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Mechanism of Mask Distortion during Resist Trimming

Naoyuki Kofuji[1] and Hideo Miura[2]

[1]Hitachi, Ltd., Central Research Laboratory

1-280 Higashi-Koigakubo, Kokubunji-shi, Tokyo 185-8601, Japan

Phone: +81-42-323-1111 E-mail: naoyuki.kofuji.mj@hitachi.com

[2]Fracture and Reliability Research Institute, Graduate School of Eng., Tohoku Univ.

6-6-11-712 Aoba, Aramaki, Aobaku, Sendai 980-8579, Japan

1. Introduction

In accordance with the trend to scale down microprocessor units (MPUs), it has become necessary to achieve a gate size smaller than the photoresist-mask size that can currently be achieved by lithographic techniques [1]. A trimming process using plasma etching has therefore been used to reduce the photoresist- mask size. However, it has been reported that photoresist masks distort during the trimming process, especially at the edge of the wafer [2]. It is forecast that by 2010 it will be necessary to achieve a photoresist mask width of 18 nm, reduced from the current 45 nm, by using the trimming process [1]. In such a high trimming-ratio process, distortion of the photoresist mask will be a critical issue. Some suspect that ion irradiation on the side of the resist mask causes mask distortion [2]. However, the detailed mechanism of mask distortion is poorly understood.

To address this issue, the authors have investigated the mechanism of resist-mask distortion and, consequently, reported that asymmetrical irradiation of oxygen radicals distorts the resist mask [3]. Following up on that investigation, in the present study, we investigated the reason that oxygen-radical (O*) irradiation distorts a resist mask.

2. Experimental

The assumed mechanism of resist-mask distortion is shown in Fig. 1. The O* irradiation creates a degraded layer with compressive stress on the resist surface. Asymmetrical irradiation of O* radicals, caused by non-uniform spatial distribution, therefore creates unbalanced stress on the resist-mask surface, causing mask distortion. To verify this mechanism, we investigated the composition and stress of the degraded layer on the resist mask.

An 8-inch wafer with a blanket resist film on it was used as the sample in this investigation. It was exposed to O* radicals using an electron-cyclotron-resonance plasma-etching system (M511). To ensure that only O* radicals were irradiated, a punched metal plate was installed between the plasma source and wafer to prevent ion irradiation of the wafer.

To evaluate the stress on the resist surface, the bow height of the sample was measured by an optilever laser-scanning system (FSM128L). The stress value is given by Storney's law with the measured bow height [4,5]. The sample was also examined by X-ray photoelectron spectroscopy (XPS) to determine the surface composition of the degraded layer.

3. Result and discussion

3.1 Stress measurement

Under the assumption that a degraded layer of compressive stress exists on the resist surface, the amount of stress on this layer is given by the following equation [6].

$$\sigma_s = (\sigma_1 - \sigma_2)\frac{d_o}{d_s}. \qquad (1)$$

σ_s: stress on degraded layer
σ_1: stress on resist film with degraded layer
σ_2: stress on resist film without degraded layer
d_s: thickness of degraded layer
d_o: thickness of bulk resist

Here, σ_1 can be obtained by measuring resist-film stress just after O* irradiation, and σ_2 can be obtained by measuring resist-film stress after removal of the degraded layer. Accordingly, after O* irradiation, resist-film stress was measured first. Second, the degraded layer was removed by argon-ion (Ar^+) sputtering. The resist-film stress measured by these processes is plotted in Fig. 2. According to this figure, while resist-film stress gradually decreases during the O*-irradiation step, it drops rapidly during the Ar^+-sputtering step. This result indicates that the degraded layer with compressive stress is created on the resist-film surface after the O*-irradiation

The stress on the degraded layer was evaluated next. According to Fig. 2, the thickness of the degraded layer d_s is estimated as 2 nm, the thickness of bulk resist d_o as 475 nm, and the stress differential σ_1–σ_2 as 9 MPa. Equation (1) therefore gives the stress on the degraded layer as 2 GPa. This value seems large enough to distort the resist mask because Young's modulus of organic materials is around 2 GPa [7].

3.2 XPS analysis

The sample used in the stress measurement was analyzed by XPS to determine the surface composition before and after Ar^+ sputtering (see Table 1). Note that the composition before Ar^+ sputtering means that of the degraded layer, while that after sputtering corresponds to that of the bulk resist. According to Table 1, the bulk resist contains 9% fluorine, 3% nitrogen, 17% oxygen, and 71%

9% fluorine, 3% nitrogen, 17% oxygen, and 71% carbon. In the case of the degraded layer, on the other hand, fluorine was reduced to 8%, nitrogen was not detected, and oxygen increased to 14%.

