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THIN FILM THICKNESS MEASUREMENT FOR EVALUATION OF RESIDUAL LAYER OF NANO-IMPRINT LITHOGRAPHY USING NEAR-FIELD OPTICS

Minamiguchi S., Usuki S., Takahashi S., Takamasu K.
Department of Precision Engineering, The University of Tokyo
Hongo 7-3-1, Bunkyo-ku Tokyo, 113-8656, JAPAN
E-mail: m-ssyyuu11@nano.pe.u-tokyo.ac.jp

Abstract: *Since a thin resin film with thickness of several 10nm remains as a residual film between the imprinted patterns and the substrate in the nano-imprint lithography process, it should be eliminated by reactive ion etching. To implement the 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 thickness of the residual resin film before the etching process. In this article, we proposed a novel optical measurement method for the residual film thickness based on the near-field optics. As a result, the near-field optical responses are affected in relation to the film thickness and a distance between the resin surface and a fiber apex. We concluded that it is possible to measure the thin film thicknesses within 80nm with a few nm resolution by evaluating the near-field optical responses.*
Key words: *nano-imprint lithography, near-field optics, residual layer thickness, optical inspection*

1. INTRODUCTION

Nano-imprint lithography (NIL) (Chou et al., 1996), which can manufacture nano structures, is highly expected as a possible technique for reaching the next-generation lithography requirements for 32nm nodes and below (ITRS, 2006). Generally, since NIL process is unique to other nano-sized lithography techniques, NIL has such advantages that the throughput is very high (Plachetka et al., 2004) and the equipment cost is low. This NIL principle is very simple as shown in Fig.1. The first step is an imprinting process. A mold of quartz with nano-patterns on its surface is pressed into a resin layer on a substrate. The mold duplicates its protrusion patterns. The second step is the resin hardening process. The duplicated patterns are hardened by means of UV lamp exposure transmitting through the mold. Thus, reversed stamp pattern transfers on the substrate. At next step, the mold is released from the resin. Here, a thin resin layer with thickness of several 10nm remains as a residual film between the imprinted patterns and the substrate. So at the final step, the residual resin layer is eliminated by means of reactive ion etching (RIE).

To apply this NIL to semiconductor fabricating process, a critical issue is the residual layer thickness (RLT) varies due to a distribution of the mold, an intensity of pressing force and an origin of resin. Then this non-uniformity causes RIE errors. To implement the etching process with high accuracy and to maintain the original patterns for realizing NIL as a highly reliable process of semiconductor, it is recognized that measuring the RLT before etching process is seriously necessary.

There are two requirements for the measurement of the RLT. One is high lateral resolution, which needed for measuring RLT between patterns of NIL. The other is non-invasiveness. Compared with conventional methods for measurement of a film thickness, the white light interferer and the ellipsometer, which measure by using propagating light, can not apply to the NIL process due to a lack of a lateral resolution. In addition, the cross-sectional scanning electric microscopy (SEM) does not fulfill the non-invasiveness though it has a high resolution. Consequently, there has been no method to meet these demands for the process of NIL. Therefore, in order to reduce and control yield loss in the NIL process, a novel measurement method for the RLT is strongly required.

In this article, we proposed a measurement method based on near-field optics. As an initial report, at first, we discussed an optical interactive mechanism between near-field light and resin thin film, then confirmed a feasibility of the proposed method by mean of performing computer simulations and fundamental experiments. These results show that the proposed method is effective for measuring the RLT with high sensitivity.

