Spray coating of self-aligning passivation layer for metal grid lines

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Abstract

In applications such as organic light emitting diodes (OLEDs) or photovoltaic cells a homogenous voltage distribution in the large anode layer needs to be ensured by including a metal grid with a transparent conductor layer. To ensure sufficient conductivity, relatively thick metal lines are used, which increases the risk of electrical shorts between the anode and the cathode. For this reason an insulating layer is needed on top of the metal lines. The thick metal lines limit the choice of deposition method, since some methods such as spin coating require smooth surfaces and cannot be used for applying the insulator.

Here, a spray coating process has been studied as a potential alternative deposition method to create thin resistive layers on rough surfaces. Spray coating and Joule heating has been used for the alignment of insulator films on printed metal lines. It was demonstrated that spray coating can be used to cover the printed metal lines which have high peaks on them. The spray coating forms electrically insulating layers even though the film thickness is less than the height of the peaks. The leakage current through the dielectric was on the order of 10^{-6} A/cm^2.

Introduction

In organic light emitting diodes (OLEDs) the resistivity of the transparent anode material is causing a lateral voltage drop in the anode [1]. The luminance of the OLED is dependent on the voltage over the OLED, and uneven voltage distribution will lead to uneven light distribution. Integrating metal lines with the anode can reduce the resistivity of the transparent electrode. These metal lines need to be under the non-visible threshold width limit of 50 µm to prevent the interference with visual appearance. Further, the metal lines need to be relatively thick to ensure sufficient conductivity. The thickness of the lines makes the anode and cathode prone to short. To prevent the shorting the metal grid lines need to be passivized by placing an insulator layer onto the lines.

Having the passivation layer on top of the metal lines decreases the device active area. In order to minimize the surface area of the passivation layer a self-alignment method is used to localize the insulator onto the metal lines. The approach is based on Joule heating in which an electrical current is passed through the metal lines causing an increase in the temperature and the released heat cures the insulator locally on top of the metal lines. [2]

Spin coating is widely used coating method for patterning smooth insulator surfaces over large areas, because it creates films with uniform thicknesses and low surface roughness. If the surface structures are significantly higher than the coated film thickness, as in the case of OLED anode grid lines, spin coating does not offer full dielectric coverage for the surface. [3, 4] Spray coating, on the other hand, does not require smooth substrates because the aerosol from the spray coater can cover even thick patterns. For this reason the spray coating method is a simple and versatile method for applying the passivation layer on top of the thick metal lines. Spray coating is also compatible with roll-to-roll manufacturing, which lowers manufacturing costs and enables more efficient mass production.

To obtain a homogeneous passivation layer, several spray coating parameters such as substrate temperature, deposition time, gas pressure and nozzle to substrate distance have to be optimized. The parameter optimization ensures that the solvent in the ink dries fast enough so that the droplets would not significantly redissolve the sublayers. At the same time the evaporation rate should be slow enough to make sure that the droplets integrate smoothly to the previous layers.

Materials and Methods

Approximately 140 µm wide and 2.2 cm long screen printed silver lines on polyethylene naphthalate (PEN) substrate were passivated with the dielectric deposited using a spray coating and a spin coating. The polymeric dielectric solution was thermally cross-linkable poly(4-vinylphenol) (PVP) based solution, where 4,4′-(hexafluoroisopropylidene)diphthalic anhydride (HDA) was used as a crosslinking agent and tris(2-hydroxyethyl)amine (TEA) as a catalyst. The solution of PVP/HDA/TEA was dissolved in propylene glycol monomethyl ether acetate (PGMEA). The PVP (weight-average molecular M_w=25000 g/mol) concentration was 50 mg/ml, and the PVP to cross-linker and catalyst to PVP molar ratios were 10 and 0.03 respectively.

PVP/HDA/TEA solution was spin coated on the substrate with a rate of 2000 RPM. In spray deposition the used spray coater was a commercial airbrush (Silverline) where compressed air was used as a carrier gas. Few spray coating tests were performed to define the optimal coating parameters. The nozzle to substrate distance during spraying was approximately 15 cm and the spray coating pressure was approximately 1 bar. Usually the substrate is heated during the spray coating to adjust the evaporation rate of the solvent but in this case only relatively low heating temperature could be used because the cross-linking reaction would accelerate disadvantageously in the PVP/HDA/TEA solution before the actual Joule heating could be performed.

