LIGHT-EMITTING DIODES

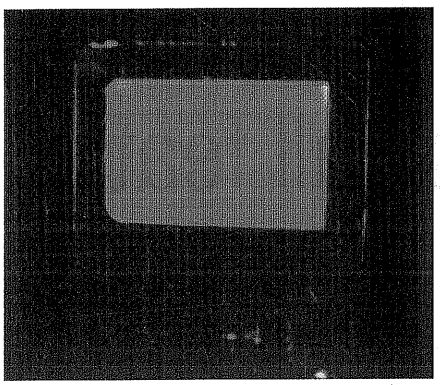
A bright outlook for quantum dots

The rapidly improved performance of LEDs based on multilayers of highly luminescent quantum dots could lead to promising applications in next-generation displays and lighting.

Alf Mews[1*] and Jialong Zhao[2†]
[1]Institute of Physical Chemistry, University of Siegen, D-57068 Siegen, Germany
[2]Key Laboratory of Excited State Processes, Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences, 16 Eastern South Lake Road, Changchun 130033, China
e-mail: *mews@chemie.uni-siegen.de; †zhaojl@ciomp.ac.cn

Technology based on semiconductor nanocrystal quantum dots (QDs) is maturing into a valuable tool for applications in opto-electronics and biomedicine, after two decades of active research. It is well known that QDs exhibit size-tunable photoluminescence, narrow emission linewidths, high quantum yield and superior photostability. Several applications of these inorganic chromophores have been proposed during the past 20 years, one of which is the ability to precisely tune the emission colour of devices by using the QDs as recombination centres. Light-emitting device structures based on a combination of conductive polymers and colloidal semiconductor QDs have also been suggested. However, the reported brightness, efficiency and lifetime of QD-LEDs are still below the requirements for commercialization.

On page 717 of this issue[1], researchers from China and the USA present their high-quality multicolour QD-LEDs, which set a benchmark in performance for those devices. Qingjiang Sun and co-workers demonstrate a QD-LED with a luminance of more than 9,000 cd m^{-2} and an electroluminescence efficiency of almost 3 cd A^{-1} that can last for several hundred hours (ref. 1). This was achieved using high-quality solution-processible QDs comprising a CdSe core and a ZnS or CdS/ZnS shell, and by careful optimization of the different device parameters, such as the conductive materials in the LED and the thicknesses of the respective layers. The work shows that detailed nano-engineering of available materials could further improve the device performance,



A red QD-LED with an emitting area of 1.5 × 2.5 cm^2 (ref. 1).

so that applications in, for instance, flat-panel displays might be possible.

The first realization of QD-LEDs was demonstrated in 1994, opening up a new field of application-driven fundamental research[2]. At that time, the devices showed a relatively low quantum efficiency (less than 0.1%) and impure emission from both the QDs and organic host materials, mainly due to the use of single- or bilayer device structures and the imbalance of carrier injection into QDs (ref. 2). A major breakthrough in device performance was achieved in 2002 when a QD-LED structure that incorporated just a single monolayer of CdSe/ZnS core/shell QDs sandwiched between organic hole- and electron-transport layers was demonstrated[3]. This multilayer QD-LED was fabricated through phase separation of the QDs and small organic molecules, and resulted in a significant improvement of the device performance towards quantum efficiencies of 0.5% at a brightness of 100 cd m^{-2}. Further optimization of performance could be achieved by multilayer QD-LEDs built on thermally crosslinked hole-transport materials, where the thicknesses of QD and organic layers could be varied independently[4]. With subsequent refinement, a maximum quantum efficiency of about 2% and luminous power efficiency of more than 1 lm W^{-1} could be realized[5,6].

In contrast to the QD-LEDs with a single monolayer of QDs, Qingjiang Sun and co-workers found that the optimized thickness of QD layers for the red, orange, yellow and green QD-LEDs were 2.0, 2.5, 4.0 and 7.0 monolayers, corresponding to layer thicknesses of 17.0, 18.75, 22.0 and 21.0 nm, respectively. The team found that the QD-layer thickness determines the electroluminescence efficiency and maximum luminance of the devices, and that the optimum thickness of the QD layer is influenced by the size and structure of the QDs for different colours. One cause of this effect might be the processing of the QDs before incorporation into the LEDs. Here, the authors used a multi-step purification process to wash away most of the organic ligands — which might modify the transport of holes and electrons within the QD layer — from the particle surface.

Although the high brightness reported by Qingjiang Sun and colleagues is impressive, it is worth noting that pure organic LEDs (OLEDs) are still more than 10 times brighter. They have a lifetime at least 100 times longer and show much higher efficiency than QD-LEDs. These devices are already on the market and are widely used in several applications. Hence, it is very unlikely that QD-LEDs will beat OLEDs in the near future in terms of device performance. However, QD-LEDs might find a niche in the market owing to their high colour purity, as the emission linewidth is of the order of 30 nm and the wavelength can, in principle, be tuned continuously from UV to infrared.

