Process Dependent Performance of Slot Die Coated OLED-Multilayers (TALK)

Sebastian Raupp[1,2], Lisa Merklein[1,2], Philip Scharfer[1,2] and Wilhelm Schabel[1]

[1] *Institute of Thermal Process Engineering, Thin Film Technology, Karlsruhe Institute of Technology, Kaiserstrasse 12, 76131 Karlsruhe (Germany)*

[2] *Innovation Lab (iL), Heidelberg (Germany)*

Corresponding author: sebastian.raupp@kit.edu

Phone: +49 721 608 43950   Fax: +49 721 608 43490

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Introduction

With a main focus on lighting applications, OLEDs offer an auspicious technique for replacing inefficient illuminants [1–3]. Large area coating technologies with high reliability need to be developed to lower the prices of OLEDs[3–5]. Besides polymers, small molecule materials are applied in OLEDs. The biggest challenges in a wet film deposition process are the realization of the multilayer architecture as well as life time issues.
Small molecules are favorable in terms of efficiency[4,5] but their film formation properties are critical. Films of small molecules are more likely to form pinholes and can be dissolved much easier than polymers[8]. Therefore it is a great challenge to apply nanometer thin layers of small molecules on top of each other by a solution deposition process.

Methods

In this work we investigate slot die coating for solution processing of a simplified OLED stack. As spin-coating is the most commonly used method for solution-processing of OLEDs [6,7] we apply it as a second process for comparing both methods in terms of film homogeneity and performance of the devices.
A simplified stack offers the possibility of changing one targeted process parameter by excluding other undesired influences in the long process chain. Therefore, the stack only consists of two or three organic layers as shown in Figure 1. All experiments are performed in batch-wise coatings with a high-precision table coater. As emissive layers small molecules, polymers and host/guest systems with different rheological properties are investigated. First, the influence of fluid formulation on the film homogeneity is investigated.
More than 300 OLEDs were produced to analyze the different material combinations regarding of performance and reproducibility. The influence of coating speed and drying time on device performance are investigated for selected OLED architectures. In addition, life time data was measured for several devices.

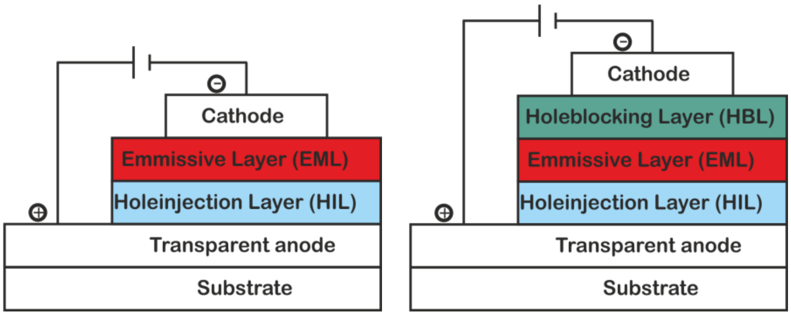

Figure 1.1 (left): OLED-Stack with two organic layers; Figure 1.2 (right): OLED-Stack with three organic layers.

Material screening

Pedot:PSS P VP.AI 4083 (Heraeus, Germany) is used as hole injection layer in every stack. The EML materials are varied as well as the HBLs (or Electron Transport Layers (ETLs)).

Prior device fabrication solubility measurements for the different materials were performed followed by knife coating as a material screening. Knife coating is performed at two different coating speeds and two different temperatures. Float glass (60x120 mm²), with a thickness of 1 mm, is used as a substrate. In order to determine the film quality, pictures are taken from the samples under UV light and the film thickness is measured using a profiler (Dektak 150, Veeco Instruments, US). In Figure 2 two samples are shown exemplarily.

In the coating in fig 2.1 inhomogeneities in form of brighter sprinkles and small circles/dots are visible. These are signs of crystallization. Also edge effects are visible. In contrast figure 2.2 is showing a homogenous coating, where no major differences in the color intensity are noticeable. Since slot die coating is more complex and expensive, coating experiments were only carried out if the knife coating results were promising.

