Fabrication of 3-D micro- and nano- structures by focused-ion-beam (FIB) machining systems

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Focused ion beam (FIB) etching equipments have shown potentials for a variety of new applications, in the area of imaging and precision micro-machining. This processing technique produces an ultra micro scale structure from a simple sensor device and enables precision cuts to be made with great flexibility for micro- and nano-structure on thin films and single crystals.

Here, we developed a 3-D FIB etching system and the method for machining a 3-D sensor structures. For FIB etching, we used a SMI-9800 (SE) from Seiko Instruments Co. Fig. 1 shows the layout of the devised sample stage based on our patent [US 6,605,225]. The functions of X, Y, Z and T-axis are same to the standard type of conventional etching methods. By adding the function of ΔT, the optical-axis is centered on the stage without changing the point of focusing on the sample position when we tilt the object. The position reproducibility by moving the sample stage to the other place is smaller than ±2 μm. In conventional mode, maximum-tilt angle of sample stage is 60 ° considered the safety distance between sample and sample stage. Here, we achieved new function of maximum-tilt angle of sample stage up to 93 ° for automatic 3-D etching by attaching new function of ΔT. The function of ΔT and R-axis including other 4-axis in vacuum adopt an electro-mechanical drive system by automatic control. However, when we use the tilt mode up to 93 °, the possible moving and etching area is limited to 10 mm^2 for inhibiting the bump of sample stage to the FIB column.

The micro- and nano- tunneling stacks were patterned on layered thin films and single crystals by the FIB machine using the sample stage. The steps of the fabrication process using FIB etching are shown in Fig. 2. A width depending on the required junction size was patterned in the sample thickness from the perpendicular direction. By tilting the sample stage up to 90 °, two grooves of the bridge were, then, etched completely from the lateral sides, in order to create the required sample size. The scanning ion microscopy (SIM) micrograph and the scheme of the fabricated submicron tunneling stack are shown in Fig. 3. The in-plane area of the tunneling junction is 0.01 μm^2. Continuing advances in nanometer fabrication technology have enabled the construction of sufficiently small tunnel junctions for the measurement of single electron tunneling effects. Figure 4 shows the I-V characteristics. We will also report fabrication of three-terminal devices with a gate electrode for direct confirmation of the single electron tunneling in the Bi-2212 stack.

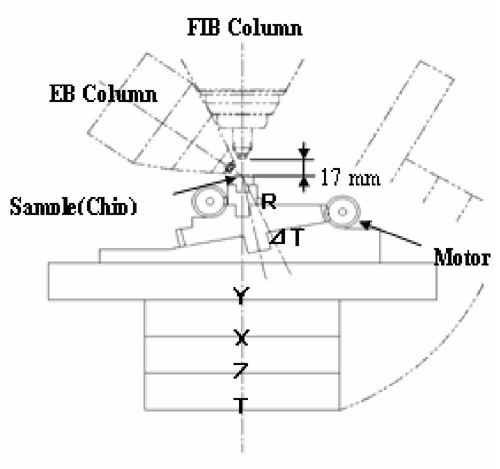

Fig. 1 Layout of the devised sample stage

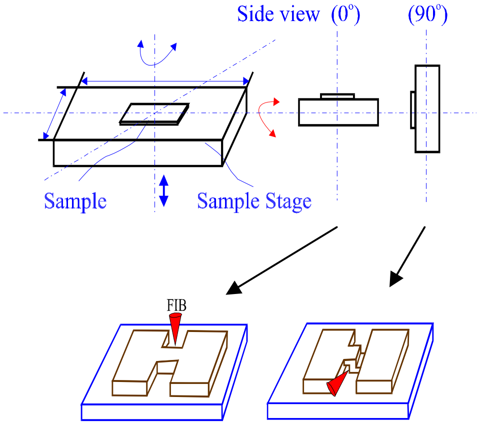

Fig. 2 Steps of 3D fabrication process using FIB

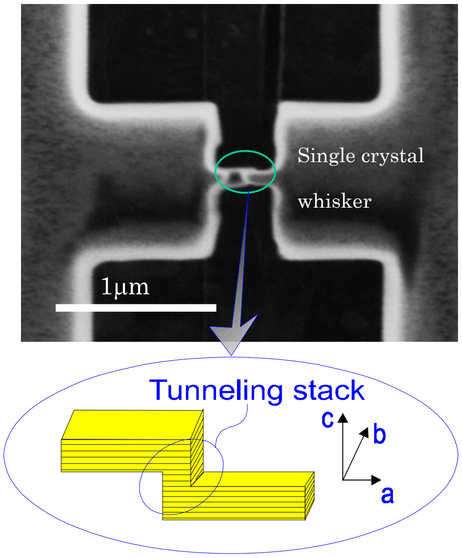

Fig. 3 Micrograph and the scheme of the fabricated submicron tunneling stack

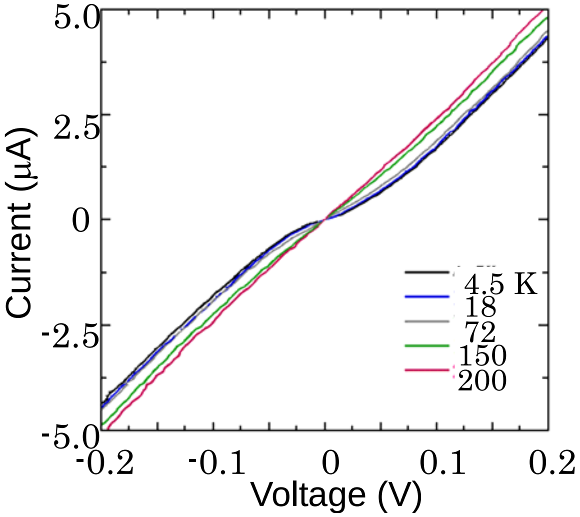

Fig. 4 I-V characteristics of the 3D stack showing tunneling characteristics