2015 R&D 100 WINNER

Powerful Laser System Improves Experimental Capabilities

PULSED laser-diode arrays are essential for pumping, or energizing, high-power solid-state lasers for materials processing, defense applications, and scientific exploration. A Livermore team, in partnership with colleagues at Lasertel in Tucson, Arizona, has integrated advances in laser diodes and electrical drivers to develop the High-Power Intelligent Laser Diode System (HILADS). The megawatt-class laser-diode pumping system delivers two-to-threefold improvements in peak output power and intensity over existing technology in a 10-times-smaller footprint.

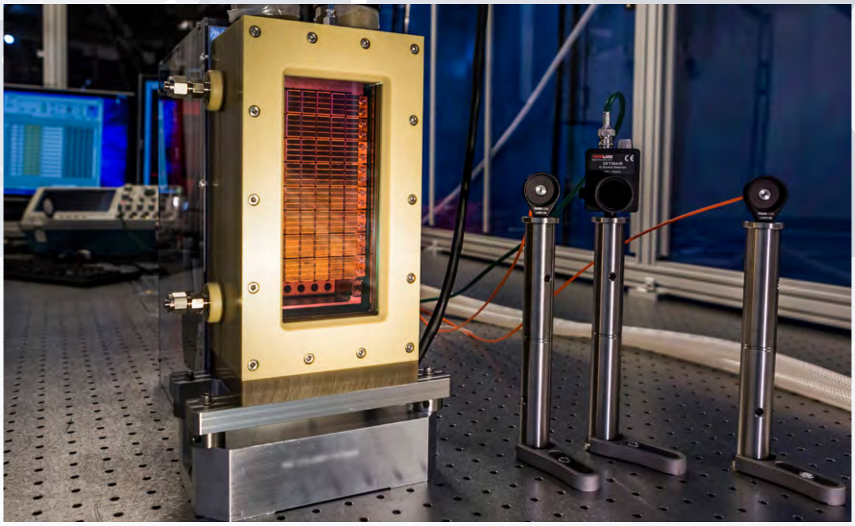
In the largest deployment of the technology to date, four HILADS devices have been integrated into the Laboratory's High-Repetition-Rate Advanced Petawatt Laser System (HAPLS). (See *S&TR*, January/February 2014, pp. 4–11.) When complete, HAPLS will be the world's highest-average-power petawatt (10^{15} or 1 quadrillion watts) laser. Within HAPLS, the four HILADS devices produced 3.2 megawatts of peak optical power at a repetition rate of 20 hertz (20 repetitions per second), making it the highest-peak-power laser-diode array in the world.

The Power of Innovation

Ultrahigh-energy laser systems, like petawatt-class lasers, require diode-array pumps that emit megawatt pulses, frequencies of at least 10 hertz, and high brightness (a combination of power and high beam quality). Until HILADS, a number of engineering challenges prevented development of such powerful and intense laser-diode pumping systems. Those challenges centered on integrating the design and assembly of multiple components: remotely located, higher power current drivers; larger stacks of diodes; optics capable of collimating (aligning) the output of the many diode chips in the stack; and a smaller footprint to save space on often-crowded laser tables that are typically placed in clean rooms where space is at a premium. Plus, minimum stress had to be placed on the diode chips to ensure their reliability over billions of pulses.

HILADS integrates a high-density diode array with an electronic driver and a control system to improve performance. The two-dimensional diode array uses diode stacks mounted on a backplane to provide cooling and mechanical alignment. Each diode stack contains 40 laser-diode chips soldered between thermally conductive metal spacers to minimize stress. Monolithic microlens arrays collimate each stack's output to maximize brightness. Specialized cables connect the array to the driver. Because of its modular design, HILADS can scale

Development team for the High-Power Intelligent Laser Diode System (HILADS): (back row, from left) Glenn Beer, Ken Charron, Paul Rosso, Chuck Heinbockel, Brian Heidl, Andy Bayramian, Dan Mason, Ed Koh, and Tara Silva; (front row, from left) Steve Fulkerson, Constantin Haefner, Steve Pratuch, Bob Deri, Carlene Kiker, Steve Telford, Jeff Horner, and Jeff Jarboe.



HILADS can produce 3.2 megawatts of peak optical power, making it the highest-peak-power diode array in the world. Shown here is one of the system's laser-diode arrays, which contains 40-diode-chip stacks arranged in an 8-by-5-channel configuration.

to larger arrays and power levels without compromising its intensity or brightness.

The HILADS two-to-threefold increase in peak optical intensity was made possible by two key innovations. The first was a novel design approach for the diode chips and their package that enables the chips to operate at higher output power while being located closer to neighboring chips. These two factors require higher efficiency and improved thermal management to avoid overheating the devices. Each HILADS stack contains 40 laser diodes and measures just 11 by 17 square millimeters—the size of a Forever postage stamp, but thicker. The diode is capable of producing greater than 500 watts of peak output power, for a total of 20 kilowatts per stack.

The second innovation was a single-optic microlens array that collimates the output of all 40 chips in a stack to increase intensity. Traditional techniques to achieve good alignment use a longer lens focal length, which can degrade the peak optical intensity of the stack. HILADS uses a custom process to rapidly map the position of every emitter on each of the 40 chips to submicrometer precision. The information is used to fabricate a single optic that contains a monolithic array of microlenses covering the entire stack. In addition to the excellent collimation it provides, the single-optic monolithic microlens array requires only one alignment step, thus significantly reducing related labor costs.

Another important advantage of HILADS comes from its compact electronics and unified, self-monitoring system interface. The HILADS controller is two times smaller than alternative solutions and can be scaled to much higher power levels. The controller chassis is small enough to be mounted below the laser table and generates no thermal air currents that would interfere with laser operations. In addition, 10-meter-long cables connecting the array and driver allow the electronics to be kept at a distance from the laser table, saving space in the clean room that houses the equipment.

A Bright Horizon for HILADS

The features and advantages of HILADS have been demonstrated in deployment on HAPLS, now under development at the Laboratory for installation in the European Union's Extreme Light Infrastructure (ELI) Beamlines facility in the Czech Republic, the world's new preeminent laser-science research facility. A key component of HAPLS, HILADS has proven extremely stable. Extensive testing of the diode stacks indicates that HILADS's lifetime will exceed 2 billion pulses.

The ELI Beamlines initiative will use high-energy diode-pumped lasers to explore light–material interactions. Once the HILADS-pumped HAPLS is installed at the facility, it will ultimately generate a peak power greater than 1 petawatt, with each pulse delivering 30 joules of energy in less than 30 femtoseconds (trillionths of a second)—the time it takes light to travel a fraction of the width of a human hair—at a repetition rate of 10 hertz. HILADS will find a bright future as part of HAPLS, which will make possible many new applications in physics, medicine, biology, and materials science. In addition, the technology will contribute to the development of laser-driven fusion power plants.

—Malone Locke

Key Words: electronic driver, Extreme Light Infrastructure (ELI) Beamlines facility, High-Power Intelligent Laser Diode System (HILADS), High-Repetition-Rate Advanced Petawatt Laser System (HAPLS), laser, pulsed-diode array, R&D 100 Award.

For further information contact Robert Deri (925) 424-5343 (deri1@llnl.gov).