Intelligent Profile Measurement for Wide-Area Resist Surface Using Multi-Sensor AFM System

Shujie Liu, Kentaro Watanabe, Satoru Takahashi, Kiyoshi Takamasu

Department of Precision Engineering, the University of Tokyo
Hongo 7-3-1, Bunkyo-ku Tokyo, JAPAN

Keywords: Photoresist Measurement, Thin Film, Multi–Ball-Cantilever, White Light Interferometer, Error Separation.

Abstract. In the semiconductor industry, a device that can measure the surface-profile of photoresist is needed. Since the photoresist surface is very smooth and deformable, the device is required to measure vertical direction with nanometer resolution and not to damage it at the measurement. We developed the apparatus using multi-cantilever and white light interferometer to measure the surface-profile of thin film. But, this system with scanning method suffers from the presence of moving stage and systematic sensor errors. So, in this paper, an error separation approach used coupled distance sensors, together with an autocollimator as an additional angle measuring device, was consulted the potentiality for self-calibration of multi-cantilever. Then, according to this method, we constructed the experimental apparatus and do the measurement on the resist film. The results demonstrated the feasibility that the constructed multi-ball-cantilever AFM system combined with an autocollimator could measure the thin film with high accuracy.

Introduction

As the demand for high efficiency of semiconductor manufacturing industry, the surface profile of photoresist material, known as a kind of soft thin film with about 500nm thickness, on the wafer is strongly hoping to be measured with high accuracy and high speed. In this report, we want to develop the mechanism to realize 10-nanometer order resolution in tens of mm width measurement.

Usually, We use light scan method to measure the surface profile quickly and highly accurately without contact, etc, con-focal microscope and white light interferometer. Here, the problem is that the thickness of resist is known as less 500 nm. When we measure it with light scan method directly, the optical properties of thin films will arise from interference and reflection. So we cannot measure the thin film right. On the other hand, the usual AFM (Atomic force microscopy) can take measurement by a probe 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 is used in micro area measurement. Since the photoresist surface is very smooth and deformable, the device that can measure the surface profile of photoresist is required to measure vertical direction with higher resolution than the horizontals and not to damage it at the measurement.

We proposed a measurement technique combining optical measurement (white light interferometer) and mechanical contact (multi-ball-cantilever) to solve the above problems and constructed the apparatus, which covered a wide area at high speed [1]. Each cantilever had a ball stylus with a diameter that did not plastically deform measured surfaces. Fig. 1 shows multi-ball-cantilever AFM concept. In measurement, probe, which is with size, is touched to the sample, then, the upper surface of probe is measured by white light interferometer with high resolution, and so the surface profile of sample is available. It is possible that measuring the large area by scanning the multiple probe cantilever with white light interferometer. Here, we use the feature, high speed of optical mechanism and no-reflection of AFM probe-cantilever, to achieve the demand for resist surface measurement.

In measurement, the multi-ball-cantilever is fixed, and the sample is moved to contact the cantilevers. The profiles of touched cantilevers are scanned by the white light interferometer.

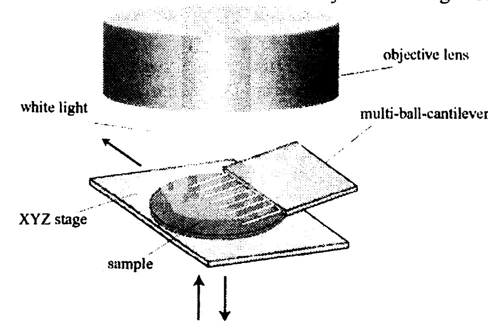


Fig. 1 The multi-ball-cantilever AFM system concept: The multi ball cantilever is fixed, and the sample is moved to contact the cantilevers. The profiles of touched cantilevers are scanned by the white light interferometer.

