Experience and plans of the JLAB FEL facility as a user facility

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(presented by Stephen Benson)

Jefferson Lab

29th International Free Electron Laser Conference

Budker INP, Novosibirsk, Russia

Aug. 30, 2007

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Outline

- Overview of the facility
  - Development timeline
  - Performance
    - IR Upgrade FEL
    - THz
  - User "Infrastructure": Planning, Advisory Committees, Safety
- Some experimental programs
  - carbon nanotubes
  - Metal nitriding/amorphization
  - Differential heating of fatty tissue
  - Experiments in dedicated THz lab
- Facility Lessons Learned
- Conclusions
- Acknowledgements

Free Electron Laser Development at Jefferson Lab

- **Designed, built and commissioned highest average power FEL (IR Demo) in 1996-98**
  - achieved **2.1 kW** at 3.1 microns (previous world record, 11 watts)
  - demonstrated power efficiency by lasing at 2.1 kW while recirculating and recovering more than 75% of the input linac energy, enabling energy recovered linacs (ERLs)
  - World class powers in the FIR (THz), visible, UV and x-ray
- **Established a versatile User Facility for the IR Demo FEL in 1999-2001:**
  - used by 30 research teams in 1999-2001
- **IR Upgrade to 10 kW completed in July 2004:**

  -obtained 14.2kW at 1.6μm in Oct. 06

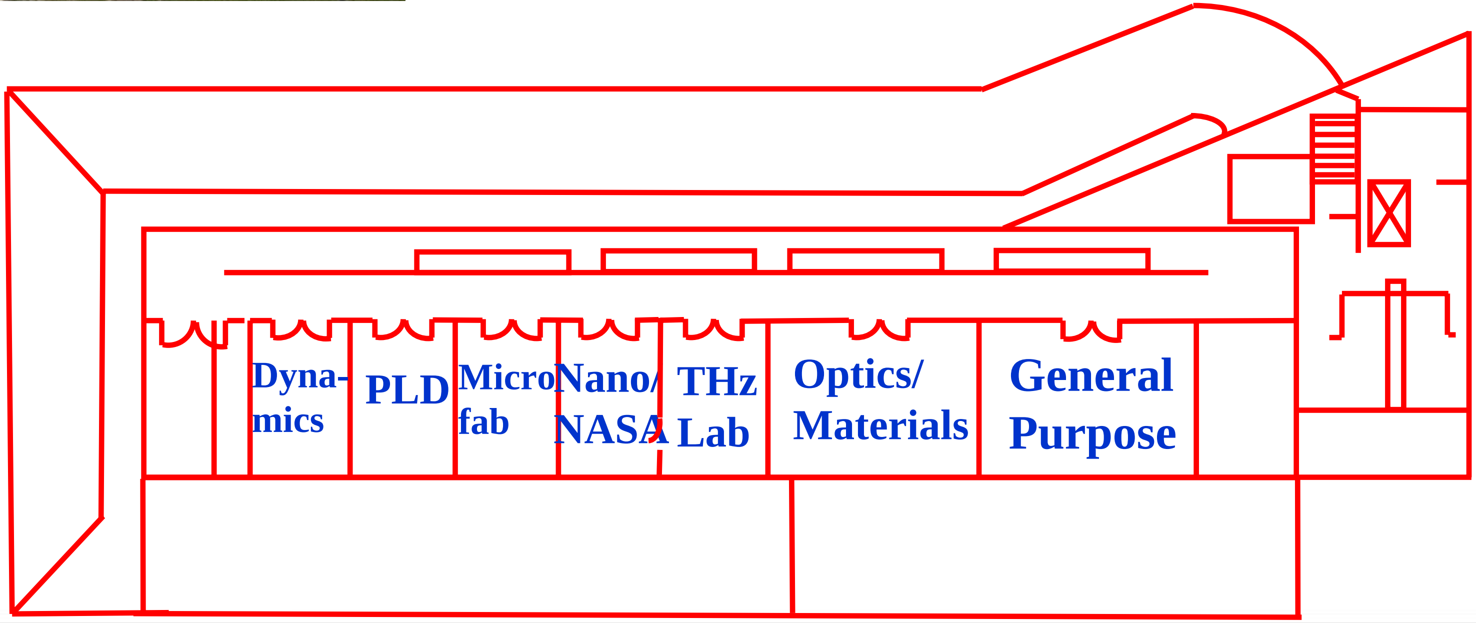
  -continuing high power FEL development

