

## H-8-5

# Mobility Improvement of Pentacene Thin Film Transistors by Introduction of H<sub>2</sub> during Evaporation

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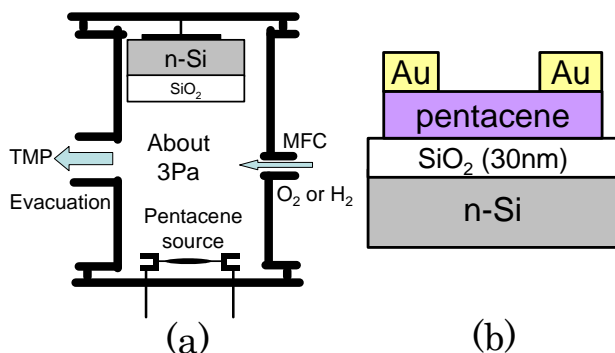
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## 1. Introduction

It is strongly required for pentacene thin film transistors (TFTs) to understand the mobility determination mechanism for its further improvement. One of strategies to improve mobility of polycrystalline pentacene TFTs is to enlarge grain size by elevating the substrate temperature during the vacuum evaporation of pentacene. Recently we have reported a further increase of grain size by evaporation at a relatively higher pressure in N<sub>2</sub> and achieved a better repeatability of the mobility value <sup>[1]</sup> compared to that of vacuum evaporated films thanks to the suppression of cracks observed in vacuum evaporated pentacene films <sup>[2]</sup>. This paper reports a mobility improvement by introducing H<sub>2</sub> during pentacene evaporation.

## 2. Experimental

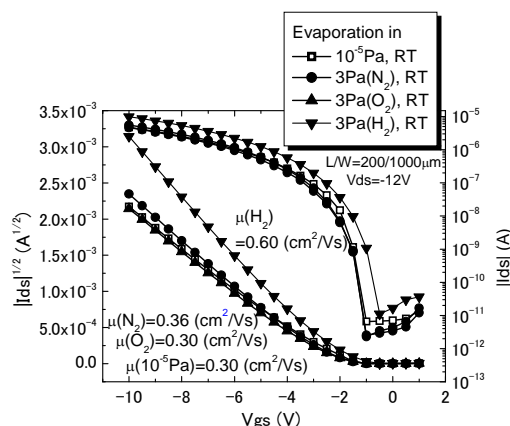
**Figure 1 (a)** shows a schematic diagram of the evaporation system. The chamber was once evacuated to 10<sup>-5</sup> Pa and the pressure was controlled to be about 3 Pa by introducing O<sub>2</sub> or H<sub>2</sub> with the mass flow controller. About 30 nm-thick pentacene film was fabricated on 30 nm-thick SiO<sub>2</sub> thermally grown on n-Si substrate. The substrate temperature was kept at room temperature and the deposition rate was 0.05 nm/s. Finally, source and drain electrodes were deposited on the film by the vacuum evaporation as shown in **Fig. 1 (b)**. The channel length and width were 200 μm and 1000 μm, respectively. For comparison, the pentacene film was also deposited in vacuum. Then, the samples were once opened to the air and moved to the vacuum probe for electrical measurements. All electrical measurements were conducted in dark condition.



**Fig. 1 (a)** Schematic diagram of pentacene evaporation system. **(b)** Schematic cross section of fabricated pentacene TFTs. Top-contact type was employed.

## 3. Results and Discussion

**Figure 2** shows current-voltage (*I*<sub>ds</sub>-*V*<sub>gs</sub>) characteristics of fabricated pentacene TFTs, together with our previous result of the film deposited in N<sub>2</sub>. It is shown that the mobility of pentacene TFTs evaporated in O<sub>2</sub> is almost same as that evaporated in vacuum or N<sub>2</sub>. It has been widely believed that higher vacuum is better for vacuum evaporation, however, the result shows that the performance of pentacene TFTs is not so sensitive to the pressure or ambient during evaporation. In addition, note that we have found that the mobility is improved when H<sub>2</sub> was introduced during the evaporation. It is also noted that the off-current and threshold voltage were not changed by the gas introduction, which means no defects nor traps were generated by the gas introduction during the evaporation.

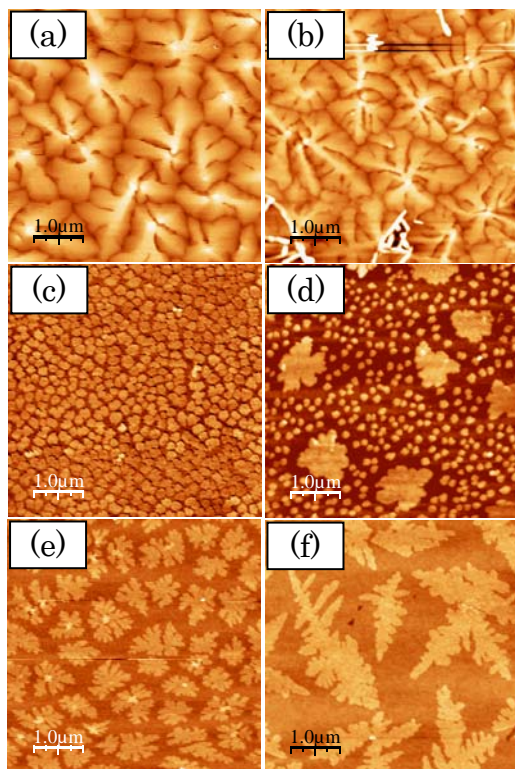


**Fig. 2** Current-voltage characteristics of pentacene TFTs. Drain voltage was -12V. The mobility was not changed by introduction of N<sub>2</sub> or O<sub>2</sub> while it was improved by introduction of H<sub>2</sub> during evaporation.

