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Letter

High-resolution inkjet-printed organic thin film transistor array with commercially applicable source-drain electrode process

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A B S T R A C T

High-resolution inkjet printing of an organic thin film transistor (OTFT) array for mass-production is still regarded as an immature technology due to the difficulty in controlling the dimension of pattern and registry with other layers in commercial large-scale substrates. Especially, in the case of on organic gate insulator (OGI) in an inkjet-printed OTFT array, it is impossible to use plasma pre-treatment of the OGI for the hydrophobicity required for high-resolution inkjet printing of an organic semiconductor (OSC) due to its non-selectivity between organic layers, both inside and outside the channel area. A novel and commercially applicable process of the source-drain (SD) electrode prior to inkjet printing of the OSC in the bottom contact structure not only allowed a selective plasma treatment for high-resolution inkjet printing of OSC on OGI without the extra photolithographic process, but also protected the channel interface from the harmful outcomes of wet or plasma processes. This method enabled uniform electrical characteristics of more than 300 thousand pixels of an OTFT array for a backplane. Based on these results, a 5.7 inch electrophoretic display (EPD), with a high resolution of 140 dots per inch (DPI), on a plastic substrate was successfully demonstrated.

Organic thin film transistors (OTFTs) have been developed for many years for applications in low-cost flexible electronics and flat panel displays (FPDs) due to their simple solution process in ambient atmosphere at low temperature [1–4]. Adopting soluble semiconductors and insulators is an advantage in commercial applications [4] because it does not involve the chemical vapor deposition (CVD) facilities required of mass-production systems with their high-cost capital investment/maintenance and gases that are harmful to the environment. Solution-processed OTFTs will offer considerable advantage when low-cost direct patterning with soluble materials becomes available. Inkjet printing has emerged as a promising direct patterning technique of OSC as a simple and non-harmful process, while the conventional photolithography printing involves a complicated process for OSC patterning, including chemicals that can damage organic active materials and result in deterioration of the electrical performance of OTFTs [5,6]. However, inkjet printing is normally not considered capable of achieving enough high resolution and is practically limited to several tens of μm in resolution due to the statistical variations of the flight direction of droplets and their spreading on the substrate [7]. To overcome this limitation, many novel methods have been suggested, such as hydrophobic substrate [8], hydrophobic bank [9], SAM-modified substrate [10], solvent dissolving well [11,12], etc. However, most of those do not satisfy the need for both high-resolution and large-area printing in practical purposes due to their low selectivity. Specifically, in the case of OGI, it is impossible to adopt the hydrophobic plasma treatment to enhance the selectivity of inkjet printing because it has no selectivity between the channel of the OGI and the bank.

In this letter, we suggest a novel and commercially applicable process for a source-drain (SD) electrode prior to inkjet printing of OSC. Based on this novel process, high-resolution inkjet printing of OSC for the large area of an OTFT backplane was realized. From the

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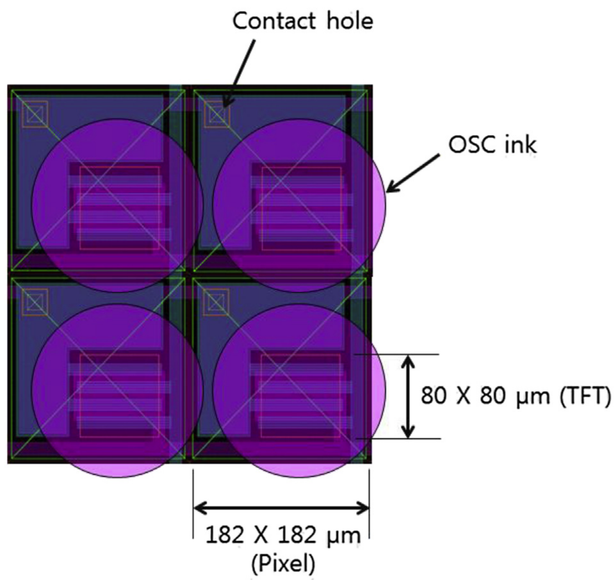

Fig. 1. Pixel design with hypothetical image of OSC drops on the TFT regions.

insulator to the semiconductor, organic materials were used with inkjet printing or spin coating without the CVD process. In addition, we fabricated a 5.7 inch electrophoretic display backed by an OTFT backplane (OTFT-EPD) with 140 DPI on a plastic substrate with uniform TFT characteristics using the proposed printing technique for flexible display application.

