Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp731-732

Hotpress Method for Thin Crystalline Organic Field-Effect Transistors

Atsuo Inoue[1], Tatsuyoshi Okamoto[1], Yuki Joho[1], Masatoshi Sakai[1],
Hiroshi Yamauchi[1], Masakazu Nakamura[1,2], and Kazuhiro Kudo[1]

[1]Department of Electrical and Electronic Engineering, Chiba University
1-33, Yayoi-cho, Inage-ku, Chiba, 263-8522 Japan
Phone: +81-43-290-3874, E-mail: a_inoue@graduate.chiba-u.jp
[2]Graduate School of Materials Science, NAIST
8916-5 Takayama, Ikoma, Nara 630-0192 Japan

1. Introduction

The performance of organic field-effect transistors (OFETs) has been drastically improved in the last decade. While single crystal OFETs (SC-OFETs) achieved high field-effect carrier mobility of the order of 10 cm^2/Vs [1], the mobility of OFETs fabricated by vacuum evaporation and solution casting have been reached the ceiling at 1 cm^2/Vs . A number of grain boundaries in the channel region is one of the causes of the performance saturation[2]. Although SC-OFETs have good performance, their conventional fabrication process using physical vapor transport is not appropriate to industrial mass-production because of the troublesome handwork such as picking up a crystal from the electric furnace and placing a crystal on a substrate. Thus a productive fabrication process of SC-OFETs is demanded for mass-production high-performance organic transistors.

Here, we propose the novel method which can fabricate large grain OFETs. Our method has good prospects for high productive fabrication process for single crystal organic devices and is also available for fabrication of flexible devices.

2. Hotpress Method

We have developed the melting process to fabricate SC-OFETs whose semiconducting layer is formed from molten semiconductor material. The hotpress method is one of the melting processes and the basic composition is schematically illustrated in Fig.1. In the hotpress method, semiconductor material powder is initially placed between two substrates. The bottom substrate has a gate electrode covered with dielectric layer and the top substrate has source and drain electrodes. The organic material is heated to its melting point so that the powder becomes the melt. In order to reduce and control the thickness of the semiconducting layer, a certain pressure is applied between two substrates, top and bottom of the semiconducting layer. Subsequently, the heater temperature is decreased and the melt is recrystallized as a thin crystalline solid.

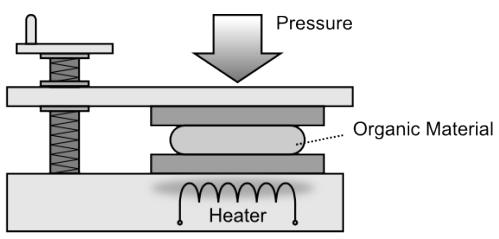

Fig. 1 Schematic illustration of the hotpress method

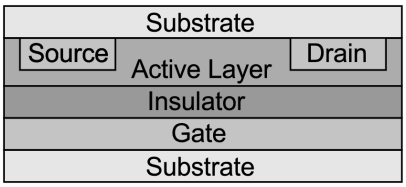

Fig. 2 Device structure of FET fabricated by the hotpress method

The process can form a large grain crystal layer than the other conventional processes such as vacuum evaporation and printing. Furthermore, flexible device fabrication is also available by our method when the semiconductor material has the lower melting point than the glass transition temperature of plastic substrates. The fact enables the combination of the hotpress method and roll-to-roll process such as laminating and thermal transfer printing. Thus the compatibility with high performance and high productivity can be achieved by our method.

3. Device Fabrication

We have fabricated OFETs by the hotpress method using TTC_{18}-TTF (Tetrakis(octadecylthio)tetrathiafulvalene, melting point 88 °C) as a test material for the semiconducting

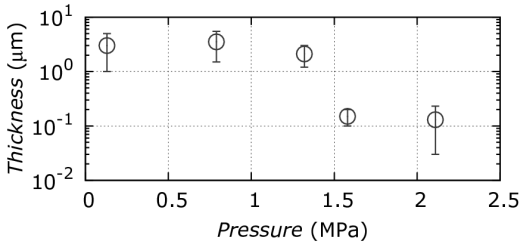

Fig. 3 Relation of active layer thickness and the pressure applied between top and bottom substrates in the hotpress method.

