Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 650-651

P-10-11L

Performance of organic thin film transistor using C_{60}/Au bilayer electrode

[1]Jaeyoung Park, [1]Sukmo Jung, [2]Hoo-Jeong Lee, and [1]Moonsuk Yi

[1]School of Electrical Engineering, Pusan National University, Busan, 609-735, Korea
[2]School of Advanced Material Science, SungKyunKwan University, Suwon, Korea
Phone:+82-51-510-2381, E-mail: msyi@pusan.ac.kr

1. Introduction

Organic thin-film transistors (OTFTs) have attracted much attention because of their many advantages, such as flexibility, low fabrication costs, and low temperature processes, which the conventional amorphous Si-based TFTs cannot offer. Their potential application encompasses a wide area including radio frequency identification tags (RFIDs), organic light emitting diodes (OLEDs), smart cards and organic solar cell [1-3]. Many recent studies have been focused onto thin film characteristics of organic semiconductor, organic insulating layers and their interface with pentancene. However, the interface between pentacene and metal electrodes also needs much research effort.

In research areas for developing organic-based electronic device, it is of great importance to enhance the injection of holes or electrons into active layer, since charge injection is very limited at the interface between metal and organic semiconductor due to high barrier heights. For instance, x-ray photoelectron spectroscopy (XPS) or ultra violet photoelectron spectroscopy (UPS) have been extensively used to study interface dipoles (existing between metal electrodes and an organic active layer), which could lower the barrier height [4-6].

Au is often adopted as a metal electrode for pentacene-based OTFT, since the barrier height is expected to be very small for the contact between Au and pentacene. During the growth of an Au layer on pentacene, nevertheless, the interface dipole forms and aligns in such a way that the barrier height for hole injection increases significantly. Thus the actual barrier height for Au/pentacene contact is quite high (0.85~1.05eV) and hence hole injection is substantially limited .[6] Therefore it is very important to reduce the intensity of the interface dipole at the Au/pentacene interface to improve hole injection.

In the present study, we utilized C_{60} as a buffer layer. C_{60} is known that it tends to be electrically neutral and that its low HOMO energy level attracts electrons while facilitating hole transport. In addition, C_{60} forms covalent bonds with metal through charge transfer, which could lead to the improvement of hole injection across the interface. [7] Owing to these interesting characteristics, C_{60} has been extensively studied for a n-type semiconductor, ambipolar OTFT, etc. Here, we report a study using C_{60} as a buffer layer between metal electrodes to enhance device performance of OTFT.

2. General Instructions

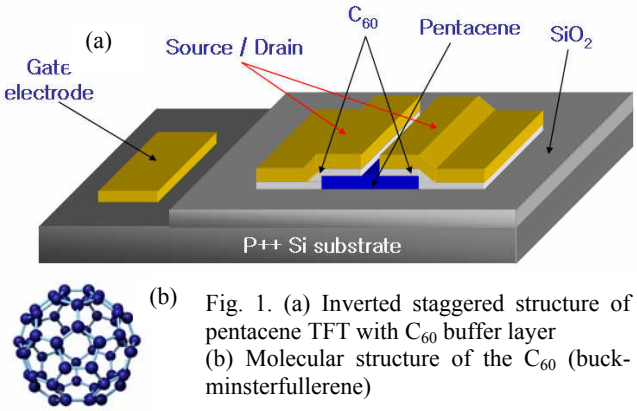

Fig. 1. (a) Inverted staggered structure of pentacene TFT with C_{60} buffer layer (b) Molecular structure of the C_{60} (buckminsterfullerene)

Figure 1 shows a schematic diagram of the transistor structure used for this work. Highly doped p-type Si wafers (~0.005Ω-cm)(100) were used as a substrate for a back gate electrode. A 600Å thick thermal SiO_2 was used as a gate insulator. The SiO_2 layer on the top for gate electrode was removed by soaking the substrate covered with patterned resist into buffered oxide etchant (BOE). Then the substrate was cleaned in trichloroethylene (TCE), acetone, methanol and de-ionized water successively. After cleaning process, it was baked in the vacuum chamber to remove extra impurities.

