IEEE NMDC 2006

IEEE Nanotechnology Materials and Devices Conference 2006

October 22-25, 2006, Gyeongju, Korea
www.ieee-nmdc.org

Theme : Emerging Nanotechnology and Impact on Technology Innovation in Industry

Proceedings

Organized by

IEEE Nanotechnology Council, USA
National Center for Nanomaterials Technology, Korea

NMP52

Organic perylene single crystal based field-effect transistor

J. W. Lee, H. S. Kang, M. K. Kim, M. Y. Cho and J. Joo*
*Department of Physics and Institute for Nano-Science, Korea University, Seoul 136-701, Korea
Email: jjoo@korea.ac.kr

***Abstract*—We report on the fabrication and characteristics of organic field-effect transistors (OFETs) using a single crystal of perylene. Perylene single crystals were relatively fast grown in furnace with flowing nitrogen gas. The OFETs were prepared by placing a perylene single crystal flake onto SiO_2/Si or polymer insulator/Si substrates. The field-effect mobility of the perylene based OFETs was measured to be 1.6×10^{-4} cm^2/Vs at room temperature.**

Keywords- organic field-effect transistor, organic single crystal, perylene, mobility

I. Introduction

Organic semiconductors with π-conjugated structure have recently attracted a great deal of attention in the field of electronics and optoelectronics [1-4]. Organic light-emitting diodes (OLEDs) and organic field-effect transistors (OFETs) based on these materials have shown the suitable performance for applications in displays and electronics. Perylene and its derivatives as active materials have many advantages due to high quantum yields of photo-luminescence and excellent photochemical and thermal stability [5]. For examples, they can be used for optical switching, electroluminescent devices [6], photovoltaic cells, and n-type FET devices [7].

There have been previous reports on the fabrication and characteristics of perylene based OFETs [8-10]. The perylene-based organic thin film transistors (OTFTs) fabricated by the evaporation onto a SiO_2/Si substrate had p-type characteristics, and the hole mobilities were in the range of $10^{-7} \sim 10^{-3}$ cm^2/Vs [8-10].

We have grown perylene single crystal for OFETs. The perylene single crystals were highly purified by zone-melting process, and a large single crystal were grown both from the melting and from the vapor phase. The measured carrier mobility of the perylene single crystal based OFETs was ~ 1.6×10^{-4} cm^2/Vs.

II. Experimental

For the growth of perylene single crystal, the perylene powder was purchased from Aldrich Corporation. Perylene single crystals were grown in the home-made furnace with a stream of continuous flowing nitrogen gas. The time for the growth was 1 ~ 3 hours, which was relatively faster than the previously reported method [10]. Figure 1 (a) shows the schematic chemical structure of perylene molecule. Figure 1(b) shows the photograph of the perylene single crystal as grown. The average size of perylene crystal was 0.3 cm^2 large with a few μm thickness.

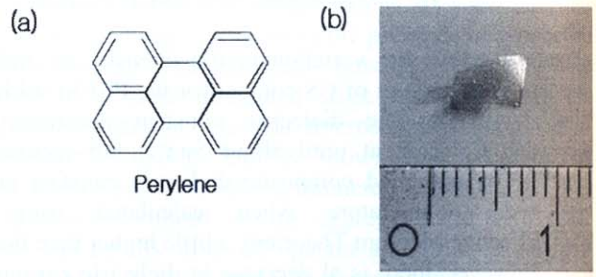

Figure 1. (a) Schematic chemical structure of perylene molecular and (b) photograph of perylene single crystal as grown.

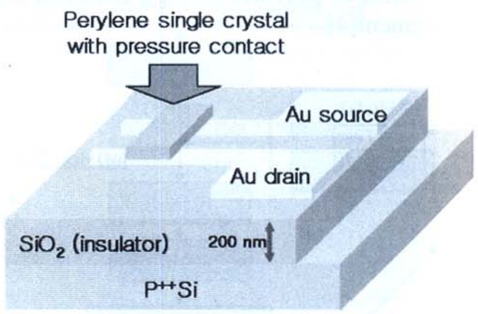

Figure 2. Schematic structure of perylene single crystal based OFETs : Channel length L is 20 μm and the channel width W is 2 mm.

Figure 2 shows the schematic diagram of the OFET pattern using the perylene single crystal. A degenerate p-doped Si wafer was used as a substrate with SiO_2 material as a dielectric layer. The source and drain electrodes were made by the deposition of Au on top of the SiO_2 with the photolithography. The channel length were 2 ~ 100 μm, and the channel width was W = 2 mm. The perylene single crystal as an active material was placed onto the Au source and drain electrodes, and the pressure contact method was used for the measurement of electrical characteristics of the devices. The current-voltage characteristics of the OFETs were measured in a vacuum chamber using two Keithley 237 SMUs with PC interface programs. Temperature dependence of carrier mobility was measured by using a Janis cryostat system.

III. Results and Discussion

The current-voltage characteristics of the perylene single crystal based OFETs are shown in the Fig. 3. Figure 3 (a) shows a plot of drain current (I_d) versus drain voltage (V_d) at various gate voltages (V_g). The perylene single crystal based OFET operates in the accumulation mode since the gate electrode was negatively biased with respect to the ground electrode. The I_d negatively increased as the gate bias increased, indicating p-type nature of the devices. The I_d almost linearly increased with increasing V_d at low V_d, and it was saturated at higher V_d ($\geq$ -20 V) due to the pinch off the accumulation layer. The saturated I_d can be modeled by the following equation [11]:

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

where the C_i is the capacitance of the dielectric layer, V_T is the threshold voltage, and the μ is the carrier mobility. Figure 3 (b) shows the square-root of saturation current ($I_d^{1/2}$) as a function of V_g. The fitting curve based upon Eq. (1) provides a field-effect hole mobility of 1.6×10^{-4} cm^2/Vs, a threshold voltage of ~ 43 V, and current on/off ratio of 10^1 ~ 10^2.

