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Analysis of the effects of reflectance and refraction generated by wafers made from fused silica, ALOxNy and TiSixNy under different light sources on pattern length and best focus

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Abstract

In semi-conductor photo-lithography processing, line-width is constantly shrinking. That is why process window requirements are becoming stricter. Under these strict conditions, the influences of focus and pattern length are more important. This investigation tries to explore the deviation of best focus and the variation in pattern length resulting from the reflectance and refraction of fused silica, ALOxNy and TiSixNy wafers are coated with the same thickness of SEPR 432 PR (Photo Resist). Experimental results indicate that after excluding the influence of photo resist impacts, the refraction generated by the auto focus light source(halogens lamp) causes deviation of the best focus, and the extent of deviation has a directly proportion relationship with refraction, and no direct relationship exists between exposure light source (laser) and the deviation of best focus. The reflectance generated by exposure light source only changes the measures of pattern length, and an inverse relationship exists between reflectance and pattern length; that is, received pattern length reduces with increasing wafer reflectance.

Keywords: Deep UV; Refraction; Reflectance

1. Introduction

Wafer throughput in micro-lithography depends on the sensitivity of the resist film to radiation. A lower exposure time required to produce a latent Image in the resist corresponds to a higher throughput [1]. The designed by watanabe et al. [2] showed that the focus margin for 0.3 μm lithography with a KrF excimer stepper is ±0.08 μm for DOF of ±0.5 μm. It is possible for an ArF excimer laser stepper to achieve 0.13 μm lithography with a DOF of ±0.5 μm by using the recently developed technique of super resolution. The wafer surface profile is structure of the device and has irregularities of 0.3–1 μm. As optical lithography will not reach the necessary resolution for future demands in microengineering. Now lithographic techniques have to be ready to produce nanostructures in a parallel way. Atoms with thermal kinetic energies have de Broglie wavelengths in the picometer regime and so they do not suffer from diffraction when focused down to a nanometer scale spot size. In the last decade the investigation of atom light interaction has shown, that the trajectories of neutral atoms can be efficiently manipulated with laser light and that optical elements for neutral atoms can be built using the resonant interaction with laser light [3–5].

The photolithographic process is further limited since a yellow light source does not promote the resist to react chemically. Accordingly, photolithography should be performed in an environment with a yellow light source. The commonly used light sources in the stepper include the G-line, the I-line and DUV (deep ultraviolet). The G-line wavelength is ∼436 nm, the I-line $\lambda = 350$–450 nm, and DUV $\lambda = 100$–300 nm. DUV wavelengths differ according to the laser gas composition: KrF $\lambda = 248$ nm, ArF $\lambda = 193$ nm and F_2 $\lambda = 157$ nm [6]. In this work, the DUV stepper's laser light source, KrF $\lambda = 248$ nm, was used.

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2. Experimental

This investigation used (1) fused silica, (2) ALOXNY, (3) TiSixNy wafers as exposure materials and used these three different wafer materials as the bottom reflective materials under a thin film of photo resist. This investigation also divided the wafer surface into a lateral axis and direct axis using matrix exposure. Various combinations of focus and exposure dose then were used to investigate the variations in wafers made from different materials using the same photo resist.

The focus of PR (Photo Resist) varies with thickness and sensibility. To obtain a reference point for the focus, this investigation used fused silica to coat SPR 432 photo-resist before the experiment to adjust the focus of the wafer via matrix exposure, and fixed the exposure dose at 35 mJ/cm^2 (best exposure dose). The focus value is assumed to be below ±0.1 μm, which is considered the best focus of experiment, focus is measured in relation to zero. This investigation adjusted the exposure dose and focus via matrix exposure to obtain the experiment results.

