Development of SFM System for Nano In-Process Profile Measurement

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나노인프로세스 표면형상계측을 위한 SFM시스템의 개발

권현규*, 최성대*, 홍성욱*

ABSTRACT

In this paper, we propose a new multi-purpose Scanning Force Microscope (SFM) system. The system can be used for nano/micro-scratching, in-process profile measurement, and observation of potential surface defects which occur during the scratching in air or liquid. Experimental results of nano/micro-scratching show that the smallest scratching depth can be controlled to be 10nm, which corresponds to the stability of the SFM system. Profile measurements of nano/micro-scratching surfaces have also been performed by the method of on-machine measurement and in-process measurement. Two measurement results were in good agreement with each other. The maximum difference was approximately 10 nm, which was mainly caused by the sampling repeatability error that influences the measurement accuracy. Also, micro-defects on the micro-scratching surface were successfully detected by the SFM system. It was confirmed that the number of micro-defects increases when the surface is subjected to a cyclic bending load. The maximum depth was less than 100nm.

Key Words: Probe, In-Process Profile Measurement, Scratching, SFM(Scanning Force Microscopy)

1. Introduction

There is an increasing demand for precision machining of high quality surfaces. One of the most important conditions for machining of high quality surfaces is the measurement method and control of the cutting depth in nano-meter level. It is also necessary to image surface damages\cite{1-3} with nano-meter resolution. Profile measurement of the surface during the machining (In-process Measurement)\cite{4-5} compared to profile measurement of the surface after the machining (On-machine Measurement) is an effective approach to make clear the cutting depth and the surface damage.

On the other hand, Scanning Force Microscopy (SFM) including Atomic Force Microscopy (AFM) has long been used to image the micro surfaces\cite{6-8}. In addition, the cantilever of AFM is a promising tool for micro-mechanical machining. In this case, it is essential to improve the stiffness of the cantilever. However, the measurement force of the contact mode AFM will also
increase simultaneously. As the results, the measurement force may cause the surface damages during the scanning. In this paper, we developed a new SFM system in which the machining (scratching) force can be controlled over a wide range while keeping the measurement force small. The new SFM system can also be used in following multi-purpose: (1) In-process profile measurement and micro-scratching test, (2) Measurements of micro defects of the scratched surfaces.

![Fig. 1 Configuration of the SFM System](image)

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![Fig. 2 Schematic of probe unit](image)

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![Fig. 3 Incident angle of the laser beam](image)

**Fig. 3 Incident angle of the laser beam**

![Fig. 4 Bending Unit in the SFM System](image)

**Fig. 4 Bending Unit in the SFM System**

2. A New Scanning Force Microscopy

2.1 Configuration of the system

Fig. 1 shows the set-up of the proposed SFM system. The system consists of five parts, which are (1) probe unit, (2) liquid container, (3) laser angular sensor, (4) X/Y scanning stage, and (5) bending unit to generate bending displacement of sample.

Fig. 2 shows the schematic of the probe unit. The probe unit is composed of a cantilever for measuring the surface and a load adding lever for nano/micro scratching. A PZT actuator (PZT1) is used to move the cantilever on which a diamond tip is attached. The probe can be used not only in profile measurement but also as a nano/micro scratching tool. The output of the angle sensor, which is proportional to the variation of the bending angle of the cantilever, is used as a feedback signal to the servo PZT(PZT1). However, it is difficult to scratch the surface of a brittle material by the cantilever because the cantilever does not have enough stiffness to generate a large force. To solve this problem, another actuator PZT2 and a load adding lever are arranged over the tip of the cantilever. The concept to use a load adding lever to generate a large machining force has already been proposed in a micro-machining probe. However, because the material of the load adding lever was a steel, the laser beam could not go through the lever. Therefore, the sensing point of the cantilever deflection angle was set in the
middle of cantilever, and the angular sensitivity of
deflection was too low. In this paper, the glass was
chosen as the material of the load adding lever. As a
result, the laser beam goes through the load adding
lever and the sensing point is set at the end of lever
where the highest angular sensitivity can be obtained.
In addition, the angular sensor employs the principle of
optical lever method. In this method, however, if the
laser beam is projected onto the cantilever with a
nonzero incident angle, an error will be caused in the
angular sensor output when the fulcrum of the
cantilever moves in Z direction as shown in Fig. 3 (b).
It is not a problem in the stage driven type but in
cantilever driven type shown in Fig. 1. For this reason,
incident angle is set to be zero so that the error can be
removed. The new SFM system has also the ability to
make in-process measurement of surface defects. An
unique bending unit can perform three-point bending in
this system. Fig. 4 shows the schematic of the bending
unit. It consists of a PZT actuator and a sample holder.
The center of the sample (Silicon wafer thickness 200
μm) is pressed by the PZT3, which is used as a load
generator to bend the sample. The sample is measured
by the SFM during the bending process.