Error Separation Approach

Scanning topography measurements using systems of multiple cantilevers suffer from the presence of scanning stage and systematic sensor errors [2] [3]. In this research, we aim to solute this problem by a kind of error separation approach, which used coupled distance sensors, together with an autocollimator as an additional angle-measuring device, proposed by Elster [4]. The topography is reconstructed by the application of least-squares, and the uncertainty associated with the reconstructed topography is derived. The gain in accuracy due to accounting for scanning stage and systematic sensor errors can be large, and high accuracies can be reached. The potentials and limitations of such a proceeding have assessed by Elster.

The model of multi-ball-cantilever and the autocollimator is shown in Fig. 2. The sensor system consists of M coupled single-distance sensors aligned along the scanning direction, the x-direction. A mirror is attached to the multiple distance sensor system, and an autocollimator is used for the additional angular moving stage measurements. The autocollimator, the moving stage carrying the sample, and the multi-ball-cantilever are rigidly fixed to the table. While the sample is moved to touch the multi-cantilever by the moving stage, from the (fixed) autocollimator and the white interferometer measurements in each of its positions, we lead to the model relation

$$\begin{aligned} y_j(x_n) &= f(x_n + D_j) + e_y(x_n) + D_j \cdot e_p(x_n) + u_j, \\ y_a(x_n) &= e_p(x_n) + u_a, \quad j = 1..M, \quad n = 1...N, \end{aligned} \tag{1}$$

where $y_j(x_n)$ denotes the distance of the j th sensor at the n th position of the scanning system from the topography. It is composed by the unknown systematic sensor errors u_j, the scanning stage errors e and the topography $f(x_n + D_j)$. $y_a(x_n)$ is moving part of the scanning stage measured by autocollimator in each of its positions. It is composed by j th systematic sensor error of autocollimator u_a and the pitching error $e_p(x_n)$.

The relations are compactly written as

$$\mathbf{Y} = \mathbf{AX}, \tag{2}$$

where **Y** denotes the measurements vector, and **X** denotes the unknown vector involving topographies. When **A** is satisfied the condition to reconstructing the topography by the application of least-squares, we would achieve to separate the presence of the considered scanning stage and systematic sensor errors.

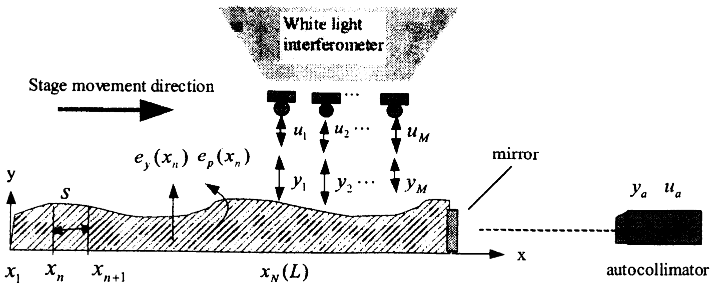


Fig. 2 Scanning system of coupled distance sensors, together with an autocollimator as an additional angle measuring device. A mirror is attached to the moving stage. The autocollimator, the moving stage carrying the sample, and the multi-ball-cantilever is rigidly fixed to the table.

Construction of Multi-Ball-Cantilever AFM System

According to this proposal, we constructed a multi-ball-cantilever AFM system involving a multi-cantilever with balls to measure the surface of resist film shown in Fig. 3.

The white interferometer used for the experimental studies is a ZYGO NewView6300. Using the interference strength detection method FDA (Frequency Domain Analysis), NewView6300 can detect height information with a height resolution of 0.1 nm and profile heights ranging from 1 nm to 15000 μm. As a new feature, white LED with high brightness combined with the optical system of halogen lamp is added to NewView6300, and it can measure the surface of the sample with a high aspect ratio. On software, the new film application is used to measure the thin film from 1.5μm to 50μm in thickness. In this system, an XY stage (COMS PT100C-50XY) and a Z stage (PI P-541.TCD) are used to move the sample stage. The resolutions are 1μm and 0.8 nm respectively. The multi-ball-cantilever is NANOWORLD Arrow TL8-50 used 8 cantilevers spaced 250 μm apart, and each cantilever holds a ball stylus 10.9 μm in diameter. The spring constant of the cantilever is 0.03 N/m. According to multiple sensor approach, the autocollimator (5LAB HAWK-301HR) is set in the multi-ball-cantilever AFM system for self-calibration, and the autocollimator resolution is 1".

