CRYS-QD
SALT MACROCRYSTALS OF CD-FREE QUANTUM DOTS FOR STABLE WHITE LIGHT GENERATION

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Project context and objectives

For about a decade, the lighting technologies pass through a period of revolution aiming high efficiency and high quality lighting employing light-emitting diodes (LEDs). Today, in many parts of the world incandescent lamps were banned because of their inefficiencies. The fluorescent lamps being more efficient then the incandescent counterparts, however, still remain inefficient compared to LEDs. Furthermore, they suffer from poor light quality, mercury content and health problems associated with flickering.

There are two main approaches of white light generation involving LEDs. In the first case, blue-, green-, and red-emitting LEDs are simultaneously used to realize a white color while the second architecture involves the use of blue- (or rarely UV-) emitting LEDs combined with a color converting material. Because of their high quantum efficiencies, phosphors are the most widely preferred materials as color converters. However, being rare-earth doped materials they suffer from serious supply issues involving political crises. In addition, they are naturally broadband emitters whose emission tails reaching the deep red region where the eye is not sensitive enough and consequently decreasing the luminous efficiency.

The quantum dots being efficient narrow band emitters with broad absorption bands, which allow for significant control of the white light spectrum and optimization of the device performance in contrast to phosphors, are promising candidates for replacing them. However, frequently used quantum dots are made of Cd atoms which makes them questionable materials from environmental point of view. Therefore, Cd-free quantum dots are of significant importance for a reliable environment friendly devices. Another important drawback of colloidally synthesized quantum dots is their sensitivity to environmental effects when embedded into devices using encapsulants such as silicone. Furthermore, their stability to heat still remains poor. As a remedy to these challenges, our team developed the embedding of quantum dots into large scale salt crystals.

In this particular project, we developed a white LED involving Cd-free quantum dots embedded in salt crystals. The studies that we carried out within the framework of this seed project have been the first account of Cd-free macrocrystals and their application in LEDs. We aimed to obtain a Cd-free macrocrystal based white LED possessing a color quality scale (CQS) >85 and luminous efficacy of optical radiation (LER) >300 lm/W_{opt} together with a correlated color temperature (CCT) >3500 K. CQS was preferably used instead of color rendering index (CRI) as it was found out that CRI might present the color rendition performance not very accurately when narrow emitters are employed.

Brief description of the main results

The spectral requirements were studied theoretically to realize photometrically efficient white light emitting diodes employing Cd-free macrocrystals. In addition to the theoretical works, InP/GaP/ZnS colloidal quantum dots were synthesized using SILAR technique and these QDs were transferred to water phase prior to crystallization. This step turned out to be the most crucial part. Nevertheless, a, still non-optimized, phase transfer protocol was found, yielding stable QD solutions in H2O but causing losses of PL-QY to 10-15 % of the initial value. The crystallization process was carried out in a variety of salts such as NaCl, KCl and Borax, and these salts were integrated on to LEDs using silicone. Because of the stability problems of red emitting QDs, crystallization process was not successful as in the case of yellow QDs. Therefore, white LEDs were prepared using yellow QD crystals and the characterization of the white LEDs was carried out.

Final results, potential impact and use

Within the framework of this project, we successfully investigated the spectral requirements to realize photometrically efficient white light generation. In addition, InP/GaP/ZnS quantum dots in nonpolar solvents were synthesized. The ligand exchange of theses QDs from nonpolar solvents to polar solvents was carried out, however, the stability of the quantum dots in water turned out to be an important challenge. QD embedded macrocrystals were successfully grown using NaCl, KCl, and disodium tetraborate (Borax). These macrocrystals were integrated on a blue LED using silicone encapsulate. Finally, the photometric characterization of these LEDs was carried out. The obtained white LED exhibited a CQS of 33, a LER of 257 lm/W_{opt} at a CCT of 2130 K.