PART I

Lithographic Processing

RECENT PROGRESS IN EXCIMER LASER LITHOGRAPHY

I.Higashikawa, M.Nonaka, T.Sato, M.Nakase, S.Ito, K.Horioka and Y.Horiike
Toshiba Corp. VLSI Reseach Center,
1 Komukai Toshiba-cho Kawasaki, 210 Japan

ABSTRACT

A KrF excimer laser exposure method has been developed for laboratory use, which employs 10 to 1 achromatic projection lens of 0.37 NA and 5 x 5 mm field size , and a TTL alignment system using the double diffraction method, which was realized by the use of the achromatic lens. Novolak type mid-UV resists, such as AZ-5214 and PR-1024, were best suited for use in 248 nm exposure, considering the sensitivity and etching resistance from a practical viewpoint, and an additional post exposure baking process also improved the resist profile. The dependences of the exposure characteristics on the energy density per pulse and pulse frequency of these resists were not observed in the region of the practical exposure conditions. An alignment precision of $\bar{x}\pm3\sigma = 0.2$ μm was achieved for the alignment mark consisting of poly Si pattern. Thus, a 0.3 μm line and space pattern was realized by using tri-level resist process and a 0.2 μm gate pattern was successfully fabricated on the coplanar pattern with a 0.4 μm step.

INTRODUCTION

A variety of the KrF excimer laser reduction projection techniques [1-8] have been reported for the last two years as shown in Table 1. Since then, the excimer laser lithography has been expected to realize patterning below 0.5 μm feature size as well as today's 0.5 μm optical lithography in VLSI manufacturing.

	AT&T Bell Lab.	GCA	Matsushita	Toshiba	Nikon	Nikon	Canon	Mitsubishi	SONY
NA	0. 38	0. 35	0. 36	0. 37	0. 4	0. 37	0. 35	0. 37	0. 35
Wavelength (nm)	248	248	248	248	248	248	248	248	248
Δλ(FWHM) (nm)	0. 005	—	0. 007	~0. 4	–	~0. 4	–	~0. 4	0. 002
Type	chromatic	chromatic	chromatic	achromatic	chromatic	achromatic	chromatic	achromatic	chromatic
Reduction ratio	1/5	1/5	1/5	1/10	1/5	1/10	1/5	1/10	1/5
Field size (mm)	20φ	20φ	15×15	5×5	15×15	5×5	5φ	5×5	4×4
Resolution (k=0. 8) (μm)	0. 52	0. 57	0. 55	0. 54	0. 50	0. 54	0. 57	0. 54	0. 57
Alignment precision (μm)	±0. 25 (2σ)	±0. 3 (3σ)	±0. 3 (3σ)	±0. 2 (3σ)	±0. 15 (3σ)	—	—	—	
ref	1	2	3	4		5	6	7	8

Table 1 Specification for KrF excimer laser exposure systems reported in previous publications.

At present, two approaches in the combination of lens and laser source have been developed for excimer laser lithography. One is a lens system with chromatic aberration correction and the conventional broadband KrF laser.

Mat. Res. Soc. Symp. Proc. Vol. 101. ©1988 Materials Research Society

The other is an all quartz chromatic lens system with a spectrally line-narrowed KrF laser. Now, much effort has been concentrated in the early practical use of the excimer laser stepper employing the latter combination, because of the difficulty in fabricating the achromatic lens with a large field size. However, this type of stepper now faces the following major issues: (1) Decrease in intensity due to spectral narrowing, center frequency drift and short lifetime of the excimer laser source. (2) TTL(through-the-lens) alignment method [9], because the change in the focal distance becomes tens of centimeters, when a He-Ne laser used as an alignment light passes through the projection lens designed for 248 nm. (3) No resist which satisfies the three factors of photosensitivity, resolution and dry etching resistance simultaneously.

This paper reports Toshiba's recent progress in the excimer laser lithography technolog, focusing on the evaluation results and issues on commercial resists for KrF excimer laser exposure, a newly developed TTL alignment technique using a double diffraction method and an actual patterning with this system.