After coating the dielectric was cured by passing an electric current through the metal lines, which heated the conductors and the non-cured insulator around the silver lines was rinsed off with acetone. Different Joule heating currents and times were tested and the best result was achieved with current-time combination of 300 mA for 1 s. The schematic view of the fabrication procedure is described in Figure 1.

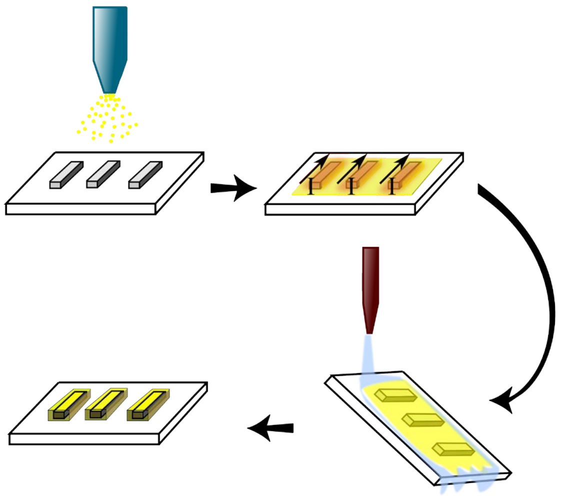

Figure 1. Experimental procedure for used for deposition of the dielectric on metal lines.

The leakage current and line profile were measured from device consisting of sandwiched electrodes. A 50 nm thick copper electrode was evaporated on cured dielectric film forming a capacitor having an area of 0.15 mm^2. Leakage currents were measured with a semiconductor parameter analyser (Agilent 4155B). Films were observed by optical microscope (Olympus BX51) using bright field setting, a reflective illuminator, objective lenses (Olympus MPLAN 20×/0.25), and a digital camera (ARTRAY ARTCAM). The roughness of the dielectric film was characterized with an optical profilometer (Veeco Wyko).

Results and Discussion

It was first demonstrated that spin coating is not a suitable method for applying the dielectric layer on the thick printed silver lines. As shown in Figure 2 the dielectric stayed only locally on the lines. The dielectric did not cover the edges and the mid-section of the line. Thus it can be concluded that the spin coating is not a suitable method for passivation of the thick lines. The estimated spin coated dry film thickness is from 200 to 500 nm, which is only tenth of the printed silver line thickness.

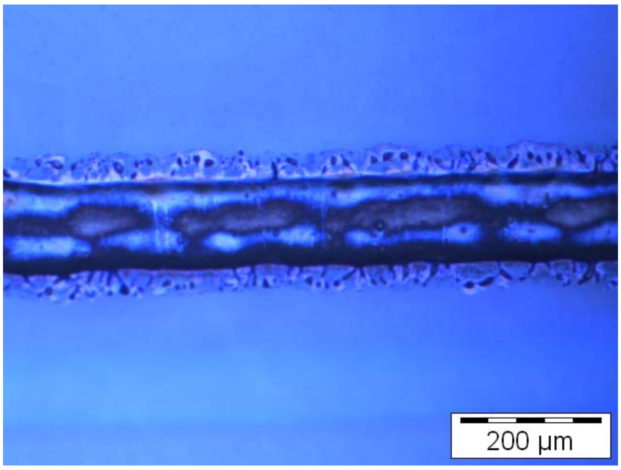

Figure 2. Microscopic image of the spin coated dielectric on printed silver line.

During the spray coating, the samples were placed on top of a hot plate so that the hot plate would dry the ink just enough to ensure even layer formation. Without heating the dielectric film on the substrate stayed in a liquid form during spraying. The wet ink agglomerated and formed individual drops, and the curved substrate forced the ink to gather to the lower areas of the substrate. A hot plate was used under the substrate to set the substrate temperature to 35 °C. The temperature was sufficient to evaporate the solvent but did not cross-link the polymer.

Figure 3 presents an optical profilometer image of the reference sample (non-passivated printed silver line), where few higher peaks can be observed on the conductor surface. These high peaks are potential points for leakage current to flow through the dielectric layer because it is complex to get the dielectric to stay on top of the high peaks and to cover them completely.

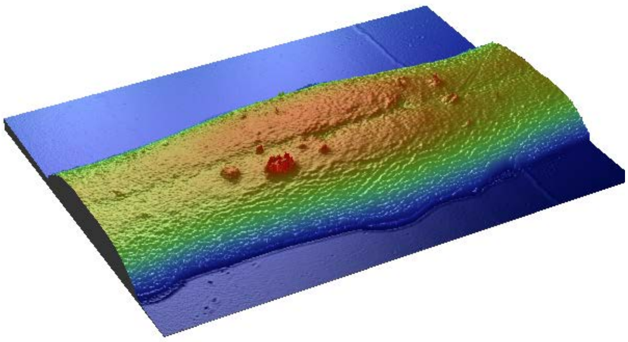

Figure 3. Optical profilometer image of the reference sample profile with 20× magnification.

