Production technologies for large area flexible electronics

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Abstract

There is a wide variety of printed large area flexible electronic devices and at the same time a number of different visions and estimates for this new emerging industry and market. But as every new industry or technology, printed electronics has to overcome technology red brick walls, survive the valley of death for the start-ups and spin offs and be competitive enough against existing technologies, like silicon technologies.

The talk wants to give a broad picture on these new markets and describes the potential market outlook based on the Organic Electronic Association roadmap. Out of the five markets defined by the OE-A the author describes two markets in detail, the market for OPV and flexible display.

Then the talk tries to give a definition of common characteristics for printed electronics and the potential of not only single printed devices, but for integrated products which can consist of only printed devices or a mix of printed and silicone devices, also described now in literature as hybrid devices.

Keywords: Printed Electronics, coating, printing, laser, nano-imprint, scaling-up processes, production lines

Scale up process from Lab2Fab

Out of the broad picture the talk focuses then on how to scale up processes from lab to fab, from the view of an equipment maker being in high tech developing markets like fuel cells, lithium ion batteries and solar for more than fifteen years. In detail you find the typical approach in R&D in new technologies from sheet-to-sheet developing small samples to small scale ink and substrate intensive roll-to-roll (R2R) units, where processes are not totally stable and developed. The next critical step and the point of failure of a number of start-up companies and university teams is the scale up from small working width low speed into pilot coater and printers which operate in a working width of up to 1.000 mm and operate at around 30m/min.

The players which are surviving this step realize that there are new processes which have to be integrated into this type of pilot systems, like laser patterning, nanoimprinting and lithography. Now the next step is to run the mentioned processes inline. This means they need the same speed ration than the established pilot methods to reach a preproduction yield or output.

After definition of processes, industry accepted specifications of equipment and standards of processes the next upscale is into fab systems including frontend processes like scribing of ITO and backend processes like the encapsulation of single modules or devices or other pick&place processes.

From this overview the talk then gets more detailed into needed process parameters, print systems, laser scribing or patterning, nano-imprint and coating systems.

Process parameters

In R2R processes the control of the substrate, means in registration, elongation and tension control is the key to get good printing or coating results. There the need of process controls, mechanical systems like dancer control or load cells for tension control, registration cameras, edge guiding and high accuracy servo drives. Decoupling every single coating or printing process from the other 4 or 5 other application processes is here the key.

After control of the substrate the control of the behaviour of the applied inks, dispersions or thermoplast systems regarding viscosity, shear behaviour and other fluid properties. With the type of solvents being used which can be organic solvents or water based ones the result of the coated or printed layer can be very much different. Specifically if we are looking for very precise layers regarding thickness variations and layers under 1µ down to 80nm we have to have a good understanding of the ink behaviour in the printing process for example in the nip point between the printing rollers. The same impact we have in drying or curing parameters like airspeed of the dryer nozzles, temperature zones in the different dryer zones and also the type of temperature delta being brought into the process. The final part, but most important one for Lab2Fab scale up processes is the quality control combined with process analysis and statistics regarding defects, layer thickness, device or layer performance. Therefore non-destructive measurement systems like radioactive or spectroscopy thickness measurement, surface analysis with camera systems and also inline ramen have to be integrated and have to give an inline feedback loop to the print and coat or other systems.

Registration control

In printed electronics we apply not one layer we apply a number of layers onto a substrate. These layers can be full scale coated or printed structures and they have to be placed precisely on top of each other. The precision we are looking for is in the 1-5 µm range, if you think about transistors or others. And this accuracy we need in cross web and down web direction. This is very difficult to reach and for sure one of the red brick walls in printed electronics. We reach on 300 mm wide webs with a speed of 30m/min an accuracy of 20µm in both directions. Specifically with nano scale transparent layers which have a high transmission index we face the topic that we need cameras with a very high resolution. And if these cameras are operated in EEX proof solvent based environment they have to be designed after ATEX regulation. The other topic in registration processes is that if you have non printing step like coating or laminating in between you need to register this process also otherwise the next station will lose its XY position.

Print Systems

The use of printed electronics implements also the use of full area coated layers and the use of structured or patterned layers with functionality. We see here a use of traditional printing systems like screen printing, flexo, gravure and offset systems and new printing systems like inkjet and laser lifting processes. A structuring method which is also mentioned in combination with printing id R2R photolitho and laser ablation. Laser ablation will be described in the next chapter.

With all mentioned printing methods the key is registration accuracy, line width or resolution and the throughput in m/sec or m/min.

The other topic is that we use inks with different solvents, layer thicknesses and accuracies which always impacts the overall result of the finished product which is normally combined of different layers and laminated structures.

