Mechanical nano machining of Si wafer by quantitative determination of ductile/brittle-machining transition point

Eun-chae Jeon[1,2], Na-Ri Kang[3], Kyu-Min Lee[1], Jin-Ho Cha[1], Ju-Young Kim[3], Yun-Hee Lee[4], Tae-Jin Je[1,2], Doo-Sun Choi[1]
[1]*Dept. of Nano Manufacturing Technology, Korea Institute of Machinery and Materials, Korea*
[2]*Dept. of Nanomechatronics, University of Science and Technology, Korea*
[3]*School of Mechanical and Advanced Materials Engineering, Ulsan National Institute of Science and Technology, Korea*
[4]*Div. of Industrial Metrology, Korea Research Institute of Standards and Science, Korea*
jeonec@kimm.re.kr

Keywords: Nano machining, Si wafer, Ductile/brittle-machining, Transition point

Abstract

Si wafer was mechanically machined at nano scale based on quantitative determination of the ductile/brittle-machining transition point in this study. It was possible to determine the transition point by investigating the abnormal decrease of the cutting force. The machined patterns had sharp V-shapes, which pattern is hard to machine using lithography technology; the patterns had no brittle fractures nor any burrs.

1. Introduction

It is much important to fabricate or machine nano patterns on Si wafers in the field of nanotechnology. Generally, nano patterns on a Si wafer are fabricated by chemical machining methods coupled with lithography technology. However, it is difficult to use these methods to machine V-shape patterns, which are the most important shape in the optics fields. On the other hand, mechanical machining methods using diamond tools can machine various types of pattern shapes, including V-shapes, with low cost. Severe brittle fracture phenomenon (brittle-machining) is generally observed, as shown in Fig. 1, when Si wafers are mechanically machined. However, some papers have reported that Si wafers can be machined without brittle fractures at very low force and small depth scale [1,2]. These papers reported a ductile-machining phenomenon by simply using an SEM or an optical microscope; quantitative analysis was insufficient. Therefore, the transition force of ductile-machining to brittle-machining was determined quantitatively and nano patterns without brittle fractures were mechanically machined in this study.

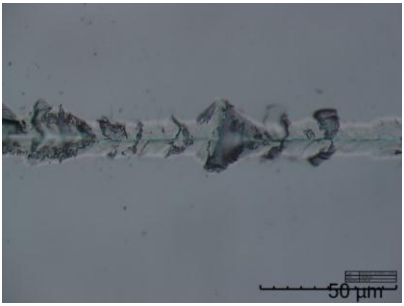

Figure 1: An example of a brittle fracture around a machined pattern on a Si wafer

2. Experimental procedures

Normal/lateral forces and displacements at nano scale should be measured simultaneously during the mechanical machining in order to achieve the purpose of this study. Since general planning systems and dynamometers are not suitable for this condition, a nano scratch tester (Nano Indenter G200, Agilent), was selected in this study. Generally, a nano scratch tester is used to measure adhesion and wear properties of thin films at nano scale. However, the nano scratch tester has a similar structure and its test procedures are much similar to the machining procedure. The nano scratch tester uses various types of indenters which match with machining tools and measures normal/lateral forces and indentation depth in-situ which allows it to match with the cutting force and the depth of cut, respectively. Therefore, the nano scratch tester can be used for nano machining.

Increasing the force from 0mN to 400mN, we machined a pattern on a Si wafer with a V-shaped diamond tool (a Berkovich tip) in order to determine the transition point from ductile machining to brittle machining. The Si wafer was machined again at a force lower than the force of the transition point, and the shape of the machined nano patterns were measured by SEM and AFM.

3. Results and discussion

There were three different machining regions in the machined pattern (Fig. 3): no brittle fracture (region 1, ductile-machining), discontinuous brittle fracture (region 2, ductile/brittle-machining) and fully brittle fracture (region 3, brittle-machining). We matched the shape of the machined pattern with the force data extracted from the nano scratch tester directly, and found that the lateral force fluctuated when discontinuous brittle fractures were occurred in region 2 as shown in Fig. 3. Since the first fluctuation indicated the first brittle fracture and indicated the transition point of ductile-machining to brittle-machining, we assumed that only ductile-machining would be occurred under the force of the first fluctuation point.

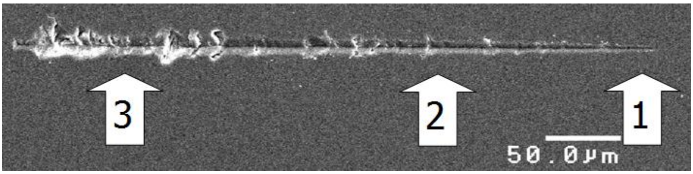

Figure 2: A nano scratch tester used for nano machining of a Si wafer

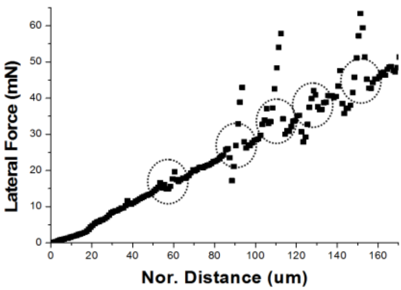

Figure 3: Lateral force data versus normal distance of the machined pattern

Five nano patterns were machined on the Si wafer at a fixed force value smaller than the force of the first fluctuation. There were no brittle fractures nor burrs at any of the nano patterns shown in Fig. 4, as if the Si wafer were a metal. The profiles of the machined nano pattern were measured by AFM at three points; these profiles showed almost the same sharp V-shapes, as expected and as shown in Fig. 5. Therefore, it was verified in this study that a V-shape can be machined mechanically on a Si wafer by quantitative determination of the transition point from ductile-machining to brittle-machining.

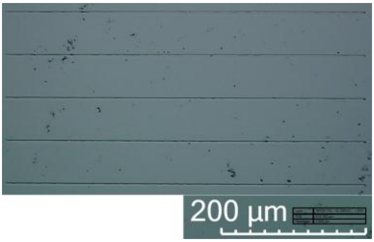

Figure 4: Five machined nano patterns having no brittle fracture nor burr on a Si wafer

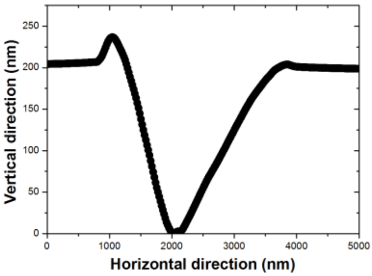

Figure 5: Profiles of the machined nano pattern measured by AFM

4. Conclusions

A Si wafer was machined mechanically without brittle fractures or burrs under the force of a transition point from ductile-machining to brittle-machining. The transition point was determined quantitatively by analyzing the fluctuation of the lateral force.

References:

[1] P. N. Blake et al., “Ductile-Regime Machining of Germanium and Silicon,” J. Am. Ceram. Soc., **73**, pp. 949-957, 1990.

[2] T. P. Leung et al., “Diamond turning of silicon substrates in ductile-regime,” J. Mater. Proc. Tech., **73**, pp. 42-48, 1998.

[3] J. Gong et al., “Micro- and nanopatterning of inorganic and polymeric substrates by indentation lithography,” Nanoletter, **10**, pp. 2702-2708, 2010.