Characteristics of CA Resist in EUV Lithography

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According to the synchronous scanning of the mask and wafer with EUVL laboratory tool (ETS-1) with reduction optical system which consisted of three-aspherical-mirror in the NewSUBARU facilities succeeded in the line of 60 nm and the space pattern formation in the exposure region of 10 mm × 10 mm.

Comparing the result of exposure characteristics for positive-tone resist for KrF and EB, KrF chemically amplified resist has better characteristics than EB chemically amplified resist. The development of suitable resist for EUVL that the resolution performance and sensitivity are good, and the amount of outgassing is low will be advanced based on KrF resist.

Keywords: Extreme Ultraviolet Lithography, large field exposure, CA resist

1. Introduction

The semiconductor industry plays a very important role in the information technology (IT). According to the SIA roadmap, by the year of 2006, minimum feature size of 70 nm on wafer is required. The extreme ultraviolet lithography (EUVL)¹⁾ is a promise technology for fabricating a fine pattern less than 70 nm. This technology has to be developed in the pilot line until 2004 to meet this schedule²⁾. In 1999, we had fabricated 56-nm-width line and space pattern in the exposure area of 10 mm × 2 mm in size in the static exposure utilizing ETS-0^{3,4)} which consists of three-aspherical-mirror imaging optics⁵⁾. However, as for the practical use, it is very important that both to achieve large exposure area and to fabricate fine patterns. The exposure test standing ETS-1 was developed in Himeji Institute of Technology which consists of three-aspherical-mirrors, objective, and the mask and wafer scanning stages. Using the mask and wafer scanning stages, pattern width of less than 70 nm can be achieved in the exposure area of 30 mm × 28 mm in size. The optical housing was made of invar to decrease the affect of

the thermal expansion. Furthermore, we have proposed an EUVL mask with Cr absorber pattern. The Cr mask absorber pattern wet-etching technology for the optical lithography is extended to use that for the EUV lithography. In static exposure using Cr mask, 60-nm-width line and space pattern, 40-nm-width isolated line and 150-nm-width hole pattern were replicated⁶⁾.

The chemically amplified resist for EUV lithography requires following characteristics: 70 nm or less resolution, size accuracy 10 nm or less, sensitivity for 13-14 nm is 10 mJ/cm² or less, low edge roughness, a environmental, low outgassing, and wall slope 85° or more. However, resist for EUVL has not optimized yet.

In this paper, we describe the fine pattern replication in the scanning exposure utilizing ETS-1 three-aspherical-mirror imaging system. Furthermore, we describe the exposure characteristics of the positive-tone resist in EUVL based on the suitable resist for KrF and EB.

The development of the ETS-1 was performed in collaboration with the Association of Super-Advanced Electronics Technologies (ASET). And

the development of the chemically amplified resist was performed in collaboration with Tokyo Ohka Kogyo Co., LTD.

2. Large-Field Exposure

2.1. ETS-1 laboratory tool

Figure 1 shows the configuration of the ETS-1, respectively.

This system operated at the wavelength of 13.5 nm. Numerical aperture is 0.1. The resolution on the wafer estimated to be 60 nm. The depth of focus is 1.9 μm for a 0.1 μm line and space pattern. The magnification of the imaging optics is 1/5. The 8 inches wafer can be used. Furthermore, 8 inches mask and 6025 ULE reticule can be used. The vacuum environment is necessary for the exposure. The whole system consists the illumination optics, the scanning and the alignment mechanisms, the three-aspherical-mirror optics⁷⁾. 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 of the EUVL laboratory tool. This tool is installed in a thermal chamber which is located at the end of the beamline BL3⁹⁾ at the NewSUBARU synchrotron facility⁸⁾. The thermal chamber keep the clean degree of class 100 which can be controlled the temperature within $23 \pm 0.5^\circ\text{C}$.