EXPERIMENTAL

Exposure System

Figure 1 shows a diagram of the excimer laser exposure and TTL alignment system, developed for laboratory use. A KrF(248 nm) excimer laser beam was introduced to the illumination optics by mirrors, which did not employ a special equipment to eliminate speckle noise. Then, a reticle pattern was printed to a wafer on an X-Y-Z-0 stage through a 10 to 1 reduction achromatic projection lens of 0.37 NA and 5 x 5 mm field size, fabricated from quartz and CaF_2 materials. The vertical position of the wafer surface was monitored by an oblique incident beam type optical positioning sensor for focusing.

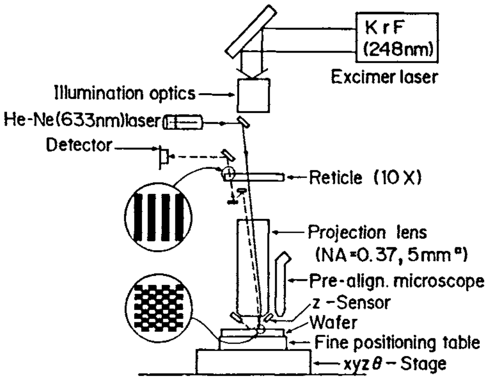


Fig. 1 Diagram of mexcimer laser exposure and TTL alignment system developed for laboratory use.

The TTL alignment scheme was as follows: Checker grating patterns and stripe grating patterns were prepared on a wafer and a reticle, respectively. The grating pattern on the wafer was illuminated by a He-Ne(632.8 nm) laser alignment light, which passed through the reticle window and the projection lens. The distance between the focal plane for the alignment beam and that for the exposure light beam was measured in advance to be 5.24 cm. To contrast with the difficulty in the TTL system using the chromatic lens case described in earlier, the achromatic lens which was used allowed us to provide such short distance. Only the two first order diffracted beams from the wafer checker gratings were focused to the stripe gratings on the reticle employing bending mirrors, which corrected the distance by 5.24 cm. Thus, the interference between the diffracted beams and the reticle gratings generated the so called moire pattern. The moire pattern was used for the alignment signal which changed periodically as a function of the relative position between the two gratings on the wafer and the reticle. The special feature of this alignment method is its high S/N ratio sensitivity and its defocus-free property. These have been already confirmed using the g-line exposure [10].

The X-Y stage was driven by DC motors with the step and repeat mode, and the fine positioning for the TTL alignment was carried out by piezo actuators.

Experimental Conditions

PMMA(poly-methyl-methacrylate: Kanto Chemical), PMGI(poly-dimethyl-glutarimide: Shipley), MP-2400(Shipley), RD-2000N(Hitachi Kasei), AZ-5214(Hoechst) and PR-1024(McDermid) were evaluated as resists for use in 248 nm exposure. These were spin-coated on either a bare Si wafer or a tri-level resist substrate, where the intermediate layer was polysiloxane with 0.2 μm in thickness and the bottom layer was OFPR-5000(Tokyo Ohka) with 1.7 μm in thickness.

Baking was done by conventional hot plates. PMMA, PMGI, MP-2400 and RD-2000N were developed by the dip mode at room temperature, and AZ-5214 and PR-1024 were developed by the puddle mode at 15°C.

RIE(reactive ion etching) of the intermediate and bottom resist layers was carried out employing CF_4-H_2 at 10 mTorr and O_2 at 15 mTorr(2 Pa.), respectively.

RESIST PROCESS FOR EXCIMER LASER LITHOGRAPHY

Transmission Spectrum of Typical Deep-UV Resists

Table 2 shows comparison of the absorption coefficient for 248 nm, sensitivity and pattern profiles of 0.4 um lines and spaces for PMMA, PMGI,MP-2400 and RD-2000N. As suggested from the transmission spectra of these resists shown in Fig. 2, the absorption in 248 nm demonstrates that both PMMA and PMGI of a main chain scission type resist provide higher resolution but lower sensitivity than novolak type resists. Novolak type resists, such as MP-2400 and RD-2000N, show high sensitivity, while posi-type MP-2400 and nega-type RD-2000N exhibit triangular and undercut profiles due to high absorption in phenol bonding, respectively. These results indicate that the sensitivity and resolution of presently available resists used for excimer laser lithography trade off with each other. Considering the throughput and the tolerance to subsequent plasma processes, the use of a novolak type resist is desirable. However, since MP-2400 is usually developed by a metal-alkali-ion solution, it may cause serious sodium and potassium contaminations to the process line.

