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Copper-phthalocyanine based organic thin film transistor

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Abstract — **Copper-phthalocyanine based organic thin film transistors (OTFTs) were fabricated. Cu-Pc thin films as an active layer were deposited onto the SiO_2 layer as a gate insulator by using organic molecular beam deposition system. The OTFT devices showed p-type characteristics with field-effect mobility and threshold voltage as 1.22×10^{-3} cm^2/Vs and -40 V, respectively. The activation energy was estimated to be 0.073 eV, through the temperature dependence of carrier mobility.**

Keywords – organic thin film transistor; copper-phthalocyanine; carrier mobility

I. Introduction

Organic semiconductors with π-conjugated structure have recently attracted considerable attention due to their successful applications in optical and electronic devices [1]. Metal phthalocyanines are the promising π-conjugated molecules to be used in the fabrication of electro-optic devices [2]. The copper-phthalocyanine (Cu-Pc) has an excellent chemical and thermal stability at ambient atmosphere. The Cu-Pc material has applications to chemical sensors [3] and organic solar cells [4]. In this paper, we report the morphology of Cu-Pc thin film and electrical characteristics of Cu-Pc based organic thin film transistor (OTFT). The carrier mobility of the Cu-Pc based OTFTs was measured to be $1.22\times10^{-3} cm^2/Vs$. Through temperature dependence of mobility, the activation energy (E_a) was estimated to be ~ 0.073 eV, indicating the existence of one trap level.

II. Experiment

The chemical structure of Cu-Pc molecule is shown in Fig. 1 (a). The Cu-Pc material have been commercially available from Aldrich Chemicals (97% purified), and no further purification process was performed. Fig. 1 (b) shows the schematic structure of side view of the Cu-Pc based OTFT. The Cu-Pc molecules were deposited onto the SiO_2 gate insulating layer by organic molecular beam deposition (OMBD) method. The surface morphology of Cu-Pc films was visualized by scanning electron microscope (SEM); (Hitachi S-430). The deposited Cu-Pc film for the fabrication of the OTFTs has ~ 110 nm thickness. The deposition rate of Cu-Pc molecules was ~0.3 Å/min under a pressure of 2×10^{-7} Torr. For the Cu-Pc based OTFTs, the channel length was $L \approx 5$ µm, and the channel width was $W \approx 2$ mm.

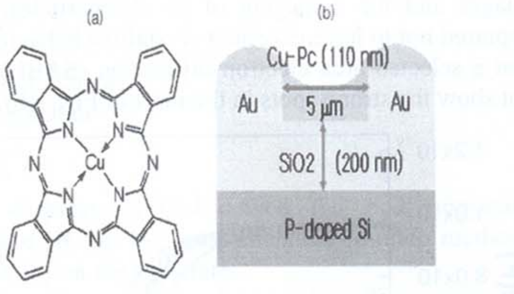

Figure 1. (a) Schematic chemical structure of Cu-Pc molecule and (b) schematic structure of side view of Cu-Pc based OTFT.

Figure 2. SEM image of Cu-Pc thin film at the room temperature.

III. Results and Discussion.

Fig.2 shows the SEM image of the surface of the Cu-Pc thin film. We observed the homogeneous small crystal grains with an average diameter of ~10 nm. The existence of homogeneous small crystalline grains as shown in Fig. 2 results in the performance of OTFTs with relatively higher saturation mobility.

Fig. 3 shows XRD pattern of Cu-Pc thin films deposited onto glass surface. The Cu-Pc materials for the XRD experiments were annealed at 150 °C. The XRD pattern shows the existence of a crystalline peak at 6.9°, which corresponded to the (100) diffraction peak of the α-phase of the Cu-Pc crystal. This is the environmentally stable crystal form at the annealing temperature lower than 200 °C [5]. The observed crystalline peak at (100) direction indicates the possibility to achieve high mobility due to the π-π orbital staking.

