Molecule-based single electron transistor

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Abstract

Molecule-based electronic devices, utilizing self-assembled monolayer of chemically synthesized organic molecules and Au nanoparticle, were fabricated and their electrical transport properties were investigated. The current-voltage characteristics of the sample was nonlinear at temperatures below 70 K and the gate modulation curve exhibited periodic current oscillation, attributed to the Coulomb oscillation, up to 40 K. The peak position in the differential conductance curve shifts with the increase of magnetic field, due to the Zeeman splitting of the electronic energy states of the Au nanoparticle.

Key words: Molecular electronic device, Coulomb blockade, quantum confinement

1. Introduction

Electron transport in chemically synthesized organic molecule attracts much attention in recent days [1], in connection with their potential applications to nanoscale electronic device. The major challenge for utilizing molecules for the key component of the electronic device is to attach electrical leads to the nanometer-sized molecules and measure their electrical transport properties. A variety of device structures and measurement methods [2–4] were proposed and realized to determine the electrical transport properties of individual molecule in a reliable manner. But there still remains many issues to be cleared. In this paper, we report the fabrication of molecule-based electronic devices and their electrical transport properties.

2. Sample preparation

The sample was fabricated by using self-assembly and electrostatic trapping method. First, the metal electrodes with the gap distance of about 20 nm is prepared by electron beam lithography and double-angle evaporation of 40 nm-thick Ti film and 40 nm-thick Au film [5] on a Si substrate covered with a 500 nm-thick thermally grown SiO_2 layer. Then the self-assembled monolayer (SAM) of nitro-amine (2'-amino-4-ethynylphenyl-4'-ethynylphenyl-5'-nitro-1-benzenthiolate) molecules was formed on top of Ti/Au electrodes by conventional method [4]. In order to connect the source and the drain, Au nanoparticle of the size comparable to or greater than the gap distance was trapped electrostatically. For the electrostatic trapping, a droplet of solution containing Au nanoparticles is dropped near the gap and slowly-varying bias voltage is applied. The current is monitored to determine the end point. Though we have intended to trap single nanoparticle, scanning electron micrographs taken after measurements revealed that trapping of two nanoparticle is not a rare occasion.

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3. Results

We have measured the electrical transport properties of the prepared device. The device has a double-junction structure and is expected to exhibit single-electron tunneling behavior if the SAM is thin enough to act as a tunnel barrier. The trapped Au nanoparticle then can be considered as a quantum dot. In such single-electron transistor, two energy scales determine the electrical transport properties of the device; Coulomb gap energy and the quantum confinement energy of the Au nanoparticle.

The current-voltage characteristics is linear at room temperature and becomes nonlinear at temperatures below 70 K. The gate modulation curve, shown in Fig. 1, exhibited periodic current oscillation, attributed to the Coulomb oscillation. For the gate modulation, we have used a back gate. Two oscillation periods can be distinguished, implying probable formation of multiple junctions [6]. Scanning electron micrographs showed two Au nanoparticle trapped in the gap. The Coulomb oscillation persists up to 40 K.

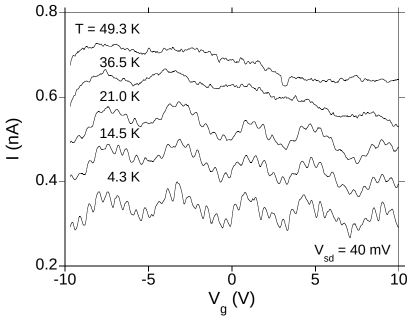

Fig. 1. The temperature-dependent gate modulation curves of the sample. The source-drain bias voltage was 40 mV. For comparison, the curves are displaced vertically in an arbitrary manner.

For a small-sized nanoparticle, the quantum confinement effect as well as single-electron tunneling effect must be taken into account [5]. We have measured the evolution of differential conductance curves with the external magnetic field. As shown in Fig. 2, the peak position which may correspond to the internal energy state of the Au nanoparticle shifts with the magnetic field. From the rate of the peak position shift with the magnetic field, $e\Delta V/H$, the $g-$factor can be estimated. For a free electron, $g-$ factor is close to 2. In a nanometer-sized metal, however, due to the spin-orbit scattering, $g-$factor was known to have any values in the range of $-2 \leq g \leq 2$ but anomalously large value of $g-$ factor was also reported [7]. All the $g-$ factors we have obtained from peak position shift were in the range of $-2 \leq g \leq 2$ except one with a relatively large value of 4.3.

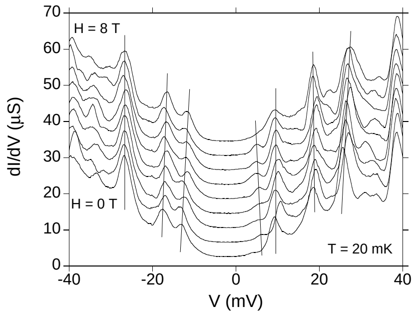

Fig. 2. The evolution of the differential conductance curves with the magnetic field. The magnetic field intensity was from 0 to 8 T with the increment of 1 T. For clarity, each curve was displaced vertically.

Of about 10 samples fabricated, three samples exhibited Coulomb oscillation and one of them exhibited hysteretic gate modulation curve, possibly due to a floating node formed near the trapped Au nanoparticle.

Acknowledgements

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