# Intermittent slot die coating of low viscous solutions.


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Presented at the 17th International Coating Science and Technology Symposium
September 7-10, 2014
San Diego, CA, USA


Introduction.
Recent publications in the field of flexible electronics show more and more interest in technologies like slot die and slide coating. These technologies have proven their potential already during several decades in industrial production processes e.g. for photographic film and magnetic or adhesive tape manufacturing. Some keywords which appeal to t researchers, that are dealing with the application of functional thin layers from solutions, are: extreme high layer uniformity, pre-metered and contactless. However, these technologies are not easily transferable to the new emerging applications. The new products and processes have different, highly demanding requirements to endeavor. One issue to tackle is the coating of patches instead of continuous layers by means of intermittent coating.
The development of flexible electronic products has a global interest of companies, research institutes and universities. Some of the flexible electronics already reached maturity, like the lithium ion battery production others are currently still in the research phase, like Organic Light Emitting diodes ( OLED) for displays and lighting.

Intermittent coating.
In flexible electronic device designs, several organic layers have to be stacked on top of each other. In organic photovoltaic (OPV) modules, the layers even have to be shifted with respect to each other to form series connected modules of the individual cells. The necessity of patch coating can therefore well be illustrated by the picture of an OPV device in Figure 1.

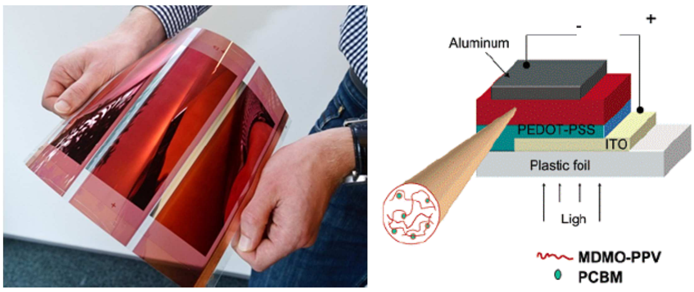



Figure 1. Design and possible layer structure of an organic photovoltaic module.

The patterning of functional layers in machine direction is not the most complicated problem which had to be encountered, but creating an accurate start and stop of the layers with acceptable layer thickness variation by means of slot die coating is rather complicated. Fluid dynamics of the feeding system, dynamic wetting and design of functional process parts are much more complex processes. The coating process has to switch in a relative short time span from stable to unstable and back to stable again in order to initiate the temporary breaking up of the coating bead.

The visco capillary model of Ruschak (1976) is useful to estimate the stable and unstable coating conditions with respect to parameters viscosity, surface tension and coating gap. Figure 2 shows that the menisci of low viscous solutions of about 1 to 10 mPa.s are able to bridge the coating gap even up to large gap/film thickness ratio’s and this is a typical viscosity range used for applications in flexible electronics.

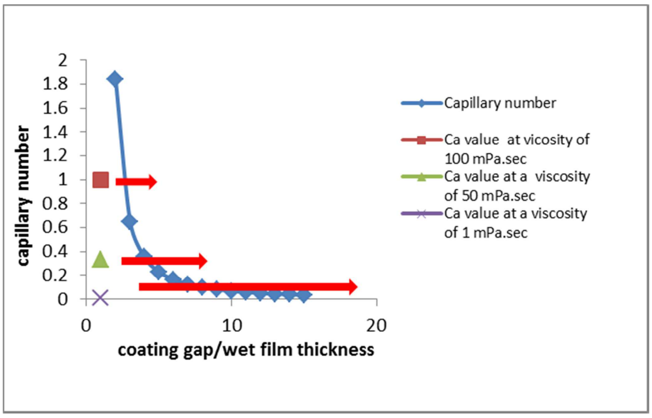



Figure 2. Visco capillary model of Ruschak (1976)

Experimental.

An estimation based on the visco capillary model showed that an even bead break up couldn’t be realized without increasing of the coating gap to at least 500µm. Initial test were performed to explore boundary conditions with respect to the leading edge of the coating using low viscous solution. The results of Figure 3 illustrate the non-uniform leading and trailing edges of the slot coatings. The formation of the coating bead at the die lips seemed to be rather unpredictable. Therefor the wetting of the coating solution on the die lips was studied by means of the of the high speed video camera and the results are depicted in Figure 4. This experiment was performed with a Pedot:PSS solution with a viscosity of 10mPa.s and a surface tension of 32 mN/m

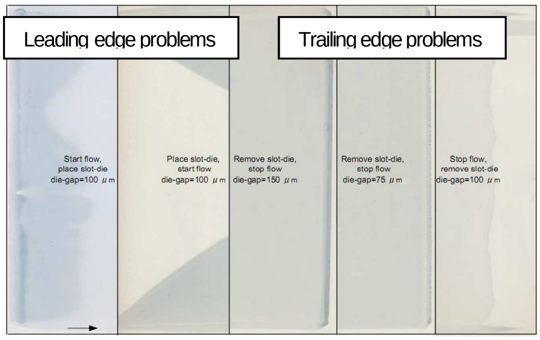



Figure 3. Scans of start and stop of sot die coatings. Wet thickness 10 µm, flow rate 13 ml/min, coating speed 5 m/min.

In the most ideal situation the volume of solution on the die lips corresponds to the volume of the coating bead. This behavior is influenced by several factors which were rather difficult to vary. For example the die lip geometry is an important factor but unfortunately only one die lip geometry could be studied.