The illumination optics that consists of two glancing mirrors was designed to satisfy the illumination area size of $50 \text{ mm} \times 10 \text{ mm}$ on the mask. The first mirror of illumination optics has a rotating mechanism, and it was rotated while

exposing. Furthermore, to achieve the uniform dose in the illuminated area, the first illumination C1 mirror is rotated while the exposure, and obtained uniform pattern in the exposure area of $10 \text{ mm} \times 1 \text{ mm}$.

The resist was spin coated with on Si wafer of 8-inch diameter. Using the coating-and-developing system of Clean Track Mark-8 (Tokyo Electron Ltd.) carried out resist coating and development. Table 1 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 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.). Using this exposure tool, 60-nm-width line and space, 40-nm-width isolated line and 150-nm-width hole pattern has replicated on a wafer.⁶⁾

2.2. Exposure results

The exposure area in static exposure is $10 \text{ mm} \times 1 \text{ mm}$ in size. Replicated resist pattern width on a wafer was magnified in the reduction ratio of 1/5 in comparison with the mask absorber pattern.

To extend the exposure area in the vertical

Fig 1. Configuration of the ETS-1 laboratory tool.

direction, the mask and wafer stage were synchronized-scanned in the vertical direction. The mask stage moved 5.02 times faster than the wafer stage. This scanning ratio obtained by the length of the vertical direction of the replicated pattern becomes 1/5 of the vertical direction of the pattern on the mask. As shown in Figure 2, it is achieved that the 100-nm-width of line and space pattern and the 60-nm-width of line and space pattern, in the exposure area of 10 mm $\times$ 10 mm in size. It is confirmed that the ETS-1 system has a capability to fabricated 60-nm-node lithography with the mask and wafer stages with synchronized scanning. However, the dose uniformity was not so good, because the carbon contamination was deposited on the mask, which due to the hydrocarbon. The mask contamination appeared in the term of total two months in static exposure. Typical vacuum total pressure pressure and the hydrocarbons of 2×10^{-5} Pa and 1×10^{-6} Pa ,respectively. In the next stage, the contamination control has to be investigated.

3. Evaluation of CA resist characteristics

3.1. Utilized resist for this experiment

The chemically amplified (CA) resist¹⁰⁾ for EUV lithography requires as follows characteristics: resolution is 70 nm or less, size accuracy 10 nm or less, sensitivity for 13-14 nm is 10 mJ/cm² or less, low edge roughness, a high environmental stability, low outgassing, and wall slope angle of greater than 85° or more. However, resist for EUVL has not optimized yet.

ZEP520 (Nippon Zeon Co., Ltd.) positive-tone resist for EB that is non-CA resist has high

resolution and chemical high environmental stability. However, sensitivity and contrast of ZEP520 is small⁶⁾. Therefore, CA positive-tone resist is investigated in the exposure characteristics.

3.2. Evaluation results and discussions

Chemically amplified positive-tone resist from A to D (Tokyo Ohka Kogyo Co., Ltd.) are listed in table 1. Table 1 shows the resist processing conditions for these resists.

We obtained that the photospeed of the resist A is 9.0 mJ/cm² which is described in reference 11). The photospeeds in table 2 are computed based on the sensitivity of the resist A multiply by the relative exposure time ratio. The photospeed of EB resist is smaller than KrF resist. The photospeed of ZEP520 is one order larger than that of CA resists.

Figure 3 and 4 show the SEM photograph of 120 nm width lines and spaces patterns and 80 nm width lines and spaces patterns of each resists, respectively. In this experiment, the resist processing condition was optimized by the purpose of decreasing edge roughness rather than the obtaining high resolution. The prebake temperature was raised to decrease the film losses, the amount of the residual solvent was decreased and the diffusion of the acid was controlled. The PEB temperature was lowered to shorten the diffusion length of the acid and to decrease the film losses. To decrease the film losses, the development time was shortened. As shown in table 2, the photospeed of the resist C and D are higher than that of the resist A and B. Therefore, amount of generate acid in the resist C and D during exposure is larger than that the resist A and B. Thus, the lost of the film

Fig. 2 Large field exposure pattern of ZEP520.

