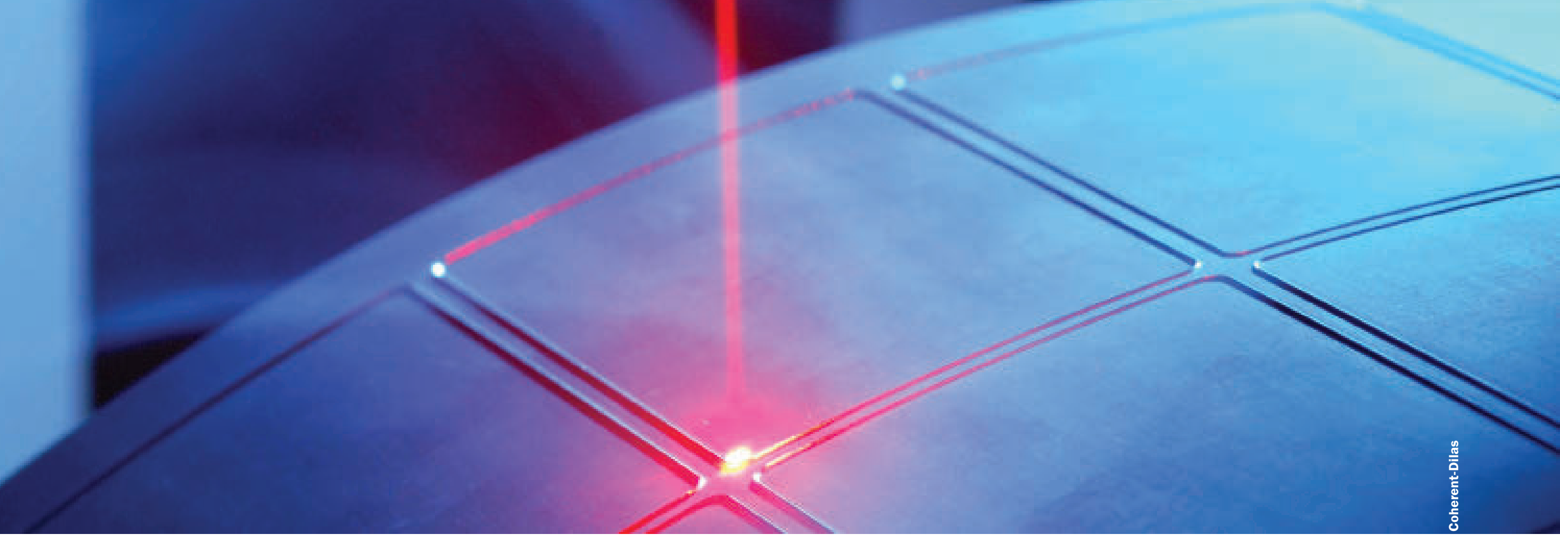


A laser diode system heat treating metal. Making systems with greater power would make it feasible to cost-effectively cut metal using such lasers.

Semiconductor Lasers Power Up

With increasing power, brightness and new wavelengths on the horizon, semiconductor lasers may one day be as ubiquitous as LEDs.

BY HANK HOGAN
CONTRIBUTING EDITOR

Improvements to semiconductor lasers promise big changes, from increases in power to expanded wavelengths.

Other innovations could mean faster data rates for a bandwidth-hungry world. And then there are self-driving cars. Equipped with lidar, autonomous vehicles are likely to spark demand for improved semiconductor lasers. Finally, researchers are investigating semiconductor lasers that can be built to output any desired wavelength, enabling new uses.

For some applications, what's important is not just increasing the power that a semiconductor laser can deliver. Instead the key is achieving more intensity per unit area.

"The real trend is to increase brightness. That means to get more power with a better beam quality, or for fiber-coupled products, more power out of smaller fibers," said Jörg Neukum, product line manager for high-power diode lasers at Mainz, Germany-based Coherent-Dilas, which manufactures high-power diode laser components and systems based on a scalable edge emission architecture.

Neukum added that more power alone means that only some direct applications can be targeted, like plastic welding. In the kilowatt regime, the direct applications are hardening, cladding and additive manufacturing. In contrast, greater brightness would allow semiconductor lasers to tackle cutting and other uses.

