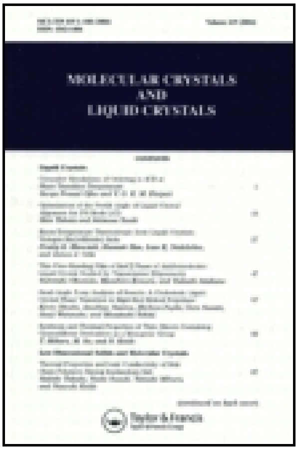

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N-channel organic field effect transistors (FETs) with $F_{16}CuPc/SiO_2$(300 nm)/Si and $F_{16}CuPc$(20 nm)/Polyimide(320 nm)/Si structures were fabricated, and the transistor electrical characteristics measured in the air and in a vacuum at a pressure below 1.3 Pa were compared. The threshold voltage V_{th} and the mobility μ of the transistor with the SiO_2 gate insulator are strongly dependent of the ambient pressure during the measurements, while those of the transistor with the Polyimide gate insulator are nearly independent of the ambient pressure during the electrical measurements. The change of the transistor characteristics on the ambient pressure might be attributed to the absorption and desorption of some negatively charged chemical species on the transistor channel interface region.

Keywords: organic thin film transistor; perfluorinated copper phthalocyanine; polyimide

1. INTRODUCTION

Organic field-effect transistors (OFETs) have been widely studied due to their potential applications in flat-panel displays, complement circuits and sensors [1–3]. In these applications, organic complement circuits are very attractive because of their inherent advantages of low power dissipation, high device stability, and a good noise margin [4].

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In previous work, some materials for organic semiconductors such as Pentacene were reported to exhibit hole transport [5], and materials including Fullerenes were reported to exhibit electron transport [6]. Although many of these report on p-channel transistor characteristics with hole transport, not many papers reports on electron transporting n-channel transistor characteristics and the instability of those n-channel transistors have been reported, and many papers reported on transistor characteristics measured in a vacuum chamber. It is generally considered that the characteristics of organic transistor are significantly influenced by the ambient pressure during the storage.

Recently, it is reported that Perfluorinated copper phthalocyanine ($F_{16}CuPc$) shows electron carrier transport measured in the air [7]. $F_{16}CuPc$ is one of the organic semiconductor materials which are chemically stable in ambient pressures. But it has not been frequently reported on whether I_D-V_{DS} characteristics of $F_{16}CuPc$ Field Effect Transistors (FETs) depend on the ambient pressure during the electrical measurements. It is suspected that the chemical structures between organic semiconductors and gate insulator materials also have influences on the stability of the transistor characteristics. It is also interesting to investigate $F_{16}CuPc$ transistors with different gate insulator materials such as SiO_2 and Polyimide [8,9] because the transistor instability may depend on the gate insulator materials. Therefore, we investigated the influence of the ambient pressure during the measurements of the electrical characteristics on I_D-V_D characteristics of $F_{16}CuPc$ FETs using SiO_2 or Polyimide (PI) films as a gate insulator.

2. EXPERIMENTAL

The molecular structure of $F_{16}CuPc$ used in this study is shown Figure 1. It is regarded that this materials with a strong electro-negativity caused by fluorine atoms enhances electron injection from the source electrode into the channel region of the $F_{16}CuPc$ transistor. Figure 2 is the schematic of the $F_{16}CuPc$ organic field effect transistor (FET) investigated here. In this study, two types of gate insulators, SiO_2 and Polyimide (PI) on heavily doped n-type Si substrates were prepared. The heavily doped Si (100) substrate is used as a gate electrode with a 300 nm-thick thermally grown SiO_2 layer as gate dielectric. In the case of using PI as a gate insulator, the PI films were spin coated on the heavily doped n^+-Silicon substrate, and was successively cured at 140°C for 2 minutes, 200°C for 30 minutes, and 350°C for 60 minutes on a hot plate in the air. The thickness of the PI film measured using Ellipsometry was 320 nm. Since the dielectric constant of the PI film is

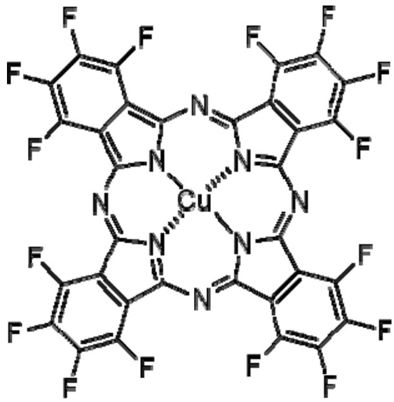

FIGURE 1 Molecular structure of perfluorinated copper phthalocyanine ($F_{16}CuPc$).