3. Results and discussion

3.1. Method used to obtain the best focus

Best focus is the diagram that is best similar with reticle and obtained by altering the focus given fixed exposure dose. Best focus exposes 17 sets of patterns on the surface of the wafer coated with positive resist (SEPR 432), and each pattern set comprises nine sets of horizontal pattern and nine vertical patterns. Each of these nine sets of patterns comprises five rhombus patterns, and the ratio of length to width of these rhombus patterns in the reticle is 30:1. The pattern shapes change with focus variation. The length of each rhombus pattern is measured, revealing an association between long length and good focus. The condition for the experiment to obtain the best focus is SEPR 432 Photo Resist, Exposure Dose $=36$ mJ/cm^2, Exposure step $=0.15$ μm, focus variation ranges from $+1.4$ to -1.4 μm.

3.2. Focus exposure theory

Fig. 1 clearly illustrates a cone shaped distribution and positive and negative symmetry of light sources from the lens to the wafer surface. Given focus $=+1.4$ μm and focus $=-1.4$ μm, the exposure area of CD Bar exceeds focus $=0$ μm. Consequently, the size of CD Bar is not different given focus $=0$ μm and focus $=\pm 1.4$ μm. Pattern length is longest when focus $=0$ μm, because exposure area is smallest and pattern length is shortest when focus $=\pm 1.4$ μm because exposure area is maximized. However, these phenomenon only occur on positive resist. For negative resist opposite results are obtained. Positive resist is characterized by the lighted area producing photo-acid and alkali developer, which is eliminated following neutralization because of the balance between acid and alkali. DUV light source has a cone shape distribution, and positive and negative symmetry exists between the lens and the wafer surface. When exposure location is on the top of the cone, then this investigation assumes focus $=0$ μm. The focus distance increases with the distance of the exposure location from the top of the cone. The cone area is smallest when focus $=0$ μm, and thus the lighted area is less than for focus $=\pm 1.4$ μm while the pattern length is longer or bigger. The lighted area of positive resist increases given focus $=\pm 1.4$ μm. Besides, probably because of the serious defocus or the reduced capacity to display diagram borders, pattern length is reduced and an irregular pattern forms given focus $=\pm 1.4$ μm, as illustrated in Fig. 2(a) and (b) it is revealed that high wafer surface reflectance can cause CD bar to smaller at TiSixNy wafers, and (c) low reflectance makes CD bar become larger and wafer surface remain Photo Resist. From Fig. 3, it is found that line-width measured after exposed with high dose is much smaller than that when exposed with low dose, When exposure dose is low, line-width is wider than that exposed at high dose. This can be attributed to the facts that at high exposure dose, the absorption of high energy of PR enhances the reaction capability of neutralization. Therefore, there will be more areas to be neutralized. Those impurities after neutralization can be rapidly washed away by DI water. However, too high of exposure dose can cause line-width to become very small. As a result, the aspect ratio becomes too large. Therefore, CD bar cannot hold back the turbulent force caused by DI water as neutralized area is washed, causing CD bar to collapse.

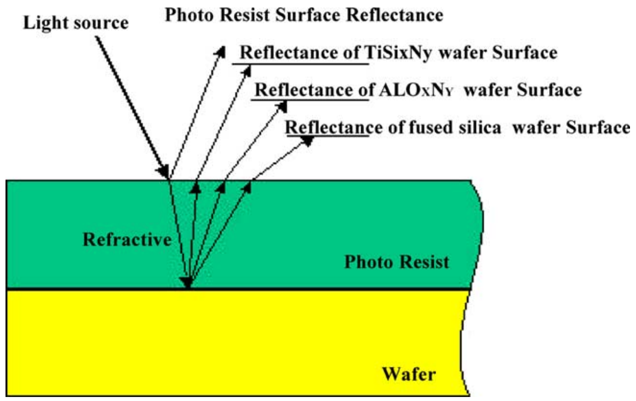


Fig. 1. Stepper exposure diagram, best focus locations following refraction on photo resist and wafer surface by auto focus light source.

