Phase Defect Observation Using an EUV Microscope

Kazuhiro Hamamoto1,3, Yuzuru Tanaka1,3, Takahiro Yoshizumi1,3, Yasuyuki Fukushima1,3, Hideaki Shiotani1,3, Noriyuki Sakaya2,3, Morio Hosoya2,3, Tsutomu Shoki2,3, Takeo Watanabe1,3 and Hiroo Kinoshita1,3

1 Laboratory of Advanced Science and Technology for Industry, University of Hyogo
3-1-2 Koto, Kamigori-cho, Ako-gun, Hyogo 678-1205, Japan
2 HOYA Corporation R&D Center Bldg. 3-3-1 Musashino, Akishima-shi, Tokyo 196-8510, Japan
3 CREST-JST Kawaguchi Center Bldg., 4-1-8 Hon-cho, Kawaguchi-shi, Saitama 332-0012, Japan

ABSTRACT

We constructed the EUV microscope (EUVM) for actinic mask inspection which consists of Schwarzschild optics (NA0.3, 30X) and X-ray zooming tube. Using this system, EUVL finished mask and Mo/Si glass substrates are inspected. EUVM image of 250 nm width pattern on 6025 Grass mask was clearly observed. Resolution can be estimated to be 50 nm or less from this pattern. The programmed phase defect on the glass substrate is also used for inspection. By using EUV microscope, programmed phase defect with a width of 90 nm, 100 nm, 110 nm, a bump of 5 nm and a length of 400 µm can be observed finely. And the programmed phase defect of 100 nm-wide and 2 nm pit was also observed. Moreover, a programmed defect with a width of 500 nm is observed as two lines. This is because phase change produced with the edge of both sides of a programmed defect. Thus, in this research, observation of a programmed phase defect was advanced using the EUV microscope, and it succeeded in observation of the topological defect image inside a multilayer film. These results show that it is possible to catch internal reflectance distribution of multilayer under the EUV microscope, without being dependent on surface figure.

Keywords: EUV Lithography, EUV microscope, mask, defect

1. INTRODUCTION

Extreme ultraviolet lithography (EUVL) has been proposed as a next generation lithography at the 32 nm node around 20091). Defect-free mask fabrication is one of the critical issues to lead EUVL into production. Based on the ITRS2), defect widths of less than 20 nm are required at the 32 nm node.

There are two types of defects in an EUVL mask. One is amplitude defect and another is a phase defect. Amplitude defects are either particles on a surface of the multilayer or flaws in the multilayer. These defects can be detected directly by measuring the intensity of EUV light which is scattered from the defects. On the other hand, phase defects are produced when the multilayer is deposited over a bump or pit on the substrate. These phase defects are swellings and depressions on the surface of the multilayer.

There are two techniques of detecting a small swelling on the surface: using deep ultraviolet (DUV) light and using EUV light at the exposure wavelength. Mask defect inspection using VUV light is a conventional method in optical lithography3, 4). However, this inspection is difficult to detect defects on a EUVL mask because defects to be detected are much smaller than the inspection wavelength. So, it is extremely difficult to detect defects of 50 nm or less using DUV light. Furthermore, since the characteristics of phase defects depend on exposure wavelength, it is necessary to observe phase defects with the same wavelength as the exposure wavelength.

Several systems of using EUV light have been reported. In 2004, MIRAI-ASET examined the phase defect inspection5, 6). This method detects dark-field signal from mask defects using a LPP as a light source and a Schwarzschild optics with a NA of 0.2 and a magnification of 20. Using this system, a programmed defect of 70 nm width and 2 nm height was detected.