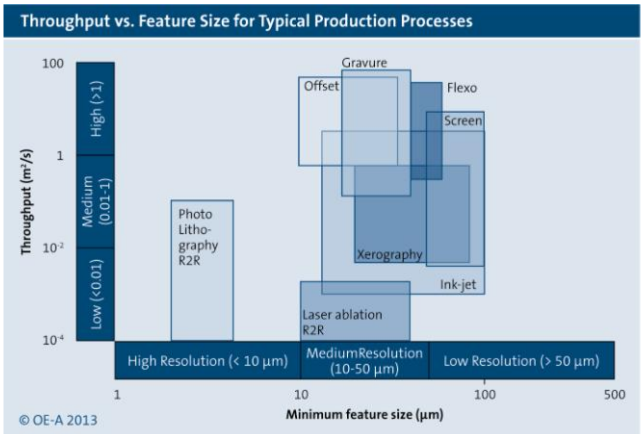

Fig. 1. Throughput vs. Feature Size for Typical Production Processes

Laser patterning

Today, flexible organic solar cells are slowly finding their way into industrial R2R production. Advantages like ease of installation, robustness and high efficiency at indirect illumination open up diverse applications in building integrated systems or mobile electronics devices. By avoiding vacuum deposition steps, the requirement of low-cost-production can be fulfilled. This is possible with the so-called inverted layer structure, which allows purely solution-based deposition.

Nano imprint / Hot embossing

In this part of the talk the author shows two different methods to form nano or microstructures on film, the so-called UV nanoimprint and the thermal nanoimprint or hot embossing method.

Both methods define a structure into a polymer substrate or the coating of a polymer substrate and are used in a number of technologies like lightguides, microfluidics and other structured surfaces. Coatema implements R2R processes which can combine both processes up to a working width of 1.000 mm.

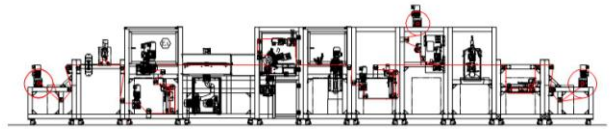

Fig. 2. Drawing of a Coatema Coating machinery with nano-imprinting unit

Slot die coating

The misunderstanding with printed electronics is that only printing methods are being used. In 80 percent of OPV applications we have seen the use of slot die systems for the hole conductive layer or photoactive layer. Specifically stripe coating with slot dies has been and is very popular since 2002 in the business. A slot die is a premetered coating system in which the coating liquid (ink) is fed by a dosing pump at a well-defined volume rate. Gear pumps are typically used as they provide a flow rate being widely independent from counter pressure. The coating thickness is determined by the flow rate, the coating width and the web speed only. All other parameters (like the slot width, the gap between slot die and substrate and others) have to be adjusted to achieve a sufficient process stability but are not directly involved in coating thickness.

The liquid is pumped into a distribution chamber (manifold) and then is pressed through the slot. If no counter measures are taken, the volume flow at the slot edges is slightly smaller (typically by some %) than in the middle of the slot, caused by slight pressure loss in the manifold. The simplest way to reduce this effect is to design the manifold as large as possible. Fig. 3 shows the basic pressure requirements for homogeneous coating.

If on the other hand a large manifold is not appropriate (e.g. because of extreme ink costs) there are more sophisticated designs possible to achieve a homogeneous coating. Typically a well-designed slot die can achieve a coating homogeneity of well below 1%.

Slot dies are non-contact coating systems and can (depending on the web speed and rheological properties of the ink) be used even in curtain mode on rough surfaces.

$\Delta P3 = \Delta P1 - \Delta P2$

Basic precondition for flat profile: $\Delta P3 << \Delta P1$

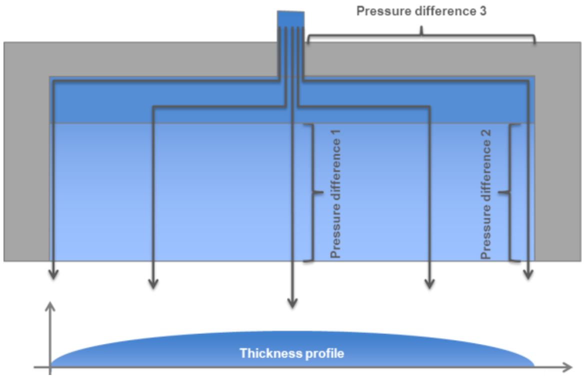

Fig. 3. Theoretical thickness profile of a Slot Die

Upscaling to fab layouts

After explaining the fundamental technologies being used in printed technologies today, the question rises how to transfer or implement these technologies in state of the art printed electronics fabs. The red brick walls to overcome here are stability, reproducibility and high yield of processes. To scale from pilot R2R processes you need players which have background in designing and building semiconductor fabs in combination with R2R experts which have background in building big scale production equipment. The author shows here some developments which are near to fab designs and shows a layout of such a R2R printed electronic fab layout.

Conclusion

In summary the talk intends to give some ideas how the today operation of R2R production technologies looks like and how the midterm future could look like. One of the ideas is to avoid technologies which are not scalable into big scale industrial production like spin coating or other non R2R methods. There will be and there have to be tremendous economies of scale for large area printed electronics to be competitive against other technologies. One step to it is to use R2R technologies on a large scale in real fab environments to prove the idea of low cost printed electronics using printing, coating and other R2R application technologies.