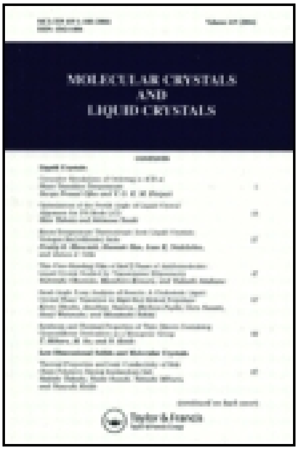

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Effects of Metal Electrodes on the Performance of Vertical Type Organic Thin Film Transistor Using C_{60}

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Vertical type organic thin film transistor (OTFT) using organic semiconductor such as C_{60} was fabricated. C_{60} shows n-type semiconducting property and has relatively high electron mobility. Vertical type OTFT using n-type active material has a layered structure of ITO(drain)/C_{60}/metal(gate)/C_{60}/metal(source). The semiconductor layers and electrodes of OTFTs were deposited by vacuum evaporation technique. The static characteristics of the fabricated OTFTs were investigated. Especially, the effects of C_{60} layer thickness, source electrode and gate electrode on the performance of vertical type OTFTs were studied.

Keywords: C_{60}; OTFT; source and gate electrodes; static characteristics; vertical type transistor

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INTRODUCTION

Organic field effect transistors (OFETs) have been received much attention for flexibility, low cost, simple process and large area device. However conventional field effect transistors (FETs) using organic semiconductor materials have low-speed, low-power and high-resistivity because of their long channel length between drain and source electrodes. On the other hand, vertical type static induction transistor (SIT) is a promising device to improve the problems because of the high-speed and high-power operation owing to the very short distance between source and drain electrodes [1–5]. The vertical type organic FETs are suitable for high speed and large current density.

In this work, we have fabricated vertical type organic transistor consisting of ITO(drain)/C_{60}/metal(gate)/C_{60}/metal(source), and then investigated the transistor characteristics. C_{60} was used as n-type active material, which shows high electron mobility [6]. In general, it can be argued that the characteristics of organic transistor were influenced by carrier mobility and density. Thus, we have used several kinds of metals as source and gate electrodes to optimize the device characteristics. Source and gate electrodes such as Au, Ag, Al, and LiAl are used, because the work-function of the electrodes affects on the electron injection and carrier density. Additionally, the effects of C_{60} layer thickness on the on-off ratio of vertical type transistor were investigated.

EXPERIMENTAL

N-type vertical type OTFTs consisting of glass/ITO(drain)/n-type semiconductor/metal(gate)/n-type semiconductor/metal(source) were fabricated. All layers were fabricated on patterned ITO glass substrate using vacuum evaporation technique (ULVAC VTR-300M/1ERH evaporator) under 10^{-6} Torr. ITO coated glass substrate with sheet resistance less than 20 Ω was cleaned ultrasonically with a series of organic solvents. During the evaporation, the substrate temperature is maintained at room temperature. Firstly, n-type organic semiconductor material was deposited onto the patterned ITO glass substrate. C_{60} used as n-type semiconductor material was purchased from Aldrich. Co. Ltd. The evaporation rate of C_{60} was maintained at 0.5 Å/sec. The thickness of C_{60} layer was approximately 500, 1000 and 1500 Å, respectively. Secondly, Al gate electrode was fabricated with a patterned mask of 100 μm grid type. The structural control of Al gate electrode is very important in the performance of the vertical type OTFT [7,8]. Thus, the Al gate having 100 μm grid type was used in the present work. The thickness of Al gate electrode was 300 Å. The grid type Al gate electrode should be buried in C_{60} active layer. Second organic semiconductor layer was deposited onto the gate electrode by the same thickness and method of first layer. Lastly, source electrode was deposited with several kinds of metal. In order to explore the effects of source electrodes on the static characteristics of the vertical type OTFT, metals such as Au, Ag, Al and LiAl were used. The thickness of source electrode was approximately 1000 Å. The static characteristics of vertical type OTFT were investigated using Keithley 237 and 2400 programmable source meter.

