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Oxygen plasma treatment for wettability improvement of alkyl terminal self-assembled monolayer as gate dielectrics

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Abstract

We have improved wettability on alkyl self-assembled monolayer (SAM) with oxygen plasma treatment. Momentary plasma treatment onto gate dielectric surface causes threshold voltage shift of about 1 V and 50 % degradation of mobility. On the other hand, after long-time plasma treatment for 90 s, threshold voltage returns to almost initial value of -0.3 V. TFT with plasma treatment works within low operation voltage of 2.5V with mobility of 0.06 cm^2/Vs. Wettability of gate insulator surface is improved by plasma, and a TFT using drop cast semiconductor on lyophilic insulator surface shows mobility of 0.003 cm^2/Vs at 2.5 V.

1. Introduction

Solution process plays important role in mass production for organic/flexible electronics. Therefore, many researchers have developed various ways to control wettability of surface. For example, hydrophilic polymer layer [1] or UV exposure process [2] have been studied. To realize low-voltage operation, some pioneer researchers have tried to apply UV exposure process onto very thin gate dielectrics which consists of self-assembled molecules, and achieved 4 V operation of TFT [3]. In this study, we utilize oxygen plasma instead of UV light for shortening of process time.

2. Experimental

Fabrication process

Organic thin film transistor (TFT) is fabricated by thermal deposition process and solution process. Fig. 1 shows schematic cross-section structure of organic TFT. As a gate electrode, we deposit aluminum onto a silicon substrate with 300 nm thick silicon oxide by thermal evaporation through the shadow mask. Subsequently, the aluminum layer is exposed to vacuum oxygen plasma in order to form aluminum oxide layer. After that, the substrate is immersed into the 2-propanol solution of 5 mM n-octadecylphosphonic acid. Some devices are exposed to oxygen plasma after SAM forming. N-type organic semiconductors named TU-1 and TU-3 are deposited by thermal evaporation and drop cast, respectively. In this study, 1-methylnaphthalene is utilized as solvent. Finally, we deposit Au onto the organic semiconductor by thermal deposition as source/drain electrode.

Measurement

For transfer characteristics measurement, gate voltage is swept from 0 to 2.5 V with drain voltage of 2 V. Mobility, threshold voltage and the other electric characteristics are calculated from saturation region of transfer curves. All measurement was carried out in the atmospheric air.

3. Result and discussion

Oxygen plasma treatment effect

Fig. 2 shows transfer curve and leakage current in TFTs with various gate dielectric conditions. TFTs with only aluminum oxide as dielectrics shows mobility of 0.06 cm^2/Vs. On the other hand, TFTs with aluminum oxide and SAM shows mobility of 0.13 cm^2/Vs. When we apply momentary plasma treatment for 0.3 s onto a SAM surface in the fabrication, threshold voltage in TFTs moves to high voltage side by about 1 V. However, with plasma treatment for 90 s, threshold voltage returns up to -0.3 V. Mobilites of each TFT are 0.06 (for 0.3 s) and 0.08 (for 90 s) cm^2/Vs.

Large leakage current at 2.5 V is obtain without SAM in fig. 2 (a). TFT with self-assembled monolayer shows smaller leakage of less than 10 nA at 2.5 V even with oxygen plasma treatment (see Fig. 2 (b, c, and d)).

Short-time plasma treatment partially oxidizes surface of SAM, and can increase amount of dipole

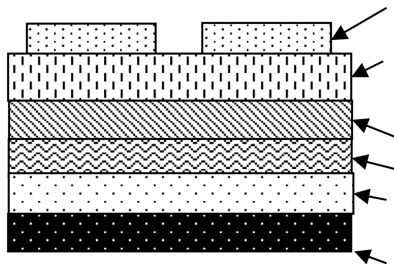

Fig. 1 Schematic TFT structure. Semiconductor layer is formed with two ways. One is thermally evaporation and the other is drop cast film.

