Discovery of Non-blinking Semiconductor Nanocrystals Advances their Applications

May 28 2009

(PhysOrg.com) -- Substantial advances for applications of nanocrystals in the fields requiring a continuous output of photons and high quantum efficiency may soon be realized due to discovery of non-blinking semiconductor nanocrystals. This discovery recently announced by scientists at the Naval Research Laboratory, University of Rochester, Cornell University and Eastman Kodak Company is an important step to the use of the nanocrystals in various practical devices ranging from low-threshold lasers to the solar cells and biological imaging and tracking. The complete findings of the study are published on line in the May 10, 2009, issue of the journal *Nature*.

Colloidal nanocrystals are a new class of optical materials that essentially constitute a new form of matter that can be considered as "artificial atoms." Like atoms, they have discrete optical energy spectra that are tunable over a wide range of wavelengths by varying the nanocrystals' size. The widely tunable absorption band edge is controlled mainly by the nanocrystal size, resulting in widely tunable emission spectra. This tunability combined with the optical stability of nanocrystals and the great chemical flexibility in the nanocrystal growth have resulted in the widespread nanocrystal applications in use today.

Nanocrystals show quite high photoluminescence quantum efficiency of up to 70% at room temperature. The missing 30% efficiency turns out to be an intrinsic property of nanocrystals. Studies of single colloidal nanocrystals show that they randomly turn their photoluminescence on and off even under continuous light illumination. Dr. Alexander Efros,

from NRL's Center for Computational Material Science, describes the blinking problem in this way, "Imagine the irritation and frustration you would feel if the bulb in your reading lamp started to blink. These same emotions are experienced by engineers and scientists who study single colloidal nanocrystals and try to use their fluorescent properties for biological imaging or lasing" (*Nature Materials*, vol. 7, 612 (2008)).

The blinking in nanocrystals was first reported 13 years ago, and it came as a surprise to researchers. Today, researchers agree that the blinking happens because when illuminated, nanocrystals can be charged (or ionized) and then neutralized. Under normal conditions when nanocrystal is neutral, a photon excites an electron-hole pair, which then recombines, emitting another photon and leading to photoluminescence. This process is called radiative recombination. If however, the nanocrystal is charged, the extra carrier triggers a process called non-radiative Auger recombination, where exciton energy is transferred to an extra electron or hole. Auger recombination occurs orders of magnitude faster than the radiative recombination.

So photoluminescence is almost entirely suppressed in charged nanocrystals. Scientists still do not fully understand the origin of the charging and neutralization process. One of the photoexcited carriers (the electron or the hole) must be ejected from the nanocrystal. At some later time, the ejected charge returns to the nanocrystal (restoring charge neutrality and therefore radiative recombination). The details of these processes occur still are not understood.

Scientists are attempting to eliminate the problem of blinking nanocrystals. One common solution is to suppress nanocrystal ionization. This could be done, for example, by growing a very thick semiconductor shell around the nanocrystal core. However, blinking was reduced, not eliminated, because the fundament processes responsible for blinking - the non-radiative Auger recombination- were still present.

The team of researchers at University of Rochester, Eastman Kodak Company, Cornell University and NRL have taken a significant step toward solving this problem by synthesizing gradually-graded alloy CdZnSe core nanocrystals capped with a ZnSe semiconductor shell that never blinks. The highly unusual multi-peaked photoluminescence spectra clearly indicates also that these nanocrystals always have an extra charge. The observation of photoluminescence from charged (ionized) nanocrystals is direct proof that the nonradiative Auger recombination has been weakened by three orders of magnitude.

The Auger rate suppression is connected with softening the abrupt confined potential of typical core/shell nanocrystals in the structures with a radially graded alloy of CdZnSe into ZnSe. Future efforts will be focused on optimization of these nanocrystal structures with a goal to eliminate the nonradiative Auger processes completely. By completely suppressing blinking associated with Auger processes and "keeping the nanocrystal light bulb turned on," as Dr. Efros explains, researchers look to future breakthroughs for photonics, laser, and other optical applications of nanocrystals.

Provided by Naval Research Laboratory (news : web)