3.3. Influence of wafer surface materials on best focus variation

When the variation of focus is confined within the scope of ±1.4 μm, the experiment found that wafers made from different materials produced different focus variation even if they were coated using the same SPR 432 photo resist.

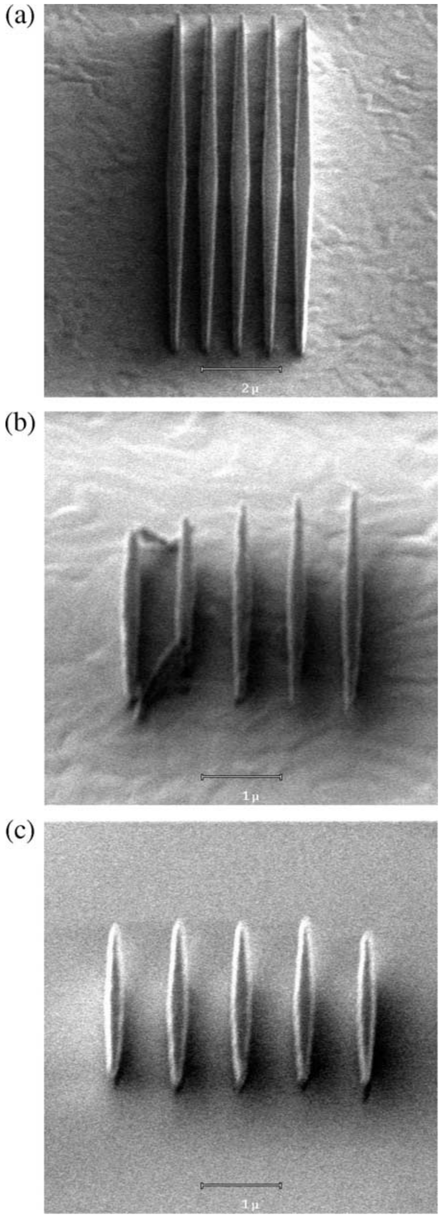


Fig. 2. Observed with the applied materials SEM at a scanning angle of +45°, (a) fused silica wafer exposure dose=46 mJ/cm^2 and focus=0.0 μm, (b) ALOxNy wafer exposure dose=56 mJ/cm^2 and focus=−0.45 μm (c) TiSixNy wafer exposure dose=56 mJ/cm^2 and focus=−0.15 μm.

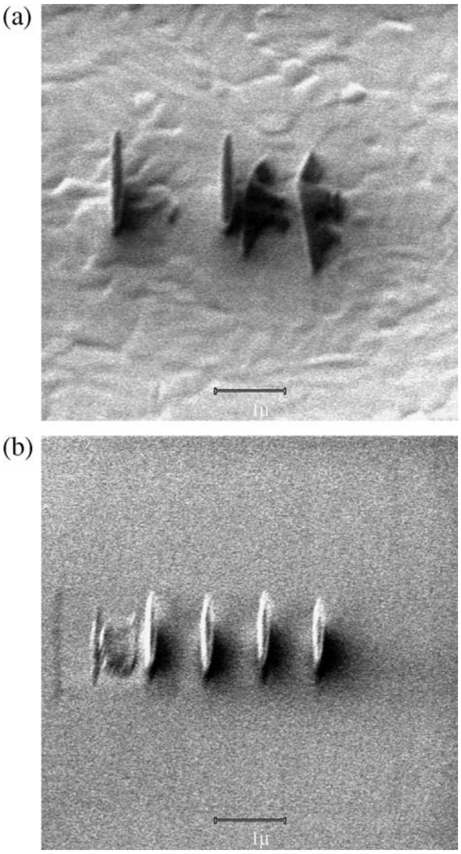
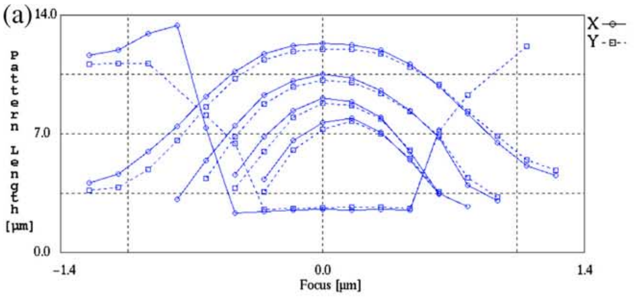


