NANOFABRICATION OF SILICON DUE TO TRIBO-CHEMICAL REACTION BY AFM TIPS SLIDING IN ATMOSPHERE

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SUMMARY
Scanning probe microscopy (SPM) has potential for nanofabrication of engineering functional nanometer scale materials and devices. In this study, atomic force microscope (AFM) nanofabrication properties based on tribo-chemical local oxidation due to diamond tip sliding on silicon in ambient atmosphere are studied. AFM tribochemical processing layers are expected to act as etching mask for selective wet etching or direct oxidation. Micro-protuberance and groove processing are performed using diamond tips sliding of an AFM in an atmosphere. To control the height of protuberance and the depth of groove, the processed height and depth dependencies on load and diamond tip radius are evaluated. By using about 100 nm radius tips, both protuberance and groove can be produced. Silicon is removed at higher load and raises at lower load. This phenomenon of protuberance processing with tribochemical reaction is speculated that local atomic destruction of bonds occurs with a concentrated stress. Sliding enhances the reaction of silicon with oxygen and water that exists on the surface or circumstance. This reaction forms silicon oxide, and then processed parts raise. To clarify the possibility of these processed parts of silicon surface for the application to wet etching mask, etching properties with KOH solution are evaluated at room temperature. The sliding of diamond tips produces the silicon oxide layer that works as KOH etching protective mask.

Keywords: Tribo-chemical reaction, Nanofabrication, Atomic force microscope, Silicon, Local oxidation

1 INTRODUCTION
Lithography is one of the most important technologies for the fabrication of nanostructures. Scanning tunnelling microscopy (STM) and related techniques such as scanning probe microscopy (SPM) are useful for the evaluation of microtribological properties [1,2]; these techniques involve scanning with a tip, which includes a piezoelectric element. SPM is promising for the nanofabrication of engineering functional nanometer-scale materials and devices. SPM can realize some critical fabrication of nanostructures. Several attempts have also been made to use SPM techniques for the local deposition and modification of surfaces [3,4]. One of these techniques involves the direct oxidation of silicon [5]. Under ambient conditions, room temperature with humidity ranging between 60% and 80%, the oxidizing agents contained in the absorbed water layer drift across the oxide layer under the influence of a high electric field produced by voltage applied to the probe. This SPM-generated oxide can function as a mask for the etching step, or can be used directly as an insulating barrier.

The mechanical friction method for the fabrication of silicon nanostructures on a H-passivated Si(100) substrate using an atomic force microscope (AFM) in the contact mode in air is another technique[6].

Protuberances are formed on a silicon surface by diamond tip sliding with an AFM [7, 8, 9]. Oxide mask patterns could withstand a selective wet etching process for pattern transfer. If proper mechanical actions due to diamond tip sliding were applied on a silicon surface, mechanochemical local oxidation would be expected. These AFM tribochemical processing layers are expected to acts as etching mask for selective wet etching or direct oxidation.

In this study, AFM nanofabrication properties based on tribochemical local oxidation due to diamond tip sliding on a silicon surface in ambient atmosphere are evaluated. First, nanometer scale protuberance and groove processing are performed using diamond tip sliding with an AFM in atmosphere. The etching properties with the KOH solution of the processed parts are then evaluated.

Figure 1: Micro protuberance tribochemical processing by diamond tip sliding

2 EXPERIMENTAL METHOD
2.1 Processing method
Experimental nanoprocessing method is shown in Fig.1. A diamond tip with a certain load by means of an AFM, Si (100) specimens are driven with a piezoelectric element and slid with diamond tip. 256 times scanning for a vertical direction, to the sliding direction are
performed. Mechano-chemically polished Si (100) wafers are directly slid by diamond tip. Profile changes of processed parts are observed at light load with spreading scanning range. Radii of the diamond tip are about 50 nm, 100 nm and 200 nm.

2.2 Additional KOH solution etching

These oxidized layers are expected to acts as etching mask for KOH solution. Therefore, to apply these processed parts as etching mask, the etching properties of KOH solution are estimated. These processed wafers are then etched in 10 % KOH solution at room temperature. To evaluate the difference of etching rate between processed parts and unprocessed parts, the etched profiles of processed area are evaluated by AFM.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Tribochemical nano processing

A diamond tip of about 200-nm-radius sliding produces nearly 0-3 nm height protuberances on the silicon surface, as shown in Fig.2. The mean height of protuberances processed with 10, 20, 30 (A-A'), 40, 50, 60 (B-B'), 70, 80, 90 (C-C') μ N are 0.4, 1.1, 1.7, 2.1, 2.4, 2.6, 2.7, 2.8 and 2.9 nm, respectively. Protuberance height increases with applied load. About 50-nm-radius diamond tip sliding produces 0-20-nm-deep grooves on the silicon surface at load from 10 to 40 μ N. Plastic deformation and wear debris sediments are accumulated around the processed square grooves, as shown in Fig.3. Groove depth also increases with applied load. In contrast, by using about 100-nm-radius diamond tips, both protuberances and grooves are produced, as shown in Fig.4. Silicon is removed at higher load and raises at lower load.

