

Characteristics of 9,10-Diphenylanthracene Field-Effect Transistors Obtained by Using Oxidization-Treated Silver Electrodes

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Abstract

Organic field-effect transistors (OFETs) containing a 9,10-diphenylanthracene (DPA) layer were fabricated with oxidation-treated silver electrodes, and their electrical properties were investigated. The OFETs had a structure that consisted of a heavily doped n-type Si wafers (SiO_2) gate dielectric layer, followed by a silver layer oxidized by an ultraviolet-ozone surface treatment, and a DPA layer. The drain currents and mobilities of the OFETs with the oxidized silver (i.e., AgO_x) layer were dramatically higher than those of the layer-free OFETs, because the AgO_x layer, which had high oxidizability, contributed to hole injection as it oxidized the surface of the DPA layer.

1. Introduction

Organic field-effect transistors (OFETs) containing silver nano-ink as a printed electrode are studied extensively for use in large-area applications such as artificial skin and sensors [1,2]. Generally, large drain currents are essential for high sensibility and high responsivity in these applications. For this reason, several studies have been conducted on various methodologies to improve the carrier injection property between the organic active layer and the source-drain (S-D) electrodes. The insertion of a thin metal-oxide layer with a high work function (WF) as a hole injection layer in OFETs has been shown to be an easy and effective way to improve the carrier injection property [3]. However, there are few reports on the direct chemical modification of the silver electrode's surface to improve this property.

Meanwhile, we have found that an evaporated, oxidation-treated silver layer exhibited a high WF defined by the oxidation conditions and demonstrated an increase in the drain current and a decrease in the contact resistance in of pentacene FETs by oxidizing the surface of the S-D silver electrodes [4]. Oxidizing layers can potentially promote carrier injection from a metal contact into an organic semiconductor when they are placed between these two components [3]. However, the effect produced by the insertion of an oxidizing layer on the magnitude of a drain current has not been examined previously in OFETs containing an organic semiconductor that has a deeper ionization potential (IP) than pentacene. Therefore, in this study, we fabricated BC-OFETs containing an active layer having a deep IP and an oxidation-treated silver electrode and discuss its impact on the electrical characteristics of the OFETs.

2. Experimental Details

BC-OFETs containing various types of S-D electrodes were fabricated by vacuum evaporation on heavily doped n-type Si wafers with a 300-nm silicon dioxide (SiO_2) gate dielectric layer. First, the SiO_2 surface was treated with hexamethyldisilazane (HMDS) vapor. It was then separately rinsed with toluene, acetone, and isopropyl alcohol, followed by drying with a stream of nitrogen gas. The fabricated OFETs had a gate electrode/n-type Si wafer/ SiO_2 /Cr adhesive layer (5 nm thick)/S-D electrodes/organic active layer (70 nm thick) structure. To investigate the impact of the AgO_x layer, a 50-nm Ag layer with or without oxidation by an ultraviolet-ozone treatment (UV/ O_3 , Filgen, Inc., UV253E), a 50-nm Au layer, or a 50-nm Au/1-nm MoO_x layer was applied to the S-D electrodes. A ferromagnetic shadow mask, which could adhere well to the wafer fixed onto a magnetic plate, was used to protect the HMDS-treated SiO_2 surface of the channel area from oxidation during fabrication. The channel length (L) and width (W) were 70 μm and 0.5 cm, respectively. 9,10-Diphenylanthracene (DPA), which has a deeper IP than pentacene, was deposited at a rate of 0.04 nm/s without the

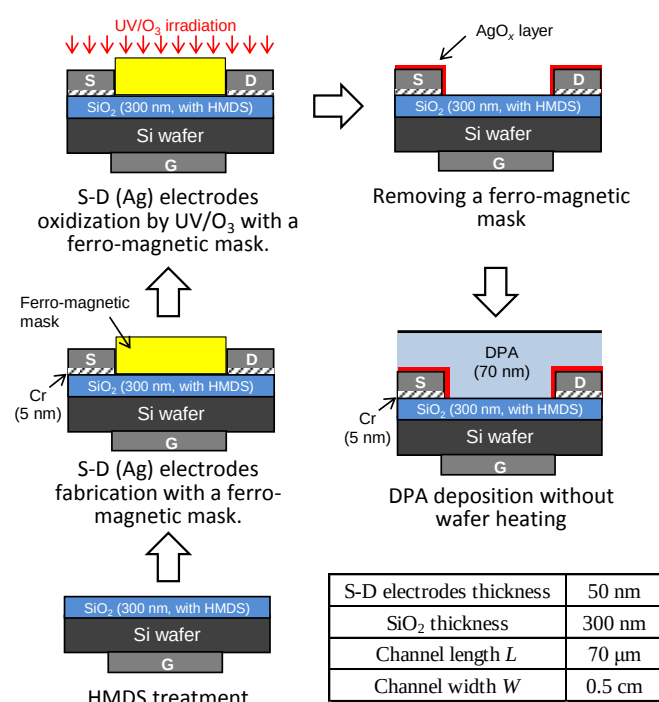


Fig. 1 OFET fabrication process.

wafer heating. After fabrication, the OFET characteristics were measured using a semiconductor characterization system (Agilent Technologies, E5263A) in the dark at room temperature.

