons are bunched in superposition of two counter-propagating traveling waves, which form a standing wave inside the cavity, and when a special two-wave resonance condition takes place. This scheme should provide an enhancement of the frequency multiplication factor and improve selectivity of excitation of the high-frequency output wave.

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Transverse Mode Control in 75-GHz FEM Based on 2D Distributed Feedback THPOS44

Andrey Arzhannikov, Peter Kalinin, Alexander Kuznetsov, Sergey Kuznetsov, Stanislav Sinitsky, Vasiliy Stepanov (*BINP, Novosibirsk*), Naum Samuilovich Ginzburg, Nikolay Peskov, Alexander Sergeevich Sergeev, Vladislav Zaslavsky (*IAP RAS, Nizhny Novgorod*)

The paper devoted to the progress in 70 GHz FEM experiment exploiting 2D distributed feedback and high-current sheet electron beam generated by the ELMI accelerator (INP RAS, Novosibirsk). At the current stage a hybrid Bragg resonator consisted from 2D up-stream and 1D down-stream reflectors separated by regular waveguide was used. The radiation spectrum was measured using heterodyne technique. It was shown that the 2D Bragg reflector with suffiecent extraction for the transverse electromagnetic fluxes provides selection over the transverse mode indexes. At the same time the multi-stable generation with different freqeunces correspoding to excitation of different longitudinal modes was observed. This effect was caused by variation in the beam voltage and current during a single shot. A typical microwave pulse represents a consequence of several 300 - 500 ns spikes which chraterized by exitation of different longitudinal modes. Based on simulation the longitudinal mode selection can be improved with decrease in the length of regular resonator section.

Isochronous Bend for a High Gain Ring FEL THPOS45

Alexander Nikolaevich Matveenko, Oleg Alexandrovich Shevchenko, Nikolai Aleksandrovich Vinokurov (*BINP, Novosibirsk*)

The recently proposed ring free electron laser (FEL) consists of several undulators with isochronous bends between them. Isochronous bends are necessary to preserve the beam bunching between undulators. Such FEL configuration may be used as an independent soft X-ray source or as a master oscillator for an X-ray FEL (high gain harmonic generator or other type). The lattice of the compact 500-MeV

60 degree bend for a soft X-ray (50 nm) FEL is proposed. Fundamental restrictions due to quantum fluctuations of synchrotron radiation and technically achievable fields to construct isochronous bends of a shorter wavelength ring FEL are discussed.

THPOS46 Numerical Modeling of the Novosibirsk Terahertz FEL and Comparison with Experimental Results

Oleg Alexandrovich Shevchenko, Alexander Viktorovich Kuzmin, Nikolai Aleksandrovich Vinokurov (*BINP, Novosibirsk*)

Recently a new high-power terahertz FEL has been put in operation at the Siberian Center for Photochemical Research in Novosibirsk. The first lasing at the wavelength near 140 micrometer was achieved in April 2003. Since then some experimental data were obtained which required theoretical explanation. In this paper we use a simple 1-D model for numerical simulations of the FEL operation. The model is based on excitation of multiple longitudinal radiation modes by charged discs. We restrict our consideration to only the fundamental transverse mode. This approximation is valid in the case of long-wave FELs. We compare the results of numeric simulations with some analytical estimates and experimental data.

THPOS47 Start-To-End Simulations of the Energy Recovery Linac Prototype FEL

Christopher Gerth, Marion Bowler, Bruno Muratori, Hywel Owen, Neil Thompson (*CCLRC/DL/ASTeC, Daresbury, Warrington, Cheshire*)

Daresbury Laboratory is currently building an Energy Recovery Linac Prototype (ERLP) that serves as a testbed for the study of beam dynamics and accelerator technology important for the design and construction of the proposed 4th Generation Light Source (4GLS) project. Two major objectives for the ERLP are the operation of an oscillator infra-red FEL and demonstration of energy recovery from an electron bunch with an energy spread induced by the FEL. In this paper we present start-to-end simulations including the FEL of the ERLP. The beam dynamics in the high-brightness injector, which consists of a DC photocathode gun and a super-conducting booster, have been modelled using the particle tracking code ASTRA. After the main linac, in which the particles are accelerated to 35 MeV,

particles have been tracked with the code ELEGANT. The 3D code GENESIS was used to model the FEL interaction with the electron beam. Different modes of operation and their impact on the design of the ERLP are discussed.

