Science & Technology

Advances toward the ultimate laser

by Charles B. Stevens

At the April 17-19 University of Rochester conference on "Lasers and Particle Beams for Fusion and Strategic Defense," scientists from the Los Alamos and Lawrence Livermore National Labs announced major advances in their work to perfect the ultimate laser: the Free Electron Laser, otherwise known as the FEL. The Livermore results indicate that a large, ground-based FEL prototype beam weapon, utilizing orbiting mirrors can be built before the end of this decade. Los Alamos revealed that their compact FEL would be capable of being placed in space. But a prototype would probably only be ready sometime later than that of the ground-based Livermore FEL.

The Livermore FEL is actually a laser amplifier that greatly multiplies the power of a conventional laser input. The Los Alamos system is a true FEL which needs no other input. Both are based on converting highly accelerated electron beams into laser light. The Livermore FEL amplifier experiments are designed to demonstrate that laser light can be extracted rapidly, in a single pass, from the e-beam, while the Los Alamos system is based on relatively slow extraction of the laser light from an e-beam passing continuously through the FEL. Livermore appears to have demonstrated the crucial concept of a "tapered wiggler," which is a prerequisite for significant amplification. The Los Alamos FEL, because of its relatively slow extraction, has a potentially high efficiency and can therefore make a compact system which could be based in space. Recent Los Alamos experiments have achieved 10 megawatt outputs, demonstrating the principles of the pure FEL concept at high powers.

How the FEL works

Any time an electric charge, such as an electron, changes the direction of its motion, an electromagnetic wave is generated. For example if we cause many electrons—in other words an electric current—to move back and forth in between the ends of a one-yard-long, metal rod, an electromagnetic wave will be generated. In very general terms, the electromagnetic wave will have a one-meter-long wavelength. To make shorter wavelengths, the antenna—the rod—most be made smaller.

In the FEL a free electron beam is used instead of an antenna. Magnetic fields cause the electrons to oscillate (wiggle) back and forth. But with relativistic electrons—electrons traveling at nearly the speed of light and therefore a Relativistic Electron Beam (REB)—the size of the wiggle is relativistically contracted. As a result of this relativistic contraction, the effective wavelength of the emitted electromagnetic radiation is shortened. The same would occur if a regular antenna were moving at nearly the speed of light, but it is much easier to accelerate free electrons to such speeds.

The Livermore and Los Alamos FELs

The main difference between the Livermore and Los Alamos FELs is that the Livermore system is not a true Free Electron Laser. Instead, it is only used to amplify a laser beam generated by a more conventional laser, such as the KrF. The Livermore FEL amplifier is therefore designed so that the input laser beam can extract a lot of energy from the REB in a single pass through the FEL wiggler. The Los Alamos FEL is a true free electron laser. In this case only a small portion of the input REB is transformed into electromagnetic radiation. This laser output is trapped between two mirrors and the REB is recirculated so that many passes are made through the lasing wiggler chamber. When the pulse reaches sufficient power levels, it is optically switched out of the chamber. This repetitive extraction and buildup of the Los Alamos FEL makes it potentially far more efficient and compact.

The Livermore FEL has scored a number of recent breakthroughs. Utilizing the ETA electron beam accelerator earlier this year, Livermore scientists have demonstrated the principles of high-power FEL amplifiers through experiments at microwave wavelengths.

More recently, they have carried out experiments which appear to demonstrate that a "tapered" wiggler works. Because the Livermore system is based on a large extraction of the e-beam's energy in a single pass, this means that the electrons are going to be significantly slowed down as they move through the wiggler. The FEL wavelength output depends on the electron velocity and magnetic field strength. Therefore to keep the output at the same wavelength as the electron slows, it is necessary to increase the wiggler magnetic field strength—that is, to actually decrease the "wavelength" of the electron oscillation. This means that the actual wiggle of the REB follows a tapered conical path which relativistically is transformed into an even-wavelength cylindrical path.

