A Study on the Fabrication of Micro Structure using Chemical Mechanical Micro Machining Process

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ABSTRACT

The dimensions of structures are generally determined by the size of the mechanical tool in the mechanical micro machining process. However, the size of the mechanical tool is limited by the mechanical properties of the tool, such as elasticity limit, yield strength, fracture and buckle that is caused by the machining resistance force. To overcome these drawbacks and enhance the surface quality and form accuracy in mechanical micro machining, this study proposes a new method of micro machining with the aid of chemical solutions. The chemically reacted layer on the substrate restricts the plastic deformation of work material and results in the lower machining force, tool wear reduction and high form accuracy compared to other methods. The characteristics of the chemically reacted layer were analyzed in terms of thickness, hardness change, indentation test, and scratch test. From the groove machining test results, the proposed process proved to be effective.

Keywords : Si wafer(100), chemical solution, chemically reacted layer(CRL), potassium chloride(KOH), chemical mechanical micro machining

1. INTRODUCTION

The micro fabrication technology is increasingly advanced with the industrial development such as medicine, aerospace. Moreover, the research and products of MEMS (Micro Electro Mechanical System) based semi-conducts process have been developed over the world. However, it is necessary not only to induce complicate system but also complex process with mask. In micro mechanical machining, unlike etching or photolithography technique, it is required to overcome the increased shear stress on the substrate [1]. As the resisting shear stress is radically increased in case of machining the microstructure according to the reduction of depth of cut, it is difficult to remove the diminutive material efficiently unlike the macro machining. As a result, the general micro mechanical machining is difficult to get the high machine-ability and fine surface quality. The curve in the Figure 1 shows that as the chip thickness becomes smaller, the resisting shear stress at the cutting edge of a solid bite tool becomes extremely large, approaching the theoretical shear stress [2,3].

There are several basic studies to fabricate the microstructure by mechanical micro tool. K. Tagashira studied about the generation mechanism of microchip on the steel with chemically reacted layer. It was observed that the chemical absorption at the cut chip and the much dislocation area. Generating the reacted layer reduced working force and progressed surface roughness [4]. M. Yoshiro studied on the silicon scratch test. It was confirmed that micro mechanical machining in the high hydrostatic pressure had reduced the micro fracture [5].

In this study, the chemical mechanical micro machining process was proposed. The chemical solution generates a new layer with different quality on the material surface. The analysis of the chemically reacted layer on the material surface is a very importance in this process. The thickness, hardness change, indentation test, and scratch test of the chemically reacted layer were done and evaluated. Figure 2 is shown the basic procedure schematic diagram of the chemical mechanical micro machining process. The generation of the chemically reacted layer has priority over mechanical machining.

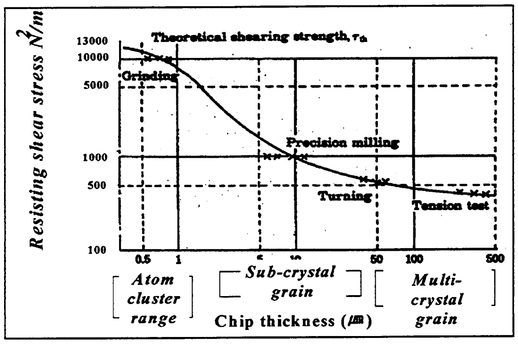


Figure 1 Relation between chip thickness and resisting shear stress

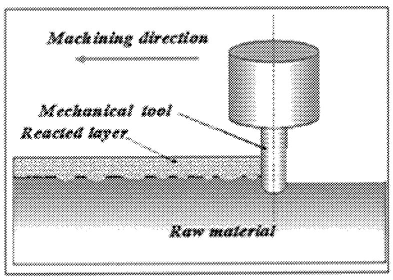


Figure 2 Schematic diagram of chemical mechanical micro machining process

2. EXPERIMENTAL SETUP

The system for mechanical micro machining is shown in Figure 3. The resolution of X, Y, and Z axis has 0.1μm order. Specially, the PZT with the minimum incremental 0.01μm was attached on the Z axis for the control of the cutting depth. The workpiece was hold by vacuum holder on the substrate. The load cell with 0.01g level order was located the substrate below. It used to detect the mechanical tool contact point, and measure the machining force.