The Two-Beam Free-Electron Laser Oscillator THPOS48

Brian McNeil (*Strathclyde University, Glasgow*), Neil Thompson (*CCLRC/DL/ASTeC, Daresbury, Warrington, Cheshire*)

A one-dimensional model of a free-electron laser operating simultaneously with two electron beams of different energies [1] is extended to an oscillator configuration. The electron beam energies are chosen so that an harmonic of the lower energy beam is at the fundamental radiation wavelength of the higher energy beam. Potential benefits over a single-beam free-electron laser oscillator are discussed.

[1] B. W. J. McNeil, M.W. Poole and G.R.M. Robb, this issue.

The Realisation of a Pulsed Tabletop Free Electron Maser for Industrial Applications THPOS49

Colin Wright, Ahmed Al-Shamma'a, James Lucas, Robert Stuart (*UoL-EEE, Liverpool*)

There is increasing interest in the use of microwave power for industrial applications. A pulsed microwave source is beneficial as it allows the high electromagnetic fields of a high power pulse to be applied to a target without excessive heating. The FEM is a tunable source with ability to operate across a wide range of frequencies from 8 to 12GHz. Using higher frequencies than the standard 2.45GHz magnetron increases the fields obtained and also has beneficial scaling effects on some applications, such as microwave induced plasmas. The FEM main components will be presented in this paper, including an electron gun, a rectangular waveguide cavity in a low cost permanent magnet undulator structure and a single stage depressed collector for energy recovery. The cost of the FEM is presently comparable to a similar output TWT but the FEM has much scope for development, either by scaling down in size to

increase operating frequency >100GHz, or by increasing the beam current >1A to increase the output power, or both. In addition, the paper will discuss the applications of the FEM system as a tabletop source for UV, Ozone, Chemistry and material processing.

THPOS50 Using Coherent Synchrotron Radiation from 15 fs, LINAC-Generated Electron Bunches for Ultrafast IR/Laser Pump, X-ray Probe Experiments with fs Synchronism

Bernhard W Adams (*ANL/APS, Argonne, Illinois*)

Model calculations show that wakefield effects in the SLAC linac can be used to compress electron bunches to 15 fs or less. The coherent synchrotron radiation (CSR) from these bunches appears at mid-infrared wavelengths, and is naturally synchronized to x-rays (non-FEL) emitted from the same bunch in an undulator. This property is highly interesting for vis./IR pump, x-ray probe experiments to measure femtosecond dynamics in molecules and condensed matter. Further compression of the electron bunches to a few fs seems possible at the penalty of large fluctuations of the bunch length (due to RF phase jitter). The CSR from these bunches can be used as both, highly synchronized pump light and (through its wavelength spectrum) as an indicator of the degree of compression, permitting the selection of x-ray data from the very shortest bunches. The power level of the CSR exceeds that of typical seed laser oscillators (Ti:Sapphire, etc.). If necessary, standard laser technology can be used for further amplification.

[1] B.W. Adams, Rev. Sci. Instrum., in print (2004)

This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences under the contract W-31-109-ENG-38.

