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Potential Profile and Opto-Electronic Properties at Nano Interface of Conducting Polymer and Metals

Keiichi Kaneto and Wataru Takashima

Graduate School of Life Science and Systems Engineering,
Kyushu Institute of Technology, 2-4 Hibikino,
Wakamatsu-ku, Kitakyushu, Fukuoka 808-0196, Japan
Phone:+81-93-695-6042 E-mail: kaneto@life.kyutech.ac.jp

1. Introduction

Organic materials has been realized as electro active elements in opto-electronics devices such as solar cell, light emitting diode and transistors, because of the flexibility, unique properties and low cost fabrication[1]. It should be noted that most devices are functionalized at the interface of junctions with different materials, such as pn junction, Schottky junction and ohmic junction. At the junctions, carrier blocking and injection, photo carrier generation and carrier recombination are taking place, resulting in rectification, photovoltaic effect and light emission, respectively. The mechanisms have been well studied in inorganic semiconductors, however, little is known in organic semiconductor and molecular materials. In this report, electronic structure, transport properties and photocarrier generation mechanism at the interface of conducting polymer, polythiophene and metals are mentioned. The results suggest ways of improvement of the device performance in opto-electronics devices based on junctions between organic materials and metals.

2. Experimental procedures

Head to Tail coupled poly(3-hexyllthiophene), P3HT, was purchased from Aldrich Chemical Co. Ltd and used as obtained. The P3HT was dissolved in chloroform by 5wt% and cast on a glass substrate as shown in Fig.1. Au and Al were evaporated in vacuum with the thickness of approximately 50 nm. The structure of diode was planer type for the measurement of potential profile, in order to pick up the potential at several locations[2]. Sandwich type of the diode was also fabricated to study the photovoltaic effects and contact resistance of metals and P3HT. Probe with the tip radius of 50 nm was sharpened by the technique of electrochemical etching as used to make a tip for a scanning tunneling microscope. The probe was moved by a micromanipulator with the accuracy of 3 nm along the channel between Al and Au electrode.

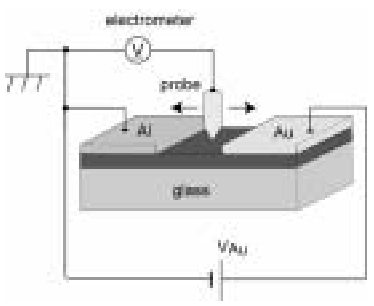

Fig.1 Cell configuration of Al/P3HT/Au diode.

3. Results and Discussion

Current-voltage (*I-V*) characteristic of the diode for the bias of Au against Al is shown in Fig.2, namely, the positive Au is a forward bias. The result indicates an excellent rectification with the ratio of more than 500, which results from the Schottky like junction at Al/P3HT and ohmic junction at P3HT/Au. Photovoltaic effect and transport properties of the diode have been studied in detail and revealed that photocarriers are predominantly generated at the Al/P3HT interface[3]. The thickness of the Schottky junction has been estimated to be approximately to be 50-100 nm.

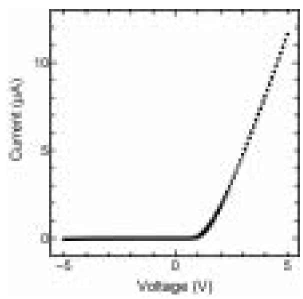

Fig.2 Current voltage characteristics of Al/P3HT/Au diode.

Figure 3 shows the potential profile along the channel with the parameter of bias voltages. It is interesting to note that at negative biases, namely, the Au electrode was negative to the Al electrode, a sharp potential cliff appears at the interface of Al/P3HT within the distance of 2 μm from the Al edge. The result indicates that most of the bias (more than 94%) is applied to the Al and P3HT interface, where the resistance in extraordinary large compared with P3HT region and is known as the depletion layer of the Schottky junction. On the other hand, a slight potential drop was observed at P3HT/Au junction where the junction is characterized by the ohmic junction, namely, the ***I-V*** characteristics is linear[4]. The resistance of P3HT/Au ohmic contact is much smaller than that of Al/P3HT Schottky junction, as supposed from the potential profile of Fig.3. However, the resistance of ohmic contact is really large, depending on the procedure of fabrication. It should be noted that the I-V characteristics are mostly determined with contact resistance at metal interfaces, if the channel length of the diode is less than several μm or a sandwich type cell is employed.

