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# Complex Impedance Analysis and Photo-induced Effects of Semiconducting Pentacene Films

T. Nishimura, T. Yamada, T. Yokoyama, K. Kita, K. Kyuno and A. Toriumi

Department of Materials Science, School of Engineering, The University of Tokyo,
7-3-1 Hongo, Bunkyo, Tokyo 113-8656, Japan
Phone: +81-3-5841-7161 E-mail: nishimura@adam.t.u-tokyo.ac.jp

## 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 basic material properties of pentacene film in terms of dielectric properties and of photo-induced effects by using Au-Pentacene-Au structures and $n^+$ Si gate FETs.

## 2. Experimental

### *2.1 Sample Fabrication*

MIM structure and top-contact type FET are schematically shown in **Fig. 1**. Each of devices was fabricated on 50nm-thick $SiO_2$ thermally grown on $n^+$-silicon substrates. The heavily doped silicon substrate acts as gate electrode in FET. Pentacene film was grown by the vacuum evaporation with deposition rate of 0.05nm/s and substrate temperature of 25 ºC. The base pressure was about $10^{-5}$ Pa. Au electrodes for contacts were thermally evaporated. In the MIM device, pentacene thicknesses were varied from 260 to 400 nm. FET device sizes were W/L=1300μm/100μm and 1300μm/500μm with 50 nm-thick pentacene. Electrical characteristics were measured at 25 ºC in the air. A fluorescent light of microscope fixed on apparatus was used for investigating the photo-induced effects.

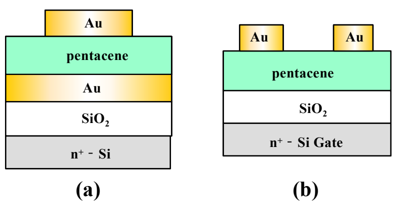


**Fig. 1 (a)** MIM structure. **(b)** Top contact type FET structure.

### *2.2 Dielectric and Electrical Properties*

Impedance Z measurements of pentacene were performed in MIM structure by applying ac amplitude of 100mV with a frequency range from 20Hz to 1MHz. **Fig. 2** shows the measured impedance plot in the complex plane for two samples. Two semicircular arcs which can be described by a simple $R_pC_p$ parallel circuit in the inset of Fig. 2 are obtained. **Fig. 3** shows the pentacene thickness dependence of $S/C_p$ (S: upper electrode area). From this slope, the dielectric constant of pentacene perpendicular to the film is estimated to be about 6. The anisotropy of the conductance of pentacene was measured using devices (a) and (b) in Fig. 1. The conductivity of parallel to *ab*-plane was

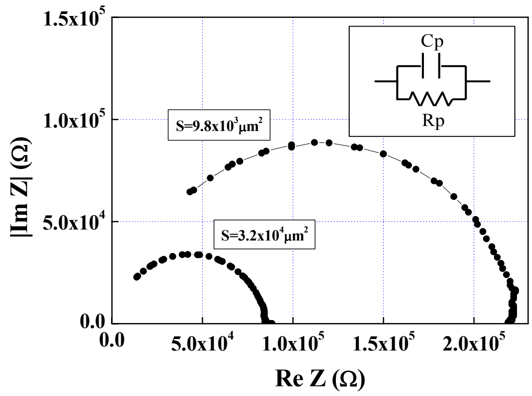


**Fig. 2** Impedance plots in the complex plane for pentacene MIM device with two kinds of surface areas.

approximately calculated from $I_{ds}$-$V_{ds}$ in device (b) at Vg=0 in the linier region, by taking account of channel length, width, pentacene thickness. The resultant anisotropy is about 100 ($\sigma_{//}/\sigma_{\perp}$=100), where the grain difference on Au from that on $SiO_2$ was not considered.

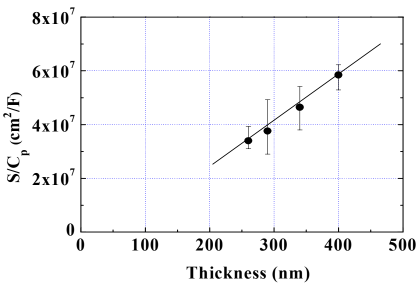


**Fig. 3** S/Cp (S: Size of upper electrode Cp: Capacitance of pentacene) versus pentacene film thickness.

### *2.3 Photo-induced Effects*

First, photon absorption was measured by using the spectroscopic ellipsometry. **Fig. 4** shows the extinction coefficient of pentacene film as a function of photon energy. A strong absorption peak is observed at $h\nu$=1.8 eV with a couple of shoulder peaks, as reported [3]. We consider that this main peak corresponds to the pentacene energy gap. Then, a fluorescent light was applied to MIM structure with semi-transparent electrode investigate the photo conductivity. **Fig. 5** shows that the resistivity decreases and is flattened after 1000 sec. This indicates that the light induces more free carriers in the film. By switching off the light, the resistivity sharply increases with the time.