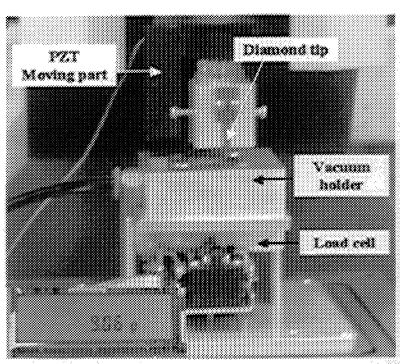


Figure 3 Experimental setup for chemical mechanical micro machining process

3. ANALYSIS

To apply the chemical mechanical micro machining process, as one of the examples for chemical mechanical micro machining, Si (100) wafer of the brittle nonmetallic material was chosen. The properties of Si wafer as the brittle material are very well known. It can take advantage of prior work. In this section, the generation and the analysis of the chemically reacted layer were done.

3.1 Generation of the CRL

The material removal mechanism of brittle material consists of many brittle failure phenomena such as crack, brittle fracture, cleavage, etc. To avoid brittle failure damage in the surface, the surface quality of Si wafer was changed by the chemical solution. To make the hydrated layer on the Si wafer, the potassium hydrate (KOH) was used as the chemical solution. Table 1 shows the conditions of the chemical solution. The KOH 10wt% solution meets pH 12 by the buffered chemical (acetic acid), and changes Si-O to $Si(OH)_4$ on the Si wafer. The chemical reaction equation is shown below.

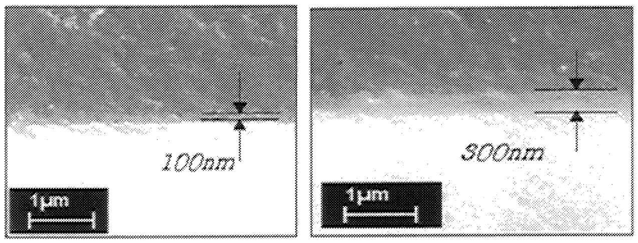
$$\equiv \text{Si-OH} \Leftrightarrow \text{Si-O-} + H^+$$

Table 1 condition of chemical solution

Chemical solution	KOH
Concentration	10 wt%
PH	12
Buffered chemical	Acetic acid
Ambient temperature	Room

3.2 Thickness of the CRL

The thickness of the chemically reacted layer is observed through the SEM image and XPS analysis. As shown in Figure 4 (a), (b), the thickness of the chemically reacted layer is not clearly shown because the layer has a continuous mode between the changed surface and the raw material. But the thickness of the chemically reacted layer is about 100nm, and 300nm in the case of 5 min, or 10 min dipping time, respectively. To clearly define the layer thickness in the case of 5 minute dipping time, XPS analysis was used (Figure 5). From the XPS depth profile, the thickness is about 80nm in the case of 5 minute dipping time. The hydrated layer that is compulsively generated acts on the reduction of the micro fracture, and decreases the working force.



(a) dipping time : 5 min (b) dipping : 10 min

Figure 4 SEM image of the CRL(section view)

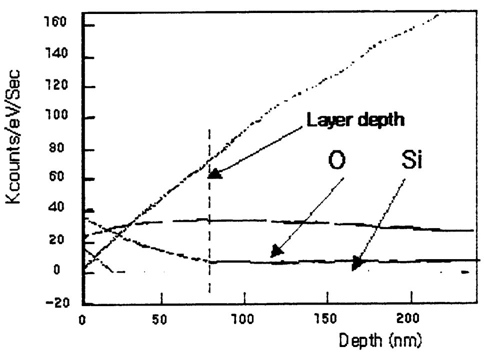


Figure 5 XPS depth profile of the CRL (dipping time : 5 min)

3.3 Hardness

To identify the changed surface property, the micro hardness test was performed. The concentration rate of chemical solution is 0wt%, 5wt%, 10wt%, 20wt%, 50wt%. The graph of Figure 6 shows the test results in 10minute dipping time. Increasing the chemical concentration from 0wt% to 50wt% of KOH, the hardness is reduced from 365.3[HV] to 293.8[HV]. From this result, it is certain that the chemical solution over 10wt% makes the soft layer on the Si wafer. As the optimal chemical concentration condition that did not etch the surface, KOH 10wt% was used.