Harmonic Cascade FEL Designs for LUX, a Facilty for Ultrafast X-ray Science THPOS51

Corlett John, William M Fawley, Gregory Penn, Alexander A Zholents (*LBNL/CBP, Berkeley, California*), Weishi Wan (*LBNL/ALS, Berkeley, California*), Matthias Reinsch, Jonathan Wurtele (*UC Berkeley, Berkeley*)

LUX is a proposed facility for ultrafast X-ray science, based on an electron beam accelerated to 3-GeV energy in a superconducting, recirculating linac.Included in the design are multiple FEL beamlines which use the harmonic cascade approach to produce coherent XUV & soft X-ray emission beginning with a strong input external laser seed at 200 nm wavelength. Each cascade module generally operates in the low-gain regime and is composed of a radiator together with a modulator section, separated by a magnetic chicane. The chicane temporally delays the electron beam pulse in order that a "virgin" pulse region (with undegraded energy spread) be brought into synchronism with the radiation pulse. For each cascade, the output photon energy can be selected over a wide range by varying the seed laser wavelength and the field strength in the undulators. We present numerical simulation results, as well as those from analytical models, to examine predicted FEL performance. We also discuss lattice considerations pertinent to harmonic cascade FELs, as well as sensitivity studies and requirements on the electron beam.

Work supported by the U.S. Dept. of Energy under Contract DE-AC03-76SF0098.

Smith-Purcell Radiator Development: Current Status and Future Plan THPOS52

Kwang-Je Kim (*Enrico Fermi Institute, Chicago, Illinois ; ANL/APS, Argonne, Illinois*), Albert Crewe, Oscar Kapp (*Enrico Fermi Institute, Chicago, Illinois*)

Effort to develop a Smith-Purcell radiator in the high-gain free-electron laser (FEL) regime has been underway since 2002 at the Enrico Fermi Institute of The University of Chicago as a laboratory-scale source of terahertz radiation. By modifying a used Cambridge S-200 scanning electron microscope, we were able to observe Smith-Purcell radiation in the spontaneous emission regime. However, the nonlinear behavior of the radiation as a function of the beam current

we observed appears to be due to blackbody radiation from the heated grating, not due to the FEL gain as reported previously [1]. We are studying two approaches to enhance the gain: developing higher brightness sources and generating flat beams.

[1] J. Urata, et al., Phys. Rev. Lett. 80 (1998) 516.

Work supported in part by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38 and by grants from the Illinois Board of Higher Education; the Illinois Dept. of Commerce and Community Affairs and the National Science Foundation (#5-27483 and #PHY 0104619).

THPOS53 Novel Method for Phase-Space Tomography of Rapidly Evolving E-beams

Kevin Chalut (*Duke University, Durham, North Carolina*), Vladimir Litvinenko (*BNL, Upton, Long Island, New York*)

Traditional tomographic methods based on Radon transformation require a full set projections covering full 180-degrees. This technique is applicable only to a stationary distribution of electrons, which do not evolve. In addition, this method can't work with incomplete sub-set of data such as a few projections covering total angle of few degrees. We present novel method of tomography working with a limited number of non-degenerated linear projections. We present the description of the method, discuss its advantages as well as limitations. We compare the method with the Radon transformation. We present the application of this method to the study the dynamics of e-beam in longitudinal phase space using dual sweep streak-camera with psec resolution. This method allowed us to restore the evolution of e-beam during a giant pulse in a storage ring FEL when the distribution of the electrons changes completely during one synchrotron oscillation. We discuss another possible applications of this method in advanced FEL systems, where effects of space charge, nonlinearities or coherent synchrotron radiation impair traditional diagnostics methods.

Characterization of Storage Ring FEL operating in the Giant Pulse Mode THPOS54

Igor Pinayev, Kevin Chalut (*Duke University, Durham, North Carolina*), Vladimir Litvinenko (*BNL, Upton, Long Island, New York*)

In this paper we present the experimental results on the storage ring free electron laser operating in the giant pulse mode with variable repetition rate. The experiments were conducted in the wide range of the electron beam energies from 270 MeV to 600 MeV with the giant pulses generated using a gain modulator. Dependence of the peak and average power, and the other properties and parameters of giant pulses on the pulse repetition rate are studied. In particular, it is found that the average lasing power in the giant pulse mode reaches levels of 70-90% of that in the CW power mode. Applications of such mode of operation are discussed.

