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Novel Solution Process for Inch-Sized Single-Crystalline Organic Semiconductors and Application for Arrayed TFTs

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Abstract

A method of continuously growing large-domain organic semiconductor crystals is developed to fabricate multiple arrayed high-mobility organic transistors. Solution of an organic semiconductor is held at the edge of a moving blade in order to grow large area crystalline thin film. As the result of continuous evaporation of the solvent at an elevated temperature around 100 °C with the supply of the solution in the same rate, the organic crystals steadily grow on the substrate to the size of inches. Arrays of field-effect transistors exhibit high performances with the mobility up to 10 cm^2/Vs based on the large-domain crystal films.

1. Introduction

Solution-processed organic field-effect transistors (OFETs) are well investigated as a promising candidate for the next-generation electronic components. Large area and high-speed devices are surely desired toward the application for such high-speed application as RF-ID tags or active matrixes. Although there are several report related to the solution method to grow single crystalline to increase charge carrier mobility[1,2], large-area processability is still big issue toward large scale application. Here we report new solution-crystallization method to grow single crystalline organic semiconductor continuously in order to form large-area single-crystalline thin film of organic semiconductor.

2. General Instructions

We have employed a newly developed organic semiconductor material of 3,11-didecyldinaphtho[2,3-*d*:2',3'-*d*']benzo[1,2-*b*:4,5-*b*']dithiophene (C10-DNBDT) as a soluble and high mobility *p*-type semiconductor. The solution of C10-DNBDT was supplied to the edge of the solution-holding blade. Simultaneously, the substrate was continuously moved slowly toward the direction indicated in Fig. 1(a) in order to regulate crystal growth direction. The crystalline thin films were continuously formed at the edge of the solution-holding blade. Surprisingly, inch-scaled domain which can be seen even by our eyes are formed as shown in cross-polarized pictures (Fig 1(b) and 1(c)).

Transmission XRD measurements were performed to clarify the crystallinity of the film. Clear latticed Laue spots are reproducibly observed indicating that the domain is indeed a single crystal as shown in Fig 1(d). We note that this feature is very different from the polycrystalline thin film fabricated by such common solution method as spin-coating.

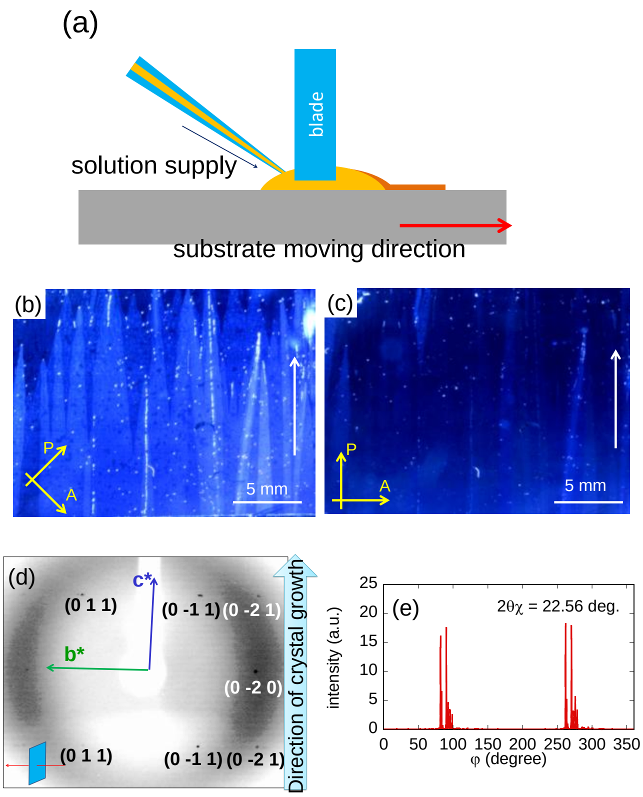

Fig. 1 (a) Schematic lateral illustration of present method to grow single-crystalline thin films. (b, c) Cross-polarized pictures of the present C10-DNBDT thin film. The direction of the polarizer (P) and analyzer (A) are indicated by yellow arrows. (d) Imaging-plate images for transmission-XRD measurements. (e) X-ray diffraction pattern of φ-scan for the (0 2 0) peak. φ = 0° was defined as crystal growth direction.

Furthermore, preferable orientation of the crystal axis was confirmed by phi-scan measurement of glazing-angle X-ray diffraction as shown in Fig 1(e). The orientation of the crystallographic axis against crystal growth direction is reproducible within ~8°. Present solution crystallization method can form highly oriented single crystalline thin films in large-area over a few-cm-square and can also control crystal orientation.

Finally, we also evaluated characteristics of arrayed 5 × 5 TFTs fabricated on the single-crystalline thin film (Fig. 2(c)). Arrayed source and drain electrodes were vacuum evaporated on top of the thin film. Fig. 2(a) and 2(b) shows typical transfer and output characteristics of the present TFT which exhibits the mobility as high as 9.5 cm^2/Vs in saturation region. The entire transistor fabricated on the same thin film exhibited mobility more than 3 cm^2/Vs and the average mobility was 7.5 cm^2/Vs. On/off ratio was better than 10^5 for all devices.

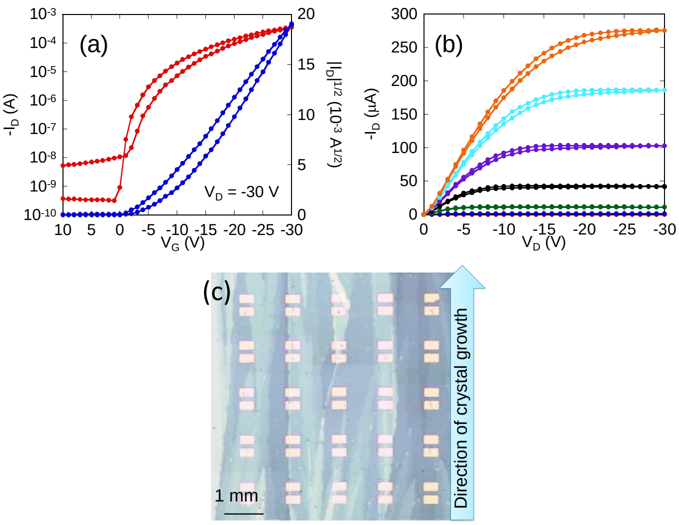

Fig. 2 (a, b) Typical (a) transfer and (b) output characteristics of C10-DNBDT single-crystalline thin-film transistors. (c) Optical microscope view of 5 × 5 TFTs array on the C10-DNBDT single crystalline thin film.

3. Conclusion

We have described the development of novel solution crystallization method that can form large-area single-crystalline thin film continuously. A formed single domain has length of an inch-size and shows excellent crystallninity. Thanks to the large area of the single crystalline film, we can fabricate arrayed TFTs with excellent performance. This easy solution method and high-mobility OFETs are helpful toward practical application of large-area and high-speed printed electronics

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Appendix

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