H<sub>2</sub> has a property as a reduction agent and might suppress the oxidation of pentacene molecules. However, this effect is not likely to be dominant for the observed mobility improvement because the performance was not degraded by evaporation in O<sub>2</sub>.

**Figures 3 (a)** and **(b)** show AFM images of about 30 nm-thick pentacene films deposited in vacuum and H<sub>2</sub>, respectively. It is shown that the difference in grain sizes is small. On the other hand, **Figs 3 (c)** and **(d)** show AFM images of about 1.2 nm-thick pentacene film deposited in vacuum and about 0.6 nm-thick one deposited in H<sub>2</sub>, respectively. Some large grains are observed in the first layer of the film deposited in H<sub>2</sub> while only small grains are observed in that deposited in vacuum. Furthermore, the grain

size of the second layer deposited in  $H_2$  is much bigger than that deposited in vacuum as shown in **Figs. 3 (e) and (f)**. First and second layers are more important for carrier conduction than upper ones. Therefore, it is considered that the mobility improvement is caused by this grain size increase of the interfacing pentacene with  $SiO_2$ .

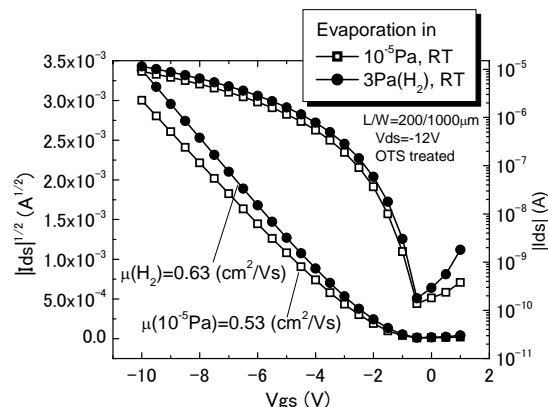


**Fig. 3** AFM images of pentacene films. (a) about 30 nm-thick evaporated in vacuum. (b) about 30 nm-thick evaporated in  $H_2$ . (c) about 1.2 nm-thick evaporated in vacuum. (d) about 0.6 nm-thick evaporated in  $H_2$  (e) about 3 nm-thick evaporated in vacuum. (f) about 3 nm-thick evaporated in  $H_2$ .

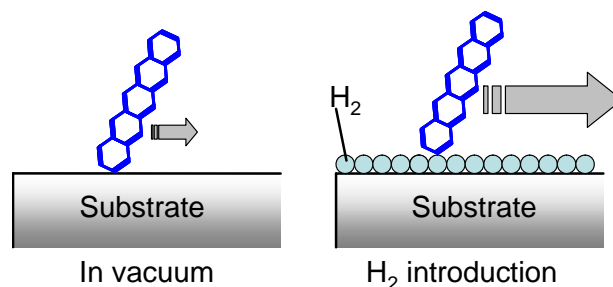
**Figure 4** shows  $I_{ds}$ - $V_{gs}$  characteristics of pentacene TFTs deposited at room temperature in vacuum and  $H_2$  on OTS treated  $SiO_2$ . It is shown that the mobility is also improved by  $H_2$  introduction as same as the case of films evaporated on  $SiO_2$  in Fig. 2. This result indicates that  $H_2$  introduction improves the mobility of pentacene TFTs on both hydrophilic and hydrophobic surface because  $SiO_2$  surface should be changed from hydrophilic to hydrophobic by OTS treatment.

The mechanism of the mobility improvement has not been clear yet, however, we propose a possible mechanism on the basis of experimental results as shown in **Fig. 5**. When  $H_2$  is introduced, it is adsorbed on the substrate and covers the surface. It is considered that  $H_2$  is physically adsorbed, not chemically, because the mobility improvement is observed in pentacene TFTs evaporated on both hydrophilic and hydrophobic surfaces. It is expected that the surface migration length of pentacene molecules deposited on the surface covered by  $H_2$  increases because a terminating hydrogen of pentacene molecule is expected to weakly interact with  $H_2$  gas compared to hydroxy group or

other gasses such as  $N_2$  or  $O_2$ . This fact may result in the increase of grain size and improvement of molecular ordering of the films. For further discussion, experiments from the viewpoints of crystallinity and molecular ordering are needed.



**Fig. 4** Current-voltage characteristics of pentacene TFTs on OTS treated  $SiO_2$ . Drain voltage was -12V. The mobility was also improved by introduction of  $H_2$  during evaporation.



**Fig. 5** Schematic diagram of proposed mechanism for mobility improvement by introducing  $H_2$  during evaporation.  $H_2$  is physically adsorbed on the substrate surface which increases migration length of deposited pentacene molecules.

#### 4. Conclusions

We have found the mobility improvement of pentacene TFTs by introducing  $H_2$  during the film evaporation of pentacene for the first time. The threshold voltage and off-current were not changed. This fact has been observed in the hydrophobic surface as well as hydrophilic one. A mechanism that physically adsorbed  $H_2$  covers the substrate surface has been proposed from the viewpoint that the surface migration length of deposited pentacene molecules may increase under  $H_2$ . It is expected that a further improvement of mobility is achieved by optimizing the substrate temperature.

#### Acknowledgement

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#### References

- [1] T. Yokoyama et al., M&BE4 abstracts (2007) 77.
- [2] M. Nakamura et al., IPAP Conf. Series **6** (2005) 130.