ADVERTISEMENT FEATURE

SEMICONDUCTOR LASERS: TRANSFORMING MANUFACTURING

A NEW BREED OF SEMICONDUCTOR LASER invented at Kyoto University is promising to transform applications ranging from LiDAR to manufacturing.

For many years, semiconductor lasers, tiny chips emitting light, have been the workhorse of the optical communications industry, sending data signals around the world via a web of optical fibres. However, for many other applications, especially those requiring intense laser light — such as marking or cutting metals — they are simply not up to task.

The chief problem is their poor beam quality, which arises from the typical geometry of semiconductor lasers. Most high-power designs are so-called edge emitters, made from a sandwich of different semiconductor layers, and they emit light from a narrow, slit-shaped region on the side. The output light therefore has limited brightness and is a stripe-shaped beam that strongly diverges as it travels.

This awkward beam shape is hard to collect and manage, making it difficult to create the nearly perfectly circular, intensely focussed spot required for many applications. It is also hard to scale up semiconductor lasers to very high output powers of hundreds of watts or kilowatts due to thermal problems.

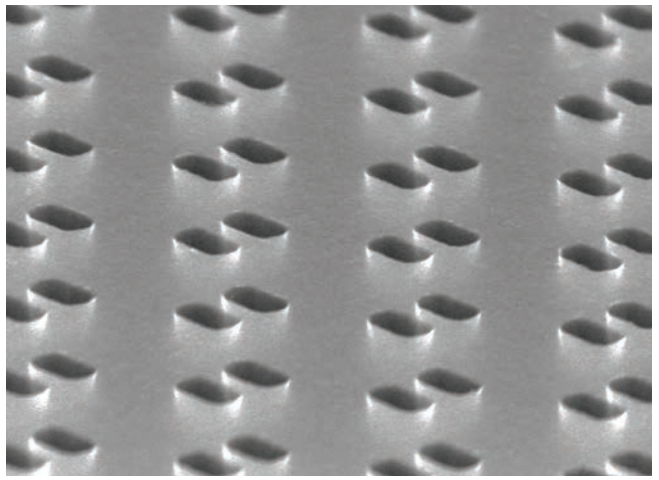
As a result, other laser technologies such as CO_2 gas lasers, Nd:YAG crystal lasers, or fibre lasers have become the preferred solution for many materials processing tasks in manufacturing industries. However, these are all large, complex and relatively expensive, and so a compact semiconductor alternative is highly attractive, especially if it could be cheaply mass produced.

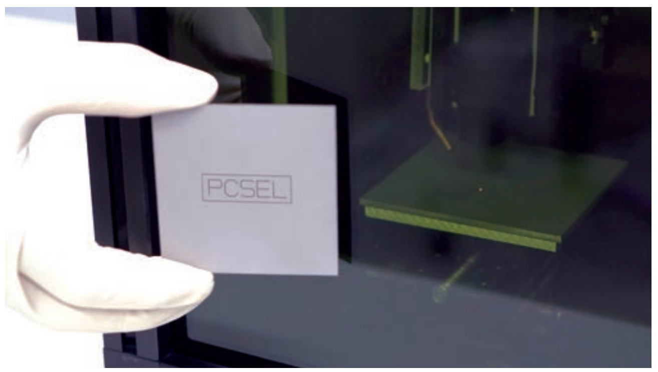
Now, it appears that after two decades of development, a semiconductor laser design that meets these needs has finally arrived. Welcome to the photonic-crystal surface-emitting laser (PCSEL). Invented by Susumu Noda's research group at Kyoto University in 1999, the PCSEL is uniquely able to directly emit a circular beam of outstanding brightness and low divergence (as small as 0.1 degrees) vertically from the top. Additionally, the emitted light is spectrally very pure, with a single sharp emission wavelength.

HIGHLY DIRECTED BEAM

All of these attractive attributes come directly from the laser design. So how is a PCSEL different from other types of semiconductor laser? The answer is that it makes use of a photonic crystal — a semiconductor layer patterned with a custom-designed periodic array of specially-shaped small air holes (nanometre scale). This structure sets up a special resonance condition, causing a narrowband, highly directional emission. The shape, size and period of the air holes are critical to the laser operation, and Noda says that machine learning and even quantum computing are now being used to analyse and optimize the design and the performance of their PCSELs.

Because the beam leaves the PCSEL from the top, not the side, the design is scalable to make large-area lasers with light





▲ **A scanning electron microscope image of a photonic crystal (top); A demonstration of metal-surface processing (bottom).**

emitting regions on the scale of millimetres, or potentially even centimetres in diameter. The latest PCSELs from Kyoto now have output powers in the region of tens of watts for continuous wave (CW) operation and even higher powers for pulsed operation. "Forthcoming developments are expected to push output power to around 100–1000W CW, at which point PCSELs will become extremely promising light sources for smart materials processing, and might replace CO_2 lasers and fibre lasers," says Noda. "We have already demonstrated the processing of a metallic surface [with a PCSEL] for the first time."

Beyond their outstanding beam quality and potential for high power operation, there's another appealing characteristic of PCSELs: the ability to make them 'smart' by directly building in extra functionality.

The most recent smart designs of PCSELs are based on a matrix of adjacent emitters that are individually controlled, which enables built-in beam-steering and beam-shaping functionality. This makes them a very promising option for creating a highly compact LiDAR (laser range finding) sensor system for cars and autonomous vehicles, as well as other sensing tasks.

