Fantastic plastic

Organic materials can enable innovative, low-cost, compact devices. Many fascinating projects were presented at Photonics West. But, as **Nadya Anscombe** finds out, challenges still remain

Organic photonic devices are generally thought of as less efficient and less stable than their conventional inorganic counterparts. But at this year's Photonics West conference researchers from across the world showed that organic photonic devices have made great strides in recent years and can even outperform conventional devices. Novel approaches to device design include hybrid structures, frequency doubling techniques, indirect electrical pumping and the incorporation of strange and exotic materials.

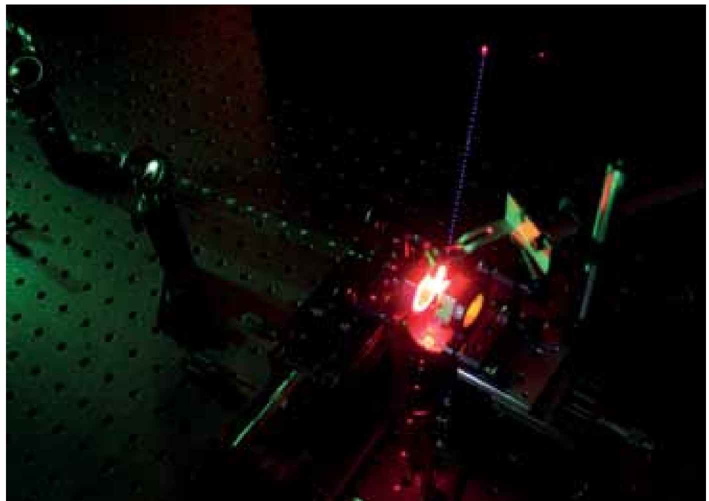
Perhaps one of the strangest materials to use in an LED has to be fish DNA. Yes, fish DNA. Andrew Steckl and his colleagues from the University of Cincinnati and the Air Force Research Lab in the US have developed bio-organic LEDs that use salmon DNA to improve the efficiency of conventional OLED devices. In conventional OLED structures, a hole-blocking layer is introduced to enhance the electron-hole interaction in the emitting layer. In Steckl's BiOLED structure a thin film of salmon DNA is used as an electron blocking layer on the other side of the emitting layer. This, together with the hole-blocking layer, further enhances radiative recombination and results in higher efficiency. As well as being an excellent electron blocking layer, the DNA layer's electronic structure means it also allows unimpeded hole transport into the emitting layer.

'The DNA we use is not a synthetic DNA, but a natural by-product from salmon fishing,' explains Steckl. 'It is a cheap, abundant material and has very useful electrical and photonic properties.'

The DNA is first extracted from waste salmon sperm and freeze-dried. At this stage, the strands of DNA have a very large molecular weight. In order to increase conductivity, these long chains are broken down by dissolving the DNA in water. The water-soluble DNA material is then treated with a surfactant to make it soluble in organic solvents and therefore suitable for spin-coating.

'After reducing the molecular weight, the molecular weight is still relatively large and DNA behaves in a similar way to other organic materials that can be incorporated into OLEDs,' says Steckl. 'However, we were surprised how well the material worked. Our BiOLEDs were brighter and had a higher efficiency than our OLEDs without the DNA layer.'

At Photonics West, Steckl



University Paris 13/CNRS

This long-exposure photograph shows a vertical external-cavity surface-emitting organic laser (VECSOL) that is compact and easy to make. Using frequency doubling, researchers in France have managed to make this laser emit in the UV. Visible in the image is the green pump laser and the UV emission perpendicular to it (made visible using a piece of paper), as well as a small leakage (in red) from the cavity

IBM Research

The key element in IBM Research's hybrid silicon/organic laser is two lines of silicon rods which form a subwavelength phase grating. The scale bar corresponds to 1 μm and his colleagues presented a multi-colour array of BiOLEDs. The different colours of each of the BiOLEDs in the array was as a result of different fluorophores incorporated into the DNA – an established labelling technique in biochemistry. These results indicate that their approach lends itself to the fabrication of LED arrays. Their long-term goal is to fabricate the entire OLED from natural biopolymers, in other words using only renewable and biodegradable materials.

