Characterization and application of biochemically fabricated inorganic nanoparticle

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Biomolecule mediated fabrication of inorganic nanomaterial-biomolecule hybrid system and utilization of resulting hybrid nanocomposite is promising direction for the nano-electronic device fabrication. The functionality of recognizing and solidifying inorganic material is called biomineralization. Some kind of biomolecules such as viruses, proteins, DNAs and certain amino acid sequences have an ability of biominaralization and construct inorganic nanomaterials such as nanoparticles and nanowires. We employed cage-shaped supramolecular protein, apoferritin, to obtain uniform bionanodot (BND) architecture of cobalt oxide nanodot (Co-BND) [1] which used as a charge storage node of FNGM. The restricted protein cage was used as a template for uniform Co-BND synthesis. In order to utilize fabricated BND-ferritin hybrid nanocomposite for device fabrication, it is necessary to understand the precise electronic properties of bio-derived inorganic nanomaterials, such as electronic energy structure and charge retention capability. In this contribution, we demonstrate the characterization of electronic properties of single BND synthesized in the vacant cavity of ferritin by using scanning probe microscopy (SPM), such as Kelvin probe force microscopy (KFM) and scanning tunneling microscopy/spectroscopy (STM/STS). We have examined the charge storage capability of single Co-BND with KFM by monitoring the potential change with varying applied substrate potential for charge injection, and the electronic band structure of the single Co-BND with STS by measuring current-voltage characteristics of single BNDs. We also demonstrated the applicability of ferritin and its bionanodot for electronic devices by fabricating the floating nanodot gate memory with Co-BND as the charge storage node and confirming the memory effect due to the charge confinement to the embedded Co-core.

Figure 1(a) and 1(b) show the STM image of Co-BND deposited on highly oriented pyrolytic graphite (HOPG) and I-V characteristics measured on top of the observed Co-BND, respectively. For STM/STS measurements, Co-BND accommodated ferritins were deposited on HOPG and protein shell of ferritin molecules were eliminated by heat treatment prior to the measurement. Co-BNDs appeared as circular bright dot in STM image and cross-sectional profile indicated that the diameter of the Co-BNDs were approximately 7 nm. It is consistent with the size of reported Co-BND synthesized in ferritin cavity.[2] I-V curve of the Co-BND showed suppressed tunneling current around zero bias voltage. The width of the suppressed region and the current flow at the edge of suppressed region are interpreted as the band gap of Co-BND and resonant tunneling through the edge of valence band and conduction band of the Co-BND, respectively. Calculated tunneling conductance from I-V curves suggests that the band gap of ~2.1 eV and the positions of occupied and unoccupied levels of the Co-BND.

To evaluate charge storage capability, surface potential changes caused by the charge injection to the single Co-BNDs were examined by KFM. Topographic (Fig. 2a) and potential (fig. 2b and 2c) image of Co-BNDs deposited on the SiO_2 surface are depicted in Figs.2. Prior to the potential observation, charge injection to the Co-BNDs were carried out by scanning the sample surface with an electrically biased AFM tip under tapping mode. Circular dot structures in topography (Fig. 2a) correspond to the Co-BNDs on the SiO_2 surface. Average height of 6.4 nm is consistent with the reported size of Co-BND.[2] The surface potential of Co-BND changed after charge injection depending upon the polarity of applied bias voltage.

Fig. 2(b) shows the potential image obtained after charge injection at V_{sub}= -2 V. Co-BND appeared darker relative to the surrounding SiO_2 surface. On the other hand, after charge injection at +2 V (Fig. 2c), the Co-BNDs appeared brighter than SiO_2 surface. These results indicate that Co-BND can store the charge and can be used as the charge storage node of FNGM.

Fig. 3 shows the drain current-gate voltage (I_D-V_G) characteristics of Co-BND FNGM. I_D-V_G showed clear hysteresis due to the charge confinement in the embedded Co-BND.

References:

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[2] A. Miura, T. Hikono, T. Matsumura, H. Yano, T. Hatakeyama, Y. Uraoka, T. Fuyuki, S. Yoshii, I. Yamashita, Jpn. J. Appl. Phys. **45** (2006) L1.

Figures:

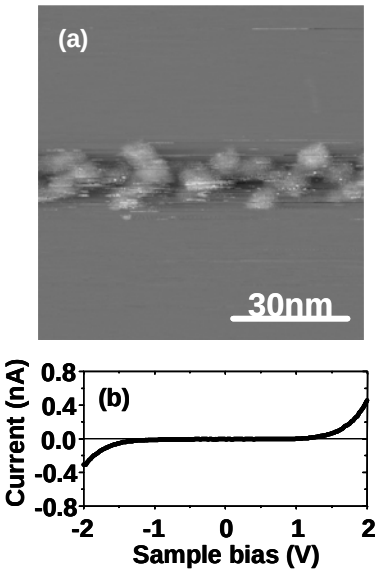

Fig. 1. (a) STM image of Co-BND deposited on HOPG. Observation conditions are: I_t=0.15 nA, V_{sub}=1.7 V. (b) I-V characteristic obtained from single Co-BND observed in Fig. 1(a). I_t=0.15 nA.

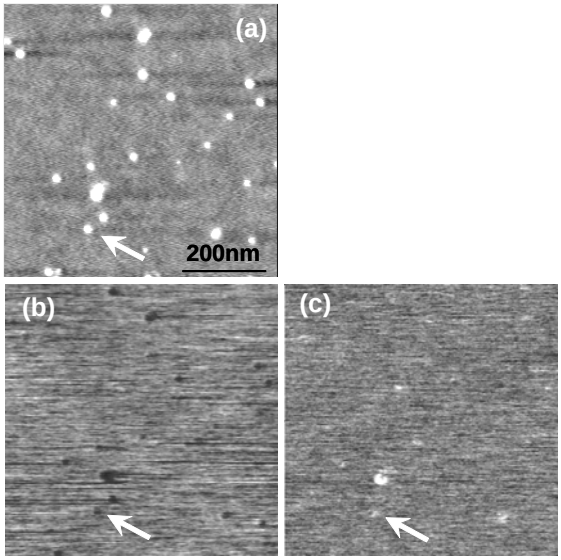

Fig. 2. (a) Topographic and (b), (c) potential image of Co-BND on SiO_2 surface. Topography was observed tapping mode AFM. Charge injection was carried out at (b) V_{sub}=-2.0 V and (c) V_{sub}=+2.0 V, respectively. Corresponding position of BND is indicated by arrow.

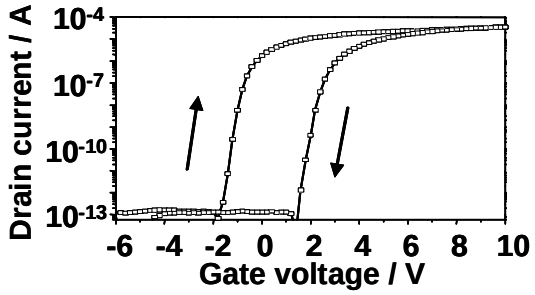

Fig. 3. I_D-V_G characteristics of Co-BND embedded MOSFET with a 10-μm gate length and width. The gate voltage is swept from -10 V to +10V and back to -10 V.