Thus, AZ-5214 and PR-1024 resists, which can be developed by a metal-ion-free solution, were investigated. Fig. 3 shows a 0.4 μm line and space pattern of AZ-5214,(a), and PR-1024,(b), where both resist thicknesses were 0.5 um and the exposure doses were 120 mJ/cm^2 and 100 mJ/cm^2, respectively.

Cambridge University Press
978-1-107-41104-3 - Laser and Particle-Beam Chemical Processing for Microelectronics: Symposium held December 1-3, 1987, Boston, Massachusetts, U.S.A.
Edited by Daniel J. Ehrlich, Gregg S. Higashi and Modest M. Oprysko
Excerpt
More information

Better features were obtained for PR-1024. Figure 4 compares the transmission spectra for AZ-5214, PR-1024 and MP-2400 resists before and after 248 nm exposure. An appreciable breaching effect was not observed for these resists. However, the 248 nm transparency for PR-1024 was considerably superior to that for AZ-5214, although MP-2400 showed more transparency in 248 nm. This better feature of PR-1024 may have resulted from the higher transparency in 248 nm.

Resist	α_{248} (μm^{-1})	Sensitivity (J/cm^2)	0.4μm L/S
PMMA	0.08	32	
PMGI	0.58	10	
MP2400	2.74	0.1	
RD2000N	3.25	0.1	

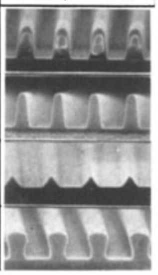


Table 2 Absorption coefficient for 248nm, sensitivity and profile of 0.4 μm line and space.

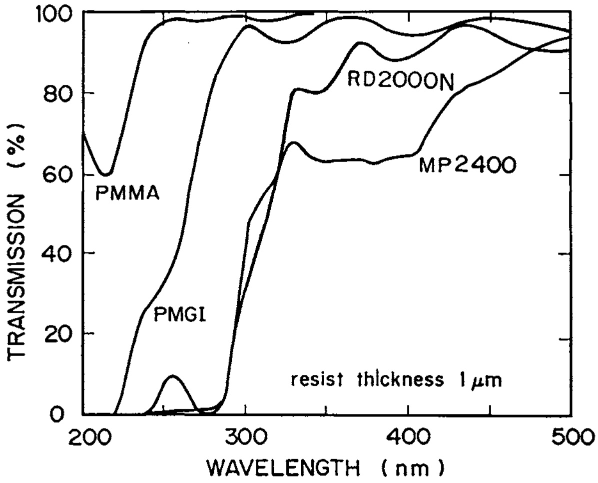


Fig. 2 Transmission spectra of PMMA, PMGI, RD-2000N and MP-2400.

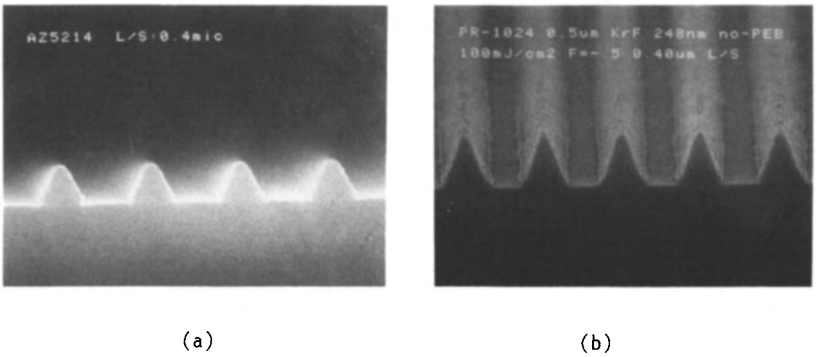


Fig. 3 0.4 μm line and space resist pattern of (a) AZ-5214 and (b) PR-1024.