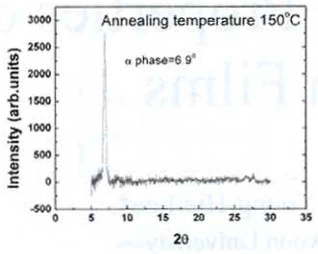

Figure 3. XRD pattern of Cu-Pc thin films deposited onto glass.

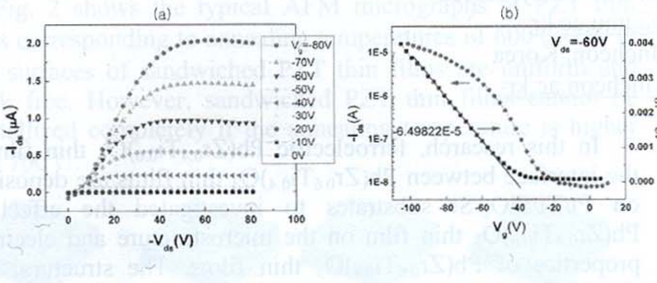

Figure 4. (a) The Output and (b) Transfer characteristics of a Cu-Pc based OTFTs.

Fig. 4 (a) shows the drain-source current characteristics of the Cu-Pc based OTFTs as a function of drain-source bias. As negative gate bias increased, the current level between drain-source electrodes increased indicating p-type operative characteristics. In the saturated region ($-V_{ds} > 40$ V), I_{ds} can be described as the following Equation [6];

$$I_{ds} = \frac{WC_i}{2L}\mu(V_g - V_T)^2, \qquad (1)$$

where μ is the field-effect mobility, V_T is the threshold voltage, W is the channel width, the L is the channel length, and C_i is the capacitance per unit area of the insulating layer (C_i=17.2 nF/cm^2) [5]. Fig 4 (b) shows the mobility of the Cu-Pc based OTFTs and the saturation mobility based on Eq. (1) was estimated to be ~ 1.22×10^{-3} cm^2/Vs, and threshold voltage (V_T) was ~ -40 V. The current on-off ratio of the Cu-Pc based OTFTs was measured to be ~10^3.

Fig. 5 shows the temperature dependent of saturation mobility of the OTFT devices. We measured the temperature dependence of mobility in the range from 100 K to 300 K at the gate voltage V_d = -60 V. The mobility decreased with lowering temperature as shown in Fig. 5. The slope of Fig. 5 represents the activation energy for major charge carriers in an active material of OTFT devices. The saturation mobility (μ_{sat}) of the device can be related with the E_a and temperature based on the Arrhenius *equation* [7];

$$\mu_{sat} \propto \exp\left(\frac{E_a}{k_B T}\right), \qquad (2)$$

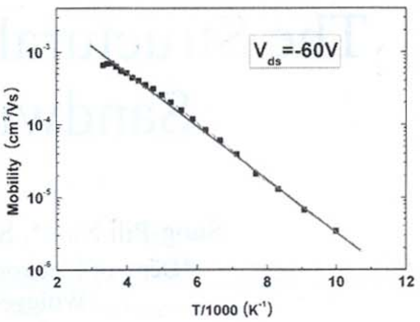

Figure 5. Temperature dependence of field-effect mobility of Cu-Pc based OTFT at the drain-source voltage -60 V.

where the k_B is the Boltzmann constant. The activation energy E_a was estimated to be ~0.073 eV. This implies the existence of one shallow trap in the active material.

IV. Summary

The Cu-Pc based organic thin film transistors were fabricated through organic molecular beam deposition method. We observed the homogeneous crystalline grains average diameter (10 nm) of Cu-Pc thin film through SEM experiments. The observed crystalline XRD peak at 6.9° indicates the formation of α-phase of Cu-Pc materials. The mobility of the Cu-Pc based OTFT was ~1.22×10^{-3}cm^2/Vs, and threshold voltage was ~ -40 V. Through temperature dependence of mobility, the activation energy was estimated to be $E_a \approx 0.073$ eV.

Acknowledgment

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