approximately 3.4 and that of SiO_2 is 3.7, the equivalent gate insulator thicknesses of the SiO_2 and the PI films are almost the same. After these gate insulators were prepared, the $F_{16}CuPc$ films for the semiconductor layers were deposited by thermal vapor deposition at an estimated deposition rate of 0.2 nm/s under the base pressure of 1.0×10^{-3} Pa. The $F_{16}CuPc$ was purchased from Sigma-Aldrich Co., and was used without further purification. Then, a gold film was thermally evaporated through a shadow mask to define the source

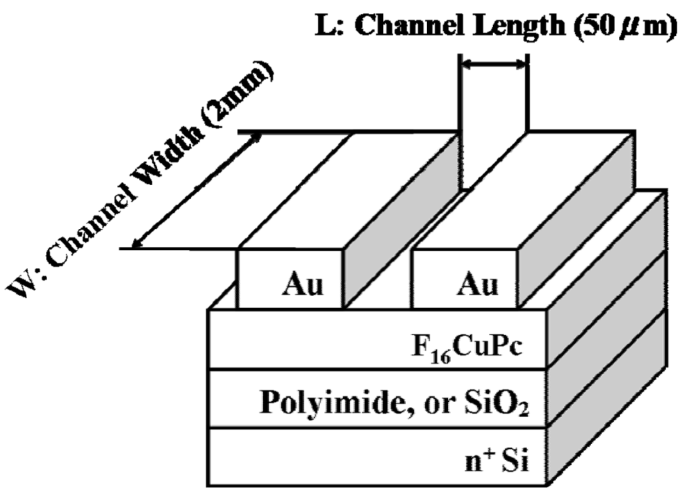

FIGURE 2 Schematic of top contact FETs with $F_{16}CuPc$ or SiO_2 as a gate insulator.

and drain electrodes. The defined channel length and width were 50 μm and 2 mm, respectively. Please note that the surface of the SiO_2 prior to $F_{16}CuPc$ deposition received no special treatment in the case of fabricating the SiO_2 transistor.

The transistor characteristics were measured in a vacuum chamber (FP-1500C, Japan Micronics, Inc.) using the Semiconductor Parameter Analyzer, HP4145A. The measurements of these transistors were performed using the vacuum chamber which was filled with air or evacuated at the pressure below 1.3 Pa.

3. RESULTS AND DISCUSSION

Figure 3 shows the relationships between the drain–source current (I_D) and the drain–source voltage, V_D at different gate–source voltages, V_G from 0 to +70 V for the n^+-Si/iSiO_2/$F_{16}CuPc$/Au FET as measured in the air. The function of the transistor with the positive gate voltage range suggests that an n-channel transistor was fabricated, and that electrons are accumulated in the channel region. With the increase of V_D, the saturation region can be clearly observed. Figure 4 corresponds to the transistor characteristics measured after the vacuum chamber was successively pumped down to the pressure below 1.3 Pa. As clearly seen, the drain current measured under the

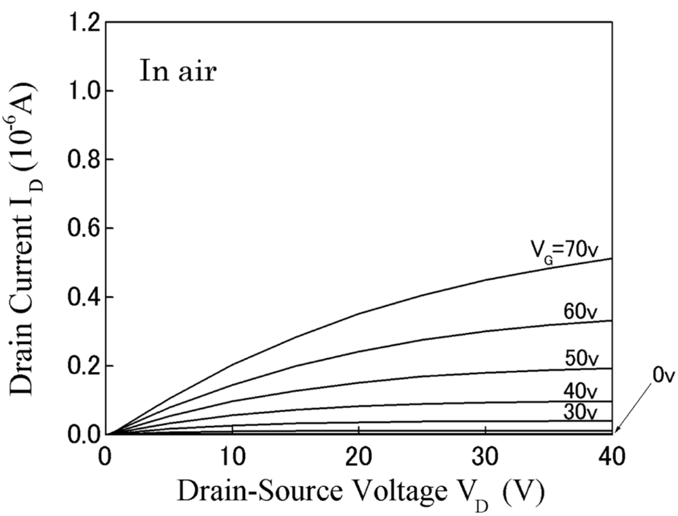

FIGURE 3 I_D-V_D characteristics of n^+-Si/SiO_2/$F_{16}CuPc$/Au FET as measured in the air.

