Integrated photonic microstructure enables highly directional emission from Eu OLED

Organic light-emitting diodes (OLEDs) have enormous potential for use as low-cost light sources for displays and for general illumination. However, a hurdle to be overcome prior to using them in applications such as autostereoscopic (naked-eye) three-dimensional displays and visible-light wireless communication is that their Lambertian (isotropic) emission profile must be modified to one that is more directional. Recently, S. Zhang and colleagues at the University of St Andrews demonstrated an approach to creating directional-emission OLEDs based on integrating a photonic microstructure into a solution-processable europium-based OLED. The result was nearly an order of magnitude increase in the fractional emission in a specific direction, as reported in the February 4 online edition of *Advanced Optical Materials* (DOI: 10.1002/adom.201300441).

Previous attempts by the group to modify the emisswion profile of Eu-based OLEDs with commercially available materials involved integrating a photonic grating into the OLED stack by stamping a two-dimensional array of pillars into the emissive layer using an elastomeric mold. While this resulted in partly directional emission, a significant amount of Lambertian background light was also present, limiting the emission enhancement in a specific direction to only a factor of two over control devices. Additionally, the enhanced direction was fixed by the period of the grating, and could not be tuned in a given device.

These problems were overcome by constructing an architecture in which a Eu-based OLED pixel and a photonic grating structure (both 4 mm × 4 mm) were independently built on the same glass substrate, adjacent to one another and displaced by 8 mm. Graham Turnbull, who co-leads the St Andrews team, said, "By separating the light generation and extraction, we have more freedom to independently optimize the electrical and optical performance to realize highly directional emitters."

The grating was composed of a square array of pillars with a depth of 80–90 nm and periods ranging from 275 nm to 365 nm, covered by an 80-nm layer of silver. Using a fiber-coupled CCD spectrometer, the researchers analyzed the spatial pattern of light emitted from the grating element, at a range of angles from the substrate normal. Compared to control OLEDs lacking the grating, each device displayed highly enhanced emission at a specific angle, with up to 90% of the total emitted light from the grating falling within a cone with FWHM ~15°.

The researchers also demonstrated the use of a flexible substrate, by imprinting the photonic grating on polyethylene terephthalate (PET) and coupling this to the OLED glass substrate with index-matching oil. This configuration resulted in similar directional emission as the all-glass substrate devices, but the PET could be mechanically bent through a range of 38°, dynamically modifying the direction of emission while maintaining the emission enhancement. One remaining issue with the device is that the ratio of light emitted through the photonic grating to the direct emission through the bottom substrate is only 8%. However, the researchers suggest that this could be improved by altering the substrate aspect ratio or by coupling more of the emission into the substrate.

While there are no current commercial applications of this technique, some possibilities include on-chip optical biosensors, autostereoscopic (naked-eye) 3D displays, and visible-light communications. The St Andrews team is part of the UP-VLC research program, a collaboration funded by the UK Engineering and Physical Sciences Research Council (EPSRC) to investigate technologies for visible-light communications (sometimes referred to as "LiFi"). While OLEDs have a slow electronic modulation bandwidth that limits their suitability for direct use in communications, the short fluorescence lifetime of the emitters may enable a hybrid OLED approach combined with nitride-based LEDs for high-data-rate transmission.

Integrated diffracting structures in OLEDs have been investigated for other reasons by various researchers. Franky So of the University of Florida said that using directional-emission OLEDs for autostereoscopic displays would be "an interesting concept." So's group is investigating OLEDs fabricated on high-index corrugated structures in order to improve total light extraction and thus external quantum efficiency, using a photoetching process. In contrast to the highly ordered structures intended to enhance directional emission, these structures are intentionally fabricated without regularity, to preserve Lambertian emission.

As researchers increasingly develop techniques to integrate photonic structures into OLEDs and improve efficiency and performance characteristics, these devices are likely to find their way into new applications ranging from sensors to communications and digital displays. Given these results, you should definitely be watching OLEDs—in more ways than one.

Colin McCormick

Correction

In the Interview in *MRS Bulletin* **39** (3) 2014, p. 216, the CERN's superconducting coil is made of niobium titanium, not neodymium titanium.

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