2. MEASUREMENT PRINCIPLE

We proposed a measurement method of the RLT with the thickness below 100nm based on near-field optics. The measurement concept of this proposed method is shown in Fig.2. In order to detect an optical response between near-field light and a resin thin film, an optical fiber with a fine aperture below 100nm is applied. It is positioned on the narrow valley between imprinted patterns and is illuminated with a laser,

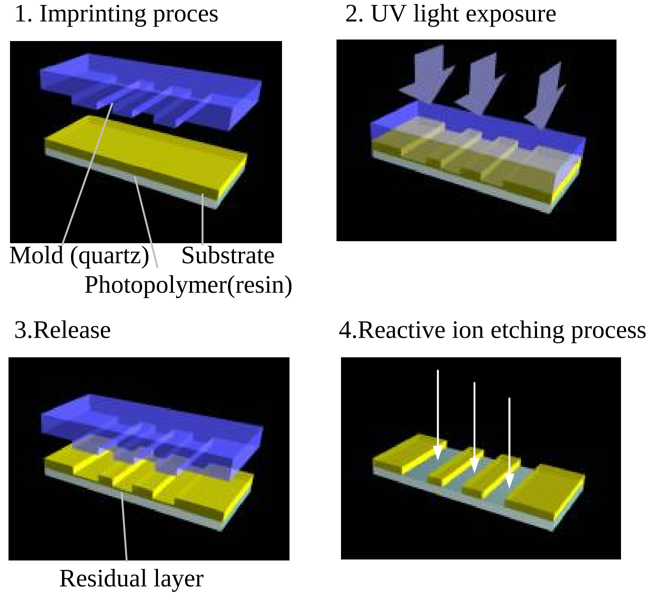


Fig.1 Procedure of nano-imprint lithography

meanwhile approaching the vicinity of the surface of the resin residual layer. A near-field light is generated on the apex of the fiber and interacts with dipoles in the resin film and the substrate. This interaction value changes on the distance between apex of the fiber and the surface of resin layer (here we call this distance as aigap). The near-field optical response can be detected through the fiber. Here, this near-field optical response is expected to include information of the RLT. Therefore, our proposed method has a possibility to measure the RLT of the NIL process.

One of remarkable advantages of this method is using near-field light. Since this method can be expected to have non-invasiveness, it is compatible with inspection for accuracy lithography. Moreover, since a size of the generated near-field optical depends on just the aperture size of the fiber, we expect a high lateral resolution beyond a diffraction limit. For these reason, this method has high practical possibility for reaching the needs of NIL process.

3. ANALYSIS OF NEAR-FIELD OPTICAL RESPONSE

3.1 Analysis By FDTD Simulation

3.1.1 Simulation model

In this study, we performed Finite-Difference Time-Domain (FDTD) simulations (Yee, 1966, Taflove et al., 2000) to give a discussion of the near-field optical response. This FDTD method is conducted by means of deviding the simulation range to fracturing cell and solving the propagating erectric field using the maxwell's equations under boundary conditions on each cells. So, it is suitable for analysis of local erectric field. we perfomed it for analysis of a

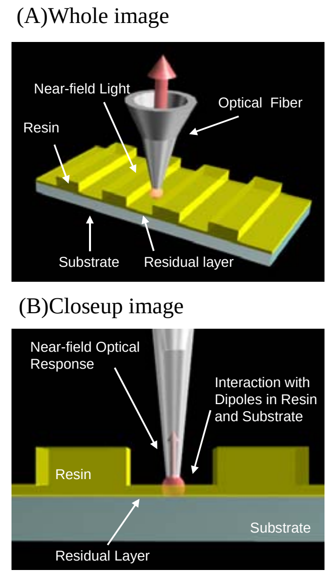


Fig.2 Measurement concept of RLT based on near-field optics

near-field light which interacted with a resin thin film.

The FDTD simulation model is shown in Fig.3. Here, we chose the fracturing cell sized 5nm cubes and the simulation range 1000nm x 1600nm x 1700nm respctively. As an initial study, we dealt with the flat resin layer to analize the interaction between the near-field light and the resin thin film. The resin layer with various thickness is positioned on the silicon substrate. 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 1.000, 1.456, 3.882 and 1.450 respectively. Under these conditions, various simulations were conducted with such parameters that airgap were 10nm-350nm and RLT were 0nm-50nm. Then we analyzed the intensity of the light propagating into the fiber as the near-field optical response.

