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Effects of Moisture on Pentacene Thin-Film Transistors with Polyvinylpyrrolidone Gate Insulator

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We report the effects of ambient moisture on the electrical characteristics of pentacene-based thin-film transistors (TFTs) with polyvinylpyrrolidone (PVPy) as a gate insulator. For the condition of relative humidity below 40%, pentacene TFT exhibited a stable operation without a shift in the threshold voltage upon a gate voltage sweep direction. However, the degradation in field-effect mobility and subthreshold slope critically occurred with increasing the relative humidity. Furthermore, the threshold voltage shifted toward the positive direction upon a gate voltage sweep direction. These characteristic degradations under the influence of moisture can be explained by charge-trapping of absorbed polar H2O molecules at the pentacene/PVPy interface.

1. Introduction

Intensive interest in organic thin-film transistors (OTFTs) owing to their simple and low-temperature processability has expedited efforts to develop commercial applications for OTFTs in electronic devices, such as driving elements for flexible displays, RFID tags, and large-area sensors [1-3]. However, in spite of remarkable progress in device performances, OTFTs still suffer from the characteristic degradation by moisture and oxygen in air [4]. In particular, gate insulators play an important role in the operational stability of OTFTs. On this account, the electrical and environmental stability issues in OTFTs are required to be interpreted by the nature of gate insulating materials.

Polyvinylpyrrolidone (PVPy) is a unique polymer which provides a remarkable properties such as good initial tack, transparency, chemical and biological inertness, very low toxicity as well as cross-linkable flexibility [5]. Therefore we believe that PVPy is suitable for gate insulator in OTFTs. However, there are few reports on the characteristics of PVPy and its applications to organic electronic devices. In this work, we have utilized PVPy as a new gate insulator for OTFTs and investigated the electrical characteristics of OTFTs with varying the relative humidity. These results are discussed.

2. Experimental

Pentacene-based organic TFTs with the PVPy insulator were fabricated. For the deposition of PVPy, PVPy (4 wt% in ethanol) was spin-coated and baked at 100°C for 40 min in a vacuum dry oven followed by procuring at 60°C for 20 min. Its thickness was about 3500 Å confirmed by α-step profilemeter. After completion of the curing processes, a 600-Å-thick pentacene layer was thermally evaporated and top-contact/bottom-gate OTFTs were constructed by depositing 50-nm-thick Au source/drain electrodes, where the channel length (L) and width (W) were 90 μm and 300 μm, respectively.

3. Result and Discussion

Fig. 1 shows the transfer curve measured at the drain-source voltage of –30 V under the relative humidity below 40%. The calculated field-effect mobility and the extracted threshold voltage were 0.23 cm^2/Vs and −12.7 V, respectively. And the on/off current ratio was observed to be about 5×10^4 with a subthreshold slope of 3.2 V/decade from the inset. Of particular interest is its stable operation without a shift in the threshold voltage upon a gate voltage sweep direction. Indeed, the threshold voltage shift in this device was less than 0.1 V.

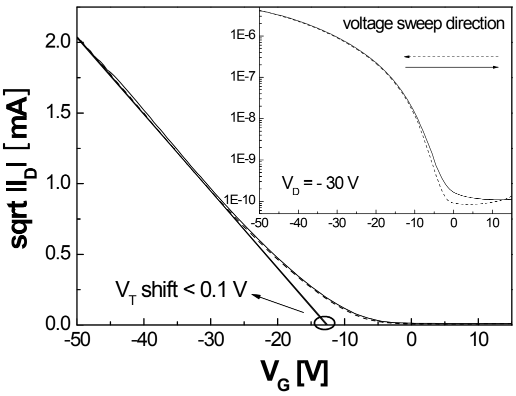


Fig. 1. Transfer curve of OTFT with PVPy. The inset shows $Log_{10}|I_D|$ versus V_G plot.

In order to investigate the effects of ambient moisture on the electrical stability of devices, typical transistor characteristics were measured with varying the relative humidity. Comparing the initial characteristics immediately obtained after device fabrication with those re-measured after 30 min under different relative humidity, it was found that the device performance rapidly degraded following exposure to ambient moisture. Fig. 2 shows that the degradation in field-effect mobility and subthreshold slope critically occurred with increasing the relative humidity. And also, it was observed that the threshold voltage pronouncedly shifted toward the positive direction upon a gate voltage sweep direction for the device exposed to the relative humidity of about 50 %, as shown in Fig. 3. From the threshold voltage shift of about 6 V, the trapped charge density at the pentacene/PVPy interface was calculated to be about 3.5×10^{11} cm^{-2}.

