Recent Developments On Intermittent Coating

<u>Ike de Vries</u>[1], Harrie Gorter[1], Gerwin Kirchner[1], Thomas Kolbush[2], Klaus Peter Crone[2], Alexander Pankratz[2], and Pim Groen[1]

[1]Holst Centre/TNO, High Tech Campus 31,5605KN Eindhoven, the Netherlands

[2]Coatema Coating Machinery GmbHRoseller Str. 4, 41539 Dormagen, Germany

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Introduction.
Recently, several publications on slot die and slide coating have demonstrated an increasing interest in these long-established technologies, which have already for decades proven their usefulness in the industrial manufacturing of photographic films and magnetic tapes. As non-contact processes, they also have potential for emerging applications like solution processed organic light emitting diodes (OLEDs) and perovskite solar cells (PPV). A particular advantage compared to contact processes is that they minimize the risk for particle contamination and other damage to the vulnerable thin layers which might already be present on the substrate. However, transferring these techniques to large scale OLED and PPV manufacturing has turned out to be difficult so far. While traditionally, coating processes have been used to produce continuous uniform films, many of the thin functional layers in OLED or PPV devices need to be patterned. This can be achieved either via post-deposition patterning (e. g. selective removal of the layers by means of ablation or re-dissolv-ing) or by coating processes which inherently deposit the functional inks only where they are supposed to be. Typical examples for this latter approach are stripe coating, intermittent coating, which allow patterning in the web direction and perpendicular to it, respectively. A particular challenge to the intermittent slot die coat-ing of OLED and PPV inks is their rather low viscosity, compared e. g. to traditional photographic film ma-terials, which makes the controlled stopping and starting of the ink flow rather difficult. As a consequence, functional layers deposited by these techniques frequently suffer from ill-defined edge quality and an inho-mogeneous layer thickness.

The research presented here describes the development and testing of slot die heads with novel features which significantly improve the process of intermittent coating of low viscosity functional inks. The work has been carried out within the PI-SCALE project which is part of the European Union's Horizon 2020 Framework Program for Research and Innovation. Its main goal is the integration of existing European infra-structure for flexible OLED manufacturing into a pilot line which can support the growth and development of the European OLED industry.

Novel intermittent coating process designs.
One of the most critical challenges of intermittent slot die coating is to obtain an even start and stop of the coated patches with straight contact lines and uniform film thickness. For OLED and PPV applications, the regions of disturbed layers at the leading and trailing edges should not exceed a width of 1 mm and 2 mm, respectively (Figure 1). Our research aimed at reducing the widths of these non-uniform edge regions for inks with viscosities in the typical range for OLED and PPV applications (1-10 mPa.s) to values within the specification ranges. Previous results have shown that the lower the viscosities of the coating solutions, the more difficult it becomes to fulfill these requirements [1]. This is because high capillary and low inertial forces enable a high mobility of the coating liquid in the coating bead during breakup. As the lateral redistribution of the inks in the bead occurs within a few milliseconds, processes which should counteract this phenomenon should act on a timescale in the millisecond range or faster.

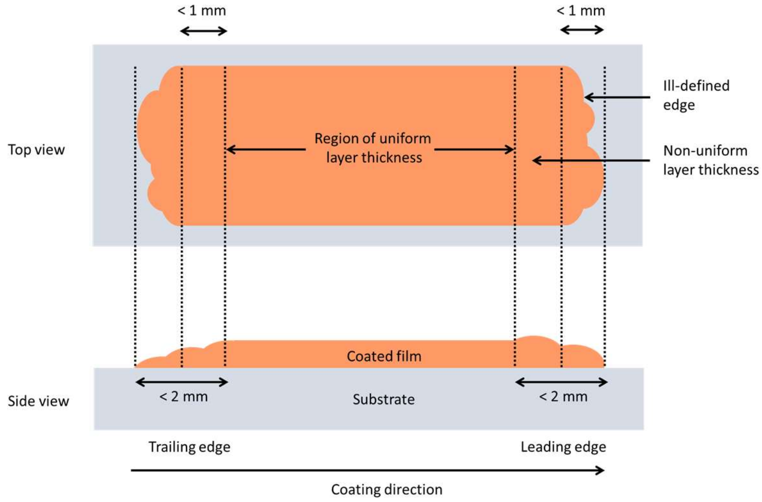

Figure 1. Requirement for leading and trailing edges regarding uniformity of the coated layer

For that aim, two novel slot die designs have been tested and evaluated. The first has a switchable downstream die lip which can force the coating bead to breakup by widening the slot gap (
Figure 2). The motion of the die lip is generated by a piezo element which has a response time of around 1 msec.