RESULTS AND DISCUSSION

Drain-source current (I_{DS}) at a constant drain-source voltage (V_{DS}) decreased with increasing a gate voltage (V_G) at a C_{60} active layer thickness of 2000 Å as shown in Figure 1. The electron carriers injected from the source electrode flow between source and drain electrodes through potential barrier near the gate electrode. The gate electrode blocks the carrier migration from source electrode to drain electrode due to the formation of double Schottky barriers [7]. The potential barrier is increased with the increase of gate voltage [9]. Thus, I_{DS} could be controlled by the negative gate voltage. I-V characteristics of vertical type organic transistors using C_{60} layers having various thickness were shown in Figure 2. As increasing the thickness of C_{60} layer, I_{DS} was decreased. However, the on-off ratio showed a maximum value of 66.7 at a thickness of 2000 Å, which implies that I_{DS} can be controlled effectively at the optimum thickness of n-type active layer. In order to explore the effects of different source electrodes on the performance of fabricated OTFTs, several source electrodes having various work-functions were used. Table 1 showed the transistor properties of devices using Au, Ag, Al and LiAl as source electrode. I_{DS} at a constant V_{DS} decreased with increasing the metal work-function of source electrode, because high metal work-function of source electrode forms high potential barrier to the active layer [10,11]. When the LiAl having low work-function was used as a source electrode, the potential barrier near the gate electrode could not control the excessive electron carrier effectively owing to the increase of off current between source and gate electrodes. The high on-off ratio was obtained in Al source electrode. Thus, we next tried LiAl as gate and source electrodes to improve the on-off ratio. Figure 3 is plotted I_{DS} versus V_G in vertical type organic transistors using LiAl as gate electrode. The maximum on-off ratio of 236 was obtained when LiAl was used as gate and source electrodes. It may be argued that the result is mainly due to the formation of high potential barrier compared to the Al gate electrode. Especially, the on-off ratio of device

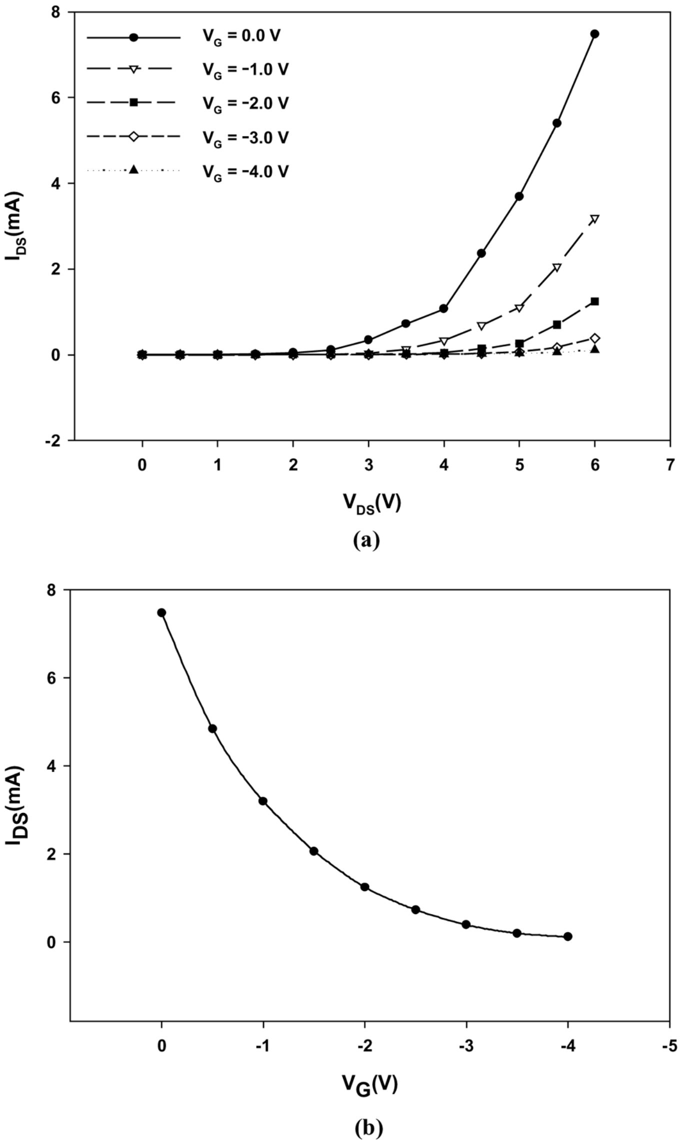

FIGURE 1 I-V characteristics of vertical type OTFT consisting of Al/C_{60} (1000 Å)/Al gate/C_{60} (1000 Å)/ITO. (a) Plot of I_{DS} versus V_{DS} at various V_G and (b) Plot of I_{DS} versus V_G at a constant V_{DS} of 6 V.

using Al and LiAl as source and gate electrodes was higher than the device of Al source and gate electrodes. Now, it should be noted that the LiAl source and gate electrodes are the most promising among