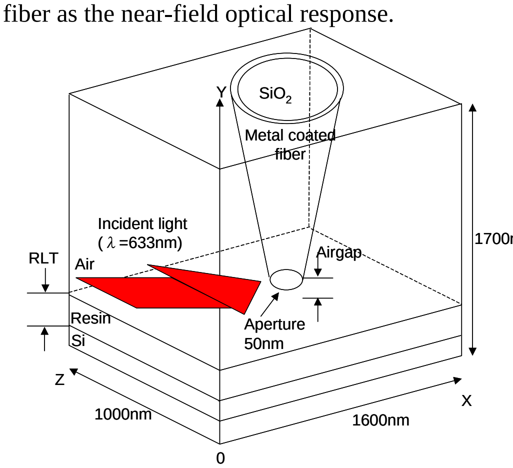


Fig.3 Simulation model

3.1.2 Simulation result and discussion

In order to analyze fundamental characteristics of the optical response, which is detected via the fiber, we focused on an optical response in the specific condition of RLT 0nm. Fig.4 describes a simulation result, which is relation of airgap and optical response at P and S polarized laser illumination. To begin with, we divided the result to two regions in which near-field interaction

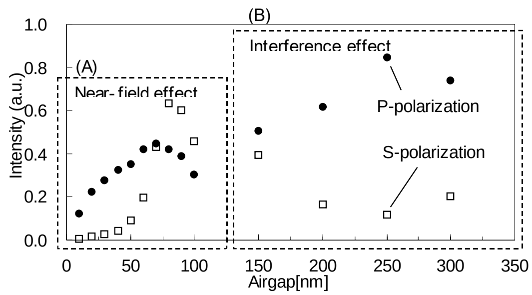


Fig.4 Relation of airgap and optical response

is expected to be predominate (airgap is below 100nm : region A in Fig.4) and in which it is not predominate (airgap is over 100nm : region B in Fig.4). Then we configured concept models and discussed then.

Fig.5 (A) shows the concept model of region A. Since near-field light is generated in the just vicinity of the fiber apex, the contribution of near-field interaction to optical response lessen dramatically with arigap increasing. Additionally, when airgap is small, optical intensity become less, which called a screen effect. This effect can be explained by next reason. When a laser illuminates the fiber, the fiber itself, which is shaped as upside-down triangle, screens from the laser incoming to the fiber apex. Thereby we determined the intensity in region A by multiplying the two effects. The intensity curve means the generation efficiency of the near-field light around the apex is suppressed when airgap is small value.

Fig.5 (B) shows the concept model of region B. Here we deal with an interference effect beside the screen effect. Since incident light reflect on the surface of the substrate, the interference wave occurs above the substrate. These interference waves of each polarization oscillate with an opposite phase by π. The interference of P-polarization peaks on the substrate. Whereas, that of S-polarization lessens near the substrate. So we decided an intensity in region B by using the screen effect and the interference effect.

Considering these concept models, we defined a detection model in all airgap, which is shown in Fig.6. The intensities of both polarizations peak in airgap below 100nm due to near-field effect. Whereas, the interference waves, which have opposite phases, are observed in airgap over 100nm. Considering from Fig.4 and Fig.6, our proposed detection model combined the near-field effect and the interference effect has a good agreement with the simulation result based on FDTD. Now since we are targeting at the RLT with thickness below 100nm, it is confirmed that

