Polychromatic liquid crystal laser arrays

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VIEW FROM…LC2CAM

Flowing crystals glow

The photonics applications of engineered liquid crystals extend far beyond their use in displays. High-density optical data storage, tunable lasers and metamaterials are just a few of the other opportunities.

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Attendees look energized for the workshop participation in the mountainous Boulder, Colorado.

Liquid crystals doped with nanosized particles, dyes and other additives could be the answer for creating a new breed of photonic material with enhanced properties, such as increased birefringence, dielectric anisotropy or optical gain. In particular, when doped with photoresponsive and light-emitting dyes, such engineered liquid-crystal materials may play a valuable future role in a wide range of applications ranging from optical switching and diffractive optics to optical data storage and tunable lasers.

This was the exciting message that *Nature Photonics* took home from the recent Light-Controlled Liquid Crystalline Complex Adaptive Materials (LC2CAM) International Workshop held in Boulder, Colorado, USA, from 6 to 10 August[1].

Liquid crystals are an interesting phase of matter; they share the unique properties of crystalline solids and ordinary fluids. The molecules are often rod- or plate-shaped, with their optical properties governed by the ability to align their orientation collectively.

Since their discovery in 1888 (ref. 2) liquid crystals have not only helped advance our fundamental understanding of condensed materials, but also played a vital role in the information technology (IT) industry. For instance, the development of high-quality flat-panel displays, non-mechanical beam-steering devices and switching elements in optical telecommunication networks would not have been possible without liquid crystals. It is not an overstatement that liquid-crystal technology accounts for about half the current television display market by value.

Now it appears that research in the area is shifting towards creating new types of liquid-crystal device by combining them with other materials.

"Many current studies are focusing on further enhancing the optical and photoresponsive properties of liquid crystals by doping them with nanoparticles, dyes and other additives," said Ivan Smalyukh from the University of Colorado at Boulder, USA, who was also the chairman of the workshop.

Azobenzene dye is the most popular choice because of its high photosensitivity and the opportunity to create a large birefringence. When azo-dye molecules are exposed to resonant light, they undergo *trans–cis* photoisomerization, which induces the reorientation of liquid-crystal molecules, as Smalyukh explained.

Indeed, more than one third of the presentations in the workshop were dedicated to the latest findings in combining azo-dye with liquid crystals. In his talk, István Jánossy from the Hungarian Academy of Sciences described the enhanced nonlinear transmission properties that result from liquid crystalline cells doped with azobenzene. Jánossy showed that in the presence of azobenzene dye, the optical torque in the reorientation process can be enhanced significantly.

An interesting application of azo-dye-doped liquid crystals was also presented by Sin-Doo Lee from Seoul National University, Korea, who described a rewritable optical memory. The design is based on a binary grating in a dye-dispersed liquid-crystal/polymer composite. Reorientation of the liquid crystals produces rewritable optical memory bits owing to modulation of the optical axis within the interpolymer networks. According to Lee, such dye-doped liquid-crystal binary gratings could also be useful for applications in optical diffraction, optical modulation and beam steering and splitting.

On the other hand, doping liquid crystals that have a periodic structure with laser dyes can result in a gain medium with distributed feedback and thus lead to the creation of tunable or switchable lasing. For example, a red–green–blue laser based on new blue-phase liquid-crystal materials with a stability over a wide temperature range, from +80 °C to −20 °C, was presented by Harry Coles from the University of Cambridge, UK.

According to Coles, blue-phase liquid crystals are highly fluid self-assembled three-dimensional cubic defect structures that are thermally stable over narrow temperature ranges (0.5–2 °C) in highly chiral liquid crystals. They may be thought of as examples of tunable photonic crystals with many potential applications.

Laser-dye-doped blue-phase liquid crystals can self-assemble to form a material with a three-dimensional photonic bandgap. By applying an electric field, the reflected 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

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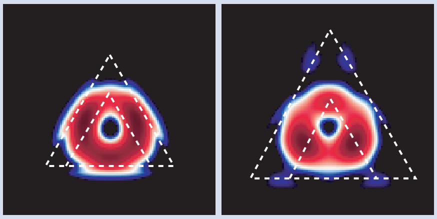
SEMICONDUCTOR LASERS

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 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.



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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