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3 V-driven flexible organic transistors with mobility exceeding 2 cm^2/Vs

Kenjiro Fukuda[1], Naoya Uchiyama[1], Tsuyoshi Sekitani[2], Ute Zschieschang[3], Hagen Klauk[3], Tatsuya Yamamoto[4], Kazuo Takimiya[4], and Takao Someya[1,2]

[1]Univ. of Tokyo, Dept. of Applied Physics,
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
Phone: +81-3-5841-6756 E-mail: fukuda@ntech.t.u-tokyo.ac.jp
[2]Univ. of Tokyo, Dept. of Electrical and Electronic Engineering,
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
[3]Max Planck Institute for Solid State Research Heisenbergstr. 1, 70569 Stuttgart, Germany,
[4]Hiroshima Univ. Department of Applied Chemistry,
Higashi-Hiroshima,Hiroshima, 739-8527, Japan

1. Abstract

We fabricated organic thin-film transistors (TFTs) using dinaphtho[2,3-b:20,30-f]thieno[3,2-b]thiophene (DNTT) as p-type semiconductors and phosphonic acid self-assembled monolayers (SAMs) as gate insulators, and optimized the transistor characteristics by systematically changing the alkyl chain length of the SAMs. When n-tetradecylphosphonic acid was used as a gate insulator, mobility of the TFTs exceeded 2 cm^2/Vs in the saturation regime and the on/off ratio more than 10^6 at operation voltage of 3 V or less.

2. Introduction

Organic thin-film transistors (TFTs) have attracted considerable attention since they are one of the key elements in realizing large-area, printable, and flexible and/or stretchable electronics, large-area sensors, and actuators. We have reported that the pentacene TFTs using the SAMs as gate dielectrics exhibited high performances within 3 V [1-3]: the estimated field-effect mobility at saturation regime is as high as 0.7 cm^2/Vs, and the ON/OFF ratio exceeds 10^5.

Yamamoto and Takimiya et al., recently reported an air-stable, high-performance p-type organic semiconductors, DNTT; those TFTs exhibits mobilities higher than 3.0 cm^2/Vs when octadecyltrichlorosilane (OTS)-functionalized Si/SiO_2 substrates are used [4,5]. Additionally to the high performances, DNTT TFTs are very stable in air, so it is expected that DNTT is promising candidate for “post pentacene” on organic semiconductors.

In this study, we fabricated DNTT TFTs on flexible polyimide film using single-monolayer molecule SAMs as very thin gate dielectrics. We systematically investigated the relations between transistor characteristics and the alkyl chain length of phosphonic acid SAMs.

3.Fabrication process

A cross-sectional image of the fabricated TFTs are schematically shown in Fig. 1. First, a 25-nm-thick Al layer functioning as a gate electrode was deposited on a 75 µm thick polyimide base film through a shadow mask in a vacuum evaporator. The gate dielectric layers consisted of a thin layer of aluminum oxide (5 nm) and a molecular SAM of phosphonic acid. The aluminum oxide film was prepared by oxygen-plasma treatment (300 W, 30 min) in order to obtain sufficient hydroxyl group density for molecular adsorption [6]. The SAM was prepared from a 2-propanol solution at room temperature. Five types of phosphonic

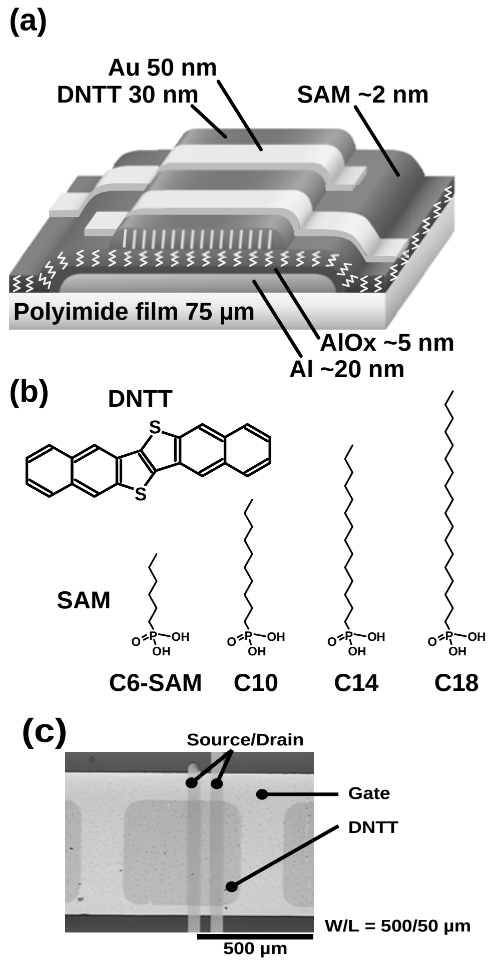

fig.1. (a)The cross-sectional illustration of the organic TFTs. (b)The chemical structure of the DNTT and octadecyl-phosphonic acid SAMs. (c)The optical micrograph of the fabricated TFTs.