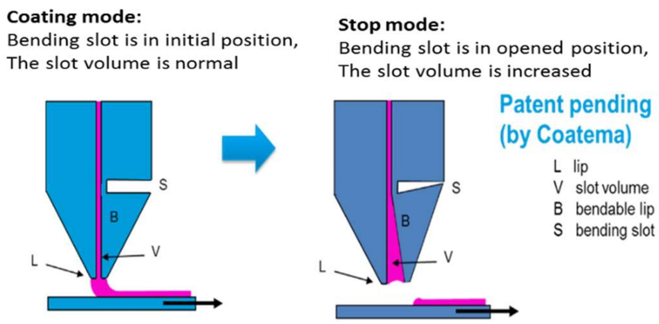

Figure 2. Schematic drawing of the intermittent coating slot die with switchable die lip

The second die design makes use of the so-called suck-back principle and is depicted in
Figure 3. Rather than simply stopping the ink flow, the liquid is actively retracted, thereby accelerating the process of bead breakup. This is achieved by a suck-back pump driven by a high speed piezo element. In order to increase the effect and decrease the response time of suck-back on the coating bead, a second manifold is positioned close to the exit of the slot die, but also not too close in order to have an even pressure distribution in the second manifold over the width of the slot die.

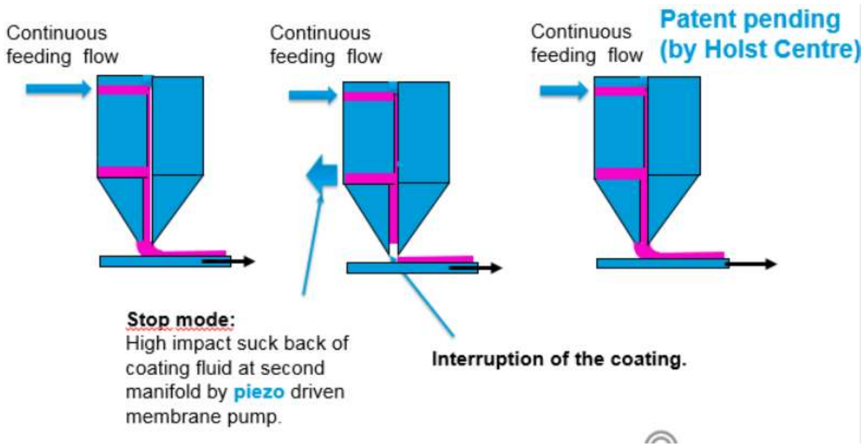

Figure 3. Schematic drawing of the double manifold die design.

Experimental.
For the test with the switchable die lip, a low viscous (2 - 5 mPas) water/PVA solution was used at a machine speed of 5 m/min. Both the leading and trailing edges showed a well-defined start and stop of the coated layer (Figure 4). Also the layer thickness variation in the coating direction stabilized within a short range of less than 1mm. Thus, both requirements for the edge definition have been met successfully using this approach.

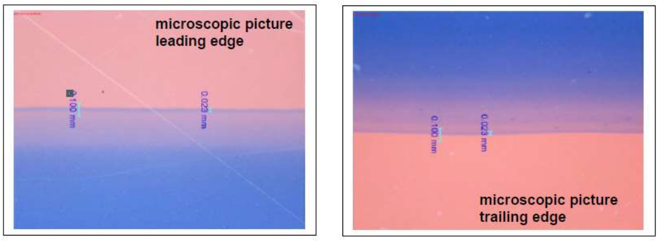

Figure 4. Microscopic images of leading and trailing edges
with the switchable die lip design.

The double manifold slot die combines two main principles for coating bead interruption. Besides the option to widen the bead by means of retraction of the slot die, the most important aspect was the addition of the piezo driven piston pump. Initial optimization tests with this pump were performed offline, in order to be able to estimate the response time during the coating process over the width of the slot die. For these measurements, the test setup which is depicted in Figure 5 was used.

