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Self-Aligned Fabrication Process of Organic Thin-Film-Transistors on the Flexible Substrate Using Photo-Sensitive Self-Assembled Monolayers

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1. Introduction

Organic thin-film transistors (OTFTs) are intensively studied due to the possibility of using low-cost solution patterning and deposition techniques coupled with such OTFT futures of light-weight and flexible[1)]. To fabricate OTFT using low-cost printing process, two key issues should be overcome. First one is that materials not only active but also source/drain (S/D) regions of OTFTs should be solution processable. Another key issue is layer-to layer alignment. In spite of recent remarkable progress in printing technology, the alignment accuracy is still in the order of several micro-meters. Therefore, development of device structure and its fabrication process that provide accurate definition of the device components without increasing process complexity is required.

Although we proposed the alignment-free printable electrodes by using the hydrophobic self assembled monolayer (SAM) with a back substrate exposure technique[2)], it could be used only on a quartz substrate because the hydrophobic SAM decomposes on irradiating the deep-UV light (λ<200nm) and changes to the hydrophilic one. In the case of the quarts substrate, the deep-UV light transmitted through the substrate; however it could not pass through flexible-plastic substrates. In order to make the flexible OTFTs, a new hydrophobic photo-sensitive SAM which could decompose by a long-wavelength irradiation is needed.

In this study, we developed a new hydrophobic long-wavelength-sensitive SAM and a novel process fabricating alignment-free printable electrodes for flexible OTFTs, where solution-processed S/D electrodes are self-aligned to a gate electrode by using the SAM optically patterned by back substrate exposure technique.

2. Device fabrication

The TFT fabrication processing steps are shown in Fig. 1. After patterns of gate electrodes of sputtered Al formed on the flexible-plastic substrates, a gate insulator was spin-coated. The gate insulator has a layered structure of polyimide (KYOCERA chemical Co.) and SOG (spin-on glass, AZ electronic materials). The hydrophobic long-wavelength-sensitive SAM film was formed by dipping the substrate into the SAM solution and then it was heated 10 min on the hot plate at 110 ºC. The substrate was then exposed from the back with UV light. The irradiation wavelength was above 350 nm which could pass through the flexible-plastic substrate. After the irradiation, the substrate was rinsed with 2.38 w% of TMAH aqueous solution (tetra-methyl-ammonium hydroxide, TOK) about 1 min and rinsed with water.

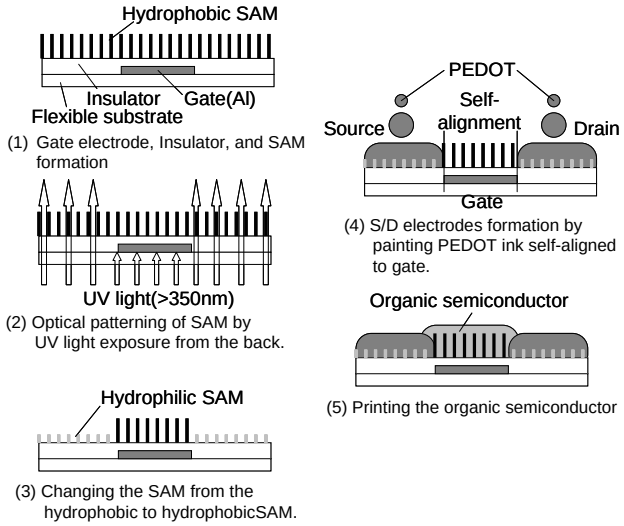

Fig.1 Organic TFT Fabrication process steps.

S/D electrodes were fabricated by spin-coated PEDOT-PSS ink (Aldrich) on the hydrophilic patterns interposed between the residual hydrophobic patterns just above the gate-electrodes. Finally, the organic semiconductor layer was printed between the source and the drain electrodes.

The chemical formula of the hydrophobic long-wavelength-sensitive SAM is shown in the inset of Fig. 4. The details of synthesis and purification of the SAM was presented elsewhere[3)].

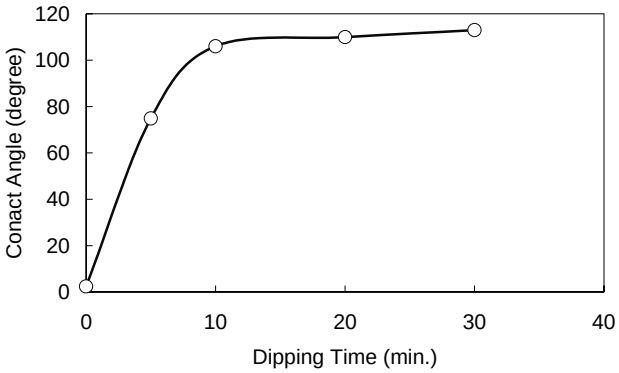

Fig.2 Contact angle changes on the surface of the substrate as a function of the dipping time into the SAM solution.

