Active-Matrix Backplane with Inkjet Printed Organic Thin-Film Transistors (OTFTs) for QR-LPD

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Abstract

Active matrix organic-TFT(OTFT) array for Quick-Response Liquid Powder Display (QR-LPD) was fabricated by use of inkjet printing technology.

To define the shape and size of patterns formed by inkjet printing, we adopted a novel surface modification technique called photocatalytic lithography. Photocatalyst such as TiO_2 oxidizes various organic materials in an excited state. Therefore photo-mask with a photocatalytic layer, irradiated with ultraviolet (UV) light, can oxidize selectively the surface of the organic material layer facing the phtocatalytic and then form hydrophobic and hydrophilic patterns. Ink-droplets ejected from ink jet print head spread only on the hydrophilic area and set like the mask pattern.

We have developed to apply this technique to fabricating flat panel display components such as color filter, biomedical tools, and so on. The combination of inkjet printing and photocatalytic lithography enables fine patterns to be formed in a few steps and at low cost.

In this study, we obtained well-defined source and drain electrode in which the channel length is below 10 micron by use of inkjet and photocatalytic lithography. As a result, high contrast image consist of 10 inch, 80 dpi QR-LPD active matrix array was refreshed successfully.

Introduction

We aim at providing low-cost electronic products that consist of printed circuits including active components, such as transistors and diodes on plastic substrate. OTFT is one of promising device that is suitable for fabrication with printing technology to obtain active switch in electronic circuit.

On development of such plastic-electronics related products, one of our targets is to achieve high throughput with Roll-to-Roll compatible process. Many efforts have been paid for developing OTFTs with high performance by various research groups [1, 2], but most of them still have issue on mass-production because they are not free from vacuum process or relative low throughput process. We have been developed surface modification technique to control wettability on a surface of substrate [3]. Application of similar technique enabled us to develop fabrication method of PLED and color filter for LCD with ink jetting [4, 5]. In this study, we report a result on utilization of photo-assisted surface modification technique with inkjet printing for fabrication of OTFT. This led to achieve highly uniform and sufficient switching performance in electronic characteristics with developed printing method.

OTFT with Inkjet Printed Source and Drain Electrode

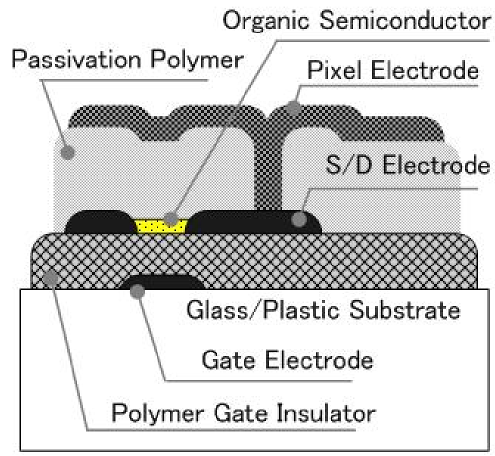

Figure 1. *Schematic cross sectional structure of the all-solution processed OTFT backplane in this work (not to scale)*

In this work we choose conventional bottom-gate structured OTFT as shown in Figure1 from the viewpoint of simplicity of fabrication. At first scan-line and gate electrode consisted of Ag were patterned onto glass or plastic substrate with solution process. Then polymer for gate insulator was applied onto these electrodes. To achieve sufficient field effect mobility, surface roughness of gate insulator should be smooth enough [6]. Careful choice and controlling condition, 0.6nm of Ra was obtained. To adapt driving voltages of OTFT to operating voltage of QR-LPD, we controlled thickness of gate insulator layer as 1micrometer. Then, by use of Photocatalytic lithography, hydrophobic and hydrophilic patterns like shape of source and drain electrodes were formed on the surface of the gate insulator, and Ag ink was ejected to the hydrophilic area by inkjet printing. 20μΩcm of resistivity with 300nm thickness after thermal curing was obtained. Figure 2 shows the magnified image of source and drain electrodes. With this printing technique, resolution of printed source and drain electrode was limited to around 50μm.

