High Resolution Printing of Conducting Lines in µm Range

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ABSTRACT

We demonstrate an Ultra-Precise Deposition (UPD) technology for fabrication of next-generation displays. UPD allows deposition of highly-concentrated silver pastes (up to 85% wt. of solid content) on complex substrates. The printed feature size is in the range from 1 to 10 µm, with the electrical conductivity up to 40% of the bulk value.

1 Introduction

Additive manufacturing transforms the landscape of modern microelectronics and recent years have witnessed a tremendous progress in display fabrication [1]–[4]. This results in increasing complexity and miniaturization of displays, and therefore the need for efficient, precise, and cost-effective fabrication techniques is very clear.

In this contribution we present an Ultra-Precise Deposition (UPD) technology to print micrometric conductive structures on a wide variety of complex substrates. UPD allows maskless deposition of highly-concentrated silver pastes, up to 85% wt. of solid content. The resulting printed structures are uniform regardless of the wetting properties of the substrates. Printed features size is in the range from 1 to 10 µm, with the electrical conductivity up to 40% of the bulk value.

2 Ultra-precise deposition

The unique operating range for the UPD technology, compared to other printed electronics techniques [5]–[7], is defined by the combination of high-viscosity paste and fine printed features. This can be achieved by a simultaneous optimization of the paste, process parameters, and printing nozzle. In Figure 1 we sketch the working principle of the UPD process: highly-concentrated silver paste is directly deposited on the substrate using a printing nozzle with the opening diameter in the range from 0.5 to 10 µm.

Due to the proper design of the paste, it is stable inside the nozzle and can be extruded through such a narrow opening. The stationary viscosity of the pastes is in the range from 10,000 to 1,000,000 cP, but these are non-Newtonian fluids: the effective viscosity of the paste at the tip of the nozzle is orders of magnitude lower, due to shear thinning.

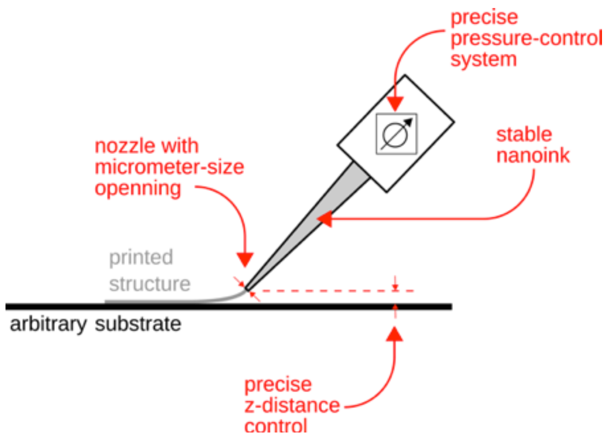

Figure 1 Sketch demonstrating Ultra-Precise Dispensing (UPD) approach.

The process is governed by pressure, and thus the precise pressure-control system is a vital part of the setup. We also use vision algorithms to control the distance between the nozzle and the substrate.

The printed structures are characterized by feature size in the range from 1 to 10 µm and remain uniform regardless of the wetting properties of the substrate: the moment the paste is extruded from the nozzle, its viscosity returns to the stationary value. Therefore, it is possible to print on materials with very different wetting properties, such as oxides (e.g. SiO_2), nitrides (e.g. SiN_x), metals, glass, and foils (e.g. PI, Kapton), as well as to print on junctions (metal/semiconductor/insulator) and cover vertical steps.

3 Results

3.1 High-resolution printing of micrometer-size conductive features

UPD provides means for high-resolution printing of conductive structures, with the resolution defined both as the size of the printed features, as well as the distance between them. In Figure 2 we show an example set of silver lines printed on a PEN foil. The line width is 3.2 µm and the interline distance is 0.7 µm, as can be seen in Figure 2b). It is important to notice that the lines are clearly separated: the interline distance is kept constant and there are no points of contact, which would result in a short circuit.