2.2 Performance of the system

In order to investigate the measuring and the
micro-scratching performance of the SFM system,
stability of displacement detection, repeatability of
profile measurement, and the relationship between load
and angular sensor output were investigated. Fig 5
shows the feedback voltage variation under a stable
condition, which indicates the stability of displacement
detection of the SFM. It can be seen that the SFM
system drifted approximately 15nm in 5 minutes. Fig 6
shows the profile measurement result and the
repeatability error (the difference between the first
profile measurement and the second profile
measurement on the same surface) under the conditions
of Table 1. Examination of which can be used to
determine micro-scratching force, was obtained by
indentation experiments. Fig 7 shows the experimental
results. The indentation depth increased with the applied
voltage to PZT2 that was proportional to the deflection
of the load adding lever.

![Graph 1: Drift of SFM system](image1)

![Graph 2: Repeatability error](image2)

### Table 1 Measurement conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Precision grid plate</td>
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<tr>
<td>Sample material</td>
<td>Silicon wafer</td>
</tr>
<tr>
<td>Depth of groove(μm)</td>
<td>150</td>
</tr>
<tr>
<td>Stiffness of cantilever(N/m)</td>
<td>1</td>
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<tr>
<td>Material of cantilever</td>
<td>Stainless steel</td>
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<tr>
<td>Tip radius(μm)</td>
<td>Less than 100</td>
</tr>
<tr>
<td>Measurement area(μm)</td>
<td>10×10</td>
</tr>
<tr>
<td>Image pixels</td>
<td>100×20</td>
</tr>
<tr>
<td>Scan speed(mm/s)</td>
<td>0.2</td>
</tr>
<tr>
<td>Contact load(1-V output V)</td>
<td>0.8</td>
</tr>
</tbody>
</table>
3. Experimental Results

3.1 Surface measurement results

Based on the indentation results in Fig. 7, 2-dimensional micro-scratching and on-machine profile measurement were carried out (Fig. 8). As shown in this Fig. 8, micro-scratching was done over an area of A with a large scratching force generated by the load adding lever. After the scratch, the force was released and the surface was measured over an area B by the same probe. Fig. 9 shows a on-machine profile measurement. The sampling interval was 0.1μm. The sample was mounted in the container, which was fixed on the sample holder as shown in Fig. 1. The micro-scratching length (A) was 5μm with a cutting depth ranging from approximately 20nm to 100nm in proportion to the voltage of PZT2. The cutting and measurement were performed in pure water. Fig. 10 shows the scanning pattern of 3-dimensional micro-scratching. The scratching surface was measured by the on-machine measurement method. The result is shown in Fig. 11. The measurement area is larger than the cutting area which is the same as the 2-dimensional case. The result shows that the center part of the surface was clearly scratched in Fig. 11. The scratched surface profile was also measured during the scratching. The feedback signal, which corresponds to the output of the angular sensor, was sampled by a voltage meter and was taken into a personal computer via GP-IB. This signal indicated the profile height in micro-scratching. Fig. 12 shows the result of profile measurements of the surface during the scratching (In-process measurement).
3.2 Comparison of in-process measurement and on-machine measurement

Fig. 13 shows 3-dimensional results of the same micro-scratching surface measured by the in-process measurement and the on-machine measurement. Fig. 13(a) shows the result of in-process measurement, and 13(b) shows that the on-machine measurement. The two results were in good agreement with each other.

Fig. 13(c) shows the difference of the two results. The maximum difference was approximately 10nm, which was mainly caused by the sampling repeatability error that influences the measurement accuracy.

4. Measurement of Surface Defects

4.1 Experimental method

Micro-defects on the micro-scratching surface were observed by the new SFM system. First, sample (Silicon wafer thickness 200μm), which was placed on the bending unit, was scratched by the SFM system. It was measured by the SFM system under different bending conditions continuously. In order to investigate the surface damage effect by the cyclic-bending, a cyclic-bending test was performed. A function generator was used as the bending stage controller to apply a cyclic bending load to the sample. The deflection of
sample was 500nm and the frequency was 10KHz.

4.2 Experimental results

Fig. 14 show measurement results of the micro-defects around the scratching area. Fig. 14(a) shows the result without bending the sample. Defects, which usually occur during micro-scratching, could not be observed in this measurement. Fig. 14(b) and Fig. 14(c) show the results after cyclic-bending for $6 \times 10^7$ times and $1.8 \times 10^7$ times respectively. It can be seen that micro-defects around the micro-scratching surface begin to occur in Fig. 14(b), and the number and size of defects (irregular lines on the surface) increased in proportion to bending times. The result confirmed the new SFM system to detect the micro-defects.

![Fig. 14(a) 3-dimensional surface measurement before bending.](image)

![Fig. 14(b) 3-dimensional surface measurement after bending(0.6x107times).](image)

Fig. 14(c) 3-dimensional surface measurement after bending(1.8x107times).

5. Conclusions

The above results are summarized as follows:

1. A new multi-purpose SFM system has been designed and constructed. This system can perform micro-scratching and in-process profile measurements. The results of scratched show that the smallest scratching depth can be controlled to be 10nm, which corresponds to the stability of the SFM.

2. Micro-defects on the scratching surface have been observed. It is confirmed that the number of micro-defects increases when the surface is subjected to a cyclic bending load. The maximum depth was less than 100 nm.

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References