  -operating for scientific users and other sponsors

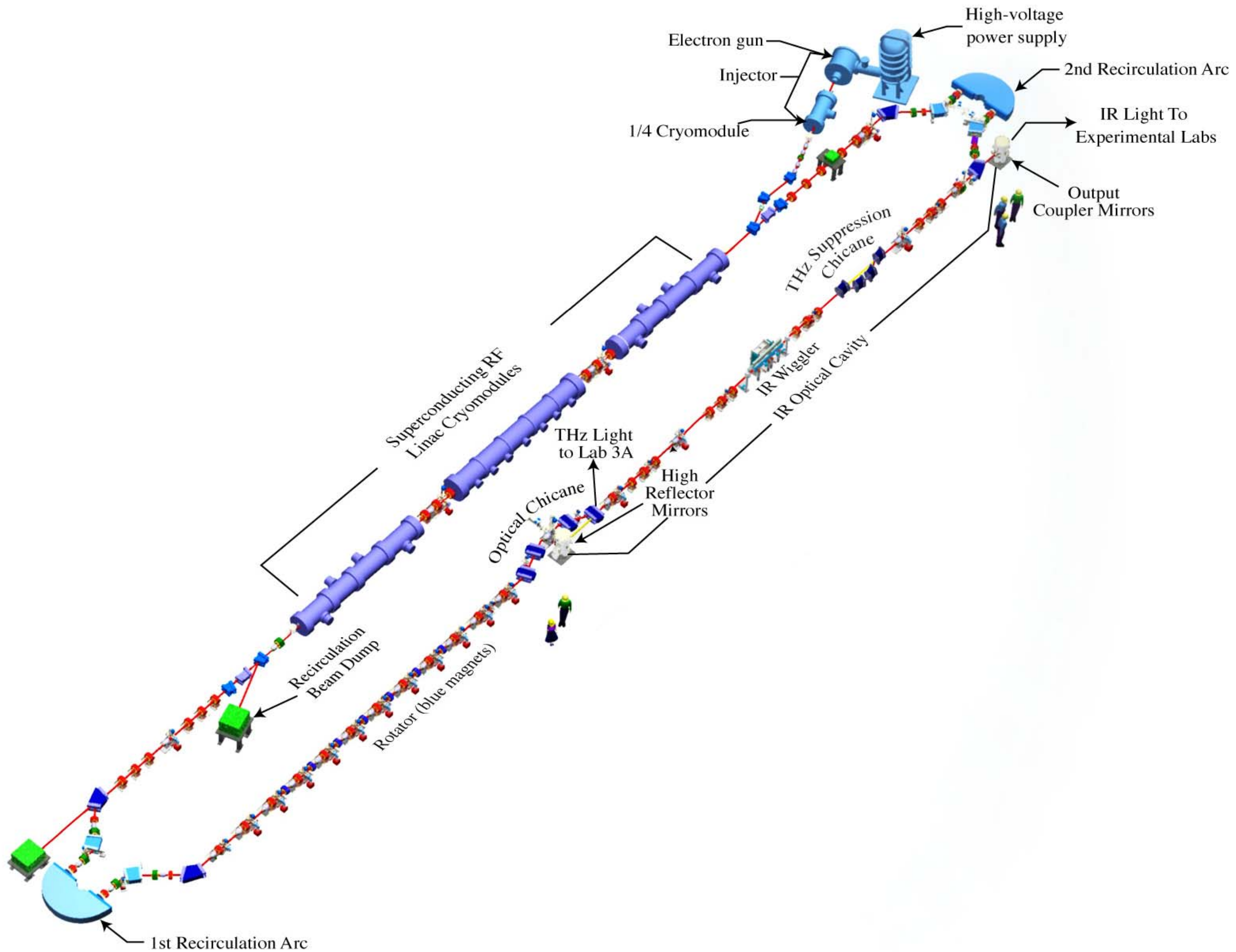
The Free Electron Laser User Facility

Current User Facility has 7 Labs

- Lab1 General set-ups and prototypes
- Lab 2 Materials studies
- Lab 3 THz dynamics and imaging
- Lab 3a NASA nanofab
- Lab 4 Aerospace LMES
- Lab 5 PLD
- Lab 6 FEL + lasers for dynamics studies



The 10 kW IR Upgrade FEL



Summary of High Power Lasing To Date

Short wavelength results to date:

wavelength (μm)	**1.1**	**1.6**	**2.8**	**6.0**
pulsed (kW)	**2.5**	**14.6***	**6.7**	**10.6 (1s)**
cw (kW)	**2.2**	**14.6***	**6.7**	**8.5**

-Short wavelength performance improves as we develop and test low absorption (<few 100ppm) dielectric coatings for high power optics

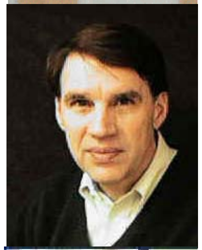
-* Oct. 06 cryomirror tests with ~40k sapphire substrate

The Laser Personnel Safety System (LPSS)

- Each User Lab LPSS monitors individual lab's hazard to Users
- Smart card system authenticates and permits users to enter only those rooms associated with their experiment.
- When running cw there are two modes:
  - Users excluded from room
  - Users run experiment in enclosed hutch.
- FEL can be used with or without class 4 lasers
- Users can align FEL to their experiment with low duty factor beam (pulsed beam):
  - 2Hz, 250 μs, 4.68 MHz

We have an active FEL Program Advisory Committee

- Philippe Guyot-Sionnest, **University of Chicago, Physics**
- Richard Haglund, **Vanderbilt, Physics, Materials Science**
- Lou DiMauro, **Ohio State, AMO Physics, Chemistry**
- John Sutherland, **East Carolina University, Biology**
- Harvey Rutt, **U. of Southampton, UK, Opto-electronics, Eng. Sci.& Math**


Program Advisory Committee meetings:

Nov. 2000, June 2001, Jan. 2002, Mar. 2003, Mar. 2004, Mar 2005, Mar 2006, May 2007.

