Development of Multi-Ball-Cantilever AFM System for Measuring the Profile of Soft Thin Film Surface

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Abstract

We proposed the method of using a multi-ball-cantilever AFM for measuring the surface profile of soft thin film. At first, we performed the computer simulation to verify the feasibility of this method. Then, we developed the multi-ball-cantilever AFM system using a multi-ball-cantilever that had 8 cantilevers in 2 mm and each cantilever had the ball stylus with 10.9 µm of diameter. The fundamental experiments were carried out using this system and we confirmed the feasibility for measuring the surface of soft thin film with high speed and high accuracy.

1 Introduction

As the demand for high efficiency of semiconductor manufacturing industry, the surface profile of photo resist material, known as a kind of soft thin film with less 500 nm thickness, on the wafer is strongly hoped to be measured with high speed and high accuracy. Usually, AFM (Atomic force microscopy) is used to measure the surface of the material with high accuracy. However, if the measurement object is softer than the AFM stylus tip, AFM may deform it in measurement, and the speed is limited because AFM can measure the only narrow area. In order to realize high accuracy and high speed for measuring the surface profile of soft thin film, we proposed the method of using a multi-ball-cantilever AFM (Fig. 1), which has more than one cantilever for wide area and high speed in measurement and each cantilever has the ball stylus with diameter to avoid the plastic deformation of measured surfaces. Therefore, in this research, to verify the feasibility of this proposed method, we performed the computer simulation that reflects the relationship between the shape,

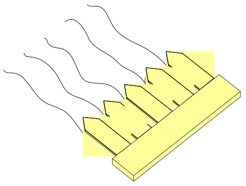
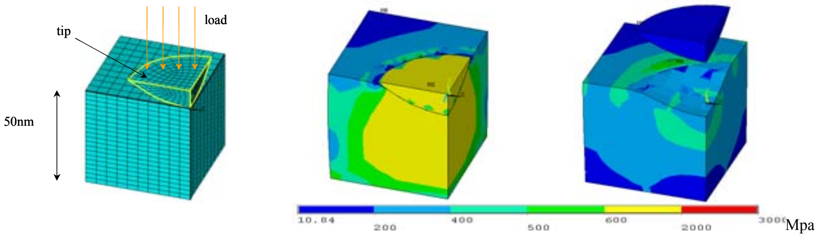


Figure 1: The multi-ball-cantilever.

size and load of the indenter and the deformation of resist surface with FEM (Finite Element Method). Then, according to the simulation, we developed the multi-ball-cantilever AFM system using a multi-ball-cantilever that had 8 cantilevers in 2 mm and each cantilever had the ball stylus with 10.9 µm of diameter.

2 Indentation simulation by FEM

To investigate the influence of the AFM stylus on the resist surface, the nonlinear structural analysis were simulated with analysis software ANSYS using the finite element method. It was assumed to push into resist by spherical silicon indenter. By physical symmetry, 1/4 area was analysed with an element model like Fig. 2 (a) for the case of AFM stylus of 100 nm diameter. One stress deformation result when the indenter was pushed in the resist of 10 nm was shown in Fig. 2(b) and (c). Fig. 2 (b) showed the maximum loading and (c) illustrated the stress distribution and the plastic deformation after the process of unloading. As the result, the corresponding plastic deformation was confirmed after the unloading process. This simulation confirmed that the surface of resist was transformed plasticity by the AFM stylus. Then, the simulation analysis of the relationship between diameter of the stylus and the value of the plastic deformation was examined using seven kinds of stylus diameters of 10 nm, 20 nm, 50 nm, 100 nm, 1 µm, 10 µm and 100 µm. From the simulation, it was known that the diameter was bigger the plastic deformation was difficult to be caused by the same force. We also find when the maximum stress was more than the yield stress and begins to generate the plastic deformation [1]. In the next section, we used the ball stylus with 10.9 µm diameter which is safe with the force smaller than 99.43 µN.



