Field Effect Transistors Formed with Thin Films of Alkyl Substituted Hexabenzocoronene

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1. Introduction

Research on organic field effect transistors (FETs) attracts significant attention in the recent years. Organic thin film FETs have shown charge transport mobility in the range of 0.001 to 1 cm²/Vs and are expected to apply for smart cards, identification tags and displays [1]. In forming these thin films, solution-processing of organic semiconductors has considerable merit for low-cost device manufacturing and major progress has been made using polymer semiconductors [2]. Only a few attempts have been taken to form well ordered thin films from solution of small semiconductor molecules [3], since it is generally due to the poor solubility of small conjugated molecules.

Transformation of molecular structure by incorporation of substituents onto small conjugated molecules is expected to induce improvement of solubility. However the substituents are anticipated to disturb the carrier transport between conjugated molecules as well. In this paper, the structure and transport properties of thin films solution processed with alkyl substituted hexabenzocoronene (HBC) and are compared with those of sublimed films of both alkyl substituted HBC and non-substituted HBC.

2. Results and Discussion

Semiconductor materials

Haxa-alkyl (C₃H₇₂) substituted HBC (6R-HBC) was synthesized by Diels-Alder reaction of bis(alkylphenyl)-acetylene[4]. Tetra-alkyl substituted HBC (4R-HBC) and Di-alkyl substituted HBC (2R-HBC) were synthesized by the reaction between bis(alkylphenyl)acetylene and diaklylated tetra-phenyl cyclopentadienone, tetraphenyl-cyclopentadienone, respectively. And hexa-phenyl benzene derivatives were converted to HBC structure by Friedel-Crafts reaction. They were purified by recrystallization from CHCl₃ solution. Non-substituted HBC of commercially available products was used without further purification.

Fabrication of Thin films and FETs

Solutions of alkyl-substituted HBC (0.03wt% to 1wt% xylene solution) were applied to silicone substrate (2000rpm) to form the films. And sublimed films were also grown on silicone substrate under the pressure of 10⁻³Torr.

FETs were fabricated by using the electrode patterned substrates, where the source and drain electrodes of Au/Ti were photo-lithographically patterned on the silicone with the oxide thickness of 200nm. FETs were made by depositing the semiconductor films on the substrates to form bottom contact structure.

Fig.1 Synthesis of 6R-HBC

Fig.2 X-ray diffraction patterns of films
a) 6R-HBC sublimed film (Ts=40 °C)
b) 6R-HBC solution processed film
c) HBC sublimed film (Ts=40 °C)
Results and Discussions

The solution processed film of 6R-HBC showed the diffraction peak with the spacing of 2.2nm corresponding to half of molecular diameter of 4.0 to 4.3nm and 6R-HBC molecules were assumed to be oriented with molecular axis perpendicularly to the substrate plane. The film of 6R-HBC prepared by sublimation showed the almost same diffraction peak. This indicates that crystalline films are successfully fabricated by both solution processing and sublimation.

In contrast, the sublimed film of HBC showed diffraction peaks assigned as (ool) (l=1,2) with the spacing of 1.18nm. This indicates that HBC molecules are oriented perpendicularly to the plane, with the same fashion of 6R-HBC. From these results, HBC molecules both HBC and 6R-HBC tend to stack together to form crystalline films which resemble to that of pentacene thin films [5] in which molecular axis are aligned to perpendicularly to the substrate plane.

Id-Vg curves of solution processed and sublimed 6R-HBC FETs are shown in Fig.3. Solution processed FET exhibited good performance with the field effect mobility of 0.034cm²/Vs and on/off ratio of 4 \times 10³, which was larger than those of sublimed FET with the mobility of 5 \times 10³cm²/Vs and on/off ratio of 1 \times 10³.

It has not been clearly understood the reason for better performance in the wet-processed films but it might be the difference in molecular orientation of stacked molecular array in the films since R-HBC conduction path is assumed to be one-dimensional. It is noteworthy that the mobility of R-HBC film was the same order with that of non-substituted HBC film, 0.042cm²/Vs in spite of no alkyl substituents disturbing transport between stacked conjugated molecular columns. Conduction anisotropy (\(\frac{\\mu_{//}}{\\mu_{\perp}}\)), ratio of the conductivity along the plane (\(\mu_{//}\)) to the conductivity perpendicular to the plane (\(\mu_{\perp}\)), of the films proved to be 10² and 2, in R-HBC sublimed film and HBC film, respectively. It means that alkyl substituents act as a conduction barrier and easy-conduction-axis of R-HBC film lies in-plane direction that is consistent with the assumed molecular orientation from the diffraction pattern.

Further studies of forming ordered structure of the films are required to improve FET performance and are in progress.

Other substituted HBCs (4R-HBC, 2R-HBC) having less conduction barrier, alkyl substituents, in the molecules, are expected to form ordered films that exhibit quasi-two-dimensional conduction and the results will be presented at the conference.

3. Conclusions

Alkyl substituted HBC (6R-HBC) is capable to form the ordered films both by solution casting or sublimation. The FET of solution cast film shows the field effect mobility of 0.034cm²/Vs and on/off ratio of 4 \times 10³. The conduction anisotropy of the film shows that in-plane conduction is predominant which is consistent with molecular orientation in the film.

Acknowledgements

A part of this work belongs to “Advanced Organic Device Project” which OITDA contracted New Energy and Industrial Technology Development Organization (NEDO). I would like to express sincere thanks to Mr. Yutaka Natsume of Asahi Kasei Corporation for measuring X-ray diffraction patterns and Mr. Masahiro Kawasaki for FET analysis.

References