PLASMA PHYSICS

Japan Pumps Up Budget for Table-Top Short-Pulse Lasers

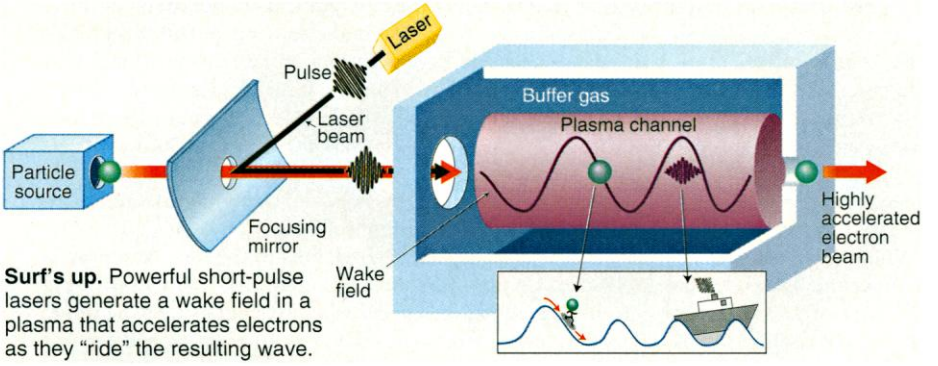
TOKYO—The nation that makes radios the size of credit cards and tape recorders small enough to slip into shirt pockets has set its sights on a new target for miniaturization. This time, however, the customers will be physicists and other researchers rather than consumers. And the goal is anything but small: to squeeze the capabilities of high-power lasers, devices that fill warehouse-sized buildings and pack many times the power of the entire U.S. electrical grid, into a new generation of lasers that can fit on a table top.

The task will fall to the Japan Atomic Energy Research Institute (JAERI), which announced last October that it plans to spend between $80 million and $100 million a year—not including salaries—over the next 5 years to set up the Advanced Photon Research Center in Keihanna Science City outside Osaka. The center's goal is to vastly extend the abilities of current short-pulse lasers (see box), which achieve staggering power levels by packing all of their output into a pulse lasting a tiny fraction of a second. If it succeeds, the center will go on to turn these lasers into new tools for accelerating particles, creating holographic x-ray images of living cells, and exploring ultrahigh-speed phenomena by using rapid-fire laser pulses as strobes.

"Our philosophy is to concentrate on table-top science," says Masashi Iizumi, director general of JAERI's efforts in both synchrotron radiation and photon research. With researchers able to afford their own lasers and accelerators within the budgets of many university departments, says theoretical physicist Toshiki Tajima of the University of Texas, "good experimentalists will not be limited by the money available, only by their imaginations."

Despite the financial commitment from JAERI, a public corporation affiliated with Japan's Science and Technology Agency (STA), the goal faces formidable odds. Aside from building lasers for industry, Japan has made only small gains in advanced laser research. "U.S. scientists are really far ahead in this field," says Akihiko Nishimura, an official in STA's Atomic Energy Bureau. Nishimura sees JAERI's interest in the center as an attempt to stake out a new research mission to compensate for dwindling public support of its original mandate—atomic energy. Iizumi admits that JAERI has little experience in laser-related research, but others say that its work in nuclear radiation and laser isotope separation make it the most suitable STA-related agency to carry out the work.

The JAERI program aims to build on recent advances overseas in high-power, compact lasers. In the mid-1980s, researchers developed novel ways of generating and amplifying short laser pulses, making possible compact and inexpensive laser systems. These short-pulse lasers turn out just millijoules of energy, but because the pulse is focused down to a spot just a few micrometers wide and lasts just tens of femtoseconds (a quadrillionth of a second), they can achieve intensities many times greater than those of the largest existing lasers, such as the $175 million Nova laser at Lawrence Livermore National Laboratory in California.



Surf's up. Powerful short-pulse lasers generate a wake field in a plasma that accelerates electrons as they "ride" the resulting wave.

One of the beam lines at Nova is being upgraded to generate peak power of a petawatt (10^{15} watts), or 1000 terawatts. It will operate with comparatively long pulses of up to a picosecond (1 trillionth). That length is vital for compressing and heating pellets of hydrogen isotopes for fusion experiments, one of Nova's primary roles. E. Michael Campbell, head of laser activity at Livermore, says the lab also hopes to use the upgraded line for accelerator and x-ray laser research. But the laser's long pulses and low repetition rate—one an hour—will limit the work to basic principles. "To make an actual accelerator you have to have a high rep rate," Campbell says.