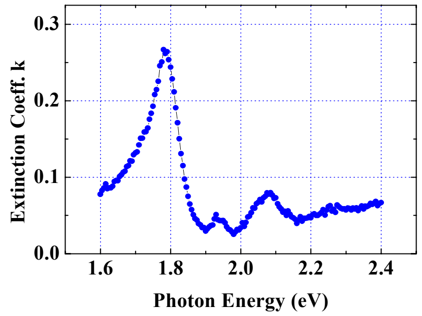


**Fig. 4** Extinction coefficient of pentacene film measured by spectroscopic ellipsometry

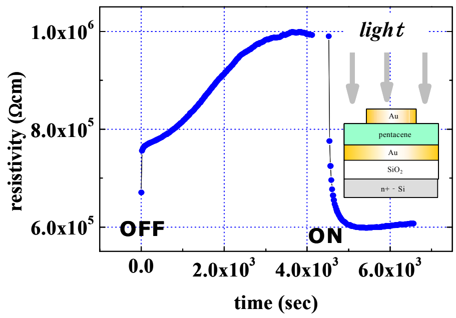


**Fig. 5** ρ(t) versus the time after switching-off the light for MIM device.

*2.4 Light irradiation with Bias on MIM Structure*

It was reported in pentacene FET that the threshold voltage shift depends on applied bias under illumination [4]. We have also observed this effect, which suggests an interaction of carrier excitation with electric field. We further investigated the same type of experiment on MIM structure. In this case, it is expected that the pentacene/$SiO_2$ interface effects can be reduced as small as possible. **Fig. 6** shows the measured impedance plots in the complex plane for three kinds of conditions, where (a) in dark and without bias, (b) with light and without bias, and (c) with light and with bias (V=6V), respectively. In the case of (c), the bias was switched off just before the measurement. The results clearly indicate that the resistance decreases with irradiation, and that it further decreases with an electric field under illumination.

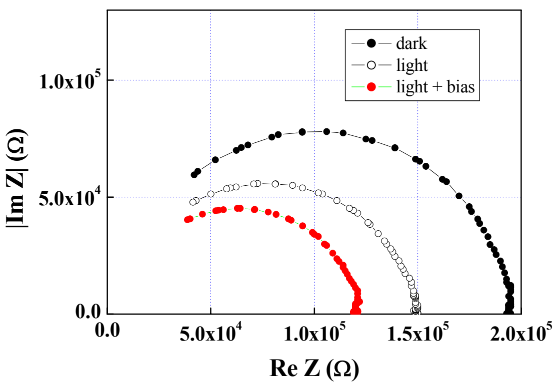


**Fig. 6** Impedance plots in the complex plane for three kinds of conditions (a) in dark and without bias, (b) with light and without bias, (c) with light and bias, respectively. In the case of (c), the bias was switched off just before measurement.

## 3. Discussion

The fact that anisotropy of electrical conductivity is relatively large is reasonable if π-conjugated system of pentacene film is considered. From the results of photo-induced effects on electrical resistivity of pentacene, it is supposed that free carriers are excited over the band gap. There seem a couple of free carrier decay processes in the film. **Fig. 7** shows that in the middle of the time, two log(t) dependent mechanisms seem to be involved with carrier decay process. This will not be explainable by the parallel conduction model but by two limiting process in series. It is inferred that an electric filed might detrap the carriers localized at grain boundaries, and that the conductive percolation path might be closed in the film which could sharply enhance the resistivity.

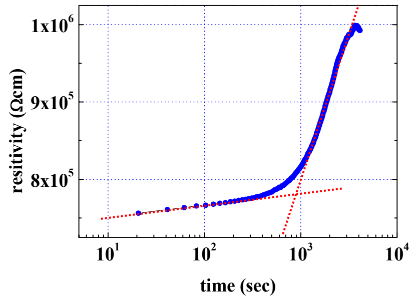


**Fig. 7** ρ(t) with time after switching off the light. The middle region was magnified in the semilog plot of the data in Fig. 5.

## 4. Conclusion

Impedance analysis and photo-induced effects have been investigated. The conductivity anisotropy and dielectric constant were evaluated. Time-dependence of ρ after turning off the photo-irradiation suggests an existence of a couple of excess carrier decay processes. Photo-induced effects will become an important issue for high performance pentacene TFTs.

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**References**

[1] H. Klauk et al., IEEE Trans. Electron Devices **46** (1999) 1258.
[2] T. Komoda et al., Jpn. J. Appl. Phys. **41** (2002) 2767.
[3] S. S. Kim et al., Thin Solid Films **420-421** (2002) 19.
[4] H. Tachibana et al., Extended Abstract of the 51st Spring Meeting on The Japan Society of Applied Physics and Related Societies. No.3 (2003) 1418.