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Tunnel current measurement of MgO and MgO/Fe/MgO nanoregions during TEM observation

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Abstract

Conductance measurements of nanostructures with simultaneous transmission electron microscopy (TEM) were performed on thin insulating MgO films (2–3 nm thick) and MgO/Fe/MgO tri-layer films (2 nm/1 nm/2 nm) deposited on tip-shaped Au electrodes. A movable counter electrode was used to choose nanoscale regions with contact areas smaller than 10 nm^2 for investigation. Systematic measurements on MgO films taken by keeping contact with the counter electrode provided a tunnelling barrier height of about 1.4 eV. The conductance of an MgO/Fe/MgO double junction composed of Fe nanoparticles showed the Coulomb-blockade-like characteristics at room temperature. The threshold voltage breaking the Coulomb blockade corresponded to the value estimated from the geometry observed by TEM.

Keywords: Transmission electron microscopy; Scanning tunnelling spectroscopy; MgO film; MgO/Fe/MgO film; Coulomb blockade

1. Introduction

In recent years, the conductance of nanostructures such as the single electron transistor (SET) [1] has been intensively investigated The miniaturization of current paths by controlling the thickness of the tunnel barrier and reducing the size of the Coulomb islands to only a few nanometers plays a key role in the development of usable devices operated at room temperature

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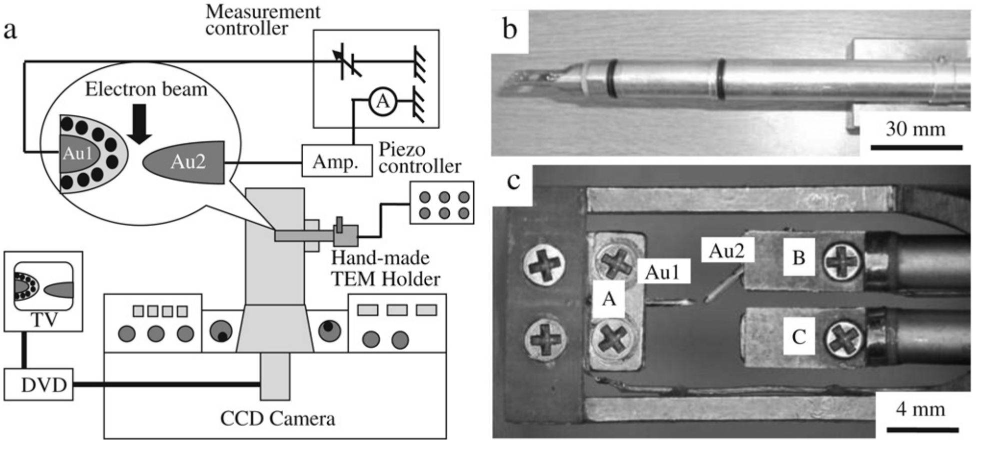

Fig. 1. (a) Schematic drawing of the experimental system, (b) TEM specimen holder and (c) margin of the holder where specimens are placed.

(RT). Therefore, an important area of research is the characteristic features of nanoparticle systems [2–4].

The tunnelling current of nanostructures is strongly influenced by their geometric arrangement. With this in mind, Uri et al. [5] clearly demonstrated the electron charging effect of a single Coulomb island by means of scanning tunnelling microscopy (STM). In this case, however, images cannot be observed during the electrical scanning tunnelling spectroscopy (STS). On the other hand, Hirose et al. [6] performed *in situ* imaging of a nanoparticle system during the tunnelling measurements using a TEM/STM combined apparatus (TEM: transmission electron microscopy; even without the feedback control, the word STM is used in this report). In this case, metal–insulator granular films (40 nm thick) composed of metallic nanoparticles dispersed in an insulator matrix were contacted by a tip-shaped electrode and a clear Coulomb blockade (CB) effect was observed at RT when the contact area was smaller than 250 nm^2. Even in this condition, however, there were about 200 nanoparticles within the contact area. Experiments using a particle system having a simple geometry (e.g. reduction in the number of particles) are required for more detailed discussion on the geometry and electronic character.

In the present work, the TEM/STM method was applied to insulating very thin MgO films (2 nm thick) and MgO/Fe/MgO tri-layer films (5 nm thick). Using movable tip-shaped electrodes with sharp apexes, nanoscale regions less than 10 nm^2 were selected. The current–voltage (I–V) measurements and the simultaneous TEM observations were performed, and the barrier height for the tunnelling conduction and the CB effect were discussed by comparing them with the observed geometry.

2. Experimental procedure

Two Au electrodes were set in a TEM, one of which was covered by the sample layer (i.e. MgO or MgO/Fe/MgO). Here, the electrode covered by the sample is called Au1 and the bare Au is called Au2. The conduction properties were measured between Au1 and Au2.

A schematic drawing of the experimental system is shown in Fig. 1a. The TEM is attached with a custom-made TEM holder, a piezocontroller, a current-to-voltage amplifier, an STM measurement controller, and a CCD camera system. The TEM instrument was a JEM 2010