Organic light emitting diodes (OLEDs) and hybrid quantum dot organic LEDs (QD-OLED) have received much scientific interest as fully solution-processable, tunable solutions for lighting applications with high efficiency. However, accurate structural characterization of the devices and correlation with their degradation behavior is often limited due to the beam sensitivity of the organic layers. Here, however, we are able to describe results with such systems on a complete morphological and compositional study of stacked OLEDs and Si Quantum Dot LEDs (SiLED) [1]. These high quality contributions to nanoscience were achieved using an image corrected FEI Titan 80-300 operated at 300kV. Initial BF-TEM and HAADF-STEM imaging was performed under strict low-dose conditions (dose <100 e/nm²), but as the morphology of the organic multilayers remains stable even at significantly higher doses after pre-illumination at low current. A more detailed compositional analysis using EFTEM and STEM-EDX mapping was performed to image the composition of the different 2.5-35 nm thick organic and hybrid layers. The resulting elemental distribution is in very good agreement with the nominal composition of the different layers, e.g. shown in Fig. 1 and 2 for the C, N, O, S, Si and F distribution in a SiLED device.

A comparison of the as-fabricated and electrically driven SiLEDs as well as SiLEDs prepared using monodisperse and polydisperse SiQDs [2] was carried out to correlate the morphological and compositional features with the degradation behavior and was combined with electroluminescence and photoluminescence life-time studies. This analysis showed that the morphology and composition of the SiLED is preserved during normal operation of the devices even though the electroluminescence is reduced to 20% during this operation, which is attributed to atomic scale processes within the SiQDs themselves. In contrast, at high voltage/current, significant electromigration of SiQDs into the hole blocking layer TPBi is observed, whereas no change for the other organic layers can be detected. For non-size separated SiQDs, device life-times are significantly reduced compared to SiLEDs built from monodisperse SiQDs. This seems to be related to both percolating path of larger nanoparticles inside the SiQD layer as well as diffusion/electromigration of extremely small nanoparticles into the hole-blocking layer. We expect that these results are not only valid for SiLEDs but also transferable to other QD-based LEDs.

References:

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Fig. 1: Schematic representation of the SiLED stack and HAADF-STEM cross-section image with corresponding EDX maps (scale bars 20 nm).

Fig. 2: Zero-loss filtered BF-TEM image of a SiLED cross-section together with low-loss EFTEM images and elemental maps for silicon, carbon, oxygen and nitrogen (scale bars 50 nm).