- rated 18 proposals for IR-Demo FEL 3 Outstanding
10 Excellent
5 Good

We ran 17/18 proposals by IR-Demo shutdown

<u>20 proposals in present portfolio</u>

Key FEL Program Accomplishments in 2006-2007

- **FEL User Results:**
- Very long carbon nanotube (CNT) production runs for NASA-LaRC at >1 kW on target at 1.6 microns; record production (>7 g/hr) and purity levels (> 80% single wall CNT) for laser ablation.

  Laser nitriding of titanium experiments for the Univ. of Göttingen

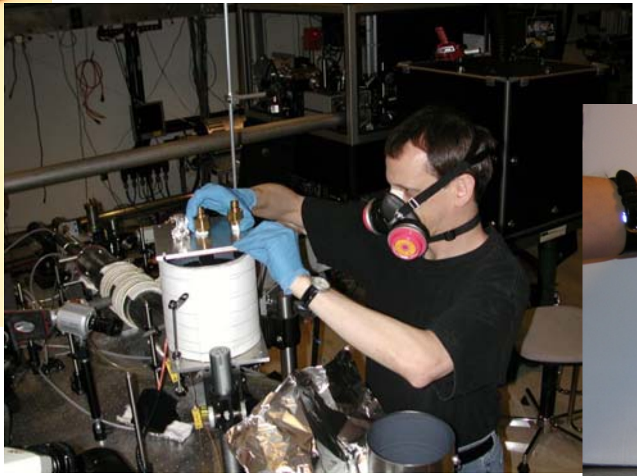
  Pioneering experiments completed on differential heating of fat tissue at 1.2 and 1.7 microns; resulting in best paper for Harvard PI at International Conference of Lasers in medicine and Surgery (Boston, April 2006).

  New type of THz interferometer and vacuum THz spectrometer demonstrated on THz beamline; World's first THz movies.

NASA/JLab Nanotube Synthesis - Research to Production

From Target to Product, 100% In-House

New and used target



Product, ~1 hour of beam time

- Production with 750 W at 1.6 micron is now routine.
- Production rate of 2-6 g/hour of as-grown, high quality, “research grade” raw material is already cost competitive in $400/g market.
- Nanotube diameter is strong function of laser parameters, suggesting the possibility of “designer” tubes (selectable diameter likely… chirality, maybe?).
- Experimental trends indicate improved gross and net yield with soon-to-be-available shorter FEL wavelengths and higher power (no scale-up issues).

Mike Smith NASA LaRC

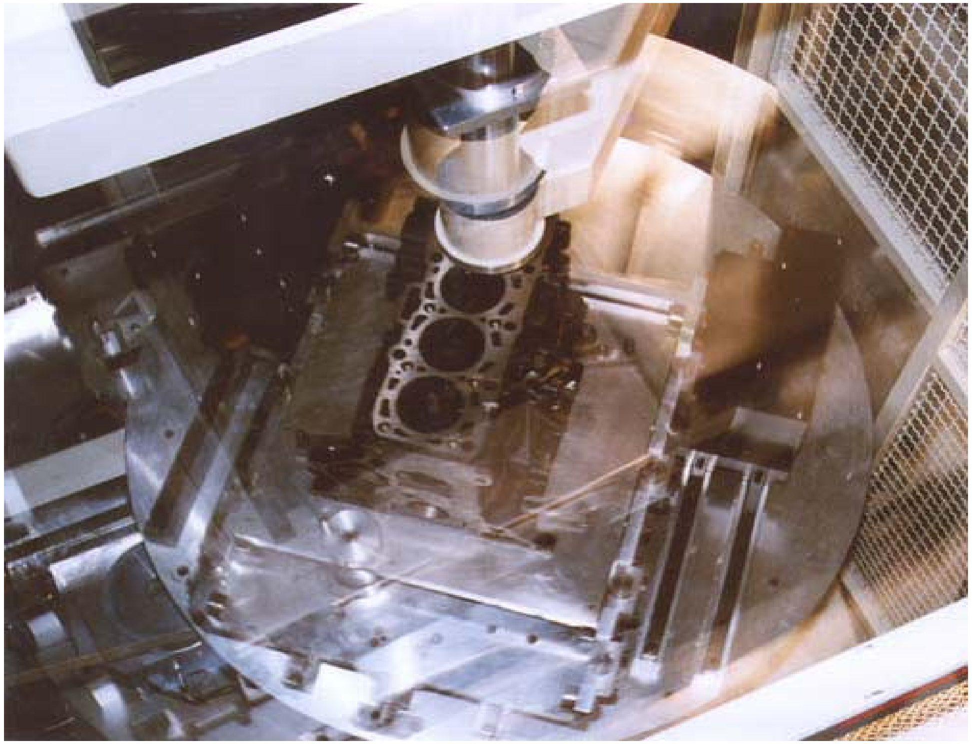
Metal surface treatment

- Laser treatments typically bring the surface nearly to or at melting point
  - Enhances reaction rate with cover gas
  - Nitriding enhances hardness → increased wear resistance
  - Amorphizing, due to high quench rates, is another way to increase wear resistance.

