Pattern Replication in EUV Interference Lithography

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Extreme ultraviolet interference lithography (EUVIL) beamline which employed a single grating was constructed at the BL3 beamline in NewSUBARU synchrotron radiation facility. Bending magnet was attempted as a light source, and Ta layer was employed as an absorber layer of $0^{th}$ order light in transparent grating. Using this system, 400-nm L&S resist pattern was replicated on a wafer, which shows possibility of EUV interference lithographic technology employing bending magnet as a light source.

**Keyword:** EUV resist, chemically amplified resist, interference lithography

1. Introduction

Extreme ultraviolet (EUV) lithography is the most promising technology for 32 nm node, and it is required for the high volume manufacturing lithographic technology around 2011. Resist materials and process technologies are one of the three top issues. High sensitivity and low line edge roughness (LER) have to be achieved simultaneously. In a stand view of resist material, the exposure characteristics of resist itself should be studied to design and synthesis which can satisfy the specification. A LER is affected by aberration and flare of the imaging optics. The flare of less than 10% is required for an exposure tool of 32 nm node beyond. On the other hand, since the interference lithography (IL) does not require complicated and expensive imaging optics, IL has an advantage for a examination of LER of resist.

A Lloyd’s mirror interferometer systems and single grating interference (SGI) system are proposed for replicating a periodic pattern. The Lloyd’s mirror interferometer (LMI) system is based on a single mirror. Replicated resist resolution of LMI is limited by temporal coherence $L_c$, which can be described by $L_c = \lambda^2 / \Delta \lambda$, where $\lambda$ is an exposure wavelength.

On the other hand, replicated resolution of SGI is limited by spatial coherence. In general, the spatial coherent length, $L_s$, is related to its angle distribution, $\sigma$, by the relation of $L_s = \lambda / \sigma$.

In this paper, we would like to discuss an EUV interference lithography using a single grating interference (SGI) system and a bending magnet as a light source.

2. Single Grating System

Figure 1 shows the principle of SGI system. The $0^{th}$ order, the $1^{st}$ order, and the $-1^{st}$ order rays are produced by a transparent grating. As shown in Fig. 1, if two grating is used, the $1^{st}$ order ray produced from one window grating interferes with $-1^{st}$ order ray produced from another window of a grating, and an interference fringes is created at the suitable position. Then if the resist inserted at the suitable position, periodic pattern of a resist will be replicated on the basis of interference fringes.

The diffraction condition of grating can be described by the following equation,

$$m \lambda = d (\sin \theta_i - \sin \theta)$$

(1)

where $m$ is number of order, $d$ is pitch of grating, $\theta_i$ is an angle of the incident light and
\( \theta_i \) is an angle of transmitted light.

**Two Windows**

![Image](image)

**Fig.1 Principle of SGI system**

On the other hand, the pitch of interference fringes \( p \) is calculated,

\[
p = \frac{\lambda}{2 \sin \theta}
\]  

(2)

where \( \theta \) is the half of the angle between the propagate directions of the two beams. In this system, \( \theta \) in eq. (2) is equal to \( \theta_i \) of eq. (1) when incident light is parallel light, i.e., \( \theta_i \) equals 0. Thus we have the relations between the pitch of the interference fringe and the pitch of the grating as follows

\[
p = \frac{d}{2}
\]  

(3)

this equation has equality when \( \theta_i \) of eq. (1) equal 0.

SR light which is produced from the bending magnet of the electron beam storage ring is led to the two glancing mirrors. After these mirrors, the beam size and divergence become to be 20 mm in diameter and divergence of ±0.75 mrad respectively. Then the SR light is led through the 4 jaw slits, shutter and a 0.15-μm-thick Zr/Si filter. The centroid wavelength of the reflectivity spectrum is 13.5 nm and full width at half maximum (FWHM) is 0.7 nm. Finally, EUV light led to SGI system. SGI exposure chamber maintains typically the vacuum pressure in the order of 10⁻⁵ Pa using a turbo molecular pump and scroll dry pump. Loadlock system for exchanging wafer sample was attached to the exposure chamber to change a 4-inches wafer.