Table 1. Resist processing conditions.

	type	Prebake	PEB	Development	Rinse
resist A	KrF-CA	130°C, 90 s	110°C, 90 s	60 s (NMD-3)	de-ionized water
resist B	KrF-CA	120°C, 90 s	140°C, 90 s	45 s (NMD-3)	de-ionized water
resist C	EB-CA	150°C, 90 s	130°C, 90 s	45 s (NMD-3)	de-ionized water
resist D	EB-CA	140°C, 90 s	130°C, 90 s	45 s (NMD-3)	de-ionized water
ZEP520	EB-non CA	180°C, 180 s	-	240 s (o-xylene)	IPA

Fig. 3 120-nm-width line and space pattern.

Fig. 4 80-nm-width line and space pattern.

thickness during development affects the edge roughness. The thickness of the resist C and D change 10-15% during development.

The results of the resist characteristics CA positive-tone resist optimized for KrF has better characteristics rather than those for EB. As shown in Figure 3 and 4, resolution capability of the resist A and B has less than 60 nm.

EUV lithography requires the vacuum environment for the exposing the resist. By EUV irradiation, outgassing species due to hydrocarbons decompose to the carbon which contaminate on the mask surface and the reflective mirror surface. As a result, these reflectivity become lower. Therefore, the low outgassing resist is required. The outgassing experiment was carried out at the ETS-1 chamber. The exposure area on a wafer was 10 mm × 1 mm in size. The M-QA200F quadruple mass spectrometer (ANELVA Co., Ltd.) was connected to the ETS-1 chamber to detect the outgassing ion species from the resist. The typical base pressure in the ETS-1 chamber is maintained at 2.4×10^{-5} Pa. For each resist, partial pressure

displacement is obtained by subtracting the partial pressure after exposure to that before exposure for the mass number from 1 to 60. In order to obtain the amount of real partial pressure of outgas, the following equation is used.

$$\text{Resist outgassing} = ((\text{just beginning of irradiation})_{\text{resist}} - (\text{before irradiation})_{\text{resist}}) - ((\text{just beginning of irradiation})_{\text{Si wafer}} - (\text{before irradiation})_{\text{Si wafer}})$$

Resist outgassing by EUV irradiation is shown in Fig. 5. Partial pressure displacement of ZEP520 shows a lot of hydrocarbon greater than 44 amu.

The amounts of outgassing of hydrocarbons from CA resist for KrF is higher than that for EB. It has been understood that the outgassing of CA resist is chiefly due to the decomposition of the protecting group as a result by the measurement of outgassing as described in reference 12) and 13). The amounts of outgassing of hydrocarbons from CA resist for KrF is higher than that for EB. The protecting group decomposes easier from the resist A and B compare with the resist C and D.

Fig. 5 resist outgassing by EUV irradiation.

Table 2. Characteristics of the resist.

resist	Type	photospeed (mJ/cm ²)	edge roughness	resolution	outgassing
resist A	KrF	9.0	middle	≤ 60 nm	middle
resist D	KrF	5.7	small	≤ 60 nm	middle
resist B	EB	2.0	large	80 nm	low
resist C	EB	1.8	large	80 nm	low
ZEP520	EB	42.0	small	60 nm	high

Therefore it is considered that the amount of outgassing from CA resist depends on the protecting group of resist and does not depend on the sensitivity because the displacement of the partial pressure of just before and just after irradiation is obtained. The characteristics of the resist are shown in Table 2.

Totally resist characteristics presents the resist B has best exposure characteristics in the evaluated resist. However, the outgassing has to be refined.

4. Conclusions

Using the mask and wafer stage with synchronized-scanned in the vertical direction, 60-nm-width is replicated in the exposure area of 10 mm × 10 mm size.

EB resist has high sensitivity and large edge roughness, and the resolution performance is bad. The amount of outgassing is low. KrF resist has small edge roughness and good resolution performance, but the amount of outgassing is a little high. From the result of evaluated CA positive-tone resist in EUV lithography, the resist that is optimized for KrF has better exposure characteristics than that of optimized for EB.

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