On the much larger Livermore ATA e-beam, scientists have recently demonstrated a new method of guiding and focusing electron beams. Normally, magnetic fields are used

in the accelerator to guide and focus the electron beam as it is accelerated to high velocities. Instead, ATA researchers have developed what they call the Antigone concept. A low pressure gas is introduced into the accelerator vacuum chamber and a small, pulsed laser is used to generate a thin, cylindrical plasma in this gas. The plasma both guides and focuses the electron beam through the accelerator. The same principle has also been demonstrated for propagation of the REB through the atmosphere. Thus the Livermore FEL could do double duty. First as a laser to intercept missiles in their boost phase. Then as a particle beam weapon in which the REB is directed onto warheads as they approach the United States.

The Livermore ATA will be used to demonstrate high-power FEL operation at infrared wavelengths within the coming year. The next stage will then be the construction of a prototype beam weapon. The same general technology can, with some modifications, be used to build laser fusion power plants.

The Los Alamos FEL

As announced at Rochester, the Los Alamos FEL has also demonstrated high power lasing—upwards of 10 million watts—at the microwave wavelength. Plans for construction of an even more powerful FEL capable of being tuned to infrared wavelengths were presented at the conference. The stage following this would be the construction of a prototype space-based weapon.

The Los Alamos FEL is not dependent on a conventional laser input and can thus be "tuned" to a wide range of frequencies. It also has intrinsically higher potential efficiencies. These are the prerequisites for revolutionizing current industrial technology. Presently, the primary form of energy used in industry is heat—fundamentally incoherent infrared radiation. The Los Alamos FEL will provide the means for accessing efficiently the entire range of the electromagnetic spectrum—at least that of x-rays to radio waves—coherently and at high power densities.

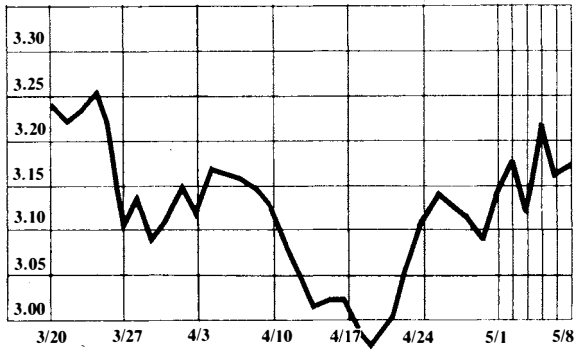
Most significantly, though, these FEL advances demonstrate that humanity is on the verge of perfecting a laser which has the potential of mastering the entire known electromagnetic spectrum. This universal laser will not only provide an efficient and effective means of defense, but will also revolutionize science and industry. The reason is that the FEL has the potential of being both tunable and highly efficient.

Industrial productivities will be increased many thousand-fold. The reason is that ordinary production-line operatives will be able to access materials on an atomic and subatomic scale. The operative will actually engineer the very molecules of the desired product output. At present this form of molecular engineering is only approximated in the electronics industry. The FEL will provide the high powers, versatility, and efficiency to extend molecular engineering to all forms of industrial practice.

Currency Rates

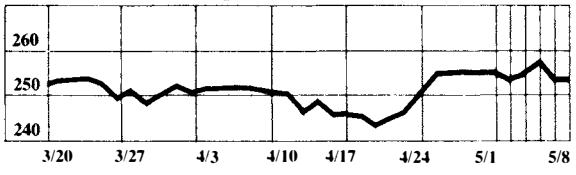
The dollar in deutschemarks

New York late afternoon fixing



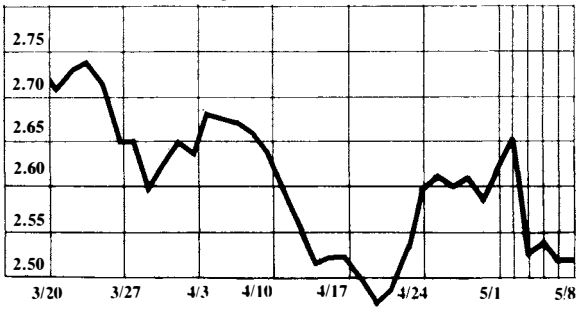
The dollar in yen

New York late afternoon fixing



The dollar in Swiss francs

New York late afternoon fixing



The British pound in dollars

New York late afternoon fixing