Bead behavior in a non-continues slot die coating regime

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Abstract:

Sheet-to-sheet slot die coating is a crucial intermediate technique to bring organic and large area electronics (e.g. OLED and Flexible OPV) towards mass roll-to-roll productions. The coating on substrate has to be uniform within nanometers. Additional settings are added to the slot die coater for a better control of the coating bead. Two reoccurring device defects were observed and the coatings process was analyzed. The first defect was an increasing layer thickness due to accumulation of coating material to the slot die lips. The second defect was cross directional barring due through bead fluttering. The right speed settings could prevent the defects. Use additional settings to circumvent these coating defects leads to limitations in reproducibility and prevent easy layer thickness adjustments.

I. Introduction:

In the next decade disruptive innovations of Organic and Large Area Electronics (OLAE) will occur. The first OLAE applications have already entered the consumer markets (e.g. Organic Light Emitting Diodes (OLED) on glass, flexible photovoltaics), but this innovation will reach its full potential when high volume processes like solution processed roll-to-roll production significantly decreases the manufacturing costs. In OLAE devices electrical current travels perpendicular through the functional large area layers. The applied layers have to be very uniform and defect free to prevent current from leaking away through low resistance areas (thinner layer) or shorts (direct anode-cathode contact because of coating defects) e.g. a layer thickness variation of functional layers in an OLED are clearly visible because of non-uniform light emission. The roll-to-roll slot die coating process is very suitable for producing large area uniform thin films of organic materials in high volumes as described in applications for photovoltaics by Galagan et al.[1] and Wengeler et al.[2]. The Visco-Capillary behavior of the coating bead in continues slot die coating is well described by Kistler and Schweizer [3] and Higgens et al. [4] in mediocre and high viscous materials. The behavior of low viscous materials for OLAE is more difficult but it can be improved by introducing a specific factor *n* in the Visco-Capillary Model described by Peters et al.[5] or by combining simulations and practical experiments, as described by F. Jakubka et al. [6]. However, before entering full scale roll-to-roll production from laboratory spin-coating, an intermediate slot die coating process is a logical step to prevent waste of the rare and expensive novel materials. Sheet-to-sheet slot die coating processes are very suitable for this purposes. Both coatability, layer-compatibility and efficiencies can be tested on an up scalable process with limited usage of materials.

II. Experimental

Materials

The water based low viscous mock up material used for these coating tests consists of give full name water soluble Polyvinyl Alcohol (PVA), surfactant and dye. The glass substrates used were cleaned with isopropanol (IPA) before the coating tests.

Methods

The process of non-continuous sheet-to-sheet slot die coating differs from roll-to-roll continuous slot die coating in the following way: due to the limited substrate size and limited coating stroke there is no room for ramping up to a stable and uniform layer. The applied layer has to be uniform almost instantaneously. Furthermore, most of the OLEA inks for functional layers have low viscosity and need to be very thin. Control of the fluid-bead between the slot die and the substrate is essential to minimize the leading and the trailing edge. In Figure 1 a schematic view

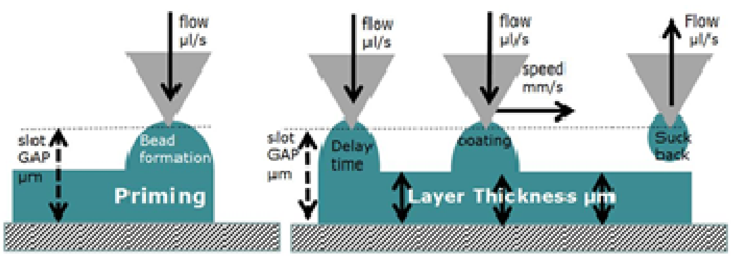

Figure 1 *Sheet-to-sheet slot die coating process with priming plate.*

of the sheet-to-sheet process is given.

The additional settings of the sheet-to-sheet slot-die coating process are: the introduction of a priming plate for bead formation, material pre-charge by delay time during feeding, acceleration, deceleration, control of the slot die speed and material suck back at the end of the coating. In Figure 2 the acceleration of the slot die is measured and depictured. All these extra settings will give more possibilities to obtain a uniform layer but will also mask when the coating is obtained outside the slot die coating window and is made in a mode in between knife-coating and slot die coating.

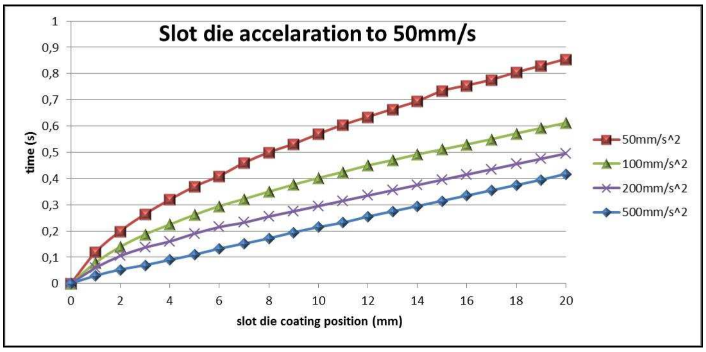

Figure 2: *Measured acceleration speeds at beginning of coating of sheet-to-sheet slot die.*

III. Typical sheet-to-sheet slot die coating defects:

The typical sheet-to-sheet related defects are always in machine direction (md). In sheet-to-sheet slot die coating issues related to layer thickness none-uniformities are often encountered : wet layer thickness can slowly increase from the beginning to the end of the substrate, while leaving a very thick trailing edge. This effect is clearly visible in devices as OLEDs, very vulnerable to layer thickness variations. Beside the emission intensity also the color of the emitted light can change, in particular in top emission devices, as shown in Figure 3.

