ecoDOTs
NOVEL ECO-FRIENDLY LUMINOPHOR QUANTUM DOTS FOR ENERGY EFFICIENCY SOLID STATE LIGHTING

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Project context and objectives

The use of Cd-free quantum dots, their physics and uses in energy transfer hold a great promise for future environmental friendly applications. The aims of this project have been to design and develop radically new, environmentally friendly, nanostructured material alternatives to conventional phosphors for the future production of innovative color conversion LEDs that outperform today's phosphor based LEDs in terms of their photometric performance including color rendering index, color homogeneity and correlated color temperature with respect to high luminous efficacy of optical radiation. Today's traditional phosphors solely rely on the use of combinations of rare earth ions in a ceramic host. While this conventional type of phosphors is good at photon conversion with high quantum efficiency, there exist fundamental problems related to their photometric performance. Among them, photometric issues associated with their large emission bandwidth (and thus inevitable emission tail toward long wavelengths), combined with the problems of uncontrolled scattering due to undesirably large particle sizes (causing color coordinates to change over angle) are crucial. Also, the fact that China is the major holder and supplier (currently 95-97%) of rare earth ion resources (necessary for conventional phosphors) worldwide raises a strategically critical issue. Therefore, novel eco-friendly luminophor alternatives as proposed herein are essential to the solid-state lighting future of Europe.

Now scientific research is ready for a fundamental advancement to design and produce an entirely new generation of luminophor nanomaterials based on rational nanophotonic and photometric design. Such a scientific challenge is addressed and accomplished by combining innovative materials in the ecoDOTs project. The basic innovative research approaches involve:

i) the development and use of Cd-free colloidal semiconductor quantum dots (nanocrystals – NCs) from environmentally friendly materials such as InP and ZnS as the colour converting units with large absorption cross-sections, and fine tuning of their emission,
ii) the enhancement of the coating performance by opportunely using high refractive index and low absorption metal oxide particles to achieve enhanced light extraction, and

iii) the state of the art modeling and verification of photometric performance of the materials and assemblies and their integration and validation on test LED devices along with photometric evaluation.

Brief description of the main results

In this project, we demonstrated the synthesis, characterization, and in film temperature dependent energy transfer study and emission kinetics among the different sized InP/ZnS quantum dots. Using different sized InP/ZnS dots in a mixed form in a film structure, we observed up to 80% FRET efficiency and donor lifetime modifications from 18 ns to 4 ns. The suppression of the nonradiative channels in the quantum dots as being cooled to cryogenic temperatures has been observed as well for the InP/ZnS quantum dots. The experimental lifetime modifications of the donor and acceptor quantum dots as a result of energy transfer are in good agreement with our theoretical approach based on the exciton-exciton interaction among the dots. We investigated metal oxide nanoparticles with the aim of enhanced light extraction with better colour mixing. We showed the enhancement of LED color-conversion coating film by opportunely using high refractive index and low absorption particles such as TiO_2 nanoparticles of various sizes. We also verified photometric performance of the color-converting materials and assemblies on LED devices along with photometric evaluation.

Final results, potential impact and use

To date the photometric performance of Cd-containing II-VI semiconductors could not be exceeded. Therefore, the development, optimization and application of Cd-free nanomaterials for colour conversion purposes, which are compatible to large-scale, environment-friendly manufacturing, is a main novelty of this seed-project. Furthermore, incorporation of these nanoluminophors into controlled scattering medium enables unprecedented colour homogeneity.

In the present project we concentrated our efforts on band-gap emitting InP NCs. Reproducible up-scaling of the synthesis of stable, processable (compatible with silicone or alternative sol-gel matrices) and simultaneously strongly emitting (with QY of >50%) InP NCs is still a challenging task, which is addressed in the ecoDOTs seed-project.