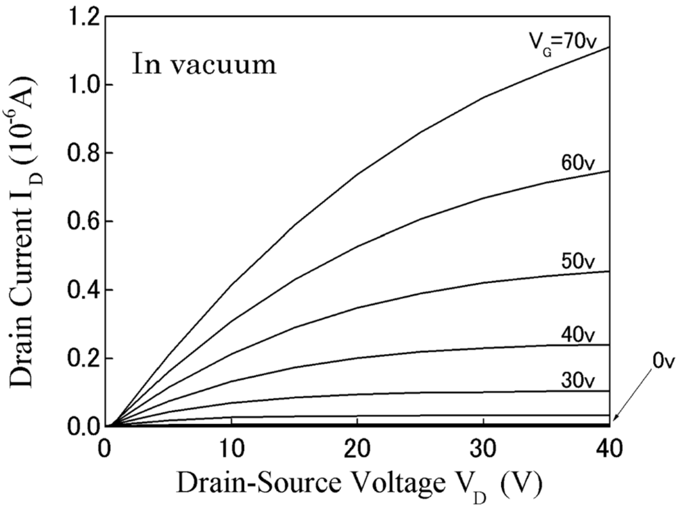

FIGURE 4 I_D-V_D characteristics of n^+-Si/SiO_2/F_{16}CuPc/Au FET as measured in vacuum of 1.3 Pa.

vacuum is approximately two times larger than that measured in the air. These characteristics are nearly reversible following the successive change of the ambient pressure.

Figures 5 and 6 show the I_D-V_{DS} characteristics of the same n^+-Si/PI/F_{16}CuPc/Au FET measured in the air and in the vacuum below 1.3 Pa, respectively. The drain current measured under the vacuum is almost equal to that in air. Figure 7 shows the relationships of the square root of I_D and gate voltage V_G for those F_{16}CuPc FETs evaluated in this work. The field effect mobility μ and threshold voltage V_{th} were extracted from the figures 3–7 in the saturation region ($V_D = 40$ V) using the following equation.

$$\mu = \frac{2L \cdot I_D}{W \cdot C_{OX} \cdot (V_G - V_{th})^2} [cm^2/V \cdot s] \tag{1}$$

where the value of C_{OX} is the capacitance per unit area of the gate insulator and V_{th} is the threshold voltage. It shows that the transistor with the PI gate insulator exhibited the minimal change of the drain current, I_D and the threshold voltage, V_{th} before and after the ambient evacuation. The extracted μ and Vth of these FETs are summarized in Table 1. The threshold voltage V_{th} with SiO_2 gate insulator shifted from 18.1 to 11.0 V when the ambient pressure changes from the air to the vacuum. On the other hand, V_{th} of the PI gate FET shifted from −1.2 to −2.3 V when the ambient pressure changed from the air to the

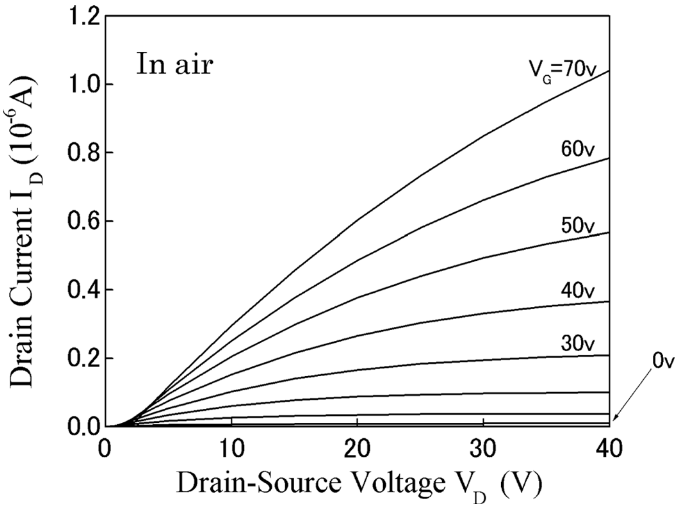

FIGURE 5 I_D-V_D characteristics of n^+-Si/PI/F_{16}CuPc/Au FET as measured in the air.

vacuum. It is noted that the mobility of the SiO_2 transistor shows a notable increase and the threshold voltage decreases as the ambient pressure decreases. The larger positive V_{th} shift of the SiO_2 transistor