Pentacene was purchased from Aldrich and used without any further purification. Pentacene films were grown in an organic molecular beam deposition (OMBD) chamber under the pressure of 1.0×10^{-6} Torr. During the active layer formation, the rate of deposition was maintained at 0.1Å/s and the final thickness was 40nm. After the active layer deposition, a C_{60} layer(with a various thickness of 10, 15, 20, 30, 50Å) was deposited without breaking the chamber vacuum in the same OMBD chamber. Finally, 40nm thick Au electrode was formed using effusion cell. The channel width(W) was 2000 ㎛ for all TFTs, and channel lengths(L) were varied between 50 ㎛ and 100 ㎛. All films were grown by OMBD system at the base pressure below 10^{-6} Torr.

The electrical property of the OTFTs was measured in a light-isolated probing station connected to a semiconductor parameter analyzer (ELECS Corp. EL423) at room temperature in air.

The addition of a C_{60} buffer layer resulted in a significant improvement in electrical properties of an OTFT device. Fig. 2. and 3. show I_D vs. V_{SD} curves obtained by scanning V_D from 0V to -30V at the steps of V_{GS} from 0V to -20V by -5V. In the saturation regime, $V_{SD}>(V_{GS}-V_T)$, we obtained filed-effect mobilities (μ) based on the fol-

lowing equation :

$$I_D = \frac{W\mu C_i}{2L}(V_{GS} - V_T)^2$$

where, W and L are channel width and length, respectively, C_i the gate capacitance per unit area, μ the effective field effect mobility, and V_T the threshold voltage. The mobility increased from 0.147 cm^2/Vs for the devices without any buffer layer to 0.364 cm^2/Vs for those with the buffer layer.

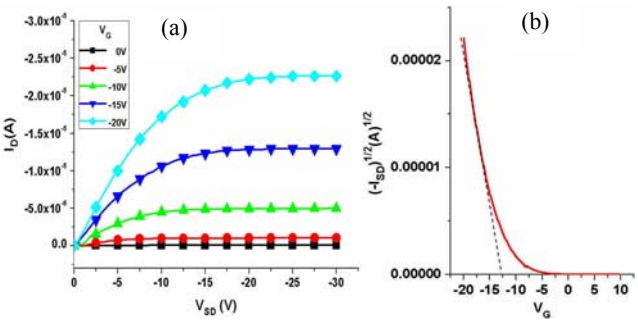

Fig. 2 (a) I_D vs V_{SD} output curve and (b) transfer curves of Au electrode OTFT.

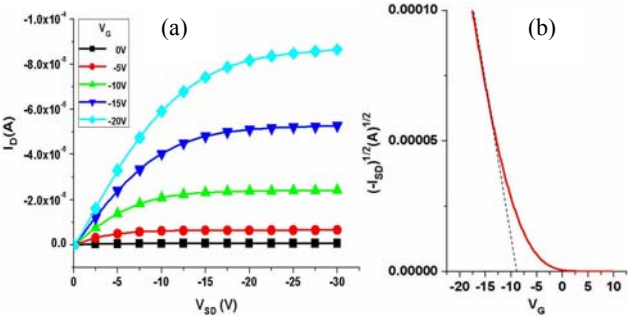

Fig. 3 (a) I_D vs V_{SD} output curve and (b) transfer curve C_{60}/Au electrode OTFT.

