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Characterization of hydrogen treated Pentacene OTFT

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1. Introduction

Organic semiconductors have been provided as an alternative to traditional inorganic materials for circuitry in plastic-based devices such as smart cards and package tags because of their potential for lower processing costs and compatibility with low temperature processing [1]. Extensive research has been carried out to identify new materials with promising properties, high charge carrier mobility and high current modulation (on/off ratio).

Among all candidate materials for OTFT, pentacene exhibited the most excellent properties. By the vacuum-evaporation technique, mobility as high as 0.62 cm^2/Vs was reported [2]. This has been attributed to a highly ordered morphology, close to that of a single crystal. Normally, growing a single crystal organic film from vapor phase, a stream of inert or reducing gas is used [3]. Hydrogen gas is one of the most used carrier gases.

In this study, we tried to evaluate the effect of hydrogen post-annealing on device performance and the influence of hydrogen plasma treatment will also be considered.

2. Method

An OTFT device was fabricated from a heavily doped silicon wafer, which was used as the substrate and gate electrode. After thermal oxidization, a 100 nm thick layer of SiO_2 was grown on this substrate to serve as the gate dielectric. On top of this surface, gold source and drain electrodes were defined with a shadow mask. HMDS was coated following the deposition of the gold electrodes. Then the pentacene active layer of 40 nm was thermally deposited at a deposition rate of 0.1-0.2 Å/s under a base pressure of 3.0×10^{-6}Torr from commercially available pentacene powder. Some devices were annealed in hydrogen ambient at substrate temperature of 100°C and process pressure of 500mTorr. Others were treated with hydrogen plasma under the same condition in addition to plasma power of 100 W.

The I-V measurements were performed with a HP4156A parameter analyzer at room temperature. The gate bias (Vg) for hole accumulation in the pentacene channel layers was carried out by applying negative bias to heavily doped silicon. The source was grounded and the drain was negatively biased. The AFM images were collected with a DI 5000 atomic force microscope.

3. Results

Figure 1 shows the typical drain current–voltage curves of various gate voltages for pentacene OTFT. Mobility of this device was calculated as 3.45×10^{-5} cm^2/Vs from the equation,

$$Id,sat = (W/2L)\ \mu\ Ci\ (Vg-Vth)^2 \qquad (1)$$

where μ is the field-effect mobility, W the channel width, L the channel length, Ci the capacitance per unit area of the insulator layer and Vth the threshold voltage. For the devices reported in this work these parameters had values of Ci = 1.2×10^{-8} F/cm^2, W = 1 cm, and L = 25 μm. Although the mobility is quite low as compared with other work, it is believed the purity of purchased pentacene plays a dominant role. For the same process condition, mobility as high as 0.02 has been obtained in our earlier study.

Nevertheless, after hydrogen ambient annealing, the saturation current can be improved significantly. Figure 2 shows the relationship between the carrier mobility and different hydrogen treatments for various OTFT devices fabricated at diverse deposition temperature. The increased mobility for the hydrogen-annealed sample is due to a minimization of deep trapping states, electrically active defects in organic materials and impurity levels. However, the hydrogen plasma treated sample, which was expected to have a positive ion doping effect for p-channel device, did not reveal the increased carrier mobility. This is attributed to the hydrogen radicals that, produced from plasma, react with the pentacene molecules and transform some unsaturated bonds to saturated ones, thus destroying the aromatic characteristic relating to carrier mobility.

Figure 2 also indicates that as deposition temperature is raised, the mobility will also increase, no matter with or without hydrogen treatment. This phenomenon is related to the grain size, growing larger with increased deposition temperature, as the AFM images in Figure 3 show. In addition, the AFM images in Figure 3(d) show that the grain size has nothing to do with the hydrogen treatment.

With the aid of hydrogen treatment, the trap sites around the grain boundary or the surface of organic film can be eliminated. As a consequence, the leakage paths around the grain boundary are reduced. This lowers the off state current, so a better on/off dynamic ratio can be obtained. Figure 4 shows the drain current in logarithmic

scale for devices treated with and without hydrogen treatments. The on/off ratio of the sample without treatments is barely 10^2. After the hydrogen treatment, the on/off ratio can be increased to 10^7 and 10^6 for the sample annealed in H_2 and the one treated with hydrogen plasma respectively. Figure 5 suggests that among various treatments, the hydrogen plasma treated sample exhibits the best current modulation ability. In spite the inability of offering higher carrier mobility, plasma treatment can efficiently suppress the leakage current, which results in the highest dynamic ratio.

