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Performance Recovery of n-channel Perfluoropentacene Thin Film Transistors by High Vacuum Annealing

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1. Introduction

Both n and p-channel operation of pentacene TFTs have been recently reported [1] and an importance of the appropriate source(S)/drain(D) material selection for both channels has been pointed out [2]. This paper discusses an annealing effect in high vacuum condition with and without a temperature increase, on the samples with the air exposure in order to evaluate the oxygen effect on the performance degradation. We investigated perfluoropentace ($C_{22}F_{14}$) (PF-pentacene) for n-channel TFT material.

2. Experimental

Fig. 1 shows a schematic cross section of the fabricated PF-pentacene TFT. 50nm thick PF-pentacene film was deposited at 25 ºC on 30nm-thick SiO_2 thermally grown on p-Si substrate. The base pressure was 4×10^{-5} Pa and the deposition rate was 0.05nm/sec. The sample was once taken out to the air, and then moved to another vacuum chamber for evaporating Au electrodes on the PF-pentacene film. The cannel length and width were 100μn and 1000μm, respectively.

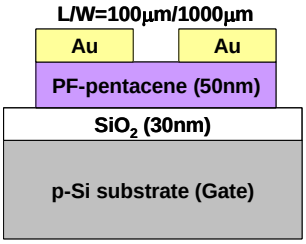


Fig.1 Schematic cross section of PF-pentacene TFT with top source and drain.

For the electrical measurement, the device was moved to another vacuum chamber equipped with electrical measurement. First, current-voltage (Id-Vg) characteristics were measured in the air. Second, after leaving the sample for 24 hours at the pressure of 1×10^{-5}Pa, the pure oxygen was injected by using the mass flow controller to a certain pressure. Id-Vg characteristics were measured at 10Pa, 1×10^{-2}Pa, 1×10^{-3}Pa, 1×10^{-4}Pa and 1×10^{-5}Pa after the pressure was stabilized for about 1 minute. Furthermore, the substrate was annealed at 50 ºC at the pressure of 1×10^{-5}Pa. The annealing temperature was kept for 10 minutes. After the substrate temperature was lowered to the room temperature, Id-Vg characteristics were measured again for investigating the effect of the thermal annealing. We also used X-ray diffraction (XRD) and scanning electron microscope (SEM) to investigate the crystal structure change by the thermal annealing.

3. Results and Discussion

Fig. 2(a) and (b) show the electrical characteristics change by the oxygen introduction and by the thermal annealing. As shown in Fig. 2(a), the threshold voltage are gradually shifted to a lower voltage as the pressure is lowered. In addition, by the thermal annealing of the film under the high vacuum condition, the threshold voltage is lowered to 8V as shown in Fig. 2(b). The results are considered to be due to the fact that the adsorbed oxygen causes the threshold voltage shift. It is interesting that the threshold voltage is not lowered below 13V even at the lowest pressure without the thermal annealing. This result indicates some oxygen cannot be removed from PF-pentacene film in the high vacuum condition. The thermal annealing can remove the oxygen deeper inside the film.

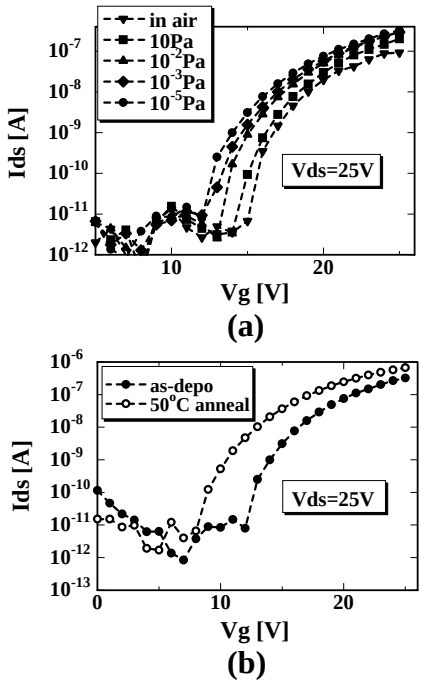


Fig.2 (a) Electrical characteristics change of PF-pentacene TFTs with changing the ambient pressure. The threshold voltage shift was saturated around Vg=13V at the lowest pressure. (b) Electrical characteristics change of PF-pentacene TFTs by the thermal annealing in the high vacuum condition. Threshold voltage is further lowered down to 8V.

