Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 690-691

P13-9L

Bottom Contact Organic Thin-Film Transistors with Reduced Contact Resistance

Masahiro Kawasaki, Shuji Imazeki, Toshihide Kamata[1], and Masahiko Ando

Optoelectronic Industry and Technology Development Association (OITDA)
1-1, Central Higashi 1-Chome, Tsukuba-city, Ibaraki, 305-8562, Japan
Phone: +81-29-861-3024 E-mail: kawasaki.m@aist.go.jp
Hitachi, Ltd. Adavanced Research Laboratory
1-1, Omika-cho 7-chome, Hitachi-shi, Ibaraki-ken 319-1292
[1]National Institute of Advanced Industrial Science and Technology (AIST)
1-1, Central Higashi 1-Chome, Tsukuba-city, Ibaraki, 305-8565, Japan

1. Introduction

Organic thin-film transistors (TFT) have received interest due to their simple and low cost process. Among TFT structures, bottom contact configuration, with organic semiconductor deposited onto prefabricated source/drain electrodes, is suitable for printing process, but it usually has field-effect mobility lower than that of top contact configuration. This is caused by high contact resistance, R_c, between source/drain electrodes and semiconductor, becoming a substantial part of the total TFT resistance[1)]. Self-assembled monolayer (SAM) on the electrode surface is reported to reduce R_c[2)], but details of the treatment condition and mechanism for reducing R_c are still unclear.

In this paper, we show that electrode-edge shape and SAM treatment condition should be optimized to reduce R_c directly extracted from transfer characteristics of the bottom contact TFTs with different channel lengths. Causes for reducing R_c will be discussed in terms of grain growth of semiconductor film at electrode edge and energy barrier height for carrier injection.

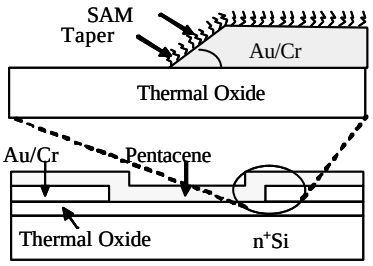

Fig.1 Schematic TFT cross section.

2. Experiments

Schematic cross section of TFT sample is shown in **Fig.1**, using heavily doped silicon as substrate and gate electrode with thermally grown silicon dioxide of 300nm as gate dielectric layer. 50nm/1nm thick Au/Cr was deposited by evaporation and patterned by photolithography with lift-off method to make source/drain electrodes. Finally, 50nm thick pentacene film was deposited by thermal evaporation at 2×10^{-6} Torr without heating. Surface morphologies of pentacene were observed by using atomic force microscopy (AFM).

Two kinds of substrates were prepared with different average taper angles of 30 ° and 5 ° in the source/drain electrode edge by changing setting positions of substrates relative to Au/Cr evaporation source in a process chamber. Octadecanethiol (ODT) whose the kinetics and adhesion mechanism on Au are well characterized[3)], was dip-coated to make SAM on the electrodes from 0.1 or 1 mM octane solution. Contact angles of pure water and work functions of the SAM treated electrodes were measured.

Channel lengths, L, were varied from 5 μm to 400 μm to extract R_c[4)], with a constant channel width of 2000 μm.

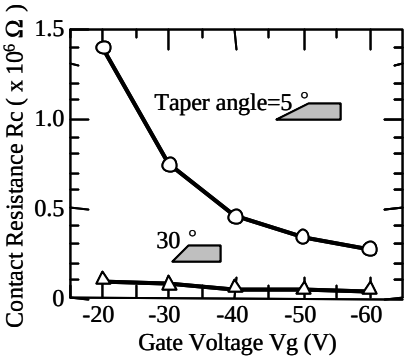

Fig.2 R_c vs. V_g with different taper angle of electrode edge.

3. Results and Discussions

Gate voltage, V_g, dependence of R_c with different taper angles of electrode edge without SAM treatment is shown in **Fig.2**. R_c with moderate taper angle of 5 ° is more than one order of magnitude higher than that with steep taper angle of 30 ° in low V_g region. R_c with moderate taper abruptly decreased with increasing V_g, but still much larger than that with steep taper. This V_g dependence suggests R_c should be related to field-effect conductivity of pentacene

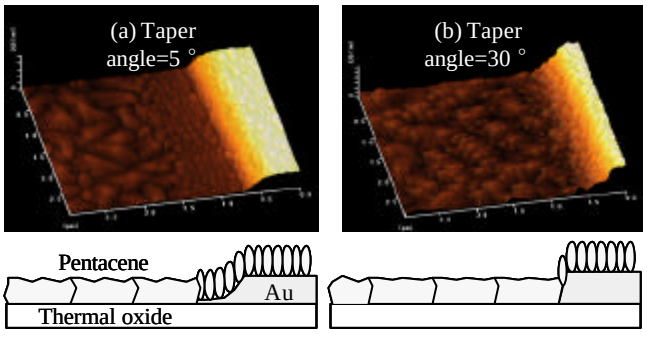

Fig. 3 Surface morphologies of pentacene dposited on regions of Au electrode edge with different average taper angle.

