EUV Interference Lithography at BL9 Beamline in NewSUBARU

Extreme ultraviolet lithography (EUVL) [1] is a most promising lithographic technology for next-generation lithography of the 32 nm node around 2013. EUV resist development is one of the critical issues related to the use of EUVL technology in the high volume manufacturing (HVM) of semiconductor devices. According to the International Technology Roadmap for Semiconductor (ITRS) [2], the pattern resolution, exposure sensitivity, and line width roughness (LWR) of EUV resists are the significant factors to the fabrication of the electric devices such as Microprocessing Unit (MPU), Ferroelectric Random Access Memory (FRAM), Static Random Access Memory (SRAM), and Dynamic Random Access Memory (DRAM). To maintain the lithographic throughput in HVM, the resist exposure sensitivity has to be high. In addition, to maintain the function of electric devices, the line edge width of resists should be very small. For example, according to the ITRS, 1.2 nm (3σ) of LWR for 22-nm-half-pitch (HP) node and 0.6 nm (3σ) of LWR for 11-nm-HP node are required. Thus, the fluctuation of the resist pattern width has to be maintained at 1/10 of the molecular size of the resist. Therefore, the paradigm shift of the resist material is required.

Up to now, the full field exposure tool such as α-demo tool is used to evaluate the EUV resist for the 32-nm-HP node. Since the imaging resolution of these tools is limited to 25 nm, the exposure tool should have an imaging resolution of 22 nm and below. Thus, the EUV interference lithography tool was constructed at BL9 beamline in NewSUBARU [3]. The light source of this beamline is a 10.8-m-long undulator (LU) [4]. The synchrotron radiation flux created from LU is approximately 1,000 times larger than that from the bending magnet. In addition, LU light has excellent spatial and time coherences.

Figure 1 shows the principle of EUV interference lithography (EUV-IL). In the EUV-IL, the dual beam interference system is used [4]. Transparent grating has two windows. From each grating, EUV incident light is diffracted into –1st, 0th, and +1st orders. Then, double periodic interference fringes are created at the intersection point of the –1st-order diffraction light from one grating and +1st-order diffraction light from another grating. The diffraction condition of each grating can be expressed as $m\lambda = d(\sin\theta_f - \sin\theta_i)$, where m, d, θ_f, and θ_i are number of diffraction order, pitch size of grating pattern, angle of transmitted light, and angle of incident light, respectively. In addition, the pitch size of interference fringes p is expressed as $p = \lambda/(2\sin\theta)$, where θ is half of the angle between the propagation directions of the two beams of the –1st and +1st diffraction orders. Considering normal incident light, the incident light angle may be expressed as $\theta_i = 0$. Then, the pitch size of interference fringes p is expressed as $p = d/2$. Thus, half-size of the grating pattern size can be replicated in a wafer. In EUV-IL, the distance of two windows has to be smaller than the coherence length. In addition, if the grating pitch pattern d becomes smaller, the diffraction angle θ_f of –1st and 1st diffraction orders becomes larger. Then, if the distance of the two windows of a transmission grating is constant, the distance between a grating and a wafer becomes smaller. Thus, a large spatial coherence length is required to achieve the practical distance between a grating and a wafer for imaging a resist pattern on a wafer.

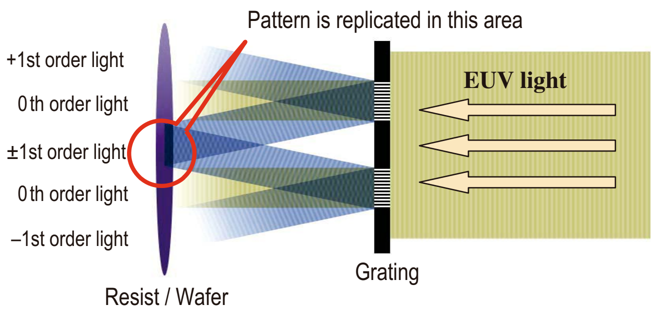

Fig. 1. Schematic of BL9 beamline and exposure chamber.

Figures 2(a) and 2(b) show the photographs of BL9 beamline and exposure chamber for EUV-IL, respectively. The LU source spectrum with the peak in a specific wavelength can be obtained by tuning a gap between the upside and downside of undulator magnets. The brilliance of EUV light of an undulator as a source is approximately 50,000 times higher than that of a bending magnet as a source. Figure 2 shows that the EUV light was focused on a pinhole using an optical component. At the pinhole position the beam is focused at a size of 10 μm in the y-direction. The distance from the pinhole to a resist is maintained to be approximately 3.3 m. Since high wavelength range larger than 20 nm is removed using a 0.2-μm-thick zirconium (Zr) filter, the light is monochromated to be a wavelength of 13.4 nm on a resist sample.