Fig. 3. Collapse of CD bar for (a) ALOxNy wafer at exposure dose of 56 mJ/cm^2 and focus=−0.65 μm (b) TiSixNy wafer at exposure dose of 56 mJ/cm^2 and focus=−0.45 μm, picture taken by applied materials SEM vision.

From the comparisons of focus variation curves in Fig. 4(a)–(c), three kinds of wafers have different materials and different best focuses even given identical exposure and PR conditions. The best focus is 0.061 μm for wafers with fused silica surface, 0.200 μm for wafers with ALOxNy surface, and 0.061 μm for wafers with TiSixNy surface. From the analysis of Fig. 1, when laser light projects into photo resist, the light go through the PR thin film area and produces refractive and reflectance because PR comprises sensitive doses. This investigation did not consider the influence of refractive and reflectance in the thin film area on the experiment, because SEPR 432 PR was required in all experiments. The reflectance varies with wafer surface materials. The experiment results found that the three wafers had different best focuses. Comparing these three experimental conditions, reflectance=11.82% and best focus=0.200 μm if the wafer is coated by ALOXNY, while reflectance=17.63% and best focus=0.245 μm if the wafer surface is coated by TiSixNy. The difference between the two reflectances is 5.81%, while that of best focuses is only +0.045 μm. Comparing reflectances when using ALOXNY and fused silica as the wafer surface materials, the difference is only 0.26%, but the difference in best focus is 0.139 μm. Therefore, no necessary relation exists between best focus and material reflectance. To analyze the influences on best focus is the refractive phenomenon of auto focus light sources. The experiment used a halogen lamp as an auto focus light source because halogens light source refractive phenomenon caused the light source to refract at an angle when the sensor received the plane with the best focus. Consequently, the planes of best focus differ for different materials. After reflecting different wafer materials with halogen light sources, this investigation found the planes of auto focus via PR film refraction, as follows: fused silica=0.023 μm, ALOXNY=0.199 μm,

(a)



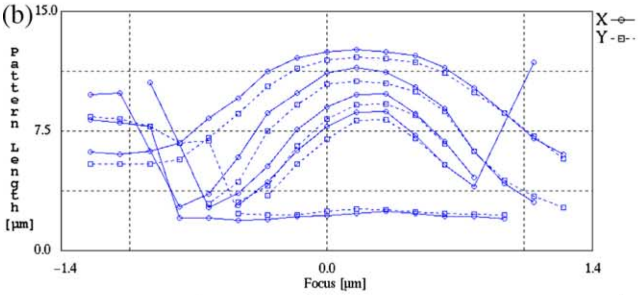
Fused Silica

$\lambda = 248nm$

reflectance = 12.03%

Fused Silica Best Focus Pattern Length			
Exposure(mJ/cm2)	X(μm)	Y(μm)	X/Y
16	13.495	0	no good
26	12.622	12.339	1.023
36	10.611	10.264	1.034
46	9.281	8.912	1.041
56	7.931	7.699	1.030

(b)



