SiMM Is Anything But Simple

FROM delicate surgical procedures to cutting and welding metals, diode-pumped solid-state lasers offer a wealth of uses. A Livermore team has won an R&D 100 Award for a modular packaging technology for the smallest, most powerful, and least expensive laser diode pumps ever.

A silicon microchannel cooling system makes it possible. This technology, called SiMM for silicon monolithic microchannel, relies on photolithography and high-production etching techniques to produce thousands of miniscule, 30-micrometer-wide channels in silicon substrates. Water flowing through these microchannels cools the laser diode bars that are attached to the silicon, allowing the diodes to perform at higher average power than previously possible.

On each SiMM, a tiny package of 10 diode bars can be combined with as many microlenses—which collimate the laser light—to create a unit from which large diode arrays can be built. The microlenses attached to each package, developed and patented by Livermore scientists, give unsurpassed optical brightness. Livermore holds three other patents as well for new developments associated with SiMM.

To date, Livermore has fabricated arrays that put out power of up to 45 kilowatts. Yet these powerful arrays measure just 10 by 18 centimeters.

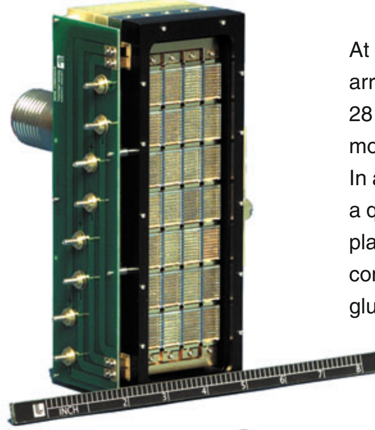
Cooling Is Key

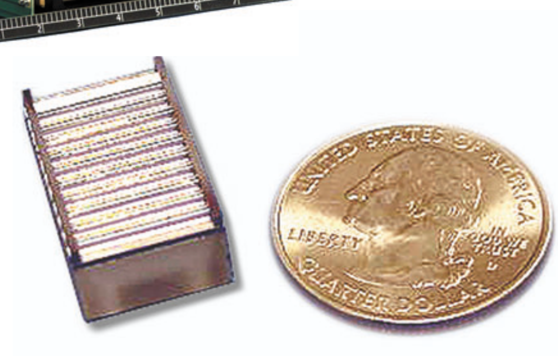
"Because laser diode bar arrays are semiconductor devices, their performance suffers as their temperature increases," notes physicist Ray Beach, who leads the team. Cooling is a challenging problem because laser diodes generate high heat intensity, yet must operate near room temperature. Efficient cooling is thus the cornerstone of any technology that proposes to increase the power output of laser diodes.

Although laser diodes are extremely efficient devices by ordinary laser standards, typically converting nearly 50 percent of their electrical consumption into light, the remaining 50 percent shows up as heat.

The use of silicon in the cooling system is critical. Because photolithographic and etching technologies are so well developed for silicon, arrays of precision microchannels can be easily and inexpensively fabricated in this material. Silicon makes it possible to place thousands of 30-micrometer-wide microchannels close to the heat-producing laser diode bar arrays. It also allows multiple bars to be located on a single substrate, with an equal number of cylindrical microlenses, all attached in a single fabrication step.

Members of the SiMM team are, from left, Larain DiMercurio, Joe Satariano, Jacqueline Crawford, Barry Freitas, Gary Loomis, Terri Delima-Hergert, Dave Van Lue, Ray Beach, Kurt Cutter, and Everett Utterback. Missing from the photo are Cathy Reinhardt and Jay Skidmore.





At left is a 41-kilowatt laser diode array constructed from 28 individual packages of silicon monolithic microchannels (SiMMs). In a SiMM package below, next to a quarter for scale, 10 diode bars placed in V-shaped grooves are combined with 10 microlenses glued into silicon runners.

But why use silicon rather than materials with higher thermal conductivities, such as copper? In compact heat sink structures with flowing water, the best way to control the overall temperature rise is to minimize the thickness of the boundary layer where stagnant water meets flowing water. It is in this boundary layer that the largest temperature rise occurs. Because boundary-layer thickness scales relative to channel width for the flow conditions in the SiMM package, the best material for the cooling system is one that permits easy fabrication of narrow channels. With copper, the channels would have to be wider. It turns out that better thermal performance is gained by using a material that permits tiny microchannel fabrication—silicon—rather than a material with higher thermal conductivity.

The laser diode bars can be precisely placed on the SiMM in V-shaped grooves etched on the front surface of the package. These grooves are generated with the same technology that creates the microchannels in the back side of the silicon. Because the V-shaped grooves are defined with a photolithographic process, the diode bars can be located with micrometer precision relative to one another over the entire SiMM package. Senior engineering associate Barry Freitas, lead developer of the SIMM package, is responsible for this innovative diode bar mounting technology.

The cylindrical microlenses are located with the same micrometer precision in a ladderlike frame of silicon runners. The microlenses are preloaded and glued into the silicon runners to form a structure of 10 lenses. The entire 10-lens assembly is then attached to the SiMM package in a single step. The microlens array serves to collimate the radiation of the laser diode bars from its original 30-degree divergence angle down to a beam with a divergence angle of only about 0.5 degrees. Finally, a glass block seals off the base of the microchannels and serves as a manifold for the cooling water as it flows in and out of the package.

Benefits Abound

Two other approaches compete with the new SiMM cooling technology. The first one relies on stacking single diode bar array packages, a process known as rack and stack. The individual packages are fabricated of copper and use larger macrochannels to flow cooling water. The other technology relies on mounting the laser diode bars on thermally conductive bar mounts and attaching them to a backplane cooler through which water flows.

The primary improvements of the SiMM package over these technologies are in its integration of high-performance heat removal within the high-density, multibar package and the use of low-cost fabrication methods. First, the thermal engineering of the SiMM package allows it to produce an average exitance (irradiance in the emitted laser beam) that is 2.6 times greater than that of its nearest competitor. Second, the use of a monolithic cooler is unique to SiMM. By attaching 10 individual laser diode bars to each SiMM cooler, rather than one bar per cooler as in the rack-and-stack method, the cost of the cooler package is spread over 10 bars. Finally, the majority of the cost of diode-pumped solid-state lasers is in the diode arrays that serve as their pump excitation sources. These lasers thus benefit tremendously from the low-cost fabrication methods in SiMM. SiMM's cost per watt is less than one-third that of its nearest competitor.

Let's Get Together

The innovative SiMM is already being incorporated into new military defense systems. In the near future, a 1-megawatt version will become a key element in the award-winning laser described on p. 8. That laser, the most powerful solid-state laser system in the world, is currently pumped using flash lamps but will soon incorporate the smaller SiMM diode-pump array. An award winner meets an award winner.

—Katie Walter

Key Words: R&D 100 Award, silicon monolithic microchannel (SiMM) laser diode array, solid-state laser diodes.

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