B-7-2

Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp702-703

Mobility Improvement in Top-Gate Benzothienobenzothiophene Organic Transistors Processed by Spin Coating

Fumio Mochizuki[1], Toshiyuki Endo[1], Takashi Nagase[1,2], Takashi Kobayashi[1,2], Kazuo Takimiya[3], Masaaki Ikeda[4,5], Hiroyoshi Naito[1,2]

[1] Department of Physics and Electronics, Osaka Prefecture University
Sakai 599-8531, Japan
e-mail: mochizuki@pe.osakafu-u.ac.jp
[2] The Research Institute for Molecular Electronic Devices (RIMED), Osaka Prefecture University
Sakai 599-8531, Japan
[3] Department of Applied Chemistry, Hiroshima University
Hiroshima 739-8527, Japan
[4] Functional Chemicals R&D Laboratories, Nippon Kayaku Co., Ltd.
Tokyo 115-8588, Japan
[5] Center for Organic Photonics and Electronics Research (OPERA)
Kyushu University, Fukuoka 819-0395, Japan

1. Introduction

Organic field-effect transistors (OFETs) have received much attention as potential candidates for the fabrication of low-cost, light-weight, flexible, and large-area electronic devices. In recent years, solution-processable OFETs based on soluble organic semiconductors are attracting increasing interest as key devices for realizing printed electronics, and field-effect mobilities higher that of hydrogenated amorphous silicon (~1 cm^2/Vs) have been achieved in soluble semiconducting small molecules of pentacene and benzothienobenzothiophene derivatives [1].

Dioctylbenzothieno[2,3-b]benzothiophene (C_8-BTBT) has attracted considerable interest owing to its high mobility and high air stability [1]. C_8-BTBT spontaneously forms a well-ordered structure even by spin coating and high mobilites ranging from 0.46-1.80 cm^2/Vs have been reported in bottom-gate OFETs with spin-coated C_8-BTBT films [1]. Recently, it has been shown that the film crystallinity can be improved through crystal growth via drop cast and extremely high mobilities of 5 cm^2/Vs [2] and 9.1 cm^2/Vs [3] have been reported in bottom-gate C_8-BTBT FETs with single-crystalline films. However, these methods can prevent the fabrication of OFETs with a small variation of characteristics at large area and have been reported to cause high threshold voltages ranging from -17 to -45 V [2,3].

We have been investigating the fabrication of C_8-BTBT FETs using the spin-coating technique, which is advantageous for large-area fabrication and low device-to-device variation. In previous study [4], we have fabricated C_8-BTBT FETs with a top-gate configuration using fluoropolymer gate insulators by spin coating and found that the top-gate configuration enables reproducible fabrication of C_8-BTBT FETs with high mobility, low threshold voltage, and high electrical stability. The fabricated devices exhibit mobility of 1.59 ± 0.40 cm^2/Vs and threshold voltage of -1.48 ± 3.02 V. The maximum mobility is 2.8 cm^2/Vs. In this study, we investigate the influence of organic solvents used for spin-coating processes on the performance of top-gate C_8-BTBT FETs. The high mobility exceeding 4 cm^2/Vs is achieved in OFETs fabricated by spin coating.

2. Experiments

Figure 1 shows the schematic of the device structure of fabricated top-gate C_8-BTBT FETs. Source and drain Cr/Au electrodes were fabricated on glass substrates using vacuum deposition. The substrate surfaces were treated with UV/O_3 to enhance the wettability of C_8-BTBT solutions. For organic solvents for C_8-BTBT, we used chloroform, hexane, toluene, chlorobenzene, cyclohexanone, and mesitylene, which have boiling points of 61, 69, 111, 131, 156, and 165 ºC, respectively. After dissolving C_8-BTBT into solvents, C_8-BTBT solutions were spin-coated onto the substrates. Then, an amorphous floropolymer of CYTOP™ (Asahi Glass) was spin-coated on the C_8-BTBT layers. Finally, Al gate electrodes were evaporated on the CYTOP layer. We fabricated devices having a channel width of 3 mm and different channel lengths ranging from 50-350 µm. The FET characteristics were measured in an inert N_2 environment using Keithley 6430 and 2400 source meters.

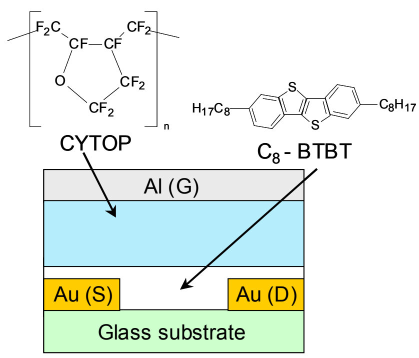

Fig. 1 The schematic structure of top-gate C_8-BTBT FETs.

Table I Maximum field-effect mobilities of top-gate C_8-BTBT FET fabricated using different organic solvents.

