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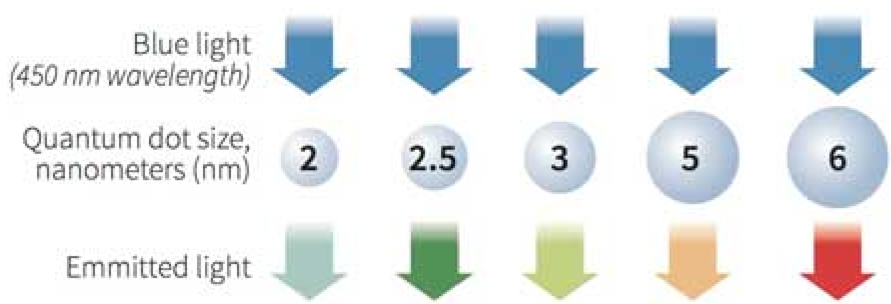
What are quantum dots?

Quantum dots (QDs) are man-made nanoscale crystals that that can transport electrons. When UV light hits these semiconducting nanoparticles, they can emit light of various colors. These artificial semiconductor nanoparticles that have found applications in composites, solar cells and fluorescent biological labels.

Nanoparticles of semiconductors – quantum dots – were theorized in the 1970s and initially created in the early 1980s. If semiconductor particles are made small enough, quantum effects come into play, which limit the energies at which electrons and holes (the absence of an electron) can exist in the particles. As energy is related to wavelength (or color), this means that the optical properties of the particle can be finely tuned depending on its size. Thus, particles can be made to emit or absorb specific wavelengths (colors) of light, merely by controlling their size.



Quantum dots are nanoscale man-made crystals that have the ability to convert a spectrum of light into different colors. Each dot emits a different color depending on its size. (Image: RNGS Reuters/Nanosys)

Quantum dots are artificial nanostructures that can possess many varied properties, depending on their material and shape. For instance, due to their particular electronic properties they can be used as active materials in single-electron transistors.

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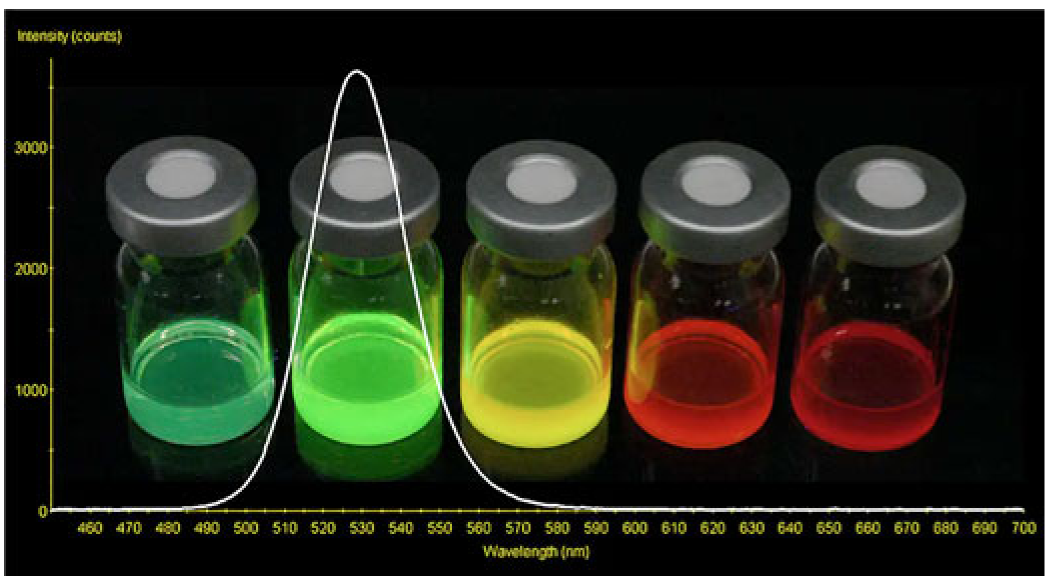
applications in such areas as catalysis, electronics, photonics, information storage, imaging, medicine, or sensing – needs to be capable of churning out large quantities of nanocrystals where each batch is produced according to the exactly same parameters.

Because certain biological molecules are capable of molecular recognition and self-assembly, nanocrystals could also become an important building block for self-assembled functional nanodevices.

The atom-like energy states of QDs furthermore contribute to special optical properties, such as a particle-size dependent wavelength of fluorescence; an effect which is used in fabricating optical probes for biological and medical imaging.

So far, the use in bioanalytics and biolabeling has found the widest range of applications for colloidal QDs. Though the first generation of quantum dots already pointed out their potential, it took a lot of effort to improve basic properties, in particular colloidal stability in salt-containing solution. Initially, quantum dots have been used in very artificial environments, and these particles would have simply precipitated in 'real' samples, such as blood. These problems have been solved and QDs have found numerous use in real applications.



Vials of quantum dots producing vivid colors. For instance, a cadmium-based quantum dot showing pure, highly specific green color response. (Image: NASA)

Quantum dots have found applications in composites, solar cells (Grätzel cells) and fluorescent biological labels (for example to trace a biological molecule) which use both the small particle size and tuneable energy levels.