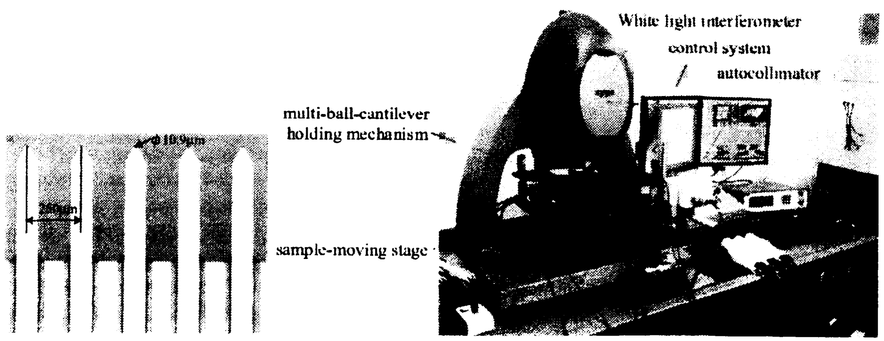
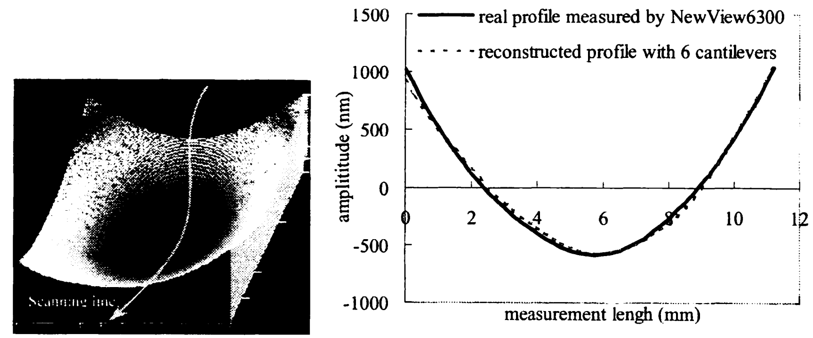


Fig. 3 The multi-ball-cantilever and the photography of multi-ball-cantilever AFM system.

Experiments

We carried out the scanning experiments on resist surface. A sample of resist film is about 25μm in thickness applied on the silicon wafer. Here we derive the surface profile of resist by the thin film application of NewView6300, which can detect the thickness and surface profiles of thin film from 1.5 μm to 50 μm in thickness. The sample profile image is shown in Fig. 4 (a). The height is about 1600 nm in the scanning length of 11.25 mm.

In the experiment, we use 6 cantilevers to calculate the resist profile. The scanning interval is 250μm. The benefit of additional autocollimator in combination with the proposed system can be confirmed. Fig. 4 (b) shows the reconstructed surface profile. Height of about 1600 nm is obtained. The average deviation in every measurement point to the real profile is 31.3 nm.



(a) Resist sample (b) Reconstructed resist profile by error separation method

Fig. 4 Measurement on the resist surface.

Summary

In order to measure the surface profile of resist film, we developed the multi-ball-cantilever AFM system, in which according to the scanning stage and systematic sensor errors of system we constructed the autocollimator. Then we did the experiment in resist material with 11.25 mm in width and 1600 nm in height. The topography is reconstructed with the deviation of 31.3 nm. The developed mechanism was verified possibility to measure the resist material in high accuracy.

References

[1] Shujie Liu, Shuichi Nagasawa, Satoru Takahashi and Kiyoshi Takamasu: *Journal of Robotics and Mechatronics*, Vol.18, No.6, 12(2006), 698-704.
[2] Satoshi Kiyono and Wei Gao: *Prec Eng*, 16, 3 (1994) 212-218.
[3] Wei Gao, Jun Yokoyama, Hidetoshi Kojima, Satoshi Kiyono: *Prec Eng*, 26 (2002) 279-288.
[4] Elster C, Weingärtner: *Prec Eng*, 30, 1 (2006) 32-38.