4. Conclusions

We have demonstrated the hydrogen-annealed pentacene organic TFT with better mobility and higher on/off ratio. Meanwhile, hydrogen plasma treatment can also lower the leakage current, but at the cost of that active hydrogen radical partially destroying the delocalizing ability of charge carriers, hence lightly reducing the charge mobility. Nevertheless, hydrogen treatment is still an efficient way to improve device performance.

References

[1] A. Dodabalapur, Z. Bao, A. Makhija, J. G. Laquindanum, V. R. Raju, Y. Feng, H. E. Katz and J. Rogers, Appl. Phys. Lett. **73**, 142 (1998).

[2] J. H. Schon and C. Kloc, Appl. Phys. Lett. **79**, 4043 (2001).

[3] H. Sirringhaus, N. Tessler and R. H. Friend, Science **280**, 1741 (1998).

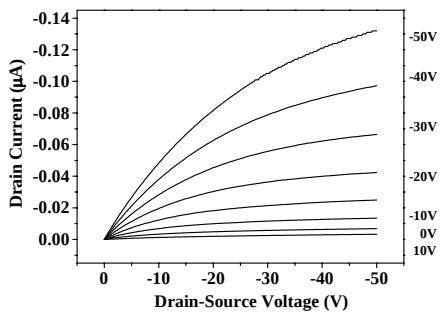

Fig. 1 Drain current (Id) versus drain-source voltage (Vds) for various gate voltage (Vg), for a pentacene thin film transistor.

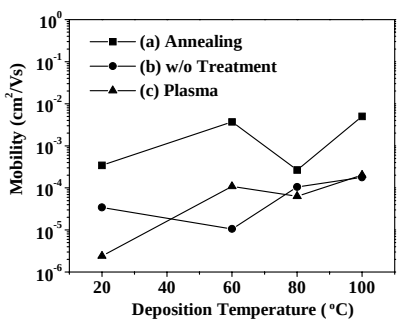

Fig. 2 Plots of mobility versus diverse deposition temperature under various treatments: (a) with hydrogen annealing for 10mins, (b) without any treatment and (c) with hydrogen plasma treatment. for 10mins.

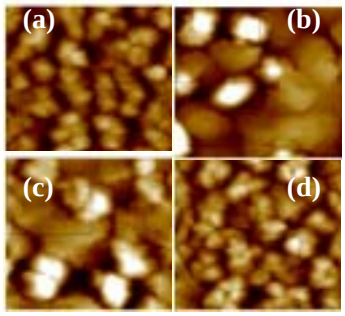

Fig. 3 Atomic force microscope images of diverse deposition temperature: (a) Tsub = 25°C, (b) Tsub = 60°C, (c) Tsub = 80°C and (d) Tsub = 25°C with hydrogen plasma treatment

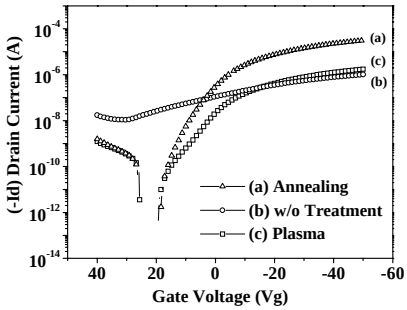

Fig. 4 Drain current versus gate voltage of different treated devices: (a) with hydrogen annealing for 10mins, (b) without any treatment and (c) with hydrogen plasma treatment for 10mins.

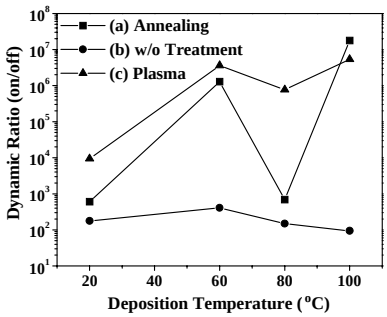

Fig. 5 Dynamic ratio versus various deposition temperatures of different treated devices: (a) with hydrogen annealing for 10mins, (b) without any treatment and (c) with hydrogen plasma treatment for 10mins.