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Lower power consumption technique on organic circuits for roll-to-roll process.

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Abstract

We have established lower power consumption technique for roll-to-roll process. We have removed any vacuum process or spincoating process from forming of a gate dielectric to realize roll-to-roll fabrication in the near future. The forming process of a gate dielectric consists of solution process and atmospheric plasma process. In this study, we have chosen self-assembled monolayer (SAM) as a gate dielectrics due to its simple process. First, metal gate electrode is exposed to atmospheric oxygen plasma, followed by immersion into SAM solution. We have improved about three order of magnitude of leakage current through gate dielectrics by optimization of temperature and time in atmospheric plasma treatment. Finally, we have acquired mobility of 1.4 cm^2/Vs for p-type organic transistor. And also we have achieved to fabricate organic invertor and ring oscillator driving with a low operation voltage of 2V.

1. Introduction

Flexible electronics have been expected to be fabricated in roll-to-roll process in order to realize mass product and to reduce its cost. To realize it, many pioneer researchers have developed printing processes or solution techniques on organic semiconductors or electrodes with organic compound solutions[1][2], nano metal inks[3] and so on. And also, gate dielectrics have been formed by solution processes[4]. However, almost of all previous process for gate dielectric have required either a spin coat technique[5] or a vacuum process[6] if we reduce operation voltages of organic devices. Unfortunately, those methods might not suit for continuous fabrication, and increase running cost.

To solve this problem, we use a self-assembled monolayer (SAM) as a part of a gate dielectric. It is because SAM requires just a simple immersion process[7]. For this material, it is problem that oxygen plasma treatment in vacuum is essential if we want SAM to be formed with high packing density. Considering leakage current in organic transistor, we also have to prepare a metal oxide layer to form close-packed SAM on it. Therefore, in this study, we utilize an atmospheric plasma to make metal oxide layer instead of vacuum plasma.

2. Experimental procedure

First, we deposited metal aluminum onto the Si/SiO_2 substrate by thermal evaporation. Aluminum oxide layer was prepared by atmospheric oxygen plasma. We changed substrate temperature and exposure time, and investigated those dependence for electrical characteristics. After that, we immersed substrate into isopropylalchol solution with SAM molecular named n-octadecyl phosphonic acid. Concentration of this SAM solution were 5 mM. After two hours, we rinsed substrate with isopropylalchol. Organic semiconductors were prepared by thermal evaporation through a shadow mask. In this study, we used two kinds of organic materials as a semiconductor layer. One was dinaphtho-[2,3-*b*:2',3'-*f*]-thieno-[3,2-b]-thiophene (DNTT, Sigma-Aldrich Co.) for p-type channel[8], and the other was benzobis(thiadiazole) derivative (TU-1, Ube industries, Ltd.) for n-type channel[9]. At last, Au electrode was deposited onto semiconductor layer by thermal evaporation, and formed source and drain electrodes. Nominal channel width and length were 500 um and 40 um, respectively.

In this fabrication process, we used a thermal evaporation method to form gate electrode, semiconductor, and source/drain electrodes. However, Al deposition onto film is commercially available in roll-to-roll process (e.g. snack packages), and the other layers can be replaced with solution process as we said in this introduction.

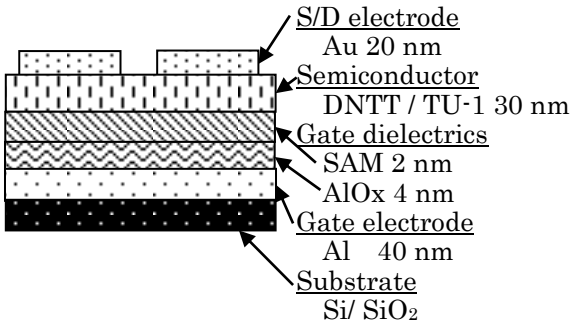

Fig. 1 Schematic TFT structure. Atmospheric plasma is utilized to form AlOx layer. Temperature and time is fixed to 100 deg.C and 90 sec. as standard condition in this study.