To replicate resist pattern caused by an interference fringes formulated from a single grating, distance between a single grating and a wafer and tilt position of a grating have to be aligned. In order to control the gap between grating and wafer along light axis, we used Z-motion stage which can be moved by a pulse motor in vacuum pressure order of 10⁻⁶ Pa, and the stage moving resolution is 1.5 μm. Furthermore, we installed the \( \alpha \) and \( \beta \) axis stages which can control the grating tilt position around by horizontal and vertical directions.

3. Fabrication process of single grating

Figure 2 shows a configuration of a final structure of a fabricated transparent grating with two windows. Since the light angle distribution on a single grating is 0.35 mrad, calculated coherent length is 38.6 μm. The distance \( L \) between the two windows has to be smaller than the spatial coherent length. Therefore the width \( W \) of one-side window and the distance between two windows \( L \) were designed in 10μm and 30μm, respectively.

![Image](image)

**Fig.2 Configuration of a fabricated transparent grating with two windows.**

Figure 3 shows the fabrication process of a transparent two window grating, a 4-inches silicon wafer coated with \( \text{Si}_3\text{N}_4 \) layers on the both sides of a wafer in 300-nm thickness is prepared. Since the transmittance of \( \text{Si}_3\text{N}_4 \) layer of 300-nm thick is 7.4% at the wavelength of 13.5 nm, it could not take a good contrast of interference. Therefore, 100-nm tantalum was employed as an absorber of EUV light, which has a good absorbance of 99.8% at 13.5-nm. Ta layer was deposited on a \( \text{Si}_3\text{N}_4 \) layer using magnetron sputtering system. ZEP520 resist was coated with 450-nm thickness. The resist pattern was replicated by electron beam lithography. The resist pattern was transferred to the tantalum and \( \text{Si}_3\text{N}_4 \) layer by a dry-etching using CF₄ gas. Ta and \( \text{Si}_3\text{N}_4 \) can be etched continuously in the same condition using dry etching system.

Resist was removed by dry etching process using O₂ gas and cleaning process using mixed solution of HCl and H₂O₂ to the ratio of 1:1. Backside of \( \text{Si}_3\text{N}_4 \) of a demanded aperture was removed by a CF₄-dry-etching process using glass mask. Aperture area on silicon substrate was removed by a wet etching process using KOHaq. During this process, \( \text{Si}_3\text{N}_4 \) layer acts as an etching
mask. Then the transparent grating which can be used in interference lithography was fabricated.

Figure 4(a) shows eight transparent gratings with two windows which was fabricated on a 4-inches wafer. Figure 4(b) shows a photograph of 800-nm-L&S Si$_3$N$_4$ grating pattern observed by an optical microscope.

Figure 5 shows a photograph of a replicated ZEP520A resist pattern of 400-nm line and space (L&S) pattern using a 1600-nm-pitch single grating which was observed by a scanning electron microscope (SEM). Exposure time was around 10 s with a 0.2-um-thick Zr/Si filter. As a result, using a bending magnet as a light source, we obtained interference replicated pattern. Figure 6 and 7 show the close up of the exposure pattern. 400-nm L&S pattern was cleanly observed. However, the pattern contrast is not perfect because of low temporal coherence of the bending magnet.
In addition, a 200-nm L&S pattern was tried by a 400-nm L&S grating, but up to now high contrast pattern could not resolved due to temporal coherence of the light source. Temporal coherence should be improved by multilayer mirror or filter.

0th order  ±1st order  0th order

Fig.6 Replicated ZEP520A resist pattern of 400-nm line and space (L&S) pattern observed by scanning microscope.

Fabricate. To improve the contrast of interference fringes, Ta absorber layer was coated on the grating for EUV interference lithography. Using the transparency grating, SGI lithography system was constructed to the BL3 beamline at NewSUBARU. Using SGI lithography combined with a bending magnet as a light source, 400 nm L&S pattern is replicated. Although coherence of bending magnet is much smaller than undulaor source, this result shows a possibility of applicable of another compact, more simple and cheaper source, such as laser plasma source, discharge source and high harmonic generation of short-pulse laser.

References
2. Three top issues in EUVL, EUVL international symposium 2007.
4. Conclusion
Transparency grating was succeeded to

Fig.7 Replicated ZEP520A resist pattern of 400-nm line and space (L&S) pattern cut by scanning microscope.