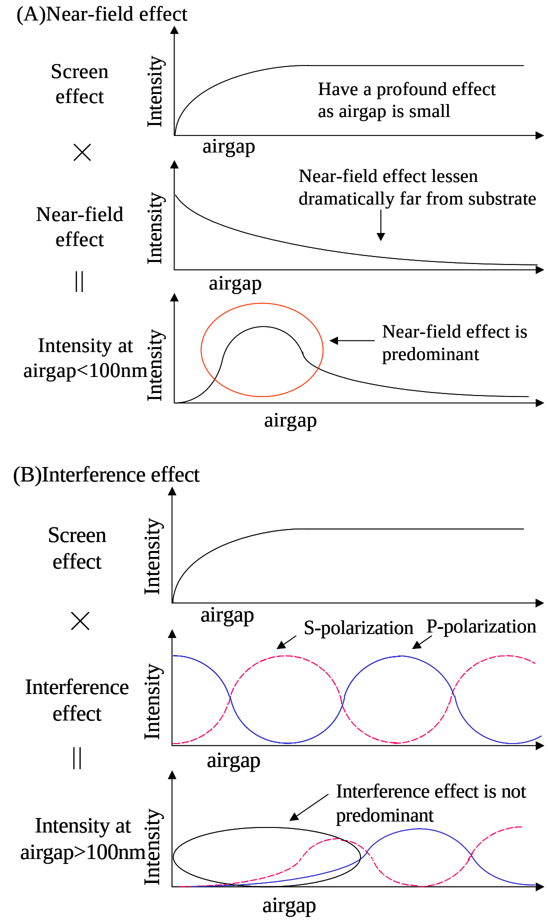


Fig.5 Detection model of optical response

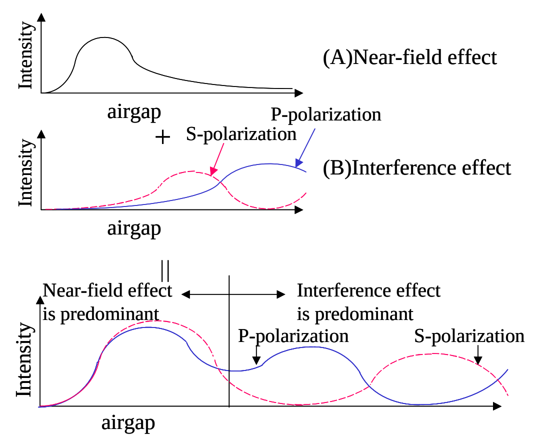
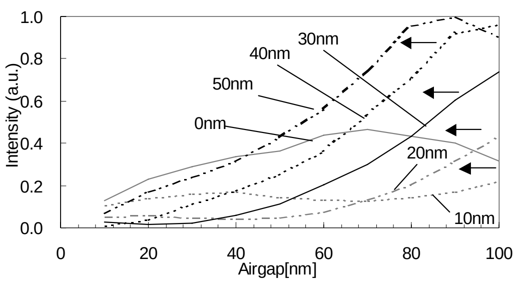


Fig.6 Detection model combined with near-field effect and interference effect

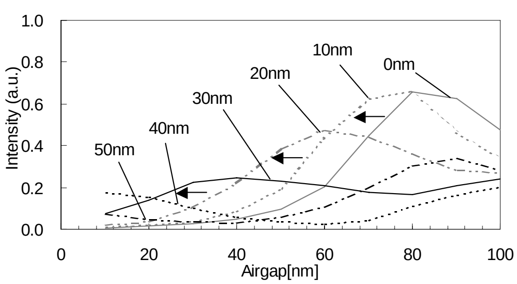
the optical response is given by mainly influence of the near-field effect.

Subsequently, we demonstrated FDTD simulation in cases that the RLT were 0nm, 10nm, 20nm, 30nm, 40nm and 50nm respectively and airgap were 10nm-100nm in every 10nm. The result is described in Fig.7(a) on P-polarized laser illumination, in Fig.7(b) on S-polarized laser illumination. As we see in both figures, the optical responses change on the variation of RLT. Especially, when we look at the shapes of the intensities of 10 to 50 nm in Fig.7 (a) and of 0 to 50nm in Fig.7 (b), these results indicate a shift to left as the resin thickness increase. More noteworthy is this airgap shift value almost agrees with 10nm, which corresponds to the difference of the thickness. This means the resin layer corresponds to air. Therefore, the near-field light interacts mainly with not resin layer but the substrate. Consequently, this optical response may well include information of a distance from the substrate to the fiber apex.

