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Transport Property of Magnetic Nanojunction Prepared Using Substrate Transformation

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Ni thin film patterns were prepared on plastic substrates by electron beam vacuum evaporation. A pin hole mask made of Cu grid mesh was placed just underneath the substrate so that evaporated Ni was deposited in spot form onto substrates. The substrates were driven in stepwize mode during deposition by means of the stepping motor gear train and/or the piezoelectric manipulator in order to "draw" arbitrary pattens of the nanostructure. When the substrate was stretched or bended after depositon, Ni pattern broke up and the narrow wire or dot pattern could be formed. We ovserved the Coulomb blockade and a complicated magnetoresistance property in these patterns.
Key words: subtrate transformation, nanojunction, Ni, Coulomb blockade, magnetoresistance

1 INTRODUCTION

Quantization of the conductance has attracted much attention in the field of magnetic metals and the break junctions and nanocontacts are expected for new sensing devices[1]-[3]. In particular, the ballistic magnetoresistance (BMR) coming from the confined domain wall within the contact exhibits huge magento-resistance (MR)[4]. Those nanojunctions are usually prepared by breaking wires or contacting sharpend wires. When the junction is used for devices, it is required to be deposited on the substrates. A challenge is made to fabricate contacts by electron beam lithography and etching process[5], however BMR has not yet been observed.

In this work we have deposited Ni wires on the transformable plastic substrates. After deposition the substrates were stretched or bended to break up the wire on them. The wires became seprated and narrow wire or dot pattens could be formed. Transport properties of those pattens have been investigated.

2 EXPERIMENTALS

We have deposited Ni patterns using a vacuum evaporation technique after evacuating the chamber below 4×10^{-5} Pa. A pressure during the deposition was 1.3×10^{-4} Pa. The deposition rate was 0.1 nm/s. Polyether-ether-keptone film, Sumilite FS-1100C (Sumitomo Bakelite Co., Ltd.) with thickness 20 μm, is used for substrates in the stretching experiment. On the other hand, for bending experiment transparent sheets for an over head projector (thickness 0.1 mm) were used for the substrate.

Just underneath the substrates we had set a pin hole mask. The mask was made by piling plural Cu grid meshes (400 mesh and 100/400 mesh). Size of pin hole was 8 μm for the smallest one. The spacing between the substrate and the mask was about 0.1 mm.

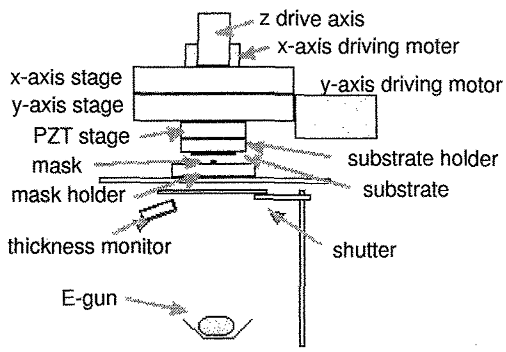
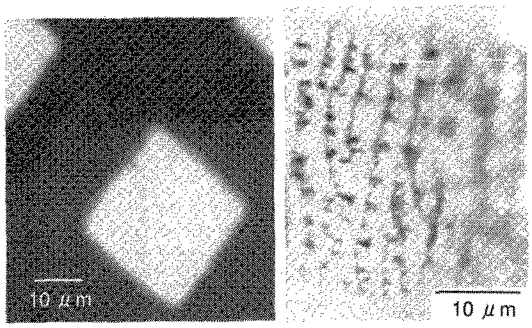


Figure 1: Schematic view of evaporation apparatus.

The substrate was placed on the X-Y-Z stage in the vacuum chamber of specially made apparatus as shown in Fig. 1 so that the stage can be moved to "draw" the Ni wire pattern. The stage is driven by the stepping motor for X-Y-Z direction with the resolution of 1 μm. As for the X direction a piezoelectric driver is also equipped to move more precisely.

Substrate stretching was carried out using a universal testing instruments (Shimadzu Autograph AGS-10KNH) at 5 kg-f. Bending was carried out to fold the transparency around a knife edge with its back.

