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Fabrication of single electron transistor using cage-shaped protein supramolecule

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1. Introduction

Single electron transistor (SET) has been attracting considerable attention due to its potential toward extremely small size and low-power consumption [1]. The operation of the SET is based on the Coulomb blockade phenomenon in electron transportation. Technological challenges in the SET device fabrication are making a small nanoparticle (NP) that works as a Coulomb island and sandwiching it with two tunnel junctions. In this study, we present novel fabrication process for the SET structure with "Bio Nano Process" (BNP). The BNP we have proposed is a new biological method that can produce nanometric functional inorganic structures [2,3]. We use biomineralization, self-assembly and vulnerability of the protein supramolecules. To date, we artificially synthesized a variety of uniform NPs (ϕ6nm) within a cage-shaped protein, apoferritin (ϕ12nm). Using this heterocomplex of the apoferritin and an inorganic NP, called ferritin, we have been developing nanoelectronic devices such as floating nanodot gate memory [4]. Besides our group, a flash memory with protein-mediated assembly of nanocrystal floating gate was reported [5].

2. Experimental

A SET device is drawn schematically in Fig. 1. Resist patterns for the nanogap-electrodes were prepared by electron beam lithography over the back gate covered by a SiO_2 layer. Ti (2nm) and Au (10nm) films were deposited on the patterned substrate by electron beam evaporation. After lift-off process, a pair of electrodes separated by a nanogap as large as ferritin was obtained. Under appropriate condition which is realized by adding surfactants, ferritins are adsorbed on a Ti surface while adsorption on SiO_2 surface is suppressed [6].

Ferritin with In and Co NPs were synthesized by the method described elsewhere [7,8]. The ferritin solution was adjusted appropriately and dropped on the substrate with the nanogap-electrodes. After this adsorption process for 30min., the sample was rinsed with pure water, expecting the ferritin to deposit only at the position between the electrodes. UV/ozone treatment eliminated outer protein shell of the ferritin and left NP in the nanogap-electrodes [9].

The sample was set in a measurement system and was cooled to 4.2K under He gas. Current-voltage (I-V) characteristics were measured with a semiconductor parameter analyzer.

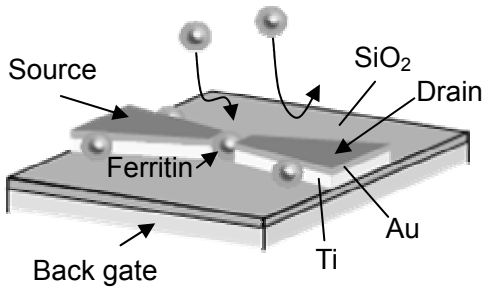

Fig. 1 Schematic drawing of SET device. Ferritins are attracted only by the Ti surface. The attractive force becomes maximum between the Au/Ti electrodes.

3. Results and Discussion

After the ferritin placement process, the sample was observed by SEM. The ferritins are successfully placed between the electrodes as shown in Fig. 2. This result indicated that ferritins were adsorbed by the attractive interaction with the Ti surface during the thermal agitation in the vicinity of the nanogap-electrodes and trapped at energetically stable position to form the SET structure. Two tunnel gaps formed between the NP and the electrodes were regulated and the same size with the thickness of protein shell of the ferritin. This is ideal for the SET structure fabrication and improves producibility of the structure. Moreover, excess ferritin adsorptions on the substrate, which can work as electron traps, were greatly suppressed. One of the I-V characteristics for the SET device with In NP is shown in Fig. 3 with dI/dV curve. Coulomb-staircase like behavior was observed. The step position of the staircase was determined from the peaks in dI/dV curve. The interval of the steps was about 260mV. The capacitance calculated from the interval is in the order of 10^{-19}F. This value is reasonable for the ϕ6nm NP [10]. The drain current dependency on gate bias was investigated. As shown in Fig. 4, Coulomb-oscillation like behavior is observed. The drain current changed periodically with increasing the gate voltage. This indicated that the gate bias varied chemical potential in NP and the electrons were transferred. Besides the SET device with In NP, we also observed the similar behaviors

with the SET device with Co NP.

Now, we have a plan to deposit insulator such as SiO_2 film over the SET device for stable operation. The device characteristics will be discussed in detail.

3. Conclusions

Here, we demonstrated the novel process for the SET device structure through the BNP. This process improved the producibility of the device structure. The successful construction of the SET device indicated that the fusion technology of biology and semiconductor fabrication process will become a powerful method to construct functional nanostructures in the nanotechnology.

Acknowledgements

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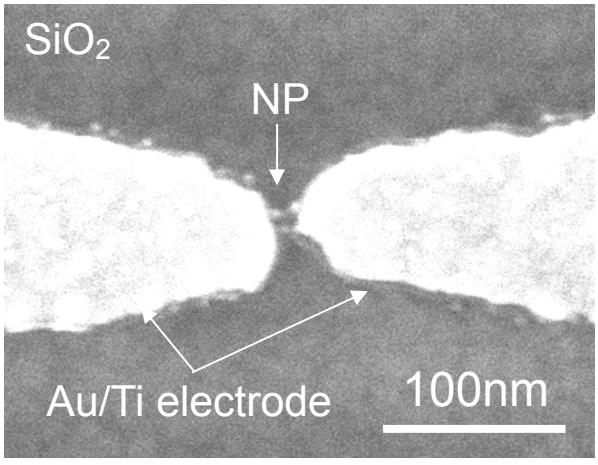

Fig. 2: Placement of ferritin with In NP between Au/Ti electrodes. Ferritins are adsorbed between the electrodes. Ferritin adsorption on SiO_2 surface is greatly suppressed.

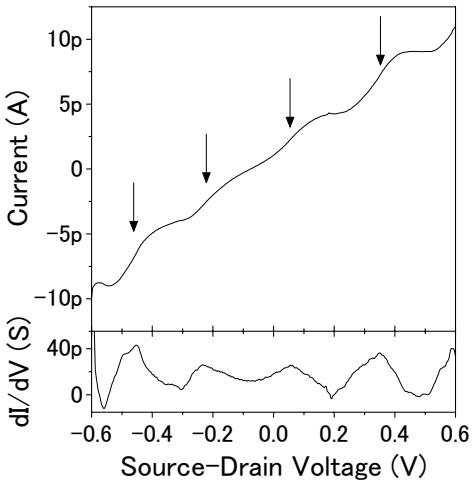

Fig. 3: I-V curve of the SET device with In NP. Gate bias is set 0V. The arrows indicate the step positions in the Coulomb staircase like behavior, which are determined from the peaks in the dI/dV curve.

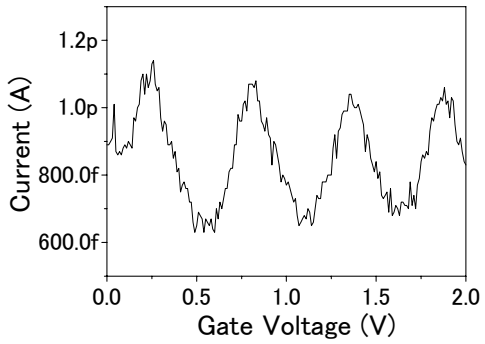

Fig. 4: Drain current as a function of gate voltage. Source-Drain voltage is set 0.4V. The drain current changes periodically with increase in the gate voltage.