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# Formation of Gold Nanowires on MgO Surfaces

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## ABSTRACT

Gold nanowires were fabricated on the stepped MgO (100) surfaces. The stepped MgO (100) surfaces were produced by polishing (100) surfaces at an inclined angle ~1º toward a [110] direction. An atomic force microscope image indicates that gold nanowires have grown at the steps on MgO (100) surface with a height of ~ 2 nm and a width of ~60 nm.

## INTRODUCTION

Recently nano-size materials have been paid attentions due to their diverse potentials in the fields of laser, optics, computer, electronics, biomedical science, and so on. Moreover, the nano-size materials provide the fields to study fundamental physics such as the quantized conductivity and the quantum Hall effect [1].

Regardless of any actual applications at this stage, the gold nanowire formation on MgO (100) surfaces was attempted. As shown later in the experimental results section, we have observed that the annealing single crystalline MgO (100) surface at high temperature in an oxidizing atmosphere can cause the step formation along two possible [110] directions on the (100) surface. By tilt-polishing the surface toward one of [110] directions by an angle of ~1°, we may depress the step formation of the other of two possible [110] directions, as shown in Fig.1.

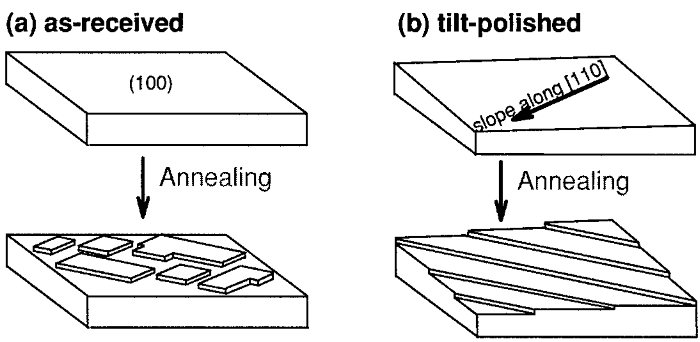



**Figure 1** Schematic model of the regulated steps for the tilt-polished MgO surface. (a) Two possible [110] directional step edges can be formed on an as-received MgO (100) surface. (b) One-directional step edges can be formed on the tilt-polished MgO surface.

Once we obtain such regulated steps, we may fabricate gold nanowires by depositing gold and by a suitable annealing recipe. We expect that gold atoms have the tendency to accommodate at the step sites, and the accumulation of the gold atoms leads to the formation of gold nanowires.

During this research, we have come across a series of recent publications by Himpsel's group [2] in which the step arrays of Si were formed on a Si (111) 7x7 reconstructed surface by miscutting a Si substrate and special annealing procedures. They also deposited $CaF_2$ to make some patterns for the formation of nanowires or quantum dots, which is similar to the way of the lithographic procedures. Their method on Si has been established and the applications are also in a process. For our case, the substrate is a single crystalline MgO that is transparent in visible-near IR range, and it may have an advantage for the optical applications.

## EXPERIMENTAL

The substrates were purchased from Princeton Scientific Corp. (Princeton, NJ) and were cut into smaller pieces suitable for the optical transmission measurements and the atomic force microscopy. The transmission measurements were made with a UV-Vis-NIR spectrophotometer (Hitachi U3501), and the morphologic images were made with an atomic force microscope (AFM, Digital Instrument Nanoscope III). The tilt-polishing was carried out with a home-made polishing device with three kinds of alumina polishing powders with water and with ortho-phosphoric acid. After polishing, the MgO substrates were annealed at 1200°C with a tube furnace in an oxidization atmosphere (an oxygen flowing tube furnace). The annealed substrates were observed with the AFM to see how the steps were formed. Gold was deposited to the substrates by using an e-beam evaporation device (Thermionics model 100-0030) in a high vacuum chamber with a background pressure of $10^{-7}$ torr. The gold deposited samples were observed with the AFM and the transmission measurements were carried out before and after every thermal annealing.