The structure of the patterns were observed by optical microscope, scanning electron microscope (SEM) and atomic force microscope (AFM). Transport properties were measured with dc 2-terminal



(a) Before stretching (b) After stretching

Figure 2: An example of nanowire array fabricated by stretching Ni pattern deposited on Sumilite substrate.

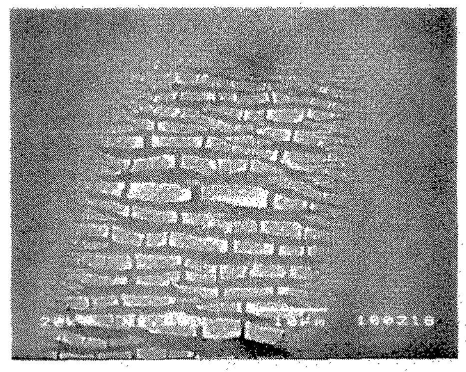


Figure 3: SEM image of Ni patterns stretched in two directions.

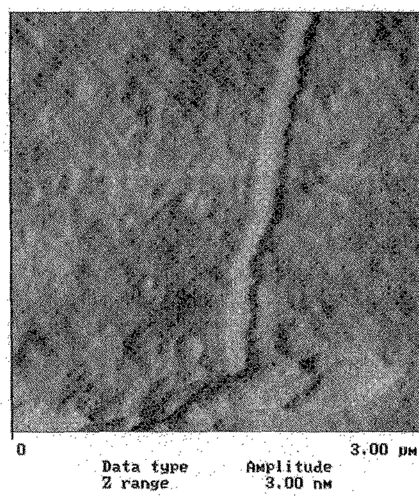


Figure 4: AFM amplitude image of crevice appeared in Ni pattern.

method in the applied field up to 7 kOe.

3 RESULTS AND DISCUSSION

3.1 Substrate stretching

Optical micrograph of the Ni square pattern deposited on Sumilite subtrate is shown in Fig. 2 (a). The film thickness is 30 nm. When the substrate is stretched, the Ni film breaks up and compose wire structure as shown in Fig. 2 (b). Here, the arrows indicate the stretching direction and the stretching ratio is 15 %. Sumilite film has anisotropy in its plastic transformation and the Fig. 2 (b) shows the result of stretching in easy direction. Each wire keeps almost parallel with each other and the width is almost 1 μm. This width depends on the Ni film thickness and becomes smaller as the thickness becomes smaller.

Figure 3 is a SEM micrograph of the result of stretching in two directions. The film is stretched in the vertical direction of the micrograph at first by 1 % and then 2 % to horizontal direction. Although the stretching rate is very small, the plastic transformation occurs locally in the various part of the substrate asynchronously and it is very large compared to nominal ratio. Here again the parallel wire pattern is realized by this stretching method and second stretching causes transverse fissures to wire. Careful observation reveals that some of the fissures have something like a very small bridge or dot. These structure brings the transport properties mentioned below.

We had expected that the sheering stress should induce the crystal lattice landscape and form atomic size steps or narrowing of the wire pattern. However, the AFM amplitude image shown in Fig. 4 exhibits that the breaking seems to occur at the columnar boundary of the Ni film. Hence, it is found that making break junctions by this method is difficult.

Transport property was measured using the wire pattern like the Fig. 3 sample. The film thickness was 20 nm and distance between electrodes was about 20 μm. Typical $I-V$ characteristic is shown in Fig. 5. The $I-V$ curve exhibits nonlinear increase in current with increasing voltage. The current begins to flow after the voltage becomes 0.42 V. We tried to fit the Simmons formula [6] to this curve, but the result was not good. It is because this character is attributed to the Coulomb blockade formed in the fissure of the wires. When we apply the charging energy $E_C = e^2/2C$ to this 0.42V and assume the sphere shape, the size of the dot causing this blockade is estimated as 14 nm diameter. SEM observation of the fissured structure implies that there exist some columns peered off from the edge and the electron tunnels the vacuum barrier of broken wire through these columns.

