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Ultra-low Contact Resistance in Two-Monolayer Organic Single-Crystal Transistors

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Abstract

Organic single-crystal films composed of two monolayers are fabricated by precise control of temperature during continuous crystallization of the films at an edge of a blade (continuous edge-casting). Based on the two-monolayer single crystals, very high-performance organic field-effect transistors (OFETs) are formed, exhibiting mobility of 13 cm^2/Vs. Furthermore, the contact resistance (R_c) of the two-monolayer OFETs is only 46.9 Ω·cm for top-contact geometry, which is essential for high-speed transistor response. The value is the lowest among ever-reported OFETs.

1. Introduction

Organic field-effect transistors (OFETs) are expected to be one of the next-generation electronic devices because of their unique mechanically soft properties and compatibility with printing technology. Recent progress on the development of organic semiconductor materials elevated the carrier mobility up to the values greater than 10 cm^{2}V^{-1}s^{-1} particularly when single crystals are used as the active layers.[1-2] Single-crystal OFETs with such a high carrier mobility have great advantage for relatively high-speed application such as RF-ID tags or integrated logic circuits in sensor devices. However, equally crucial to achieve high-frequency response is to achieve low contact resistance because the influence is more pronounced in shorter-channel OFETs. Therefore, reducing contact resistance is one of the most important challenge for high-speed transistors. Here we focus on high-mobility single-crystal OFETs with only two-monolayer organic semiconductors. The ultrathin molecular layers are indeed favorable to minimize resistance of accessing the charge-accumulated channel, so that high mobility and the ultra-low contact resistance are realized.

2. Results and Discussion

Organic single-crystal films were coated by continuous edge-casting technique described in Fig. 1(a).[3] Organic semiconductor solutions were supplied to the solution-holding blade with moving the substrate at a constant speed. Organic crystals have grown toward the blade in one direction, thus highly-oriented single crystalline films can be obtained. We selected a p-type organic semiconductor material, 3,11-dioctyldinaphtho[2,3-*d*:2',3'-*d*']benzo [1,2-*b*:4,5-*b*']dithiophene (C_8–DNBDT–NW), which is more soluble in organic solvent than previously reported compound, C_{10}–DNBDT–NW.[2] This improved solubility contributed to lower the process temperature to 60–70 °C, leading to fabrication of extremely-thin organic crystalline films (Fig. 1(b) and 1(c)). The thickness of the single crystal was approximately 8 nm, corresponding to two-monolayer film.

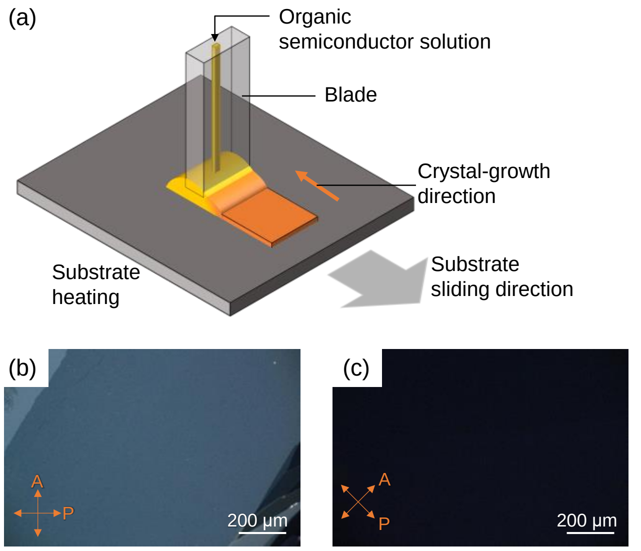

Fig. 1(a) A schematic image of continuous edge-casting method. (b)(c) Polarized optical microscopic images of the two-monolayer single-crystalline films. The direction of analyzer (A) and polarizer (P) are shown as yellowish arrows.