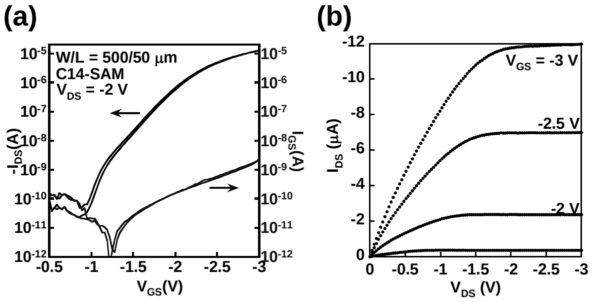

fig.2. (a)The transfer characteristic of the TFT on C14-SAMs. (b) The corresponding output characteristics of the TFTs on C14-SAMs.

acids with different alkyl chain lengths were used as the SAM gate dielectric material: n-hexyl (C6-SAM), n-decyl- (C10-SAM), n-dodecyl- (C12-SAM), n-tetradecyl- (C14-SAM), and n-octadecyl- (C18-SAM) phosphonic acid (Fig. 1b). The DNTT was deposited to form 30-nm-thick channel layers on the dielectric layers. Finally, a 50-nm-thick Au layer was evaporated through a shadow mask to form source and drain electrodes. For comparison purposes, we also fabricated TFTs with only aluminum oxide as a gate dielectric (without any SAM). The nominal channel length and width were 50 μm and 500 μm, respectively.

4. Results

DC characteristics of the DNTT TFTs were measured using a semiconductor parameter analyzer (4155C, Agilent Technologies) in air. Figure 2 (a) shows the typical transfer characteristics of fabricated TFTs with the C14-SAM. V_{GS} was swept from 0.5 to –3 V with the application of V_{DS} = –2 V. Figure 2 (b) shows the source-drain current (I_{DS}) as a function of the source-drain voltage (V_{DS}). The gate voltage (V_{GS}) was swept from –0.5 to –3 V in steps of 0.5 V. The estimated mobility at saturation regime is 2.1 cm^2/Vs, and ON/OFF ratio is more than 10^5.

Figures 3 (a) and (b) show the mobility in the saturation regime and on/off ratio as a function of the alkyl chain length. The average mobility of the TFTs using only AlO_x as gate dielectrics is 0.37 cm^2/Vs. The average mobility increases from 1.0 to 1.9 cm^2/Vs as increasing the alkyl chain length from 6 to 14, while further increasing the alkyl chain length to 18 causes the mobility to drop to 1.8 cm^2/Vs. This tendency is almost the same with the TFTs using pentacene as semiconductors [3,7]. We have already reported that C14-SAMs gave the most flat surface on aluminum oxide layer, whose RMS value was 0.76 nm [3], so this is the reason for the highest mobility of the DNTT TFTs with C14-SAMs. The mobility in this study is 3 times higher than that of the other report by Zschischang *et al* [8]., in which the DNTT and C14-SAMs were used. The on/off ratio improves from 10^4 for TFTs with C6-SAM to above 10^6 for TFTs with C14- and C18-SAMs. The maximum mobility is 2.1 cm^2/Vs for C14-SAM gate dielectrics and the maximum ON/OFF ratio is 2.1 by 10^6 for C18-SAM

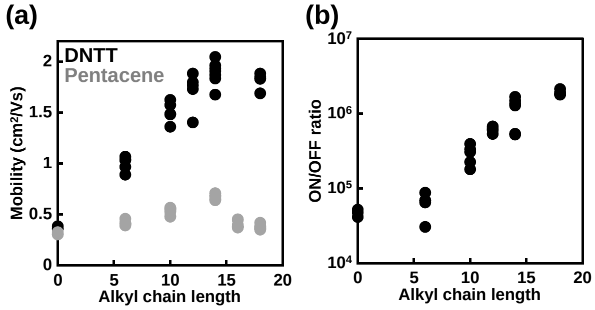

fig.3. The alkyl chain length dependence of the transistor characteristics. (a)The mobility as a function of the alkyl chain length of SAM dielectrics. The Gray dots indicates the results of the TFTs usin pentacene as semiconductors [3]. (b) The ON/OFF ratio.

gate dielectrics. This results are extremely high performance for organic TFTs at 3 V of operation voltages.

5. Conclusion

We fabricated the high mobility, 3 V operational organic TFTs using a plastic base film, DNTT as p-type semiconductors, and n-tetradecylphosphonic acids as self-assembled gate dielectrics. The mobility is higher than 2.1 cm^2/Vs in the saturation regime at an operation voltages within 3 V and the on/off ratio exceeded 10^6. This high performance organic TFTs can achieve the high-speed, low power consumption applications for organic TFTs.

Acknowledgements

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