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Nanoscale Processing on Silicon by Tribochemical Reaction

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The properties and mechanism of silicon protuberance and groove processing by diamond tip sliding using atomic force microscope (AFM) in atmosphere were studied. To control the height of protuberance and the depth of groove, the processed height and depth depended on load and diamond tip radius were evaluated. Nanoprotuberances and grooves were fabricated on a silicon surface by approximately 100-nm-radius diamond tip sliding using an atomic force microscope in atmosphere. To clarify the mechanical and chemical properties of these parts processed, changes in the protuberance and groove profiles due to additional diamond tip sliding and potassium hydroxide (KOH) solution etching were evaluated. Processed protuberances were negligibly removed, and processed grooves were easily removed by additional diamond tip sliding. The KOH solution selectively etched the unprocessed silicon area, while the protuberances, grooves and flat surfaces processed by diamond tip sliding were negligibly etched. Three-dimensional nanofabrication is performed in this study by utilizing these mechanic-chemically processed parts as protective etching mask for KOH solution etching.

Keywords : Microprocessing, Tribochemical processing, Local oxidation, Protective etching mask, Atomic force microscope

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. These techniques involve scanning with a tip that includes a piezoelectric element. SPM is promising for the nano-fabrication 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 [1,2]. One of these techniques involves the direct oxidation of silicon [3]. 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. Protuberances [4] are formed on a silicon surface by diamond tip sliding with an AFM. 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, mechanic-chemical local oxidation would be expected. These AFM tribochemical processing layers are expected to act 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.

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 is driven with a piezoelectric element and slid with diamond tip. Scanning 256 times on a vertical direction along sliding direction are performed. Mechanic-chemically polished Si (100) wafers are directly slid by diamond tip. Profile changes of processed areas are observed at light load with spreading scanning range. Radii of the diamond tip are about 50 nm, 100 nm and 200 nm.

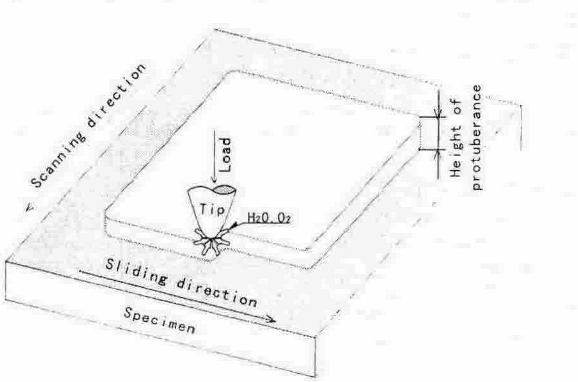

Fig.1 Micro protuberance tribochemical processing by diamond tip sliding

2.2 Additional KOH solution etching

These oxidized layers are expected to act 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

To control the height of protuberance and the depth of groove, the processed height and depth dependencies on load and diamond tip radius were studied. Diamond tip of about 200 nm radius sliding produces 0-5 nm height protuberance on the silicon surface as shown in Fig.2 (a). In contrast, about 50 nm radius tip sliding produces 0-20 nm deep grooves on the silicon surface as shown in Fig.2 (b). Both protuberance height and groove depth increase with increasing applied load. Both protuberance and groove are produced using about a 100 nm radius tip as shown in Fig.3. Silicon is removed at higher load and rises at lower load [5]. The hardness of processed parts is higher than that of unprocessed parts, therefore, oxidation of silicon is speculated to be caused. In the case of 50 or 100nm tips, surface maximum shearing stress becomes larger than strength of silicon, a plastic deformation occurs and then silicon is removed to side and front.

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. Fig. 4 (a) shows the groove and protuberance produced by nearly 100-nm-radius diamond tip sliding. The depth of grooves processed at 80 μ N and the height of protuberances processed at 40 μ N are about 5 nm and 1 nm, respectively. Fig.4 (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 n m . Both processed protuberances and grooves are changed to silicon oxide by diamond tip sliding [6]. The etched surface profiles are similar to those processed tribochemically 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.

4. REFERENCES

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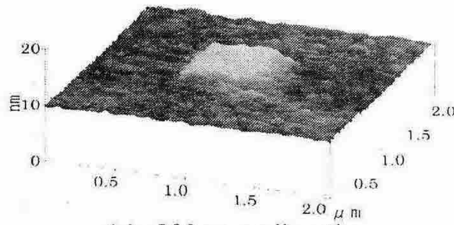
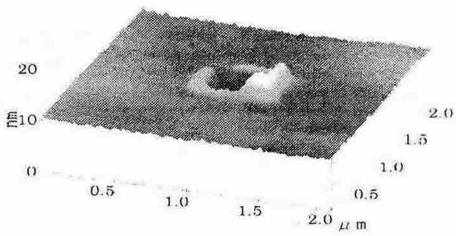


(a) 200nm radius tip



(b) 50nm radius tip

Fig.2 Micro protuberance and groove profiles Processed

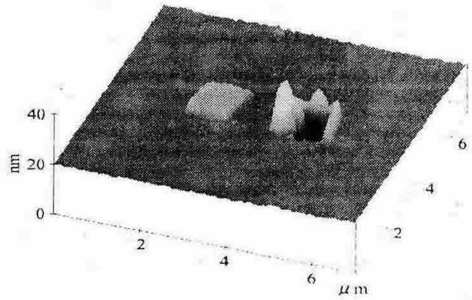
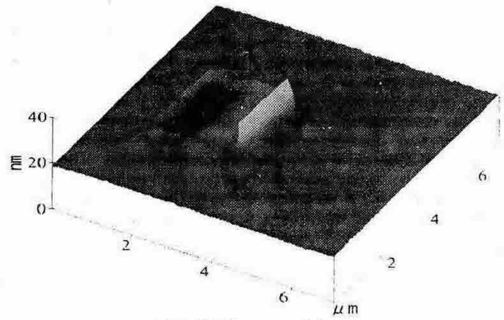
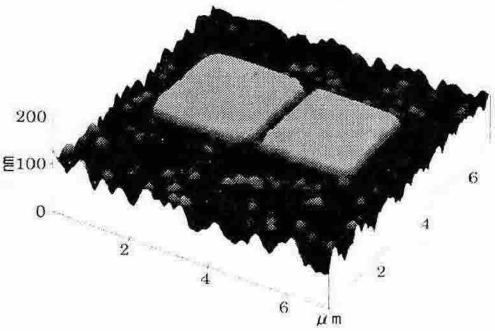


Fig.3 Protuberance and groove processed by 100 nm radius diamond tip sliding



(a) Before etching



(b) After etching

Fig.4 Profile changes of protuberance and groove due to additional KOH solution etching