Development of residual layer thickness measurement system for nano-imprint lithography based on near-field optics

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Abstract

In order to realize nano-imprint lithography (NIL) as a highly reliable lithography technique for the next-generation semiconductor fabrication process, it is seriously necessary to measure the thickness of the residual resin layer with thickness of several 10 nm remaining between the imprinted patterns and the substrate. In this paper, we discuss a novel optical measurement method for the residudal layer thickness (RLT) of nano-imprint lighograpy based on near-field optics, the lateral resolution of which does not depend on the diffraction limit due to the wavelength. These theoretical and experimental anlyses suggest the proposed method has the possibility of measuring the RLT within 80 nm range with a few nm resolution by evaluating the near-field optical responses.

1 Introduction

Nano-imprint lithography (NIL) [1], which can manufacture nano structures, is highly expected as a possible technique for reaching the next-generation lithography requirements for 32nm nodes and below [2] . But in nano-imprint lithography process, a thin resin film with thickness of several 10nm remains as a residual layer between the imprinted patterns, so it should be eliminated by reactive ion etching. In order to implement this etching process with high accuracy and to maintain the original patterns for realizing NIL as a highly reliable lithography process of semiconductor, it is seriously necessary to measure the residual layer thickness (RLT) of resin film before the etching process. The conventional optical measurement method for a film thickness such as ellipsometer, cannot be applied to RLT measurement of NIL. Because the lateral resolution of conventional optical method has reached physical limits imposed by the light wavelength. On the other hand, the cross-sectional scanning electric microscopy does not fulfill the non-invasiveness though it has a high resolution. In order to overcome these serious problems, we have proposed a novel measurement method of RLT based on the near-field optics [3]. In this proposed method, the RLT can be evaluated not by using propagating light like conventional optical method, but by using near-field light, in which the lateral resolution is independent of the light wavelength (Figure1).

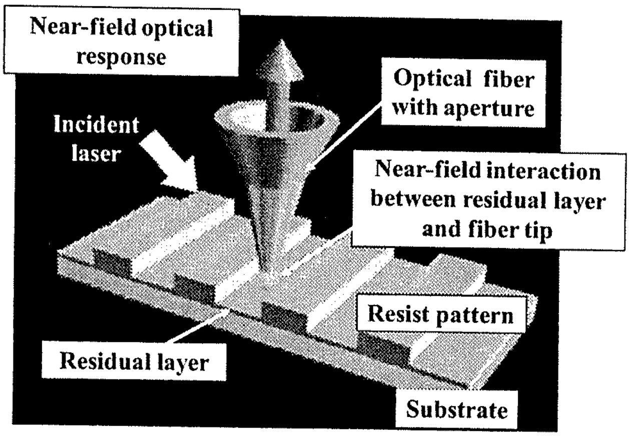

Figure 1: Concept of proposed method

2 Numerical simulation using FDTD method

In this study, we performed the Finite-Difference Time-Domain (FDTD) simulation[4], which is based on the maxwell's equations, to give a discussion of the near-field optical response from the resin thin film. The FDTD simulation model employed in this research is shown in Figure.2. Here, we chose the fracturing cell sized 5nm cubes and the simulation range 1000nm x 1600nm x 1700nm respectively. As an initial study, we dealt with the flat resin layer to analyze the interaction between the near-field light and the resin thin film. The optical fiber is positioned above the resin layer on the substrate. This fiber, which is coated with 10nm gold film, has a 50nm aperture on its apex. As a light source, a laser (wavelength is 633nm) illuminates around the apex of the fiber from the left side with an incident angle 45 degrees. The refraction index of the air, the resin layer, the substrate and the core of the fiber are