Solvent	Chloroform	Hexane	Toluene	Chlorobenzene	Cyclohexanone	Mesitylene
Boiling point [°C]	61	69	111	131	156	165
Solution concentration [wt%]	0.75	0.75	2.0	2.0	1.0	2.0
Maximum mobility [cm^2/Vs]	2.8	0.15	2.7	4.1	3.7	0.81

3. Results and discussion

Table I summarizes the maximum field-effect mobility, boiling point, and C_8-BTBT concentration for each organic solvent. We find that the maximum mobility of 2.8 cm^2/Vs in our previous report in which the chloroform solvent was used can be further increased using chlorobenzene or cyclohexanone as the solvent. The C_8-BTBT FETs fabricated using chlorobenzene exhibit the highest mobility of 4.1 cm^2/Vs and the high average mobility of 3.7 cm^2/Vs (channel length: 350 μm). It is also found that FETs fabricated using organic solvents having higher boiling points tend to exhibit higher mobility, except for the devices using hexane and mesitylene. The considerably lower mobilities observed in these devices probably result from lower film uniformities, which can increase charge trapping by grain boundaries. A similar improvement in the mobility using high-boiling point solvents has been reported in polymer semiconductors [5] and semiconducting small molecules [6] and can be explained by improving molecular ordering due to a slow evaporation of organic solvents having high boiling points. The transfer characteristics of top-gate C_8-BTBT FETs fabricated using chloroform and chlorobenzene solvents are shown in Fig. 2. The devices using chlorobenzene show steep subthreshold slopes and low average threshold voltage of -4.1 V as well as devices using chloroform, indicating that the trap density at the interface between CYTOP and C_8-BTBT is low [4].

Figure 3 shows the atomic force microscope (AFM) images of C_8-BTBT films spin-coated from chloroform and chlorobenzene solvents. It can be seen that the use of chlorobenzene solvent increases the sizes of microcrystalline domains and reduces the surface roughness of C_8-BTBT films. The root-mean-square roughnesses for chloroform and chlorobenzene solvents are approximately 50 and 40 nm, respectively. These results suggest that the increase in the domain size and the film flatness are responsible for improving mobility in top-gate C_8-BTBT FETs.

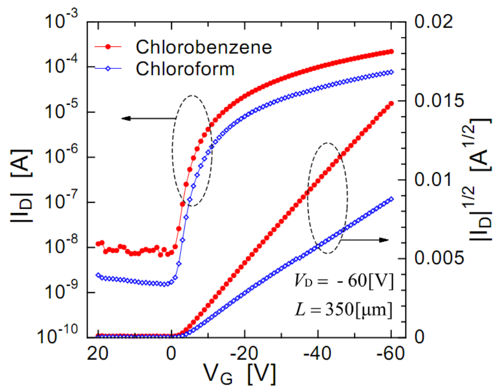

Fig. 2 Transfer characteristics of top-gate C_8-BTBT FETs fabricated using chloroform and chlorobenzene as solvents.

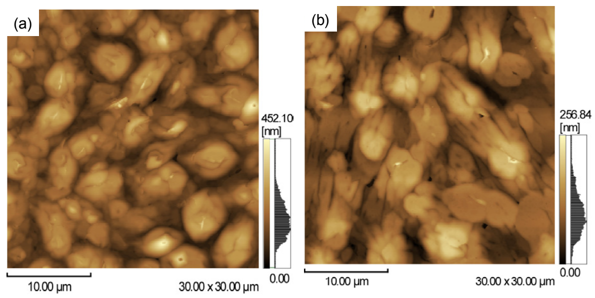

Fig. 3 AFM images of spin-coated C_8-BTBT films using (a) chloroform and (b) chlorobenzene as solvent.

4. Conclusions

To improve field-effect mobility of top-gate C_8-BTBT FETs processed by spin coating, we have investigated the influence of organic solvents on electrical characteristics of C_8-BTBT FETs. It is found that spin coating of C_8-BTBT using high-boiling point solvents leads to higher mobility. The highest mobility of 4.1 cm^2/Vs has been achieved in C_8-BTBT FETs fabricated using chlorobenzene solvents.

Acknowledgements

This research is granted by the Japan Society for the Promotion of Science (JSPS) through the "Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)," initiated by the Council for Science and Technology Policy (CSTP).

References

[1] H. Ebata, T. Izawa, E. Miyazaki, K. Takimiya, M. Ikeda, H. Kuwabara, and T. Yui, J. Am. Chem. Soc. **129**, 15732 (2007).
[2] T. Uemura, Y. Hirose, M. Uno, K. Takimiya, and J. Takeya, Appl. Phys. Express **2**, 111501 (2009).
[3] C. Liu, T. Minari, X. Lu, A. Kumatani, K. Takimiya, and K. Tsukagoshi, Adv. Mater. **23**, 523 (2011).
[4] T. Endo, T. Nagase, T. Kobayashi, K. Takimiya, M. Ikeda, and H. Naito, Appl. Phys. Express **3**, 121601 (2010).
[5] J.-F. Chang, B. Sun, D. W. Breiby, M. M. Nielsen, T. I. Sölling, M. Giles, I. McCulloch, and H. Sirringhaus, Chem. Mater. **16**, 4772 (2004).
[6] Y.-H. Kim, Y. U. Lee, J.-I Han, S.-M. Han, and M.-K. Han, J. Electrochem. Soc. **154**, H995 (2007).