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Hiroshi Touda [a], Hirokazu Tada [a] & Kazumi Matsushige [a]

[a] Department of Electronic Science and Engineering, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan

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Evaluation of Carrier Mobility of Phthalocyanine Films in NH_3 and NO_2 Gas Atmosphere by Field Effect Measurement

HIROSHI TOUDA, HIROKAZU TADA and KAZUMI MATSUSHIGE

Department of Electronic Science and Engineering, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606–8501, Japan

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The carrier mobility of titanyl-phthalocyanine (TiOPc) films was evaluated based on field-effect measurements at the presence of electron acceptor gas (NO_2) and electron donor gas (NH_3) molecules. The increase in carrier density due to NO_2 adsorption was found to be a dominant factor of an increase in the dark electric conductivity. On the other hand, the decrease in conductivity at the presence of NH_3 gas was contributed by the decrease in both carrier mobility and carrier density. The adsorbed gas molecules were found to play an important role not only in carrier density but also in the carrier transport.

Keywords: Field-Effect Transistor (FET); gas adsorption; titanyl-phthalocyanine; carrier mobility

INTRODUCTION

The dark electric conductivity of metal phthalocyanines (MPc) is easily modified by the presence of gases [1]. Most MPc compounds are known to show *p*-type semiconducting behavior [1, 2]. Their conductivities increase at the presence of electron acceptor gases such as O_2 and NO_x, and decrease with electron donor gases such as NH_3. These experimental results are explained by the change of the hole concentration in the MPc films [3]. There have been only a few reports which consider the effect of gas molecules on the carrier transport mechanism, although there are many reports on the measurement of carrier mobility of organic semiconductors. Assadi *et al.* showed that the hole mobility of poly (3-hexylthiophen) is affected by the atmosphere for the measurement [4]. More recently Kudo *et al.* described that the carrier mobility of MPc films is affected by film structure and by oxygen gas exposure [5]. These works lead to a considerable interest in the effect of gas molecules on the carrier trans-

port mechanism in organic films.

In the present study, we evaluated the field-effect carrier mobility of titanyl-phthalocyanine (TiOPc) films at the presence of NH_3 and NO_2 gas molecules. The effect of gas adsorption on the carrier density and carrier transport will be discussed.

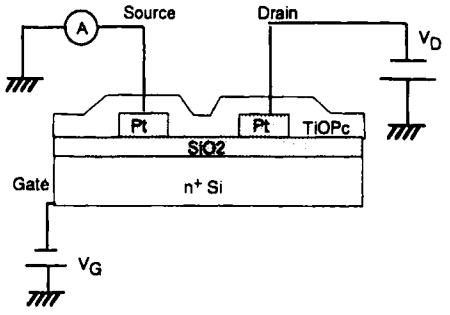

FIGURE 1. Schematic view of the FET

EXPERIMENTAL

Figure 1 shows a schematic view of the FET cell. Highly doped n^+-Si(111) plate was used as the gate electrode on which the SiO_2 layer with the thickness of 180 nm was formed by thermal oxidization. The interdigital Pt electrodes with the thickness of 30 nm were prepared on the surface, and served as drain and source electrodes. The electrode consisted of 32 pairs with 25 μm in spacing and 6 mm in width. The TiOPc films were prepared in a vacuum chamber with a base pressure of 1×10^{-4} Pa on the substrate. The growth rate and thickness were about 0.4 nm/min and 40 nm, respectively. The specimens thus prepared were taken out from the growth chamber and introduced into the measurement chamber immediately.

The FET characteristics of the specimens were investigated in the chamber in which the atmosphere could be controlled. The standard gas of NH_3/N_2 (100 ppm, Nippon Sanso) and NO_2/N_2 (100 ppm, Nippon Sanso) was diluted at an appropriate concentration with pure N_2 gas (99.999%, Nippon Sanso) using a mass flow controlled gas blender (Stec, SECB-2) , and was introduced into the measurement chamber.

