Design of a Long Wavelength FEL for Experiments under High Magnetic Fields

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Design and system choices for our Nijmegen FIR-FEL
• Combining pump-probe options with very narrow bandwidth output in a single instrument
Nijmegen Center for Advanced Spectroscopy
On Large Scale Research Facilities in the Netherlands

The Nijmegen Center for Advanced Spectroscopy

- *NanoLab* (Rasing)
- *Trace gas Facility* (Harren)

*Design of a Long Wavelength FEL* to facilitate access to Nano-Science and Technology for Small and Medium size enterprises

part per billion range (1 ppb = 1:10⁹), 100 times more sensitive than best commercially available equipment
Nijmegen Science Faculty

HFML (Maan)

NMR pavillion (Kentgens)

Science faculty: opening 2007
Magnetic Field Landscape

Destructive pulsed
Capacitor driven pulsed
(55T → 80T)
Regulated quasi CW (→35T)
Hybrid magnets (41T → (45T !!)
Resistive magnets (33T)
Superconducting magnets

18T

Nijmegen HFML Facility
Nijmegen High Field NMR (33T, 1.27 GHz)

NMR and HFML: NMR towards Instrumentation above 1 GHz

- 33 T
- 40 kA
- 20 MW
NMR by mechanical detection

\[ F_z = M_z \frac{\partial B}{\partial z} \]

\( B_0 = 4.7 \text{T} \)

Gradient

Vacuum

Fiber optic interferometer

Cantilever

B\textsubscript{1} coil
Magnetic Resonance Force Microscopy
Elementary Excitations in Magnetic Fields

- Pseudogaps of high-Tc superconductors
- Superconducting gaps
- Antiferromagnetic resonance
- Ferromagnetic spin waves
- Lattice vibrations and polarons
- Electron spin and oscillation resonances

Science Drivers (I)

- Magnetic field (T)
- Frequency (THz)
Probing Dynamic Interactions and Inhomogeneous Effects

(A) 90° pulse: implies full saturation of the transition: a challenge in the THz: inducing a $\pi/2$ pulse
pulselength 100 ns: 100 Watt
pulselength 50 ns: 400 Watt

(B) Need for two pulses with variable time-separation:
time-separation up to a few $\mu$s

(A+B) We need a continuous narrow bandwidth FIR pulse
Dynamic Nuclear Polarization:

Coupling of EPR-NMR: dragging as many nuclear spins as possible into a pure quantum state . . . . .

NMR science needs to meet two contradicting demands:
(a) (weak) coupling to help pull nuclear spin: INTENSE FIR!
(b) no-coupling during the (enhanced) NMR phase MORE INTENSE!
Dynamic Nuclear Polarization: Coupling during collisions: e.g. in Xe Hyperpolarization.

Off-Line Preparation Times of Hyperpolarized Samples are Minutes.

CW FIR NEEDED!?
Molecular Spectroscopy in the THz:
More than molecular recognition

From Electronic (UV) $\rightarrow$ IR (NH, NO, CH \_ = structure) $\rightarrow$ (to) FIR
(large scale motion or functionality)
Consequences of Nijmegen Users:

REQUESTED BUT IMPOSSIBLE:
- continuous wave to 20 picoseconds time-resolved pump-probe
- continuously tunable light source with a variable bandwidth ranging from $1.10^{-5}$ to Fourier limited at all pulse structures
- tunable power output up to 10 kWatt
- 100% duty cycle
- wavelength between 10 $\mu$m (30 THz) and 10 mm (0.03 THz)

FOR HIGH MAGNETIC FIELDS ONLY:
- quasi-continuous wave, tunable light source
- bandwidth down to $1.10^{-5}$
- macro-pulses of length up to 10 $\mu$s
- (macro pulse) power of 1 kWatt
- high overall duty cycle

Compare: the USCB-FIR-FEL, Santa Barbara, and the Israeli FEL project, Tel Aviv).
Design Choices:

**philosophy:**
allowing (quasi) continuous wave operation with a narrow bandwidth as well as 20 picoseconds time-resolved pump-probe experiments, continuously tunable

**design aim:**
an RF Linac (1 to 1.3 GHz)
a linear cavity with an interferometer (Michelson / Fox-Smith) and 20-30 simultaneous optical pulses

**Output:**
quasi CW-output after post-cavity filtering, 100 Watt
or
micro-pulses (20-50 psec pulses, 10 kWatt during the 10 μs macro-pulse).

Wavelength: from 100 μm (3 THz) to 1.5 mm (200 GHz).
The THz FEL - Operation
The Narrow Band THz FEL - Operational Principle

Oepts and Colson (1990), Bakker, Oepts, Van der Meer et al. (1993), Oepts, Weits, Van der Meer et al. (1996-1998), Szarmes, and Madey (1993), Israeli Project (2005) and others ...
Generation of Phase-Locked Pulses (FELIX, 1990-1999)

Experiment at 69 nm

Bandwidth of single micro-pulse (2.5 cm⁻¹)

After phase locking of the micro-pulses (☺ and ☹ (spontaneous coherence)

Bandwidth (=quality of phase coupling) of Fox-Smith about 0.0015 cm⁻¹

Ideal: external filtering of single longitudinal cavity mode (0.0002cm⁻¹ or BWL macro-pulse)
Generation of Phase-Locked Pulses (FELIX, 1990-1999)

Fox-Smith: inserting path differences (= multiples of the micro-pulse distance)

Michelson: Measuring the inter-pulse coherence
Results from Weits et al.: 

Interferogram:
Up to 1.8 meter path difference in analysing Michelson!
External Selection with Fabry-Perot Etalons:
Study Themes:

- optimal design for intracavity phase locking between 100 μm and 1.5 mm
- controlling the spontaneous coherence and interferometer induced coherence
- material research on low-loss optics and frequency filters
- maximizing duty cycle

Planning:
- January 2008: detailed plan for hybrid, FEL and Building
- 2008-2010: construction and commissioning
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