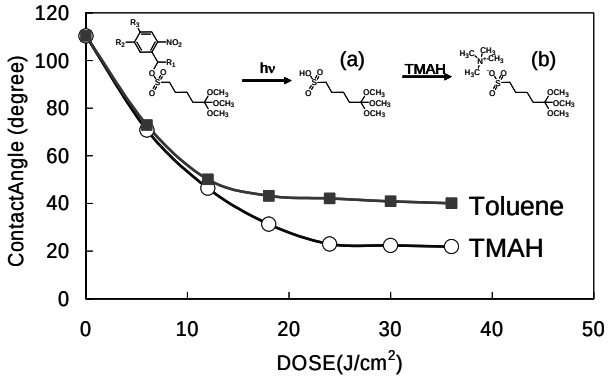

Fig. 4 Photo-decomposed curve of the SAM (Inset: Reaction scheme of SAM)

3. Results and Discussion

The SAM formation was checked by the contact angle of water on the substrate. Figure 2 shows dipping time dependence of contact angle of water. The contact angle of the water on the non-treated surface of the substrate was about 3 degree. After 10 min dipping in the SAM solution, the contact angle of water on the substrate was saturated at about 110 degree. The surface morphology of the SAM coated substrate was examined by using AFM. Figure 3 shows the AFM image on the substrate after 20 min dipping treatment. The line profile indicates that the film was formed single or double layers of SAM-molecules since the long dimension of the SAM was about 0.3 nm.

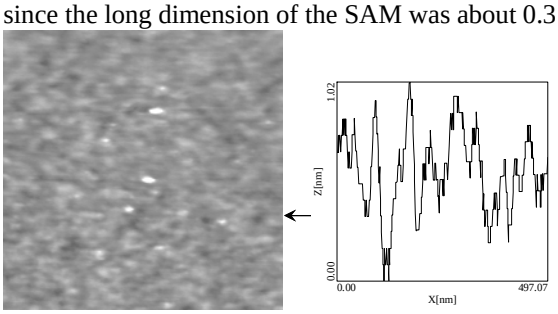

Fig. 3 AFM image of the Hydrophobic SAM

The sensitivity curve of the SAM decomposition is shown in Fig. 4. The open-circle and square show the contact angle changes of SAM by TMAH and toluene treatment, respectively. The contact angle was dropped gradually with increasing irradiation doses. This result indicates that the SAM film is photo-decomposed by back substrate exposure and its wettability can be changed from hydrophobic to hydrophilic. At a dose of 25 J/cm^2, the contact angle as low as 40 degree was attained when the SAM was treated by toluene. We found that TMAH treatment was effective to reduce the contact angle; the contact angle change from 110 to 21 degree was achieved. This is attributable to a high wettable salt (Fig. 4 inset (b)) formation by TMAH with hydroxyl group of photo-decomposed product (Fig. 4 inset (a)) of SAM. On the other hand, in the case of toluene treatment, SAM was reacted only formation of hydroxyl group (Fig. 4 inset (a)).

When PEDOT solution is spin-coated on hydrophobic and hydrophilic SAM films, PEDOT film is formed only on hydrophilic SAM film. By using the photo induced change of SAM wettability, the conducting materials was successfully patterned. As can be seen in Fig. 5, 20 μm gap pattern self-aligned to gate electrode was successfully formed. The printing method with this technique will be useful to fabricate low-cost and high-performance flexible OTFT devices.

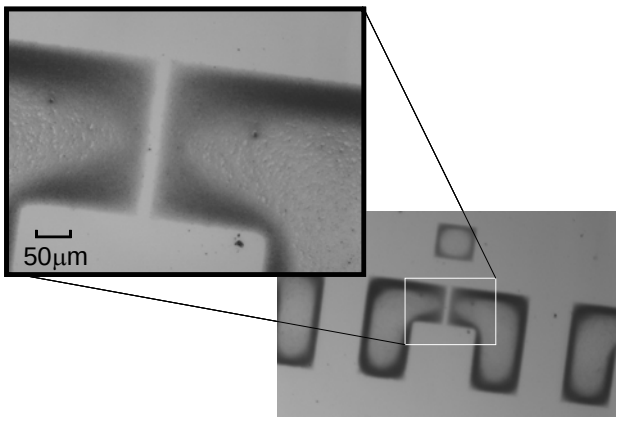

Fig. 5 PEDOT patterns by using the SAM wettability

4. Conclusion

A process fabricating alignment-free printable electrodes for flexible-OTFT was proposed. By using a new long-wavelength-photo-sensitive SAM and back substrate exposure technique, solution-processed source/drain electrodes can be self-aligned to a gate electrode. A 20μm gap pattern of PEDOT was successfully formed by spin-coating on a plastic substrate.

References

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