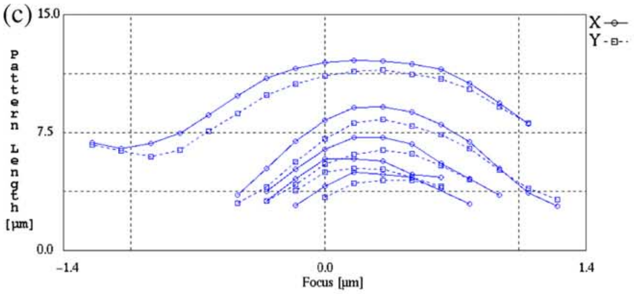
ALO_XN_Y

$\lambda = 248nm$

reflectance= 11.82%

ALOxNy Best Focus Pattern Length			
Exposure(mJ/cm2)	X(μm)	Y(μm)	X/Y
16	0	8.577	0.000
26	12.85	12.365	1.039
36	11.518	10.961	1.051
46	10.014	9.411	1.064
56	8.93	8.263	1.081

(c)



$TiSi_XN_Y$

$\lambda = 248nm$

reflectance = 17.63%

TiSixNy Best Focus Pattern Length			
Exposure(mJ/cm2)	X(μm)	Y(μm)	X/Y
16	12.34	11.61	1.063
26	9.257	8.327	1.112
36	7.258	6.401	1.134
46	5.97	5.276	1.132
56	4.947	4.494	1.101

Fig. 4. Pattern length focus process latitude smiley curve obtained by deep UV together with SEPR 432 photo resist from wafers made using (a) fused silica, (b) ALOxNy or (c) TiSixNy via matrix exposure.

TiSixNy = 0.210 μm. The factor of influence on best focus thus is the refraction on the wafer by the auto focus (halogens lamp) light source, not the reflectance on the wafer by the exposure (laser) light source.

3.4. Influence of wafer surface materials on DOF (depth of focus) variation

DOF indicates that focus changes under fixed exposure dose; that is, focus changes from positive to negative with zero as datum. The experiment can accept some values within a certain scope. The scope of focus in the experiment is ±1.4 μm. Any measured point in this scope is considered acceptable by the experiment. From Fig. 4, wafers made from different materials, even given identical PR and exposure conditions, obtain different DOF. Improving imaging effects requires deeper DOF. From Eq. (1), possible influences on DOF include wavelength (λ), numerical aperture (NA) and K_2. Meanwhile, from Eq. (2), the only method of changing DOF under the same conditions of NA with λ is to control K_2. Previously, many researches in this field proposed only that potential influences on DOF include photo resist and some process parameters. However, this investigation found that wafer surface material is an important influence on DOF. Three kinds of wafer are compared, with exposure dose = 56 mJ/cm^2, fused silica DOF = 0.9 μm, ALOxNy DOF = 1.2 μm, and TiSixNy DOF = 0.75 μm. Wafer material influences the results of DOF

$$R = \frac{K_{\mathrm{PR}}\lambda}{NA} \tag{1}$$

$$\mathrm{DOF} = (K_{\mathrm{PR}} + K_{\text{wafer surface material}} + K_{\mathrm{other}})\frac{\lambda}{NA^2} \tag{2}$$

3.5. Influence of exposure dose on pattern length variation for different wafer surface materials

From Fig. 4, exposure dose is a key influence on pattern length. This investigation found that pattern length decreased with increasing exposure dose, regardless of wafer material. From the mutual comparisons in Fig. 4, wafers made from three different materials display different pattern lengths given the same exposure dose. However, these wafers display the same curve trends. Given the same PR thickness, the most import influence on pattern length is PR sensitivity. However, because the experiment used the same PR, this investigation did not consider the influences of sensitivities on the experiment results. To reduce the influence of PR film on the experiment results, the PR film of these wafers is limited to 6500 ± 200 Å, and the homogeneity of PR film is 3 sigma < 0.03 μm.