The fluid dynamics during retraction of the slot die is at least as important as during the start-up. The breakup of the coating bead was in all test samples far from uniform. At the trailing edge of the coating, large thickness variations in

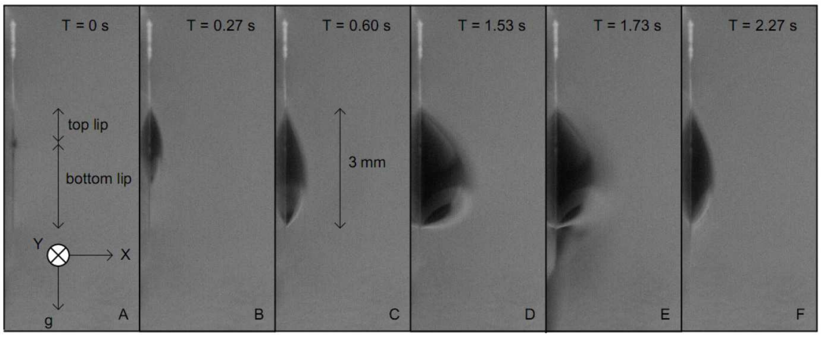
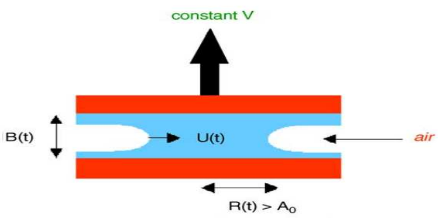



Figure 4. Bead formation of Pedot:PSS at the die lips (side view) at a flow rate of 28 ml/min.

the dry layer were observed in the coating direction as well perpendicular to the coating direction. This could be expected on beforehand because of the mobility of low viscous coating liquids. This dynamic behavior was studied by means of a glass plate with on top a small metal strip to mimic the die lips. The distance between the glass plate and metal strip could be controlled accurately to simulate the coating bead. The retraction speed of the metal strip could be controlled and the dynamic behavior was visualized through the glass by means of a high speed video camera. Using a high viscous glycerol liquid so called viscous fingering could be noticed. These so called Rayleigh instabilities are clearly visible Figure 5




Coating liquid = glycerol
μ = 1.412 Pa*s
γ = 64 mN/m

Gap 50 µm,
Retraction speed
5 mm/s

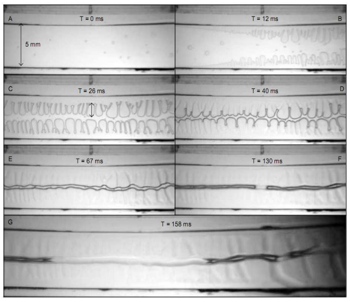


Figure 5. Width of bead just before break-up is non-uniform bead breaks up at multiple places.

At low viscosities however the mobility of the liquid is much higher and even at high retraction speeds the bead is retracting quickly to the center point in in y direction of the coating gap which forms a thick droplet shaped layer after

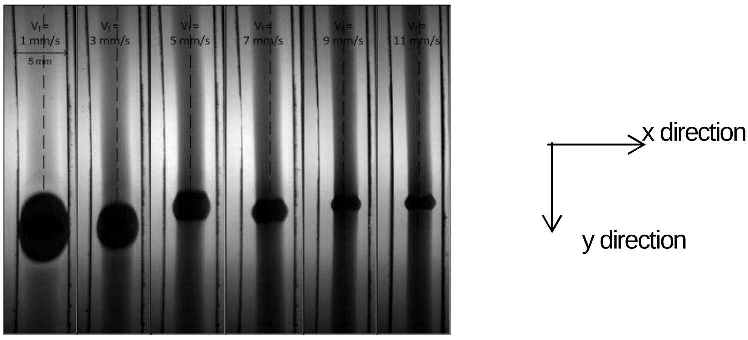



Figure 6. Thickness profiles scans along the trailing edge of the Pedot::PSS coating for different retractions speeds.( gap 100 µm)

final break up. The volume of the central drop decreases with increasing top plate velocity. In the image scans of trailing edges of a Pedot:PSS coating is shown. At slow retraction speeds (1mm/sec) the coating bead almost completely retracts towards the center position of the gap in y direction, forming a large droplet. This phenomenon decreases with increasing retraction speeds. Figure 6 also shows that not only in y direction but also in the x direction the coating solutions accumulated at the center position . This observation is supported by light extinction measurements of the dried rim which are depicted in Figure **7**. At higher retraction speeds, the dry thickness of the of the Pedot:PSS increases at this center position too. Optimization of retraction speeds of the slot die and gap distances still has to be investigated.

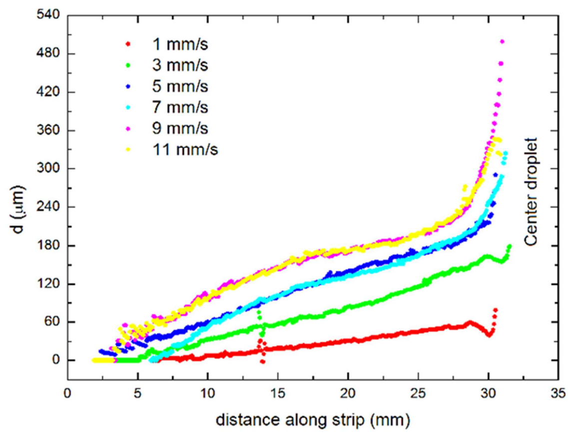



Figure 7. light extinction measurements data of the trailing edges in y direction.

Conclusion:

Intermittent coating of low viscous solutions can only be achieved by means of quick increase of the coating bead, otherwise the coating bead will contract and form an uniform trailing edge.


Acknowledgements.

The authors would like to thank our partners in the research program Panasonic, Smit Ovens , VDL flow, Bosch Rexroth and the Dutch Ministry for Economic Affairs for technical and financial support.