Fine Pattern Replication by EUV Lithography

Kazuhiro Hamamoto¹, Takeo Watanabe², Harushige Tsubakino¹, Hiroo Kinoshita², Tsutomu Shoki³ and Morio Hosoya³

¹Department of Materials Science and Engineering, Faculty of Engineering, Himeji Institute of Technology
2167 Shosha, Himeji, Hyogo 671-2201, Japan
²Laboratory of Advanced Science and Technology for Industry, Himeji Institute of Technology
3-1-2 Kouto, Kamigori-cho, Ako-gun, Hyogo 678-1205, Japan
³HOYA Corporation Electro-optics Company R&D Center
3-3-1 Musashino, Akishima-shi, Tokyo 196-8510, Japan

Fine pattern replication utilizing 3-aspherical mirror system settled on NewSUBARU beamline is described. The exposure system is composed of three aspherical mirrors, and the NA is 0.1. The diffraction limited resolution of 60 nm was exposed on exposure area of 10 mm × 2 mm. The Cr mask pattern fabricated by the wet etching method was used for the extreme ultraviolet lithography mask. The pattern of 100 nm or less can be formed by with this Cr mask, and using photoresist of ZEP520 and SAL601. The line and space pattern width of 60 nm was fabricated with ZEP520. In addition, it has been understood that the isolation line of 43 nm width was replicated. Furthermore the hole pattern of 150 nm was replicated.

Keywords: Extreme Ultraviolet Lithography, Cr mask, fine pattern, hole pattern

1. Introduction
The semiconductor industry plays a very important role in the information technology (IT). In 2006, 256 Gbit DRAM with a gate length of 70 nm will be demanded in the IT industry. The extreme ultraviolet lithography (EUVL) [1] is a promise technology for fabricating a fine pattern less than 70 nm. To meet this schedule, this technology has to be developed in the pilot line until 2004 [2]. As for the practical use, it is very important that both to achieve large exposure area and to fabricate fine patterns. At Himeji Institute of Technology, large exposure field EUV camera which consists of three aspherical mirrors was developed [3]. In 1999, 56-nm-width pattern was fabricated using this camera and with electroplated Ni absorber mask [4]. However the edge roughness of the Ni absorber pattern was not so good. We have proposed an EUVL mask with Cr absorber pattern. In this paper, we describe about fine pattern fabrication using the Cr absorber mask. Because that, as for the mask absorber pattern etching technology, the Cr mask technology which has been using in the optical lithography can be extendable to use that in EUVL technology.

2. Experiment
2.1. Exposure system
Figure 1 shows the configuration of the EUVL beamline in the NewSUBARU synchrotron

![Fig. 1 Configuration of the EUVL beamline.](image-url)
radiation facility. It has collimating optics that consists of two glancing mirrors and illumination optics that consists of two glancing mirrors. Table 1 shows the specification of the EUVL laboratory tool. The exposure wavelength is 13.5 nm. Numerical aperture is 0.1. The resolution on the wafer is estimated to be 60 nm. The depth of focus is 1.9 \mu m for 100 nm line and space pattern.

**Table 1 Specification of the EUVL laboratory tool.**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical aperture</td>
<td>0.1</td>
</tr>
<tr>
<td>Imaging optics</td>
<td>three aspherical mirrors</td>
</tr>
<tr>
<td>Demagnification</td>
<td>1/5</td>
</tr>
<tr>
<td>Resolution</td>
<td>60 nm ($\lambda = 13.5$ nm)</td>
</tr>
<tr>
<td>Depth of focus</td>
<td>1.9 \mu m</td>
</tr>
<tr>
<td></td>
<td>(100 nm line width)</td>
</tr>
<tr>
<td>Exposure field (static)</td>
<td>30 mm $\times$ 1 mm</td>
</tr>
<tr>
<td>Exposure field (scanning)</td>
<td>30 mm $\times$ 28 mm</td>
</tr>
<tr>
<td>Wafer size</td>
<td>8 inch</td>
</tr>
<tr>
<td>Mask size</td>
<td>8 inch</td>
</tr>
<tr>
<td>Exposure environment</td>
<td>In vacuum</td>
</tr>
</tbody>
</table>

**Fig. 2 Configuration of the EUVL laboratory tool.**

**Fig. 3 Photograph of the EUVL laboratory tool.**
The magnification of the imaging optics is 1/5. The 8-inch-wafer and 8-inch-mask can be used. The vacuum environment is necessary for the exposure. Figure 1 and Figure 2 show the configuration and the photograph of the EUVL laboratory tool, respectively. The EUVL laboratory tool consists of the illumination optics, the scanning and the alignment mechanisms, the three-aspherical-mirror optics [5]-[6]. These whole mechanism are set on the vibration isolated activated bench to protect from the vibration affect. Furthermore the load-lock chamber for exchanging wafer is connected to the vacuum chamber for the EUVL laboratory tool. This tool is installed in a thermal chamber which is located at the end of the BL3 beamline at the NewSUBARU synchrotron facility. The thermal chamber keeps the clean degree of class 100 which can be controlled at the temperature within 23±0.5°C. The SR light source is a bending magnet of the NewSUBARU storage ring, and the storage ring is operates at the electron energy of 1.0 GeV. The illumination optics that consists of two glancing mirrors was designed to satisfy the illumination area size of 50 mm×10 mm on the mask. However the dose uniformity was not so good. To achieve the uniform dose in the illuminated area, the first illumination C1 mirror is rotated around beam axis during the exposure, and obtained uniform pattern in the exposure area of 10 mm×2 mm in wafer [7].

