Correlative Microscopy in Life and Materials Science

MIM.4.050

Correlative Light and Electron Microscopy (CLEM) for Characterization of Light Converting Inorganic Phosphors

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Keywords: Solid state lighting, LED, phosphors, correlative microscopic imaging techniques, microstructure, characterization, particle analysis

Light Emitting Diodes (LED) have been introduced in all fields of lighting applications and are increasingly overcoming established technologies. Not only since the prohibition of incandescent lamps within the European Union LEDs are attractive candidates for replacement of classic lighting concepts in the consumer market as they are highly efficient. White LEDs with luminous efficacies of more than 250 lm/W have already been demonstrated [1]. Further advantages of the LED are a long lifetime and their small size, which allows high design flexibility.

Since LEDs are optical semiconductor devices with a well-defined bandgap, they basically emit monochromatic radiation. White LED light can for example be achieved by the combination of two (yellow and blue) or three (red, green and blue) LEDs. But next to other disadvantages the color rendering of this multispectral approach is very low. Higher color rendering indices can be achieved by phosphors which convert the short-wavelength radiation of a blue or UV LED into broad emission bands covering a large spectral range [2].

Next to good color rendering properties, the phosphor materials also have to be very efficient to obtain a high luminous efficacy together with the emitting semiconductor device. To minimize losses, optical absorption should be kept low. This is also important to minimize thermal effects since degradation or other aging artefacts should not occur over the whole lifetime of a LED [3]. Furthermore, sustainable materials should be used for light conversion due to environmental issues. A high uniformity of the phosphor materials over a long time of production is another important demand to ensure a stable LED quality. Therefore, the performance of a LED as shown in Figure 1 strongly depends on the phosphor materials and their microstructure plus its stability during the LED operation.

In this contribution we will present microstructural investigations of light converting inorganic phosphors using light microscopy (LM) and scanning electron microscopy (SEM). Different phosphor materials will be analyzed and changes in the microstructure after light exposure will be shown. Additionally, the advantages of different contrast mechanisms like color, polarization, and dark field imaging in LM combined with backscattered electron imaging or energy dispersive x-ray analysis will be demonstrated. Combining both imaging techniques by the correlative light and scanning electron microscopy (CLEM) enables characterization of identical regions of interest with both microscopes [4,5], whereas this method is very efficient and flexible. As an example Figure 2 shows the same sample area within a distribution of different phosphor particles. In these CLEM images the same particle formation is visible under different contrasts. This technique is very useful to correlate information of the LM (e.g. color, optical activity, particle density) with the visualization and analysis techniques of the SEM (e.g. particle size, surface morphology, cathodoluminescence, element distribution) for a deeper understanding. Furthermore, quantitative data analysis and statistics about the microstructural parameters can be performed effectively now.

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6. We kindly acknowledge financial support from the “Akademische Gesellschaft Lippstadt” as well as from the “Ministerium für Innovation, Wissenschaft und Forschung des Landes Nordrhein-Westfalen”.

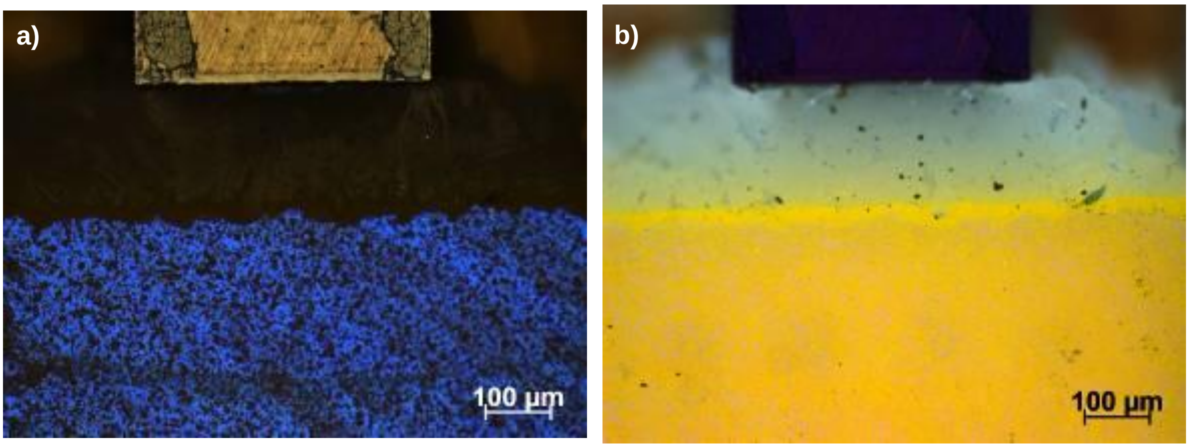

Figure 1. LM images of a LED chip with active area (below) and contact pad (above). a) Brightfield image; b) Polarized light image showing emission from the yellow phosphor.