Model of height increasing processing of the silicon surface speculated from processing properties is shown in Fig.5. This phenomenon of protuberance processing with tribochemical reaction is speculated that local atomic destruction of bonds occurs by a concentrated stress. Sliding enhances the reaction of damaged silicon with oxygen and water that are present on the surface due to the destruction of silicon-silicon bonds. This reaction forms silicon oxide or silicon hydroxide, and thus the height of processed part increases. This tribochemically processed layer thickness is greater than the protuberance height.

In the case in which the radius is 50 nm or 100 nm with a higher applied load, the surface maximum shearing stress exceeds the strength of silicon, and then plastic deformation occurs, followed by the removal of silicon to the sides and front as a result of sliding. However in plastic deformation, oxygen and water also react tribochemically with silicon similar to that, which occurs during height-increasing processing.
The nanoindentation hardness of both processed protuberances and grooves is nearly 10% higher than those of unprocessed parts. Therefore, not a soft silicon hydroxide but a silicon oxide layer is speculated to be formed on the surface of processed protuberances and grooves.

3.2 Tribo-mask for etching

The etching properties with KOH solution of processed parts are evaluated at room temperature. The differences in etching properties between processed parts and unprocessed parts are evaluated by an AFM. Figure 6 shows the profile changes of the protuberances and grooves due to etching with 10% KOH solution. Figure 6 (a) shows the groove and protuberance produced by nearly 100-nm-radius diamond tip sliding. The depth of grooves processed at 80 µN and the height of protuberances processed at 40 µN is about 5 nm and 1 nm, respectively. Figure 6 (b) shows the profiles etched with 10% KOH solution for 30 minutes. The KOH solution selectively etches the unprocessed silicon area, while it negligibly etches the protuberances and grooves processed by diamond tip sliding. The height difference between processed and unprocessed parts is nearly 50 nm. Both processed protuberances and grooves are changed to silicon oxide by diamond tip sliding, as shown in Fig.5. The etched surface profiles are similar to those of the tribochemically processed protuberance and grooves before etching. Therefore, with additional KOH solution etching, the plastic deformation and wear debris sediment of both start and end points of sliding are negligibly etched, unless these layers had extensive damage. These processed silicon oxide layers have chemical etching resistance to KOH solution.

Figure 7 shows the profile change of lines and spaces processed by diamond tip sliding due to KOH solution etching. The 2-µm-long lines, which had 1000 nm distance between them, were formed by diamond tip sliding. Little protuberance could be observed at the centre of sliding lines, by AFM measurement, as shown in Fig.7 (a). After KOH solution etching, the corner lines are clearly observed as shown in Fig.7 (b). The line heights are 40 - 42 nm. The sliding of diamond tips even without a profile change can produce local silicon oxide that functions as a KOH etching protective layer. The sliding of diamond tips produces the silicon oxide layer that works as KOH etching protective mask.

4 CONCLUSIONS

The following results were obtained.

(1) Micro-protuberance and groove processing were performed using diamond tips sliding of an atomic force microscope (AFM) in an atmosphere. The processed height and depth dependencies on load and diamond tip radius were evaluated. About 50 nm radius diamond tip sliding produced 0 - 20 nm deep grooves on the silicon surface at load from 10 to 40 µN.

In contrast, diamond tip of about 200 nm radius sliding produced nearly few nm height protuberances on the silicon surface. By using about 100 nm radius tips, both protuberance and groove can be produced. Silicon is removed at higher load and raises at lower load.

(2) The phenomenon of protuberance processing with tribochemical reaction is speculated that silicon reads with oxygen and water that are present on the surface. This reaction forms silicon oxide, and then processed parts rise.

(3) To clarify the possibility of these processed parts of silicon surface for the application to wet etching mask, etching properties with KOH solution are evaluated. The sliding of diamond tip produces the silicon oxide layer that works as KOH etching protective mask.
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5 REFERENCES