International SEMATECH was developed a mask defect inspection system like MIRAI’s7, 8). The SR light focuses on a mask by Schwarzschild optics and detects bright-field image and dark-field image with a photodiode and a channel plate, respectively. Furthermore, they observed the bright-field image from mask surface with a zone plate, and they observe an absorber pattern of 70 nm width. Furthermore, Extech had developed EUV imaging tool in last year. EUV
image that is illuminated mask sample and magnified by 10X optics is converted to visible light image by Celium-YAG scintillator\textsuperscript{9). And visible image is magnified by visible imaging objective and tube lenses. As described above, development of a mask defect inspection system was done in many research institutions, but we thought that mask inspection in bright-field which obtains a real replication characteristic is better. So, we construct EUV microscope for areal image mask inspection\textsuperscript{10-12).}

2. EUV MICROSCOPE

2.1 EUV Microscope

Figure 1 shows the configuration of the actinic EUV microscope installed at the BL-3 beamline in the NewSUBARU SR facility\textsuperscript{13).} It consists of Schwarzschild optics, a Mirau interferometer for phase-shift interference measurement, an X-Y sample stage, a focus detector, an X-ray zooming tube connected to a CCD camera, and an image processing computer. It is installed in a vacuum chamber evacuated down to $1 \times 10^{-5}$ Pa, and the vacuum chamber is set on a vibration isolation table.

![Fig. 1 Configuration of the EUV microscope](image)

2.2 Schwarzschild optics

The system employs Schwarzschild optics with 0.3 NA and 30X magnification. Our simulation predicted that the system can resolve 10-nm-wide isolated lines under practical illumination conditions. The figure error of the mirrors was less than 0.4 nm and the mid-frequency surface roughness was less than 0.15 nm. These mirrors, made of Zerodur, were fabricated by ASML Tinsley. Mo/Si multilayers were coated on these optics by an X-ray instruments company in Russia. D-space matching of less than 0.01 nm has been achieved at the wavelength of 13.5 nm. The wave-front error of the Schwarzschild optics after assembly was measured with a Fizeau interferometer (ZYGO GPI) and found to be about 2 nm (rms). This optics was installed in an optical housing made of Invar to prevent the thermal expansion effect.

2.3 X-ray zooming tube

The X-ray imaging system is composed of an X-ray zooming tube, a CCD camera, and an image processing computer. The mask image is projected to an X-ray zooming tube (Kawasaki Heavy Industries Co., Ltd.) with electromagnetic lenses that can be tuned to vary the magnification in the range from 10 to 200. Therefore, considering the magnification of the Schwarzschild optics, the total magnification of the microscope system is from 300X to 6000X. The resolution of the X-ray zooming tube is 0.3 µm on a CsI photocathode. Defects of 10 nm in size are magnified by the Schwarzschild
optics to 300 nm. Thus, the resolution of the X-ray zooming tube is sufficient to enable the detection of 10 nm defects and to produce diffraction-limited images of mask patterns. The X-ray zooming tube has a field of view of 1.5 mm x 1.5 mm at the CsI photocathode, which corresponds to 50 µm x 50 µm on the sample surface. The electron image that is created by photoelectric transfer on the photocathode is magnified by the electrostatic lenses and focused on a microchannel plate (MCP). The magnified EUV microscope images are taken into a CCD camera and displayed on the screen of the image processing computer, and the image data can be stored in the computer.

2.4 Mechanism of phase defect inspection

Figure 2 shows the mechanism of phase defect inspection. EUV light illuminate and penetrate in Mo/Si multilayer. However, on the both sides of programmed defect, incident light does not reflect in the place where the structure of the multilayer was disarranged. And the incident angles near line edges is changed, and the reflected intensity becomes weak according to the Bragg’s equation. These reflected light is collected by Schwarzschild optics and imaged on X-ray zooming tube. So, this method can image the phase defect directly, regardless of the surface figure.

3. EXPERIMENTAL

We observed the finished EUVL mask and mask blanks with programmed substrate defects using the EUV microscope without the Mirau interferometer.