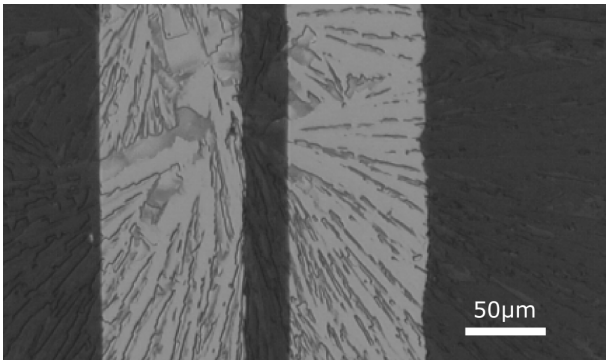

Fig. 4 The optical micrograph of the active layer on the top substrate.

layer. The device structure is top contact/bottom gate staggered arrangement FET as shown in Fig.2. A pair of 13×19 mm glasses or polyimide films was used as top and bottom substrates. All electrodes are 30 nm thick thermal evaporated Au/Cr. The channel length and width are 20 μm and 5 mm, respectively. A 600 nm thick parylene layer was used as a gate dielectric.

To form the semiconducting layer, TTC_{18}-TTF powder was placed between two substrates and heated at 100 °C by the heater on the upper-side of the hot clamp. In order to examine if the pressure between the two substrates was able to control the thickness of the active layer, we systematically varied the applied pressure. The heating time, the duration of the highest temperature, was 1 minute on all sample. As shown in Fig.3, we found the higher pressure make the active layer thin in the hotpress method. Although the thinner active layer was desired for a good transistor performance in our staggered structure devices, the higher pressure tended to cause gate leakage on the electrical measurements. Therefore we adopted approximately 0.5 MPa as the pressure parameter. Increasing the heating time also decreases the thickness of the active layer. By increasing the heating time to 10 minutes, sub-micrometer-thickness active layers were obtained. This suggest that the organic melt spreads and even spills from the gap of two substrates at the higher temperature than the melting point.

4. Transistor Characteristics

The transistor characteristics of TTC_{18}-TTF FET fabricated by the hotpress method using glass substrates are shown in Fig.5. Typical p-type FET characteristics with a field-effect mobility of 4.6×10^{-3}cm^2/Vs in the saturation region was obtained. The mobility is 7 times higher value than TTC_{18}-TTF FET which we fabricated by solution casting in our previous research.

After measuring the characteristics, we tore off the substrates to investigate the fabricated active layer with an optical microscope. The optical micrograph shown in Fig.4 revealed that the active layer was consists of a number of crystals, both on the bottom substrate and the top substrate. A large single crystal which covers channel width was not grown in the

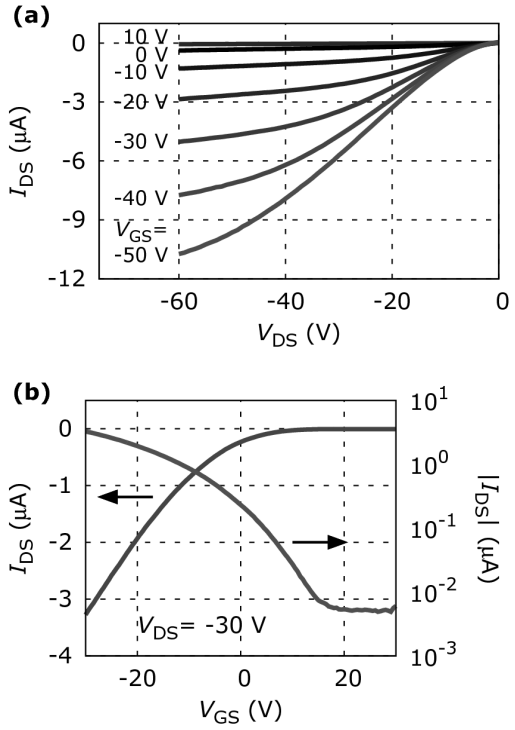

Fig. 5 Transistor characteristics of TTC_{18}-TTF FET. (a) Output characteristics. (b) Transfer characteristics.

growth condition, however, the plate-like crystals which sufficiently fill the 20-μm channel length were obtained and they were clearly different from the needle-shaped narrow crystals grown by the casting method. The thickness of the active layer measured by the stylus profilometer was about 0.22 μm.

We have also fabricated the TTC_{18}-TTF FET using polyimide films as top and bottom substrates. The FET exhibited p-channel transistor characteristics and proved the hotpress method can utilize for the flexible device fabrication. This suggests good prospects for roll-to-roll process such as laminating and thermal transfer printing.

5. Conclusion

We have fabricated TTC_{18}-TTF FET by the hotpress method. In comparison with our previous TTC_{18}-TTF FET fabricated by solution casting, the larger plate-like crystals were grown and p-type transistor characteristics with 7 times higher mobility were obtained. The transistor characteristics was also obtained on the FET using polyimide films. The capability for flexible device fabrication will be the hope for the industrial roll-to-roll processes such as thermal transfer printing and thermal lamination.

References

[1] J. Takeya *et al.*, Appl. Phys. Lett. **90** (2007) 102120.

[2] G. Horowitz, M. E. Hajlaoui, Adv. Mater. **12** (2000) 1046–1050.