

# The rise of colloidal quantum dots

This issue features a theme on colloidal quantum dots, bringing together primary research findings and overviews, along with articles on the commercialization of this technology.

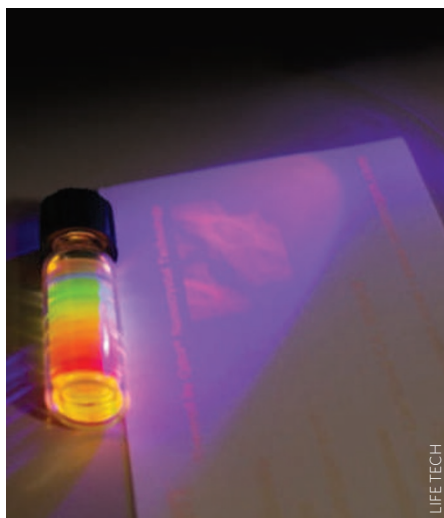
It is a commonly held belief that a material's composition defines its optoelectronic properties. Although this is indeed often the case, when semiconductors are scaled down in size, they can behave very differently from their bulk counterparts. Indeed, quantum dots — semiconductor nanocrystals with diameters in the range 2–10 nm — show size-dependent optical properties due to the effect of quantum confinement. Perhaps the most striking of these properties is that the monochromatic light emission from quantum dots is not only highly efficient but can be tuned by simply changing their diameter.

Furthermore, suspending such quantum dots in an organic polymer solution allows them to be printed and poured like a photonic ink onto a substrate, opening an avenue to easy, low-cost fabrication. Combined with efficient, narrowband light emission, this means that these tiny suspended semiconductor dots are now being explored for cheap, bright LEDs in lighting and displays, fluorescent labels in biomedical imaging and broadband solar cells, to mention just a few applications.

**There are currently an impressive number of companies commercializing quantum dots and dot-based devices.**

The June issue of *Nature Photonics* has a special theme on colloidal quantum dots, presenting the latest results from several research groups and commercial companies in this area. This theme gathers a collection of two primary research papers on a quantum dot LED display and an image sensor, a progress article on quantum dot photovoltaics, a News and Views article and an Out of the Lab piece charting commercialization of the technology. The compilation clearly demonstrates the great progress that colloidal quantum dots are making, not only in terms of device performance but also towards deployment in a wide variety of applications.

The LED is one of the devices in which quantum dots can be put into good use thanks to their ease of colour tunability, high brightness and narrow emission bandwidth. Nevertheless, large energy barriers for hole



and electron injection into the quantum dot layer limit the device performance. On page 341, Kyung-Sang Cho and colleagues from the Samsung Advanced Institute of Technology demonstrate how the energy barriers can be overcome by using specific crosslinking and thermal annealing of the colloidal quantum dot layer and incorporating sol-gel-processed TiO<sub>2</sub> as the electron transport layer<sup>1</sup>. Their device shows a high luminance (12,380 cd m<sup>-2</sup>), low turn-on voltage (1.9 V) and high power efficiency (2.41 lm W<sup>-1</sup>). When incorporated into a display device with an active matrix backplane, the approach shows potential for high-performance, easy-to-fabricate, large-area displays and illumination sources.

On the other hand, colloidal quantum dots can also be used to create infrared photodiodes. This capability is detailed on page 332 of this issue by Rauch and colleagues from Siemens AG, University of Linz and Universität Karlsruhe, who have fabricated an array of inorganic-organic hybrid bulk-heterojunction photodiodes containing solution-processed PbS nanocrystalline quantum dots integrated with an amorphous silicon active matrix (a-Si AM) backplane<sup>2</sup>. The image sensor made from the photodiode array shows excellent performance for near-infrared detection up to 1.8 μm, with rectification ratios of ~6,000, minimum lifetimes of one year and external quantum efficiencies up to 51%.

What's interesting about the achievements of these two groups is that they demonstrate that integration of colloidal quantum dot optoelectronics with silicon backplane electronics is practical, which is of great importance if the technology is going to find its way into products.

The findings are put into context by Seth Coe-Sullivan from the quantum dot start-up firm QD Vision in a News and Views article on page 315, where he shares his thoughts on the role played by colloidal quantum dots in vision and sensing in particular, and on the challenges that remain<sup>3</sup>.

Indeed, a look at the Out of the Lab article on page 307 immediately tells us that colloidal quantum dot technology has already garnered great attention in the world of commercialization<sup>4</sup>. The race to bring quantum dots to the market in fact started back in the early 2000s, and there are currently an impressive number of companies commercializing quantum dots and dot-based devices.

Firms are now able to mass-produce quantum dots with accurate dimensions and a variety of coatings, and are busy exploring their potential in applications ranging from displays and biomedical imaging to photovoltaics and quantum inks for fighting currency counterfeiting.

The prospects for solution-processed photovoltaics based on colloidal quantum dots are outlined in this month's Progress Article by Edward Sargent from the University of Toronto<sup>5</sup>. As he explains on page 325, the attraction of the technology is that it promises to reduce the cost per area of solar cells and extend their absorption wavelength to infrared region where half of the solar energy lies.

One thing is for sure: the research behind colloidal quantum dots is growing and sooner rather than later will be evident in the world around us in the form of brighter, more colourful displays, energy-efficient lighting and custom-designed fluorescent tags for biological imaging. □

## References

1. Cho, K.-S. *et al. Nature Photon.* **3**, 341–345 (2009).
2. Rauch, T. *et al. Nature Photon.* **3**, 332–336 (2009).
3. Coe-Sullivan, S. *Nature Photon.* **3**, 315–316 (2009).
4. Graham-Rowe, D. *Nature Photon.* **3**, 307–309 (2009).
5. Sargent, E. H. *Nature Photon.* **3**, 325–331 (2009).