Investigation on Electrical Properties of TIPS Pentacene Organic Thin-film Transistors by Cr Thickness of Suspended Source/Drain

Kyung Seok Kim[1,2]*, Kwan Soo Chung[2], Yong Hoon Kim[1], Jeong In Han[1]
[1]Information Display Research Center, Korea Electronics Technology Institute, #68 Yatap-dong, Bundang-gu, Seongnam-si, Gyeonggi-do, 463-816, Korea
[2]Dept. Electronic Engineering, Kyung Hee University, #1 Seocheon-dong, Giheung-gu, Yongin-si, Gyeonggi-do, 446-701, Korea

**Phone : +82-31-789-7276, E-mail : gundam8080@naver.com*

Keywords : OTFT, Thin film transistor, TIPS pentacene

Abstract

We investigated the effect of Cr thickness on the electrical properties of triisopropylsilyl pentacene organic thin-film transistor (OTFT) employing suspended source-drain electrode. With Cr thickness of 10 nm, the field-effect mobility, on/off ratio and subthreshold slope were 0.017 cm^2/Vs, 8.78×10^3 and 10 V/decade, respectively. By increasing the Cr thickness to 100 nm, the field-effect mobility was increased to 0.032 cm^2/Vs, on/off ratio to 1.12×10^5 and subthreshold slope to 1 V/decade.

1. Introduction

Recently, there has been a growing interest in the fabrication of pentacene-based organic thin-film transistors (OTFTs) [1] due to their significant impact on low-cost, mass produced electronics using flexible substrates. [2-3] The development of simple, solution-phase processing methods to deposit semiconducting organic molecules would facilitate the development of new technologies such as large active matrix displays and inexpensive, mechanically flexible "plastic" electronics.[4-7] Pentacene has received special attention because single crystals [8] and thin films [9-10] exhibit high carrier mobility. So we expect that OTFTs will have a ripple effect at portable device market. Many researchers have devoted their efforts to improve device performance parameters such as hole mobility, on/off current ratio, threshold voltage, subthreshold slope, focusing on the relationships among the device structures, pentacene film morphology, gate dielectrics, chemical treatments on the surface of gate dielectric, and charge transport properties. Therefore, many remarkable achievements in device properties have occurred. In particular, a high hole mobility of ~3.3 cm^2/Vs and high on/off ratios over 10^6 were reported [11], and several inorganic and organic gate dielectric films have demonstrated to prove their feasibilities. In order to improve the performance of organic transistor, we analyzed and compared the electrical properties of TIPS pentacene such as field effect mobility, on/off ratio, subthreshold slope and threshold voltage. OTFTs change only etching processing time without change of structural design. We obtained the different thickness of Cr layer and could compare electrical properties of OTFTs. As a result of employment with thick thickness, we obtained good properties such as high field effect mobility, high on/off ratio, low subthreshold slope.

2. Experimental

We fabricated the device as the structure shown in Fig. 1. We deposited Cr with thickness of 100 nm on a cleaned glass substrate at room temperature by DC sputtering equipment with power of 400 W, and deposition pressure of 6 mTorr. Then we patterned the gate electrode by photolithography process. As a gate dielectric, Poly 4-vinylphenol (PVP) was deposited on the gate electrode by spin coating. The concentration of curing agent of PVP melamine-co-formaldehyde and PVP were 5 wt% and 10 wt%, respectively. We first put the sample in a convection oven set at 90°C for 5 minutes to remove the excess solvent in the film. Then, the PVP was thermally cured at 175°C for one hour to cross-link. More detailed results on the electrical properties of our PVP can be found elsewhere. [12] For a comparison, we used Au of 100 nm and Cr of 10 nm, 30 nm, and 100 nm, respectively. Cr was deposited on the PVP insulator for suspended source-drain (SSD) by e-beam sputtering system and Au of 100 nm was deposited by thermal evaporator. Au is usually used as Ohmic contact material because most of organic semiconductors are p-type. [13-14] In fact, Cr layer was deposited originally to improve adhesion of Au and gate insulator. However in this paper, Cr layer was used for SSD structure. Fig. 2 shows the optical image of OTFT with overetched Cr underlayer.

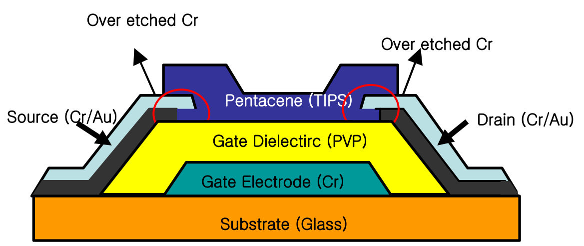


Fig. 1. The vertical structure of TIPS pentacene OTFT with suspended source-drain (SSD) electrode.