Fig. 4 selects the best focus for analyzing the relationship between exposure dose and pattern length. The same exposure dose is compared for different wafer surface materials, with exposure dose = 26 and 56 mJ/cm^2 being selected as the analytic condition. Given exposure dose = 26 mJ/cm^2, fused silica wafer pattern length $X = 12.622$ μm and $Y = 12.339$ μm, ALOXNY wafer pattern length $X = 12.850$ μm and $Y = 12.365$ μm, and

TiSxNy wafer pattern length $X=9.257\,\mu m$ and $Y=8.327\,\mu m$. Pattern lengths X and Y indicate the longest measures of 1:30 rhombus pattern measured on wafer surface under vertical and horizontal exposure, respectively. The measurements of pattern lengths X and Y differ because of the astigmatism. Fused silica reflectance = 12.03%, ALOXNY reflectance = 11.82%, TiSixNy reflectance = 17.63%. The reflectance of fused silica/ALO*X*N*Y* is 1.017, while the value of pattern length X of ALO*X*N*Y*/fused silica is 1.018, and the value of Y is 1.00. The reflectance of fused silica/TiSixNy is 0.682, the value of pattern length X of TiSixNy/fused silica is 0.733, and the value of Y is 0.674. Given exposure dose = 56 mJ/cm^2, pattern length X is 7.931 μm, fused silica wafer $Y=7.699\,\mu m$, ALOXNY wafer pattern length $X=8.930\,\mu m$ $Y=8.263\,\mu m$, and TiSixNy wafer pattern length $X=4.947\,\mu m$ $Y=4.494\,\mu m$. The value of pattern length X of ALO*X*N*Y*/fused silica is 1.125, while the value of Y is 1.073; moreover, the value of TiSixNy/fused silica pattern length X is 0.623, while the value of Y is 0.583. The experimental data demonstrates that an inverse relationship exists between reflectance and pattern length; pattern length decreases with increasing wafer surface reflectance, while energy reflected by the wafer surface increases. The energy absorbed by the photo resist increases reflectance, enabling PR to absorb more energy and decreasing pattern length.

The pattern length measured by high exposure dose is less than that measured by low exposure dose. The key reason for this difference is that the PR is made of sensitive materials which produce a more sensitive reflection on encountering strong light. When using high exposure dose, PR absorbs high energy and enhances the neutralization capability. Therefore, more areas are neutralized and impurities are quickly washed out by DI water.

3.6. Astigmatism

From Fig. 4(a)–(c), pattern lengths X and Y are different, meaning that the curves of the active line and the dotted line do not overlap. Pattern lengths X and Y indicate the longest measurements of a 1:30 rhombus pattern on the wafer surface under vertical and horizontal exposure, respectively. A difference between the measures indicates that the focuses of lenses X and Y of the Stepper exposure machine do not share the same location, causing the experimental difference in the X and Y focuses, which is an unavoidable error. The only way to solve the problem of astigmatism is to enhance the lens quality or turn the lens angle to the optimum area of the X and Y ball surface of the lens. Fig. 4 has given the phenomenon that different exposure materials cannot improve astigmatism. The observed $X/Y=1$ in some areas do not mean improved astigmatism because the change of focus may reduce the measures. Precise measurements of astigmatism should use best focus as a reference point.

4. Conclusions

The components of photo resist influence the measures of best focus. However, the experiment found that the same PRs coated on the wafers of different materials and also influence best focus. The PR focus shift results mainly from sensitivity, while the wafer focus shift results from the refraction factor. Pattern length changes according to measured exposure dose. However, pattern length also changes if wafers made from different materials are exposed under the same exposure dose. The experiment found that wafer reflectance was a key factor. An inverse relationship exists between reflectance and pattern length, with wafer reflectance increasing with decreasing pattern length. The more reflectance, the more energy will be reflected by wafer surface. The reflected energy is absorbed by photo resist. Consequently, energy absorption by PR increases with increasing reflectance, thus reducing the pattern length. To prevent these two effects, the wafer surface can be coated with a layer of totally reflective photo resist. Industry currently is using the photo resist of bottom ARC (Anti-Reflection Coating), but the reflectance of bottom ARC is approximately 60–70% and cannot be improved. Presently, improvements in this field are being researched.

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