3.1 Finished mask observation

A finished EUVL mask was observed using the EUV microscope. The mask with a 6025-format substrate (ULE glass, Corning Inc.) was fabricated by HOYA Corporation. Figure 3 shows an image of the mask with 300 nm-wide isolated lines. The white part is a Si surface of the Mo/Si multilayer and the dark part is the absorber material of TaBN. Clearly, the EUV microscope is capable of resolving 300 nm-wide absorber patterns on a mask, which corresponds to 75 nm-wide patterns on the wafer, on the assumption of 1/4 magnification for commercial exposure tools. It is thought that a defect of 50 nm or less can be detected from the contrast at the edge of the pattern (see Fig. 4).
3.2 Programmed phase defect observation

3.2.1 Bump defect
Multilayer mask blanks with programmed phase defects on the mask substrates were made. Bump defects were fabricated by Mo/Si multilayer coating after CrN patterning on a ULE6025 substrate. Figure 5 shows a cross-sectional TEM image of a programmed defect. If the multilayer is formed on a pattern with a height of 5 nm and a width of 90 nm, the top layer becomes swelled as shown in Fig. 5. Figure 6 shows a EUV microscope image of program defects of 1 µm-wide dots. In spite of astigmatic aberration of the illumination optics, phase defects of dots with 1 µm-wide and 5 nm-high can be confirmed.

Figure 7 shows EUV microscope images of phase defects of 90 nm, 100 nm and 110 nm-wide isolated lines. The height and the length of the lines are 5 nm and 500 µm, respectively. It is thought that the phase defect of 5 nm height was printable.
Fig. 6 EUV microscope image of programmed phase defect of 1 µm dot. Fig. 7 EUV microscope image of programmed phase defect of 90 nm, 100 nm, 110 nm isolated lines.

Figure 8 (a) and (b) are magnified EUV microscope images of 90 nm and 500 nm-wide isolated lines, respectively. There are two dark lines as shown in Fig. 8(b). From the mechanism of phase shift detection, it is thought that the light intensity decreased at the edge of the defect and a light intensity at the center of the line was not decreased as shown in Fig. 8(b).

(a)  
(b)  

Fig. 8 EUV microscope image of programmed defect of (a)90 nm and (b)500 nm isolated lines.

3.2.2 Pit defect
Bump defects are shown in previous section. But we think bump defect will be removed by cleaning technology. Pit defects are significant defect of mask substrate. For this reason, we showed the possibility of losing influence by the device of film structure in previous work15. Figure 9 shows the fabrication process of pit defect. Pit defects were fabricated by Mo/Si multilayer coating after dry etching of Si wafer substrate. In this case, there is no buffer layer under the multilayer. Several depth of the defects were fabricated. Figure 10 and 11 show atomic force microscope (AFM) image of Si substrate pattern of 500 nm-wide lines and spaces and 100 nm-wide isolated line of pit defects with 5 nm-depth before multilayer coating and EUV microscope image of after multilayer coating, respectively. Phase defects of 5 nm-depth have the capability of printable.

![Diagram of pit defect fabrication]

Figure 9 Fabrication of pit defect.
And Figure 12 and 13 show the AFM image of before multilayer coating and the EUV microscope image of phase defect of 2 nm depth, respectively. Phase defect of 2 nm-depth also has the capability of printable. It is under discussion about this result. Furthermore, it is thought that we can observe these defects or not is depends on the condition of multilayer deposition, so we want to clarify for the detail in near future.

Thus, we observed a programmed defect using the EUV microscope, and confirmed to be able to observe intensity distributions according to the change of the reflectivity in the defect.
4. CONCLUSION

We have constructed an EUV microscope system for at-wavelength areal image mask inspection. The main components of the system are a Schwarzschild optics, a focus detector and a X-ray zooming tube. Using the EUV microscope, the image of the phase defect due to a programmed bump defect of 90 nm wide and programmed pit defect of 100 nm wide were observed using the EUV microscope without a Mirau interferometer. Furthermore, for programmed defects of broad size, the edge of the program defect is observed. Using the EUV microscope, it succeeded in observation of the topological defect structure inside the multilayer. These results show that our system has a capability to detect internal reflectivity distributions, without depending on surface perturbation.

REFERENCES