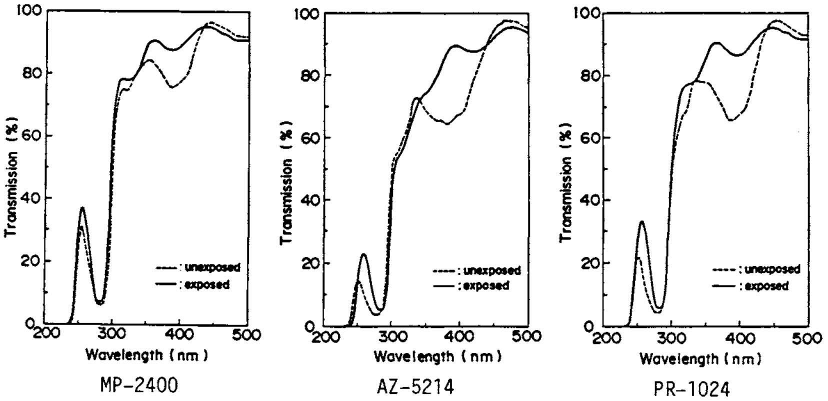
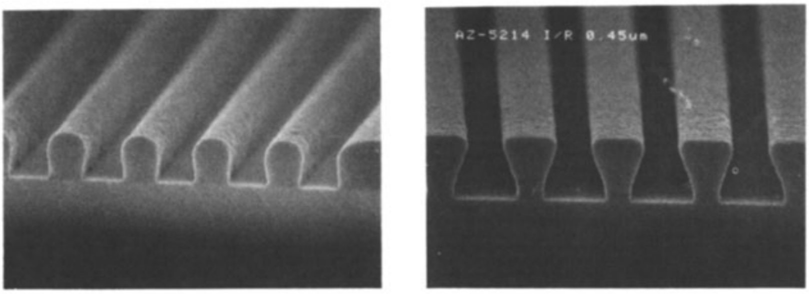


Fig. 4 Transmission spectra of MP-2400, AZ-5214 and PR-1024 before and after 248 nm exposure. (Resist thickness : 0.5 μm)

Resist Processes

AZ-5214 is known to be used as an image-reverse resist, which is performed by a simple process of baking and subsequent flood exposure. Figure 5,(a) shows a 0.325 μm lines and spaces pattern fabricated by the image-reverse process. Resist thickness is 0.4 μm. However, in the thicker coating case of Figure 5, (b), the high 248 nm absorption in the resist brings about an strongly undercut profile. Nevertheless, RIE allows a highly directional patterning of SiO_2, which is defined by the resist top dimension, as shown in Figure 6.

The post exposure baking effect was examined for PR-1024 in expectation of the improvement in the resist profile. This was because the application of this baking to AZ-5214 causes an image reversal effect. Figure 7 shows the PR-1024 resist profile after post-exposure baking at 110°C for 90 sec. The resist profile was improved compared with that without this process shown in Figure 3,(b). A flat region is observed obviously. Accordingly, this improvement is considered to have resulted from both increase in the well-known surface induction effect [11] and the smoothing of the standing waves [12].



(a) (b)

Fig. 5 Resist pattern fabricated by image reverse process of AZ-5214,
(a) 0.325 μm line and space, 0.4 μm in thickness,
(b) 0.45 μm line and space, 0.6 μm in thickness.

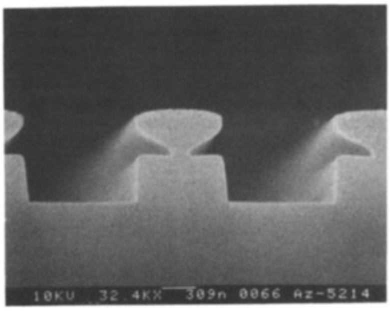


Fig. 6 Resist and SiO_2 and after RIE

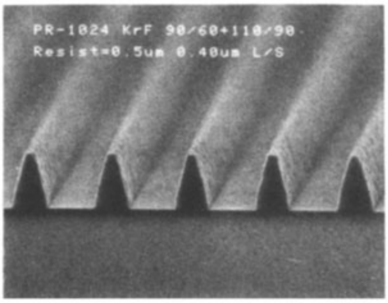


Fig. 7 0.4 μm line and space resist pattern obtained for PR-1024 by post-exposure baking process.

The excimer laser exposure tool combined with these developments of effective resist process techniques will promote the utilization of excimer laser lithography at the production level.

Repetition Rate and Pulse Energy Dependences

Excimer laser exposure is carried out by pulse exposures, which are different from conventional optical lithography. In the typical condition of 7 mJ/cm^2 at 10 nsec pulse width, the pulse peak energy reaches more than 10^5 times as compared with about 700 mJ/cm^2 of the conventional Hg-lamp used in a g-line stepper.

