Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp950-951

A Proposal of High Performance and Highly Fabricable Complementary Organic Thin Film Transistor Structure

Akira Sugawara, Yasuo Wada, Yoshinori Ishikawa and Toru Toyabe

Bio-Nano Electronics Research Center, Toyo University
2100, Kujirai Kawagoe, Saitama 350-8585 Japan
Phone: +81-49-239-1902 E-mail: y-wada@toyonet.toyo.ac.jp

1.Introduction

Organic Thin Film Transistor (OTFT) has attracted attentions, because of its potential for flexible and printable electronics and photonics devices. However, the characteristics are usually quite inferior, and the authors have shown by an OTFT simulator, Toyo University Organic Thin Film Transistor Advanced Simulator (TOTAS) [1], that the origin is in poor carrier injection capability from source/drain electrodes to channel region due to low carrier concentration of the organic semiconductor materials, rather than in poor contact characteristics and/or poor crystalline quality, as usually believed [2,3]. They also have proposed that all one has to do is to insert high carrier concentration semiconductor region at the source/drain contact region in order to improve the characteristics and to enhance the reliability [1]. In line with this, if a complementary OTFT (C-OTFT) structure is made possible, the horizon of OTFT enormously expands, because one can utilize the heritage of silicon CMOS design resources. Thus, several attempts have been made to realize C-OTFT [4,5], however, the characteristics are usually far from satisfaction. In addition, it is usually quite difficult to find out a suitable combination of n-channel and p-channel organic semiconductors, from both performance and fabrication technology points of view. This paper proposes a new high performance and highly fabricable C-OTFT structure using TOTAS simulator.

2.Results and Discussion

Figure 1 shows the top contact C-OTFT structure examined in this study. The striking feature is that the C-OTFT uses only one kind of organic semiconductor layer, in this case p-type, and that it has high concentration n-type region (n^+) for n-channel device and high concentration p-type region (p^+) for p-channel device, both at the source/drain contact area, the concept of which has never been examined before to the best of our knowledge. Bottom contact C-OTFT structure is almost identical to that shown in Fig. 1 except for the contact position.

The expected drain current (Id) – drain voltage (Vd) characteristics of n-channel and p-channel top contact devices are depicted in Fig. 2, where n^+ and p^+ carrier concentration measures 10^{20} cm^{-3}, whereas the carrier concentration of the p-type semiconductor layer (p) is 10^{15} cm^{-3}, channel length 5 μm, gate insulator thickness 300 nm and carrier mobility 0.3 cm^2 /Vs. It should be noted that the Id-Vd characteristics are almost the same regardless of the channel type. Therefore, the C-OTFT structures are quite superior from the fabricability point of view, because all one has to do is to use single type organic semiconductor material and to dope the designated n-channel and p-channel source/drain regions, and resulting in almost the same characteristics. In addition, both top contact OTFTs and bottom contact ones exhibit almost the same Id-Vd characteristics if one employs the same structural parameters.

Dependence of C-OTFT characteristics on carrier concentration of the semiconductor layer (p) between 10^{12} cm^{-3} and 10^{16} cm^{-3} is shown in Fig. 3, in which gate voltage Vg=±50V, and other parameters follow those in Fig. 2. It is clearly indicated that quite reproducible device characteristics are expected regardless of p, up to 10^{15} cm^{-3}. At the p concentration of 10^{16} cm^{-3}, however, recombination current in n-channel device and leakage current in p-channel device become apparent, and the characteristics of the devices become somewhat different. Therefore, p concentration should be lower than 10^{15} cm^{-3}, which is usually achieved because of the intrinsic low carrier concentration characteristics of organic semiconductor materials [1]. Thus, the C-OTFT structure proposed here should enable high performance and highly fabricable C-OTFT integrated circuits, by developing advanced materials which induce high electron or hole concentration in the organic semiconductor layer.

3.Conclusion

Novel high performance and highly fabricable C-OTFT device concept was proposed based on the device simulation results using TOTAS, which makes it possible to eliminate the characteristics differences between n-channel and p-channel devices, between top and bottom contact devices and among carrier concentration variations of organic semiconductor layer.

