

Photoinduced Gate Operation and Temperature Dependence in the Coulomb Staircase of Organic Single Electron Tunneling Junctions

Yutaka Noguchi, Takaaki Manaka and Mitsumasa Iwamoto*

Department of Physical Electronics, Tokyo Institute of Technology,
2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan
Phone & Fax: +81-3-5734-2191 *E-mail: iwamoto@pe.titech.ac.jp

1. Introduction

To apply organic molecules to nanoscale electronic devices, the electronic conduction properties of single molecule has been measured by using nanogap electrodes, scanning tunneling microscope (STM), metal/molecule/metal structures and so on [1-3]. Some of the papers reported Coulomb staircase behaviors due to a conductive molecule itself acts as a nanoscale conductive dot. We have also examined the current-voltage (I-V) characteristics using double barrier tunneling junctions (DBTJs), such as Au/polyimide (PI)/rhodamine dendrimer (Rh-G2)/PI/Al (or Au) and Au/PI and C₆₀ mixed film/Al sandwich-type structures. In the I-V characteristics, Coulomb staircase behaviors due to the single electron conduction through the organic nano structure was observed at a low temperature (~30 K) [4, 5]. Though it has not been enough to clarify the properties of the central electrode, interestingly, the threshold voltages of Coulomb staircase observed in our Au/PI/Rh-G2/PI/Al junction showed about -100 mV shift with increasing temperature. We analyzed the shift as the effect of space charges that exist in PI films, and showed a good agreement with the experimental results [6]. In this paper, both the photo irradiation effect and the temperature dependence were examined on Coulomb staircase appeared in Au/PI/phthalocyanine derivative (CuttbPc)/PI/Al junction. And we show a new evidence of the space charge effect on the Coulomb staircase, that is photoinduced gate operation, observed in the I-V characteristics of the DBTJ.

2. Experiment

The sample structure of our junction and the experimental setup are shown in Fig.1. PI films were deposited by spin-cast method for 1 min at 1600 rpm and CuttbPc film was deposited one layer by Langmuir-Blodgett (LB) technique at 150 Å²/molecule with horizontal lifting method, respectively. The metal electrodes Au (width: 170 μm) and Al (width: 410 μm) were evaporated under a pressure of 4×10^{-6} Torr. The thickness of the films between Au and Al is 3.9 nm estimated by the capacitance measurement. The biasing voltage was applied to Au with reference to Al, and the light (Xe lamp) was irradiated from the side of Al electrode. The sample was set on the cryostat chamber and all measurements were performed in vacuum (~10⁻⁷ Torr).

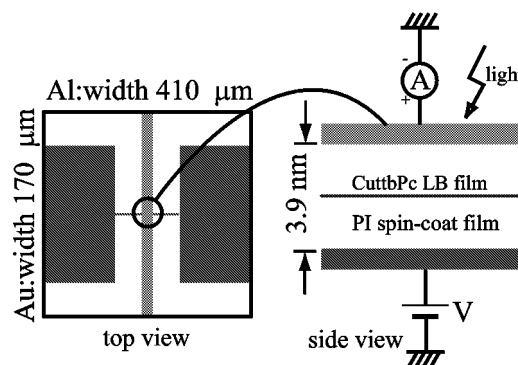


Figure 1: The sample structure and the experimental setup.

Two kinds of measurement were done for the Coulomb staircase of our junction. One is the current-time (I-t) characteristics during photo irradiation at a constant biasing voltage of 50 mV at a temperature of 15 K. The other is the temperature dependence of the I-V characteristics within the range of 15 K to 300 K in the dark.

3. Result and Discussion

Fig.2 shows the I-t characteristics at a biasing voltage of 50 mV under the 400 nm light irradiation. As shown in Fig.2, about 1.5 pA current step was observed at 118 s. It is caused as a result that the first threshold voltage due to Coulomb blockade became lower than 50 mV (see inset of Fig.2). We may call the shift photoinduced gate operation according to the field effect gate operation in single electron transistor [7]. This phenomena did not appear by 600 nm photoirradiation.

On the other hand, we had analyzed the threshold voltage of Coulomb staircase taking into account the effect of space charges in the PI tunneling layer. According to this analysis, the induced charges on the central electrode by space charges directly vary the threshold voltage of Coulomb staircase [6]. According to the measurements of the surface potential by Kelvin probe method, the properties of space charges in the PI films are similar to the photoinduced gate operation of our junction in the wavelength dependence, the response time and its density [8]. Thus we may conclude the photoinduced gate operation shown in Fig.2 is due to the reduction of space charges in the PI films by photo irradiation.