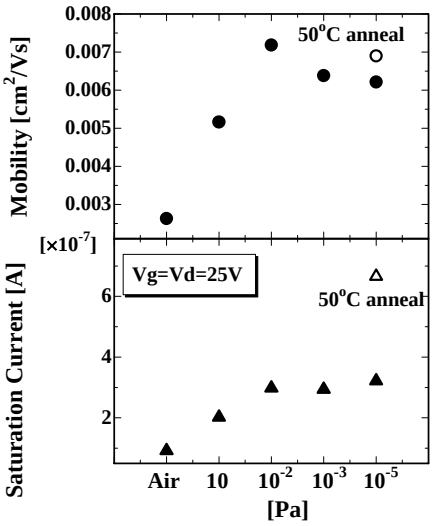


Fig. 3 Mobility (upper) and saturation current (lower) as a function of annealing pressure, together with thermally annealed sample's results. The mobility is not significantly changed by the thermal annealing. On the other hand, saturation current is dramatically increased.

Mobility and saturation current as a function of annealing pressure are shown in **Fig. 3**. It is clearly shown that when the pressure is lowered to 10^{-2} Pa, the mobility significantly increases, while in case of pressure below 10^{-2} Pa, it is saturated. On the other hand, the thermal annealing in the high vacuum condition significantly increases the saturation current, while the mobility is not much improved. Thus we think that the current degradation is mainly due to the threshold voltage shift in the oxygen. This fact suggests that the air exposure brings about the negative charging in the PF-pentacene film which shifts the threshold voltage to a higher voltage.

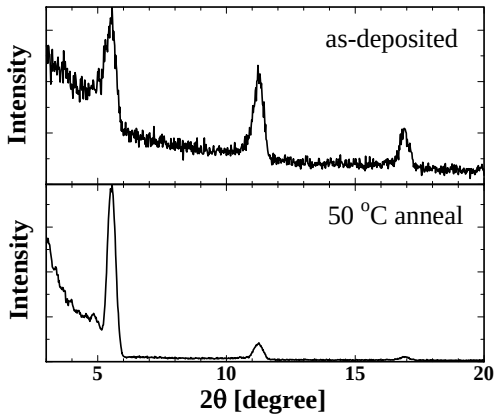
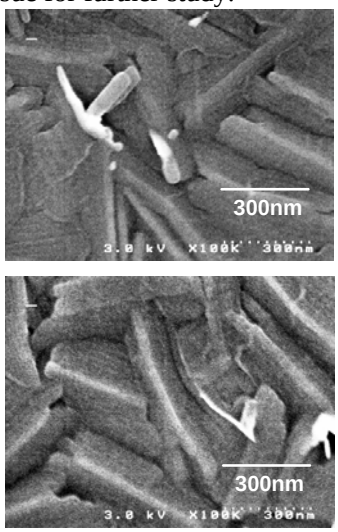


Fig. 4 X-ray diffraction patterns of as-deposited sample (upper) and annealed sample (lower). Thermal annealing clearly improves PF-pentacene crystalinity.

Finally we discuss the annealing effect on PF-pentacene from the view point of the crystal structure. **Fig. 4** and **Fig. 5** show XRD patterns and SEM images of as-deposited and 50°C thermally annealed sample. The XRD patterns show the high vacuum thermal annealing makes PF-pentacene film to be well crystallized. From SEM images, it is confirmed that the grain density of PF-pentacene becomes higher by the thermal annealing. P-channel pentacene results have shown that high mobility TFT can be realized by a well crystallized structure [3]. However, our results shows high vacuum annealing recovers only the threshold voltage to the lower value and the mobility is not so improved despite the improvement of crystal structure. This is likely because the negatively charging-up of the PF-pentacene film is a dominant effect of air exposure on the performance of PF-pentacene as mentioned previously. Therefore, if the negative charging can be relaxed by changing annealing temperature or annealing time or by using different metal for the source, the mobility might increase dramatically. This will be an issue for further study.



as-deposited sample

50 °C annealed sample

Fig. 5 SEM images of as-deposited sample (upper) and thermally annealed sample (lower). The grain density of as-deposited sample is much lower than that of thermally annealed sample.

5. Conclusion

We have investigated the annealing effects on the performance in n-channel PF-pentacene TFT with the air exposure after depositing the film. Thermal annealing in the high vacuum can dramatically recover the threshold voltage to the lower value and the mobility is not so improved. This fact suggests that the air exposure dominantly brings about the negative charging in the PF-pentacene film.

Acknowledgement

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References

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