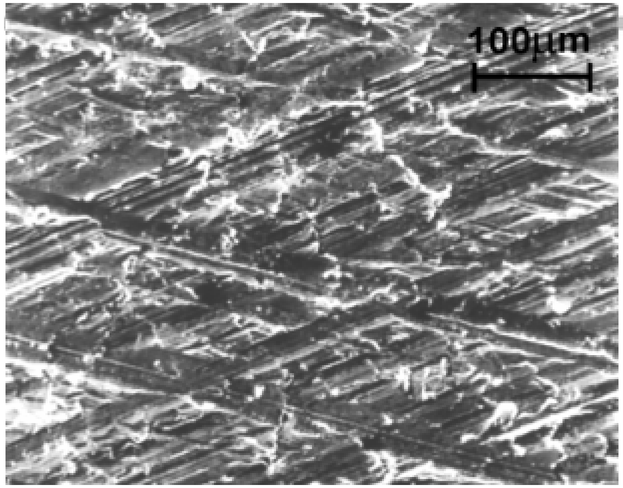
Application: Laser nitriding automobile cylinder liners (grey cast iron)

J. Lindner, AUDI AG

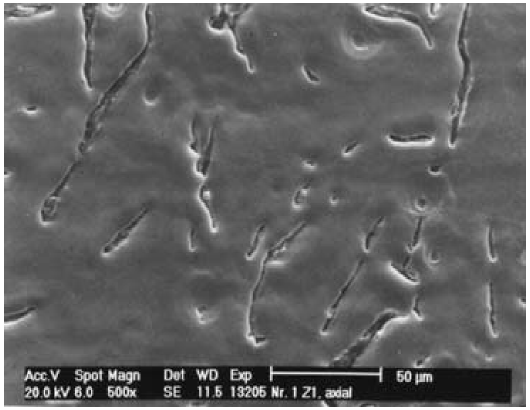
Audi



Treatment: mirror inside cylinder; rotating engine block in series production, 5 simultaneous excimer lasers



After honing

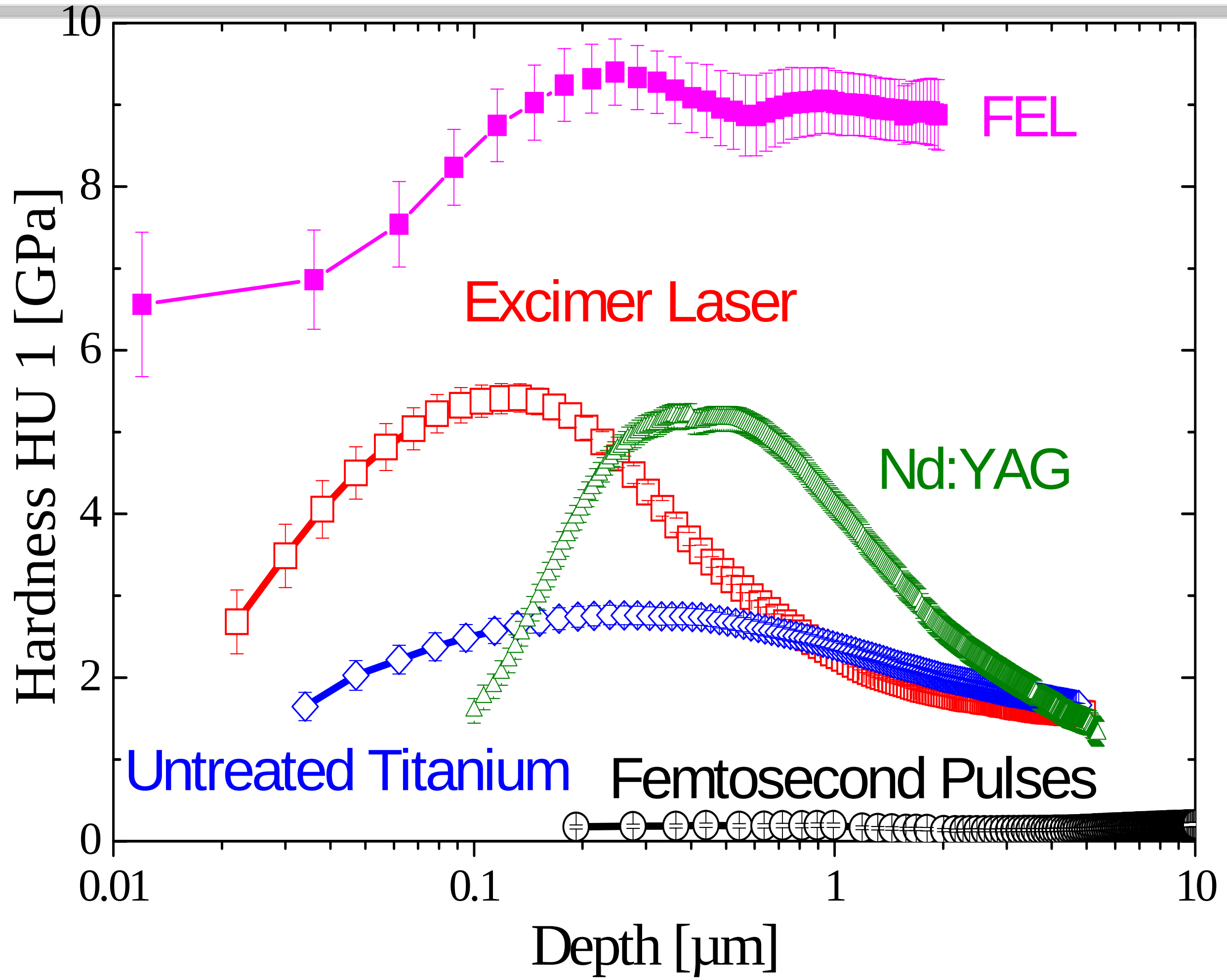


After laser treatment

Reduction of oil consumption (30x)