A semiconductive polythiophene that exhibits liquid crystalline mesophase was defined with solution process between defined source and drain electrodes. With thermal annealing of liquid crystalline organic semiconductors above phase transition temperature after patterning, we can obtain good result for field effect mobility due to self-organizing property of the material.

Passivation layer on semicondutive layer was screen printed to define contact hole between source electrode and pixel pad. Pixel pads were also printed by screen printing. By the introduction of appropriate passivation material, the transfer characteristics were maintained almost same after the passivation layer covered semiconductor and electrodes [7].

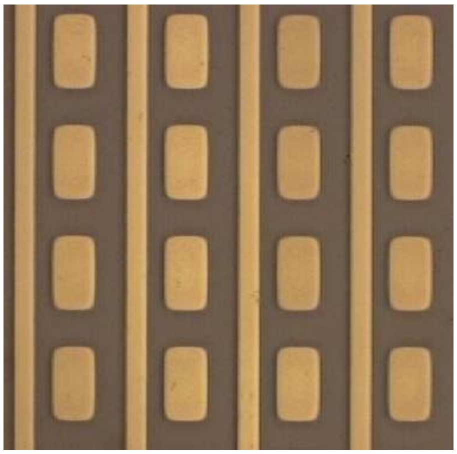

Figure 2. *Source and Drain electrodes defined with Photocatalytic lithography assisted Inkjet printing method on gate insulating polymer. Pitch of each pixel corresponds to 508 micrometer (50dpi)*

With the process written in above we fabricated two types of backplanes on glass and/or PEN substrates. One is 50dpi-resolutioned backplane that consist of 160x120 pixels i.e. 4 inch diagonal and the other is 80dpi-resolutioned 10 inch VGA backplane. Figure 3 shows Transfer characteristics of the OTFT. Obtained field effective mobility was 0.015cm^2/Vs and Vth=0V at Vds=-80V.

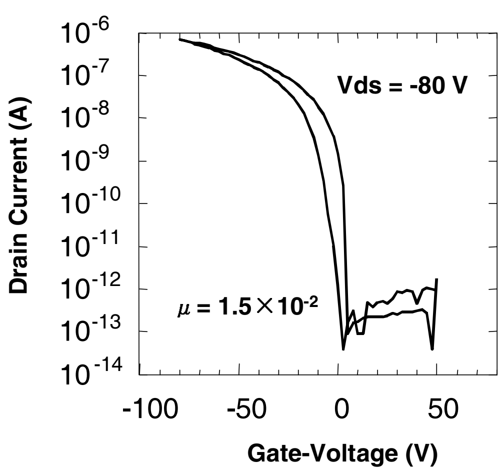

Figure 3. *Transfer characteristics of an OTFT with inkjet printed source and drain (W/L=350/70micrometer).*

Photocatalytic lithography

To obtain well-defined source and drain by inkjet printing , we adopted a novel surface modification technique called photocatalytic lithography [8]. Figure 4 shows how the hydrophobic and hydrophilic patterns are formed on the surface of gate insulating polymer by this technique. (a) First, gate insulating polymer layer, on which the surface is hydrophilic, is formed on a substrate with gate electrode. (b) Next, a TiO_2-coated photomask is placed over the substrate with the photocatalyst layer facing the gate insulator layer. The gap is approximately 10µm. The photomask is then irradiated with ultraviolet (UV) light. (c) As a result, the hydrophobic and hydrophilic patterns form due to the photocatalytic oxidized decomposition of the surface of gate insulator layer.