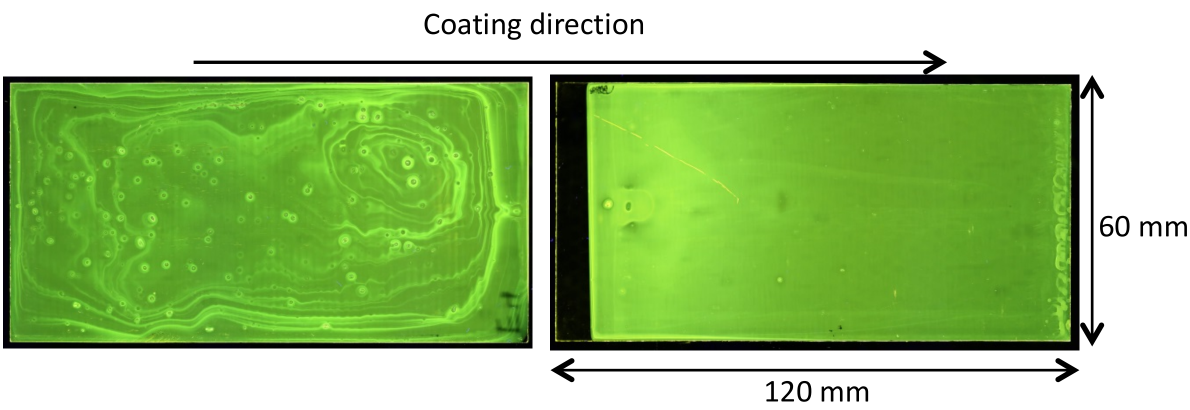

Figure 2.1 (left): knife coating sample under UV-light with F8BT from Xylene, dry film thickness 50 nm;
Figure 2.2 (right): knife coating sample under UV-light with F8BT from Toluene, dry film thickness 70 nm

Device fabrication
For device fabrication the ITO anode is prestructured with a photo lithographic process. The substrate size is 150x150 mm² giving space for a layout with 20 OLED devices (25x25 mm²). All devices are deposited in a step by step coating process. The single layers are coated from orthogonal solvents after the underlying layer is completely dry. For each coating solution, coating and drying parameters are changed to obtain the desired dry film thickness. The metal cathode consisting of the standard composition of lithiumfluoride (LiF) and aluminum (Al) is evaporated after storing the substrates for at least two hours in a vacuum oven. Encapsulation foil is used to protect the devices against oxygen and water uptake. Subsequently, the substrates are cut into the 25x25 mm² devices to fit the samples into the measurement set-up for gaining the device data.
The pixel-size of the measured OLEDs is 6x4 mm² for small (figure 3.1) and 14x14 mm² for larger pixels (figure 3.2). For the small layout one device contains four pixels.

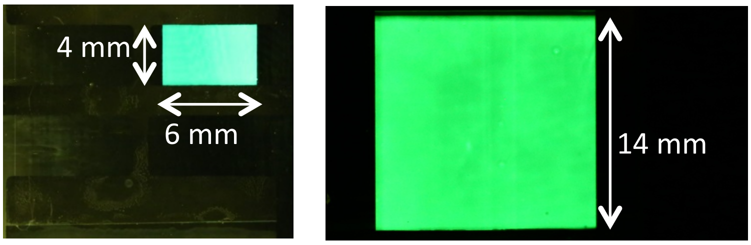

Figure 3: OLED with two solution processed layers (HIL and EML). Figure 3.1 (left): small layout with pixel-size 4x6 mm² (4 pixels in one device). Figure 3.2 (right): large layout with pixel-size 14x14 mm² (one pixel in one device).

Results

To evaluate whether the third organic layer has been deposited without dissolving the second layer devices with two and three organic layers (see Figure 1.1 and 1.2) are fabricated and their efficiencies are compared. The efficiencies are normalized with the highest value reached for the two layer devices. Current as well as power efficiencies are calculated from the measured luminance and current density.

In Figure 4 a stack of ITO / Pedot:PSS / SimCP2-FIrpic (5 w%) / LiF/Al with TPBi as the third organic layer is shown. The number of measured OLEDs – in this case eight samples for each architecture - is given in the figure itself. Besides the electrodes all layers are slot die coated.
Current efficiency as well as power efficiency are both increased with the deposition of the third layer with a factor ~ 7 compared with the devices just consisting of two organic layers. The turn-on voltage is lowered significantly from ~ 7 V down to ~ 5 V with the deposition of TPBi.