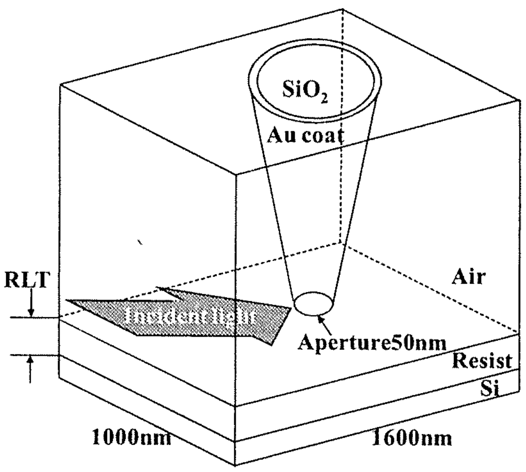

Figure 2: FDTD simulation model

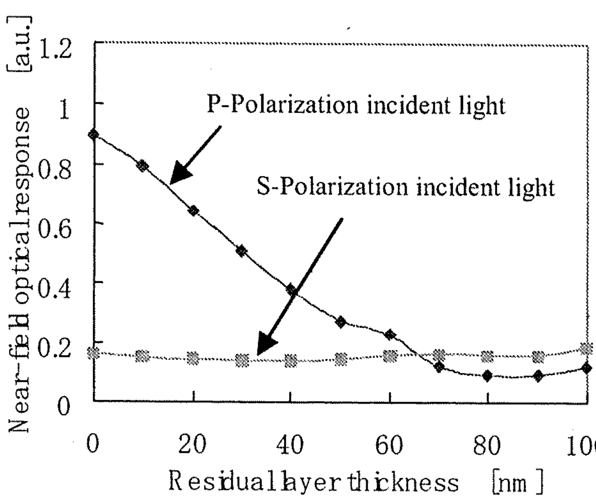

Figure 3: Simulation results

1.000, 1.456, 3.882 and 1.450 respectively. Under these conditions, we calculated the intensity of the light propagating into the fiber as the near-field optical response (NOR). Figure 3 shows the relationship between the RLT and the NOR. It can be seen that the NOR under the p-polarization incident light condition decreases almost linearly with the RLT while the NOR under the s-Polarization incident light condition remains constant. This means the proposed method has a possibility of measuring the RLT within 80 nm range using the NOR evaluated values.

3 Development of RLT measurement system based on near-field optics

For verification the feasibility of our proposed method experimentally, we have developed a basic experimental apparatus as shown in Figure 4. Linearly polarized light from a He-Ne laser (λ=633nm) is incoming onto a sample which is placed on an x-y piezo electronic actuator stage. The polarization angle can be controlled using a half wave plate. For detection of the NOR, a tapered optical fiber with the aperture size of 120nm, which is coated with 150nm gold film (JASCO Corporation), is employed to probe the near-field light of the sample. This optical fiber is fixed on the tuning fork and vibrated to the resonance frequency for the shear-force distance control [5]. The NOR signal through the optical fiber can be sensitively detected with the photomultiplier tube. We performed fundamental experiments using the developed