3.2 Bending substrate

As we described in the former section, stretching the substrates breaks the Ni pattern on it into submicron size dots or wires. However, the fissures distribute throughout the pattern. It is not prefer-

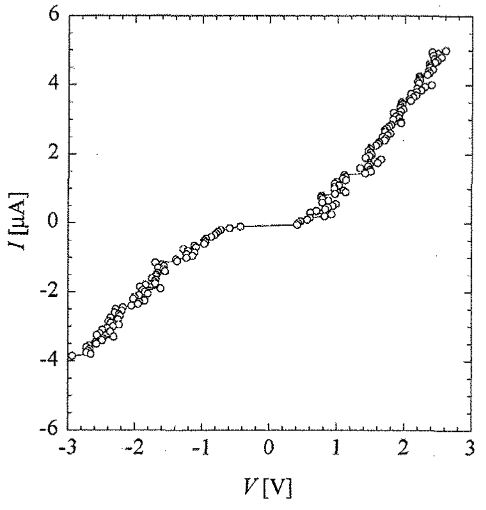


Figure 5: $I-V$ property of the stretched Ni wire pattern.

able to investigate local nanojunction or nanocontact. Therefore we have tried to bend the substrate and make fissures confined in local area. Schematic view of this idea is illustrated in Fig. 6. The direction of folding substrates is parallel or perpendicular to the wire longitudinal direction.

Figure 7 shows the voltage V dependences of the current J and resistance R before and after bending like Fig. 6 (a). The width of the wire is 10 μm and the thickness is 35 nm. As-deposited wire has linear $I-V$ characteristic and R is independent of V excepting the vicinity of the zero bias accompanying the switching noize. After bending J increases in nonlinear manner indicating that the tunneling is dominant in the conduction. R increased by a factor of 12 after bending. Simmons forumula [6] gives the barrier height $\varphi = 4.8$ eV and the barrier thickness $s = 0.52$ nm. The working function of Ni is 4.84 eV and the fitting is in good agreement.

The magnetoresistance (MR) of this sample is shown in Fig. 8. Here the magnetic field is applied in three direction, such as x, parallel to wire, y, transverse to wire, and z, perpendicular to the wire surface. The x and y direction curves for before

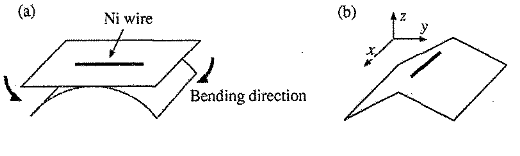


Figure 6: Schematic image of the substrate bending. (a) Fissures run transverse direction to Ni wire. (b) Fissures are parallel to wire. The coodinates definition is explained later.

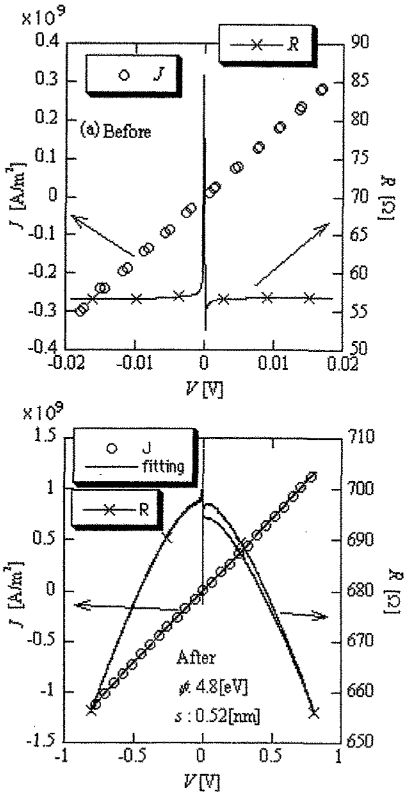


Figure 7: $I-V$ characteristic of Ni wire before and after substrate bending. Fitting curve is after Simmons formula.

bending show the origin of MR is anisotropic magnetoresistance. After bending the x direction does not include sharp change as before bending while the change of MR near $H = 0$ has larger width in y after bending. This might be the result that the magnetization is already in x direction even at $H = 0$ after bending. z direction curve also indicates larger width compared to before bending one. Bending breaks the wire into short blocks and increases the magnetization saturration field.

