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Characterization and Improvement of Light-emitting Electrochemical Cells

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Akademisk avhandling

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Abstract
The light-emitting electrochemical cell (LEC) is an emerging electroluminescent technology, which is attractive since it can deliver bright area emission at low voltage from thin and flexible devices that can be cost- and energy-efficiently fabricated by scalable printing techniques. This opens up for applications where current light emitting diode (LED) and organic light emitting diode (OLED) technologies fall short, primarily in terms of cost, sustainability and form factor. Many projected LEC applications are portable (and powered by an integrated energy storage device or by integrated wireless energy harvesting) in the realm of, for instance, MedTech, packaging, signage, security and wearables, where the available input energy is limited. Thus, achieving a high brightness at high emission efficiency, i.e. the efficiency at which the device converts electric energy to emitted light from the device structure, is critical. However, this requires a detailed understanding of the complex operation mechanism of the LEC.

When the LEC is electrically powered, the mobile ions in the active material reorganize in situ to form injection-enabling electric double layers followed by electrochemical p- and n-type doping and the formation of a p-n junction region. The emission zone (EZ), located in the p-n junction region where the injected electrons and holes meet and light is generated, is dynamic in the LEC due to the in situ electrochemical doping. This complicates the analysis of the device performance since the EZ position strongly influences the outcoupling efficiency of the light generated in the p-n junction and since the EZ width plays an important role in the internal quenching mechanisms of the LEC.

In this thesis, we present a characterization method for the measurement of the dynamic EZ in an LEC, and we add to the understanding of how an efficient LEC should be designed. The EZ position is determined with the aid of the optical microcavity effect by fitting simulated to measured angle-resolved electroluminescence spectra. By using this method, we could show that the EZ position can be shifted from close to the anode towards the center of the active material in a common LEC through the inclusion of an appropriate additive into the active material, which is very attractive since it resulted in a 60 % improvement of the emission efficiency. Secondly, we combined this method with so-called “efficiency roll-off” measurements (i.e. the drop in emission efficiency with increasing current density) to derive the internal loss factors. Specifically, by quantifying the change of the light outcoupling efficiency with the extracted shift of EZ position, we could identify and quantify the losses due to exciton quenching. We find that the efficiency roll-off in common singlet-exciton emitting LECs is mainly due to the singlet-exciton:polaron quenching (with the polarons being the electrons and holes in the organic semiconductor). Finally, we improved the EZ measurement method by considering the doping-dependent refractive index in the optical modeling, by enhancing the measured emission spectra intensity at large angles by using a half-cylinder lens, and by removing the influence from the emitter’s anisotropy with a polarizer. With this improved method, the EZ width can also be extracted, and we find that the EZ width decreases during the initial operation and that the EZ width at steady-state is ~20 % of the thickness of the active material for a common LEC device. In summary, the findings presented in this thesis contribute to a deeper understanding of the complex LEC doping structure, thus paving the way for brighter and more efficient LECs for practical applications.

Keywords
Light-emitting electrochemical cell, emission zone, external quantum efficiency

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