Analysis of Resist Removal Phenomenon Using Laser Irradiation

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Resist removal phenomenon with laser irradiation was analyzed by using a finite element (FE) method. Laser irradiation in the water can improve the resist removal effect as compared with that of normal atmosphere irradiation. A two-dimensional (2-D) micro-FE model was constructed based on the boundary surface between the Si wafer, resist and water during laser radiation. In the normal atmosphere, any effective stress did not occur along the x-axis direction in the resist. In contrast, for the laser irradiation in the water, large compressive stress was confirmed along the x-axis direction in the resist. This compressive stress in the resist is thought to improve the resist removal efficiency.

Keywords: Analysis of resist removal, Finite element (FE) method, Laser irradiation, Removal efficiency, Stress

1. Introduction

In semiconductor manufacturing process, resist removal from substrates in a conventionally uses are oxygen plasma [1,2] and/or chemicals (e.g., sulfuric acid hydrogen peroxide mixture). Environmentally unfriendly chemicals are used in a large amount and cause environmental damage [3,4]. Also, oxygen plasma ashing may cause oxidation of substrates and metal wiring because this process requires high temperature (above 250°C) [5,6]. Therefore, several resist removal methods have been developed (e.g., atomic hydrogen [7-10], UV/ozone [11,12]).

The removal of resist by laser irradiation has been investigated instead of chemical method. [13,14]. An advanced laser resist stripping method was successfully developed without causing laser damage to the Si wafer [15]. The pulsed laser irradiation in the water can improve the resist stripping effect when compared with that of the normal atmosphere irradiation. A laser irradiation of 532 nm, having large photon energy, was found to have higher resist removal efficiency than that of the wavelength 1064 nm. Positive-tone diazonaphthoquinone (DNQ) / novolak resists implanted with B, P, and As ions, respectively, were irradiated with a pulsed 532 nm laser. The novolak resist implanted with a density of 5.0×10^{15} atoms/cm^2 was stripped by 20 pulses irradiation without causing laser-induced surface damage. A scanning removal of the highly ion-implanted resist was done by using an optimized irradiation condition. A highly ion-implanted resist was continuously stripped by the scanning laser irradiation with 20 pulses [16]. And, irradiation...
with multiple laser beams by small beam diameter was confirmed as one of the methods for improvement of a resist stripping rate with high efficiency [17]. Poly-Vinyl Phenol (PVP) used as a base polymer of the KrF resist was also removed by laser irradiation in the water [18].

When the pulsed visible laser was irradiated to the resist on the Si wafer, about 60 % or more was absorbed to the Si wafer during a pulse duration of 8 ns. The temperature of the Si wafer surface rapidly rises by absorbing laser energy. By difference of the coefficient of thermal expansion between the resist and the Si wafer, displacement difference occurs horizontally for the resist and the Si wafer boundary surface. To strip the resist from the Si wafer, vertical effect is required in the resist and the Si wafer boundary surface. However, the mechanism of the removal efficiency improvement is not known regarding the laser irradiation in the water.

In this study, we investigated the analysis of resist removal phenomenon by using a finite element (FE) method. A two-dimensional (2-D) micro-FE model was constructed based on the boundary surface between the Si wafer, resist and water during laser radiation. The change of temperature, displacement, and stress was analyzed in each boundary surface. The analysis result about laser irradiation in the water was compared with that in the atmosphere.

2. Experimental procedure
The 532 nm laser beam of a circular Gaussian configuration was irradiated to the resist. The pulse width was 8 ns, and the beam diameter was 100 μm. The cross section to be shown in Fig. 1 is always an axial symmetry for the center of the beam. For this reason, a two-dimensional (2-D) micro-FE model was constructed in this study.

The element breakdowns of x-axis (direction to the laser irradiating) are as follows. (1) Resist region of thickness 1 μm: 10 dividing, (2) 400 μm region of Si-wafer: 22 dividing, and (3) 200 μm region of the water or a normal atmosphere: 30 dividing. To analyze the phenomenon in detail, the element sizes of the neighborhood of each boundary surface were 1 μm or less (Fig. 2). The change of temperature, displacement and stress was analyzed at the following binary spots. (A) the Si wafer and the resist boundary surface, (B) the water or a normal atmosphere and the resist boundary surface. Following formulas were used for this analysis: Thermal diffusion equation using the Fourier law, Equilibrium equation for stress analyses, and two governing equation. Also, heat transfer and displacement constraint were given as a boundary condition of this model.

