colour from the photonic-bandgap material can be switched to provide wavelength-tunable feedback for a red–green–blue laser.

"Our recent blue-phase materials with a wider stable temperature range allow full-wavelength tuning over the entire visible spectrum using much lower fields than those described in our *Nature* paper [ref. 3]," stressed Coles. In his opinion, this highly efficient lasing device will open the way for new practical devices that do not require polarizers, colour filters or alignment layers. Some given examples are new microscopic light sources for use in cancer and diabetes detection and the treatment of dermatological and vascular disorders, and in hand-held displays.

"I think we are in for a new generation of liquid displays that switch much faster than the current technology for large-area flat-panel displays," replied Coles when he was asked about where his liquid-crystal research would lead. He also seemed confident that multi-viewing-angle and holographic displays that have recently been announced by LG and Sharp, respectively, will benefit enormously from higher switching speeds. "The incorporation of the newer, highly energy-efficient blue-phase materials into plastic flexible displays will also lead to low manufacturing cost," he added.

Coles holds the opinion that using liquid crystal in negative-refractive-index materials is another exciting future research area. His view was supported by Smalyukh, who added that the need for cost-effective fabrication of metamaterials in large quantities had been recognized. So far, mass production has been a challenging problem because of the requirement to position nanoparticles of different shapes and material compositions on the nanoscale. "Liquid crystals that can self-assemble into many different structures at the nanometre scale are ideally suited to serve as smart matrices for controlled assembly of nano- and micro-sized particles into metamaterials to achieve tunability in effective refractive index or birefringence," said Smalyukh.

The five-day workshop was attended by nearly 200 participants, some present on site with additional access through a real-time webcast. It featured 20 invited talks, 47 oral presentations and 34 poster presentations, all saved and viewable on the workshop's website[1]. The workshop aimed to enable researchers to discuss the emerging uses of light for control of ordered soft materials and advances in the use of liquid crystals to control light. Apart from the topics mentioned above, those such as adaptive photonic crystals, optical trapping and manipulation, imaging techniques, and optical characterization and modelling techniques were also discussed.

The next workshop, themed 'Inter-Continental Advanced Materials and Photonics' (I-CAMP) summer school, will be held from 15 June to 10 July 2009 in Harbin, China.

References

1. http://www.icam-i2cam.org/conference/lc2cam08
2. Reinitzer, F. *Monatshefte für Chemie* **9,** 421–441 (1881).
3. Coles, H. J. & Pivnenko, M. N. *Nature* **436,** 997–1000 (2005).

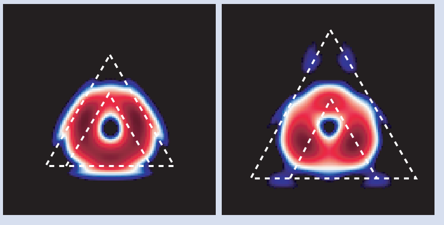
SEMICONDUCTOR LASERS

Quantum wells meet nanowires

Epitaxial growth techniques make it possible to control the thickness of semiconductor layers at the atomic level and create carefully designed quantum-well structures that trap electrons. Now, Fang Qian and colleagues from Harvard University and the Georgia Institute of Technology have combined such semiconductor quantum wells with another type of nanoscale structure that is at the heart of much research at present — the nanowire (*Nature Mater.* **7,** 701–706; 2008).

Nanowires, as their name suggests, are long structures thin enough that the electrons within are confined to the point where quantum effects take hold. The proposed applications of nanowires are numerous because of their unusual electronic and optical properties. To add device functionality, nanowires are becoming increasingly complex. Surrounding the nanowire in a shell made of a different material, for example, has been found to improve the performance of nanowire-based field-effect transistors. This same principle has now been applied to optical structures, specifically GaN nanowire lasers.

To obtain efficient optical properties, it is important to create a material with a



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flaw-free crystal structure. Qian *et al.* used metal–organic chemical vapour deposition to ensure the materials reached the required quality. Nanowires of GaN 100–200 nm across and 20–40 μm long were deposited on sapphire substrates. On top of this they grew alternating layers of GaN and InGaN — a material with a smaller bandgap than GaN that acts as the electron confining layer, or well. By varying the growth time and temperature, the well thickness and the fraction of gallium atoms that are replaced by indium atoms in the InGaN crystal can be controlled. The indium content is important for optical applications as it determines the emission wavelength. This represents a significant advantage of the approach taken by Qian *et al.* Previous nanowire lasers have been based on binary semiconductors, which offer very little scope for bandgap engineering and therefore tunability.

The laser operation of the structure is quite simple: the quantum wells provide the optical gain medium whereas the nanowire acts as the cavity. One of the designs the researchers investigated consisted of 26 quantum wells, each with a thickness of 1.5 nm separated by 1-nm GaN barriers. Four structures were grown, each with wells with a different indium content. As the amount of indium was increased, the wavelength of the optically pumped laser (operating at room temperature) tuned from 383 nm to 478 nm, thereby covering both UV and visible frequencies. An interesting observation was that the lasers with a high indium content were bent, although this did not prevent them from lasing, testifying to the efficient waveguiding within the nanowire. The reason for the bending is likely to be that the high-indium-content quantum wells were not uniform on both sides of the nanowire, leading to a build up of strain.

The demonstration that such complex heterostructures are possible will hopefully act to stimulate further research into nanowire lasers. The next goal will probably be electrically driven structures, adding further shell layers to act as electrical contacts.

David Gevaux

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