MFEL grant as administered by AFOSR

Nonlinear Beam Dynamics in the Storage Ring with FEL Wigglers THPOS55

Ying K. Wu, Jingyi Li, Stepan F. Mikhailov (*DU/FEL, Durham, North Carolina*)

Long FEL wigglers can significantly alter the nonlinear dynamics of the electron beam in the storage ring. Understanding and reducing the wiggler impact on dynamics is essential for the operation of a storage ring FEL, especially at a relatively low beam energy. The ability to study nonlinear dynamics with wigglers in great detail has been greatly enhanced by our recent development of explicit symplectic tracking technique for 3D magnetic elements including wigglers. Extensive studies have been performed for the Duke OK-5 FEL, a next generation FEL with variable polarizations. In this paper, we report our dynamics studies of the Duke storage ring with both existing planar OK-4 FEL and up-coming variably polarized OK-5 FEL. Realistic 3D magnetic field models are developed for the complex OK-5 FEL wigglers. Frequency map techniques have been extensively utilized to reveal the complicated resonance structure and dynamics limitations in the phase space. Significant dynamic aperture reduction has been observed in simulation at low e-beam

energies. Strategies to minimize the dynamic impact of the FEL wigglers are presented.

Work Supported by DOE grant DE-FG05-91ER40665 and DoD MFEL Program as
managed by the AFOSR, grant F49620-001-0370.

THPOS56 VISA IB: Ultra-High Bandwidth, High Gain SASE FEL

Gerard Andonian, Ronald Barkley Agustsson, Pedro Frigola, Alex Murokh, Claudio Pellegrini, Sven Reiche, James Rosenzweig, Gil Travish (*UCLA, Los Angeles, California*), Marcus Babzien, Ilan Ben-Zvi, Vladimir Litvinenko, Vitaly Yakimenko (*BNL, Upton, Long Island, New York*), Ilario Boscolo, S. Cialdi, Alessandro Flacco (*INFN Milano, Milano*), Massimo Ferrario, Luigi Palumbo, C. Vicario (*INFN/LNF, Frascati (Roma)*), Jung Yun Huang (*POSTECH, Pohang, Kyungbuk*)

The results of a high energy-spread SASE FEL experiment, the intermediary experiment linking the VISA I and VISA II projects, are presented. A highly chirped beam (1.7%) was transported without correction of longitudinal aberrations in the ATF dogleg, and injected into the VISA undulator. The output FEL radiation displayed an uncharacteristicly large bandwidth (11%) with extremely stable lasing and measured energy of about 2 microJoules. Start-to-end simulations reproduce key features of the measured results and provide an insight into the mechanisms giving rise to such a high bandwidth. These analyses are described as they relate to important considerations for the VISA II experiment.

THPOS57 Acceleration of Electrons in a Diffraction Dominated IFEL

Pietro Musumeci, Chan Joshi, Claudio Pellegrini, James Rosenzweig, Jay Sun, Sergei Totchisky, Gil Travish (*UCLA, Los Angeles, California*), Sergey Tolmachev, Alexander Varfolomeev, Alexander Varfolomeev Jr., Timofey Yarovoi (*RRC Kurchatov Institute, Moscow*), Salime Boucher, Adnan Doyuran, Robert England, Rodney Yoder (*UCLA/DPA, Los Angeles - California*)

We report on the observation of energy gain in excess of 20 MeV at the Inverse Free Electron Laser Accelerator experiment at the Neptune Laboratory at UCLA. A 14.5 MeV electron beam is injected

ina 50 cm long undulator strongly tapered both in period and field amplitude. A CO2 10 μ m laser with power >300 GW is used as the IFEL driver. The Rayleigh range of the laser (1.8cm) is shorter than the undulator length so that the interaction is diffraction dominated. Few per cent of the injected particles are trapped in stable accelerating buckets and electrons with energies up to 35 MeV are detected on the magnetic spectrometers. Experimental results on the scaling of the accelerator characteristics versus input parameters like injection energy, laser focus position and laser power are discussed. Three dimensional simulations are in good agreement with the electron energy spectrums observed in the experiment and indicate that substantial energy exchange between laser and electron beam only occurs in the first 25-30 cm of the undulator. An energy gradient of >70 MeV is inferred. In the second section of the undulator higher harmonic IFEL interaction is observed.