The required brightness increase varies with application, Neukum said. For instance, cutting of copper and gold would profit from brighter semiconductor lasers in the blue because those metals absorb shorter wavelengths better than they do light in the red. On the other hand, a 3D projection system could use brighter red, green and blue lasers. In such an approach, lasers at 650 and 660 nm, for example, might be employed, with filters ensuring that each eye only sees one wavelength, different from the other. Similar color splits would be used for the blue and green.

Getting the proper wavelength is a matter of using the right material recipe. Changes in impurity dopant levels can move the output wavelength around somewhat, but larger shifts require completely different materials. For example, blue and green lasers are gallium nitride based while red ones are built using aluminum gallium indium phosphide, Neukum said.

The infrared is also an area of interest to semiconductor laser makers, primarily because some applications work best with wavelengths of four microns or so. For sources beyond 2.2 µm, the material of choice is gallium antimonide, but the brightness of such semiconductor lasers is limited.

One way to boost brightness is through improved fiber coupling. Achieving this involves shaping of the diode laser beam, as well as multiplexing several beams, to fit the fiber geometry and numerical aperture.

There are other changes that can be done to the laser itself. Higher-efficiency laser diodes would convert more input electrical power to light, but today's laser diodes already do so at better than a 50 percent clip for a variety of wavelengths, Neukum said.

Lidar for self-driving cars

The question of how to achieve greater brightness is complicated by the fact that for some applications, what is important is peak and not average power. Lidar is an option, since the intensity of the outgoing laser pulse helps determine the distance and quality of the range information col-

An elliptical shape may be the key to making quantum dot lasers emit continuously and not in short bursts. The squashed shape introduces strain, which impacts the electronic levels of the quantum dot core and allows lasing with less excitation.

Philips Photonics

A semiconductor laser, in this case for a VCSEL (vertical-cavity surface-emitting laser), being loaded into an automated bonding machine as part of the production process.

lected from the light bouncing off objects. The advent of self-driving cars could mean a big market for lidar units powered by inexpensive and rugged semiconductor lasers.

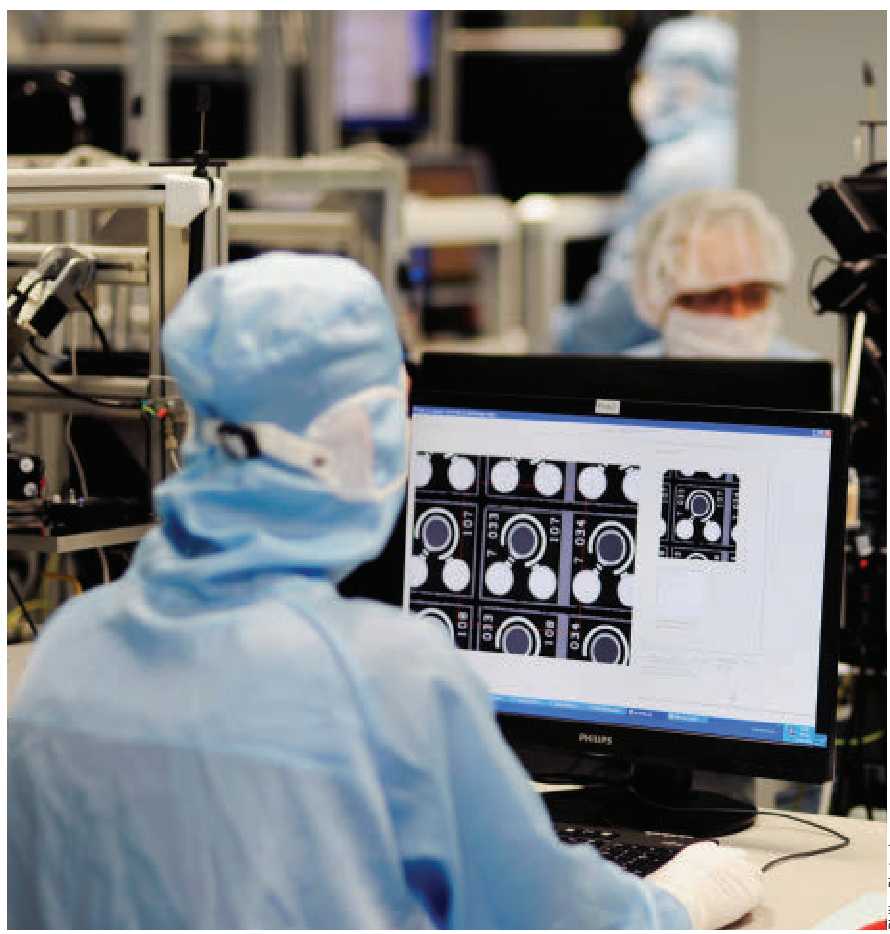
"Each car might have several of these transmitters and receivers," said Neukum.