We fabricated several transistors with different channel length by vacuum depositing source and drain electrodes on top of the two-monolayer single crystal. The mobility estimated by the slope of typical transfer-curve in linear regime (Fig. 2(a)) is as high as 13 cm^2/Vs. In addition, the output characteristics shows ohmic behavior at low drain-voltage region (Fig. 2(b))

We also evaluate the contact resistance (R_c) of these two-monolayer transistors by using the transmission line method (TLM) as shown in Fig. 2(c). In order to elucidate the impact

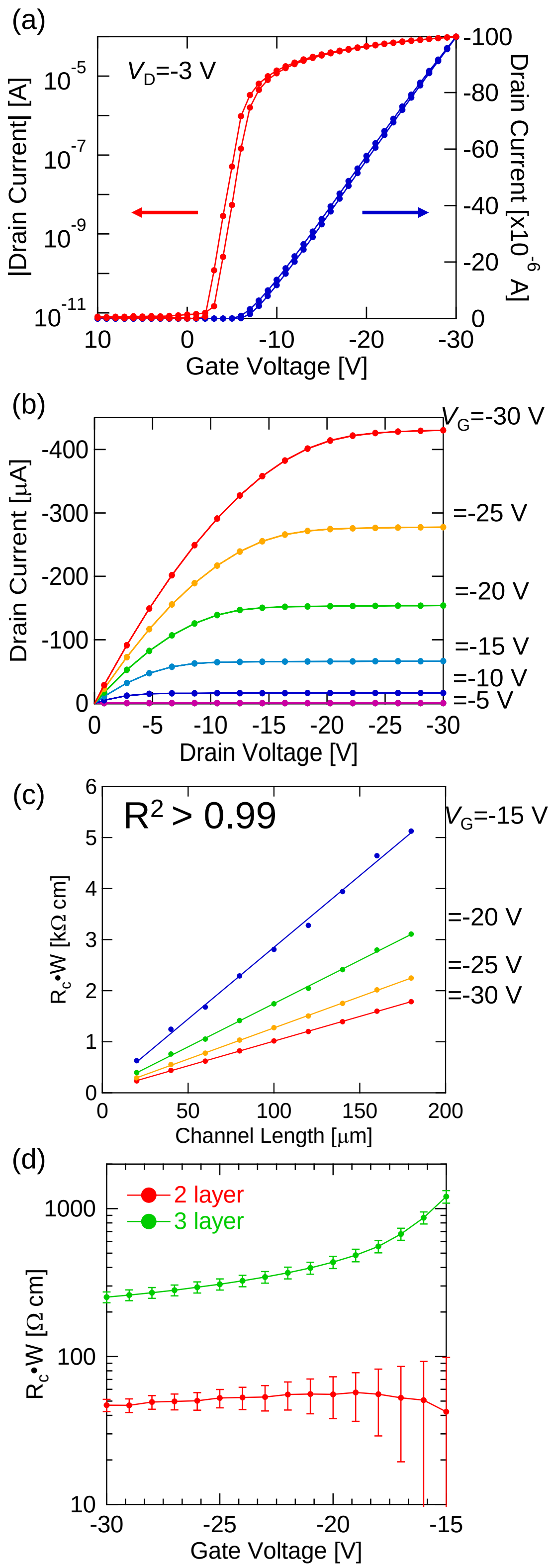

Fig. 2 (a) (b) Transfer and output characteristics of two-monolayer single-crystal transistors. (c) The TLM plots to evaluate the contact resistance (R_c) of two-monolayer OFETs. (d) Comparison of the width-normalized contact resistance (R_c· W) of two- and three- monolayer OFETs. These values are estimated by TLM plots at each gate voltage.

of film thickness on R_c, we estimated the R_c of three-monolayer transistors as a reference. Fig. 2(d) indicates that the contact resistance of two-monolayer transistors is significantly smaller than that of three-monolayer devices. Interestingly, the difference appears to be more drastic at lower gate voltages, which can be beneficial in low-voltage operation. The estimated value of R_cW of the two-monolayer devices is 46.9 Ωcm at the gate voltage of -30 V, which is the lowest contact resistance realized in OFETs reported in literature.

3. Conclusions

In conclusion, we have developed extremely thin single crystal with only two-monolayer thickness, so that the two-monolayer transistors showed excellent performance with high mobility and ultra-low contact resistance. This new system has the great potential to realize the application of organic transistors for high-speed printed electronic circuitry.

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