A Way of Realizing Display of Things Through a Roll-to-Roll Gravure Printed TFT-Active Matrix

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ABSTRACT

Display of Things (DoT) has been considered as another key technology for a ubiquitous society. The DoT means that all surfaces can be functioned as displays. Here, we would like to show a way of realizing the DoT through a roll-to-roll gravure printed TFT-active matrix.

1 Introduction

A ubiquitous society demands not only Internet of Things (IoT), but also Display of Things (DoT). The DoT means that all surfaces worked as displays (Fig. 1). To realize DoT, the display should be inexpensive, roll-able, bend-able, stretchable, and free size [1]. However, those displays cannot be manufactured by utilizing a conventional photolithography and a vacuum deposition-based technologies which have an intrinsic limit in a cost and a form factor. Therefore, we may need an innovative manufacturing method which can dramatically cut down the cost and overcome the limit of the form factor.

Fig. 1 A concept image of Display of Things (DoT).

A roll-to-roll (R2R) gravure has been modified and developed during the last two decades to meet the requirements to print electronic devices without the limit of the form factor [2]–[5]. Furthermore, since the R2R gravure can reach the printing speed of 9 m/min with an overlay printing registration accuracy (OPRA) of ± 20 μm [2]–[5], the cost issue in manufacturing the electronic devices can be resolved. Of course, although the OPRA is an important factor for the R2R gravure printed electronic devices, a web tension[6], an ink transfer [7] and a drying condition [8] should be well matched with five different electronic inks (gate, dielectric, active, drain-source, and passivation) and substrates (web). Furthermore, the five different electronic inks should be formulated to be orthogonal to each other and dried well while they are passing through the drying chamber with a given printing speed [9].

In this paper, the R2R gravure printing system including 5 different electronic inks and substrate, poly(ethylene terephthalate) (PET) was demonstrated as a practical platform (Fig. 2) as the innovative manufacturing method to fabricate an inexpensive and a rollable 78 x 3 inch^2 of thin film transistor (TFT)-active matrix which would open a way of realizing DoT. The 78 x 3 inch^2 of the R2R gravure printed TFT active matrix with 10 Pixels Per Inch (PPI) resolution was fully characterized and showed a simple fabrication process of laminating a sheet of 78 inch electrophoretic display.

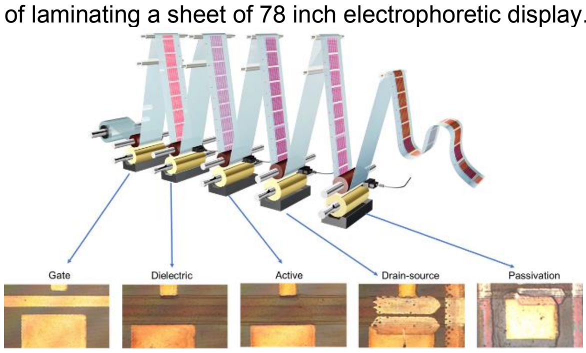

Fig. 2 Schematic illustration of the R2R gravure printed TFT active matrix.

2 Experimental

Five electronic inks for printing gate electrodes, dielectric layers, active layers, drain-source electrodes and passivation layers were respectively formulated by utilizing silver nanoparticles, $BaTiO_3$ nanoparticles, single walled carbon nanotube, silver nanoparticles and polydimethylsiloxane (PDMS) based on previous reports [2]–[5].

The R2R gravure printing process to print the TFT-active matrix on a PET roll were previously reported in detail, and the same printing process was employed in this work as well [2]–[5].

Electrical characterizations of the printed TFT-active matrix were followed exactly same procedure in the previously reported one. Also, as a reference sample, 3.2 x 3 inch^2 of TFT-active matrix with 10 PPI was laminated by electrophoretic display sheet and demonstrated as a signage by utilizing a basic driving IC[5].

3 Results and discussion

The R2R gravure printed TFT-active matrix and transfer characteristics of 11 pixels per a TFT-active matrix with a size of 3.2 x 3 inch^2, selected every 20 cm along a 10 m length of the printed TFT-active matrix were shown in Fig. 3. The device yield was 93 %, comparable to our previous results. However, a mobility is 3.05 cm^2/Vs about 10 times higher than that of the previous samples while an on-off current ratio was almost same (10^4) (Fig. 3) [5].