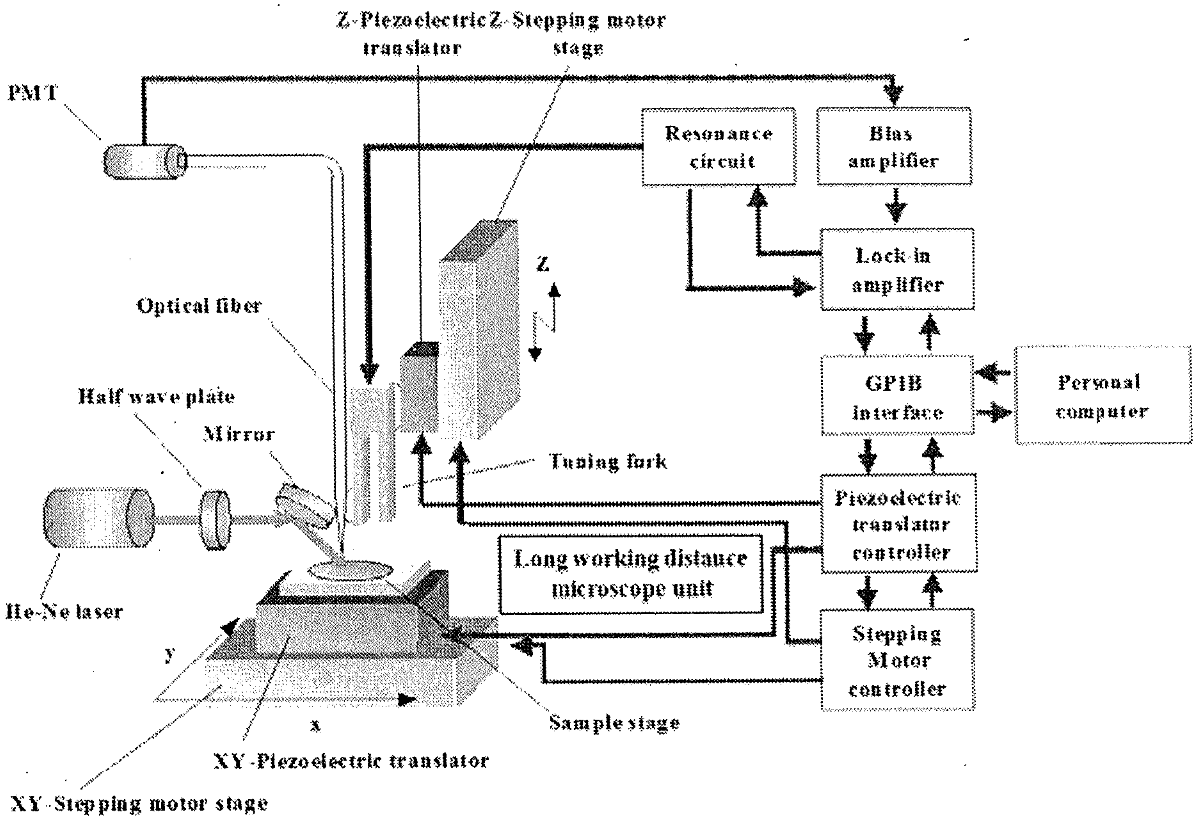

Figure 4: Residual layer measurement system based on near-field optics

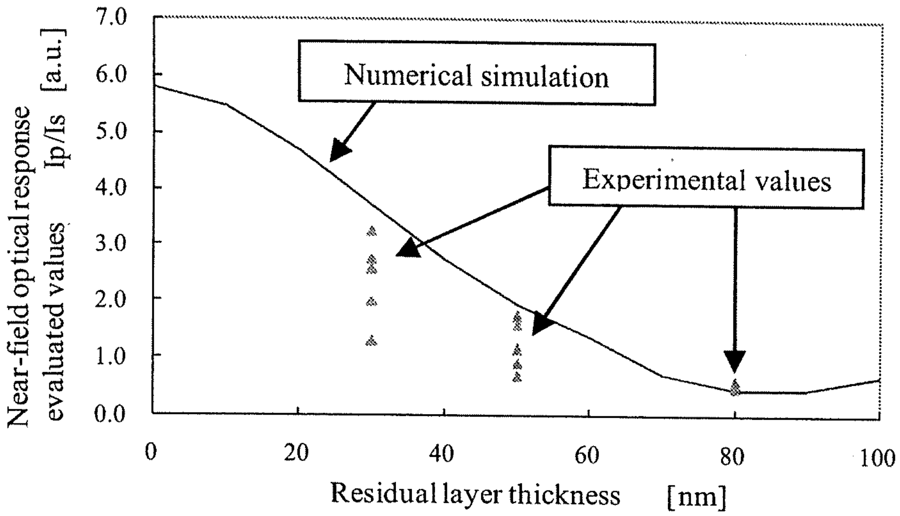

Figure 5: Relationship between NOR evaluated values Ip/Is and RLT

system mentioned above. A nano-imprint sample coated with UV sensitive resin (PAK-01) on a silicon substrate was employed in the fundamental experiments. These imprint samples were made using a mold without patterns, as the imprint loadings changed from 3kgf to 10 kgf. Figure 5 shows the relationship between the NOR evaluation values obtained changing the polarization of the incident light and the RLT. From these results, it is true that the deviation is not small especially in the thinner samples, but the qualitative characteristics obtained with these average values are almost similar to the numerical simulation.

4 Conclusions

In order to verify the feasibility of the residual layer thickness (RLT) measurement method based on near-field optics, we have developed the near-field optical response detection system of nano-imprint sample. The FDTD numerical simulations and the fundamental experiments suggest the proposed method has the possibility of measuring the RLT within 80 nm range nondestructively.

Ackowledgement

The authors would like to profoundly thank Dr. Ina of CANON Inc., Dr. Wada of Molecular Imprints Inc. and Dr. Hiroshi Goto of Toshiba machine Co., Ltd. for their valuable discussions and provision of nano-imprint samples.

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