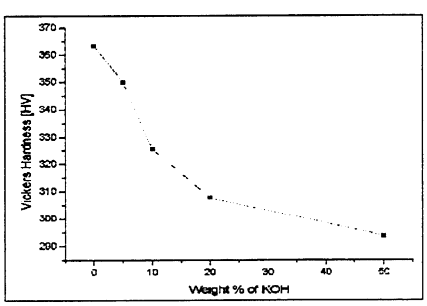
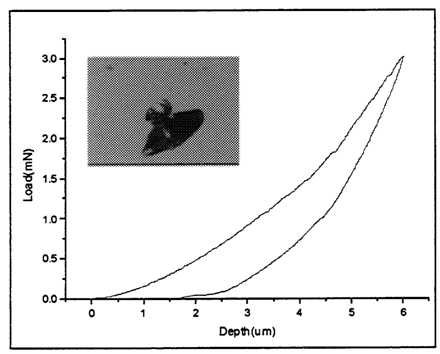


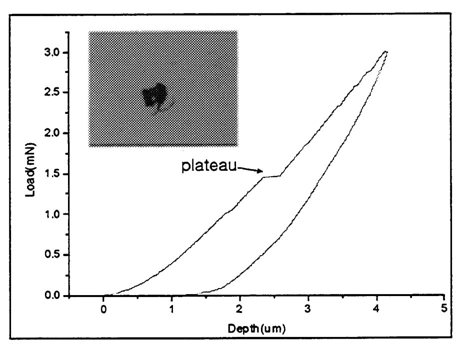
Figure 6 Relation hardness and chemical concentration

3.4 Indentation test

In order to understand how the chemically reacted layer works, the experimental condition associated with micro indentation testing was done. The plastic deformation characteristic of the indented material is accounted for by relaxing the elastic deformation loading stresses through both the introduction of new nucleated discrete dislocations and their motion within the sample. The observations of the indent-induced plastic volume and analysis of the experimental loading curve help in defining a complete set of nucleation rules. As shown in Figure 7 (a), (b), the fracture on the surface with chemical layer is smaller. The hardness and modulus value of silicon wafer (a) is 1473.3[Hv], 103.43Gpa, respectively. In the case of silicon surface with the chemically reacted layer (b), the hardness and modulus value was 48.67[Hv], 57.768Gpa, respectively. It is thought that the chemically reacted layer restricts the micro crack and fracture generation. From the experimental results, the micro channel with 5μm in the line width was fabricated (Figure 4).



(a) KOH 0wt%, silicon wafer (100), loading force : 3N, loading / unloading rate : 3N/min



(b) KOH 10wt%, silicon wafer (100), loading force : 3N, loading / unloading rate : 3N/min

Figure 7 Indentation test result and optical image

3.5 Scratch test

To identify the effect of crack occurrence restrict on the CRL, scratch test was carried out. Table 2 is shown the conditions of the test. The load is increased along with the cutting direction from 0.03N to 0.1N. The chemical solution was 0, 10, 20 wt%, and the specimens were dipped during 10 minutes. As shown in Figure 8, the frictional force is extremely raised when the load applied over 0.05N. In the case of KOH 20wt%, the friction force is as three times as higher than KOH 0wt%. The micro crack was occurred over applied load 0.05N. Figure 9 is shown the SEM image of micro crack comparison. From above analysis results, micro groove with 5μm width was fabricated (Figure 10).