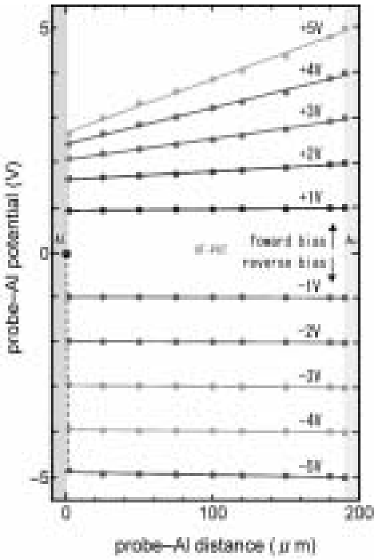

Fig.3 Potential profile of Al/P3HT/Au diode as the function of bias.

The potential profile at the forward bias of more than 2 V or the onset of forward current, the potential gradient along the channel becomes larger at larger bias, resulting in the IR drop at the bulk resistance of P3HT. However, the residual resistance at Al/P3HT still exists even at large bias, which deteermines the limit of forward current and the short circuit current of photovoltaic effect. The residual resistance is an insulating layer, which is formed at the surface of P3HT film during the evaporation of metal electrode by the thermal damage. This has been confirmed by the comparison of resistances between contacts of spin coat of P3HT on deposited Au and Au deposition on P3HT film[5]. The latter showed higher resistance than the former by more than two orders of magnitude.

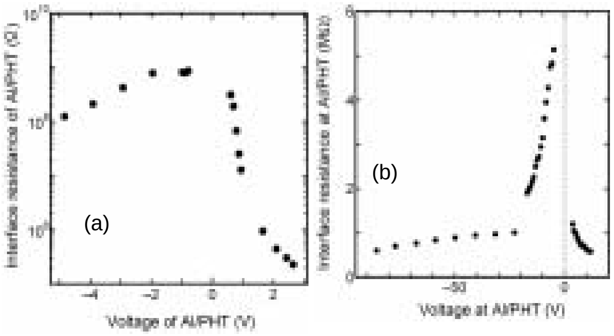

Fig.4 Bias dependence of the resistance at Al/PHT at bias voltage of (a) −5～+ 3V and (b)−100～＋15V.

Figure 4 shows the bias dependence of the Al/PHT contact resistance. At ±2V, the rectification of the diode is found to originate from the resistance difference of Al/PHT between forward and reverse bias. At the bias less than −10 V, the reversed contact resistance decreases steeply, which was observed reproducibly, being due to the Zener or avalanche breakdown of the Schottky junction, though the detail is not known at the moment.

Figure 5 shows temperature dependencies of the ***I-V*** characteristics of Al/P2HT/Au diode with sandwich type configuration. These characteristics are supposed to originate from the transport at Al/P3HT interface, taking facts of above mentioned and photocarrier generation studied previously[3]. The decrease of forward current at lower temperatures is conjectured to be due to the tunneling effect at the insulating layer of Al/P3HT. The photocarrier generation mechanism can be discussed from Fig.5 (b) by the thermal dissociation mechanism at the depletion layer.

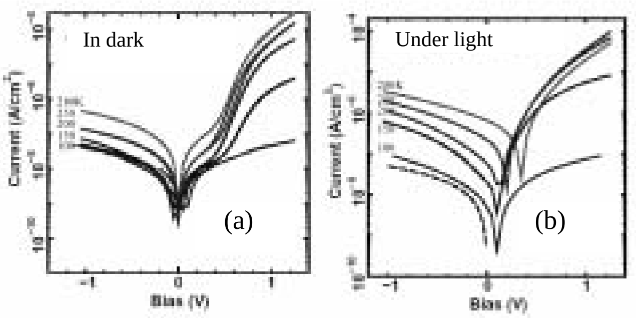

Fig.5 Temperature dependencies of the *I-V* characteristics of the diode (a) in dark and (b) under laser light at 532 nm of 0.2 W.

4. Conclusions

Electronic properties and photovoltaic effect at the interface of poly(3-hexyllthiphene) and metal junction has been studied taking the potential profiler, temperature dependence of *I-V* characteristic. It is found that the nanometric region of the junction determines the most properties of the device performance.

Acknowledgements

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