Slide courtesy of P. Schaaf - U. Göttingen

Laser Treated TiN: hardness – comparison



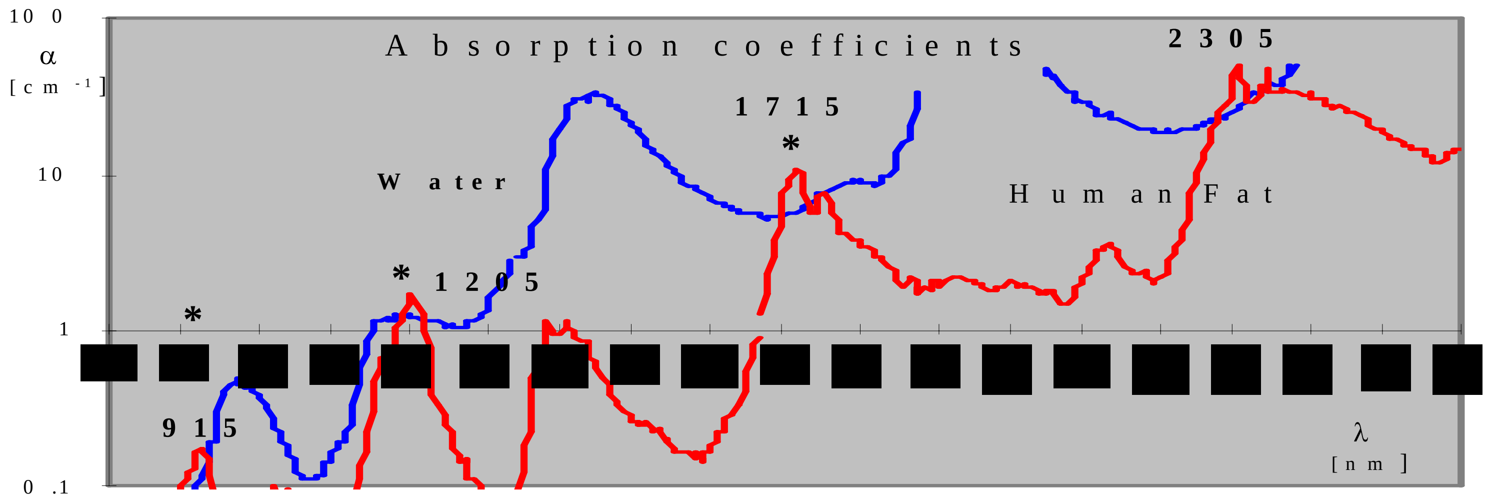
FEL highest hardness and thickest coating (>5 µm)
also smooth (w/cracks)

Excimer = „smooth“
(R_a < 0.5 µm)
Nd:YAG: Ra ~ 1-2 µm
Ti:Sapp – very soft (nanocluster)

Slide courtesy of P. Schaaf - U. Göttingen

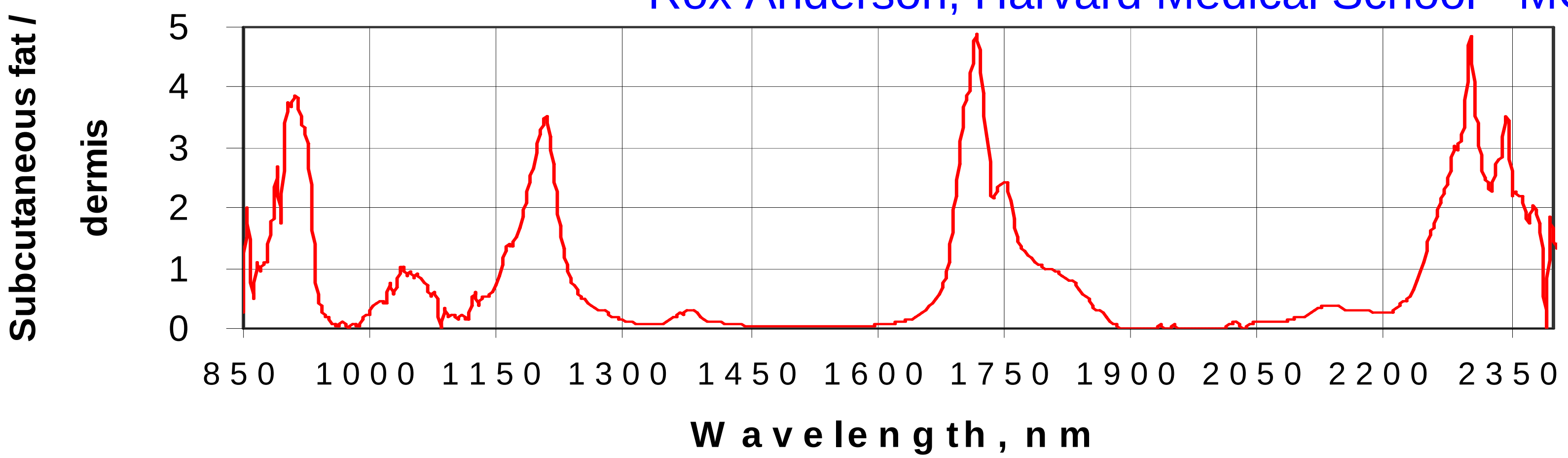
The benefits of high power and tunability - differential heating of fatty tissue