Advances in chemistry have resulted in the preparation of monolayer-protected, high-quality, monodispersed, crystalline quantum dots as small as 2 nm in diameter, which can be conveniently treated and processed as a typical chemical reagent.

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QDs are either used as active sensor elements in high-resolution cellular imaging, where the fluorescence properties of the quantum dots are changed upon reaction with the analyte, or in passive label probes where selective receptor molecules such as antibodies have been conjugated to the surface of the dots.

Quantum dots could revolutionize medicine. Unfortunately, most of them are toxic. Ironically, the existence of heavy metals in QDs such as cadmium, a well-established human toxicant and carcinogen, poses potential dangers especially for future medical application, where qdots are deliberately injected into the body.

As the use of nanomaterials for biomedical applications is increasing, environmental pollution and toxicity have to be addressed, and the development of a non-toxic and biocompatible nanomaterial is becoming an important issue.

Quantum dots in photovoltaics

The attractiveness of using quantum dots for making solar cells lies in several advantages over other approaches: They can be manufactured in an energy-saving room-temperature process; they can be made from abundant, inexpensive materials that do not require extensive purification, as silicon does; and they can be applied to a variety of inexpensive and even flexible substrate materials, such as lightweight plastics.

Although using quantum dots as the basis for solar cells is not a new idea, attempts to make photovoltaic devices have not yet achieved sufficiently high efficiency in converting sunlight to power.

A promising route for quantum dot solar cells is a semiconductor ink with the goal of enabling the coating of large areas of solar cell substrates in a single deposition step and thereby eliminating tens of deposition steps necessary with the previous layer-by-layer method.

Graphene quantum dots

Graphene, which basically is an unrolled, planar form of a carbon nanotube therefore has become an extremely interesting candidate material for nanoscale electronics. Researchers have shown that it is possible to carve out nanoscale transistors from a single graphene crystal (i.e. graphene quantum dots). Unlike all other known materials, graphene remains highly stable and conductive even when it is cut into devices one nanometer wide.

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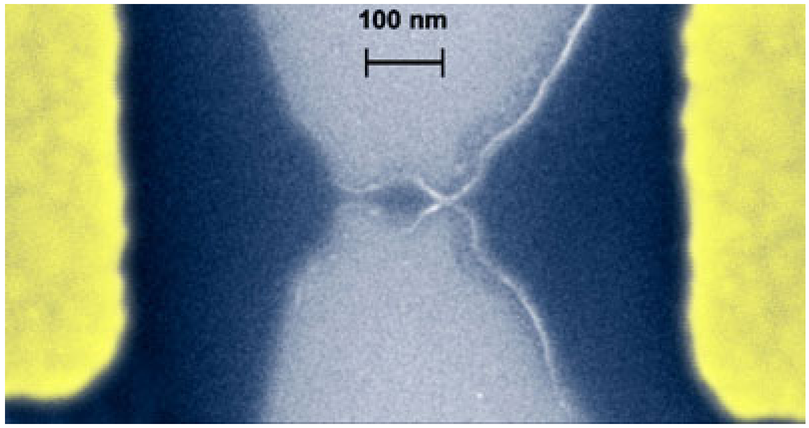

Quantum dot carved from a graphene sheet. (Image: Mesoscopic Physics Group, University of Manchester)

Graphene quantum dots (GQDs) also show great potential in the fields of photoelectronics, photovoltaics, biosensing, and bioimaging owing to their unique photoluminescence (PL) properties, including excellent biocompatibility, low toxicity, and high stability against photobleaching and photoblinking.

Scientists still are working on finding efficient and universal methods for the synthesis of GQDs with high stability, controllable surface properties, and tunable PL emission wavelength.

Perovskite quantum dots

Luminescent quantum dots (LQDs), which possess high photoluminescence quantum yields, flexible emission color controlling, and solution processibility, are promising for applications in lighting systems (warm white light without UV and infrared irradiation) and high quality displays.

However, the commercialization of LQDs has been held back by the prohibitively high cost of their production. Currently, LQDs are prepared by the HI method, requiring at high temperature and tedious surface treating in order to improve both optical properties and stability.

Although developed only recently, inorganic halide perovskite quantum dot systems have exhibited comparable and even better performances than traditional QDs in many fields.

By preparing highly emissive inorganic perovskite quantum dots (IPQDs) at room temperature, IPQDs' superior optical merits could lead to promising applications in lighting and displays.

Quantum dot TVs and displays

The most commonly known use of quantum dots nowadays may be TV screens. Samsung and LG launched their QLED TVs in 2015, and a few other companies followed not long

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next-generation displays. Compared to organic luminescent materials used in organic light emitting diodes (OLEDs), QD-based materials have purer colors, longer lifetime, lower manufacturing cost, and lower power consumption. Another key advantage is that, because QDs can be deposited on virtually any substrate, you can expect printable and flexible – even rollable – quantum dot displays of all sizes.

Nanotechnology Introduction

Nanotechnology Applications

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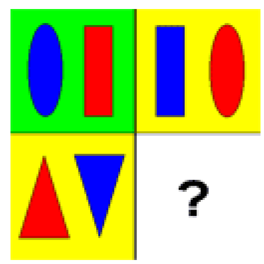

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