Semiconducting Properties of Pentacene Thin Films Studied by Complex Impedance Analysis and Photo-induced Effects

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1. Introduction

Pentacene has attracted much attention from its high mobility in the organic field-effect transistor[1),2)]. However, its semiconducting properties have not been fully understood yet. This paper reports material properties of pentacene films in terms of CV characteristics, dielectric properties and of photo-induced effects by using n^{++}/p^{++}Si gate/SiO_2/pentacene capacitors and Au/pentacene/Au sandwiched structures

2. Experiments and Discussion

2.1 Sample Fabrication

Pentacene MOS capacitors were fabricated to study semiconducting properties. The $n^{++}/p^{++}Si/SiO_2$/pentacene capacitors were fabricated, together with Au/pentacene/Au (MSM) structure. Pentacene film was grown by the vacuum evaporation with deposition rate of 0.05nm/s and substrate temperature of 25 ºC. Au electrodes for electrical contacts were thermally evaporated. In the MIM devices, pentacene thickness was varied from 260 to 400 nm. Electrical characteristics were measured at 25 ºC in the air. A fluorescent light of microscope fixed on the measurement stage was used for investigating the photo-induced effects.

2.2 C-V Characteristics

It is reported that the pentacene is a p-type semiconductor. **Fig. 1** shows that pentacene MOS capacitors behave really as a p-type semiconductor both for n^{++} and p^{++}Si gates. The flatband voltage (V_{fb}) difference of them is 1.1 V, which corresponds to the silicon band gap.

2.3Dielectric Properties

Impedance measurements of pentacene films were performed in MSM structure by applying ac amplitude of 100mV with a frequency range from 20Hz to 1MHz. In **Fig. 2**, semicircular arcs in the impedance plot in the complex plane, which can be described by a simple R_pC_p parallel circuit described in the inset, are shown for two samples. Since Cp can be evaluated by the curve fitting, the dielectric constant of pentacene perpendicular to the film is estimated from the slope of pentacene thickness dependence of S/C_p (S: upper electrode area).

2.3 Photo-induced Effects

First, photon absorption was measured by using the spectroscopic ellipsometry. As reported[3)], a strong absorption peak was observed at $h\nu$=1.8 eV with a couple of shoulder peaks. We consider that this main peak corresponds to the pentacene energy gap. Then, a fluorescent light was applied to MSM structure through the semi-transparent Au electrode for investigating the photo conductivity. **Fig. 3** shows that by the light irradiation the resistivity decreases and is flattened after 1000 sec. This indicates that the light induces more free carriers in the film. On the other hand, by switching off the light, the resistivity increases as a function of time, which cannot be understood by a single conductance modulation mechanism.

4. Conclusion

The complex impedance analysis and photo-induced effects have been investigated in pentacene films from the viewpoint of its semiconducting properties. The results suggest that the pentacene has a capacitive component inside the film, though it behaves a p-type semiconductor in FET operation. The time-dependence of ρ after turning off the photo-irradiation suggests an existence of a couple of excess
carrier decay processes in the film and/or Au/film interface.

Acknowledgement

This work was partly supported by a Grant-in-Aid for

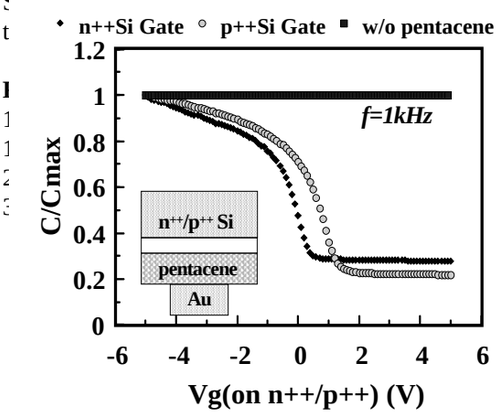

Fig. 1 n^{++}/p^{++} Si gate pentacene MOS capacitor characteristics. Flatband voltage difference between n^{++} and p^{++} gate MOS is just the silicon band gap.

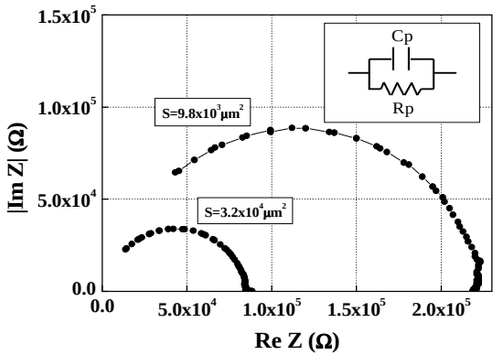

Fig. 2 Impedance plots in the complex plane for pentacene MIM devices with two kinds of surface areas. A semicircular arc is shown, which means the equivalent circuit in the inset is applicable for the analysis. From the thickness dependence of Cp, the pentacene dielectric constant is estimated to be about 6.

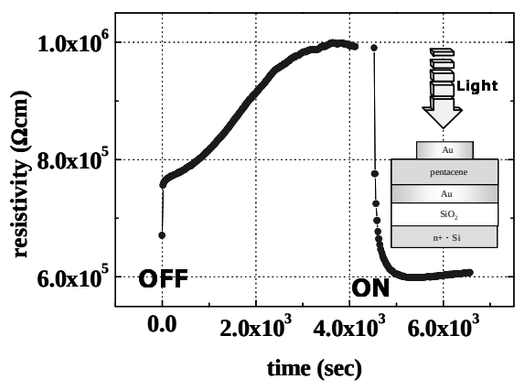

Fig. 3 ρ(t) versus time after switching-off the light for MIM device. The light is applied through thin Au film on pentacene. The effect of the light on electrical conduction in the pentacene film is clearly shown. In addition, it is found that the photo-induced conduction has a long time decay.