Log scale



Rox Anderson, Harvard Medical School - MGH

Lin scale



Fat and Water have nice “colors” in the NIR

Differential heating of fatty tissue - publicity

Monday, April 10, 2006

THE TIMES 60p

No 68630 • MONDAY APRIL 10 2006 • NEWSPAPER OF THE YEAR

Fat-burning laser will treat acne

Scientists have developed a laser technique that can melt fat under human skin. The breakthrough could herald selective laser treatment for various fat-related conditions, including lipid build-up linked with arterial heart disease, cellulite and acne.

A team of researchers from the US Department of Energy used a free-electron laser, which can produce very specific beams, to heat and break down fat without damaging other body tissue.

NEWS pages 6, 7

Fat-busting laser revolutionises treatment for acne and cellulite

A technique developed by American scientists could lead to fat-related conditions, including arterial heart disease, being melted away by high-intensity beams, reports **Sam Lister**

ACNE, cellulite and excess fat zapped with the flick of a switch? It may sound like the sci-fi dream of teenagers and the middle-aged, but scientists have developed a laser technique that can target and melt fat under the skin.

A team of researchers have used a machine called a free-electron laser (FEL), which can produce very specific beams, to heat and break down fat without damaging other body tissue.

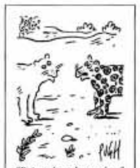
The breakthrough paves the way for laser use on various fat-related conditions, including lipid build-up linked to arterial heart disease, cellulite and acne.

Rox Anderson, a dermatologist at Massachusetts General Hospital, led the experiment using pig fat and skin samples about 2in (5cm) thick. He said that the results were proof of the principle for heating tissue with light.

The success of the study, which was conducted at a unit of the US Department of Energy, could herald a precision laser treatment for acne within years.

The condition, as with cellulite, has confounded most efforts to combat it. Questions remain over the current most effective acne drug, isotretinoin (known as Accutane), which has been linked to birth defects in children whose mothers used it while pregnant.

Cellulite — deposits of subcutaneous fat and fibrous tissue that cause a dimpling effect on the overlying skin — and other surface body fat could be targeted, as well as the fatty plaques that form in arteries, leading to heart attacks, Dr Anderson said. "We can envision a fat-seeking laser, and we're heading down that path now."



"But you're a leopard..."

Using the FEL, which is much more powerful than a conventional laser, the scientists were able to choose selected laser wavelengths that could heat up the fat, which was then broken down and excreted by the body.

They found that the process, called selective photothermolysis, did not affect the area of skin that was exposed to the beam.

Dr Anderson added that he was particularly excited by the technique's potential as a treatment for severe acne. He said that researchers wanted to see if sebaceous glands could be directly targeted with a particular laser wavelength, isolating the source of spots.

The sebaceous glands secrete a fatty substance called sebum through the hair follicles, which lubricates and protects the skin. However, excess sebum can collect and form deposits, which are associated with acne.

The results of Dr Anderson's study, which also involved researchers from Harvard Medical School, were presented yesterday at the annual meeting of the American Society for Laser Medicine and Surgery (ASLMS) in Boston, Massachusetts.

In the first part of the study the team used human fat obtained from surgically discarded, normal tissue. The tissue was exposed to a range of wavelengths of infra-red laser light (from 800 to 2,600 nanometres) using the FEL and the effects were recorded.

The researchers measured how selected wavelengths heated the fat and compared the results with those of an experiment to heat water. At most wavelengths, water is more efficiently heated by infra-red light. However, the researchers found three wavelengths — 915, 1,210 and 1,720 nanometres — where the effects were much more pronounced on fat.

The researchers then exposed fresh samples of pig skin and fat, about 2in thick, to free-electron infra-red light using the two most promising wavelengths, 1,210nm and 1,720nm.

To imitate surgical conditions, the pig skin was placed next to a window, which mimicked the application of a cold compress to a patient's skin. The researchers zapped samples with beams of infra-red laser light from 8mm to 17mm for about 16 seconds.

They found that the 1,210nm wavelength heated the pig fat up to 1cm deep without damaging the overlying skin. At this particular setting, the fat was heated to a temperature more than twice that of the overlying skin.

"The root cause of acne is a lipid-rich gland, the sebaceous gland, which sits a few millimetres below the surface of the skin," Dr Anderson said. "We want to be able to selectively

Seeing the light in hi-tech revolution

By Sam Lister

THE evolution of laser technology, first envisaged by Albert Einstein in the early 20th cent- ... sions created by, for instance, a light bulb.