Table 2 Conditions of scratch test

Start point (N)	0.03N
End point (N)	0.1N
Speed (mm/min)	16.53
Length (mm)	10
Diamond tip	20μm(radius)
Chemical solution	KOH 0,10,20wt
Dipping time (min)	10

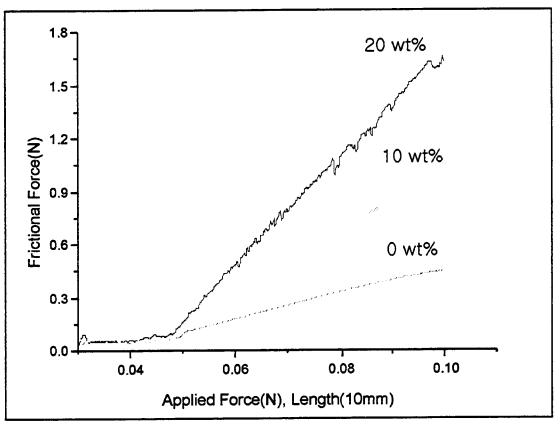
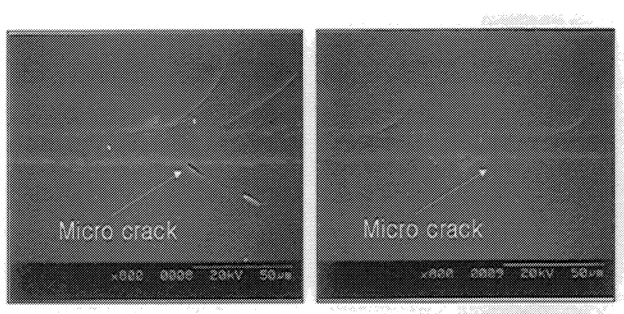


Figure 8 Comparison of frictional force



(a) KOH 0 wt% (b) KOH 10wt%

Figure 9 Comparison micro crack (load : 0.05N)

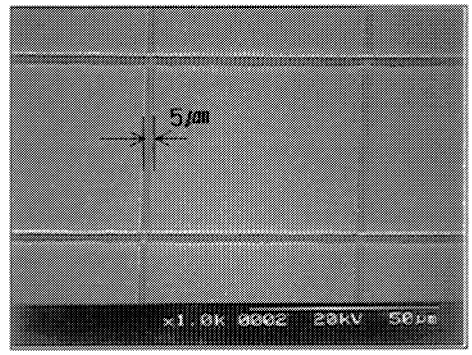


Figure 10 Fabricated micro grooves using chemical mechanical micro machining process

4. CONCLUSION

It is an important to understand and analyze the chemically reacted layer in this process. For the analysis of the reacted layer, the micro indenter, scratch tester, XPS analysis were used. It is confirm that the chemically reacted layer on the silicon wafer reduces the micro crack and facture generation. The chemically assisted micro mechanical machining gave an advantage over the groove machining with narrower and deeper grooves in comparison to the conventional machining.

From the hardness test results, the optimal concentration of the chemical solution was KOH 10 wt%. To improve the chemical reacted layer effect, the groove machining was carried out.

REFERENCES

[1] T. P. Leung, W. B. Lee, X. M. Lu, Diamond turning of silicon substrates in Ductile-regime, Journal of Materials Processing Technology, 73 (1998) 42-48.

[2] Norio Taniguchi, NANOTECHNOLOGY, oxford university press, (1996) 15-16.

[3] K. Liu, X. P. Li, Ductile cutting of tungsten carbide, Journal of Materials Processing Technology, 113 (2001) 348-354.

[4] Kohsuke, TAGASHIRA, Japan Society of Precision Engineering, The Chip Formation Mechanism of Orthogonal Cutting for Pure Iron Coated with Dilute Oleic Acid, Vol. 66, No. 12, 1917-1921, 2000

[5] M. Yoshiro, International Journal of Mechanical Sciences, Some experiment on the scratching of silicon : In situ scratching inside an SEM and scratching under high external hydrostatic pressures, Vol. 43, 335-347, 2001