References

[1] Y. Ishikawa, Y. Wada, K. Tsutsui, and T. Toyabe, Jpn. J. Appl. Phys., 49, 04DK01 (2010)., Y. Ishikawa, Y. Wada, and T. Toyabe, J. Appl. Phys., 107, 053709 (2010).

[2] I. Kymissis, C. D. Dimitrakopoulos, and S. Purushothaman, IEEE Trans. Electron Devices, **48,** 1060 (2001).

[3] N. Koch, J. Ghijsen, R. L. Johnson, J. Schwartz, J..J. Pireaux, and A. Kahn, J. Phys., Chem. **B106,** 4192 (2002).

[4] T. N. Ng, S. Sambandan, R. Lujan, A. C. Arias, C. R. Newman, H. Yan, and A. Facchetti, Appl. Phys. Lett. **94**, 233307 (2009).

[5] S. De Vusser, S. Steudel, K. Myny, J. Genoe and P. Heremans, Appl. Phys. Lett. **88**, 162116 (2006).

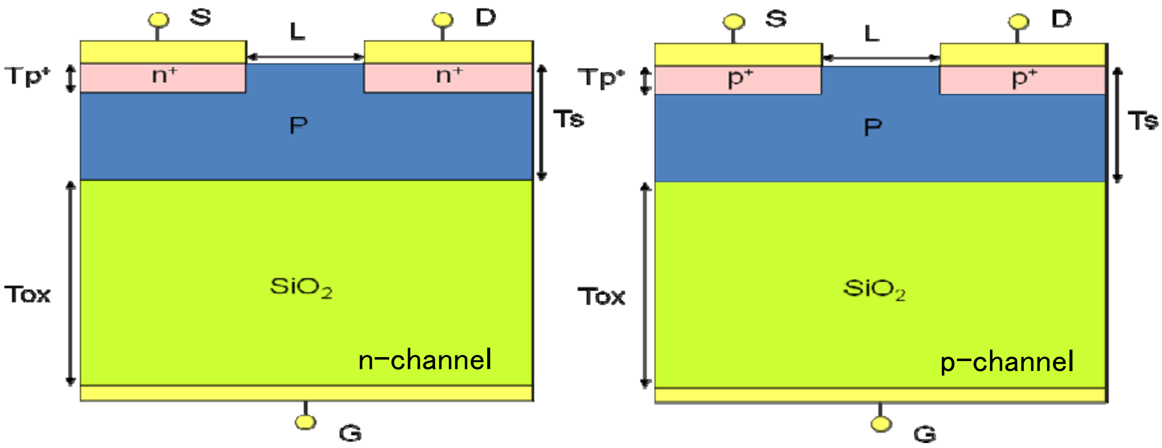

Fig. 1: Schematic cross section of the top contact OTFT structures examined in this study n-channel device (left) and p-channel device (right). Bottom contact ones have almost the same structure except for the source/drain electrodes and n^+ and p^+ regions. L=5 μm, Tox=300 nm, Ts=50 nm, p=10^{15} cm^{-3}, Tp^+=5 nm, n^+,p^+=10^{20} cm^{-3}