While the light given off by bulbs and other common light sources usually covers a wide

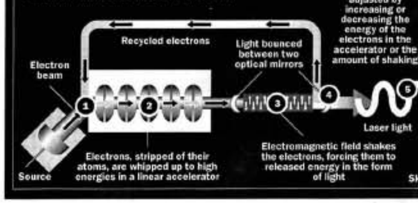
ZAPPING THE FAT

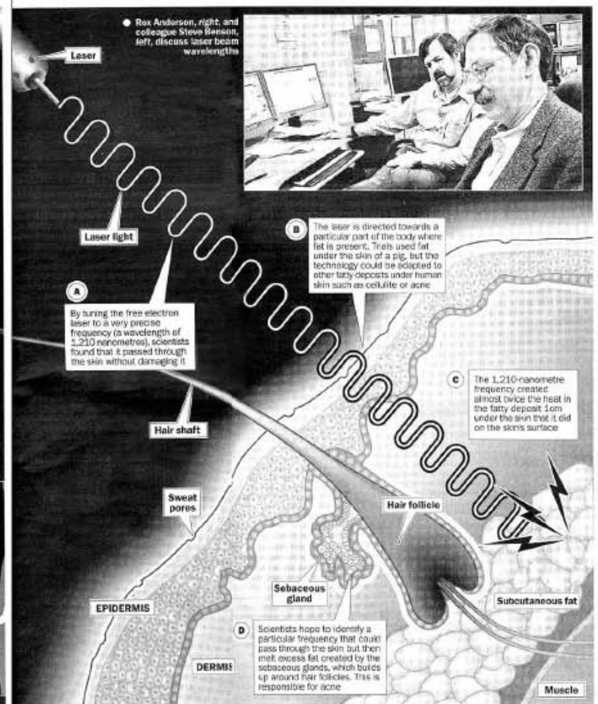
Using a free electron laser, which can provide intense and highly accurate beams of light, scientists have discovered a means of melting fat under the skin. They believe the technique could be a solution to problems caused by localised areas of fatty deposits

● Acne, *right*, is caused by an inflammation of the sebaceous glands. It is common in adolescence and results in pimples, black heads and pustules that can appear on almost any part of the body, but are usually on the face. It can result in scarring

● Cellulite, *left*, forms when the thin layer of tissue between the fat cells, often just a few cells thick, become more fibrous — like a scar. These areas then start to pull together around the fat, causing the tiny dimples and irregularities typical of cellulite

FREE ELECTRON LASER





Trivial? Spots can truly blight teenagers' lives

DR THOMAS STUTTAFORD
MEDICAL BRIEFING

ACNE and cellulite are the two conditions that the free-electron laser (FEL) may be able to help by targeting the layers of skin or subcutaneous tissue in which both have their origins. If FEL proves effective, and as yet the laser has not undergone clinical trials in human beings, its most likely assured market would seem to be acne.

Acne is a skin problem that is too easily trivialised: it can have profound effects on some people's lives. It may be so socially crippling that in severe cases it not only blights emerging social and sex lives but is also a not uncommon factor in adolescent depression and suicide.

Eighty per cent of adolescents suffer from acneform spots, an appreciable number of people continue to have them until middle age, and in women they can last until the menopause.

Acne may occasionally appear for the first time in the mid-twenties or thirties. When acne starts in adolescents, it is the almost inevitable result of the hormonal surge that occurs in puberty, which causes the skin to produce greater quantities of sebum, the oil from the sebaceous glands attached to the hair follicles, than in childhood.

Provided that the quantity of sebum produced is not too great, and debris does not block the skin pores, the oil is spread thinly across the skin and is either rubbed or washed away. If the sebum doesn't drain easily through a skin pore, the sebaceous gland is likely to become enflamed and may cause a pustular cyst. When the cyst eventually subsides, it often leaves an unsightly crater or scarring.

Acne is more of a problem in men than it is in women as testosterone is the hormone that is chiefly responsible for it. However, in women mild degrees of acne are more likely to continue throughout life. It tends to be worse in the week before menstruation, during pregnancy or in women taking the pill.

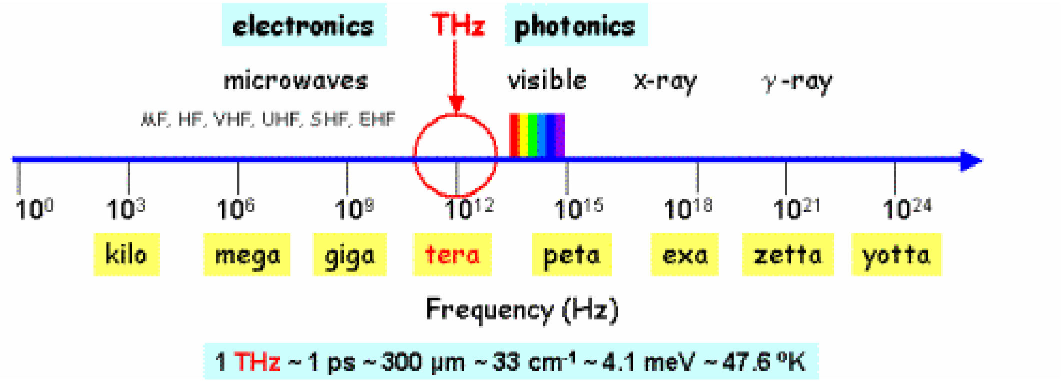
Hitherto there has nothing available to prevent acne, but it can and should be treated. Mild cases usually respond to local measures applied to the skin, but any severe acne requires antibiotics to prevent secondary infection. Several antibiotics also reduce the quantity of sebum produced.

