Dependence on Resist Stripping Efficiency to Irradiating Beam Size in Advanced Laser Resist Stripping Method

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Dependence on the stripping efficiency to irradiating beam size was investigated in an advanced laser resist stripping method. The beam size on the resist surface was changed from 0.3 mm to 3.0 mm. An intensity shape of the laser beam was Gaussian shape. At a beam diameter of 0.3mm, the stripped resist area in a beam was 15 % of 0.01 mm². In the case of beam diameter of 3.0 mm, the stripped resist area in a beam was 5 % of 0.38 mm². The stripped area improves 38 times for scale-up of the beam area of 100 times. The resist stripping efficiency was thought to depend on the heat stress due to a temperature gradient between the beam center and the regions without laser irradiation. 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.

Keyword: resist stripping efficiency, novolak resist, laser irradiation, beam size, heat stress

1. Introduction
Resist is used in the semiconductor (IC, LSI) and liquid crystal display (LCD) manufacturing process. The pattern is transferred to the resist by three processes (spin coating, exposure and development). The substrate is etched by using resist as a mask, and ions are implanted. Finally, the unneeded resist is removed. Resist removal from substrates in a semiconductor manufacturing process conventionally uses oxygen plasma [1, 2] and/or chemicals (e.g., sulfuric acid hydrogen peroxide mixture). Environmentally unfriendly chemicals are used in large amounts 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 the resist by laser irradiation instead of chemicals has the advantage of reducing environmental risks [13, 14]. An advanced laser resist stripping method for the positive-tone diazonaphthoquinone (DNQ) / novolak resist was successfully developed without causing the laser damage to the Si wafer [15]. The pulsed laser irradiation in water can improve the resist stripping effect when compared with that of conventional atmosphere irradiation. A laser irradiation of 532 nm, having large photon energy was found to have higher resist stripping efficiency than that of the wavelength 1064 nm. Moreover, the novolak resists implanted with B, P, and As ions, respectively, were irradiated with a pulsed 532nm laser. For the laser irradiation of 1 pulse, the ion-implanted resist with a density of 5.0×10¹³ atoms/cm² was completely
stripped in the same way as that of a non-implanted resist. The optical absorption of the resist surface increased as the density of the ion-implantation increased. In the case of the ion-implanted resist with a density of $5.0 \times 10^{15}$ atoms/cm$^2$, the resist was stripped by 20 pulses irradiation without occurring laser-induced surface damage. A scanning removal of the highly ion-implanted resist was also successfully stripped by using an optimized irradiation condition. A highly ion-implanted resist was continuously stripped by the scanning laser irradiation with 20 pulses [16]. To improve processing speed, it is necessary to enlarge the beam size from current 0.2 mm in diameter. In this study, we have investigated the relationship of the beam size and the resist stripping efficiency in an advanced laser resist stripping method.

2. Experimental Procedure

HMDS was spin-coated onto the Si wafer substrate using a spin-coater (ACT-300A from ACTIVE) at 3000 rpm for 60 sec. Then, the positive DNQ / novolak resist (OFPR-800 from Tokyo Ohka Kogyo Co., Ltd.) was spin-coated at 3000 rpm for 60 sec. The resist was pre-baked at 100 degrees Celsius for 60 sec. The resist thickness was found to be 1100 nm by profilometry (Dektak6M from ULVAC). The prepared novolak resist was sunk underwater.

The experimental setup of the laser resist stripping in various beam size is shown in Fig. 1. The second harmonics (532 nm) of a pulsed Nd:YAG ($Y_3Al_5O_{12}$) laser were used in this study. An intensity shape of the laser beam was Gaussian shape. The pulsed laser was irradiated using a "1-on-1" method (irradiated place was changed every pulse). A lens with a focal length $f = 300$ mm was used to focus the laser radiation onto the resist surface. The intensity of the pulses was varied with an attenuator consisting of a polarizer and a half-wave plate. The prepared resist was installed perpendicularly in a container having an aperture for laser beam incidence. The distance from the water surface to the resist was controlled using the quantity of the water put in the container. The resist was irradiated with a laser beam of 532 nm in the water at a depth of 2 mm. The irradiating beam size was adjusted to the distance of a lens and the container. The beam size on the resist surface was changed from 0.3 mm to 3.0 mm.

3. Results and Discussion

The relationship of the beam diameter and the resist stripping efficiency is shown in Fig. 2. The resist stripping efficiency (%) is defined in the ratio of removed area to the irradiated beam area. At a beam diameter of 0.3 mm, the resist stripping efficiency was 15 %. When the beam diameter enlarged, the resist stripping efficiency showed a tendency to decrease. At a beam diameter of 3.0 mm, the resist stripping efficiency decreased to approximately 5 %.