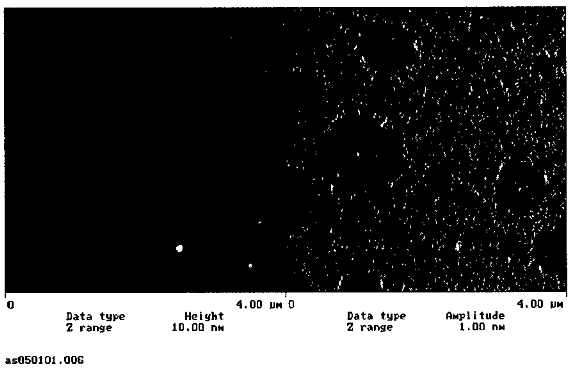
## RESULTS AND DISCUSSION

### The preparation of substrates

Fig.2 shows the AFM images of a flat MgO (a) as-received [4 μm x 4 μm] and (b) annealed substrates [8 μm x 8 μm], which was annealed at 1200°C in an oxidizing atmosphere for 5 h. In every pair of images in this paper, the left image is for the height mode and the right image is for the amplitude mode of Tapping AFM. The sides of the image frames are along the directions of crystal axes [100]. According to our cross-section analysis, the as-received substrate has a roughness of less than 1 nm as rms (the root mean square for the entire image of 512 x 512 pixels). Although it has a fairly flat surface, the morphology does not show an atomically flat surface, as shown in Fig.2 (a). On the other hand, although the annealed substrate has many steps with different edge lengths, there are atomically flat terraces between steps and the average step height is in the order of 1 nm (the cross-section analysis is not shown). The step edges are running along two possible crystal directions of [110].

This step formation along two possible crystal directions [110] of MgO led to the idea that the step arrays along only one direction of crystal axes [110] may be formed by tilt-polishing the substrate toward other [110] direction, as mentioned in the introduction and shown in Fig.1. Although our procedure for tilt-polishing and annealing is not well established yet, we have obtained nearly regulated step arrays. In Fig.3, the AFM images [2 μm x 2 μm] and the cross-section analysis are given for the MgO substrate tilt-polished and annealed at 1200°C in the oxygen atmosphere for 20 h. In Fig.3 (a), the step edges are running nearly along only one of [110] directions, which is diagonally from top-left to bottom-right. There is a crystal-like particle in the middle in this image, which is probably a MgO crystal island that was not completely annealed with the main MgO substrate. In Fig.3 (b), the cross-section analysis shows that the average step height is about 2-3 nm and the separation between steps is in the order of 100 nm.

**(a) As-received flat MgO substrate**




**(b) Annealed flat MgO substrate**

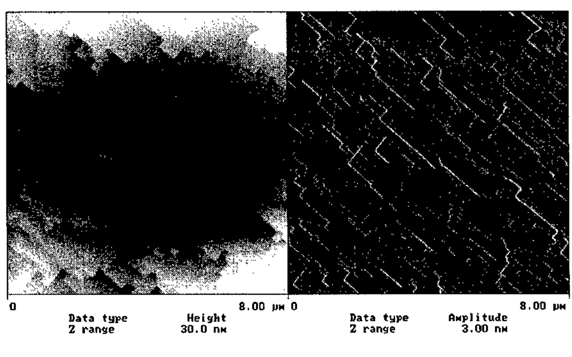
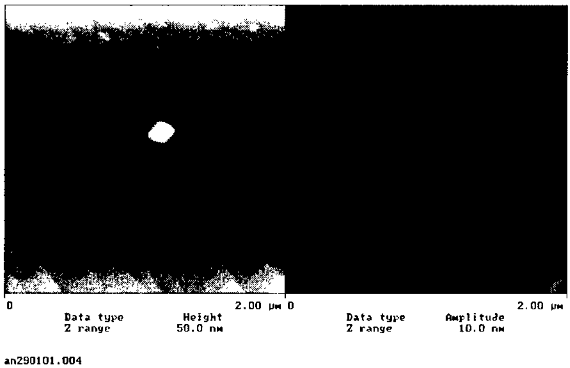



**Figure 2** AFM images of MgO substrates (a) as-received and (b) annealed at 1200°C in an oxidizing atmosphere for 5 h.

## (a) Substrate with the tilt-polishing and annealing




## (b) Cross-section analysis

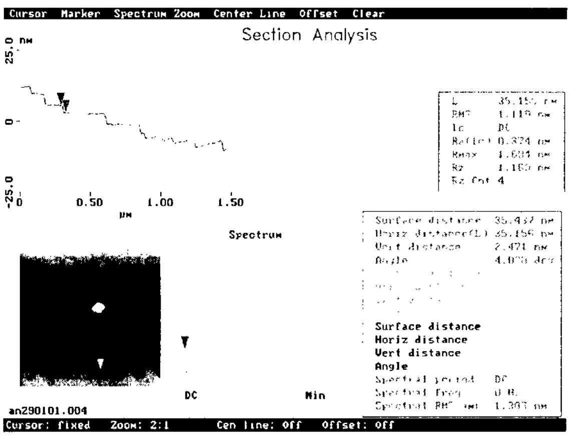



**Figure 3** AFM image of MgO substrate with the tilt-polishing and annealing in $O_2$ at 1200°C for 20 h, with the cross-section analysis.

### The gold deposited MgO

The prepared MgO substrate with the step arrays was deposited with gold of 25 Å by using an electron-beam evaporator and was gradually annealed up to 800°C. Fig.4 shows the AFM images and the cross-section analysis, which indicates that there are higher rims on the step edges. In this image [8 µm x 8 µm], there are several crystal islands, which may interact with steps to disturb the step formation.