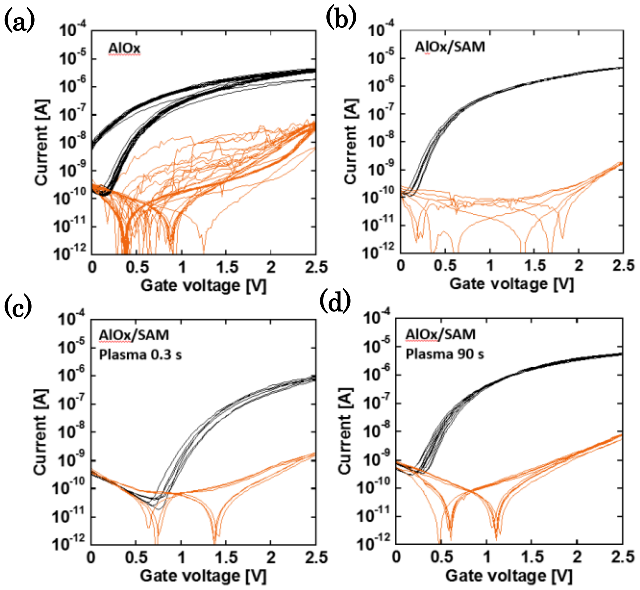

Fig. 2 Transfer curve and leakage current on organic TFTs with various gate dielectrics Black lines show drain current and orange lines show leakage current, gate current.

moment which affects trap state density and threshold voltage. On the other hand, long-time plasma treatment can completely decompose alkyl chain part of SAM. Therefore, it is considered that almost only phosphorus or phosphorus oxide/hydroxide group remains on aluminum oxide layer. In this situation, amount of dipole moment contributing threshold voltage becomes small. In leakage current, alkyl length of SAM is not mainly influential. Previous work on alkyl chain length for organic TFT, however, say that shorter-alkyl-chain SAM causes large leakage current [4]. It is considered that chemical bonding layer between phosphorus and aluminum is effective to reduce leakage current. Alkyl chain length affects intermolecular force to form high area density of SAM [5]. As a result, it is difficult to increase area density of chemical bonding for reduction of leakage current when alkyl chain length is short.

Drop cast TFT characteristics

In the next step, we fabricate TFTs using drop-cast organic semiconductor onto this lyophilic surface. Benzo-bis-thiaziazole derivative (TU-3, Ube indus., Ltd.) is chosen as soluble n-type material. 1-methylnaphthalene solution of TU-3 is drop-cast on to plasma treated SAM. Lyophobic SAM w/o plasma treatment prohibits semiconductor ink from remaining gate electrode by drop-casting(see fig. 3 (a)). On the other hand, plasma treated SAM becomes lyophilic, and droplet can spread over substrate (see fig. 3 (b)). Drop-cast TU-3 device works within 2.5 V and shows maximum mobility of 0.003 cm^2/Vs and threshold voltage of 0.6 V (shown in fig. 3 (c)). In this condition, on/off ratio becomes 10^3 with low leakage current of less than 10 nA.

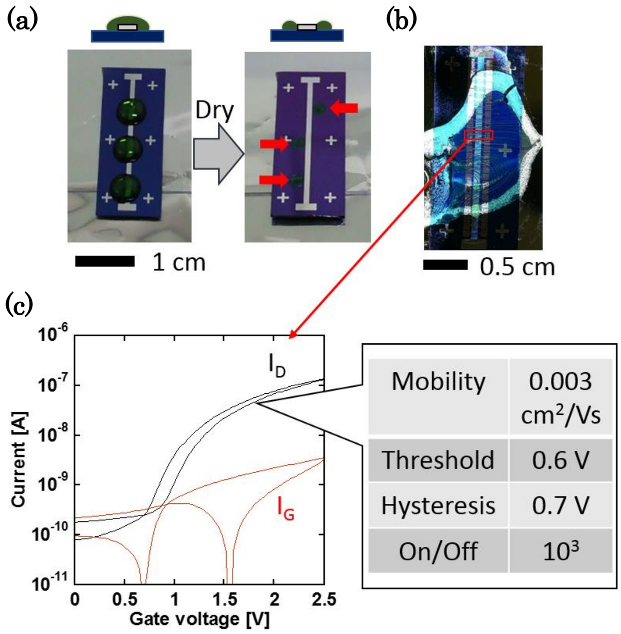

Fig. 3 Drop-cast n-type organic TFT (a) Optical image and schematic side view image of drop cast semiconductor ink on n-octadecylphosphonic acid without plasma treatment. (b) Optical image of TFT with semiconductor drop cast on plasma treated/ SAM. (c) Transfer and leakage characteristics of one of them.

4. Conclusion

We improved wettability of conventional alkyl-terminal gate dielectrics with oxygen plasma treatment. Leakage current through gate dielectric keeps almost same small value of 8.3×10^{-9}A even after plasma treatment for 90 s.

Finally, by drop casting, we achieved to fabrication of organic TFT which works with low operation voltage of 2.5 V and shows mobility of 0.003 cm^2/Vs and on/off ratio of 10^3, keeping low leakage current.

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