![Figure 1. Experimental setup of the laser resist stripping in various beam size.](image1)

![Figure 2. Relationship of beam size and the resist stripping efficiency.](image2)
Figure 3 shows photographs of the processed surfaces when a laser beam of diameter 0.3 mm, 1.5 mm and 3.0 mm were irradiated to the resist, respectively. The energy of irradiated laser beam was adjusted to the intensity at which laser damage did not occur to the Si wafer surface. At a beam diameter of 0.3 mm, only the resist for the center of an irradiated beam was stripped by circle. The stripped resist area in a beam was 15% of 0.01 mm². At a beam diameter of 1.5 mm, the stripped resist area spread to 0.09 mm². In contrast, in a beam diameter of 3.0 mm, the stripped area was 0.38 mm² of the central part of the beam. However, the resist stripping efficiency decreased to approximately 5%.

The initial process of the resist stripping is thought as follows. When the visible laser beam was irradiated to the resist on the Si wafer, the irradiated laser beam passes through resist and arrives at the Si wafer and resist interface. Approximately 36% of laser energy is reflected from the Si wafer surface, and about 60% or more is absorbed to the Si wafer during 8 ns of pulse duration. The temperature of the Si wafer surface rapidly rises by absorbing laser energy and causes local thermal expansion. The resist rises from the Si surface by a difference of the coefficient of thermal expansion between the Si wafer surface and the resist material, and a partial crack occurs. As for the coefficient of thermal expansion, a Si wafer is $2.6 \times 10^{-6}$ (K⁻¹), the common resist material is $5.0 \times 10^{-5}$ (K⁻¹). The initial process of the resist stripping by the coefficient of thermal expansion is affected by the intensity distribution of the laser beam. In other words, the distance between the center of the laser beam and regions without laser irradiation is significant. Because a laser beam of pulse width 8 ns is irradiated to the resist, regions without laser irradiation do not have thermal influence. They work as restraints to obstruct deformation for thermal expansion. As a result, heat stress occurs in a laser irradiated part. This heat stress depends on the magnitude of the temperature gradient between the beam center and the regions without laser irradiation. As for the Gaussian beam configuration, strong intensity distribution exists in the central part of the beam. Therefore, the temperature gradient is large between a beam center part and regions without laser irradiation. When the beam diameter is small, a resist stripping is caused in circle at a center of the Gaussian beam. The temperature gradient between the center of the beam and regions without laser irradiation was thought to be relatively large. The resist stripping efficiency was 15% at beam size 0.3 mm.

(a) Resist stripping at beam diameter of 0.3 mm.
(b) Resist stripping at beam diameter of 1.5 mm.
(c) Resist stripping at beam diameter of 3.0 mm.

Figure 3. Optical microscope photographs of the resist surface after irradiating with various beam diameter.
In contrast, the temperature gradient becomes small when beam diameter increases. The resist stripped area for the beam size becomes small. In the case of beam diameter of 3.0 mm, the resist was stripped in the region of 5% of the beam area. The stripped area improves 38 times for scale-up of the beam area of 100 times. To improve resist stripping rate with high-efficiency, it is necessary to use strong heat stress by a large temperature gradient at the initial process of the resist stripping. As one method to improve a resist stripping rate, irradiation with multiple laser beam was demonstrated in this study. Laser beam was divided into four and irradiated the neighboring resist surface at the same time. For this method, the small laser beam size that was available to large heat stress was preferable. A laser beam with beam diameter 0.5 mm was focused to the resist surface. The resist was stripped at four irradiated spots as shown in Figure 4. Even if the number of the beams increases more, it can be stripped similarly. This result indicated that the simultaneous irradiation with multiple beams by small beam size was effective for improvement of the processing speed with high resist stripping efficiency.

Figure 4. Resist stripping with multiple beams by small beam size.

4. Conclusion

We have investigated the dependence on resist stripping efficiency to irradiating beam size in an advanced laser resist stripping method. The beam size on the resist surface was changed from 0.3 mm to 3.0 mm. An intensity shape of a used laser beam was Gaussian shape. The resist stripping efficiency showed a tendency to decrease as the beam size increased. At a beam diameter of 0.3 mm, the stripped resist area in a beam was 15 % of 0.01 mm². In the case of a beam diameter of 3.0 mm, the stripped resist area in a beam was 5% of 0.38 mm². The stripped area improves 38 times for scale-up of the beam area of 100 times. The resist stripping efficiency is thought to depend on the heat stress due to a temperature gradient between the beam center and the regions without laser irradiation. Relatively large heat stress is obtained from small beam diameter. Irradiation with multiple laser beam by small beam diameter was confirmed as one of the methods for improvement of a resist stripping rate with high efficiency. Laser beam was divided into four and irradiated the neighboring resist surface at the same time. The resist was stripped at four irradiated spots. For the improvement of processing speed with high resist stripping efficiency, the simultaneous irradiation with multiple beams by small beam size will be one of the candidates.

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