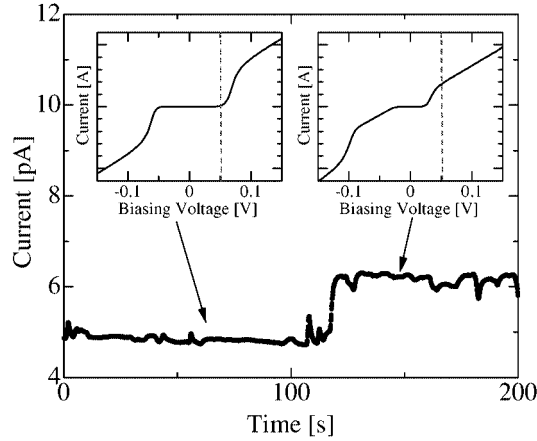


Figure 2: The current-time characteristics of Au/PI/CuttbPc/PI.Al junction during 400 nm photo irradiation at a biasing voltage of 50 mV (15 K).

We now move to the discussion about the temperature dependence. Fig.3 shows the temperature dependence of the dI/dV -V characteristics below 120 K. Coulomb staircase gradually disappeared on account of the thermal fluctuation with increasing temperature, and the threshold voltage was independent on the temperature. Fig.4 is the temperature dependence of the conductance at zero biasing voltage, where full circles indicate the experimental results and the line is theoretical one. The theoretical curve was derived by the calculation assuming only the single electron conduction through the DBTJ is dominant. Below 150 K, the experimental and theoretical conductance show a good agreement, though at higher temperature, the experimental one increases rapidly (see inset of Fig.4). This is supposed that at lower temperature, only the single electron tunneling conduction is allowed but another such as hopping or Schottky conduction mechanism become dominant at a higher temperature. This result indicates that the thermal electronic conduction is suppressed below the 150 K and thereby the threshold voltage shift was not observed in Fig.3.

4. Conclusion

The threshold voltage shift by 400 nm photo irradiation, that is photoinduced gate operation, was observed in the Coulomb staircase of Au/PI/CuttbPc/PI/Al junction at a temperature of 15 K. The surface potential measurements of the metal/PI interfacial space charges by Kelvin probe method indicate this phenomena is caused by the space charge reduction in the PI films. Moreover, the temperature dependence of the conductance at 0 biasing voltage showed a good agreement with the theoretical curve below 150 K. This result suggests only single electron conduction is allowed at lower temperature and our DBTJ operates successfully.

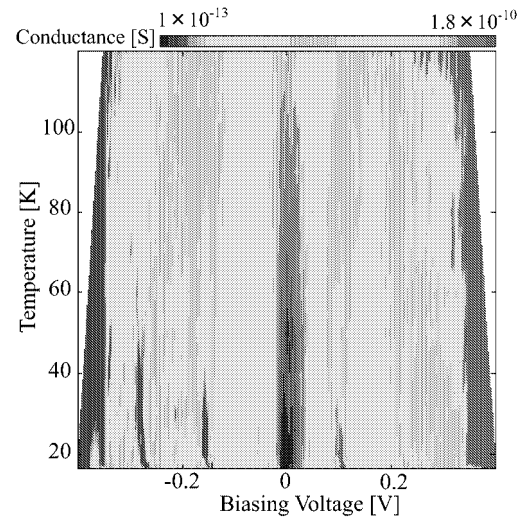


Figure 3: The temperature dependence of the dI/dV -V characteristics of Au/PI/CuttbPc/PI.Al junction.

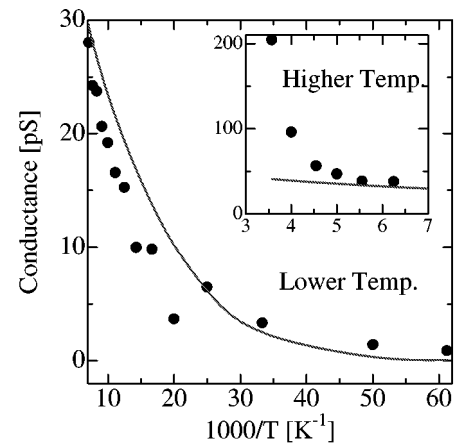


Figure 4: The temperature dependence of the conductance at zero biasing voltage.

References

- [1] H. Park, J. Park, A. K. L. Lim, E. H. Anderson, A. P. Alivisatos and P. L. McEuen, *Nature* 407, 57(2000).
- [2] D. Porath, Y. Levi, M. Tarabiah, and O. Millo, *Phys. Rev. B* 56, 9829(1997).
- [3] J.M. A. Reed, C. Zhou, C. J. Muller, T. P. Burgin and J. M. Tour, *Science* 278, 252(1997).
- [4] Y. Noguchi, Y. Majima, M. Iwamoto, T. Kubota, T. Nakahama, S. Yokoyama and S. Mashiko, *IEICE Trans. E83-C*, 1076(2000).
- [5] Y. Noguchi, T. Manaka and M. Iwamoto, to be published in *Thin Solid Films*(2003).
- [6] Y. Noguchi, M. Iwamoto, T. Kubota and S. Mashiko, *IEICE Trans. E85-C*, 1247(2002).
- [7] J.M. A. Kastner, *Rev. Mod. Phys.* 64, 849(1992).
- [8] Y. Noguchi et. al., unpublished.