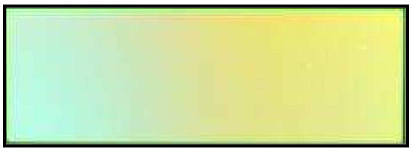

Figure 3 *An OLED with not uniform functional layer thickness.*

Another typical sheet-to-sheet related coating defect is a pattern of parallel lines, perpendicular to the machine direction, due to layer thickness variations, also known as barring. In the OLEA application of thin layers, barring is not always visible in the dry layer itself, but it will be eventually visible in OLEA applications very vulnerable to small layer thickness variations. An example of barring in an OLED is in Figure 4

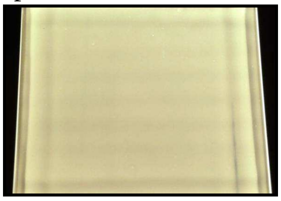

Figure 4 *Barring in OLED device*

IV. Results and discussion

Observations in the bead of the coating showed that, when layer thickness none-uniformities occur, the material accumulates at the lips of the slot die. All the accumulated material is deposited when the slot die is lifted, leaving a big trialing edge behind, as shown in Figure 5. The small land length of the sheet-to-sheet slot die lips decreases the volume in the bead but increases the material accumulation at lower coating speeds. The minimum speed depends on viscosity and surface tension but typically material accumulation problems starts to occur at speeds below 25mm/s. Increasing the speed will solve this problem. Changing the die gap has some minor influence: with a smaller gap, less material can be accumulated in the bead, and higher pressure will get more material under the slot.

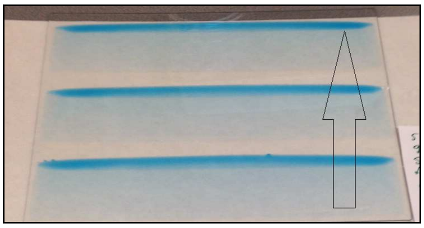

Figure 5 *Material accumulation on slot die lips at speed <25mm/s. Arrow is coating direction*

Observation of the bead during the coating process, showed fluttering of the bead which causes barring on the coated film, as shown in Figure 6. Several experiments revealed that the chances of barring in sheet-to-sheet slot die coating are very high when a thin layer, is deposited at relatively high coating speed, and with high acceleration. Typical values when barring occurs are a wet layer thickness of less than 5μm, a coating speed between 40 and 70mm/s and an acceleration of 400-500mm/s^2. Increasing the flow will help to preventing barring but it will also influence the final layer thickness. The coating speed does not only influence the height of the barring but also the length. In Figure 7 the coating speed vs the measured barring length is depictured. Lower acceleration rate of the coating speed can also prevent barring but could lead to a rather big leading edge. As shown in Figure 2 with a low acceleration it takes time (and substrate surface) to reach the desired coating speed. Before the point is reached the material will accumulate at the slot die lips and it will be deposited at once in one large cross direction bar on the substrate when the higher speed is reached.

Figure 6 *Barring in a coated layer. Arrow is coating direction.*

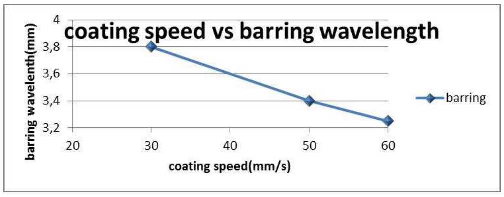

Figure 7 *Coating speed versus barring wavelength*

V. Conclusions and outlook:

Two most occurring coating defects of sheet-to-sheet slot die coating for OLAE applications are listed and analyzed. Settings that result in coating defects are shared and strategies to prevent these defects are given. To obtain a uniform and defect free coating, the coating-speed of the sheet-to-sheet slot die should be chosen in a range where neither of the above described coating problems can occur. Only when this is not possible consideration could take place to circumvent the coating problems with the additional sheet-to-sheet slot die settings (e.g. extra material pre-charge at the beginning and residual material suck back at the end). When these additional settings have to be used the coating mode is probably in a "knife-coating/slot die" mode die instead of "100% slot die" mode. The coating bead is more unstable and could lead to limitations in easy coating thickness adjustments and reproducibility. A lot of experience to judge the uniformity of these layers is also necessary. When these limitation are taken in account, sheet-to-sheet slot die coating is a very versatile coating technique for applying the many different layers for OLAE applications, very uniform and very precise with easy layer-thickness adjustments.

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