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Self-Organized Organic Field-Effect Transistors on a Plastic Substrate

Takeo Minari[1], Masataka Kano[2], Tetsuhiko Miyadera[3], Sui-Dong Wang[3], Yoshinobu Aoyagi[1], and Kazuhito Tsukagoshi[3,4]

[1]RIKEN, Advance Science Institute,
2-1 Hirosawa, Wako, Saitama 351-0198, Japan
Phone: +81-48-467-1343 E-mail: minari@riken.jp
[2]Dai Nippon Printing Co., Ltd.,
250-1 Wakashiba, Kashiwa, Chiba 277-0871, Japan
[3]Nanotechnology Research Institute, AIST
1-1-1 Higashi, Tsukuba, Ibaraki 305-8562, Japan
[4]CREST-JST, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan

1. Introduction

Since the performance of organic field-effect transistors (OFETs) has now reached that of amorphous silicon based transistors, practical applications are seriously being considered. The applications may stem from flexible and light-weight features of organic materials, which make large-area and flexible electronics possible. In order to realize the promising electronics applications, OFETs are needed to be fabricated on flexible plastic substrates with low-temperature process. On the other hand, fabrication of OFETs by printing is another promising technology. Up to now, solution processed formation of OFETs has not completely established because of the difficulty in coating and patterning organic semiconductors.

To solve such difficulties, we developed selective organization method of organic semiconductors that allows us simultaneous formation of patterned semiconductor layer from solution phase [1]. Because of the simplicity and reliability, it can be an underlying technique for printing organic electronics. In this study, large number of OFETs was self-organized on a flexible plastic substrate with using a bendable polymer insulator.

2. Selective organization of OFETs

Self-organized formation of the organic layers has been achieved by patterning self-assembled monolayers (SAMs) on the surface of the insulating layer, providing different wettability for organic semiconductor solutions. Highly doped silicon wafers with 50 nm thick thermally grown oxide layers were used as substrates. After cleaning the substrate, the silicon dioxide surface was coated with a SAM of hexamethyldisilazane (HMDS), providing uniform hydrophobicity over the entire substrate surface. The area that had been selected to be the channel region of the OFETs was then irradiated with ultraviolet (UV) light through a shadow mask for removal of the HMDS layer. This area was modified again with a SAM of phenethyltrichlorosilane (PhTS). The PhTS surface is hydrophobic for water, as is the HMDS layer, but is wettable for organic solvents. As a result, regions are modified to become wettable and unwettable, by PhTS and HMDS, respectively (Fig. 1(a)). A 0.3 wt% solution of organic semiconductor of dioctylquaterthiophene (8QT8) in toluene was prepared. The solution was then dropped onto the substrate with patterned wettability. Due to the different wettability on the surface, the solution is likely to diffuse into the wettable area, which results in organic semiconductor films patterned in the desired geometry. Arrays of polycrystalline transistors were fabricated from self-organized semiconductor films with top-contact device structure (Fig. 1(b)). A magnified image of the individual device indicates the accuracy of selective organize technique.

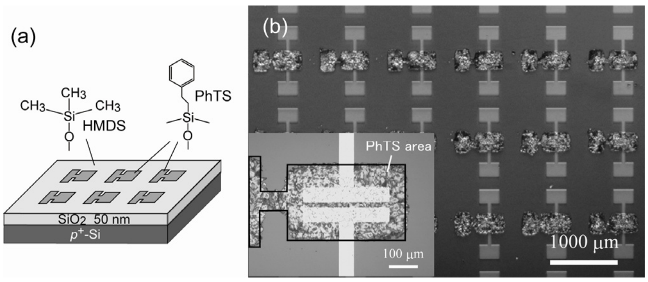

Fig. 1 (a) Schematic of a silicon dioxide substrate patterned with two SAMs having different wettability for the organic semiconductor solution. (b) Arrays of organic transistors integrated by the selective organization technique. Inset shows magnified image of the individual device. The channel length and width are 20 and 300 μm, respectively. Solid line indicates the PhTS-modified area.