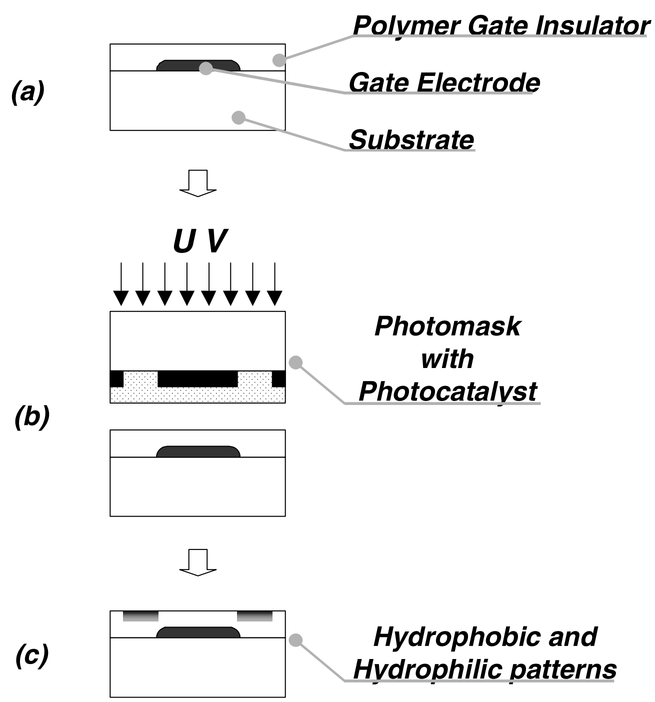

Figure 4. *Photocatalitic lithography process: (a) Formation of Polymer gate insulator on substrate; (b) UV irradiation of photomask; and (c) Resultant hydrophobic and hydrophilic patterns.*

Integration of AMOTFT backplane and QR-LPD

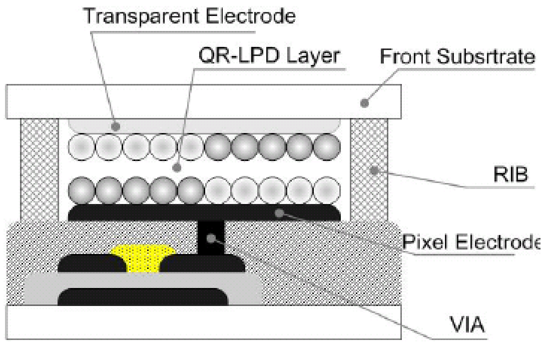

Figure 5. *Schematic cross sectional structure of QR-LPD with AMOTFT backplane.*

For demonstration of their uniformity in performance, we prototyped an AM-QRLPD [9-11] (courtesy of Bridgestone Corporation.) 4 inch diagonal, 50 dpi 160x120 dots and 10 inch diagonal VGA. Figure 5 shows schematic cross sectional structure of QRLPD with OTFT. We confirmed fast and uniform refresh of contents in the display at 300μs width of gate scan pulse voltage waveform and this corresponds to 38.4ms of frame period. In the case of driving them with a passive matrix structure, refresh of image should be done line by line to eliminate crosstalk so the duration to refresh contents is slight long though QR-LPD itself exhibit very fast response speed of 200μs [12]. With AM-OTFT backplane, the front plane could be refreshed as faster as their nature. Addition to this, OTFT can easily adapt their slight high operating voltages with tuning of appropriate thickness and distance in their structure. Figure 6 shows an image of a result of driving QR-LPD with printed AM-OTFT backplane.

Figure 6. *A QR-LPD driven with printed AMOTFT array consist of 80 dpi, 640x480 pixels (10inch VGA).*

Conclusions

As shown in results described in above, we succeeded in fabrication of high performance AM-OTFT with combination of ink-jetting and Photocatalytic lithography. Utilization of developed structure of Active-Matrix Backplane would be a strong feature in flexible substrate. This will lead to practical application of flexible large-area OTFTs, especially in signage application, not only static image but motion image that is enabled by low leakage current nor low parasitic capacitance between pixel electrode and backplane. Not as replacement of existing silicon devices, such as a-Si TFTs, AM-OTFT backplane will play a key roll to give fast refresh of contents which is to be displayed in bistable media. Even in the case of their driving voltage is slight high, due to flexile capability in adaptation of OTFT's design in structure, one will be able to easily adapt its electronic performance.

Acknowledgements

The authors would like to thank other members of the development team at DNP for their help in realizing the results described. We gratefully acknowledge Bridgestone Corporation for preparing QR-LPD.

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Author Biography

Hironori Kobayashi is a graduate of Tokyo University of Science, where he received his Master of Science in colloid and surface chemistry. He joined Dai Nippon Printing (DNP) in 1995 as a researcher in R&D Center. He started to study on inkjet printing from1998 and on organic semiconductors from 2005. He is in charge of R&D on printed electronics, especially, OTFT.