news & features

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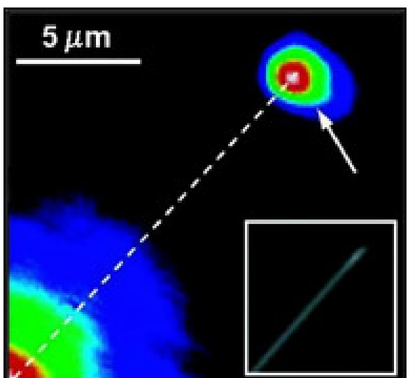
Slimline lasers could bring light onto chips

Lasers small enough to fit on chips are needed for integrated optoelectronics and photonics. They have now been made from nanowires of a semiconductor, which act as optical-fibre-like cavities.

Philip Ball



Room temperature photoluminescence image of a CdS nanowire excited 15 µm away from its end (bottom left corner of image). Arrow points to the luminescence from the end of the nanowire. Inset shows an optical image of the nanowire.

Electrically driven lasers made from individual semiconducting wires around 100 nanometres thick have been made by scientists in the USA. These devices might be small enough to allow chip-scale integration of optoelectronics and photonics.

The nanowire lasers have been built by Charles Lieber and co-workers at Harvard University in Cambridge, Massachusetts. They consist of single wires of the semiconductor cadmium sulphide, which emits blue–green laser light at wavelengths of around 495–500 nm. The Harvard group has previously made nanowires of other semiconductors with larger and smaller band gaps, such as gallium nitride and indium phosphide. So the researchers are confident that it should be possible to make nanolasers spanning the spectrum from the ultraviolet to the infrared.

Conventional miniaturized semiconductor laser diodes used for optical telecommunications and optical storage (such as compact discs) are cumbersome, much too large to fit on a silicon chip. This means that optoelectronic technology, for example in the form of circuits for converting electronic signals to optical pulses for fibre-optic transmission lines, incurs a problematic interface between the microelectronics and the photonic devices.

It would be far better if the lasers could be mounted directly on chips. Some degree of integration has been made possible by microlasers such as vertical-cavity surface-emitting lasers, in which a quantum-well laser

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cavity is sandwiched between multilayer dielectric mirrors made from thin films of semiconductors. But these devices are still gargantuan — several micrometres across — compared with the nanowire lasers of Lieber and colleagues.

In effect, the new devices are miniaturized versions of fibre lasers, in which a conventional hair-thin optical fibre supplies the laser cavity. Fibre lasers are widespread in telecommunications and medical technologies. In the nanowire laser, the wire acts as a waveguide for the stimulated emission. Thus Lieber's group has shrunk fibre lasers a thousandfold.

This is not the first time semiconductor nanowires have been made to lase: a group in California achieved that over a year ago (M. H. Huang *et al. Science* **292**, 1897–1899; 2001). They used zinc oxide nanowires, which generated ultraviolet light. But these nanolasers were optically pumped using conventional lasers. For most applications (such as optoelectronics), that is not enough: electronic pumping is required.

Lieber and colleagues have demonstrated electronic control of their CdS nanolasers deposited on a silicon substrate. The nanowires act as n-type semiconductors (electron transporters), while the silicon is doped so that it is p-type (hole transporting). The interface of the two forms a p–n junction, across which charge can be injected into the nanowire. There, recombination of charge carriers causes emission of blue–green light.

Lasing turns on above a threshold current of around 200 μA, where a broad spontaneous-emission peak collapses into very sharp peaks that are typically the fingerprint of lasing.

The applications may not be limited to optical telecommunications and information technology. Lieber and colleagues say that it might become possible to use nanowire lasers to perform laser surgery with unprecedented precision, or as optical probes for chemical and biological sensors: the nanowires may penetrate through cell walls without causing much damage. And they could be used for very high-resolution laser lithography, making use of the optical near-field to beat the wavelength resolution limit.

letters to nature
Single-nanowire electrically driven lasers
Xiangfeng Duan, Yu Huang, Ritesh Agarwal & Charles Lieber
Electrically driven semiconductor lasers are used in technologies ranging from telecommunications and information storage to medical diagnostics and therapeutics. The success of this class of lasers is due in part to well-developed planar semiconductor growth and processing, which enables reproducible fabrication of integrated, electrically driven devices. Yet this approach to device fabrication is also costly and difficult to integrate directly with other technologies such as silicon microelectronics. To overcome these issues for future applications, there has been considerable interest in using organic molecules, polymers, and inorganic nanostructures for lasers, because these materials can be fashioned into devices by chemical processing. Indeed, amplified stimulated emission and lasing have been reported for optically pumped organic systems and, more recently, inorganic nanocrystals and nanowires. However, electrically driven lasing, which is required in most applications, has met with several difficulties in organic systems, and has not been addressed for assembled nanocrystals or nanowires. Here we investigate the feasibility of achieving electrically driven lasing from individual nanowires. Optical and electrical measurements made on single-crystal cadmium sulphide nanowires show that these structures can function as Fabry–Perot optical cavities with mode spacing inversely related to the nanowire length. Investigations of optical and electrical pumping further indicate a threshold for lasing as characterized by optical modes with instrument-limited linewidths. Electrically driven nanowire lasers, which might be assembled in arrays capable of emitting a wide range of colours, could improve existing applications and suggest new opportunities.
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