Bright Future for Compact Tactical Laser Weapons

ONCE again, science fiction has predicted science fact. Remember those movies where the hero (or villain) uses a beam from a compact laser to blow a rocket out of the sky? Last December, that generic bit of sci-fi drama took a step closer to reality. In a demonstration at the White Sands Missile Range in New Mexico, the solid-state heat-capacity laser (SSHCL) burned a 1-centimeter-diameter hole straight through a 2-centimeter-thick stack of steel samples in 6 seconds. The electrical current to do so came from a wall outlet and cost no more than 30 cents. While large chemical lasers have successfully shot down tactical rockets, the SSHCL design supports the weight and size requirements for a future mobile deployment.

The SSHCL, designed and developed at Lawrence Livermore, is the prototype of a laser tactical weapon, which shows promise as the first high-energy laser compact enough in size and weight to be considered part of the Army's future combat system (FCS) for short-range air defense. The FCS is a component of the Army's vision of sensors, platforms, and weapons with a networked command and control system. The more advanced version of the laser weapon system, now under development, will be battery-powered and—at 2 meters long and less than a meter across—small enough to be mounted on a hybrid-electric high-mobility multipurpose wheeled vehicle (Humvee). In this configuration, the Humvee's generator and batteries could power both the vehicle and the laser, requiring only diesel fuel to support full operation.

The SSHCL offers speed-of-light precision engagement and destruction of a variety of targets, including short-range artillery, rockets, and mortars. There is a current need for effective protection against these weapons on the battlefield. The project is sponsored by the U.S. Army Space and Missile Defense Command and has a number of commercial partners, including General Atomics, Raytheon Co., PEI Electronics Inc., Northrop Grumman Corp., Goodrich Corp., Armstrong Laser Technology Inc., and Saft America.

Meeting the Challenges

The SSHCL delivered to White Sands for testing last September has an amplifier composed of nine disks of neodymium-doped glass (Nd:glass). In this prototype, an electrical source powers flashlamps, which in turn pump the disks, which then release the energy in pulses of laser light. The average output power of the SSHCL is 10 kilowatts, and it can deliver 500-joule pulses at 20 hertz in 10-second bursts—essentially vaporizing metal. The prototype requires 1 megawatt of input power to produce a 13-kilowatt laser beam. Project manager Brent Dane, of Livermore's Laser Science and Technology program, notes that the ultimate objective of the project is to build a next-generation system with enough electrical efficiency to

Lawrence Livermore laser technician Balbir Bhachu monitors the performance of the 13-kilowatt neodymium-doped glass version of the solid-state heat-capacity laser during a low-power test.

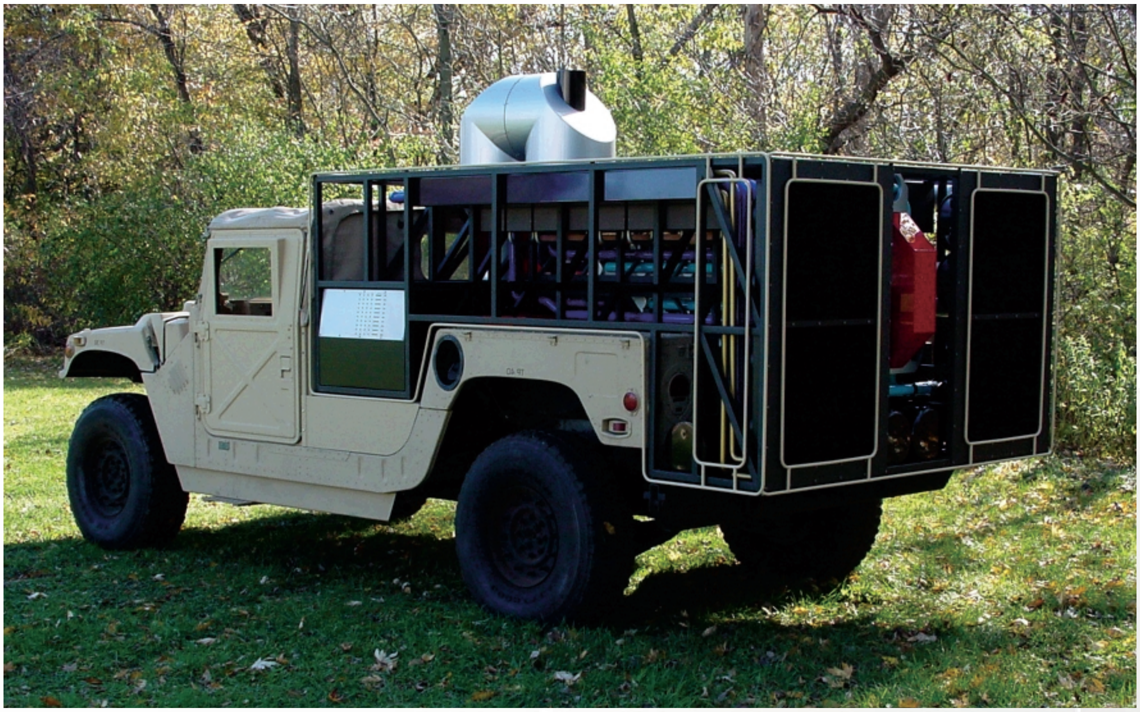
produce a 100-kilowatt laser beam from the same 1 megawatt of input power. The final version will be capable of firing 200 pulses per second.

