

# DEVELOPMENT OF SOLUTION PROCESSED MULTILAYER OLEDs

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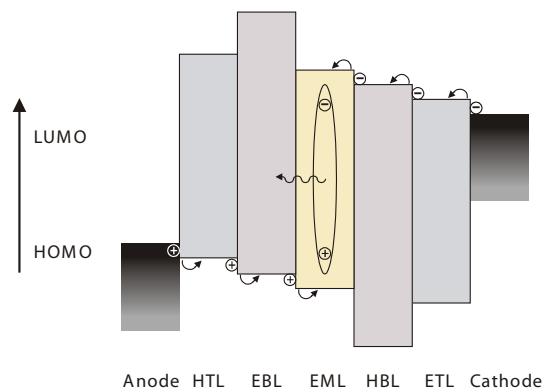
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## Introduction

Research on organic light-emitting diodes (OLEDs) has gained much attention due to the potential for cheap and ultrathin illumination sources with high viewing angle and color range. Charges are induced from the electrodes into an organic semiconducting layer and recombine to form an exciton. The relaxation from the excited to the ground state results in the emission of light [1]. In multilayer devices it is possible to improve the carrier injection efficiency from the electrodes into the light-emitting layer (EML), by layers for hole or electron transport (HTL/ETL) and blocking (HBL/EBL). Figure 1 gives an overview about the basic working principle.



*Fig. 1: Schematic of the device structure.*

Vacuum evaporation is the standard method to produce precisely defined interfaces in small molecule multilayer stacks, but it is an expensive process with high material waste. The wet chemical processing has advantages in production cost, deposition rate and area, but shows problems with the intermixing of the subsequently coated layers [2]. Although multi-layer structures are common in many industrial applications, and intermixing can be effectively prevented for several organic and inorganic layers (e.g. in the photographic industry), the specific nature of the small organic OLED molecules with their high mobility for diffusion in combination with low dry film thicknesses of only a few nanometres is challenging. For a better understanding of the physical limitations of liquid-phase processed multi-layer OLED structures,

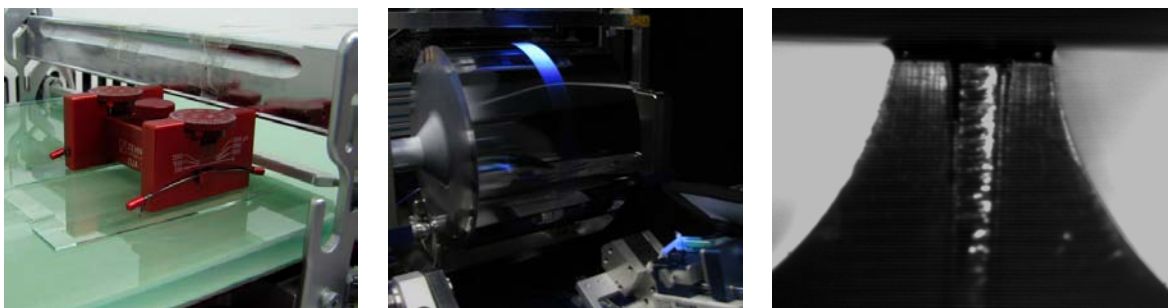
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the material mixing between two model layers during coating and drying was investigated experimentally and numerically. Commercially available small molecules originally developed for vacuum deposition were used. Comparison of simulation results with experiments demonstrate the feasible intermixing between the organic layers. As far as we know, no results for slot-die and knife coated small molecule OLED multilayer stacks with proven defined interlayer have been reported.

### **Experimental Methods**

To produce a double-layer stack, the concept of orthogonal solvents is used. The material of the second layer has to be solved in an organic liquid that does not solve any material of the first layer. Since the investigated small molecules show at least a poor solubility in most organic solvents, their behavior can only be described as low soluble or quasi-orthogonal.

Within the scope of this work, a setup for a small molecule double-layer stack was chosen with a host material for the EML as a first layer and a material for the HBL as a second layer. The material for the second layer is soluble in two different solvents - a non-orthogonal and a quasi-orthogonal solvent for the material of the first layer. In separate approaches one of the solutions for the second layer is deposited by slot-die or knife coating onto the dry first layer. Simultaneous coating of the two materials with a two-layer slot-die coater is currently under investigation (see figure 2).



*Fig. 2: Left: Experimental setup for blade coating.*

*Middle: Mini slot-die and coated small molecule layer under UV light.*

*Right: Visualization of coating flow in two-layer slot coater (cooperation with M. Schmitt, TFT).*

The intermixing of the materials of both layers is characterized by X-ray photoelectron spectroscopy [3]. By combining it with argon sputtering, we are able to analyze the atomic concentrations in a depth profile of the organic layers. The possible differentiation of the materials in the layers is proven with an evaporated double-layer reference. The use of a quasi-orthogonal solvent leads to double-layers with clear interface between the layers. The

measurement only has a resolution of around 5 nm, so it is not possible to detect the accurate thickness of a small mixing zone that may occur. With the use of a non-orthogonal solvent we can fabricate homogeneous layers, but the materials are completely mixing during the process. Also the better process conditions of slot-die coating, with reduced feed reservoir in front of the coating tool compared to knife coating, do not lead to a better result.

### **Simulation**

The diffusion of small molecules into a coated top layer was calculated by simulating the diffusion kinetics. Due to the high mobility of the material by interacting with the solvent during the process, the resulting diffusion of the molecules will lead to equalization of the concentration gradient and may lead to intermixing of the organic materials of the different layers. As boundary condition at the phase boundary the solubility limit is assumed and a constant diffusion coefficient is used, that was determined by NMR measurements. The diffusion time of the small molecules in contact with a quasi-orthogonal solvent lies in the timescale of the adjustable drying time, but is much shorter for a non-orthogonal solvent. Therefore, for quasi-orthogonal solvents the intermixing can be prevented by choosing the right process parameters.

### **Conclusion**

Double-layer stacks were produced by large-scale coating techniques. Knife and slot-die coated homogeneous double-layers were investigated. By using quasi-orthogonal solvents for two consecutive layers, a defined separated interface is created and has been proven by adequate characterization methods.

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