Figure 4 presents a passivated printed silver line where the dielectric has been spray coated on top of the line. Some scratches can be observed on the surface of the line and most likely they result from storing or handling of the samples before the passivation. The large peak at the center of the line is most likely a dust particle and not a result from the printing process.

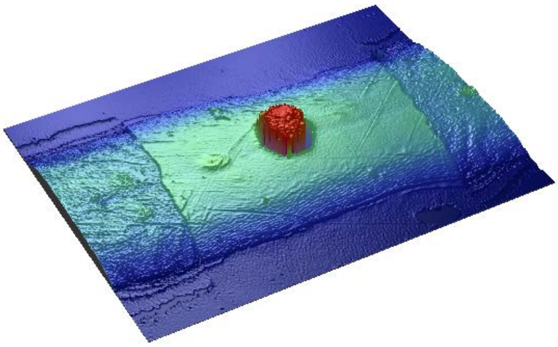

Figure 4. Optical profilometer image of the passivated silver line with 20× magnification.

The cross-section profile of the reference metal line and the passivated metal line is presented in Figure 5. The metal line width varied between the samples, thus the thickness and width of the metal lines on the reference sample and passivated sample differs. Due to this, it is not possible to determine the thickness of the dielectric film from this plot.

It can be noted that the dielectric layer does not have an effect on the surface roughness of the printed line. Furthermore similar high peaks can be observed in both the samples indicating that the dielectric thickness is less than the peak height. The peak height is approximately 1 µm.

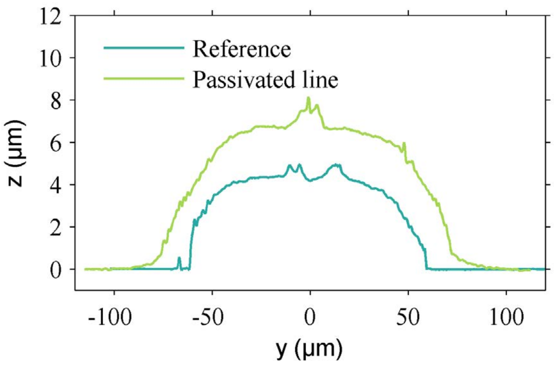

Figure 5. Cross-section profiles of the reference and the passivated line measured using an optical profilometer.

In addition to the optical profilometer imaging the leakage current measurement proved that the spray coated dielectric layer performed well as an insulator and the current through the dielectric was on the order of 10^{-6} A/cm^2. It is significant that the dielectric layer was insulating even though the peaks are not fully embedded inside the dielectric.

Conclusions

The spray coating has proven to be an effective method for applying the dielectric layer on printed silver lines. The dielectric seems to cover the lines completely even though the thickness of the dielectric layer is less than the height of the peaks that occur on the surface of the silver lines. The leakage current measurements showed that the passivation layer provides an adequate electrical insulation because the leakage current through the insulator was only on the order of 10^{-6} A/cm^2.

Acknowledgments

The research was funded by the European Union's Seventh Framework Programme (FP7-ICT-2012, project number 314362).

References

1. K. Neyts, M. Marescaux, A. U. Nieto, A. Elschner, W. Lovenich, K. Fehse, Q. Huang, K. Walzer, and K. Leo, Inhomogeneous luminance in organic light emitting diodes related to electrode resistivity, J. Appl. Phys.,100,114513 (2006).

2. M. Janka, S. Tuukkanen, T. Joutsenoja, and D. Lupo, Self-alignment method for solution-processable dielectric structures via joule heating, Thin Solid Films, 519, 6587 (2011).

3. N.P. Pham, J.N. Burghartz & P.M. Sarro, Spray coating of photoresist for pattern transfer on high topography surfaces. Journal of Micromechanics and Microengineering 15, 4, pp. 691. (2005)

4. N. Atthi, K. Saejok, J. Supadech, W. Jeamsaksiri, O. Thongsuk, P. Dulyaseree, C. Hruanun, A. Poyai, Improvement of Photoresist Film Coverage on High Topology Surface with Spray Coating Technique. Journal of the Microscopy Society of Thailand 24(2010)1, pp. 42-46.