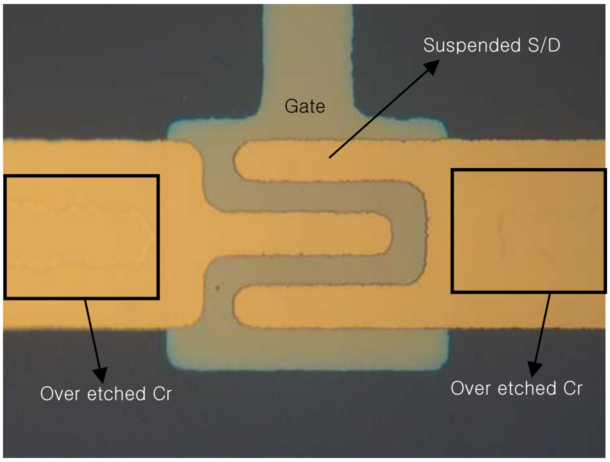


Fig. 2. An optical image of OTFT device with suspended source-drain (SSD) electrode. he device channel width W and length L are 125 μm and 10 μm, respectively.

The SSD OTFTs were fabricated with different thickness of Cr layer. After Cr layer was over etched, triisopropylsilyl (TIPS) pentacene was deposited by ink jetting. We used anisole as a solvent. The concentration of TIPS pentacene was fixed at 1 wt%. The drop diameter of TIPS pentacene was 40 μm. The current-voltage (I-V) characteristics of the fabricated pentacene OTFTs were measured by a parameter analyzer (KEITHLEY 4200).

3. Results and discussion

Fig. 3 shows the logarithmic plot of I_{ds} and represents the properties of pentacene TIPS by different thickness of Cr layer, (a) 10 nm (b) 30 nm (c) 100 nm respectively. The drain-source voltage bias was -5 V, -10 V and gate-source voltage was scanned from 20 V to -40 V. The curve was changed more rapidly from off state to on state as the Cr thickness increased. The electrical properties are the factors to determine a good performance. As clearly seen in the graph, the thickness of Cr layer has significant effect on the electrical properties of OTFT device. In the curve, the best performance can be found in devices fabricated with Cr layer of 100 nm. Table 1 shows the variation of electrical properties of pentacene TIPS OTFTs with different Cr thickness. The field effect mobility μ and the threshold voltage V_{th} were extracted from linear region of the transfer characteristic using the following equation

$$\mu_{fe} = \frac{g_m}{C_{ox}V_{ds}}\frac{L}{W} \qquad (1)$$

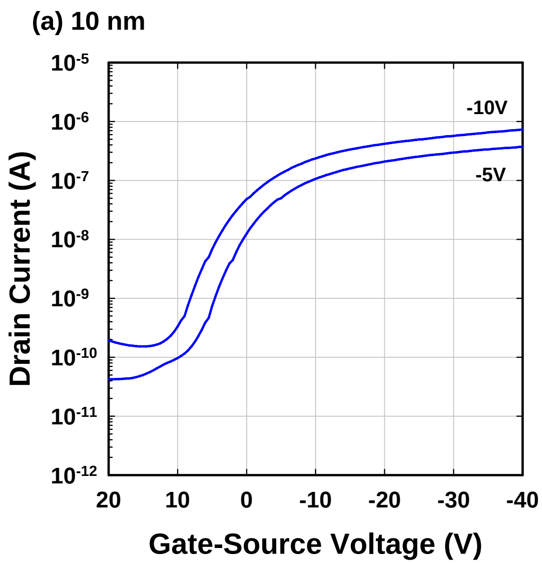
Where, g_m is the transconductance, L is the channel length, W is the channel width, C_{ox} is the capacitance per unit area of the insulating layer and V_{ds} is the drain voltage. The insulator capacitance was 6.45 nF/cm^2 and the device channel width W and length L were 125 μm and 10 μm, respectively.

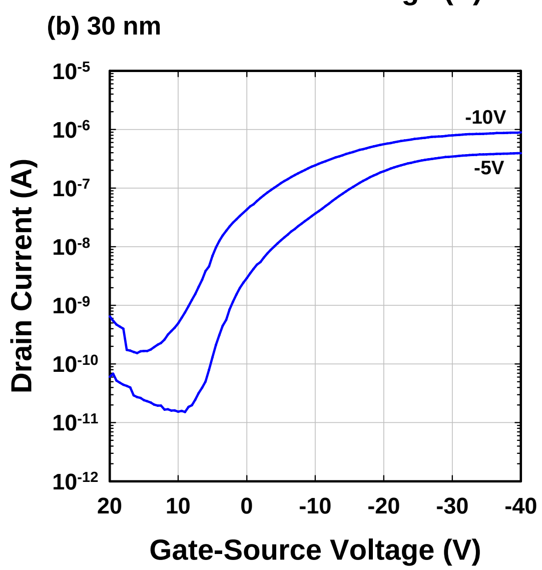
4. Summary

Generally top contact or bottom contact structure can be used for OTFTs. The performance of OTFT with top contact is better than bottom contact one in terms of field-effect mobility because the contact resistance of a top contact TFT is less than that of a bottom contact. [16]