Those features make the Livermore system "a dinosaur" for the type of research Japan wants to do, says Takashi Arisawa, deputy director of JAERI's photon research program. There are already table-top systems that can reach peak powers in the range of 100 terawatts, a development that has opened new strategies for accelerating particles and generating x-ray laser beams (*Science*, 26 November 1993, p. 1379). And Arisawa sees lots of room for improvement. "In principle, we can make a more powerful system that is one-hundredth the size [of the Livermore system]," he says.

JAERI's initial goal, for 2000, is to maintain a pulse of 30 femtoseconds (30,000 trillionths) or less while increasing peak power by an order of magnitude, to a petawatt. In addition, scientists hope to speed up by two orders of magnitude the rate at which pulses can be generated from present levels of 10 to 20 hertz. "That would be quite an achievement," says Howard Milchberg, a physicist at the University of Maryland, College Park. No one else in the short-pulse laser field is mentioning such numbers, he notes.

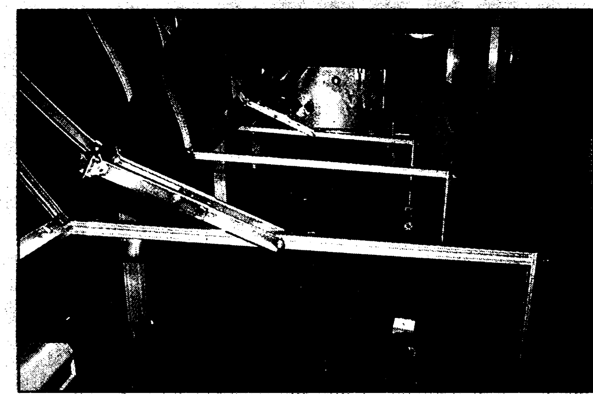
One key will be replacing the flash lamp currently used to pump energy, in the form of photons, into the laser oscillator. The oscillator reflects the beam back and forth, stimulating the emission of more light with each pass. Arisawa says that a diode laser, a type of semiconductor laser that generates photons by passing an electric current through a sandwich of semiconductor alloys, would be far more energy-efficient, compact, and reliable than flash lamps. A diode laser could also improve on the repetition rate and energy output of a flash lamp, says Arisawa.

Once these advanced, short-pulse lasers are developed, JAERI hopes to put them to use in a new generation of laser accelerators and x-ray laser systems. In a laser accelerator, laser pulses traveling through plasmas would pull charged particles along in their wake (see illustration). In an x-ray laser, the short-pulse laser would serve to pump energy into new types of oscillators where x-ray photons would be amplified into x-ray lasers. Such x-ray sources, which Arisawa calls the "premier application" of the short-pulse laser, would allow researchers to form three-dimensional holographic images of the structure of biological molecules and contribute to more powerful industrial lasers. Far into the future is the idea of generating gamma-ray lasers, by possibly combining a short-pulse laser with an accelerator's electron beam. Using a phenomenon known as inverse Thompson scattering, a laser photon colliding with an electron can be kicked to the higher energy—and thus shorter wavelength—of a gamma ray.

Texas's Tajima, who leads a theoretical group at JAERI that is looking at laser appli-

Meeting Takes Pulse of Laser Accelerators

LOUISVILLE, KENTUCKY—For the small band of physicists who hope to harness laser light to accelerate matter, a massive Japanese program to develop this and other applications of short-pulse lasers (see main text) comes at the right moment. In laboratories in the United States, Europe, and Japan, researchers are sharpening their picture of the interplay between laser light and ionized gases, or plasmas—phenomena that will be crucial to putting short-pulse lasers (SPLs) to use in practical devices such as accelerators. "A lot of the pieces are now in place to achieve the things that, a few years ago, were merely theoretical exercises," says Howard Milchberg, a physicist at the University of Maryland, College Park.



DENNIS NORMILE

Close quarters. KEK's Nakajima uses this small laser for experiments on an accelerator in an adjacent room at the University of Tokyo.