When we bend the substrate so that the fissures become parallel to wire, a micrograph is shown in Fig. 9, $I-V$ characteristic becomes concave implying the ohmic conduction prevailing. In this case, MR exhibits quite curious nature. After bending 10 μm width wire breaks into 3 wires having alomost equivalent width. MR curves are shown in Fig. 10. x direction MR increases with H mononically while that of y has abrupt switching. Besides, z direction MR is very hard to understand. Sharp magnetization reversal and relatively large coercivity imply that the magnetization eazy axis lies away from the longitudinal x direction. However, two-step switching is not explained by the magnetic anisotropy. More detailed experiments are needed to comprehend this behavior.

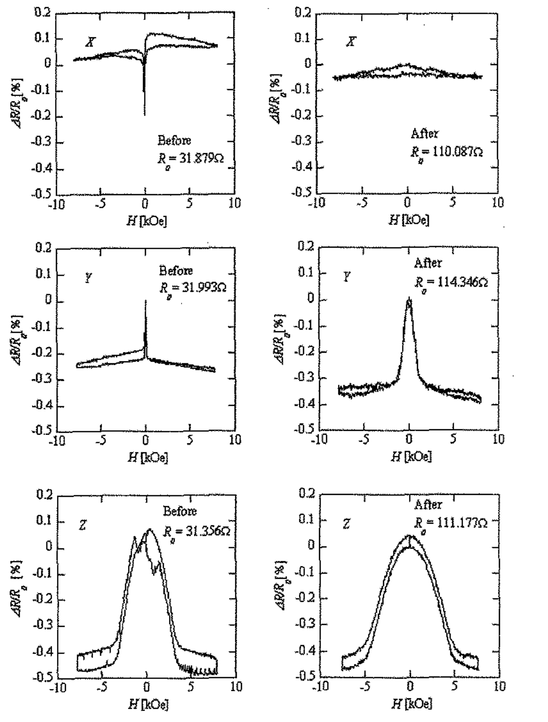


Figure 8: MR curves of Ni wire before and after substrate bending. X, Y and Z are the direction of the applied field.

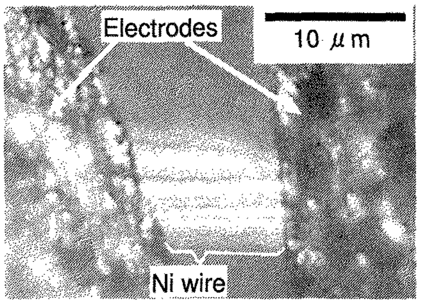


Figure 9: Micrograph of Ni wire after bending. Bending direction is as shown in Fig. 6 (b)

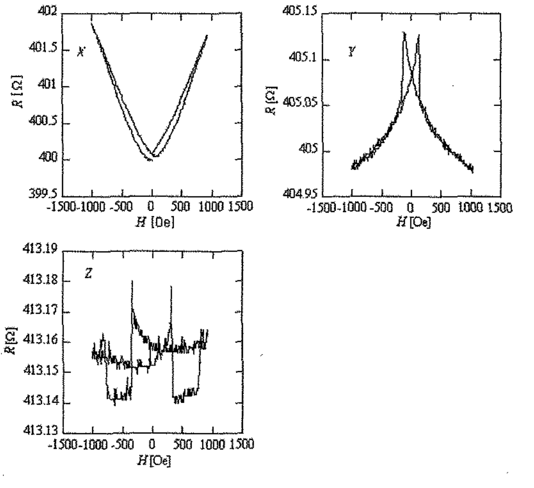


Figure 10: MR curves of the Ni wire having longitudinal fissures. The field was applied in three directions.

4 CONCLUSION

We have prepared micron sized Ni pattern by vacuum evaporation with pin hole mask and movable substrate stage. Plastic substrates enabled fabrication of submicron size dots or wires by means of stretching or bending substrate after Ni deposition. Breaking occured at the columnar boundaries of the Ni film. Broken wires exhibited tunneling conductance and some of the wire had a characteristic of the Coulomb blockade.

Breaking was more favorably controlled by bending the substrates. When the Ni wire was bended so that the fissures run in the transverse direction, only AMR was observed. On the other hand, for the longitudinal fissures AMR having sharp changes in y and z axes appeared. In particular z direction MR curve had two-step magnetization reversal and large coercivity of 800 Oe.

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