Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp523-524

# Numerical Simulation of Contact Resistance in Organic Field-Effect Transistors

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## 1. Introduction

Organic field-effect transistors (OFETs) have attracted great interest as a key technology to realize low-cost, flexible and large-area electronics, and the active-matrix organic light-emitting diode displays have already been demonstrated using an OFET backplane. Despite the early success, probrems still exist, which may limit the future widespread use of OFETs. In particular, it is well known that OFETs generally have relatively high source-drain contact resistance, which leads to the decrease in output current and in operating speed and to the increase in device-to-device variation.

To investigate charge injection processes from electrode contacts into organic semiconductors, a number of experimental [1-5] and theoretical studies [6-9] have been done, and the two dimensional device modeling for OFETs has been used to investigate the influence of injection barrier at the electrode contacts [6-8]. Ruden *et al.* have found that the work function difference between electrode and organic semiconductor causes a significant voltage drop at the contact in bottom-contact OFETs [7]. Hill has reported that top-contact devices have a contact resistance of two orders of magnitude lower than bottom-contact devices and has showed the larger gate-voltage dependence of contact resistance [8]. However, the high contact resistance and its gate-voltage dependence have generally been observed in OFETs with low energy barriers [1,4,5] and thus more detailed OFET modeling is still needed to study the origin of contact resistance.

In this study, we investigate the influence of localized states and structural disorder at the electrode contacts inherent in OFET devices on contact resistance in top-contact and bottom-contact OFETs by two dimensional device simulation.

## 2. Numerical simulation

The device structures used in the simulation are shown in Fig. 1. The representative hole transporting material of pentacene was assumed as the organic semiconductor and the physical quantities appropriate for pentacene were used (*e.g.* the hole mobility of 0.1 $cm^2/Vs$ and the ionization potential of 4.9 eV). For the gate dielectric and the source-drain electrode metal, conventional $SiO_2$ layer (300 nm in thickness) and Au (4.9 eV) were assumed, respectively. The numerical simulation of OFET characteristics

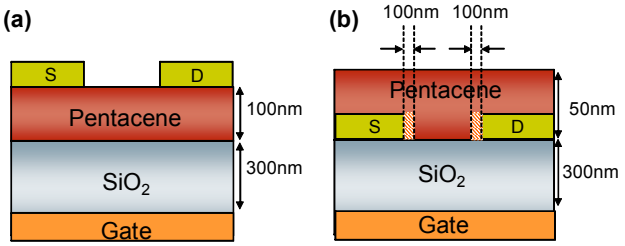


Fig. 1 Device structures of (a) top-contact and (b) bottom-contact OFETs used in numerical simulation.

were performed using a two dimensional device simulator of ATLAS (Silvaco. Co. Ltd.). For the localized states, we used the following exponential localized distribution which has often been found in organic semiconductors

$$N(E) = N_0 \exp\left(-\frac{E - E_v}{k_B T_0}\right), \qquad (1)$$

where $N_0$ is the density of localized states at the valence band edge $E_v$, $k_B$ is the Boltzmann constant, and $T_0$ is the characteristic temperature. In bottom contact devices, the disorder regions (100 nm in width) were also assumed at interfaces between electrode and semiconductor. The contact resistance was determined with the conventional transfer line method by extrapolating the total resistance obtained in OFETs with different channel lengths $L$ to $L$=0.

## 3. Results and discussion

Figure 2 shows the simulated gate-voltage dependence of contact resistance in top-contact OFETs with and without an exponential localized-state distribution having $T_0$=500 K. It can be seen that the contact resistance in the OFET without localized states is almost independent of the gate voltage, whereas the contact resistance and its gate-voltage dependence increases with density of localized states. Such large voltage dependence is consistent with the experimental results obtained from top-contact pentacene FETs with Au source-drain electrodes [4]. The observed increase in contact resistance results from charge trapping into localized states at semiconductor bulk between electrode and dielectric. The gate-voltage dependence is caused by the filling of localized states by injected charges, which leads to the increase in charge mobility to the longitudinal direction and the decrease in contact resistance at higher

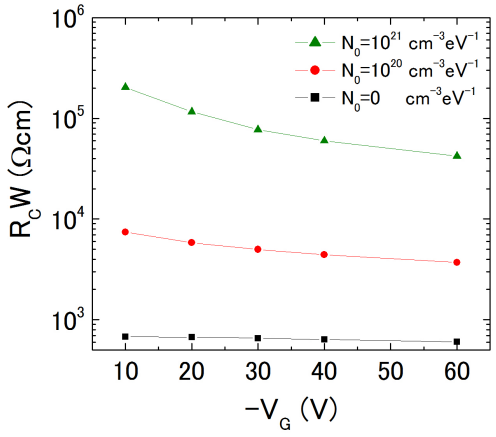


Fig. 2 Simulated gate-voltage dependence of contact resistance in top-contact OFETs with and without an exponential localized-state distribution having $T_0$=500 K.