From the results so far achieved, it is possible that the significant degradation in the device performance might be attributed to moisture penetrated into the pentacene/PVPy interface because the polar H_2O molecules can result in trapping charges, thereby generating residual charges at the interface.

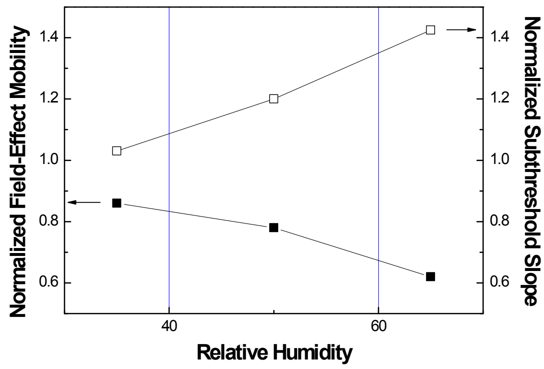


Fig. 2. Normalized characteristics of OTFTs with PVPy according to the relative humidity.

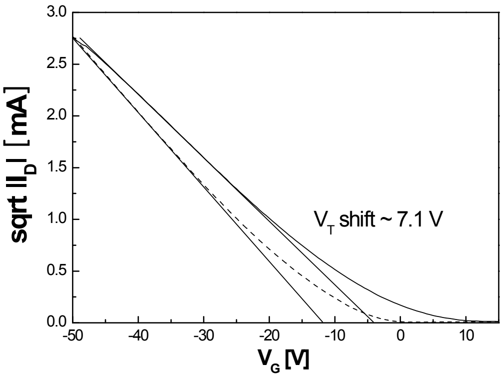
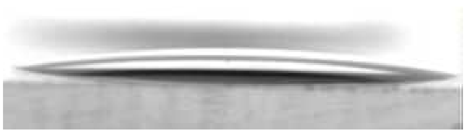
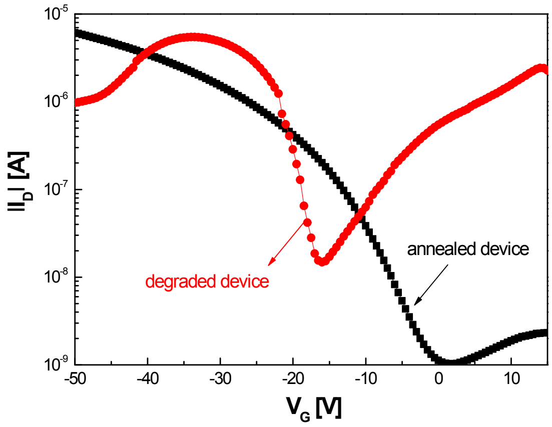


Fig. 3. Transfer curve obtained under the relative humidity of about 50%.

Fig. 4 (a) shows the microscopic image of water droplet on the PVPy layer. Surprisingly, it is observed that the PVPy film absorbed water. As a result, it can be stated that the above-mentioned characteristic degradations under the influence of moisture were attributed to the polar H_2O molecules adsorbed at the interface and even penetrated into the PVPy layer. In order to eliminate the penetrated H_2O molecules, the degraded device was annealed at 60°C for 1 h under a base pressure of 2×10^{-3} Torr. It is found that the characteristic degradations of OTFTs with PVPy can be recovered by the simple thermal annealing, as shown in Fig. 4 (b). However, the effects of moisture and thermal annealing on the pentacene film are not yet elucidated. Further investigations are required.



(a)



(b)

Fig. 4. (a) Microscopic image of water-drop on the PVPy film and (b) transfer curves of the degraded device according to the thermal annealing at 60°C.

4. Conclusion

In this paper, we have investigated the effects of ambient moisture on the electrical characteristics of OTFT with the PVPy gate insulator. The fabricated OTFTs with PVPy exhibited a significant degradation in device performance with increasing the relative humidity, which could be explained by the polar H_2O molecules penetrated into the pentacene/PVPy interface and/or even into the PVPy layer. It is thought that the water absorbent nature of PVPy facilitated the characteristic degradations in OTFTs. And we have shown that these degradations are reversible by undergoing thermal treatment at 60°C.

Acknowledgement

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