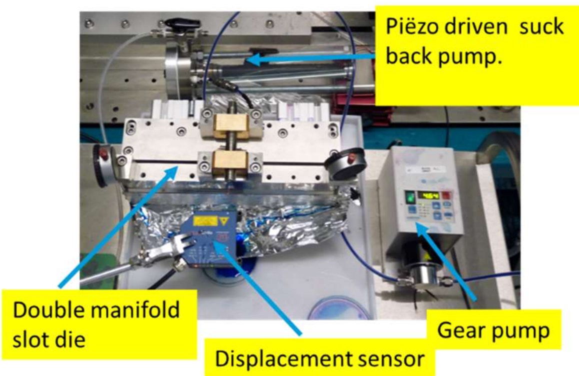

Figure 5. Test set-up to measure the response time between action of the piezo
pump and suck back effect at the die lips.

A displacement sensor was positioned at the front of the slot die. The disruption of the free flowing liquid film at the die lips due to the action of the piezo driven pump could be measured in this way. The signal output of piezo as well as the displacement sensor were simultaneously visualized on the screen of an oscilloscope (
Figure 6).

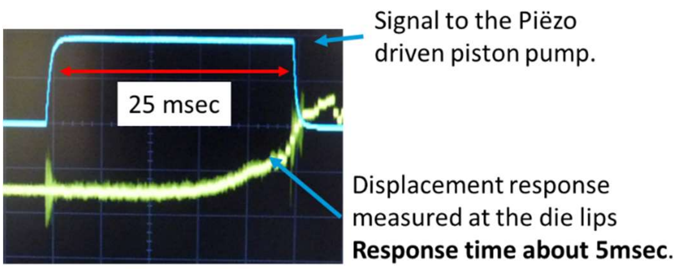

Figure 6. Screen image of the Oscilloscope which was used to measure the time delay between the action of the suck back pump and the actual effect at the die lips .

The actual coating test with the double manifold slot die was performed with a low viscous PEDOT:PSS solution at a line speed of 10 m/min. At this coating speed, vacuum had to be used to stabilize the coating bead which makes the intermittent coating even more challenging. The results of the test, depicted in Figure 7 showed straight leading- and trailing edges and a none coated gap of 6,2 mm. The complete intermittent coating interruption was therefore performed within 36 msec. The relative layer thickness variation was analyzed by means of the Gwyddion software, which measures the color intensity variation in the scanned images of the test samples. (Figure 7)

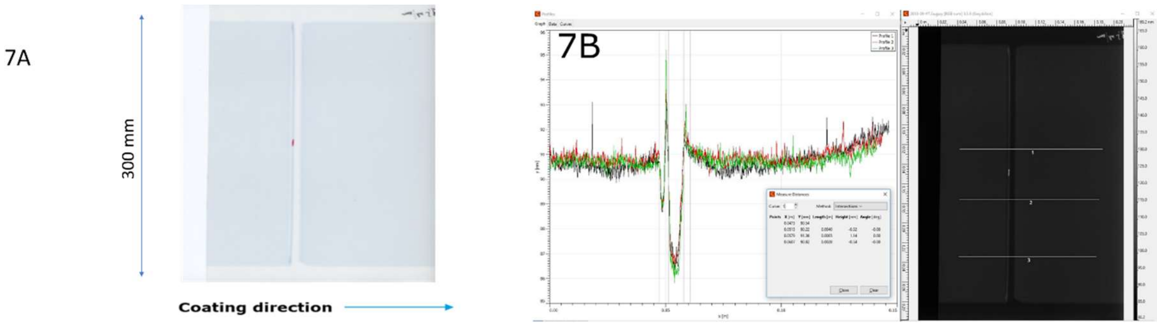

Figure 7. Image scan (7A) of leading and trailing edges of a sample from the test with the double manifold slot die and (7B) the layer thickness image measured by means the Gwyddion software.

Detailed analysis of the leading and trailing edges showed the following results:

- Leading edge width 2,8 mm
- Leading edge height 0,2 times the average layer thickness
- Trailing edge width 4,0 mm
- Trailing edge height 0,6 times the average layer thickness
- None coated gap 6,2 mm

Conclusions.

1. Two novel slot die designs for intermittent coating of low viscous solutions have been tested and demonstrated successfully.
2. The targets for the rim height of the leading edge, the trailing edge and the none coated gap could be reached. Further optimization and benchmarking of both slot die designs is currently ongoing.

Acknowledgement.
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