It's an open question as to which type of semiconductor laser will be used in the tens of millions of autonomous vehicles of the future, said Joseph Pankert, general manager of Philips Photonics of Ulm, Germany, and Eindhoven, the Netherlands. The company is a leading supplier of vertical-cavity surface-emitting lasers (VCSELs), according to Pankert.

He added that VCSELs are prime candidates for upcoming automotive lidar applications. For this use, the ability of semiconductor lasers to handle the required temperature range is important. After all, someone who gets in a car on a boiling or freezing day expects to have it work instantly.

Another rapidly growing use of semiconductor lasers can be found in mobile applications. Here, Pankert said, the price and compactness of VCSEL-based sensors is critical.

These applications have benefited from changes in how semiconductor lasers are

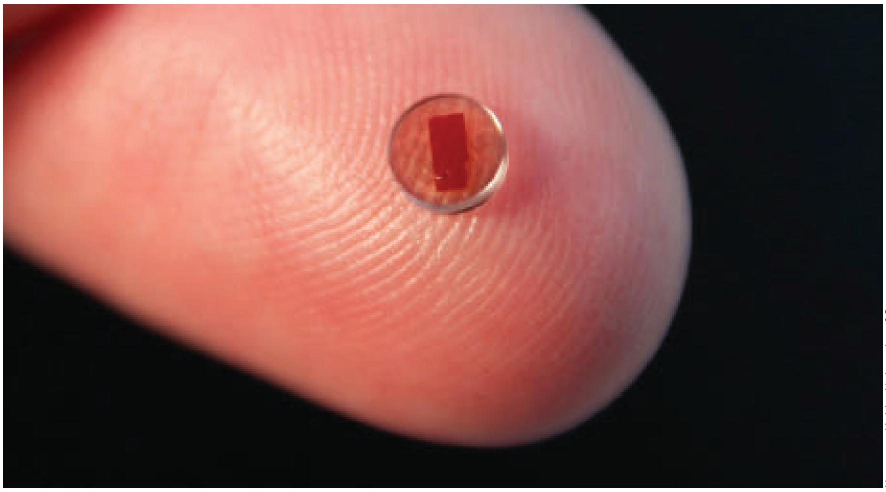


Philips Photonics

Microscopic inspection of VCSEL dice for quality control.

designed and manufactured. "Improved reliability and lifetime are major achievements over the last (few) years," said Pankert. "This clears the way for mass adoption in consumer and automotive applications."

Today, though, semiconductor lasers play a key role in optical high-speed communications for data centers, wireless networks and long-haul coherent networks, said Yasuhiro Matsui, chief chip design engineer at Finisar Corp. The Sunnyvale, Calif.-based company makes fiber optic systems and components.



Hermann Kahle, University of Stuttgart

The active part of a vertical external-cavity surface-emitting (VESCEL) laser in a diamond/semiconductor membrane/diamond sandwich. The active region membrane is surrounded by diamond for improved heat dissipation, which could be the key to upping performance.

There are two different ways in which semiconductor lasers can be used, per Matsui. In one scheme, the lasers are directly modulated through changes in current that rapidly alter the source output.

"In this case, the speed of the communication system is determined by the speed of laser diodes," Matsui said.

Typical bandwidth is around 30 GHz. However, recently 55-GHz bandwidth was demonstrated by Finisar. What this translates to in terms of data rates depends upon the modulation used, as some approaches allow more bits than others to be encoded in the data stream. Matsui noted a 100-Gbps data rate has been demonstrated with a single laser diode using PAM-4 modulation, an advanced encoding format.

In the other transmission scheme, a laser diode provides continuous-wave light. This is coupled to a modulator that then changes the output to transmit data. In this setup, the semiconductor laser must supply high maximum power, preferably at a high temperature of about 85 °C, according to Matsui. For comparison, standard commercial semiconductors are only guaranteed to work to 70 °C.

For this approach, the source and modulator could be integrated. This could be part of the expected trend toward silicon photonics, a technology that uses silicon to manipulate light. Matsui noted that integration could be accomplished via bonding of the laser diode to silicon or through optical coupling.