3. Electrical characteristics of self-organized OFETs

The principal advantage of PhTS modification is improvement of the electrical characteristics and device stability. Typical transfer characteristics of self organized OFETs are shown in Fig. 2(a). The field-effect mobility was determined to be 0.014 cm^2/V s. Gate bias-induced instability, which causes a negative threshold-voltage shift under negative gate bias stress, is known to appear as the drain current decreases against stress time. Figure 2(b) shows the decrease of drain current under continuous application of a gate voltage for devices with and without PhTS layers, and large differences are clearly observed.

The stable operation may be due to less charge trapping sites at the organic/insulator interface.

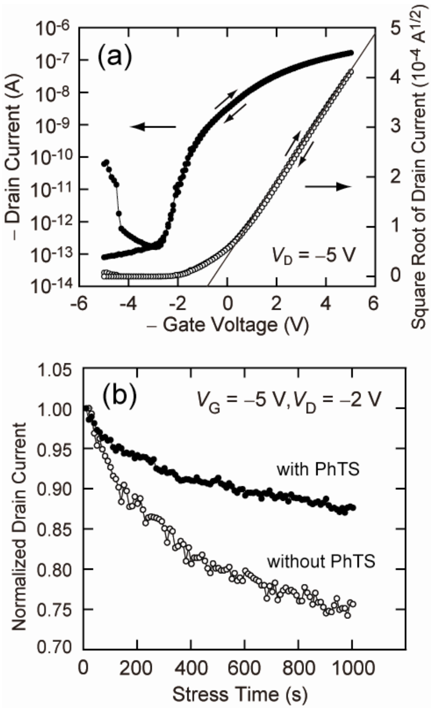

Fig. 2 (a) Typical transfer characteristics of self-organized OFETs. (b) Decay of drain current under gate bias stress for self-organized transistors with and without a PhTS layer. The current is normalized according to the initial drain current.

4. Selective organization of OFETs on a plastic substrate

Use of plastic substrates is necessary to achieve flexible electronics. Polyethylene naphthalate (PEN) film was used as a substrate. The PEN film has the glass transition temperature of 150 °C. This limits the process temperature. Since selective organization process needs a patterned wettability on insulator surface, cross-linked polyvinyl phenol (PVP) was chosen as the gate insulator material, which includes hydroxyl groups that allows the silane coupling reaction.

Ti/Au gate electrodes were vacuum-deposited on a substrate through a metal mask. Polymer insulator layer was uniformly formed on the gate electrodes. Cross-linked PVP was formed by spin-coating of a 15 wt% solution of PVP and the cross linker to form the insulator layer. Unwettable surface was obtained by octyltrichlorosilane (OTS) treatment. Then, selected area was irradiated by UV light to remove OTS, and treated again with phenyltrichlorosilane (PTS) providing wettable surface for the semiconductor solution. As a result, PVP surface was patterned with different wettabiltiy as the case of silicon dioxide substrate. After deposition of Ti/Au source and drain electrodes, organic semiconductor solution was drop-casted on the patterned substrates. As a result, semiconductor channels were selectively formed on PTS area, and the resulting devices exhibited good field-effect properties. The result indicates that the selective organization technique is applicable even on the polymer gate insulator.

5. Conclusions

In conclusion, solution-processed self-alignment of organic semiconductor films has been achieved by patterning SAMs with different wettability for organic semiconductor solutions. Semiconductor layers were selectively formed on phenyl SAM regions, and organic transistor arrays were simultaneously fabricated. Use of a PhTS layer at the organic/insulator interface significantly improved the device stability. In addition, arrays of the self organized transistors were fabricated on a flexible plastic substrate with a polymer insulator. The selective formation technique can provide rational and available direction for future plastic electronics.

Acknowledgements

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References

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