If antibiotics prove inadequate, and there are no contraindications to its use, such as the chance of pregnancy or a history of psychiatric problems, isotretinoin by mouth is highly effective and is usually recommended if there is any chance of chronic cysts, craters or scarring. Unfortunately, once this is prescribed, the patient needs supervision so that side-effects may be avoided.

Cellulite is the deposition of excess fat in the deeper layers of the skin and the superficial layers of subcutaneous tissue. There is no easy remedy, other than weight loss.

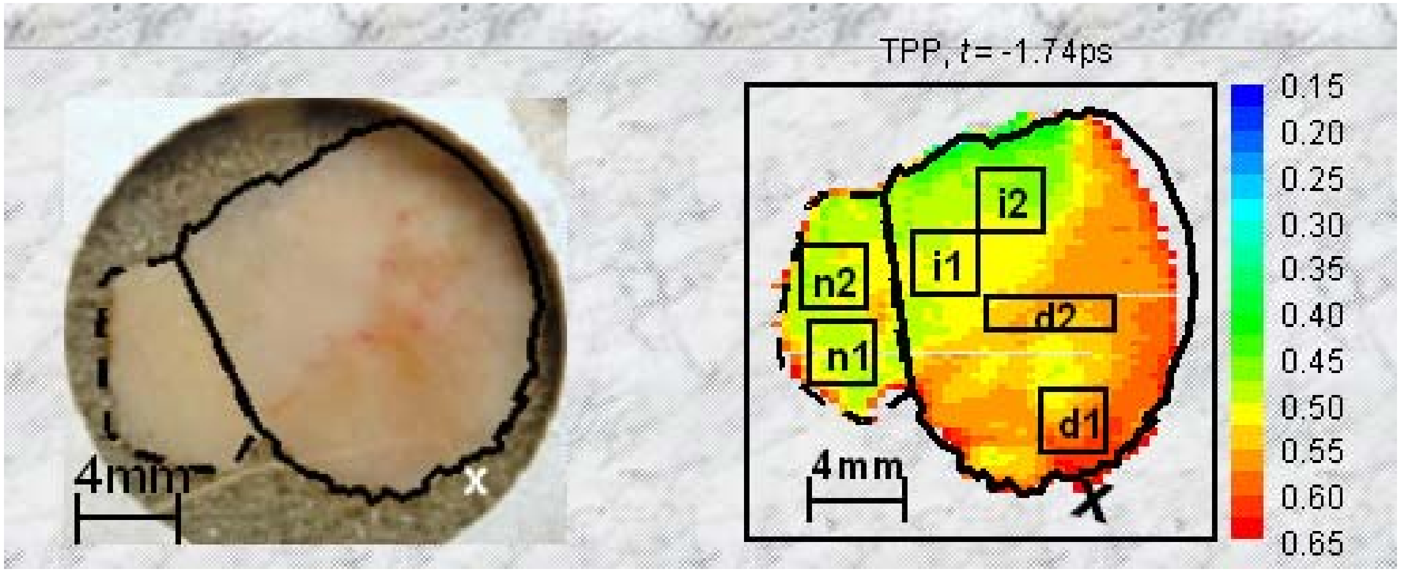
The third suggested use of the FEL would be for its adaptation so that it might destroy atheromatous plaques in arteries. This has been done before with other means but problems have arisen with distribution of debris when the plaques have been eradicated.

THz Programs at Jefferson Lab



- THz lies between electronics and photonics.
- THz broadband user facility constructed (world's highest power).
- Tissue interactions and safety limits.
- Imaging, movies.
- Magnetism, dynamics of quasiparticles, spin.
- Quantum coherence and control.
- Fundamental optical physics.
- Localization effects.
- Coherent Half- and Few-Cycle Sources for Nonlinear and Non-Equilibrium Studies.

Imaging / bio-medical cancer screening



Basal cell carcinoma shows malignancy in red. Teraview Ltd.

1 mW source images 1 cm^2 in 1 minute

100 W source images whole body (50 x 200cm) in few seconds

A Few Lessons Learned

- Optimum size of user team actively doing the experiment is ~2.
  - More people get in the way.
- Have lots of communication before the users arrive.
  - Especially important if users are coming from another country.
- Stray light, either from scattered fundamental light or the harmonics, can cause transport hardware to drift.
  - Even when water-cooled.

Upcoming facility & experimental initiatives

- Upgraded optical transport system components being installed.
  - Lower mirror absorption will decrease drift, change in beam divergence
- FEL beam delivery expanded into all labs.

- High power (5 kW) CO_2 laser system will be installed in one lab this summer.

- Commercial pulsed laser deposition system being installed.
  - Can receive beam from FEL or an ultrafast laser system.

Future Plans

- Slowly ramp up user programs with high impact science.
  - increase efficiency of user operations through integrated schedule and taking advantage of stable beam delivery to all labs.

- Ensure that user programs are of high impact to generate additional support from other agencies to increase operational hours.

JLab FEL Team