The XPS spectra of the degraded layer at F1s and N1s are shown in Fig. 3. The major component of F1s are -$(CF_2)_n$- and CF_3, while that of N1s is pyridine. The fluoride component in the bulk resist is therefore supposed to originate from the fluorocarbon-based detergent (which reduces the surface stress). The nitride component is supposed to originate from a quencher such as N-methyl pyrrolidinone (which eliminates the effect of excessive photo-acid) [8]. The O* irradiation therefore removed these additive compounds from the resist surface.

To confirm whether the amount of material removed by O*-irradiation is adequate to create such high compressive stress, the relation between the shrinkage and stress is considered in the following. When the surface layer shrinks, the stress on the layer is given by the following equation.

$$\sigma_s = \frac{\alpha E}{1-2\nu}. \qquad (2)$$

σ_s: stress of surface layer
α: shrinkage ratio of surface layer
ν: poisson ratio of surface layer
E: modulus of surface layer

The modulus and ratio assumed here were 2.7 GPa and 0.4, respectively, which correspond to those values of polymethylmethacrylate [7]. If shrinkage ratio α is 12%, corresponding to the ratio of removed material to remaining material, Equation (2) gives 1.6 GPa. The removal of the detergent and quencher is therefore thought to generate the stress on the degraded layer.

3. Summary

The mechanism of resist-mask distortion during the resist trimming process was investigated. It was found that oxygen-radical irradiation creates a degraded layer on a resist surface under compressive stress. Non-uniform spatial distribution of oxygen radicals therefore causes asymmetrical irradiation of the radicals and creates unbalanced stress on the resist-mask surface, which causes the mask distortion.

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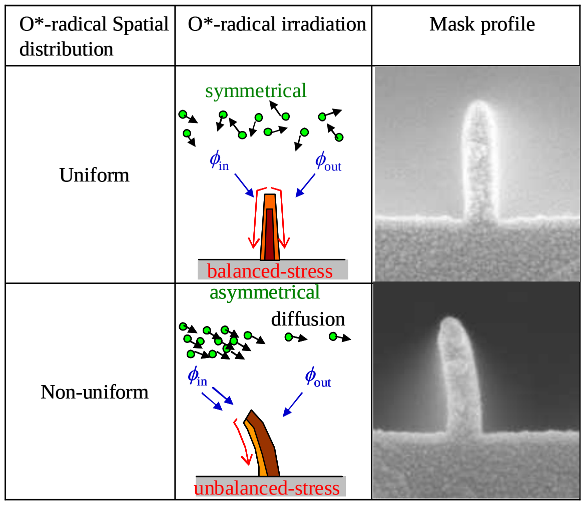

Fig. 1 The mechanism of resist mask distortion we assumed.

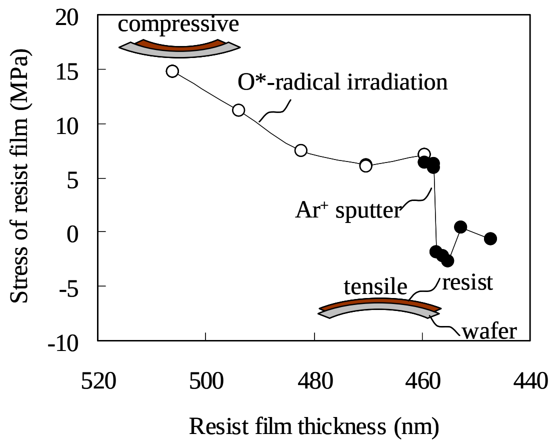

Fig. 2 Plot of resist-film stress against resist-film thickness during oxygen-radical irradiation and argon-ion sputtering.

Table 1 The surface composition of resist film

Component	Before Ar^+ sputtering (degraded layer)	After Ar^+ sputtering (Bulk resist)
C	9%	1%
O	17%	31%
F	71%	67%
N	3%	< detect limit

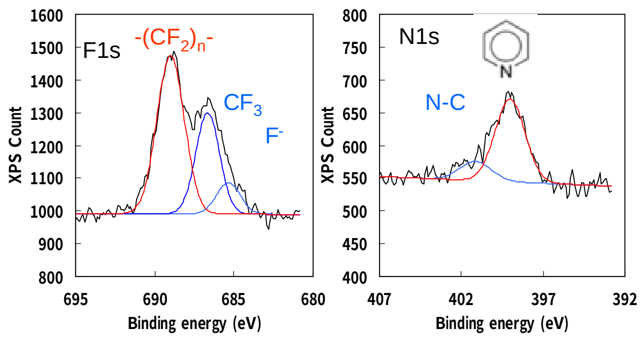

Fig. 3 XPS spectra of resist film: (a) fluorine 1s region and (b) nitrogen 1s region.