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Field-assisted Electron Injection Current in Submicron Pentacene Transistors

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I. Introduction

Many organic semiconductors show p-type characteristics, and the existing n-type organic semiconductors show lower mobilities than that of p-type materials. The demonstration of electron transport is important for the realization of low power, high speed, complementary organic field effect transistors (OFET) structures. The difficulties associated with electron transport in organic semiconductors are due to high electron trap densities, short electron lifetimes, and high injection barriers. Recently, electron transports were observed in various cases, such as Ca doped pentacene, tetracene OFET, and narrow gap organic semiconductor.

II. Experimental Results

We studied electron transport in submicron pentacene OFETs prepared on Si/SiO_2 substrates, where submicron geometry is employed to enhance the field strength at charge injector. Submicron spacing between drain and source was realized by evaporating Au at a 65 degree angle with a step etched into the oxide. Part of the 450 nm-thick oxide was etched off in buffered oxide etchant to achieve a 80 nm or 250 nm tall oxide step. The asymmetric structure of our devices yields different electric field strengths at the contacts. After the tilted Au deposition, pentacene was deposited at $50^{O}C$ substrate temperature. Prior to pentacene deposition, the wafer was primed with octadecyltrichlorosilane (OTS) vapor. Conventional pentacene OFET structures of 15 μm channel length fabricated on 450 nm thick flat oxide by our procedure showed about 0.1 cm^2/Vs mobility, at –80 V gate voltage.

A schematic diagram of device structure is shown in Fig. 1, where the contacts in transistor are denoted as U (upper contact), L (lower contact), and G (gate). SEM (scanning electron microscope) picture of the device with 250 nm-high oxide step showed that 0.8 μm channel length was realized. Figure 1 also shows time dependence of drain current. The gate voltage changes between 0, –20 V, and +20 V. In the figure two kinds of current changes are observed. One is the fast current change (~30 sec) after every gate voltage change, and the other is the slow background change which changes from –3 μA to –10.5 μA over 5 min of time.

The time dependence of current suggests that the two changes have different origins. The fast current change of 30 sec is due to the hole trap fillings. Since free holes have higher energy than trapped holes, free hole density will decrease as the system stabilizes. We explain that the slow increase of current is related to higher carrier density due to electron trap filling.

Figures 2 and 3 show the effect of oxygen doping, providing evidence for electron injection. The solid line in Fig. 2 represents characteristics obtained the day the pentacene is exposed to air, whereas the dashed line is obtained on the same device after 7 days in air. Both curves were measured with upper contact at zero voltage. Oxygen doping will shift the Fermi level of pentacene to lower energy, inhibiting electron injection from Au contacts. Thus, with the OFET operating in electron injection mode, we expect a decrease in drain current. In Fig. 2, current decreased from 8 μA to 0.4 μA after 7 days of air exposure.

Figure 3 shows currents measured in devices with different step heights. Gate voltage is 0 V in both figures. The data were taken after 7 days in air. The stronger field at the hole injecting contact (L) of the solid line is the reason of larger current at positive voltages. At negative voltage side, the solid line shows much smaller current (0.4 μA), even though the electric field at L is stronger than that of the dashed line. At negative side, the smaller current of the solid line indicates that L can not inject electrons easily, because oxygen doping made the injection and transport difficult for electrons.

In Fig. 3b, the oxide step is 80 nm high, and the device shows more symmetric currents. The solid and dashed lines show similar currents, because electric fields at the contacts are almost the same in any configuration. This demonstrates that the large difference between positive and negative currents in Fig. 3a is from the different electric field strength at the contacts.

III. Conclusions

We presented experimental results of electron currents in submicron pentacene OFETs. Time dependence and oxygen doping dependence support that electron injection is realized in our devices. Our results were explained by using a new model employing electron and hole traps.