Milchberg was one of several dozen researchers who heard more about those pieces during an evening symposium, held here in November during a meeting of the American Physical Society's division of plasma physics, on SPLs and the electric fields they create in plasmas. The goal is to create particle accelerators hundreds of times more compact—and, ultimately, more powerful—than is possible with the best conventional technology, which uses radio-frequency (RF) cavities. Instead of "surfing" on the electric fields of RF waves in these cavities, the charged particles in SPL-based accelerators would accelerate in much shorter distances by riding on the much more intense electric fields that form, like waves behind a speedboat, in the wake of a laser pulse as it tears through a plasma.

One important characteristic of the plasma, which affects propagation of the wake field, is its tendency to ring, like some fluid, electrified bell, at a frequency that increases with the plasma's density. Researchers know that high-performance wake field accelerators will have to use laser pulses shaped so that their light pressure excites plasma modes at precise resonances. Under those conditions, bunches of particles dropped into regions of the wake containing intense electric fields will accelerate uniformly, emerging more like a bag of sand than a handful thrown at the beach.

But the concept can also be used without such close attention to detail, according to Chris Clayton of the University of California, Los Angeles (UCLA), who described "a quick and dirty way to get [fast] electrons using the current technology." Clayton and co-workers—including UCLA's Chan Joshi and A. E. Dangor of Imperial College in London—used pulses that were much longer than needed to excite the optimum resonance. Plasma instabilities then eroded the pulse into a series of shorter pulses, and the resulting wake fields simply yanked electrons from the plasma and accelerated them to tens of millions of electron volts (eV). The method, Clayton thinks, might eventually be useful for making table-top electron sources in the billion-eV range for applications that don't require tight, single-energy bunches.

In more refined accelerator schemes, the total amount of acceleration will be limited by how far electrons can ride behind these intense laser pulses. In another talk, Kazuhisa Nakajima of the National Laboratory for High-Energy Physics in Tsukuba, Japan, reported preliminary evidence of pulses that remain tightly channeled over several centimeters rather than dispersing in a fraction of a millimeter, as tightly focused laser pulses ordinarily do in a vacuum or a normal gas. Although such an effect has been observed with "preformed" plasma channels created with a separate light pulse, the single-pulse, or "self-focusing," effect explored by Nakajima has remained elusive. Nakajima said he achieved the self-focusing in part by working at high gas pressures, and some researchers say they want more data to be sure of what's happening. "It's very hard to know what's going on" in the experiment, says Eric Esarey of the Naval Research Laboratory.

One possible technique for probing conditions around such a pulse was offered that evening by Michael Downer of the University of Texas, Austin, and presented elsewhere at the conference by a group at the École Polytechnique in France. Working with Austin colleagues Toshiki Tajima, Craig Siders, and others, Downer showed that the wake field structure could be probed with separate, less intense pulses of light that serve not as accelerators but as probes. These pulses propagate faster in areas where the density of plasma electrons is lower, allowing researchers to map out the shape of the roiling wake itself.

More powerful, multistage extensions of the idea, and practical applications such as table-top accelerators, will require a big boost in the overall efficiency of the laser system—the percentage of the power drawn from a source that ends up in accelerated particles—as well as a technique to synchronize a series of such devices, says Tajima, who organized the symposium. Still, he and his colleagues had heard enough to keep them talking late into the night, discussing how to harness the energy of a growing field.

–James Glanz

cations, thinks JAERI's time frame for these innovations—2 to 3 years for x-ray lasers, according to Iizumi—is "too optimistic." There is no guarantee that laser accelerators can even be built, he notes. But he adds, "I'm very excited about this initiative."

For now, Iizumi's first priority is to recruit topnotch researchers, including a director for the new center. Talks are under way with several overseas scientists, says Arisawa, although no agreements have been reached. Iizumi says it could take 5 years to reach the center's intended target of 200 scientists, who are expected to be working in new facilities at the Keihanna Science City near Osaka.

Still, many university researchers, both in Japan and abroad, wonder whether JAERI isn't rushing things. Maryland's Milchberg, for one, says JAERI's initial investment might be better spent on developing the underlying principles of laser accelerators and x-ray lasers. However, even its critics agree that, if JAERI's goal is to support a full-fledged program in compact lasers, the agency is doing the right thing by building up the necessary infrastructure. "In this country, the only crew that could do something like that would be Livermore," he says. Indeed, with JAERI poised to spend half a billion dollars over the next 5 years on compact lasers, the only thing about the program that's small may be what comes out of the lab.

–Dennis Normile