Improvement of Mobility and Stability in Pentacene-TFT by Chemical Surface Treatment

Daisuke Kumaki\textsuperscript{a}, Masayuki Yahiro\textsuperscript{b}, Youji Inoue\textsuperscript{b} and Shizuo Tokito\textsuperscript{a, b}

\textsuperscript{a}Department of electronic Chemistry, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama 226-8502, Japan

\textsuperscript{b}NHK Science and Technical Research Laboratories 1-10-11 Kinuta, Setagaya-ku, Tokyo 157-8510, Japan

Keyword: organic thin-film transistor, pentacene, \( \beta \)-phenethyl triflorosilane, air stability

1. Introduction

There is a great interest in organic semiconductors because flexibility, lightweight, and low temperature processability have huge potential for electronic devices and these applications. Recently, flexible active matrix organic light-emitting diode driven with pentacene thin-film transistors (TFTs) that takes advantage of these features has been demonstrated \cite{1}. Pentacene, with performance comparable to a-Si, has continued to be the most widely used small molecule semiconductor.

In the case of using electronic devices, stability and reliability are indispensable factor. There is large number of reports about degradation mechanism\cite{2-5} and improvement of device stability\cite{6}. In general, the performance degradation of pentacene-TFTs, such as decrease of mobility and increase of off-current and large threshold voltage shift were caused by adsorption of water and oxygen. Additionally, it is also important for stability to improve the surface of the gate insulator, because these surface treatments suppress the charge trap of formation on gate insulator.

In this paper, to improve the mobility and stability of pentacene-TFT, we have employed self-assembled monolayers (SAMs) as the chemical surface treatment material for SiO\textsubscript{2} gate insulator.

As a result of employing SAM, we could obtain the field effect mobility in excess of 1 cm\textsuperscript{2}/Vs and excellent on/off ratio over 10\textsuperscript{6}. Furthermore, the mobility over 1 cm\textsuperscript{2}/Vs has been maintained after the 2000 times of repeat stress by gate voltage scans in air.

2. Experimental

We employed hexamethyldisilazane (HMDS) and \( \beta \)-phenethyltrichlorosilane (\( \beta \)-PTS) as the surface treatment material for the SiO\textsubscript{2} gate insulator. Molecular structures are shown in figure 1a. HMDS is the most widely used SAM material. \( \beta \)-PTS has a phenyl at the end. To form the SAMs, a highly doped Si wafers with a 200-nm-thick thermal oxide were immersed for 12 h in a 1 mM solution of the \( \beta \)-PTS in anhydrous toluene or in an undiluted HMDS solution. After removing the substrate from the solution, they were cleaned in flesh toluene, acetone and isopropyl alcohol for 10 min in an ultrasonic bath to remove any excessive layers. Prior to the active layer deposition, the substrates were cleaned in ethanol.
3. Results and Discussion

3.1. Performance of pentacene-TFTs

Fig. 2 and table 1 show the drain current ($I_D$) vs gate voltage ($V_G$) characteristics and electrical properties of pentacene-TFTs, which were fabricated on the SiO$_2$ with and without chemical surface treatment.

The pentacene-TFT fabricated on untreated substrate showed the mobility of 0.21 cm$^2$/Vs and on/off ratio of $10^5$. In contrast, high mobility and low threshold voltage ($V_{th}$) were observed by using both SAM materials. Furthermore, it was notable that β-PTS showed more excellent performance than HMDS. We could obtain the field effect mobility of 1.45 cm$^2$/Vs and on/off ratio over $10^6$ in the case of β-PTS.

3.2. Improvement of air stability

Fig. 3 shows the plots of mobility, $V_{th}$ and on/off ratio vs the number of gate voltage scans ($V_G$-scans). These electrical characteristics of pentacene fabricated on treated SiO$_2$ with β-PTS were measured in vacuum. The gate voltage was scanned from 20 V to -100 V at $V_D$=-100 V a time (delay time: 1s, measurement step: 2 V, 1 s). The gate voltage scan was repeated 2000 times.

No significant changes were observed in the mobility and on/off ratios. The mobility of 0.4 cm$^2$/Vs and on/off ratio of $10^5$ were maintained after 2000 times of $V_G$-scans. This result indicates that pentacene-TFT is very stable.
Fig. 3. Plot of mobility (left) and \( V_{th} \) (right) vs number of \( V_G \)-scan. The inset shows the plot of on/off ratio vs number of \( V_G \)-scan. The gate voltages scanned from 20 V to -100 V at \( V_D = -100 \) V at each scan.

Fig. 4. \( I_D \) vs \( V_G \) characteristics at \( V_D = -100 \) V of pentacene-TFT using untreated substrate. Stable in high vacuum condition.

Fig. 5. \( I_D \) vs \( V_G \) characteristics at \( V_D = -100 \) V of pentacene-TFT with chemical surface treatment using \( \beta \)-PTS.

Fig. 6. a) Plot of mobility (left) and \( V_{th} \) (right) vs number of \( V_G \)-scan. b) Plot of on/off ratio vs number of \( V_G \)-scan. The gate voltage was scanned from 10 V to -50 V at \( V_D = -100 \) V.

Whereas the significant degradation was observed using untreated substrate.

Fig. 6 shows the plots of mobility, \( V_{th} \) and on/off ratio vs number of \( V_G \)-scan. The pentacene-TFT with surface treatment with \( \beta \)-PTS
was measured in air. The gate voltage was scanned from 10 V to -50 V at \( V_{G} = -100 \) V a time (delay time: 1 s, measurement step: 1 V, 1 s). The gate voltage scan was repeated 2000 times.

The field effect mobility over 1 cm\(^2\)/Vs and the on/off ratio over 10\(^5\) were maintained after 2000 times of \( V_{G} \)-scans in air. Threshold voltage decreased from -18 V to 0 V, followed by maintaining a constant value. Air stability of TFT characteristics was significantly improved by using \( \beta \)-PTS.

Yagi and coworkers have indicated about the relationship between interfacial trap density on SiO\(_2\) gate insulator and the increase of off-current\([6]\). It is important for the stability of TFT characteristics to suppress the adsorption of O\(_2\) and H\(_2\)O because these materials formed new trap sites. The \( \beta \)-PTS layer on the SiO\(_2\) surface suppressed the formation of new trap sites.

4. Conclusion

Top contact pentacene-TFT was fabricated on SiO\(_2\) gate insulator treated with \( \beta \)-PTS. We could obtain the field effect mobility of 1.45 cm\(^2\)/Vs and the on/off ratios over 10\(^6\). Furthermore, the \( \beta \)-PTS treatment gave good air stability. The field effect mobility over 1 cm\(^2\)/Vs and the on/off ratio over 10\(^5\) were maintained after 2000 times of \( V_{G} \)-scans in air.

References