In conclusion of the simulation study, we proposed three factors to determine the optical response, which are the screen effect, the interference effect and the near-field effect. Especially, the near-field effect is predominant in airgap below 100nm at which we are targeting. Subsequently, the optical response changes on airgap and RLT. In addition, the near-field light interacts mainly with not resin layer but substrate. Therefore, the optical response includes the information of the distance between the substrate and the fiber apex. Then the RLT is expected to be measured by the optical response.



(a)



(b)

Fig.7 (a) Relation of optical response and airgap on P-polarization. where RLT are 0nm to 50nm.
Fig.7 (b) Relation of optical response and airgapon S-polarization. where RLT are 0nm to 50nm.

3.2 Analysis by Fundamental Experiment

3.2.1 Experimental apparatus

For verification the feasibility of our proposed method experimentally, we have developed a basic experimental apparatus based on a scanning near-field optical microscope (SNOM) shown in Fig.8. 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 is controlled by means of a combination of a quarter wave plate and a polarizer. The laser power is also

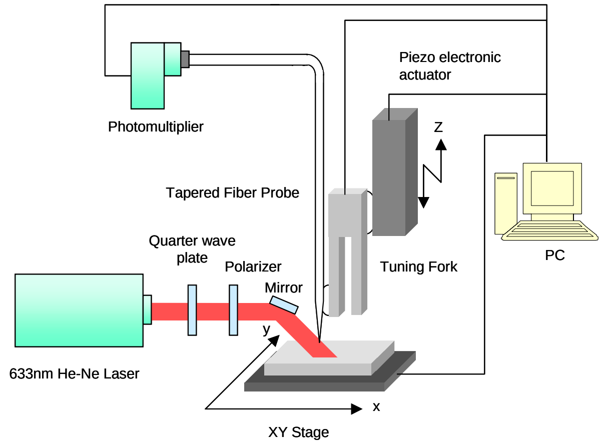


Fig.8 Schematic of experimental apparatus

fixed through the polarizer. For detection of an optical response, a tapered optical fiber is employed to probe the near-field light of the sample. This optical fiber is fabricated on a standard commercial model with the aperture size 120nm, which is coated with 150nm gold film (JASCO Corporation). A photomultiplier tube detects a light incoming into the optical fiber as the optical response. A shear-force distance control using tuning fork is employed for an airgap control technique (Salvi et al., 1998). The optical fiber is fixed on the tuning fork (resonance frequency 32.768 kHz) and vibrated to the resonance frequency for this purpose. The amplitude of oscillation of the fiber and the turning fork decreases by shear-force as approaching near the vicinity of the sample surface. This amplitude is detected and used for the airgap control. The optical signal of the photomultiplier tube and the oscillation amplitude of the tuning fork are monitored via lock-in amplifier with their synchronized frequency. All components are controlled on a PC. Other conditions correspond to simulation ones.

3.2.2 Experimental result

We performed fundamental experiments for analysis of the optical response. Fig.9 shows a figure of the experimental apparatus.

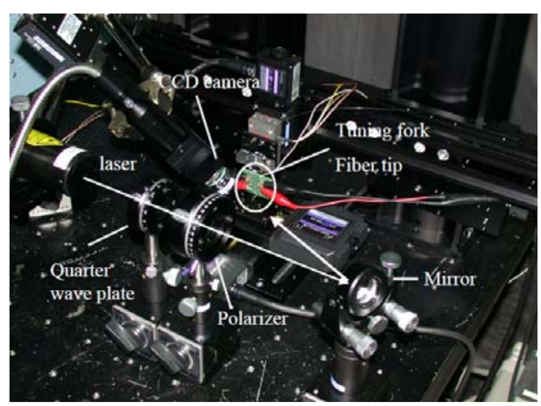


Fig.9 Figure of experimental apparatus

A nano-imprint sample, which was coated with UV sensitive resin on a silicon substrate was examined.