The dependence of the AZ-5214 exposure characteristics on the pulse energy was investigated, as shown in Fig. 8. The exposure at the pulse energy of 40 mJ/cm^2 pulse was made by placing AZ-5214 resist directly exactly on the excimer laser output window. Other exposures were performed through the optical system. For the case of the 40 mJ/cm^2 pulse, no change in the developed depth was observed in spite of an increase in the exposure dose of more than 100 mJ/cm^2. This results from a deep UV curing effect or a carbonization phenomenon caused by the absorption of almost all the laser power in the resist surface region. On the other hand, the lower pulse energy exposure ranging from 0.4 mJ/cm^2 pulse to 6.4 mJ/cm^2 pulse can offer normal characteristics curves. An appreciable pulse energy dependence was not observed in this region. This result demonstrated that AZ-5214 exposed not under an excessive pulse energy followed to the reciprocal law, for which failure has already been reported for PMMA resists [14,15].

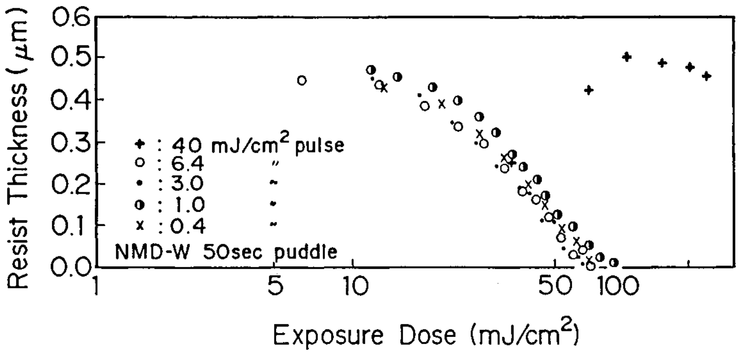


Fig. 8 Exposure characteristics of AZ-5214 with pulse energy as parameter.

The developed depth as a function of pulse frequency is shown in Fig. 9. The developed depth was kept constant. This result demonstrates that the pulse to pulse interval is relatively longer than the thermal diffusion period. Consequently, these data insist that excimer laser exposure should be carried out by as many pulses and as low energy as possible.

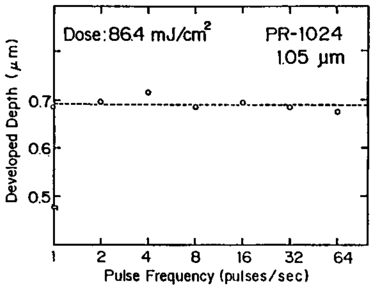


Fig. 9 Developed depth vs. pulse frequency.

Tri-Level Resist

Figure 10 shows an example of gate patterning using AZ-5214 on a coplanar structure. The obtained resist feature degraded even on a gentle slope topology. This is because the appropriate development time varies exponentially with resist thickness due to high absorption in 248 nm.

In order to overcome the problem, the authors were obliged to use a multi-layer resist system, such as a tri-level resist. Figure 11 shows a 0.3 µm line and space pattern using a tri-level resist. A fine patterning was achieved in spite of the top resist profile with a triangular shape, which was produced for all novolak resists.

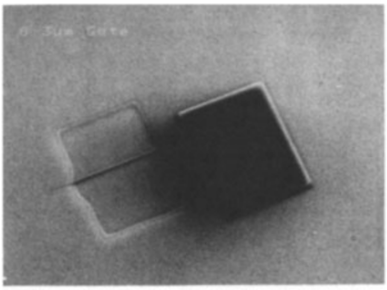


Fig. 10. Gate pattern using AZ-5214 on a coplanar structure.

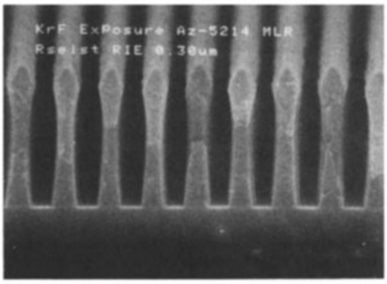


Fig. 11 0.3 um line and space pattern using tri-level resist system.