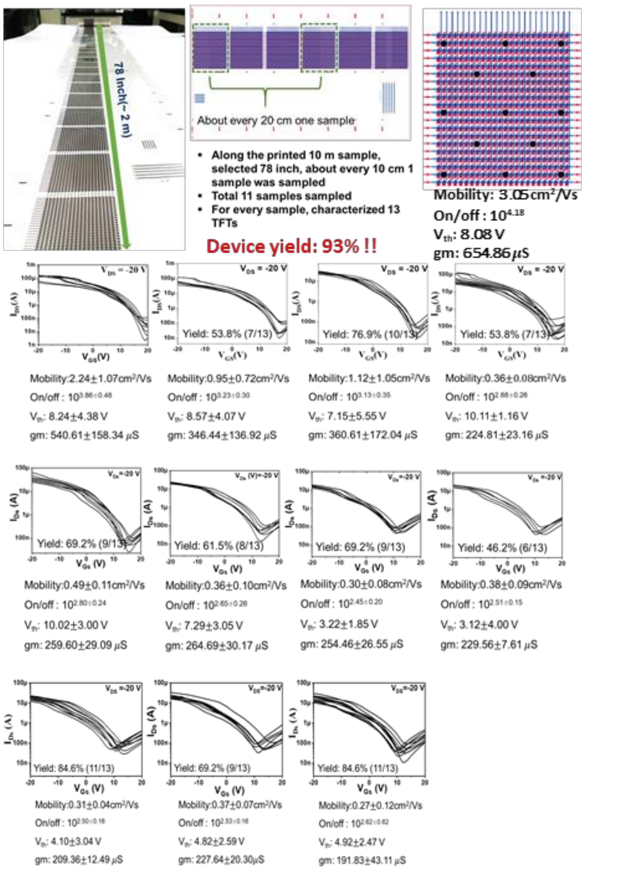

Fig. 3 The R2R gravure printed 78 x 3 inch^2 of TFT-active-matrix image and transfer characteristics of each pixel.

The resulting TFT-active matrix with 78 x 3 inch^2 was cut and laminated with a sheet of the electrophoretic display to complete the flexible electrophoretic display (Fig. 4). Since this lamination process can be integrated in the R2R gravure printing system, the roll of electrophoretic display can be manufactured with a speed of 9 m/min, the highest manufacturing speed for the display in the world. To demonstrate an operation of the R2R printed TFT-active matrix based electrophoretic display, a small reference size, 3.2 x 3 inch^2, was selected and integrated with a platform of driving IC to display characters or images with 10 PPI resolution (Fig. 5). A switching speed of each pixel was fast enough to demonstrate simple mobile images. However, details of running speed will be further optimized by minimizing parasitic capacitances of the R2R printed TFT-active matrix. Furthermore, the sheet of OLED can be tested after restructuring the pixels with 2 transistors and 1 capacitor per a pixel. Since the attained mobility of the printed TFT is reasonable to provide enough currents to turn on and turn off the OLED pixels, the OLED display could be demonstrated through the R2R gravure printing system as well.

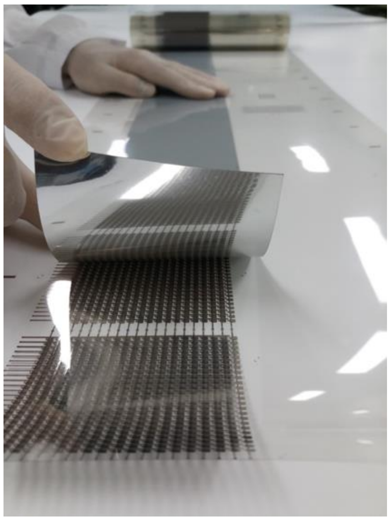

Fig. 4 Real image of simple laminating process to complete a R2R printed TFT active matrix based electrophoretic display.

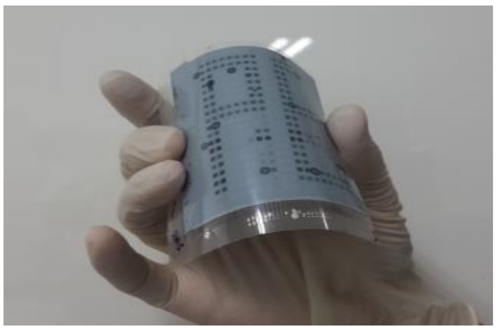

Fig. 5 Real image of the R2R printed TFT-active matrix operated electrophoretic display as a reference size of 3.2 x 3 inch^2.

4 Conclusions

The R2R gravure printing system was demonstrated as an innovative manufacturing platform for realizing the

DoT through overcoming the limit of a form factor and a cost issue in the conventional display fabrication technologies. As a reference model to demonstrate a concept of DoT, the TFT-active matrix with 78 x 3 $inch^2$ were printed by employing the R2R gravure system with a printing speed of 9 m/min and a device yield of 93%. Since the mobility of TFT in the R2R printed pixels was high enough (3.05 cm^2/Vs), the OLED based display will be successfully demonstrated using the same platform of the R2R gravure system which will open a way of manufacturing the DoT.

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