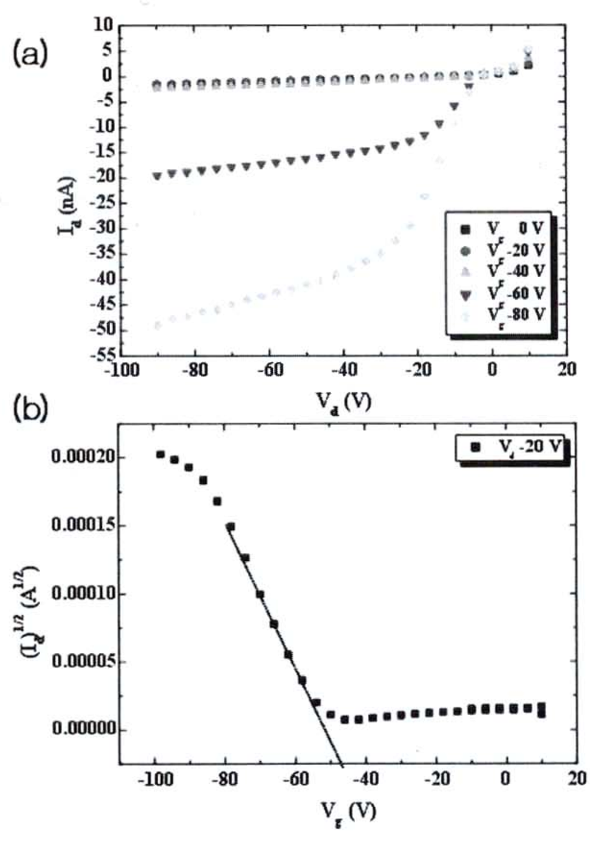

Figure 3. Electrical characteristics of the OFETs using perylene single crystal : (a) the drain current vs drain voltage characteristics measured at the different gate voltages and (b) square root of the saturation current as a function of the gate voltage in a vacuum.

IV. Summary

Organic perylene single crystals were grown for the use of active material for the OFETs. The electrical characteristics of the organic FETs using the perylene single crystal as active layer was measured. The hole mobility of the perylene single crystal OFETs was measured to be 1.6×10^{-4} cm^2/Vs. The measured hole mobility of the OFETs was higher than that of perylene vapor deposited OTFTs. We suggest that hole mobility could be increased by the improvement of the interface between the organic active layer and gate insulator.

Acknowledgment

The work was supported in part by a grant No. KRF-2004-005-C00068 from the Korea Research Foundation Grant and Hyundai-Kia motor company.

References

[1] U. Mitschke and P. Bauerle, "The electroluminescence of organic materials," J. Mater. Chem, Vol. 10, pp. 1471-1507, 2000.

[2] R. Brown, C. P. Jarrett, D. M. de Leeuw, and M. Matters, "Field-effect transistors made from solution-processed organic semiconductors," Synth. Met, Vol. 88, pp. 37-55, 1997.

[3] G. Horowitz, "Organic field-effect transistors," Adv. Mater, Vol. 10, pp. 365-377, 1998.

[4] C. D. Dimitrakopoulos and D. J. Mascaro, "Organic thin-film transistors-a review of recent advances," IBM J. Res. Dev, Vol. 45, pp. 11-27, 2001.

[5] X. He, H. Liu, Y. Li, F. Lu, Y. Li, D. Zhu, "A new copolymer containing perylene bisimide and porphyrin moieties : synthesis and characterization," Macromol. Chem. Phys, Vol. 206, pp. 2199-2205, 2005.

[6] C. H. Lee, S. H. Ryu, S. Y. Oh, "Characteristics of a single-layered organic electroluminescent device using a carrier : transporting copolymer and a nonconjugated light-emitting polymer," J. Polym. Sci., part B : Polym. Phys, Vol. 41, pp. 2733, 2003.

[7] J. H. Schön, Ch. Kloc, B. Batlogg, "Perylene: a promising organic field-effect transistor material," Appl. Phys. Lett, Vol. 77, pp. 3776-3778, 2000.

[8] S. H. Kim, Y. S. Yang, J. H. Lee, H. Y. Chu, H. Lee, J. J. Oh, L.-M. Do, T. Zyung, "Organic field-effect transistors using perylene," Opt. Mater, Vol. 21, pp. 439-443, 2002.

[9] T. Y. Choi, H. S. Kang, J. M. Koo, J. K. Lee, S. D. Ahn, J. Joo, "Trap distribution and field effect transistor (FET) of perylene by organic molecular beam deposition (OMBD)," Synth. Met, Vol. 137, pp. 929-930, 2003.

[10] M. Kotani, K. Kakinuma, M. Yoshimura, K. Ishii, S. Yamazaki, T. Kobori, H. Pkuyama, H. Kobayashi, H. Tada, "Charge carrier transport in high purity perylene single crystal studied by time-of-flight measurements and through field effect transistor characteristics," J. Chem. Phys, Vol. 325, pp. 160-169, 2006.

[11] S. M. Sze, Physics of semiconductor devices, 2nd ed., Wiley, New York, 1981.