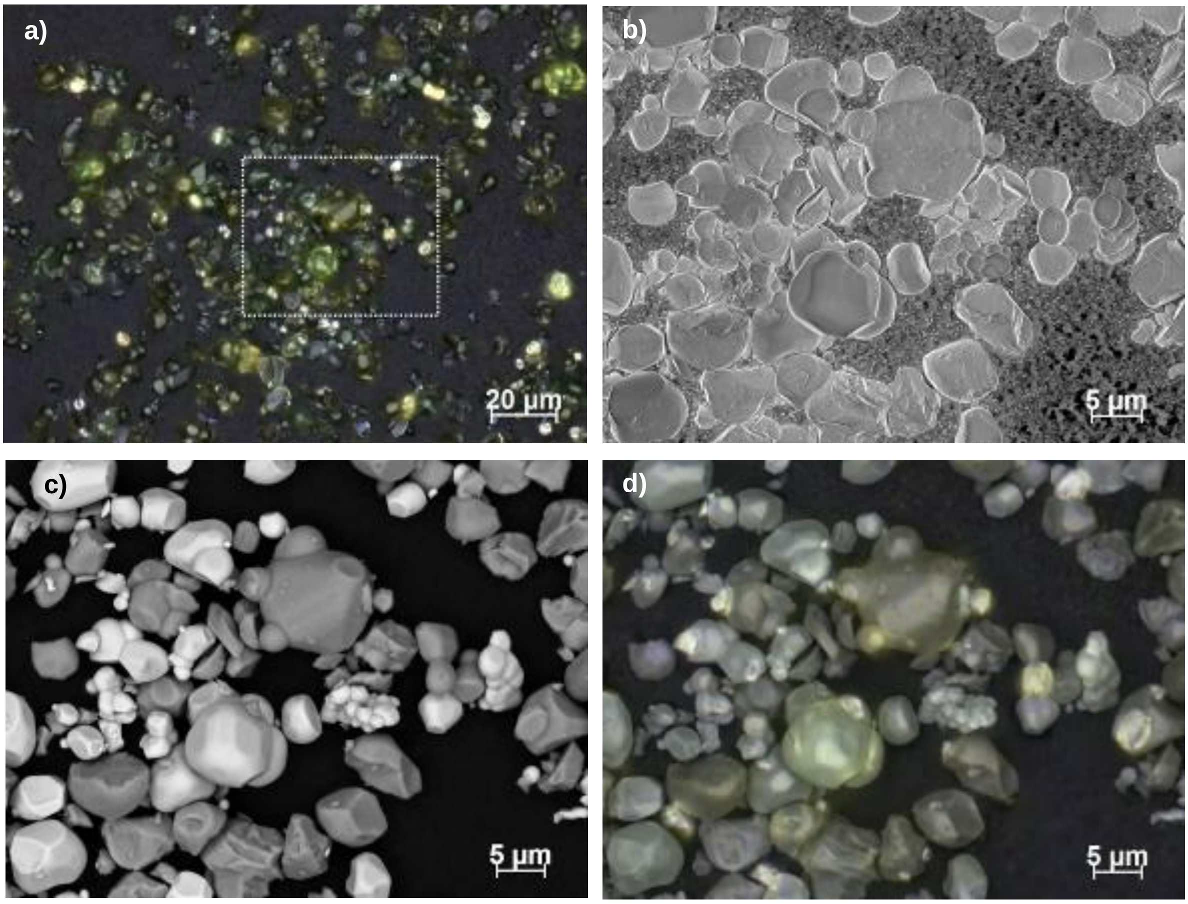

Figure 2. CLEM images of a distribution from inorganic phosphor particles. a) Brightfield LM overview image with color information, dotted rectangle indicates image area of b)-d); b) Inlens SE image showing surface morphology of the particles; c) BSE image with material contrast; d) Overlay of color information and corresponding material contrast.