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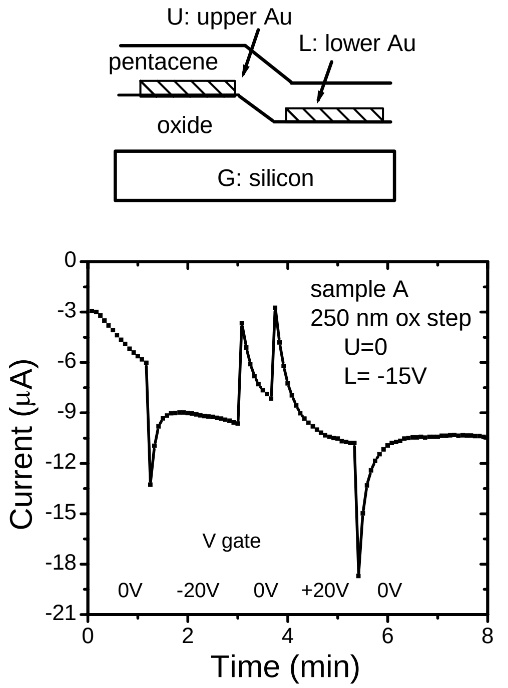

Fig. 1. Schematic diagram of the device structure, and time dependence of drain current (channel width 500 μm). The contacts are denoted as U (upper contact), L (lower contact), and G (gate). Current was measured with G = 0 V, U = 0 V, and L = -15 V.

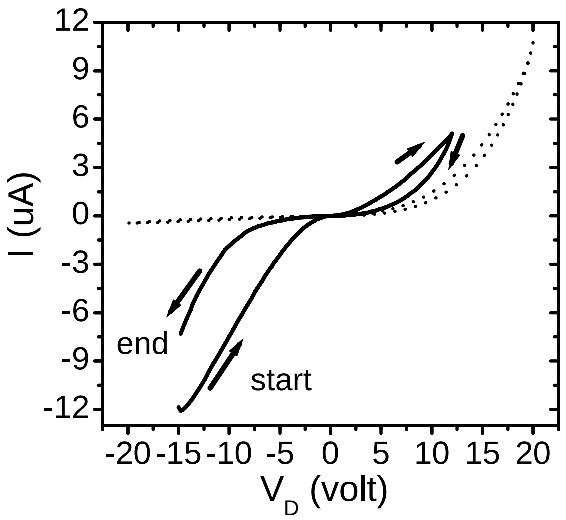

Fig. 2. Currents measured before (solid line) and after (dashed line) 7 days of air exposure. The voltage at L changes, while U is kept at 0 V. Air exposure decreased currents on negative side, because electron current is blocked by oxygen doping.

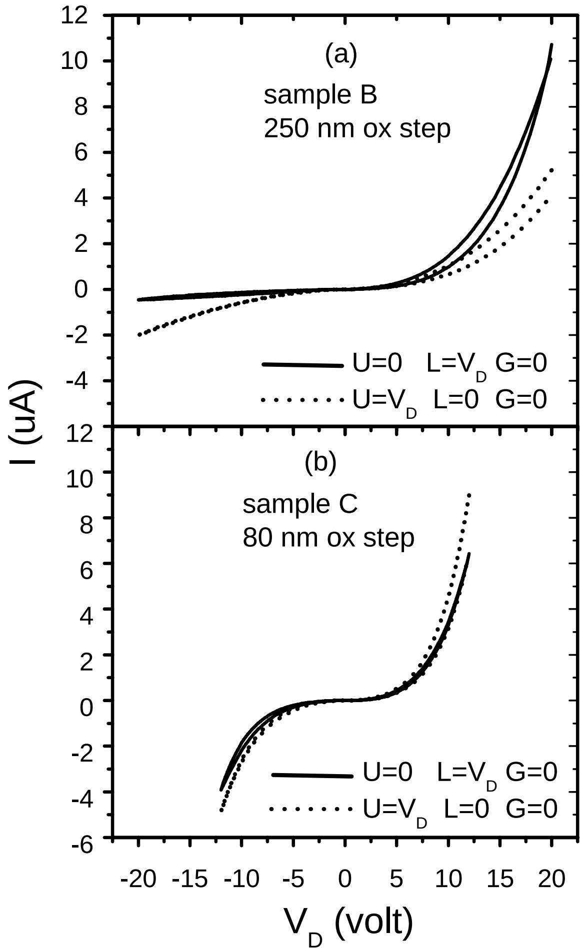

Fig. 3. Effect of oxide height on drain currents. Currents were measured after 7 days of air exposure. Voltage at U is zero in solid lines, and voltage at L is zero in dashed lines. (a) When the oxide step is high (250 nm), electric field strength at L is much stronger than the field at U. On negative voltage side, electron injection at L is blocked. (b) When the oxide step is small (80 nm), electric fields at L and U are almost same, and current shows symmetric behavior.