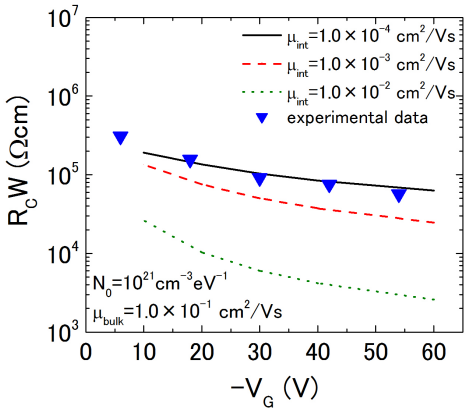


Fig. 3 Simulated gate-voltage dependence of contact resistance in bottom-contact OFETs in the presence of low mobility regions at electrode/semiconductor interfaces. The experimental data is obtained from Ref. 5.

gate voltages, as observed in Fig. 2. We also examined the influence of energy barrier height at the electrode contacts in top-contact OFETs without localized states, as reported in the literature [8] (not shown). The obtained contact resistance shows similar behavior to the previous report, but its gate-voltage dependence is much weaker than that from OFETs with localized states. These results clearly indicate that charge trapping into localized states in the semiconductor bulk is one of possible origins in contact resistance in top-contact OFETs.

In contrast to top-contact devices, the contact resistance in bottom-contact devices is not influenced by localized states in the semiconductor bulk. In the fabrication of bottom-contact OFETs, strucural disorder in organic seimconductor layers around the source-drain electrodes would be increased because of the large diffenece in surface energy and height between electrode and gate dielectric. In the surface potential measurements of bottom-contact OFETs fabricated using pentacene [2] and poly(3-hexylthiophene) [3] with Au electrodes, relativly large potential drops have been observed at the interfaces with both source and drain electrodes, suggesting the presence of large structural disoder in semiconductor at the interface with electrodes in bottom-contact OFETs. The simularted gate-voltage dependences of contact resistance in bottom-contact OFETs with disorder regions at the contacts are shown in Fig. 3. In the disorder regions, hole mobilty of three orders of magnitude lower than the bulk mobility was assumed. We see that the contact resistance significanlty increases and shows gate-voltage dependence, which is very similar to the experimental result reported in the bottom-contact pentacene FET with Au electrodes [5]. It is also found that the reported gate-voltage dependent surface potential distributions can be reproduced by considering disorder regions.

## 4. Conclusions

We have carried out the two dimensional simulation of top-contact and bottom-contact OFETs in the presence of localized states and disorder regions in order to investigate the origin of contact resistance. It is found that the contact resistance in top-contact OFETs increases and shows strong gate-voltage dependence with increasing localized-state density in organic semiconductor layers. We show that contact resistance in the bottom-contact OFETs can be explained by considering structural disorder in the vicinity of source and drain electrodes. These results clearly indicate that disorder in organic semiconductors and in OFET device geometries cause contact resistance in OFETs.


## Acknowledgements

This work was supported by the Semiconductor Technology Academic Research Center (STARC) and by a Grant-in-Aid for Scientific Research (B) from the Japan Society of the Promotion of Science.


## References


[1] P. V. Necliudov, M. S. Shur, D. J. Gundlach, and T. N. Jackson, Solid-State Electron. **47** (2003) 259.

[2] K. P. Puntambekar, P.V. Pesavento, and C. D. Frisbie, Appl. Phys. Lett. 83 (2003) 5589.

[3] L. Bürgi, T. J. Richards, R. H. Friend, and H. Sirringhaus, J. Appl. Phys. 94 (2003) 6129.

[4] S. D. Wang, T. Minari, T. Miyadera, K. Tsukagoshi, and Y. Aoyagi, Appl. Phys. Lett. **91** (2007) 203508.

[5] K. S. Lee, T. J. Smith, K. C. Dickey, J. E. Yoo, K. J. Stevenson, and Y. –L. Loo, Adv. Funct. Mater. **16** (2006) 2409.

[6] T. Li, J. W. Balk, P. P. Ruden, I. H. Campbell, and D. L. Smith, J. Appl. Phys. **91** (2002) 4312.

[7] T. Li, P. P. Ruden, I. H. Campbell, and D. L. Smith, J. Appl. Phys. **93** (2003) 4017.

[8] I. G. Hill, Appl. Phys. Lett. **87** (2005) 163305.

[9] M. Koehler, I. Biaggio, and M. G. E. da Luz1, Phys. Rev. B **78**, (2008) 153312.