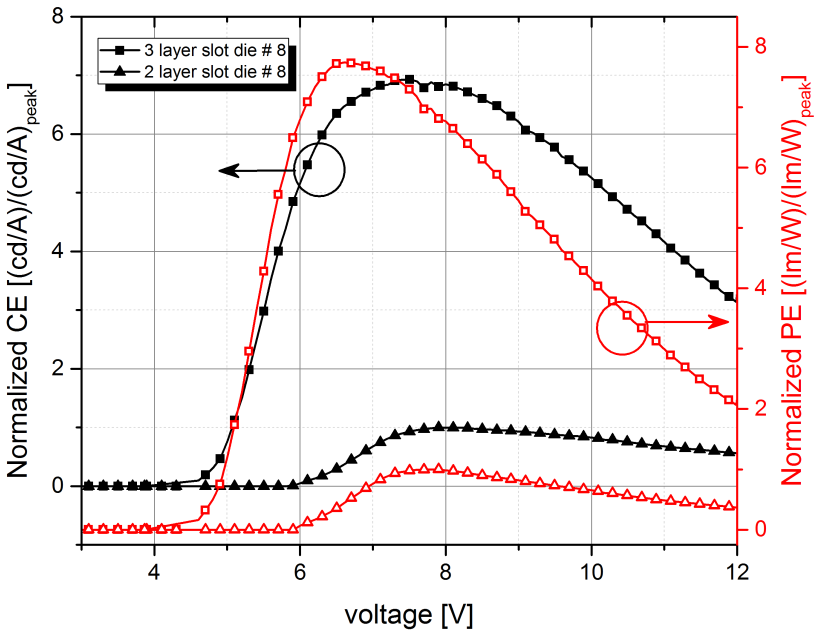

Figure 4: OLEDs with two (triangles) and three (squares) slot die coated layers (HIL, EML and ETL). Normalized CE (black) and normalized PE (red) plotted versus voltage.

This states that the small molecule TPBi has been deposited successfully on the small molecule layer of SimCP2. For comparing the deposition processes the same devices have been built with spin-coating depositing the same layer thicknesses. The results are shown in figure 5.

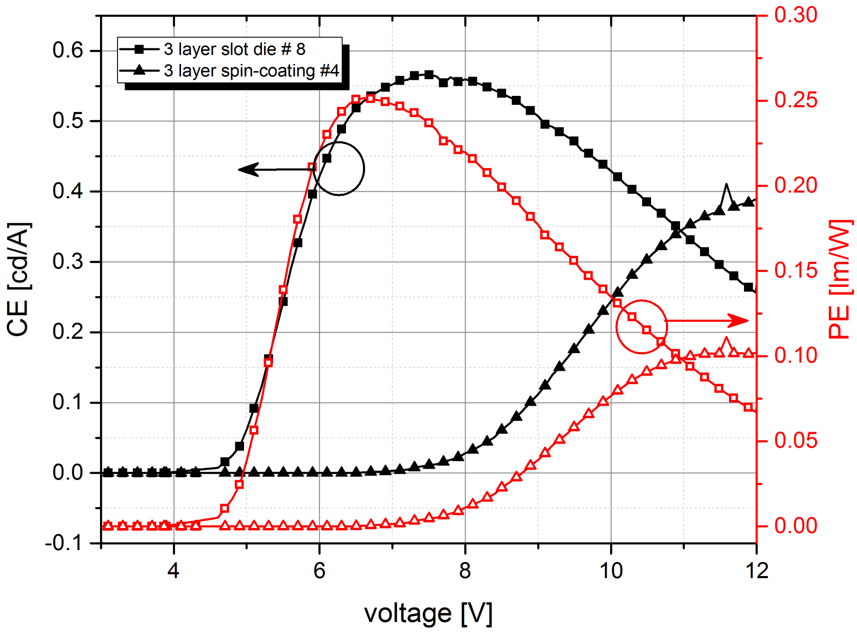

Figure 5: OLEDs with three solution processed layers (HIL. EML and ETL) via slot-die coating (squares) and spin coating (triangles). CE (black) and PE (red) plotted versus voltage.

The slot-die coated OLEDs show a much better performance. Although the spin-coated devices with three organic-layers show higher efficiencies than the devices with two layers, their turn-on voltage is slightly higher.
Two different explanations of this behavior seem to be reasonable. The liquid deposition in the spin-coating process – dropping the coating liquid in one shot on top of the EML and spinning off of the excess volume – can lead to a mechanical displacement of the EML. As a consequence intermixing and thickness variations may occur. The layer thicknesses (even though carefully adjusted) differ slightly in the processes and therefore efficiencies vary.

Conclusion

After an intensive screening for solution-processable OLED materials, eight different EMLs were solution processed, mainly applying slot-die coating in a sheet-to-sheet process. We demonstrate that we are able to slot-die coat two different small molecule layers on top of each other by increasing the device efficiency with a factor of 7.
Our ongoing research focuses on investigating film homogeneities, varying device architectures as well as process parameters. In addition we are working on several different solution-deposition processes to evaluate the limitations of each process for solution-processing of OLEDs.

Abbreviations

Al	Aluminum
CE	Current efficiency
EML	Emissive Layer
ETL	Electron transport layer
FIrpic	bis(3,5-difluoro-2-(2-pyridyl)phenyl-(2-carboxypyr-idyl)iridium(III)
HBL	Hole blocking layer
HIL	Hole injection layer
HTL	Hole transport layer
ITO	Indium-Tin-Oxide
LiF	Lithiumfluoride
PE	Power efficiency
SimCP2	Bis[3,5-di(9H-carbazol-9-yl)phenyl]diphenylsilane
TPBi	1,3,5 tris(N-phenylbenzimidazol-2-yl)benzene

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