R2R processing of flexible Organic Light Emitting Diode Devices and Organic Photovoltaic Modules.

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Introduction

The development of low cost and large area foil based organic light emitting diode (OLED) devices and organic photo voltaic (OPV) modules, using R2R coating and printing technologies, is one of the main objectives of the Holst Centre. The sequential deposition and curing of organic-based inks in a roll-to-roll manufacturing process is believed to significantly reduce the cost-price per m^2. State-of-the-art printing and coating technologies, that are capable of depositing functional layers like poly (3,4 ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS), are expected to be robust and have the potential to deliver high production yields

The functional layers of an OLED device are extremely vulnerable. The slightest contact with oxygen and/or water would be fatal for the device. Therefore the devices must be encapsulated with barrier material with an outstandingly low water vapor transmission rate (WVTR) of less than 10^{-6} g/m2.day. Complete encapsulation of an OLED device or OPV module is essential in order to meet the desired lifetime requirements [2]. This implies automatically, that the functional layers have to be patterned. Slot die coating is a widely used technique to deposit very thin and homogeneous layers, but has the drawback that patterning of the layers is complicated. In particular the interruption of the deposition of the layers perpendicular to the coating direction is extremely difficult using slot die coating technology. Combinations with other innovations, like laser ablation [4] and wetting/de-wetting, are therefore needed and hence investigated at the Holst Centre in order to introduce innovative patterning processes.

Slot die coating.

Slot die coating, while initially developed for the photographic and adhesive industries, is gaining in interest for high volume processing of organic (opto-) electronic devices. Slot die coating is an atmospheric pressure and solution-based deposition technique for thin homogeneous coatings, suitable for high speed processing up to hundreds of meters per minute. Solution-based deposition of thin films for organic photovoltaic's by means of slot die coating has already been achieved [2]. For the coating tests, a slot die unit (supplied by TSE Troller) was installed in a class 10000 clean room. A pressure difference was applied over the coating gap by means of a vacuum chamber (Figure 1**)** in order to stabilize the coating menisci. The slot die unit originally was designed to deposit homogeneous organic coatings onto 12" wide webs.

Figure 1. Slot die coating unit with vacuum chamber.

Stripe coating.
Pattering in the coating direction (stripe coating) by means of a slot die is a well known method in the field of thin layer deposition [3]. The desired pattern can be achieved by means of partial blocking of the coating flow in the die lip by using inserts, cut from a PET foil in the desired shape (called a shim). In order to explore the potential of stripe coating, the following test was preformed. A PEDOT: PSS dispersion (HILHC5 from AGFA) was coated on a substrate at a speed of 5 m/min. The substrate was a pre-treated PET foil with a thickness of 125µm and a surface tension of 60 mN/m. Prior to the coating experiment, three shims were inserted into the die lip. The widths were respectively 2.0, 5.1 and 14.4 mm. For OPV, narrow uncoated stripes (2 to 3 mm) are favorable, because this increases the effective area of the module. However for OLED devices a width of 15mm is preferred. An example of the coating result is shown in Figure 2. In this picture the uncoated stripes are clearly visible.

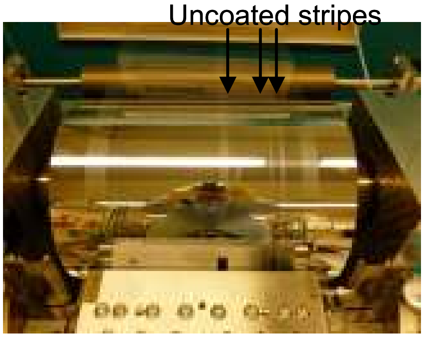

Figure 2. Slot die stripe coating of PEDOT:PSS

Controlling the widths of the uncoated stripes was complicated. Optimizing the processing conditions for one particular width showed a deviation from the original shim width for the other two. Stable multiple stripe coating with different shim widths in one coating set-up seems to be a challenge, especially as the deviation of the actual stripe width can be either positive or negative w.r.t. the shim width. (Table 1).

Width of insert(mm)	14,5	2,0	5,0
Width of uncoated stripes(mm)	12,0	2,5	8,5

Table 1. Comparison of the widths of the inserts and actual width of the uncoated stripes.

The layer thickness profile in cross direction of the coating was evaluated by means of an image scan (Figure 3) of the coated sample. The scans were preformed on a Canon flatbed scanner (Canoscan 8800F) and the raw data of the images were analysed by means of Matlab software. The results (Figure 4) show a uniform layer thickness (about 100nm) and no large variation near the positions of the shims.