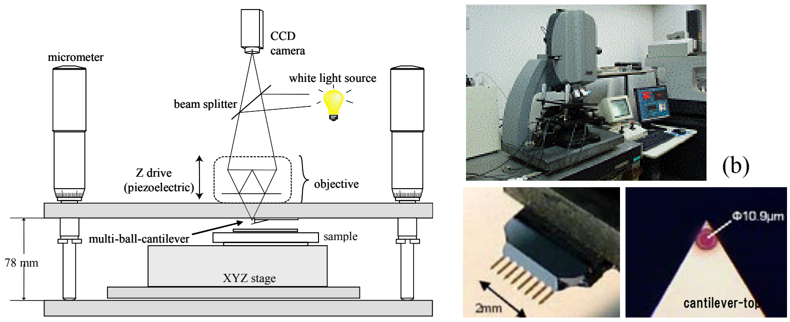
(a) element model (b) stress distribution (c) plastic deformation

Figure 2: Element model, calculated stress distribution and plastic deformation for the case of AFM stylus of 100 nm diameter. (b) Step with the max force and (c) Step after the indentation test.

3 Development of the multi-ball-cantilever AFM system

We designed the multi-ball-cantilever AFM system, multi cantilever with balls, to measure the surface of the material shown in Fig. 3(a). The main parts of this system were composed by a white light interferometer, a three-axis stage with built-in stepping motors and piezo actuators, and the multi-ball-cantilever. The sample was set on the work plane over the three-axis moving table. As a white light interferometer, NewView 5000 of Zygo Corporation was adopted. Based on white light scanning method, it could detect height information with height resolution of 0.1 nm.

The stepping motors and piezo actuators drive three axes in the system. The moving range of piezo actuators was 20 µm and the resolution is 0.1 nm by the condition of close loop. The moving range of stepping motor was 4 mm and the resolution is 25 nm. Shown as the photographs in Fig. 3 (b), (c), (d), the multi-ball-cantilever was using 8 cantilevers in 2mm and each cantilever has the ball stylus with 10.9 µm of diameter. The spring constant of cantilever was 0.03 N/m, and the thickness was 1.0 µm.



(a) (c) (d)

Figure 3: (a) Construction of multi-ball-cantilever AFM system. (b) Photograph of multi-ball-cantilever AFM system. (c), (d) Photographs of the multi-ball-cantilever.

4 Fundamental experiments

At first, using this system, we measured the step height standard with 52 nm in height and 100 µm in width [1]. We obtained the measurement value of 53.04 nm. The standard deviation was smaller than 2nm and this experimental result represented high accuracy.

Then, we tried to measure the thin film of resin material with the thickness of about 400nm shown in Fig. 4. The measurement method was shown in the Fig. 5. We used three cantilevers of multi-ball-cantilever to scan the surface along the line. Only one cantilever could be in contact with the sample, the other balls came in contact with the reference plane. By calculating the relative value, the height of each part of the thin film could be measured. Comparing to the ordinary white light interferometer, we obtained the results shown in the Fig. 6. Fig. 6 (a) was the measurement result by the white light interferometer and (b) was the result by the multi-ball-cantilever AFM system. From these results, we knew the thin film material could be measured using the multi-ball-cantilever AFM system, but it was difficult to be measured by the white light interferometer because of the multi reflection. These results showed the feasibility for measuring the thin film using this developed system.

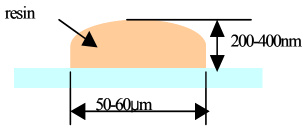


Figure 4: Model of resin material.

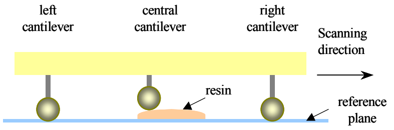
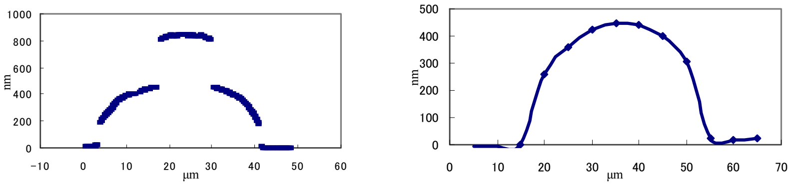


Figure 5: Measurement method.



(a) by white light interferometer (b) by multi-ball-cantilever AFM system.

Figure 6: Measurement results of resin material.

5 Conclusions

We developed the multi-ball-cantilever AFM system according to the simulation results and carried out the fundamental experiments using this system. As a result, it was confirmed that the developed system could measure the step height standard with high speed and high accuracy. We also confirmed that thin film like resin material could be measured by the multi-ball-cantilever AFM system.

Acknowledgement

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References:

[1] S. Liu, S. Nagasawa, S. Takahashi and K. Takamasu, “Profile Measurement of Resist Surface Using Multi-Ball-Cantilever AFM”, SPIE-ISOT 2005, 6049-3, 2005