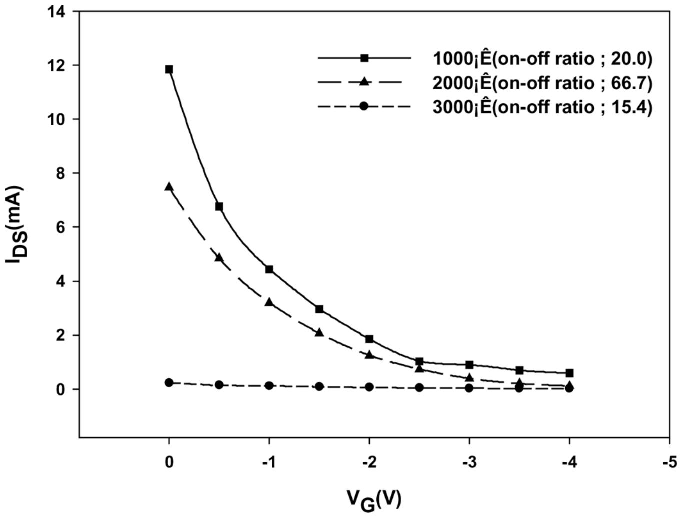

FIGURE 2 I-V characteristics of vertical type OTFT under various C_{60} layer thickness at a constant V_{DS} of 6 V.

the various metal electrodes, judging from the on-off ratio in vertical type organic transistor. Hence it must be worth discussing LiAl electrode in more detail.

CONCLUSIONS

Vertical type organic thin film transistor using C_{60} were fabricated with various thickness of C_{60} active layer and several kinds of metals as source and gate electrodes, and then the static induction transistor characteristics were examined. The prepared vertical type organic

TABLE 1 I-V Characteristics of Vertical Type Organic Transistor using Various Source Electrodes at a C_{60} Active Layer Thickness of 2000 Å

Source metal (work-function)	Gate metal (work-function)	Source-Drain Voltage(V)	Current (mA)	On-off ratio
LiAl (3.0)	Al (4.3)	3	$V_G = 0$ V; 36.383 $V_G = -3$ V; 2.8209	12.9
Al (4.3)	Al (4.3)	6	$V_G = 0$ V; 7.4710 $V_G = -4$ V; 0.1120	66.7
Ag (4.6)	Al (4.3)	6	$V_G = 0$ V; 3.4702 $V_G = -4$ V; 0.1071	32.4
Au (5.2)	Al (4.3)	6	$V_G = 0$ V; 1.5928 $V_G = -4$ V; 0.0538	29.6

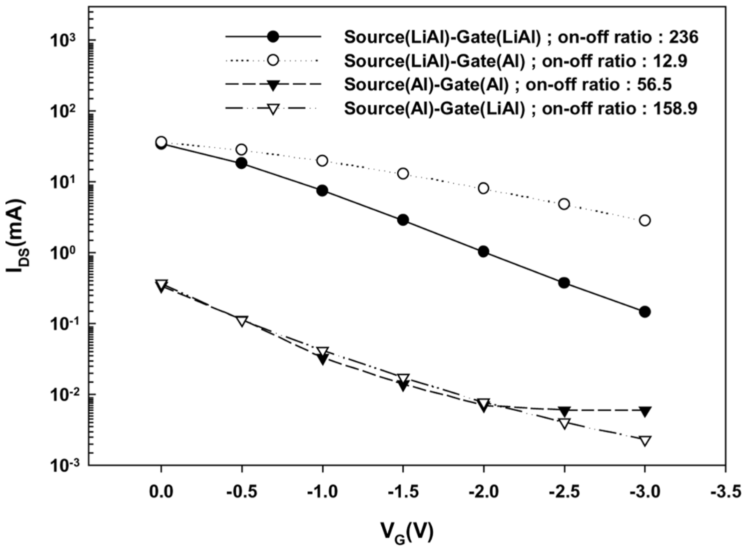

FIGURE 3 I–V characteristics of vertical type OTFT under various source and gate electrodes at a constant V_{DS} of 3 V.

transistor showed the depletion mode as like a conventional MOS field effect transistor. High drain-source current was observed in the device containing low work-function metal as a source electrode. Especially, relatively high current and on-off ratio (236) were obtained in the vertical type transistor fabricated with LiAl source and gate electrodes at a C_{60} active layer thickness of 2000 Å. It can be concluded that carrier density, film thickness and potential barrier near the gate electrode were influenced extensively on the performance of vertical type organic transistor.

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