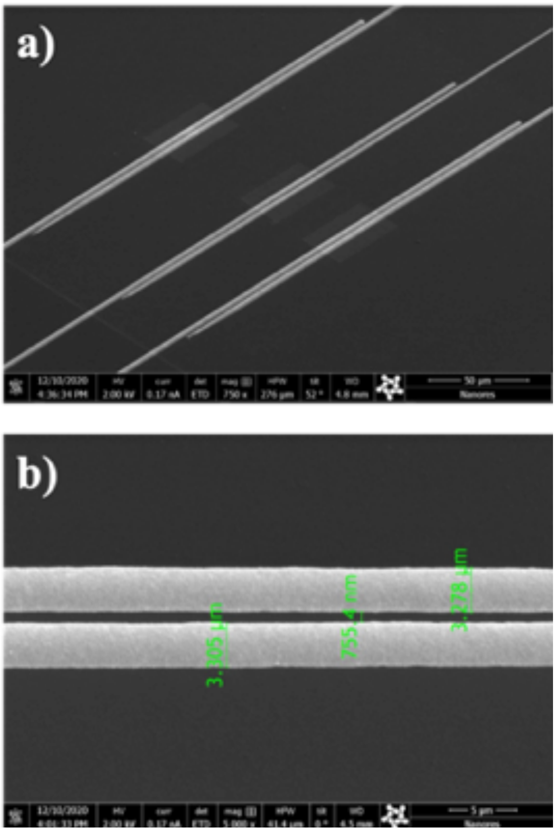

Figure 2 a) Example set of silver lines printed on a PEN foil, b) magnification of the sample.

3.2 Open-defect repair in OLED arrays

Open defects are defined as a local lack of conductive material in an OLED TFT array. Such defects may appear at the production stage and usually result in the product rejection. The problem is becoming even more significant in the case of large-area displays and ongoing miniaturization of display components with the aim of increasing the display resolution.

In Figure 3a) we show repeatable and continuous silver lines with a width of 1.7 µm and length of 20 µm printed on an OLED substrate. As a guide for eyes, the lines are indicated using white rectangles. In Figure 3b) we show magnification of the selected line, showing its dimensions and complexity of the substrate.

4 Conclusions

In this contribution we demonstrated a novel ultra-precise deposition (UPD) technology for display industry. The key capabilities of UPD include printing of micrometer-size conductive features with the electrical conductivity up to 40% of the bulk value; printing on complex substrates with different surface properties; and suitability for mass production. Thanks to these features we argue that UPD can become an indispensable element of modern production lines of next-generation displays.

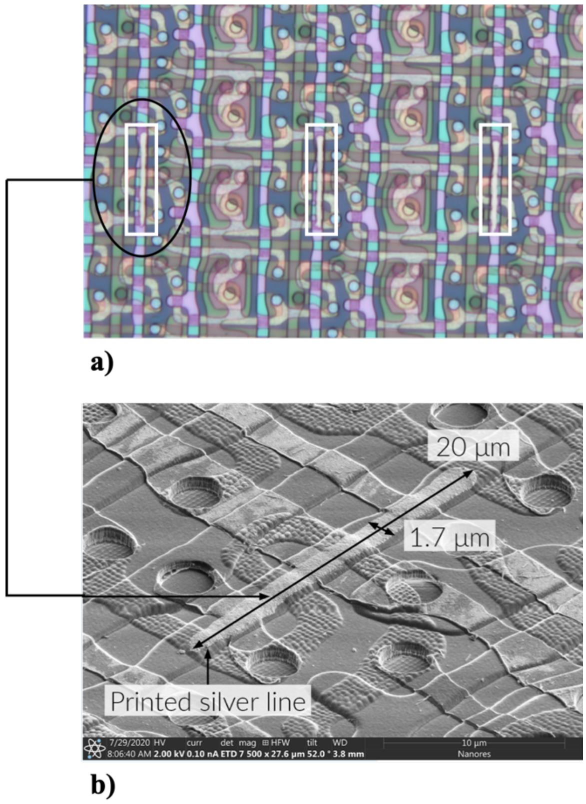

Figure 3 a) Repeatable and continuous silver lines with a width of 1.7 µm and length of 20 µm printed on OLED substrate. b) Magnification of the selected line.

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