

New Tools for New Materials

Appplied research and technology transfer are important elements in the mission of the Thomas Jefferson National Accelerator Facility in Newport News, Virginia. The major tool in these efforts is a free-electron laser (FEL), developed at the laboratory as an offspring of its fundamental investigations of subatomic particles. The success of its initial FEL in both basic and applied studies has led to a significant upgrade that will result in a FEL with greater wavelength range and power. The laser should be in operation by year's end.

The accelerator laboratory—owned by the Department of Energy and managed by the Southeastern Universities Research Association, a consortium of 59 colleges and universities—is generally known as the Jefferson Lab. It began operations in 1994 and has become a leading center for nuclear physics. Its nearly 6-GeV Continuous Electron Beam Accelerator Facility (CEBAF) pioneered the large-scale application of superconducting-radiofrequency (SRF) particle-acceleration technology. CEBAF experimenters are piecing together a clearer pic-

ture of the nucleus based on quarks, gluons, and the strong force. The SRF technology, however, does double duty at the laboratory. It enables both CEBAF's probing of nuclear structure and the use of a FEL for materials science research.

For industry, the goal of the Jefferson Lab's FEL program is to overcome the cost, capacity, wavelength, and pulse-length constraints of conventional lasers with SRF-driven FELs that offer high average power, broad wavelength tunability, and subpicosecond time structure. An energy-recovery technique, which the laboratory first demonstrated at significant power, is vital for cost-effectiveness. To recycle the 99% of the electron beam's energy not spent in the laser, the beam recirculates through the FEL's SRF driver accelerator, which slows the high-energy electrons and harvests their energy for reuse in accelerating other electrons.

The laboratory's first FEL, the Infrared Demonstrator (IR Demo), came on line in 1999 with 1.72 kW of infrared light at a 3.1- μm wavelength. For a variety of users, the IR Demo ultimately produced 1- to 6.4- μm



After electrons are released from a photocathode by a laser, they are accelerated in a string of superconducting niobium cavities like this, before an array of strong magnets converts the energy to tunable light.

wavelengths at up to 2.1 kW—more than 2 orders of magnitude higher average power than that available from any other tunable laser. The IR Demo FEL was dismantled in late 2001 for upgrading, which will extend the IR operation to the 10-kW level and provide kilowatt-scale operation in the visible and ultraviolet wavelengths down to 300 nm.

Industrial uses

IR Demo experiments showed several applications of FELs that have significant potential in industry. One technology is pulsed-laser ablation and deposition, which could benefit the manufacture of large-area films whose high quality derives from minimization of particulates. The FEL's ultrafast pulses provide a lower ablation threshold, which results in fewer particulates. Its high repetition rate means a high deposition rate and the prospect of greater control over ablation and growth dynamics. Wavelength tunability enables enhanced ablation and deposition with resonant absorption, as in polymers, in which specific resonances are used to control growth processes. About a dozen materials—from metals to polyimides to sili-

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con—have been ablated, and about half of them have been deposited as well. The work was performed at 3.1 μm and yielded deposition rates 10 to 100 times higher than those observed with excimer lasers.

Another demonstrated industrial application is laser nitriding, a method of modifying the properties of metals—for example, to attain harder surfaces with better wear and resistance to corrosion. Similar work has been conducted elsewhere with plasma immersion, ion-beam processing, and conventional lasers. The IR Demo FEL produced high-quality nitride films on iron, titanium, and silicon. Once the process is optimized, the high average power of the FEL is expected to offer commercial production rates at a competitive cost.

Carbon nanotubes have been prominent in the news because of their potential applications. Besides imperviousness to extreme heat, they have properties potentially useful for high-strength composites and nanoelectronics. However, with their molecule-wide walls, single-wall nanotubes present a range of production challenges. These problems might be circumvented or better understood by use of the FEL's repetition rate, wavelength tuning, and power. Hence, researchers conducted IR Demo studies to learn how the structures form, the optimum conditions for making them with tailored properties, and more about real-time process monitoring and control.

Creating new materials

Preliminary results from the IR Demo proved promising. The FEL synthesized single-wall carbon nanotube bundles with 3- μm light at 400 to 600 W average power, with nanotube diameters in the same 1.3- to 1.5-nm range as those produced by dc arc or tabletop pulsed-laser vaporization (PLV). FEL production rates were measured in milligrams per minute rather than milligrams per hour. Preliminary analysis suggests that at 4 to 10 nm in diameter, the FEL-produced bundles contain only about 50 nanotubes each, rather than the approximately 200 nanotubes per bundle in the 15- to 20-nm-diameter bundles produced in the other processes. A

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lower number of nanotubes per bundle represents an advantage for composites. Further work is also planned with the upgraded FEL to understand and optimize PLV processes and to create unique materials, including silicon nanowires and germanium nanotubes.

Micromachining is another attractive application. DuPont and the National Aeronautics and Space Administration (NASA) used the IR Demo FEL to micromachine polyimide, which is applied widely in printed wiring-board dielectric layers and inkjet-printer heads. Siemens used the laser for studies of micromachined metals for automotive-engine applications. Aerospace Corp.

studied micromachined glasses and ceramics, materials that the FEL makes easier to cut and shape. The company already had experience with tabletop green and ultraviolet lasers, and it exploited the FEL's tunability and power to study the fabrication of true three-dimensional microstructures. With nanoscale engineering of key features, it is expected that some satellites could be reduced to the size of baseballs or smaller.

The Jefferson Lab campus includes the Applied Research Center (ARC), established with local funding for research collaborations involving five local universities, NASA's Langley Research Center (Hampton, VA), and several high-technology corporations and start-ups. The ARC's 21 laboratories contain materials-science and materials-processing tools. Also at Jefferson Lab is a compact superconducting electron synchrotron to be used as a broadband light source from the infrared to X-rays. An industrial partner donated the synchrotron, which will be housed in an extension to the FEL building so that it can operate in concert with the FEL.

Further reading

Colson, W. B.; Johnson, E. D.; Kelley, M. J.; Schwettman, H. A. Putting Free-Electron Lasers to Work. *Physics Today* 2002, 55 (1), 35-41.

Experts share news of radiofrequency progress. *CERN Courier* 2001, 41 (9), 14-16.

Neil, G. R.; et al. Sustained Kilowatt Lasing in a Free-Electron Laser with Same-Cell Energy Recovery. *Phys. Rev. Lett.* 2000, 84, 662.

O'Shea, P. G.; Freund, H. P. Free-Electron Lasers: Status and Applications. *Science* 2001, 292, 1853-1858.

Ouellette, J. Free-Electron Lasers: A Radical Alternative. *The Industrial Physicist*, March 1997, pp. 18-21.

Patel, N. Shorter, Brighter, Better. *Nature* 2002, 415, 110-111.

B I O G R A P H Y

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