

# Thin-film transistors of rhodanine end-capped oligothiophene

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## Abstract

We have synthesized a new rhodanine end-capped oligothiophene material showing ambipolar semiconducting behavior. The thin-film transistor (TFT) performance changes by heat treatment of the thin films. The thin films become more ordered structures with increasing the heating temperature.

## 1. Introduction

Organic solar cells have been extensively investigated as potential candidates for renewable-energy systems. The power conversion efficiency above 10% was achieved by the solar cells with bulk heterojunction consisting of rhodanine end-capped oligothiophenes and fullerene derivatives as electron donor and acceptor, respectively [1]. Recently, we have found that a novel A-D-A-D-A oligomer bearing a benzothiadiazole acceptor central core coupled to terminal rhodanine acceptors via thiophene donor linker can drastically improve the photovoltaic properties by heat annealing and solvent vapor annealing [2].

Here, we report a new type of rhodanine end-capped oligothiophene ambipolar semiconductors for thin film transistors (TFT).

## 2. Experimental Section

The TFT measurement was carried out using bottom gate-top contact geometry. The C8-DRCNTV2T-HH films were prepared by spin-coating on HMDS-treated substrates of p-type Si wafer with thermally grown SiO<sub>2</sub>. Heat treatments were carried out by heating the films for 10 minutes under ambient conditions. After the heat treatment, the thin films were cooled to room temperature prior to the fabrication of top contact electrodes. The drain-source gold electrodes were evaporated through a shadow mask on top of the thin films. The channel length and the channel width are 20 μm and 2 mm, respectively.

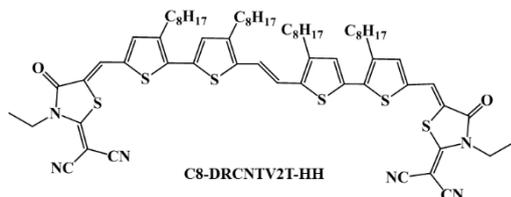


Fig.1 Chemical structure

## 3. Results and Discussion

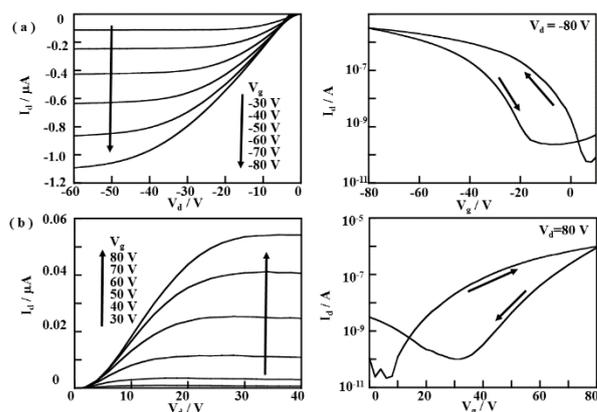


Fig.2 TFT characteristics of C8-DRCNTV2T-HH after heating at (a) 80 °C; (b) 120 °C: output characteristics (left) and transfer characteristics (right).

Figure 2(a) and 2(b) shows the plot of the drain current ( $I_d$ ) versus drain-source voltage ( $V_d$ ) and the transfer characteristics of C8-DRCNTV2T-HH TFTs after heating thin films at 80 °C and 120 °C, respectively. The device showed typical ambipolar TFT characteristics. We estimated the mobility from the saturation regime ( $V_d = \pm 80V$ ) of the  $I_d$ . The hole and electron mobility were  $1.07 \times 10^{-3}$  and  $6.78 \times 10^{-4} \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ , respectively.

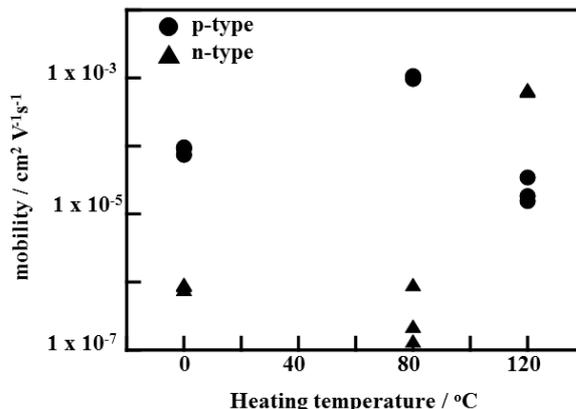


Fig.3 Temperature dependence of P- and N-type mobility of C8-DRCNTV2T-HH by heat treatment.