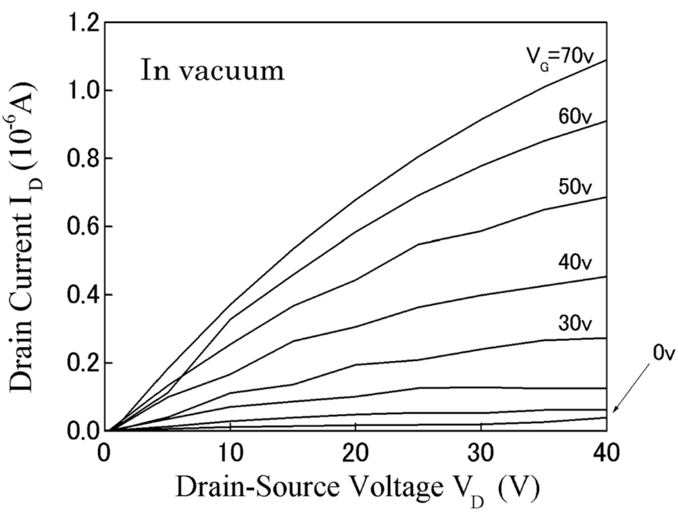

FIGURE 6 I_D-V_D characteristics of n^+-Si/PI/F_{16}CuPc/Au FET as measured in the vacuum of 1.3 Pa.

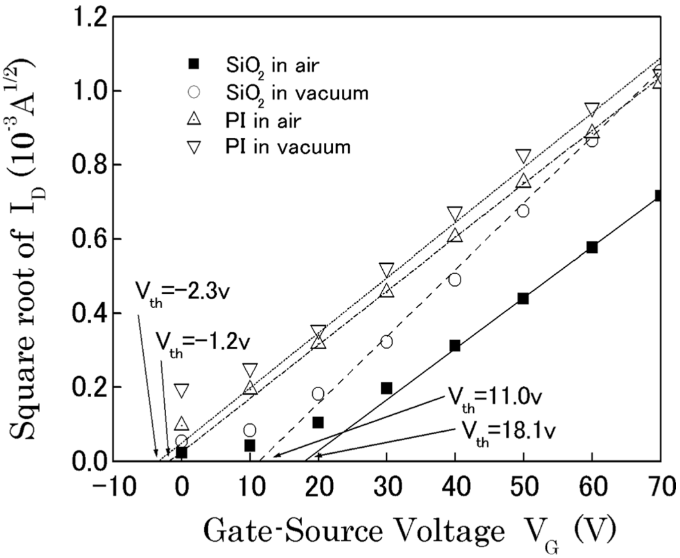

FIGURE 7 I_D-V_G characteristics of $F_{16}CuPc$ FET and SiO_2 FET as measured in the air and in the vacuum of 1.3 Pa.

compared to that of the PI transistor indicates that the $SiO_2/F_{16}CuPc$ interface is more negatively charged than the $SiO_2/F_{16}CuPc$ interface. Those characteristic changes were almost completely reversible depending on the change of the ambient pressure during measurements. It is suggested that a possibly negatively charged chemical species is removed from the $SiO_2/F_{16}CuPc$ interface during the evacuation process. It is also interesting to point out that the reversible nature suggests that the possible chemical species could be physically absorbed at the interface. On the other hand, the PI transistor shows minimal change of the characteristics during the ambient pressure changes. It has been well known that the SiO_2 surface is very hydrophilic, while the PI surface is hydrophobic. Therefore, it may

TABLE 1 Comparison of Mobility μ and Threshold Voltage V_{th} for SiO_2 $F_{16}CuPc$ Transistor and $PI/F_{16}CuPc$ Transistor

	SiO_2		PI	
	In air	In vacuum (1.3 Pa)	In air	In vacuum (1.3 Pa)
μ [10^{-8} cm^2/Vs]	0.9	1.5	1.1	1.1
V_{th} [V]	18.1	11.0	−1.2	−2.3

be speculated that the water on the SiO_2 of the $SiO_2/F_{16}CuPc$ desorbs and absorbs water depending on the measurement pressure change. The water and related chemical spices are easily negatively charged resulting in the scattering of the transporting electrons in the channel region and these negatively charged species causes the increase of the threshold voltage, V_{th}. However, more extensive works are needed before concluding the speculation.

4. CONCLUSION

The n-channel $F_{16}CuPc$ organic field effect transistors with two different kinds of the gate insulators of the SiO_2 and the Polyimide were fabricated, and the transistor characteristics were measured in the air and in the vacuum (1.3 Pa) and compared. The transistor characteristics with the SiO_2 gate insulator changes significantly depending on the measurement ambient pressure, while those of the transistor with the Polyimide gate insulator is pretty stable. These results of the transistor characteristics may suggest the advantage of the Polyimide gate insulator over the SiO_2 gate insulator on the transistor ambient stability. It was also speculated that the amounts of absorbing and desorbing negatively charged chemical species such as water from the interface of the $F_{16}CuPc$/Polyimide are much smaller compare to those from the interface of the $F_{16}CuPc/SiO_2$.

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