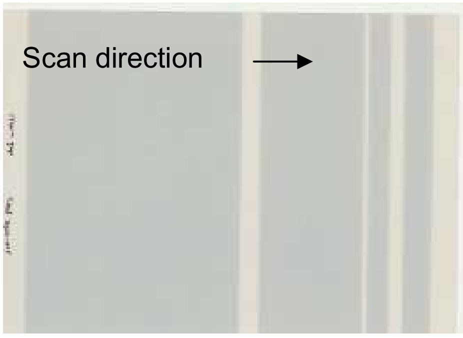

Figure 3. Image scan of a PEDOT;PSS coated sample

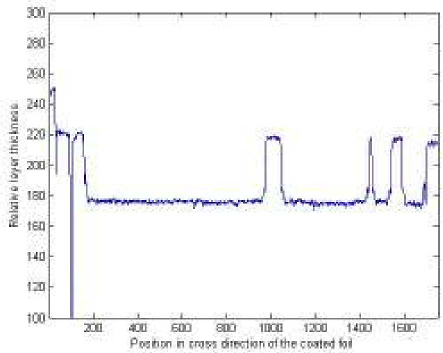

Figure 4. Layer thickness profile scan of coated layer in cross direction of the web.

Laser ablation.

Laser patterning in a R2R environment for the processing of OLEDS and OPV modules, is an interesting technology. By laser patterning, very fine feature sizes can be obtained with high process speeds from homogeneously deposited layer sequences. Proper power density adjustment, wavelength and pulse width selection of the laser beam have to be utilized for selective and effective removal of different thin layers, which is crucial for the roll to roll processes for flexible electronics. The tests were performed with an excimer laser operating at 248 nm with a pulse width of 7ns (power=50-200 mJoule/cm2). The main aim of the experiment was to selectively remove a thin layer of PEDOT:PSS (~100 nm) from the top of a substrate. Experiments have been conducted at various laser fleuence levels in order to find the ablation depth in the PEDOT:PSS layer (Figure 5). The experiments were carried out at various pulses per location in order to find the process window.The best ablation results were achieved with a laser fluence of 50 mJ/cm2 with 10 pulses per location. The PEDOT:PSS layer was removed completely without damaging the underlying substrate. A typical result is shown in Figure 6 .

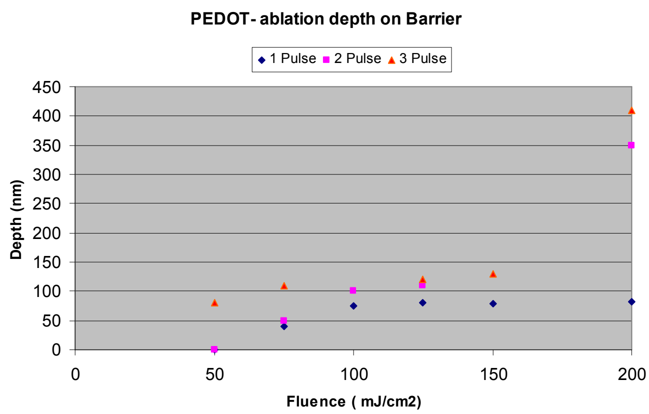

Figure 5. Ablation depth obtained for PEDOT:PSS at various laser fluences.

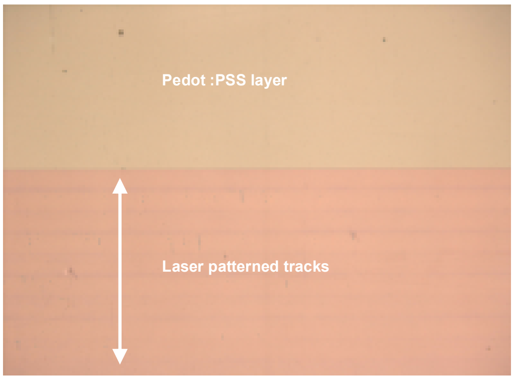

Figure 6. Ablation of PEDOT:PSS at laser 50 mJ/cm2 with 10 pulses per location.

Conclusions.
Stripe coating by means of a slot die is a suitable technology to pattern the functional layers of OLED and OPV devices in the coating direction. Major progress has been achieved in the field of laser ablation and the combination of these technologies is promising with respect to the patterning of functional layers. Further research will be required to explore the coating window of the R2R set-up. The performance of slot dies which are specially designed for this purpose, would probably lead to better results.

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