The imprint sample was made by a mold without patterns, of which the imprint loadings changed form 3kgf to 10 kgf (CANON Inc.). The thickness of the resin film had been inspected using the white interferer in advance.

The experimental result is shown in Fig.10, where the RLT are 0, 10, 50nm and airgap are 20, 40, 60, 80, 100nm respectively. The polarization of incident laser is fixed to P-polarization. Compared with the simulation result Fig.11 (quoted form Fig.7(a)), similar results was obtained in the points of slope of the curve and airgap value where optical response peak. Therefore, it is concluded that the optical response changes on thicknesses and airgap in experimental study as well as in simulation study.

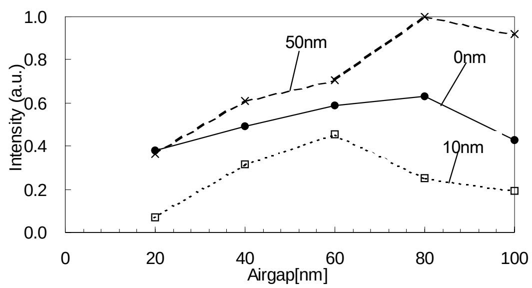


Fig.10 Experimental result on P-polarization when RLT are 0, 10, 50nm respectively

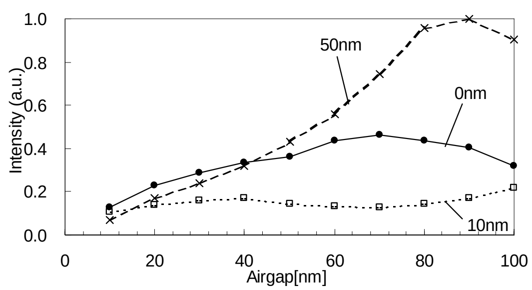


Fig.11 Simulation result on P-polarization when RLT are 0, 10, 50nm respectively quoted form Fig.7(a).

4. RESIDUAL LAYER THICKNESS IDENTIFICATION MRTHOD BASED ON NEAR-FIELD OPTICAL RESPONSE

4.1 Proposition Of RLT Identification Method

In this section, we discuss the method to identify the RLT by analyzing the optical response. Fig.12 shows a relation between the optical response and the RLT at airgap 20nm. The intensity of P-polarization decreases almost linearly with the RLT increasing. On the other hand, that of S-polarization remains almost constant. In other words an intensity of P-polarization gives information of RLT, and S-polarization gives a constant level, which varies on each measurement conditions such as a power of light source, a dark current of a detector and so on. Hence, the intensity value of P-polarization divided by that of S-polarization, the bias level can be compensated by two intensities. Here we defined this divided value an efficiency signal. Fig.13 presents the efficiency signal at airgap 20nm. It is found that the efficiency signal changes linearly within 0nm to 70nm. Therefore, this result indicates this identification method is suitable for measuring RLT below 70nm with the resolution about a few nm.