The mobility was calculated by fitting the curves observed to the following equation available for MOS-FET [6]:

$$I_D(sat) = \mu WC (V_G - V_T)^2/2L \qquad (1)$$

Here, $I_D(sat)$ is the saturated drain current, μ is the mobility, V_G is the voltage applied to the gate, V_T is the threshold voltage, L, W and C are the channel

length, channel width, and capacitance of the gate insulator, respectively.

In order to estimate the carrier density in gas atmosphere, we measured the dark conductivity of TiOPc films grown on glass substrates with inter digital gold electrodes. The carrier density, N, was estimated by the following equation using the measured dark conductivity, σ, and carrier mobility, μ, which was obtained by Eq.(1):

$$N = \sigma / e\mu . \qquad (2)$$

RESULTS AND DISCUSSION

Figures 2(a) and 2(b) show FET properties of the device measured in vacuum and NO_2 (20 ppm) atmosphere, respectively. The saturated current is found to increase in NO_2 atmosphere, indicating that the carrier mobility was modified by NO_2 gas adsorption. The carrier mobility evaluated using equation (1) was 1.1 x 10^{-5} cm^2/Vs in vacuum and 2.4 x 10^{-5} cm^2/Vs in 20 ppm NO_2. The conductivity of the films measured in vacuum and NO_2 atmosphere exhibited an increase of 770 times in NO_2 (20 ppm) atmosphere with an increase of 2.2 times in carrier mobility. Equation (2) suggests that the carrier density increased by 350 in NO_2. In the case of the adsorption of electron acceptor gas molecules such as NO_2, the increase in carrier density was a dominant factor of an increase in the dark electric conductivity. On the other hand, electron donor gas molecules such as NH_3 were found to influence the carrier transport as well

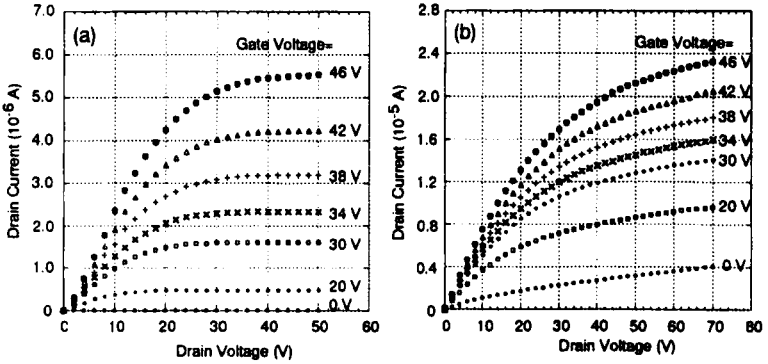

FIGURE 2. FET characteristics of TiOPc films in vacuum (a) and in NO_2 (20 ppm) atomosphere (b).

TABLE I. Evaluated values of electric conductivity, carrier mobility and carrier density in vacuum and NH_3 atomosphere.

	conductivity		carrier mobility		carrier density	
	σ (S/cm)	σ_{gas} / σ_{vac}	μ (cm^2/Vs)	μ_{gas} / μ_{vac}	N (cm^{-3})	N_{gas} / N_{vac}
vacuum	1.7×10^{-8}	1	1.2×10^{-4}	1	8.9×10^{14}	1
NH_3(50 ppm)	3.1×10^{-9}	0.18	5.6×10^{-5}	0.47	3.4×10^{14}	0.38
NH_3(100 ppm)	4.3×10^{-10}	0.025	2.1×10^{-5}	0.18	1.2×10^{14}	0.14

as carrier density as shown in Table I.

Table I summarizes the values of conductivity, carrier mobility, and carrier density measured in vacuum and in NH_3 atmosphere. The adsorbed NH_3 gas molecules were found to decrease both the carrier mobility and carrier density, which resulted in the decrease in dark conductivity.

In summary, the field-effect mobility of TiOPc films were evaluated at the presence of electron acceptor gas (NO_2) and electron donor gas (NH_3). The hole mobility was found to be modified significantly by the adsorption of gas molecules. In the case of the NO_2 gas adsorption, the increase in conductivity is found to be governed dominantly by the increase in carrier density. On the other hand, the decrease in conductivity at the presence of NH_3 gas is ascribed to the decrease in carrier mobility as well as in carrier density.

Acknowledgments
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