"We have already demonstrated PCSEL-based LiDAR scanning systems that outperform conventional ones by utilizing the high brightness and functionality of PCSELs," explains Noda. "Our PCSEL-based LiDAR systems do not require any external optics or mechanical systems so they can be miniaturized and their circular, tightly focussed beams enable higher spatial resolutions."

The present generation of PCSEL-LiDARs are around the size of a pack of playing cards.

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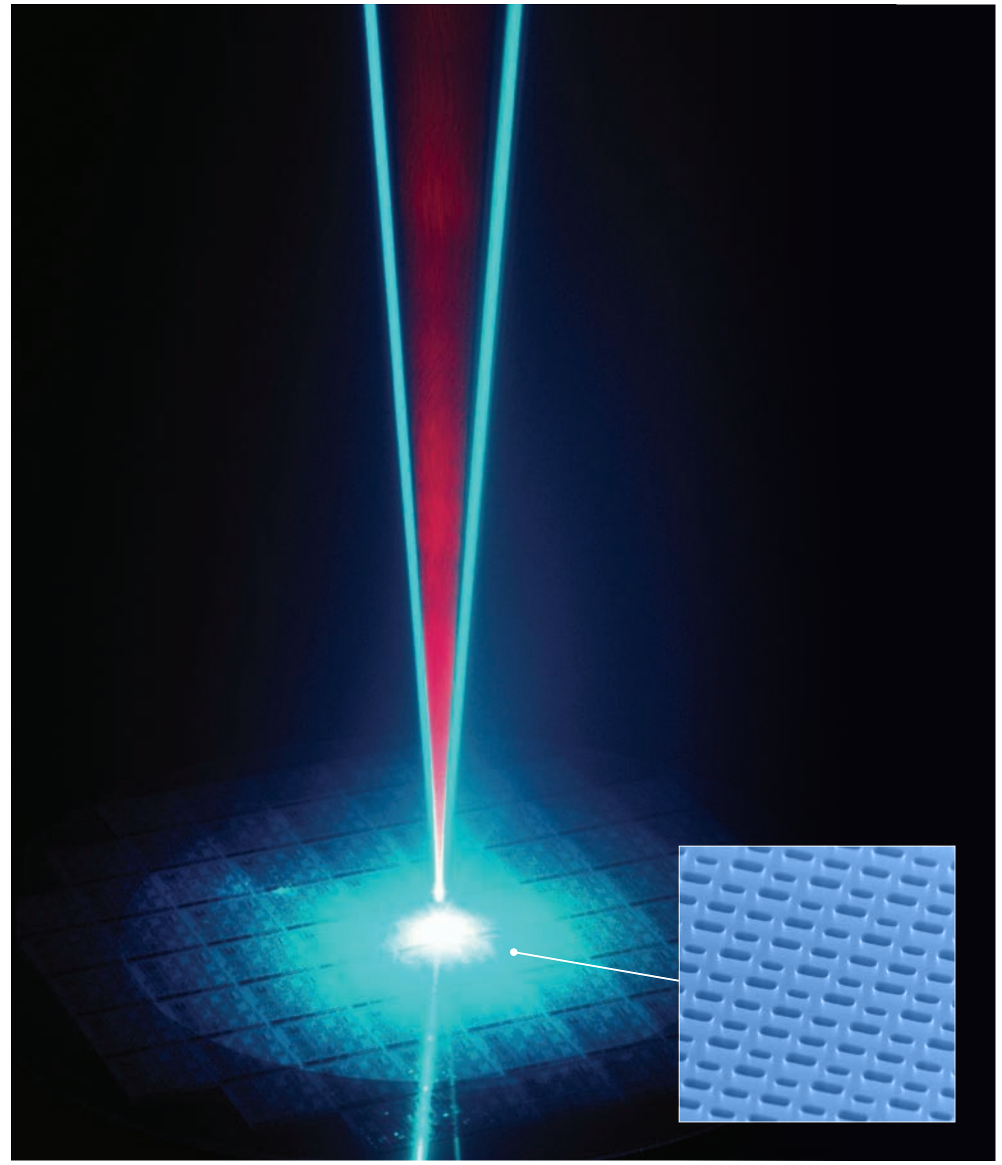

▲ **Photonic-crystal surface-emitting lasers enable built-in beam-steering and beam-shaping functionality. The inset shows a scanning electron microscope image of a photonic crystal specially-designed for this purpose.**

Kyoto University is keen to ensure that the full potential of the PCSEL is realized, and has established a Center of Excellence (COE) for the technology. The COE's two main aims are to further develop the devices and their capabilities, and to build connections with potential end users who can trial PCSELs for real-life applications. According to Noda, tens of Material Transfer Agreements have been established across Japan and internationally for the technology to be further explored and tested.

WEALTH OF OPPORTUNITY

A rich set of opportunities is being explored for PCSELs, including applications in everything from the laser-processing tasks in the manufacture of electronics, cars and solar cells, to their use in sensors and medical equipment.

First-generation devices with powers of up to 0.2W have already been commercialized and samples with improved brightness are currently being tested by partner companies, with commercialization expected to come.

To date, most efforts have focussed on making PCSELs from the gallium arsenide semiconductor system, which operates at a wavelength of 940nm in the near-infrared — but there are ongoing plans in place to expand operation to other spectral regions. Noda says that in co-operation with various partners, the use of other materials such as indium phosphide for telecommunications wavelengths (1.3-1.55 microns) and gallium nitride for operation at blue-violet wavelengths (400-430nm) is proceeding quickly.

It's quite plausible that the car of the future may either be built with the help of a PCSEL or even equipped with one to help it navigate. ■

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