2. Results and discussion
A temperature change from 0 ns (laser irradiation start) to 4000 ns in each boundary surface are shown in Fig. 3. The starting temperature before the laser irradiation is 20 degrees Celsius of the room temperature. The laser energy irradiated was enough large for a resist removal phenomenon. At the Si wafer and the resist boundary surface, the temperature-rise caused by the laser energy absorption to a Si wafer showed the same tendency for the experimental condition in the normal atmosphere and the water. The temperature suddenly rose to 500 degrees Celsius or more by absorption of the laser energy of the 8 ns pulse. The temperature decreases after 8 ns by diffusing the heat. In the resist surface 1 μm away, the temperature gradually
increases from the room temperature by a diffuse thermal arrival. The temperature-rise arrives at the maximum temperature in 3000 ns for the experimental condition in the normal atmosphere and in the water. The maximum temperature in the normal atmosphere was 44 degrees Celsius while it was around 26 degrees Celsius in the water. The temperature-rise in the water is lower than that in the normal atmosphere by a cooling effect of the water.

Fig. 3. Temperature changes from 0 ns (laser irradiation start) to 4000 ns. (a) Si wafer and the resist boundary surface. (b) Water or a normal atmosphere and the resist boundary surface.

Then, a change in the displacement with x-axis (direction to the laser irradiating) at each boundary surface is shown in Fig. 4. At the Si wafer and the resist boundary surface, the Si wafer expands with the temperature-rise just after laser irradiation. A displacement of -6 nm occurred by the atmospheric laser irradiation in 8 ns. In contrast, the displacement was only -5 nm by the laser irradiation in the water. Similar tendency was obtained at the resist surface. The displacement in the normal atmosphere was -8 nm while it was around -6 nm in the water. For the laser irradiation in the normal atmosphere, the displacement rate of the resist calculated from displacement and transition time is 1.2 m/s or more. When the water catches the resist displacement of 1.2 m/s or more, the water is tense. Thus, the water acts as a wall for a displacement of the resist. The accurate relationship of the Young’s modulus of the water and resist displacement rate is not known from experimental results. Young’s modulus of the normal water was 2.2 GPa, but large Young’s modulus was used of approximately 22 GPa in this experiment.

Fig. 4. Displacement changes from 0 ns (laser irradiation start) to 4000 ns. (a) Si wafer and the resist boundary surface. (b) Water or a normal atmosphere and the resist boundary surface.
Then, the change of the stress with x-axis (direction to the laser irradiating) at each boundary surface is shown in Fig. 5.

For the atmospheric laser irradiation, a large tensile stress of 50 MN was generated at the Si wafer and the resist boundary surface just after laser irradiation. The stress suddenly decreased to approximately zero after 30 ns. The stress in the resist surface was zero. As for the normal atmosphere and the resist boundary surface, the stress was not confirmed along the x-axis direction in the resist just after laser irradiation. This is because the resist can be displaced in the normal atmosphere freely.

In contrast, for the laser irradiation in the water, a tensile stress of 38 MN was generated at the Si wafer and the resist boundary surface just after the laser irradiation. However, the tensile stress changed in compressive stress. The compressive stress becomes about -4 MN after 30 ns, and decreases gently subsequently. The stress at the resist surface was compressive stress. The compressive stress also becomes a maximum of -3 MN after 15 ns. Because the resist could not be displaced by the water working as a wall, large compressive stress along x-axis in the resist occurred in the underwater irradiation condition. This compressive stress in the resist is thought to improve the resist removal efficiency.

These results agree with results of the laser irradiation experiment well. Figure 6 shows a photograph of the processed surfaces when a laser beam of 532 nm was irradiated to a positive-tone DNQ / novolak resist in the normal atmosphere and in the water. The energy of irradiated laser beam was adjusted to the intensity at which laser damage did not occur to the Si wafer surface in normal atmosphere.
atmospheric conditions. For the irradiation of laser beam to the resist in the normal atmosphere, the resist slightly rises from the Si wafer surface. This is due to the y-axis displacement (horizontal direction for laser irradiation) generated by a difference of the coefficient of thermal expansion between the Si wafer surface and the resist. As for the laser irradiation in the water, the change of these y-axis directions and the effect of the x-axis direction are combined clearly. The resist strips in almost all surfaces irradiated with a laser beam. Around the laser irradiation spot, the stripping resist was scattered in a cracked configuration.

4. Conclusion

We have investigated the analysis of resist removal phenomenon by using a finite element (FE) method. The change of temperature, displacement and stress was analyzed along the x-axis (direction to the laser irradiating). In the normal atmosphere, the resist and the Si wafer surface had -6 nm expansion displacement. The stress did not occur along the x-axis direction in the resist just after laser irradiation. This is thought that the resist can be displaced in the normal atmosphere freely. In contrast, as for the laser irradiation in the water, a compressive stress was confirmed along the x-axis direction in the resist. The resist could not be displaced by the water working as a wall. These results agree with results of the laser irradiation experiment. As for the laser irradiation in the water, the compressive stress in the resist was thought to improve the resist removal efficiency.

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