While Steckl and his colleagues have used unconventional materials, but a conventional device structure, others choose to use conventional materials, but an unconventional device design. Researchers from IBM Research in Zurich, Switzerland, have used a conventional material (silicon), combined with a polymer and an integrated planar Fabry-Perot cavity to make an ultra-compact hybrid laser that emits in the

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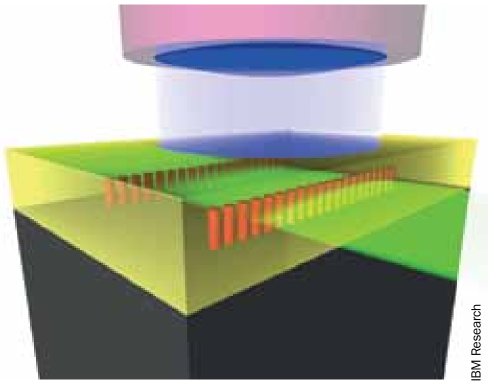
visible wavelength range. The highly reflective mirrors are two periodic sub-wavelength-sized silicon gratings and optical gain is achieved by optically pumping a conjugated polymer, which covers these structures.

'This approach brings organic photonics closer to the chip level,' explains Rainer Mahrt from IBM Research. 'It also means we can shrink the size of the resonator making the total device area an order of magnitude smaller than for lasers using photonic bandgap mirrors.'

The key elements are the high-contrast grating (HCG) mirrors made from dielectric material



IBM Research

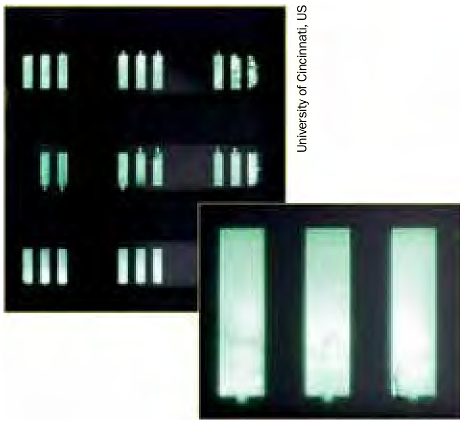
IBM Research's hybrid laser is different because, unlike devices based on photonic bandgap structures, the periodic structure is not in the propagation direction of the optical wave, but perpendicular to it

that rely on the interplay between diffraction and a phase/intensity engineering of the transmitted wave. The gratings are simply a line of silicon rods which form a subwavelength phase grating in which only the zeroth diffraction order is allowed and the transmitted wave is cancelled. A plane wave radiates on the grating and the light is transmitted partly through the rods. Because of the ➤

higher refractive index of the silicon rods, the light that travels through them acquires a phase shift of 180° at the end of the rods compared with the light that travels through the voids. This leads to a destructive interference of the transmitted light such that most of the light is actually reflected backward.

'There is a high contrast between the refractive index of the polymer and the refractive index of the silicon, so this creates a broadband structure,' explains Mahrt. 'Our device is different because, unlike devices based on photonic bandgap structures, our periodic structure is not in the propagation direction of the optical wave, but perpendicular to it. This means our device structure is much smaller than other designs.'

It also means that the emission can be modulated very rapidly. This is ideal for applications such as optical data communication. 'We have created a resonator in silicon that works in the visible and is less than 2µm long,' says Mahrt. 'As with most organic photonic structures, ours is optically pumped. But we think that perhaps by using the gratings themselves as injector material, we could move one step closer to the holy grail of an electrically-pumped organic laser.'



University of Cincinnati, US

Phosphorescent OLED array using DNA electron blocking layer

While many in the field of organic photonics believe an electrically-pumped organic photonic device is important, others have decided not to chase this dream and to concentrate on optically-pumped devices instead. 'If we accept the idea that optical pumping is OK, then we don't need a conjugated polymer and we can achieve very high efficiencies,' says Sébastien Chénais from the University of Paris in France. 'By thinking in this way, we have come up with a novel organic laser structure that is tunable, has a high-brightness, and emits in the visible or UV range.'

At Photonics West, Chénais and his colleagues presented a vertical external-cavity surface-emitting organic laser (VECSOL) that is made of a thin layer of a dye-doped polymer spun-cast onto a high reflectivity mirror and a remote concave output coupler to close the cavity. This laser architecture leads to record optical conversion efficiency for thin-film organic lasers (up to 60 per cent) together with respectable output energies (>30µJ). The open structure of the VECSOL also makes it possible to use an intracavity frequency doubling scheme to reach UV wavelengths. 'At Photonics West, we presented a compact device (1cm long) that emits 1µJ of diffraction-limited tunable UV monochromatic light at around 315nm,' said Chénais. 'This was based on a rhodamine 640:PMMA active layer and a BBO crystal for frequency doubling.'