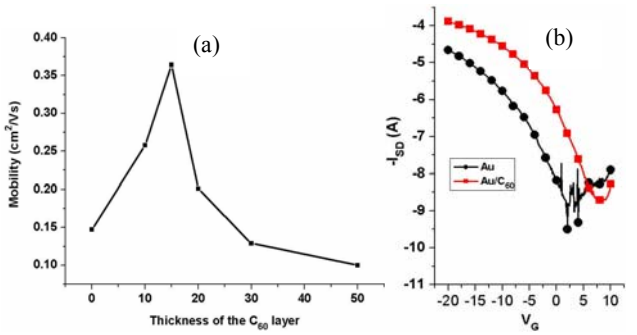

Fig. 4 (a) The field effect mobility versus C_{60} layer thickness (Å) (b) Transfer curves Au and C_{60}/Au electrode OTFT

The contact resistance in the linear region (V_{DS} = −1V) was calculated using the following equation :

$$R_{on} = R_{ch} + R_S + R_D \approx \frac{L}{W\mu C_i (V_{GS} - V_T)} + R_P$$

Where $R_P = R_S + R_D$, R_P is source and drain contact resistance and R_{ch} is the channel resistance . Also R_{ON} is the total resistance defined as $\partial V_{DS} / \partial I_D$.[8] The R_{on} at V_G=-20V of the device with C_{60}/Au electrode is found $6.62 \times 10^4 \Omega$, which is much lower than that for the Au electrode samples, $3.21 \times 10^5 \Omega$

The transfer curves shown in Figs. 2(b) and 3(b) demonstrate that the devices with the Au/C_{60}(15 Å) electrodes exhibit a threshold voltage around -8.5V, which is smaller than that for the devices with the Au electrode. Figure 4(a) shows that the field effect mobility of the OTFT reaches a peak at the C_{60} layer thickness of 1.5 Å. Figure 4(b) shows that the on/off current ratio is nearly the same for the two types of samples, around ~10^4.

These improved electrical properties of the C_{60}/Au electrodes observed in this study can be explained based on the results of several recent reports, which suggest the presence of a high energy barrier between Au and pentacene due to an interface dipole produced during the growth of an Au layer on pentacene. [6] We suggest that the C_{60} buffer layer adopted in this study provide a protection against Au diffusion into the pentacene layer and any undesirable chemical reaction between Au and pentacene, leading to a decrease in the intensity of the interface dipole and hence the facilitation of hole injection across the contact by lower contact resistance. Thus, we believe that the C_{60} buffer layer used in this study has weakened the intensity of the interface dipole, which has led to significant improvements in electrical properties found in our study.

3. Conclusions

In this study, we demonstrated the possibility of using C_{60} buffer layer to enhance the interface between pentacene and metal electrode. By inserting a thin C_{60} buffer layer, the field effect mobility increased from 0.147 cm^2/Vs to 0.364 cm^2/Vs. Also, Threshold voltage decreased from -12.5V to -8.5V. We ascribe these improvements to the reduction of the interface dipole intensity due to the presence of the C_{60} buffer layer.

References

[1] C. D. Dimitrakopoulos and P. R. L. Malenfant, Adv. Mater. Weinheim,
Ger. 14, 99 (2002)
[2] G. H. Gelinck et. al., Nature Mater. 3, 167 (2004)
[3] L. Zhou, S. park, B.bai, J. Sun, S. C. Wu, T. N. Jackson, S. Nelson, D. Freeman and Y. Hong, IEEE Electron Device Lett. 26, 640 (2005)
[4] S. C. Veenstra, H. T. Jonkman, J. Polymer Science. 41, 2549 (2003)
[5] H. Ishii, K. Sugiyama, E. Ito and K. Seki, Adv. Mater. 11, 605 (1999)
[6] A. Kahn, N. Kocha and W. Gao, J. Polymer Science. 41, 2529 (2003)
[7] N. Hayashi, H. Ishii, Y. Ouchi and K. Seki, J. Appl. Phys. 92, 3784 (2002)
[8] D. J. Gundlach, L. Zhou, J. A. Nichols, and T. N. Jackson, J. Appl. Phys. 100,024509 (2006)