LSI mask pattern observation for EUV lithography using lensless microscope

Extreme ultraviolet (EUV) lithography is a promising technology for the production of semiconductor devices at the 22 nm node and below, where the working wavelength of EUV lithography is 13.5 nm. Recently, a lithography system supplier of ASML has shipped the EUV beta tools to semiconductor companies, which is the preproduction tool for high-volume manufacturing. In the NewSUBARU synchrotron facility, we had developed the world's first full-filed EUV exposure tool [1] for the feasibility study of EUV lithography. Moreover, we have developed EUV resist evaluation tools [2] and EUV mask evaluation tools [3]. In this paper, we introduce the mask evaluation tools.

The mask is a master pattern of the LSI, which is printed on wafers with 1/4 magnification. The critical issue of EUV lithography is the production of a defect-free mask. A defect is not allowed on the mask, which will be printed on all LSI patterns. An EUV mask is of reflective type, which consists of a glass substrate, a reflective Mo/Si multilayer, and an absorber pattern. Thus, the phase structure is printable as a defect, which is a bump or a pit structure on the substrate or a particle in the multilayer. A shallow structure of 1 nm height would be printable because of the EUV short working wavelength of 13.5 nm, which cannot be detected by SEM. To evaluate the phase defect, an EUV actinic microscope is strongly required. We have developed a coherent EUV scatterometry microscope (CSM) based on a coherent diffraction imaging method at the NewSUBARU synchrotron facility, which is a lensless microscope without an objective [4,5].

Figure 1 shows a schematic view of the CSM system, which has a numerical aperture of 0.14 and a field of view of ϕ5 μm. The spatial resolution of the CSM is about 60 nm. The main structures of the CSM system are a coherent EUV source and an EUV CCD camera, which records diffraction from the pattern directly. The incident beam was monochromatized by Mo/Si multilayers. The image-forming optics are replaced by an inverse computation using scattered intensity, which is based on the coherent diffraction imaging method of ptychography. In this iterative calculation, the phase data of frequency space is retrieved. Therefore, aerial image phase data are also retrieved. The CSM thus observes a phase image of the sample EUV pattern.

Figure 2 shows a reconstructed result of the corner structure of the 128-nm line-and-space (L/S) pattern. This figure shows a complex amplitude image with the amplitude represented by brightness and the phase represented by hue. The periodic structure of the L/S pattern and aperiodic structure of the corner structure were well reconstructed. The phase structure was also well reconstructed.

Figure 3 shows a reconstructed result of phase defect squares with 1 μm width, which had a 6.2 nm height evaluated by AFM. The sample mask was an EUV mask that contained programmed bump structures on a glass substrate. Figure 3(a) shows a complex amplitude image with the amplitude

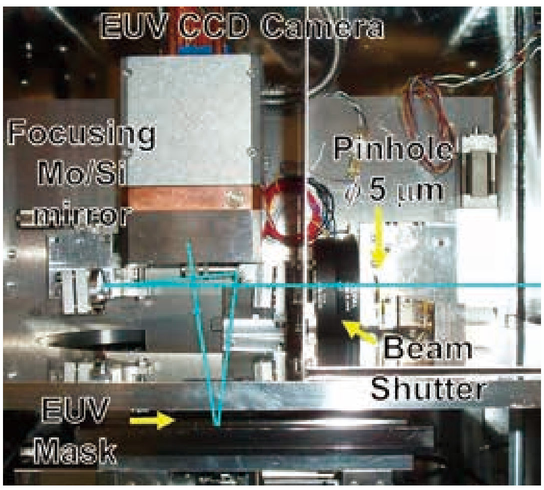

Fig. 1. Photograph of CSM system.

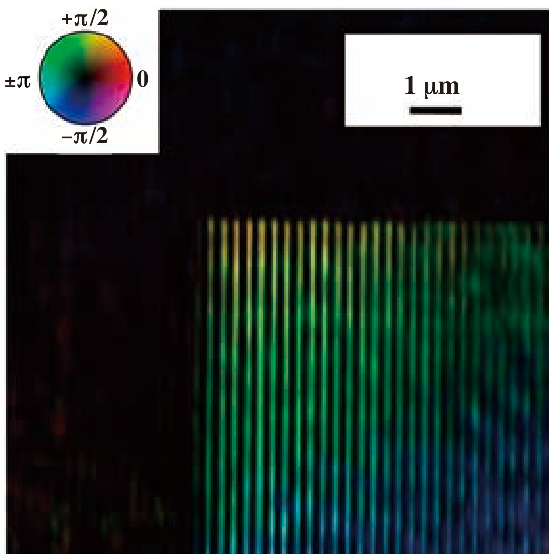

Fig. 2. Reconstructed result of corner structure of the 128 nm L/S pattern.

represented by brightness and the phase represented by hue. The defect edge was reconstructed as black, which is caused by the destructive interference of the phase structure. This edge structure was also observed in the conventional EUV microscope. In addition to the intensity information, using CSM the phase distribution was observed (Fig. 3(a)). Figure 3(b) shows a 3D image of the phase distribution. The defect had a phase angle of –33°, which means 6.1 nm in height. Therefore, the CSM result corresponded well with the AFM results. CSM showed the actinic phase distribution of the phase defect. It is known that the EUV actinic image of the small phase defect was different from the AFM results; the actinic feature of the defect is very important for defect compensation and hiding. In lithography, the mask phase information is also essential for lithography simulators to predict aerial images, which is fundamental imaging information. The actinic phase image captured using the CSM helps with the fabrication of a defect-free mask for the defect compensation and hiding method.

To characterize a smaller phase defect property, we have developed a micro-CSM system that has focusing optics of a Fresnel zone plate. Micro-CSM focuses the illumination EUV to ϕ200 nm on the defect. This layout reduces the background noise signal from the mask roughness, and enlarges the defect signal. The target defect size was less than 30 nm in width and 1 nm in height.

We have developed these lensless EUV microscopes to make the EUV mask evaluation standard with a simple layout and a high capability.

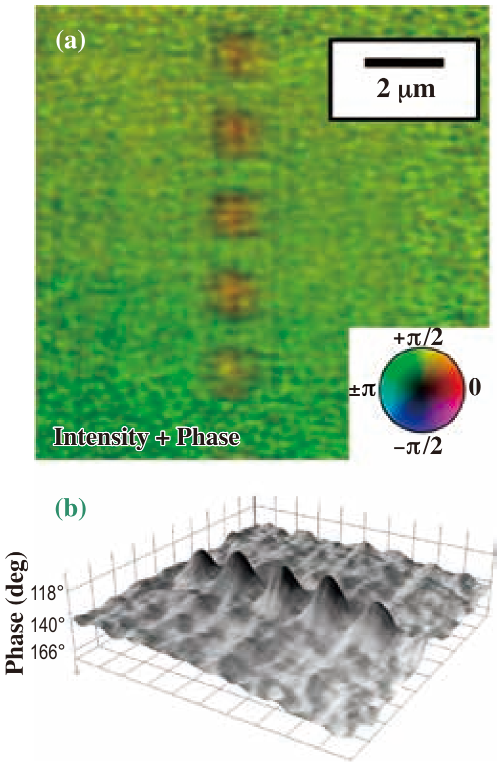

Fig. 3. Reconstructed result of phase defects. **(a)** Intensity and phase image. **(b)** 3D image of phase distribution.

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