Short Wavelength Free Electron Lasers in 2004 THPOS58

William Colson, Robb Mansfield, Sean Niles, Brett Williams (*NPS, Monterey, CA*)

Twenty-seven years after the first operation of the short wavelength free electron laser (FEL) at Stanford University, there continue to be many important experiments, proposed experiments, and user facilities around the world. Properties of FELs operating in the infrared, visible, UV, and x-ray wavelength regimes are listed and discussed.

Stability of a Short Rayleigh Length Laser Resonator with Misaligned or Distorted Mirrors THPOS59

Peter Crooker, Joseph Blau, William Colson (*NPS, Monterey, CA*)

Motivated by the prospect of constructing an FEL with short Rayleigh length in a high-vibration shipboard environment, we have studied the effect of mirror vibration and distortion on the behavior of the fundamental optical mode of a cold-cavity resonator. A tilt or transverse shift of a mirror causes the optical mode to rock sinusoidally about the original resonator axis. A longitudinal mirror shift or a change in the mirror's radius of curvature causes the beam diameter at a mirror to dilate and contract with successive impacts.

Results from both ray-tracing techniques and wavefront propagation simulations are in excellent agreement.

THPOS60 Smith-Purcell Free-Electron Laser

Charles A. Brau, Heather L. Andrews, Charles H. Boulware (*Vanderbilt/DPA, Nashville - Tennessee*)

We have developed a new theory to describe the gain of a Smith-Purcell FEL. The theory shows that the electrons interact with an evanescent mode whose frequency lies slightly below the frequency range of Smith-Purcell radiation, and whose group velocity is negative. Computations indicate that very high gain should be observed even at very low current with suitable bright electron beams. An experiment is under construction to test these predictions.

THPOS61 Phase-Space Tomography of E-beam Dynamics during Giant Pulses in a Storage Ring FEL

Vladimir Litvinenko (*BNL, Upton, Long Island, New York*), Kevin Chalut, Igor Pinayev, Samadrita Roychowdhury (*Duke University, Durham, North Carolina*)

Giant pulse mode of storage ring FEL operation provides for generation of very high peak power sufficient for effective generation high coherent harmonics. The process of generating a giant pulse results in very complicated longitudinal phase-space dynamics of electron beam. In this paper we present the comparison between theoretical and experimental results for the e-beam evolution during giant pulses in storage ring FEL. We use #fel3D and #uvfel self-consistent storage ring FEL codes for theoretical predictions. We use a novel tomographic technique* to restore the e-beam phase space dynamic from dual-sweep steak-camera images measured with OK-4/Duke SR FEL.

K. Chalut, V.N. Litvinenko, "Novel method for phase-space tomography of rapidly evolving e-beams", this conference

THPOS62 Measurements of the High-Gain FEL Radiation Properties along the Radiator

Timur Shaftan, Henrik Loos, Brian Sheehy, Li-Hua Yu (*BNL/NSLS, Upton, Long Island, New York*)

We present experimental results on evolution of properties of the

DUV FEL output radiation along the radiator. Intercepting the electron beam at the different locations inside the undulator we recorded and analyzed transverse profiles, spectra and intensity of the FEL output. Shot-to-shot fluctuations of the FEL radiation may significantly affect the accuracy of measurement. In the paper we present and discuss a single-shot measurement technique, based on a special imaging system.

