Influence of drying conditions on the uniformity of inkjet printed structures

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For large OLEDs (bigger 15x15cm²) metal grids are a standard technology to achieve uniform current distribution on the anode. For cost cut down inkjet printing of metal based inks is a well-known alternative to vacuum based processes. Printed structures for the OLED application have to be optimized in many ways e.g., a uniform profile of the printed cross-section, the specific electric resistance and the adhesion of the printed and cured layers. For these applications most of the metal inks are based on nanoparticles and organic solvents. Such fluids tend to show Marangoni convection or coffee-stain effects. Marangoni convection exists if surface tension gradients in the fluid occur during evaporation of the solvent. The metal particles can be transported by flows from low surface tension to regions with higher surface tension. In a distinctive profile the particles can agglomerate in the center of a printed line [1]. In a reverse flow, often called coffee-stain effect, the solvent evaporates faster at the three-phase-contact-line than in the center of the fluid. The particles flow to the outer regions and agglomerate near the three-phase-contact-line [2]. In a characteristic profile the maximum layer thickness is up to 4 times higher at the edges than at the center. For printed conducting structures an even profile like a dome is often optimal.

In this example 3mm wide lines were printed with a copper ink based on nanoparticles with a diameter of 1.2µm on 0.7mm thick glass substrates. A reference substrate was dried on a hot plate without forced convection at 60°C for 30 minutes. In contrast to the reference substrate two other substrates were dried with forced convection realized by additional airflow from a small fan on a hot plate at 40°C and 60°C. The reference (Fig.1.a) has a maximum layer thickness of 4µm at the center of the printed line which is about four times higher than the edges. It is supposed that Marangoni convection exist. The Marangoni convection causes the deviation in layer thickness. While the solvent evaporates, gradients in surface tension arise and the particles flow to the center. At 60°C and forced convection generated with a fan (Fig. 1.b) a local minimum in the center of the printed line exist. The maximum thickness of the layer is 2.5µm which is about 2/3 smaller than the reference substrate. The profile shows small characteristics of a coffee-stain effect. The drying time decreased from 30 minutes to 5 minutes. The airflow has an obvious impact on the profile of the printed line and the drying time. Without airflow the air at the boundary layer of the printed line is saturated with solvent. The used solvent evaporates slowly. With forced convection molecules of solvent can be taken away by the airflow. The air at the boundary layer of the printed line is no longer saturated. The solvent can evaporate faster – especially at the three-phase-contact-line. To achieve a dome shaped profile Marangoni convection and coffee-stain effects need to be balanced. Therefore the printing parameters - heat and airflow - need to be optimized. At 40°C and forced convection the maximum layer thickness is 2µm which is half of the reference profile. There are no characteristic minima or maxima existing. The cross section is a dome.

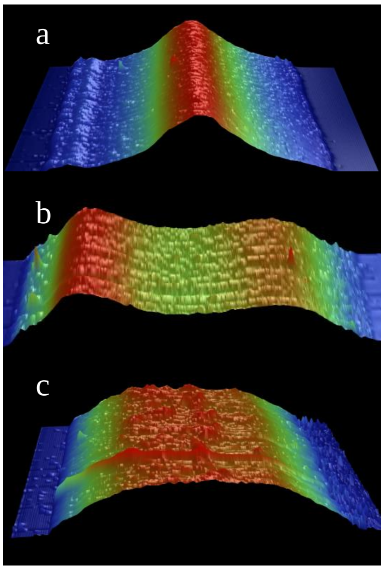

Fig. 1 a: Printed line dried at 60°C. Characteristic profile of Marangoni convection. b: Printed line dried at 60°C and forced convection. Characteristic profile of coffee-stain effect. c: Printed line dried at 40°C and forced convection. Characteristic profile of a dome.

It is shown that different drying conditions lead to different profiles of cross-section. Optimized drying parameters can lead to a nearly even dome profile.

References

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