Dissipating heat

A different type of coupling, for a different type of laser, was investigated at the University of Stuttgart. Heat is one limiting factor in getting more power out of an optically pumped semiconductor laser, or a VECSEL. The Stuttgart research team demonstrated that bonding only the submicron-thick active region of a VECSEL as a freestanding membrane onto diamond disks could be one way to dissipate heat. This approach exploits the thermal conductivity of diamond, the highest of any substance, to get around the strongly temperature-dependent performance of these devices.

"If one overcomes the bonding challenges, and perfect thermal contact between membrane and heat spreaders is realized, it should be possible to increase performance by about one order of magnitude," said Hermann Kahle, who was part of the Stuttgart team and has since gone on to post-doctoral work at Finland's Technical University Tampere.

The Stuttgart researchers published their results in the December 2016 *Optica*. In their paper "Semiconductor membrane external-cavity surface-emitting laser (MECSEL)," they noted this approach enables a variety of new material combinations for new laser wavelengths as well as offering further potential for power scaling.

Speaking of new materials, researchers are working on new types and shapes in the hopes of making better lasers. In an April 2017 *Nature* paper, an international collaboration led by the University of Toronto showed that an elliptical shape could be the key to making quantum dot lasers emit continuously and not in short bursts. The squashed shape introduces strain, which impacts the electronic levels of the quantum dot core and allows lasing with less excitation. That reduces overheating, and thanks to this, the researchers achieved continuous-wave operation.

This could be combined with the size-dependent emission of quantum dots to create laser wavelengths that currently aren't available. Yellow, for instance, is difficult to achieve with conventional lasers, particularly if a specific wavelength is desired, said Oleksandr Voznyy, a senior research associate at the University of Toronto and co-author of the paper "Continuous-wave lasing in colloidal quantum dot solids enabled by facet-selective epitaxy."

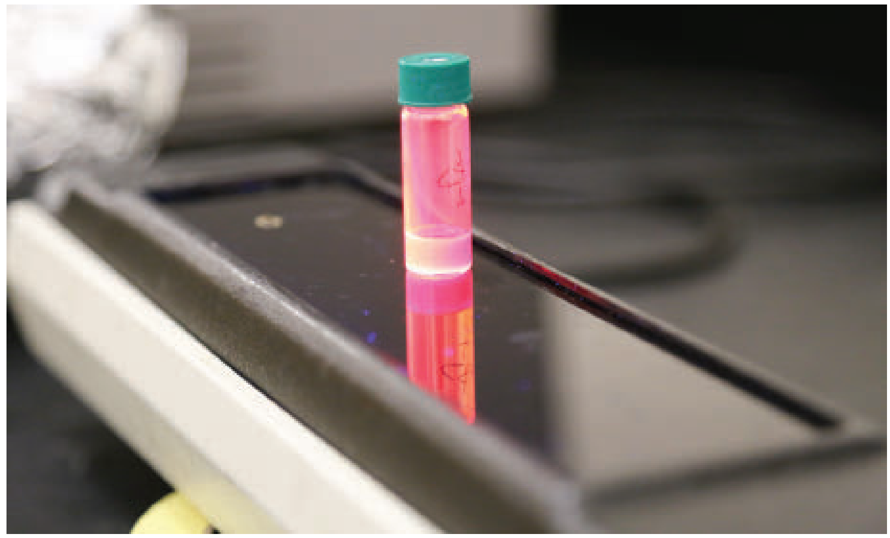
Creating cadmium selenide quantum dot cores just less than three nanometers in diameter would lead to yellow-green emission with precise control over the wavelength. Quantum dots of other materials could lase at 1550 nm, a wavelength widely used in communications.

"Right now, we are focusing on transferring our findings to infrared lasers at telecommunication wavelengths. We keep working on finding suitable materials for green lasers too, as well as going to electrically pumped lasers," Voznyy said.

The research is of commercial interest, he added. For now, though, any application is some time off, particularly since quantum dots must currently be optically pumped.

When asked about the future, Philips Photonics' Pankert predicted that VCSELs and, by extension, semiconductor lasers, will someday be present in every mobile device, every home and every car — in other words, everywhere. "Think of semiconductor lasers as eventually becoming as widespread as LEDs," he said.

Hank@hankhogan.com



University of Toronto

Quantum dots, like those seen in this vial, could form the basis for future semiconductor lasers, with precise control over output wavelength determined by the size of the quantum dots.