Fig. 1 shows the pixel design with a hypothetical image of OSC drops on the TFT regions and this design was used for all of the structures including OTFT array hereafter. The size of each pixel is 182 μm × 182 μm with a TFT of 80 μm × 80 μm. The length and width of the serpentine channel in the TFT were 6.25 and 240 μm, respectively. For high-resolution OSC-inkjet printing, the available volume of OSC ink to be printed could be increased by increasing the contact angle (CA) of the dropped ink to the substrate. To obtain high CAs for high-resolution inkjet printing, strongly modified surface energy of substrate by plasma treatment is preferred. Additionally, after the OSC ink is dropped on the surface, it must flow to its own intended TFT channel region to form a layer with uniform thickness. For this reason, the difference in CAs between the bank and the TFT channel should be introduced by selective plasma treatment.

For the selective plasma treatment, a novel SD electrode process was suggested as described in Fig. 2. In Fig. 2(a), 250 nm of sputtered molybdenium (Mo) was patterned for the gate electrode and a 450 nm Polyvinylphenol (PVP) layer was spin-coated as an organic gate insulator (OGI). After the gate and OGI process, double layers of indium tin oxide (ITO) and Mo with the thickness of 40 and 200 nm, respectively, were sputtered as the SD electrode. A photoresistor (PR) was coated on top of Mo for patterning of the SD electrode followed by UV exposure through a photo-mask. A slit mask enabled reduction of the exposure density in the channel region, which led to partial decomposition of the photo-active compound in the photoresist (PR) [13]. As a result, the partial development of the PR in the channel region created the stepped structure illustrated in Fig. 2(a). After PR patterning, Mo and ITO metal were etched sequentially for the fabrication of an electrical signal line. To define the channel region, the PR was etched using oxygen and fluorine gas plasma until the PR of the channel region was completely removed as depicted in Fig. 2(b). The etching

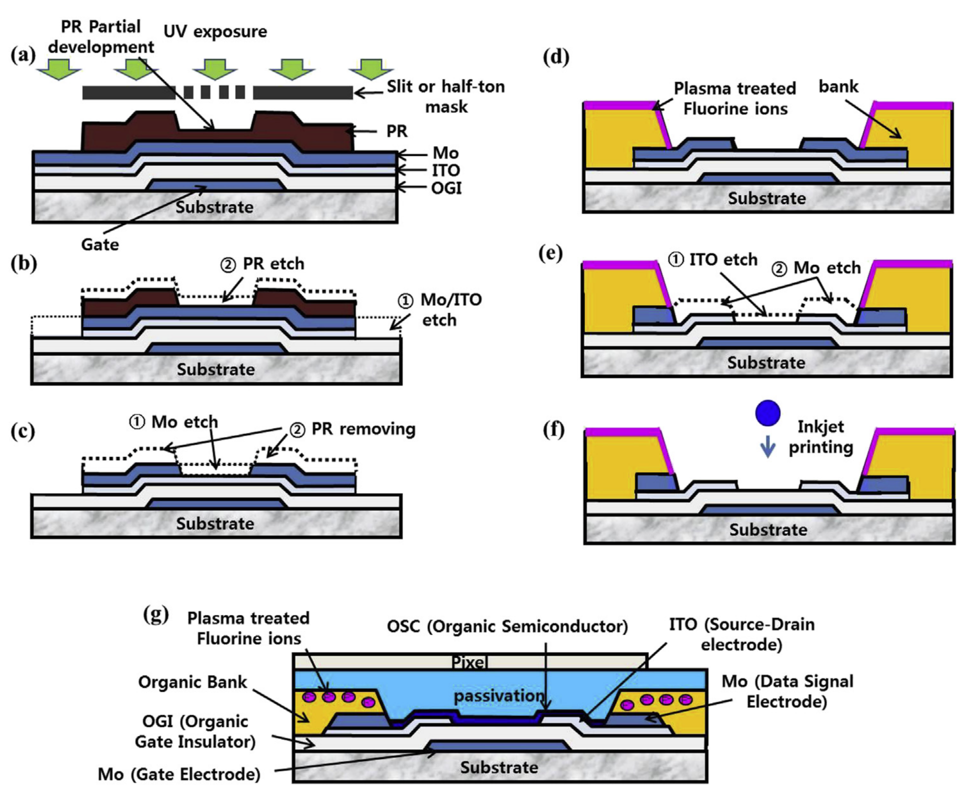

Fig. 2. Process of source-drain electrode, bank and inkjet printing and the final structure of inkjet-printed TFT. (a) Stepped patterning of PR by using a slit photo-mask. (b) The first etching of Mo/ITO double layer of source-drain metal and removing PR to make a channel formed. (c) Source-drain patterning by wet etching and removing PR. (d) Bank patterning and plasma treatment. (e) Channel open by etching of ITO and capping Mo layer. (f) Inkjet printing of organic semiconductor. (g) Cross-sectional view of inkjet-printed TFT.