Thermal Stability of Short Channel, High-Mobility Organic Thin-Film Transistors having Bottom-Contact Configuration

Masatoshi Kitamura\textsuperscript{1,2} and Yasuhiko Arakawa\textsuperscript{2,3}

\textsuperscript{1} Graduate School of Engineering, Kobe University
1-1, Rokkodai-cho, Nada, Kobe 657-8501, Japan
Phone: +81-78-803-6072 E-mail: kitamura@eedpt.kobe-u.ac.jp
\textsuperscript{2} Institute for Nano Quantum Information Electronics, The University of Tokyo
4-6-1, Komaba, Meguro, Tokyo 153-8505, Japan
\textsuperscript{3} Institute of Industrial Science, The University of Tokyo
4-6-1, Komaba, Meguro, Tokyo 153-8505, Japan

Abstract

Thermal stability of alkylated-DNTT thin-film transistors (TFTs) has been investigated. Although the properties of the TFTs degraded even for storage at room temperature, the annealing at 120 °C after the degradation improved the properties toward those at early stage. The annealed short-channel TFTs exhibited mobilities of 1.9 to 2.6 cm\textsuperscript{2}/Vs.

1. Introduction

Since high field-effect mobilities up to 7.9 cm\textsuperscript{2}/Vs were reported, alkylated dinaphthothienothiophene (C\textsubscript{n}-DNTT) has been a promising material for high mobility p-channel organic thin-film transistors (TFTs) \cite{1}. Some groups have realized such high mobilities in TFTs with C\textsubscript{10}-DNTT as channel materials \cite{2-4}. However, such high mobility is demonstrated in long-channel transistors having top-contact configuration. On the other hand, bottom-contact configuration is desirable for short-channel transistors and the high frequency operation. This is because short-channel transistors with bottom-contact configuration are easily realized by conventional photolithography.

We have demonstrated bottom-contact pentacene TFTs operating at high frequencies above 10 MHz \cite{5}. Gold/AuNi drain/source electrodes modified with pentfluorobenzothiazole (PFBT), which are effective to reduce contact resistance, were used to realize the short-channel, high-mobility pentacene TFTs \cite{6}. The modified electrodes are effective for C\textsubscript{10}-DNTT TFTs as well as pentacene TFTs \cite{7}.

DNTT-based TFTs have exhibited high stability to storage in air \cite{8}. On the other hand, it was reported that the mobilities of C\textsubscript{10}-DNTT with top-contact configuration slightly decrease with storage time \cite{3}. The cause of the degradation for C\textsubscript{10}-DNTT has not been clear.

In this work, we report thermal stability of short-channel, high-mobility C\textsubscript{10}-DNTT TFTs having bottom-contact configuration. The performance of the TFTs as-fabricated, stored and annealed is discussed.

2. Experimental

Figure 1 shows cross-section of the C\textsubscript{10}-DNTT TFT fabricated in this work. The chemical structure of C\textsubscript{10}-DNTT is shown in the inset in Fig. 1. A silicon substrate with a 35-nm-thick SiO\textsubscript{2} layer was used as a substrate of the TFT. The SiO\textsubscript{2} has a unit area capacitance of 92.3 nF/cm\textsuperscript{2}. Drain/source electrodes of Au/AuNi modified with PFBT were used to reduce contact resistance. The contact electrodes were patterned by photolithography and lift-off. The SiO\textsubscript{2} surface was treated with hexamethyldisilazane. C\textsubscript{10}-DNTT was deposited through a metal mask on a substrate heated at 100 °C. The channel width (W) was 1 mm and the channel length (L) was in the range of 2 to 40 \textmu m. The current-voltage characteristic was measured in a dry-nitrogen glove box. The TFTs were stored in the glove box for about two weeks. To investigate the thermal stability, the TFTs were annealed at 120 °C for about 15 min after the storage of two weeks. Furthermore, the TFTs were annealed at 140 °C for about 15 min. The current-voltage characteristic was measured at each step.

3. Results

Figure 2 shows drain current (I\textsubscript{D}) versus gate voltage (V\textsubscript{G}) characteristics of a C\textsubscript{10}-DNTT TFT with L = 4 \textmu m. The characteristics shows the results measured for the TFT as-fabricated, stored for two week, and annealed at 120 °C. The current dramatically decreased even for storage at room temperature in nitrogen for two weeks as seen in Fig. 2. The I\textsubscript{D}-V\textsubscript{G} characteristic exhibits an abnormal curve in the range of low voltages. The square root of |I\textsubscript{D}| non-linearly increases with V\textsubscript{G}. On the other hand, the an-
nealing at 120 °C improved the current characteristics. Although the slope of $|I_D|^{1/2}$-$V_G$ curve for the annealed TFT is slightly low as compared to that for the fabricated TFT, the on current dramatically improves.

Fig. 2 Transfer characteristics of a C10-DNTT TFT for (a) the as-fabricated TFT, (b) the TFT stored for two weeks, and (c) the TFT annealed at 120 °C after two-week storage.

Fig. 3 Channel length dependence of mobilities and on-current of C10-DNTT TFTs.

The mobilities ($\mu_{sat}$) and threshold voltage ($V_T$) of C10-DNTT TFTs with different channel lengths are summarized in Fig. 3. The values were estimated by fitting a line to the $|I_D|^{1/2}$-$V_G$ curve at a drain voltage ($V_D$) of -15 V. The mobilities for the stored TFTs decrease for all channel length. In particular, the degree of the decrease is very large in the short-channel TFTs. For the TFT with $L = 2 \mu$m, the mobility decreases from 3.3 cm$^2$/Vs to 1.2 cm$^2$/Vs. In addition, the storage for two weeks leads to increase in the absolute value of threshold voltage ($|V_T|$). On the other hand, the annealing improve the mobility for the short channel TFTs of $L = 2$ and 4 μm. In addition, the $|V_T|$ values shift to zero voltage. The changes in $\mu_{sat}$ and $V_T$ are large in the short channel TFTs. The behavior implies that the storage increases the contact resistance and the annealing suppresses the resistance.

Figure 4 shows change of mobilities and on-current of the C10-DNTT TFT with $L = 4 \mu$m. The on-current represents drain current at $V_G = -12$ and $V_D = -15$ V. The mobility decreases even at storage of one week. Although the annealing at 120 °C leads to increase in the mobility, the annealing at 140 °C causes decrease in the mobility.

Fig. 4 Change of mobilities and on-current of the C10-DNTT TFT.

4. Conclusions

We investigated thermal stability of C10-DNTT TFTs with bottom-contact configuration. The properties of the TFTs stored in a nitrogen-filled glove box at room temperature degraded even for the brief period of a few days. On the other hand, annealing at 120 °C after the degradation improved the properties toward those at early stage. The annealed TFTs have mobilities of 1.9 to 2.6 cm$^2$/Vs. However, annealing at 140 °C led to further degradation. These results suggest the existence of optimal annealing condition for high performance.

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