2.2. Cr absorber Mask for EUVL

The EUVL blank mask was fabricated by coating Mo/Si multilayer (ML) on 4-inch-wafer. An absorber layer of Cr is deposited on top Si layer of the Mo/Si multilayer by a dc magneton sputtering system. Thickness of the Cr layer is 100 nm. The Cr absorber is patterned in a wet process without damaging the multilayer. The reflectivity of Mo/Si ML was measured by reflectometer set on BL-10 in the NewSUBARU and the reflectivity of 60% was obtained. The SEM photograph of the Cr absorber pattern is shown in Figure 4. Figure 4 (a) shows the line and space pattern of 350 nm. These patterns were completely fabricated in each shot area of the mask. The edge roughness of the absorber pattern seemed to be very small in comparison with that of the mask of the KrF lithography. Therefore, it is expected that the 70 nm line and space patterns can be replicated on a wafer in good quality. Furthermore, as shown in Figure 4(b), 150-nm-width pattern was fabricated, which has capability to replicate the 30 nm pattern on a wafer.

2.3. Photoresist

In order to investigate the replication of the Cr mask, the non-chemically amplified positive-tone resist of ZEP520 (Nippon Zeon Co. Ltd.) and the chemically amplified negative-tone resist of SAL601 (Shipley Co. Ltd.) was employed. The reason why positive tone resist was used is that the amount of the best dose for positive-tone resist is distinguished more easily rather than that for negative tone resist. SAL601 has a high environmental stability because of the negative-tone chemically amplified resist, and can be expect
the high resolution.

Table 2 Resist processing conditions.

<table>
<thead>
<tr>
<th></th>
<th>ZEP520</th>
<th>SAL601</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>100 nm</td>
<td>100 nm</td>
</tr>
<tr>
<td>Prebake</td>
<td>180°C, 180 s</td>
<td>90°C, 60 s</td>
</tr>
<tr>
<td>PEB</td>
<td>---</td>
<td>110°C, 90 s</td>
</tr>
<tr>
<td>Development</td>
<td>o-xylene of 22°C, 300 s</td>
<td>NMD-3 of 23°C, 60 s</td>
</tr>
<tr>
<td>Rinse</td>
<td>IPA of 23°C, 30 s</td>
<td>de-ionized water of 23°C, 60 s</td>
</tr>
</tbody>
</table>

2.4. Experiment
The resist was spin coated with on Si wafer of 8 inch diameter. Resist coating and development were carried out by using the coating-and-developing system of Clean Track Mark-8 (Tokyo Electron Ltd.). Table 2 shows the condition of resist coating and developing process. The wafer surface treatment by HMDS (90 °C and 60 seconds) was done before coating the resist. The resist thickness was measured by utilizing the thickness-measuring system of NANOMETRICS M5100A. The Si wafer coated with resist was settled in the exposure system and was exposed. The first mirror of illumination optics was rotated while exposing. After the development, CD measurement of the resist pattern was carried out by utilizing scanning electron microscope (SEM) S-8840 (Hitachi Co. Ltd.). Furthermore, the observation of the absorber pattern on a Mo/Si multilayer was carried out by utilizing SEM S-4500 (Hitachi Co. Ltd.).

3. Result and Discussion

Fig.5 Cr mask absorber pattern of 500-nm-width line and space.

Fig. 6 Replicated pattern of 100-nm-width line and space of ZEP520.

Fig. 7 Replicated pattern of 100-nm-width line and space of SAL601.
Figure 5 shows the mask absorber pattern of 500-nm-width line and space. Figure 6 shows the replicated pattern of ZEP520. Figure 7 shows the replicated pattern of SAL601. As for the fabrication of 100 nm width line and space pattern at the thickness of 100 nm, the sensitivity of ZEP520 is estimated about six times lower than that of SAL601. The edge roughness of SAL601 is larger than that of ZEP520.

The mask pattern is shown in Figure 8 and the replicated pattern of line and space of 60-nm-width is shown in Figure 9. The replication of 60-nm-width line and space pattern was confirmed. The replicated pattern on a wafer was magnified in the reduction ratio of 1/5 in comparison with the mask pattern.

Figure 5 shows the mask absorber pattern of 500-nm-width line and space.
As shown in Figure 10, it is found that the isolated line width of 43 nm was replicated.

Figure 11 shows the mask absorber hole pattern of 750-nm-width. As shown in Figure 12, the 150-nm-width hole pattern of ZEP520 was replicated. The magnification ratio between the resist pattern and mask absorber pattern is 1/5.

4. Conclusion

The Cr mask pattern fabricated by the wet etching method was used for the EUVL mask. The pattern of 100 nm or less can be formed by using this Cr mask, and using photoresist of ZEP520 and SAL601. The line and space pattern width of 60 nm and the isolation line width of 43 nm width were replicated. Furthermore, the hole pattern width of 150 nm was replicated using ZEP520. In comparison of the 100-nm-width line and space pattern between ZEP520 and SAL601, the edge roughness of SAL601 is larger than that of ZEP520.

References