The spatial coherence of light source measurement can be determined via Young's double-slit experiment. It was confirmed that the spatial coherences using a 25 μm slit and a 10 μm slit are 544 and 1173 μm at the transmission grating position, respectively. Therefore, since a large spatial coherence length

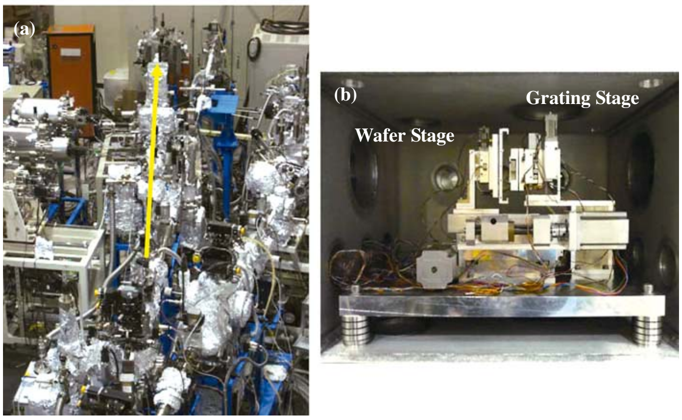

Fig. 2. Principle of EUV interference lithography.

was obtained using these optical elements, and by enlarging the distance between a grating and a wafer, the design and fabrication process of the transmission grating could be carried out effectively.

By using the 100-nm-pitch transmission grating, a 25-nm-HP resist pattern was replicated by EUV-IL. A wafer stage and a grating stage were installed in the EUV-IL exposure chamber. The wafer stage consists of *x*-, *y*-, and *z*-stages and a tilt stage, and the grating stage consists of *x*- and *y*-stages and a tilt stage. By using these stages, light axis adjustment was carried out. Figure 3 shows a photograph of a replicated ZEP520A resist pattern of 25 nm HP, which was observed using a critical-dimension scanning microscope (CD-SEM, S8840, Hitachi). In the near future, various types of chemically amplified resist will be evaluated. In addition, in a future study, we will attempt to replicate a 20-nm-HP resist pattern and below. By using a two-dimensional transmission grating, as shown in Fig. 4(a), with a four-beam diffraction, a dot or hole pattern can be replicated. In this case, by grating a 50-nm-HP dot pattern, a 35-nm-HP dot resist pattern was replicated, as shown in Fig. 4(b). The resist was ZEP520A. The resist thickness was 50 nm.

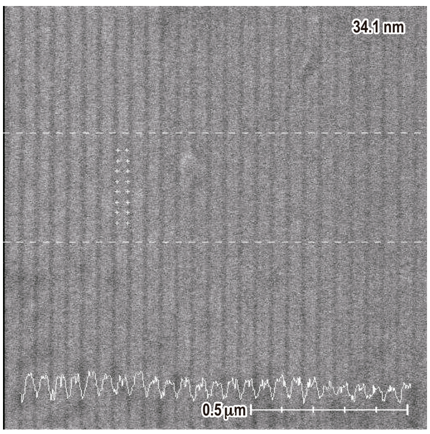

Fig. 3. SEM image of replicated resist pattern of 25 nm HP.

For the replication of a 20 nm L/S resist pattern and below by EUV-IL, we developed a fabrication process that is suitable for a transmission grating pattern of a 40 nm L/S and below. Employing a hard-mask process using a silicon dioxide (SiO_2) layer on a tantalum-nitride (TaN) layer in the fabrication of two-window transmission grating, we succeeded in achieving a fivefold higher dry-etch selectivity than that obtained by a non hard-mask process. As a result, we confirmed applicability of the 40-nm-HP grating.

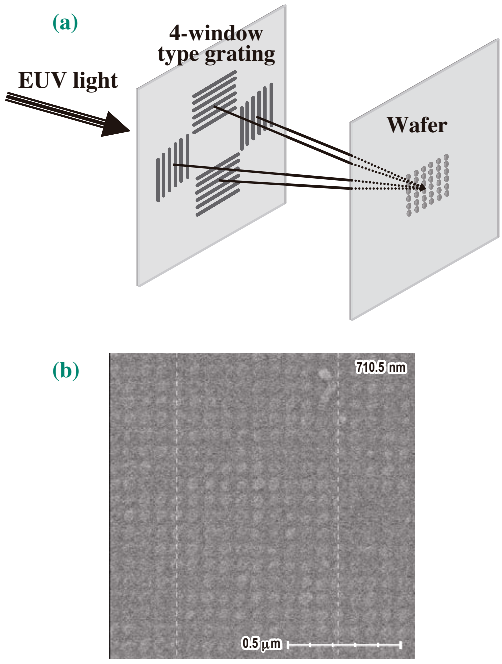

Fig. 4. (**a**) Configuration of two-dimensional transmission grating and (**b**) SEM image of replicated resist pattern of 35-nm-HP dot resist pattern.

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