Coherence Length and Pulsewidth Measurement of the KAERI THz Free-Electron Laser THPOS63

Hyuk Jin Cha, Young Uk Jeong, Byung Cheol Lee, Seong Hee Park (*KAERI, Daejon*), Seung Han Park (*YU, Seoul*)

We expect that it is possible to develop the advanced imaging technology using coherent characteristics of a compact high power FEL which is operating as a users facility at KAERI. The wavelength range of output pulses is 100-1200 μm (0.3-3 THz). Currently, the experiments are going on that measuring the coherence length of FEL beams by using a Michelson interferometer. We used a THz beam splitter (crystal quartz) and a liquid-helium cooled Ge:Ga detector for precise measurements of the interference intensities. Fringe visibilities are measured as a function of optical delay. Results on the FEL micropulse-width measurement are also reported, and we estimate the pulsewidth is approximately 30 ps.

Frequency Tuning in Volume Free Electron Lasers with Rectangular Resonator THPOS64

Vladimir Baryshevsky, Alexandra Gurinovich (*Belarussian State University, Minsk*)

Investigation of frequency tuning in volume free electron lasers with rectangular resonator is presented. Two experimental VFEL prototypes are considered: 1. VFEL with electron beam energy 10 keV, operation wavelength 4-6 mm; 2. VFEL with electron beam energy 180-280 keV, operation wavelength 2,5-5 cm. The optimal conditions for radiation tuning in each case are found. Influence of resonator transverse dimensions is analyzed. Frequency tuning ranges at independent rotation of diffraction gratings are obtained for both VFEL prototypes. Conditions necessary for frequency tun-

ing at simultaneous rotation of diffraction gratings are discussed. Comparison with experiment is given.

Biological and Medical Sciences

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FRAxS

Advances in the Physical Understanding of Laser Surgery at 6.45 microns

FRAIS01

Michael Shane Hutson (*Vanderbilt/DPA, Nashville - Tennessee*), Glenn Edwards (*DU/FEL, Durham, North Carolina*)

We previously presented a model that attributes the wavelength-dependence of FEL tissue ablation to partitioning of absorbed energy between protein and saline. This energy-partitioning subsequently influences the competition between protein denaturation and saline vaporization. The original model approximated cornea as a 1D laminar material with a 50:50 saline-to-protein volume ratio. We have now refined the microscopic geometry of the model in two important ways: (1) cornea is represented as a saline bath interpenetrated by a 2D hexagonal array of protein fibrils; (2) the volume ratio is matched to the measured value, 85:15. With this volume fraction, the specific absorption coefficient for protein is much larger than previously reported. Thus, the 2D model magnifies the differences between wavelengths that target protein, as opposed to saline. We will discuss: (1) the consistency of this model with previous, seemingly conflicting, experimental data; (2) predictions of the model, with a particular emphasis on the role of laser intensity; and (3) the experiments needed to test these predictions.

Supported by grant FA9550-04-1-0045 from the DOD MFEL Program.

Two-Color Mid-IR Pump-Probe Spectroscopy of Myoglobin and Corneal Stroma

FRAOS02

George A. Marcus, H. Alan Schwettman, Dmitri M. Simanovskii (*HEPL-FEL, Stanford*)

The study of protein vibrational dynamics provides a window into protein behavior and tissue ablation. Energy deposited in the protein amide modes can equilibrate with the solvent thermal bath indirectly via Intramolecular Vibrational Relaxation (IVR) or directly via intermolecular relaxation. An IVR dominated pathway may have a bottleneck, causing long relaxation times. Vibrationally excited proteins can be created by pumping amide I or II modes, each of

which have different absorption strengths relative to the overlapping water bend mode. By probing the transient protein absorption, we can monitor energy trapped within the protein. Conversely, by probing transient absorption in the water association band, we can monitor the arrival of energy in the thermal bath. Thermal diffusion provides an upper bound for the timescale of the energy equilibration process. In Myoglobin, the thermal diffusion time is about 10 ps. For corneal stroma, made up of alternating layers of collagen fibers and water, the thermal diffusion time is on the order of 1 ns. Two-color mid-IR pump-probe spectroscopy experiments, using an OPA synchronized to the Stanford FEL will be described.