The Livermore team is focusing on the technological challenges that remain to building the 100-kilowatt system. Dane enumerated the three areas of concentration: growing large crystals of neodymium-doped gadolinium–gallium–garnet (Nd:GGG) for amplifier disks; developing the technology needed to make diode arrays large, powerful, and cost-effective; and defining the laser architecture and technology that will allow high-quality beams to propagate precisely over long distances.

Although the prototype uses Nd:glass for its laser amplifier disks, the final version will use Nd:GGG. "There are many reasons for choosing Nd:GGG," explains Mark Rotter, an electrical engineer who is leading the diode-pumped Nd:GGG effort. "Compared with Nd:glass, Nd:GGG boasts a higher mechanical strength and higher thermal conductivity, which, in combination, will allow us to rapidly cool the disks between runs and reduce the turnaround time between laser firings. The Nd:GGG is also twice as efficient in converting pump energy to output beam energy." The challenge—to grow the crystals large enough to manufacture the nine 13-square-centimeter slabs needed for the 100-kilowatt laser—is well on its way to being met. Northrup/Grumman Poly-Scientific, the commercial partner responsible for growing the crystals, is now producing high-optical-quality Nd:GGG crystals up to 15 centimeters in diameter. The ultimate goal is to grow crystals approximately 20 centimeters in diameter.

To pump these Nd:GGG amplifier disks, the SSHCL will use arrays of laser diodes instead of flashlamps because diode arrays are more compact and efficient than flashlamps and, more importantly, diode radiation generates less heat in the Nd:GGG laser crystals. The challenge is to make the diode arrays large, powerful, and cost-effective and to come up with a cooling scheme that will work in the field.

Lawrence Livermore's Ray Beach, who leads the diode array portion of the project, explains, "Cooling high-average-power laser diode arrays is a unique and challenging problem in the field of thermal engineering. Although laser diodes are extremely efficient devices by ordinary laser standards—they typically convert 50 percent of their electric input power into light output—the remaining 50 percent of the input power shows up as high-intensity heat from a very compact source.



A life-size model, developed by General Atomics and PEI Electronics, of a mobile 100-kilowatt heat-capacity laser built on a prototype of a hybrid-electric, high-mobility multipurpose wheeled vehicle (Humvee) shows the potential compactness of a full-power weapon system.

Because the arrays operate near room temperature, there isn't much opportunity to radiate away heat or use standard electronic cooling techniques such as forced air."

Livermore engineer Barry Freitas came up with a revolutionary packaging technology that solves the problem of creating high-density diode arrays. In this approach, small laser diodes are soldered to low-cost silicon substrates that are etched with thousands of tiny (30-micrometer-wide) microchannels. Cooling water flows through these microchannels, which act as high-performance heat sinks. The team used this packaging design to create the world's highest average-power diode array—41 kilowatts of peak power from a 5- by 18-centimeter package. Arrays that produce 100 kilowatts of power are in production. Work is under way with Armstrong Laser Technology to commercialize the silicon-based diode laser package to support the production needs of the 100-kilowatt laser development.

The team is also working on an optical system that will make a beam of high enough quality—that is, sufficiently narrow, intense, and well-shaped—to propagate 10 kilometers and still hit and disable its target. "In the final system, the laser pulse will travel through nine slabs of crystal, and no matter how good the optics are, the beam will pick up distortions along the way. It's those distortions in the wavefront that we are addressing, because they decrease the power that can be extracted in the laser beam and cause that beam to diverge more on the way to the target," explains Dane.

A team led by Jim Brase in the Physics and Advanced Technology Directorate is developing an adaptive resonator system that will sense distortions in the wavefront and correct them in the system. The resonator—which is based on adaptive optics technology developed at Livermore—includes a deformable mirror, control electronics, and sensors to detect the shape of the laser pulse's wavefront. A deformable mirror will be placed inside the laser resonator, and a wavefront sensor will be used to measure the output beam during operation. The sensor measures the difference between the actual shape and a perfect, flat wavefront. Computer-controlled actuators on the mirror then raise or lower small sections of the mirror's surface to correct distortions in the incoming light so that a high-quality beam is maintained from the laser resonator.

Future Looks Bright

The solutions to these challenges are being incorporated into an SSHCL testbed—a module made up of a three-slab Nd:GGG amplifier pumped by laser diode arrays. This testbed will be configured as a laser system to demonstrate the pulse energy at a high repetition rate in 2003. The final version of the SSHCL, which would have an output power of 100 kilowatts under burst mode for several seconds, is expected to be ready to demonstrate to the Army by 2007.

Meanwhile, at the White Sands Missile Test Range, the Army, with Laboratory support, is putting the prototype through its paces, testing it on aluminum and steel to determine what types of power and pulse format will optimize the final weapon system. The Army will also use the prototype to address issues such as lethality, beam degradation due to atmospheric effects, and precision optical pointing and tracking.

The future for the solid-state laser looks promising, notes Dane. "The system we delivered to White Sands is just the starting point. The goal is to have a laser weapon system that is small, cost-effective, and mobile, which protects against tactical threats while meeting the sponsor's other military requirements. We're confident we'll meet these goals."

—Ann Parker

Key Words: laser diode array, neodymium-doped glass (Nd:glass), neodymium-doped gadolinium–gallium–garnet (Nd:GGG), solid-state heat-capacity laser (SSHCL), tactical laser weapon, U.S. Army Space and Missile Defense Command (SMDC).

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