Table 1. The variation of electrical properties of pentacene OTFTs

Cr thickness (nm)	Mobility (cm^2/Vs)	I_{on}/I_{off}	Threshold Voltage (V)	Subthreshold slope (V/decade)
10	0.017	8.78×10^3	0.8	4.5
30	0.033	2.58×10^4	1	10
100	0.032	1.12×10^5	1.5	1





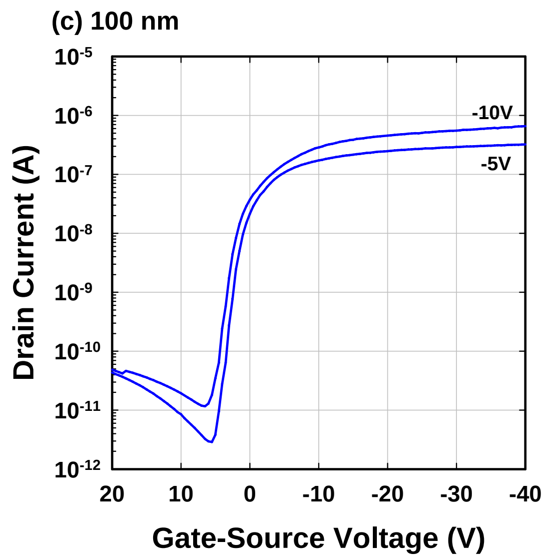


Fig. 3. The lineartransfer properties of ink-jet printed TIPS pentacene OTFTs was fabricated with different Cr thickness 10 nm (a) 30 nm (b) and 100 nm (c).

We studied to enhance the electrical properties of OTFT in this paper. In order to pass over the conventional bottom gate & bottom contact OTFT, we employed a SSD that it is like the bottom & top contact. As a result, we obtained more good properties of pentacene TIPS OTFT such as field effect mobility, threshold voltage, on/off ratio and subthreshold slope. The OTFT with Cr of 100 nm exhibited field-effect mobility of 0.032 cm^2/Vs, threshold voltage of 1.5 V, on/off ratio of 1.12×10^5 and subthreshold slope of 1 V/decade. In contrast, the OTFT with Cr of 10 nm exhibited field-effect mobility of 0.017 cm^2/Vs, on/off ratio 8.78×10^3, threshold voltage of 0.8 V and subthreshold slope of 4.5 V/decade. The OTFT with SSD showed an average field-effect mobility of 0.066 cm^2/Vs.

5. References

1. C.D. Dimitrakopoulos, D.J. Mascaro, IBM J. Res. (2001) Vol 45.
2. A.N. Krasnov, Appl. Phys. Lett. (2002), Vol 80, 3853.
3. A. Sugimoto, H. Ochi, S. Fujimura, IEEE J. Sel. Top. Quantum Electron (2004), Vol 10, 107.
4. Afzali, A. Dimitrakopoulos, C. D. Breen, T. L. J. Am. Chem. Soc. (2002), 124, 8812-8813.
5. Afzali, A. Dimitrakopoulos, C. D. Graham, T. O. AdV. Mater. (2003), 2066-2069.
6. Brown, A. R. Pomp, A. deLeeuw, D. M. Klaassen, D. B. M. Havinga, E. E. Herwig, P. Mu¨llen, K. J. Appl. Phys. (1996), 79, 2136-2138.
7. Herwig, P. T. Mu¨llen, K. AdV. Mater. (1999), 11, 480-483.
8. Jurchescu, O. D. Baas, J. Palstra, T.T.M. Appl. Phys. Lett. (2004), 84, 2061-3063
9. S. b. Lee, M. W. Lee, K. H. Kim, Y. X. Xu, C.K. Song, IEEK (2002). Vol 25, 253.
10. S. K. H, O. S. K, PSK. (2006) Vol 17, 63.
11. T.W. Kelley, D.V. Muyres, P.F. Baude, T.P. Smith, T.D. Jones, San Francisco, U.S.A., April 21– 25, 2003, Materials Research Society Symposium Proceeding (2003), vol. 771, 226.
12. K. S. Kim, K. S. Chung, Y. H. Kim, J. I. Han, IMID (2006), 1150-1153.
13. S. H. Cho, S. H. Kim, N. E. Lee, H. M. Kim, Y. W. Nam, Thin Solid Films (2005), 475, 68.
14. S. H. Cho, S. H. Kim, J. G. Lee, N. E. Lee, Microelectron. Eng. (2005), 77, 116.
15. J. B. Koo, S. H. Kim, J. H. Lee, C. H. Ku, S. C. Lim, T. Zyunga, siencedirect (2006), Vol. 156, 99-103
16. P.V. Necliudov, M.S. Shur, D.J. Gundlach, T.N. Jackson, Solid State Electron (2003) , 47, 259.