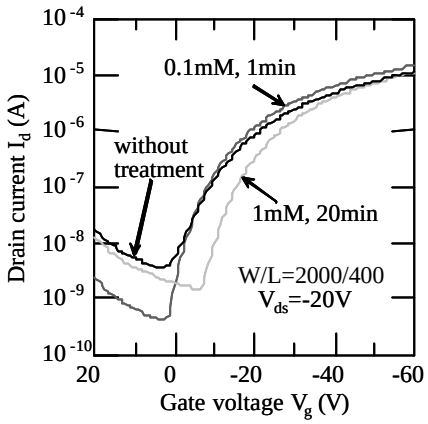

Fig.4 I_{ds} vs. V_g with various conditions for SAM treatment.

near electrode edge.

AFM images of pentacene films deposited on regions of Au electrode edge with different taper are shown in **Fig.3**, with estimated cross section of the films. It is clearly observed that in case of moderate taper, grain sizes of pentacene on the taper are small and extended to the channel area, while in case of steep taper, the small grains are just on the taper and large grains sharply appear in the channel area. In the former case, carriers (holes) injected from Au electrode should go thorough some grain boundaries causing R_c much higher than that in the latter case with smaller number of grain boundaries. Increasing V_g should accumulate carriers in the grain boundaries to reduce R_c as shown in **Fig.2**.

I_{ds}-V_g characteristics with various conditions for SAM treatment are shown in **Fig.4**. With SAM treatment with 0.1 mM solution for 1 minute, field effect mobility increases of 25% over that without treatment and off current decreases about one order of magnitude without changing morphologies of pentacene on Au electrode edge. However, excessive treatment with 1 mM for 20 min for example, decreases the mobility accompanying the threshold voltage shift, shown in the figure. In case of treatment with 0.1 mM for 1 day, on current decreases to less than 10^{-8} A, presumably due to extremely high contact resistance.

Optimum time for SAM treatment to reduce R_c was found to exist as shown in **Fig.5,** with 0.1 mM solution. With 1 min treatment, R_c decreases to almost half the value of that without treatment. But further elongation of the treatment time increases R_c accompanying the decrease in work function on Au electrode (**Fig.6**), indicating increase in Schottky barrier height at Au/pentacene since the HOMO level of pentacene and the work function of Au without treatment was almost the same at 4.8 eV.

These results can be interpreted with the self-assembly mechanism of ODT on Au[3] schematically shown in the insets. In the optimum treatment time duration, ODT monolayer covers in lying-down phase and may produce the spacing effect[5] to reduce R_c. With increasing time, the monolayer becomes high-density and standing-up phase to increase the barrier height due to the dipole moment and induce the increase in R_c.

4. Conclusions

In order to reduce the contact resistance between pentacene semiconducting film and Au electrode in TFTs with bottom-contact configuration, it is found that both the edge-shape of electrode and SAM treatment on the surface of electrode should be optimized: (1) edge of Au electrode should have steeper taper angle in order to enhance the grain growth of pentacene and reduce the grain boundaries, (2) SAM (octadecanethiol) treatment time should be optimized; long enough to cover almost all the surface of electrode with lying-down phase; short enough to prevent the increase of Schottky barrier with standing-up phase.

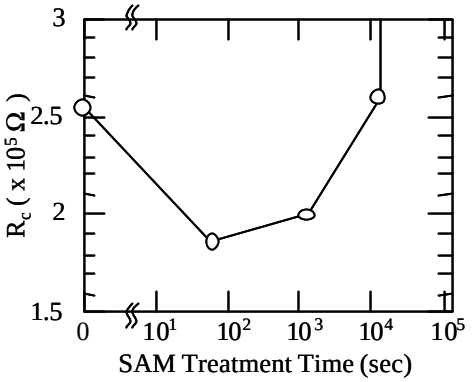

Fig.5 SAM treatment time dependence of R_c

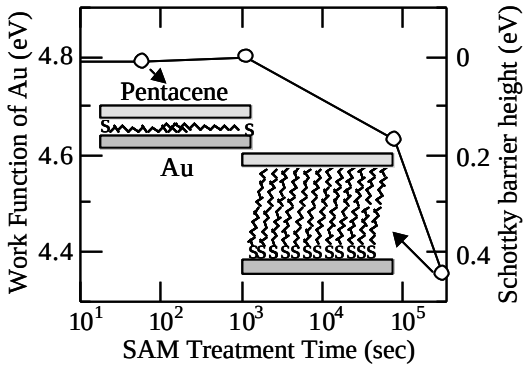

Fig.6 SAM treatment time dependence of Au work function (Schottky barrier height).

Acknowledgement

A part of this work belongs to "Advanced Organic Device Project" under contraction between OITDA and New Energy and Industrial Technology Development Organization (NEDO). Authors thank Dr. T. Minakata and Dr. M. Yoshida for useful discussions.

References

[1] P. V. Necliudov et al., Solid State Electronics **47**, 259(2003).
[2] I. Kymissis et al., IEEE Trans. Elec. Dev. **48**, 1060(2001).
[3] Self-Assembled Monolayers of Thiols, edited by A. Ulman (Academic Press, 1998), p. 81.
[4] S. Luan and G. W. Nudeck, J. Appl. Phys. **72**, 766(1992).
[5] L. Zuppiroli et al., Eur. Phys. J. **B11**, 505(1999).