Figure 3 shows heating temperature dependence of the carrier mobility of P- and N-type. The mobility was estimated from the saturation regime of the  $I_d$ . The maximum of the P-type mobility was observed after heating the films at 80 °C, which is four-order-of-magnitude higher than that of N-type mobility. On the other hand, pronounced enhancement of the N-type mobility was observed after heating at 120 °C, which is almost ten times higher than the P-type mobility. We have found that the TFT performance of C8-DRCNTV2T-HH shows ambipolar semiconductors behavior, depending on the heating temperature.

We have investigated the structure and the morphology of the thin films by measurements of X-ray diffraction (XRD) and atomic force microscopy (AFM), respectively. The X-ray diffraction (XRD) of the thin films after heating at 120 °C is shown in Fig 4. A significant change was observed in the XRD patterns of the thin films by heat treatment. No diffraction peaks were observed in the thin films before heating and after heating at 80 °C. The thin films after heating at 120 °C showed a series of diffraction peaks assigned to (00*h*) reflection. The obtained *d*-spacing (1.9 nm) can be explained by the molecular arrangement in which C8-DRCNTV2T-HH forms laminar packing parallel to the substrate.

The AFM images also showed an apparent morphological dependence on the heating temperature (Fig 5). Small crystal grains sub- $\mu\text{m}$  in size was observed in the thin films before heating and the grain size slightly increased after heating at 80 °C. In the AFM images of the thin films after heating at 120 °C, large crystal grains with terrace-like step structures were observed. These results indicate that C8-DRCNTV2T-HH changes into more ordered crystalline structures by heat treatment.

#### 4. Conclusions

We have designed and synthesized oligothiophene, C8-DRCNTV2T-HH with end-capping rhodamine. The thin films exhibit ambipolar field-effect performance. It is notable that the mobility significantly change by heat treatment.

[1] B. Kanet et al., J. Am. Chem. Soc. 137, 3886 (2015).

[2] Y. Akiyama et al., Jpn. J. Appl. Phys, submitted.

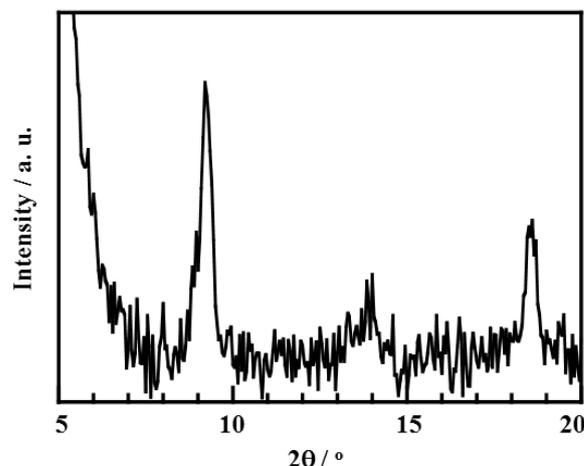


Fig.4 X-ray diffraction pattern of the C8-DRCNTV2T-HH thin film after heating at 120 °C.

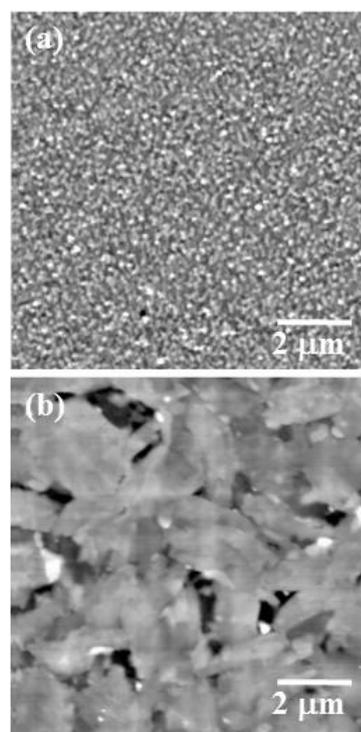


Fig.5 AFM topography images of C8-DRCNTV2T-HH thin films (a) before heating and (b) after heating at 120 °C.