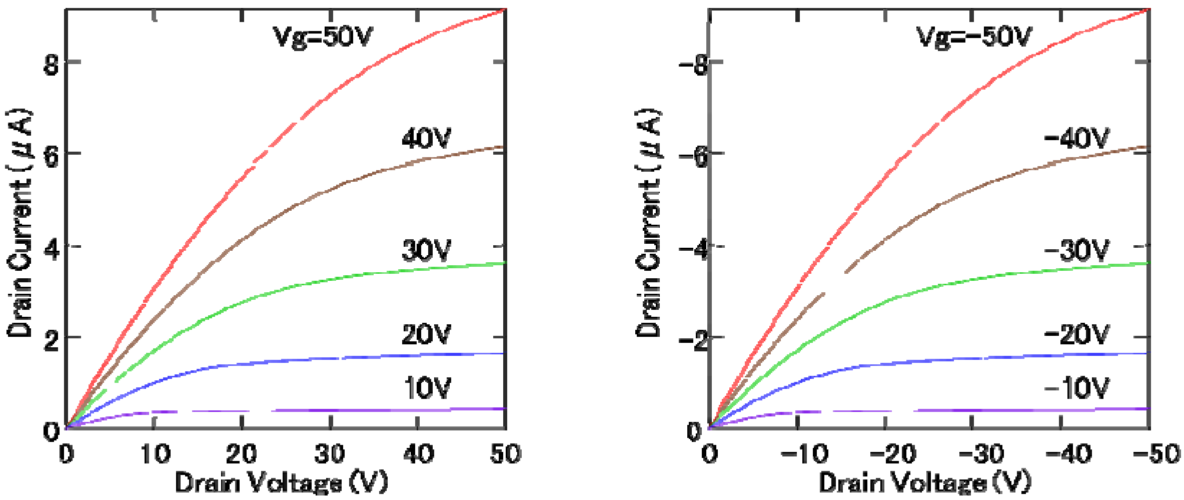

Fig. 2: Id-Vd characteristics of n-channel (left) and p-channel (right) top contact OTFT, calculated using TOTAS with the gate voltage as parameter. Almost the same superior characteristics are obtained, which indicates that this structure makes possible quite reproducible device performances. L=5 μm, Tox=300 nm, Ts=50 nm, p=10^{15} cm^{-3}, Tp^+=5 nm, n^+,p^+=10^{20} cm^{-3}

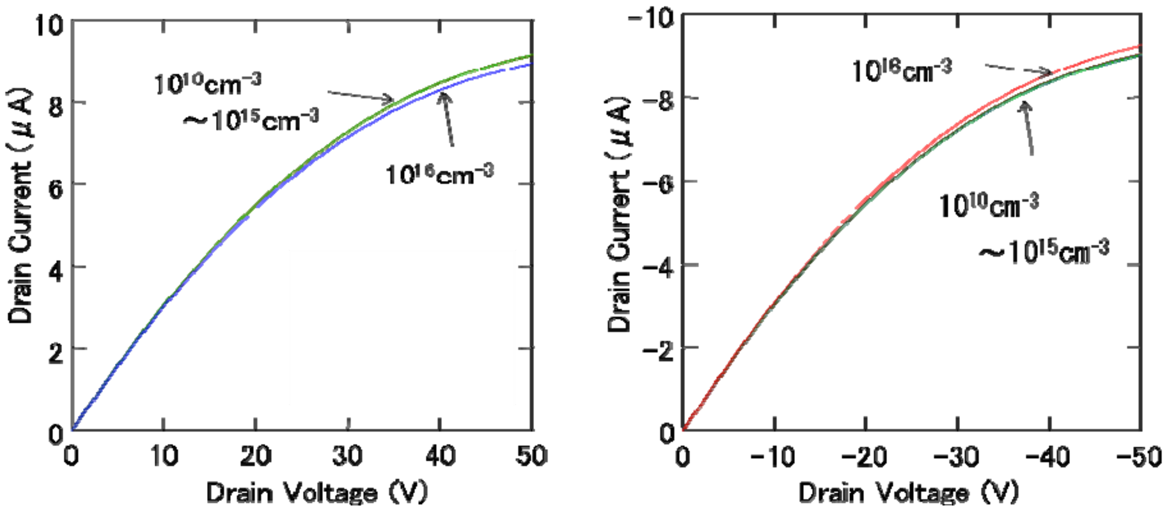

Fig. 3: Id-Vd characteristics of n-channel (left) and p-channel (right) top contact OTFT, calculated using TOTAS with the carrier concentration of semiconductor layer (p) as parameter. Almost the same characteristics are obtained, which indicates that this structure also makes possible quite reproducible device performances. It is also notable that carrier recombination (n-channel) and leakage current (p-channel) become apparent at more than 10^{16} cm^{-3} carrier concentration. L=5 μm, Tox=300 nm, Ts=50 nm, p=10^{12} cm^{-3}-10^{16} cm^{-3}, Tp^+=5 nm, n^+,p^+=10^{20} cm^{-3}, Vg=±50 V