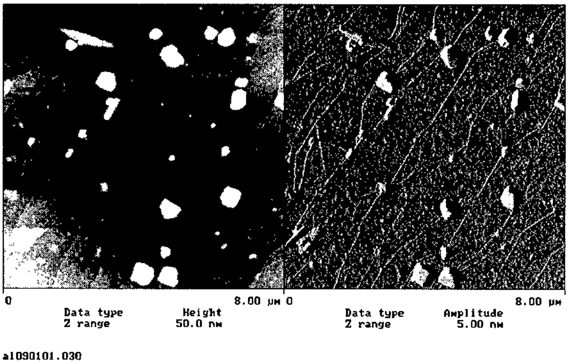



**Figure 4** The AFM images of a MgO surface deposited with gold and annealed. The MgO substrate was prepared by tilt-polishing and annealing, as mentioned in the text, and was deposited with gold of 25 Å by using an electron-beam evaporator and gradually annealed up to 800°C.

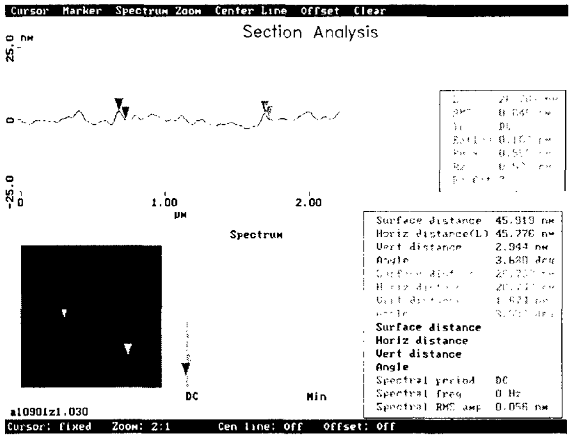
Fig.5 shows the cross-section analysis of a portion of Fig.4. The cross-section that we chose is marked with a line in the small image located at the left-bottom corner of each figure, and the numerical data are shown on the right. Fig.5 (a) shows the heights of two rims, and the rims are higher than the terrace level by ~2 nm. Fig.5 (b) shows the widths of two rims, and their widths are in the rage of 50-70 nm, which includes some uncertainty due to the AFM tip dimension, as known in AFM imaging. As shown in Fig.4, all the rims formed at the steps in the AFM image have similar dimensions, according to our observation.

We claim that these rims are gold nanowires by utilizing the regulated step arrays. There are MgO islands on the substrate, and gold particles are on the terraces as well. For the application purposes, we need to improve the substrate preparation: (1) The elimination of crystal islands, (2) the regulation of the step arrays, (3) the suitable conditions for the deposition of gold to the substrates, and (4) the suitable condition for the annealing of samples to form gold nanowires.

## CONCLUSION

We claim that gold nanowires have been formed by utilizing the regulated step arrays, which were created by tilt-polishing and annealing at a high temperature. At this stage, the preparation of MgO substrates is not well established yet, and there are problems to fabricate gold nanowires: (a) The elimination of crystal islands and the regulation of the step arrays, and (b) the suitable conditions for the deposition of gold and the annealing of the samples. We would like to continue to seek for the solutions to these problems.

**(a) The cross-section analysis for the heights of gold nanowires**




**(b) The cross-section analysis for the widths of gold nanowires**

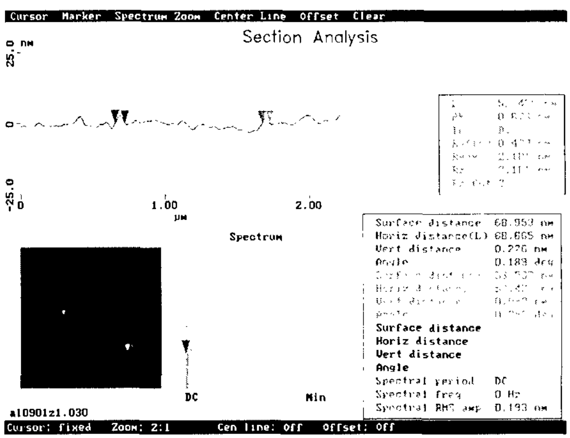



**Figure 5** The cross-section analysis of gold nanowires. The measurement of (a) the heights and (b) the widths for two nanowires.

## REFERENCES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[2] F.J. Himpsel et al. Visit the web site: http://uw.physics.wisc.edu/~himpsel/wires.html and papers therein, *e.g*. J. Viernow et al., Appl. Phys. Lett. **72**, 948 (1998); J.-L. Lin et al., J. Appl. Phys. **84**, 255 (1998); A. Kirakosian et al., Appl. Phys. Lett. **79**, 1608 (2001).