3. Results and Discussion

The dependence of the WF of the AgO_x surface on the oxidation time was determined by photoemission yield spectroscopy (Sumitomo Heavy Industries, PYS-202). As shown in Fig. 2, the WF increased with increasing oxidation time and eventually stabilized at ~ 6.3 eV, which is deeper than the IP value (i.e., ~ 5.8 eV) for the DPA layer. According to the X-ray photoelectron spectroscopy measurement results of the oxidized Ag layer, AgO was dominantly synthesized on the Ag surface for an oxidation of >60 s [4]. Therefore, the formation of AgO appears to prevent the WF from increasing further, and thus the WF becomes constant for longer oxidation times. Moreover, it is expected that the AgO_x can oxidize the surface of a DPA layer and can promote hole injection from an electrode into the DPA layer because of having a deep WF, as shown in Fig. 3.

Figure 4 shows the transfer characteristics of OFETs having AgO_x layers. For comparison, the characteristics of a conventional pentacene FET with Au electrodes are also shown. The transfer characteristics of the OFET with Au electrodes exhibit extremely low currents and the device barely worked, suggesting that hole injection from an electrode into a DPA layer in the Au-based OFET is inferior to that in the conventional pentacene FET because of a high hole injection barrier. However, a large drain current is observed for the OFET with an AgO_x layer oxidized for 60 min ($I_D = -1.04$ mA under V_{DS} and V_{GS} of -50 V and -70 V, respectively). This value is as large as that in the conventional pentacene FET ($I_D = -0.86$ mA), although DPA has a deeper WF than that of pentacene. Furthermore, the apparent mobility in the AgO_x -based OFET is estimated to be $0.79 \text{ cm}^2/(\text{Vs})$; this value is a factor of ~ 4 larger than that in the conventional pentacene FET ($0.18 \text{ cm}^2/(\text{Vs})$). Therefore, this result clearly indicates that hole injection is enhanced by oxidation of the Ag electrode surfaces.

4. Conclusions

OFETs containing a DPA layer operate only when an AgO_x layer exists on the surface of the electrodes. Therefore, we conclude that the AgO_x layer fabricated by using an UV/ O_3 treatment exhibits a higher WF and greater oxidizability, resulting in an enhancement of hole injection from the electrodes into the active layer in BC-OFETs.

Acknowledgments

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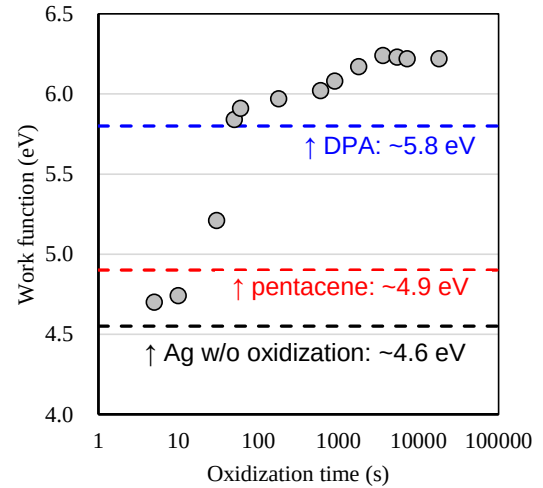


Fig. 2 WFs of the oxidized and nonoxidized Ag electrodes for pentacene and DPA layers.

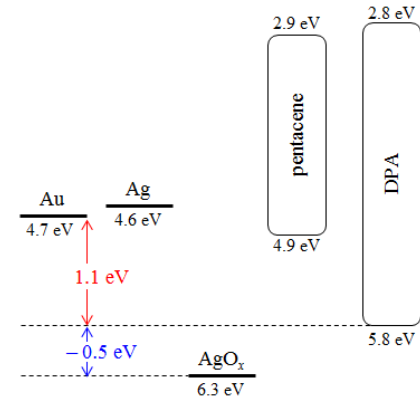


Fig. 3 Energy diagrams for evaporated Au, Ag, AgO_x , pentacene, and DPA layers.

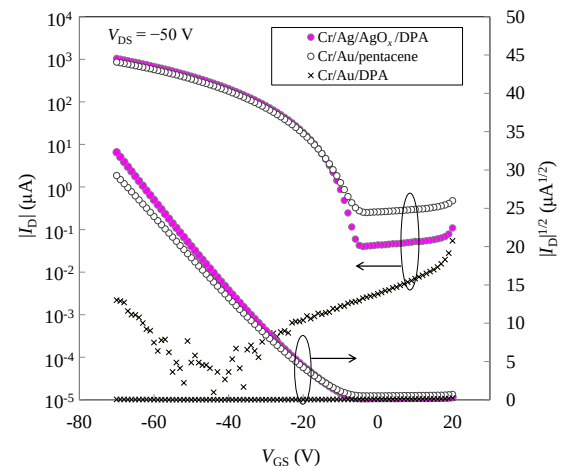


Fig. 4 Transfer characteristics at $V_{DS} = -50$ V of the OFETs with Au or AgO_x layers on the S-D electrodes. Characteristics of the pentacene FET with Au electrodes are also shown.

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