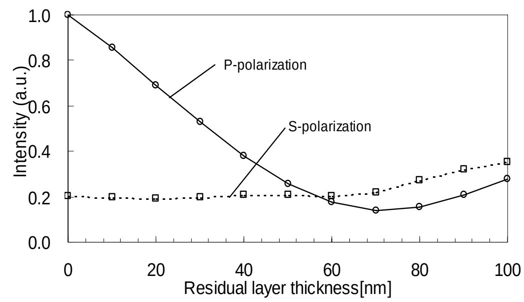


Fig.12 Relation of optical responses of P and S polarization at airgap 20nm

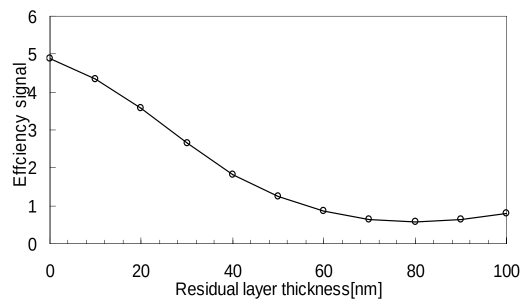


Fig.13 Efficiency signal at airgap 20nm

4.2 Characteristic Of Identification Method

We analyze characteristics of the identification method in order to optimize the experimental set up. To begin with dependence of airgap, Fig.14 shows efficiency signals at airgap 0nm, 20nm and 40nm when P and S polarized laser (wavelength 633nm) is incoming with an incident angle 45 degrees. As we see, the efficiency signals of these results shift to left with airgap increasing. Hence, the efficiency signal of airgap 0nm is the highest at RLT 0nm and has the widest measurement range approximately 80nm among 3 efficiency signals. This is because the optical response of the near-field interaction with substrate enlarges as airgap is less, so the efficiency signal increases at airgap 0nm. As a result, the condition of airgap 0nm is suitable for practical measurement.

Fig.15 shows dependence of wavelength of incident laser of the efficiency signal when airgap 0nm and incident angle 45 degrees. Both efficiency signals decrease almost linearly within 80nm at wavelength 633nm and 60nm at wavelength 488nm respectively. It means long wavelength has possibility to measure with wide measurement range. In addition, compared with their slopes of the efficiency curves, one of wavelength 488 is steeper than another. It indicates using shorter wavelength can be high sensitive measurement condition. So, these results allow us to select high sensitive measurement (using 488nm laser) or wide range measurement (using 633nm laser).

Consequently, as a proper measurement condition, airgap 0nm is proper for wide range measurement. And wavelength of incident laser should be selected by its measurement range or its sensitivity. In the highest sensitive condition, we can measure the RLT below 60nm by our proposed method.

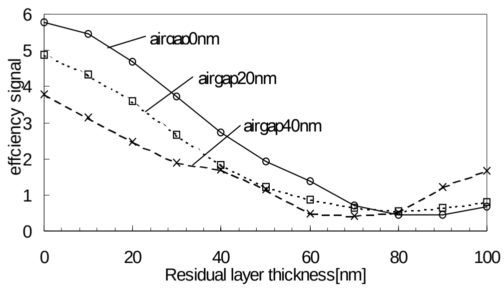


Fig.14 Efficiency signal in case of airgap 0nm, 20nm, 40nm

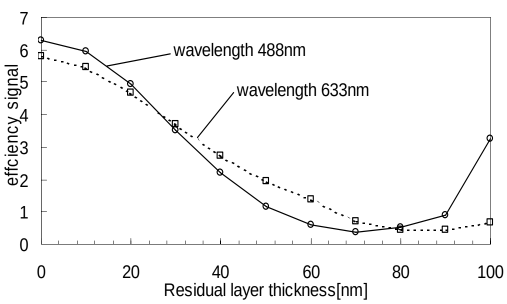


Fig.15 Efficiency signal in case of wavelength 488nm and 633nm

5. CONCLUSION

We have proposed a novel measurement method of RLT based on the near-field optics for nano-imprint lithography. A simulation and a fundamental experiment are conducted to verify a feasibility of the proposed method. The result shows that the near-field response changes on film thickness and airgap. Additionally, it is found the efficiency signal can be used for measuring RLT below 80nm with the resolution about a few nm. Therefore, it is found that our proposed method is compatible with measuring RLT in the NIL process.

Our next study is to apply our method to measuring a nano-imprint sample, which has nano-patterns on its surface. Additionally, new apparatus will be developed for practical use.

6. ACKNOWLEDGEMENT

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