This work has been supported in part by a grant from the Air Force Office
of Scientific Research (# F49620-00-1-0349).

FRAOS03 Picked FEL-Micro Pulse for Nano-Second Interaction with Bio-Molecules

Sachiko Suzuki (*OU-iFEL, Hirakata, Osaka*)

Laser pulse duration is a very important parameter to determine the threshold between thermal and nonthermal effects in laser surgery of biomedical tissue. Free Electron Laser (FEL) at Osaka University, Japan, has a pulse structure in which a macropulse (pulse width : 15μs) consists of equally separated micropulses, whose width and interval are 5ps and 44.8ns, respectively. Precise control of micropulse train may establish fast optic processes because thermal relaxation time in the tissue is about 1us. A pulse-picking system was designed in order to extract single or a few micropulses from an entire macropulse using an acousto-optic modulator (AOM) in which the light path can be temporally diffracted by an external gate signal. An extracted micropulse train was monitored by a mercury-cadmium-telluride (MCT) photodetector with 1ns response time and recorded on digital oscilloscope. A single micropulse was extracted as a result of adjusting duration of the RF wave to 50 ns which is nearly equal to the interval of micropulse. Investigation of a fast interaction between the FEL and a tissue using this system is expected.

A Giant, Narrow Resonance in the Amide I Band in Proteins

FRAOS04

Robert Austin (*PU, Princeton, New Jersey*), Britta Redlich, Lex van der Meer (*FOM Rijnhuizen, Nieuwegein*), Aihua Xie (*OKSU-Phy, Stillwater - Oklahoma*)

We have discovered that there exists a very narrow (less than 0.02 microns) wide resonance in the amide I band of myoglobin and photoactive yellow protein that can be driven to greater than 30% saturation using very narrow linewidth pump-probe spectroscopy at FELIX. The extraordinary narrowness of this transition and the extraordinary ease of saturation inplies that this band is highly anharmonic and decoupled from the other oscillators in the amide I band. We will present detailed measurments on this discovery and implications for energy flow in proteins.

Office of Naval Research

Closing Session

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FRBIS

The European X-ray Free Electron Laser Project at DESY

FRBIS01

Andreas Schwarz (*DESY, Hamburg*)

On February 5, 2003, the German Federal Ministry of Education and Research decided that the X-ray free-electron laser XFEL, proposed by the International TESLA Collaboration, should be realized as a European project and located at DESY/Hamburg. The ministry also announced that in view of the locational advantage, Germany is prepared to cover half of the investment and personnel costs for the XFEL. In the course of the last year work has concentrated on the following areas: setting up of an organizational structure at DESY for the preparation of the project, discussions with potential European partners on several levels, selection of a new site for the XFEL facility and the preparation of the 'plan approval procedure'. The present status of the technical layout of the Linear Accelerator, the SASE Undulator and Photon Beamlines and the experiment stations will be presented.

Overview of THz Radiation Sources

FRBIS02

Gian Piero Gallerano (*ENEA C.R. Frascati, Frascati - Roma*)

Although Terahertz (THz) radiation was first observed about hundred years ago, the corresponding portion of the electromagnetic spectrum has been for long time considered a rather poorly explored region at the boundary between the microwaves and the infrared. This situation has changed during the past ten years with the rapid development of coherent THz sources, such as quantum cascade laser, diodes, optically pumped solid state devices and novel free electron devices, which have in turn stimulated a wide variety of applications from material science to telecommunications, from biology to biomedicine. In this paper we review the development and perspectives of THz radiation sources and their applications with particular emphasis on the research effort carried out and planned in the frame of various European programs.

FRBIS03 **FEL Developments and Trends: A Personal Observation of FEL2004**

Mike Poole (*CCLRC/DL/ASTeC, Daresbury, Warrington, Cheshire*)

A personal impression of the conference in the framework of the ongoing activities in the field.

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