3. Result

Transfer curves of DNTT transistors with several plasma exposure times are shown in Fig.2. Drain current in off region can be reduced up to 1.5 nA at 0 V by long time exposure. Gate leakage current at -2.5 V are also dramatically improved from 8.0×10^{-6} (without plasma) to 7.4×10^{-9}A (300 sec). However, this effect of extending exposure time becomes smaller as time becomes longer. Field effect mobilities are shown in Fig.3. Exposure for 20 sec. makes transistors with high mobility of 1.3 cm^2/Vs. As exposure time become longer, mobility decreases slightly up to 1.0 cm^2/Vs. On the other hands, hysteresis in transfer curves increases from 0.03 to 0.24 V. Likewise, heating substrate improves gate leakage current from 4.7×10^{-7} (room temperature) to 9.8×10^{-9} A (130 deg.C) at -2.5 V. Transistor with 100-deg.C heating shows high mobility of 1.7 cm^2/Vs and low hysteresis of 0.06 V with 90-sec exposure. After optimization, n-type organic transistor shows good mobility of 0.17 cm^2/Vs. Complemental invertor circuit shows high invertor gain of over 300 and 3-stage ring oscillator drives with oscillation frequency of 40 Hz with only 2-V operation voltage.

4. Conclusions

We have showed lower power consumption technique for organic devices. It based on an atmospheric plasma process and self-assembling method. Longer exposure time to atmospheric oxygen plasma and substrate heating at higher temperature makes leakage current lower by three order of magnitude. Leakage current decreases exponentially by exposure time. Therefore, paying a little attention to hysteresis of transistor, we can obtain high mobility, low leakage and low hysteresis at the same time. Finally, we have achieved operation of organic invertor and ring oscillator with low voltage of 2 V.

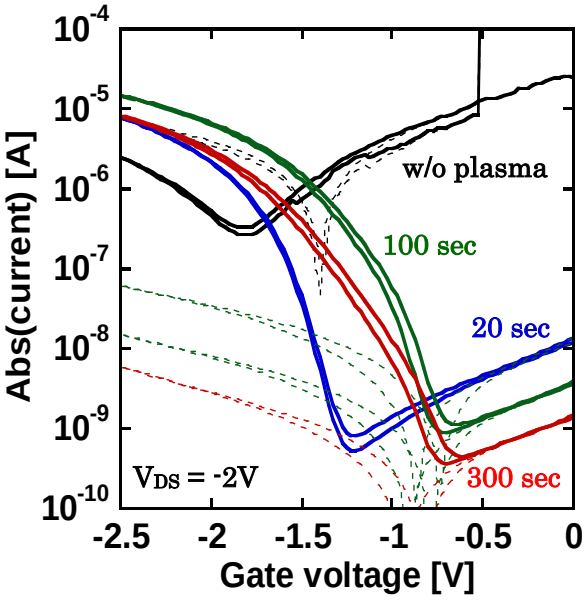

Fig. 2 Transfer curve with several exposure time. On/Off current changes with exposure time for 20 sec (blue), 100 sec.(green), and 300sec.(red). Broken line shows leakage current on gate electrode. Hysteresis of all transistors are counterclockwise.

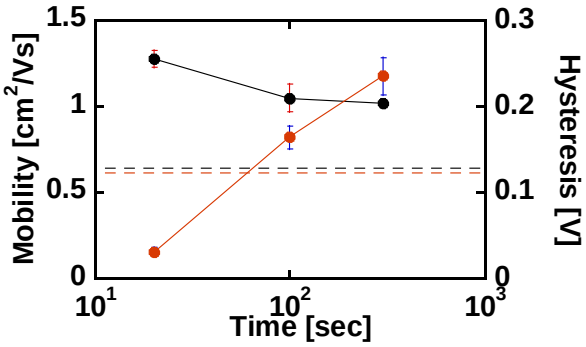

Fig. 3 Transistor mobility and hysteresis as a function of exposure time. Black dots show mobilities and orange dots show hysteresis. Broken lines describes those values in a sample without plasma treatment. Hysteresis increases from 0.03 to 0.24 V when exposure time becomes long.

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