The key to further device optimization in QD-LEDs seems to be a detailed understanding of the electroluminescence mechanism — the charge injection across the interface of the organic conductive material and the inorganic QDs. One of the potential obstacles at present is the varying quality or lack of availability of QD samples. For example, a key point in device performance might be the realization of efficient energy transfer and charge injection from the organic molecules into

the QDs, and this is strongly dependent on the surface modification of the QDs. In the past, the electroluminescence from a single monolayer of QDs within a multilayer OLED was qualitatively explained by exciton generation in the QDs, either through direct charge injection or exciton energy transfer from the organic molecules[3]. In another model, it is suggested that Förster energy transfer of excitons from the host organic material to the QDs dominates the electroluminescence process[7].

Whatever the case may be, these processes are so far assumed to be more efficient for a single monolayer of QDs because the energy and charge transport between the QDs within a thick QD layer would lead to some loss in efficiency.

The good news is that high-quality CdSe core/shell QDs are now commercially available. This reduces the complexity of the whole process for preparing QD-LEDs. As soon as the details of the underlying physical mechanism can be worked out thoroughly and the synthetic parameters can be adjusted accordingly, the performance of the QD-LEDs is expected to be further improved.

References

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BIOPHOTONICS

Big images small features

Optical coherence tomography is a powerful imaging technique. Thanks to work from the Massachusetts Institute of Technology, this technique just got faster and more powerful, with the potential to advance intricate imaging studies of the human body.

Jennifer Barton

is in the Division of Biomedical Engineering at the University of Arizona, Tucson, Arizona 85721, USA.

e-mail: barton@u.arizona.edu

Optical coherence tomography (OCT) is a biomedical imaging technique that provides high-resolution images of subsurface tissue structure. As the resolution of OCT systems has increased in recent years, the ability to measure very small tissue features has improved. Accurate measurement in living organisms has been made possible by OCT systems that acquire three-dimensional volumetric images with a uniform high resolution. But the speed and data-handling requirements of such systems can be immense — for example an image of a tissue region 10 mm × 10 mm × 2 mm in volume, with a sampling volume of 8 μm × 8 μm × 8 μm, contains over 390 million voxels (three-dimensional versions of two-dimensional pixels). On page 709 of this issue, a team led by James Fujimoto from the Massachusetts Institute of Technology (MIT) reports on an advanced endoscopic OCT system that can acquire very-high-resolution image volumes with unprecedented speed[1].

Optical coherence tomography works by shining near-infrared light on tissue and using optical interference to detect backscattering from the underlying inhomogeneities and structural features.

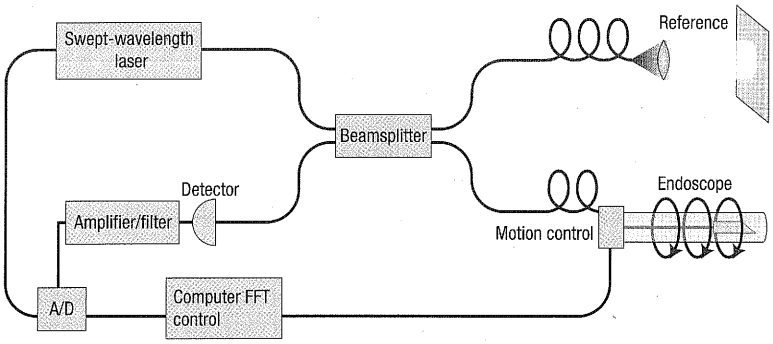

Figure 1 Schematic of a Fourier-domain OCT system. Light from a swept-wavelength laser source is divided by a beamsplitter into a reference arm containing a mirror and a sample arm containing a spiral-scanning endoscope. Reflected light is detected and amplified then stored using an analog-to-digital (A/D) board. A fast Fourier transform (FFT) is performed to extract depth-resolved reflection information. The computer also controls the scanning of the endoscope and displays the images.

The approach, which is non-invasive, can penetrate roughly 2 mm to 3 mm into a sample. First demonstrated by Fujimoto's group in 1991 (ref. 2), OCT imaging devices have steadily improved in terms of resolution and imaging speed. As with other optical imaging systems, the lateral resolution is determined by the imaging optics. However, axial resolution is defined by the spectrum of the light source. With the development of broad-bandwidth laser systems and specialized optics, OCT has in recent years achieved submicrometre axial image resolution[3].

However, these ultrahigh-resolution imaging systems tend to be relatively slow. The imaging speed in OCT systems can be restricted by the mechanical limitations of moving parts, or by signal-to-noise issues. Early OCT systems were developed in the time domain. In this approach, the light from a broadband source is split into a sample arm and a reference arm of an interferometer. The reference-arm beam (path length) is then modulated. Interference fringes are only observed when the optical path length in the reference arm matches (to within a