The researchers hope this laser design will be useful in many applications including atmospheric spectroscopy, ionisation spectrometry, chemical or biological hazard detection, and laser-induced fluorescence spectroscopy. 'The beauty of this technology is

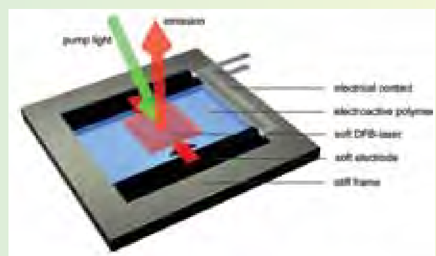
STRETCHY LASER

Artificial muscles inspired the design for a laser developed by researchers at the Fraunhofer Institute for Applied Polymer Research (IAP) in Potsdam, Germany. They have demonstrated a distributed feedback (DFB) laser that is based on elastomer technology and whose wavelength can be tuned by stretching a waveguide structure using an applied voltage. 'Our device consists of two parts,' explains Sebastian Döring from IAP. 'An dye-doped elastomer DFB laser and an electroactive substrate made from pre-stretched elastomer."

The wavelength of the DFB laser is determined by the period of a Bragg grating, which in this case, is made from an elastomer. As with artificial muscles, application of a voltage makes the laser and substrate contract. This changes the grating period and therefore the emission wavelength. Döring and his colleagues saw the emission wavelength decrease from 604nm to 557nm, a relative change of 7.8 per cent.

'This type of tuning is very controllable and precise,' says Döring's colleague Joachim Stumpe. 'It is simpler and faster than thermal tuning and has resulted in a very compact device.'

The voltage-tunable elastomer laser (VTEL) is pumped with pulsed laser light at 532nm and a repetition rate of 100Hz with an angle of incidence of 45° relative to the surface of



Fraunhofer IAP

The design for this voltage-tunable laser was inspired by artificial muscles

the active layer. Unlike other polymer-based photonics, the bottleneck is not the lifetime of the polymer as it is not the active material. 'The optical stability of the active material, the dye, is the bottleneck,' admits Stumpe. 'We know that the elastomer can be stretched and contracted millions of times without degradation, but we suffer from the same problems as conventional dye lasers when it comes to the lifetime of the dye.'

However, Döring and Stumpe are confident that this stretchy laser has many potential applications. 'Our VTEL is compact, lightweight, versatile and made from low-cost materials,' said Döring. 'We hope it will find use in many different applications, such as optical information processing, lab-on-a-chip, disposable sensors or biomedical diagnostics.'

also how easy it is to make,' says Chénais. 'You just mix the polymer and the dye and put a drop of this onto the mirror. It is very simple to align and the pump and output beams are visible. This makes it an ideal educational tool, for example.'

Chénais also believes that while electrical pumping is not possible yet, indirect electrical pumping might be. 'We have not tried it yet, but we believe that we could reach threshold using a state-of-the-art blue laser diode as a pump source,' he says.

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This idea of indirect electrical pumping was pioneered by Ifor Samuel and colleagues from the University of St Andrews in the UK. At Photonics West, Samuel gave a keynote presentation about this work, as well as his work on using OLEDs in treating skin cancer.

He says 'Polymer lasers have been unable to reach their full potential because they require an additional, bulky, laser to excite them. We took advantage of advances in nitride semiconductors and used a commercially available blue LED to pump an organic DFB surface-emitting laser. We believe this device could have applications in the detection of explosives, and have just started a project to pursue this for humanitarian demining.'

The DFB lasers developed by Samuel and his colleagues use gratings with a period of 350-400nm. In order to make these lasers, the group uses nanoimprint lithography. 'We need a simple way of making such lasers, as otherwise we would lose the advantage of simple fabrication of the polymer part of the device,' says Samuel. 'We have just demonstrated the first LED-pumped polymer laser made by nanoimprint lithography.'

While all of the above projects show great promise, they are all linked by one common challenge – lifetime of the active material. The lifetimes of their organic devices are relatively low. Some cheap products do not need long lifetimes, but there is huge optimism that lifetimes of organic materials can be increased in order to open up more applications for these devices. 'I have seen OLED lifetimes go from a few seconds to half a million hours,' said Samuel. 'I am sure that, with the amount of work being carried out in organic photonics, the problem of lifetimes can be solved." ●

University Paris 13/CNRS

The intracavity frequency-doubled VECSOL. On the left is the Brewster-angle dichroic separator, next to it (on its right) the BBO frequency-doubling crystal, and on the right the closing curved mirrror, which has high reflectivity in the UV and in the red.