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SHORT COMMUNICATION

LASER INDUCED PHOTORESIST THIN FILM REMOVAL FROM SILICON WAFER SURFACE

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Laser induced cleaning of silicon wafer covered with photoresist thin film was studied. We have used ultraviolet laser beams with wavelength 248 nm and 313 nm. Experimental results have evidenced that a good cleaning of the surface can be obtained with a proper choice of the irradiation conditions (intensity, number of pulses). The removal of the photoresist in the irradiated region was obtained for laser intensities of the order of 10^7 W/cm^2 and multipulse laser irradiation. Also photoresist removal from the silicon surface can be obtained for one pulse or for a low number of laser pulses, but for incident intensity greater than the melting threshold of the silicon substrate. In this case the very accurate selection of the incident energy is more important to avoid substrate surface damage.

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Photoresist is one of the most important materials used in microelectronics. It is a photosensitive polymer deposited in a thin film on the surface of the silicon wafer. After irradiation with UV light through a mask and a consequent treatment with a developer, the selective corrodation effect results in mask form reproduction on the surface. After this step of the technological process, the photoresist thin film removal is realized by using a lot of chemical substances.

We have tried in our experiments to remove the photoresist layer from the silicon wafer surface by using pulsed laser irradiation (PLD). Laser radiation interaction with polymers was extensively studied in the last years. UV laser radiation effect on polymers can be separated into intrinsic absorption of the film material, absorption at structural faults, etc. Also, the film substrate interface as well as the substrate material by itself can act as absorbing regions.

Table 1. Laser irradiation region morphology was studied as a function of incident laser energy fluence and intensity to evidence the cleaning and damage thresholds.

Wavelength	248 nm	313 nm
Pulse duration FNHM	30 ns	7 ns
Laser spot radius on the target surface	0.86 mm and 0.14 mm	0.6 mm and 0.5 mm
Laser spot area on the target surface	0.57×10^{-2} and 0.16×10^{-3} cm^2	1.3×10^{-2} and 0.82×10^{-2} cm^2
Incidence angle	normal	normal
Repetition frequency	10 Hz	20 Hz

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The aim of our research was to evidence the irradiation regimes for which laser removal (cleaning) of the photoresist (polymer) thin film from the silicon can be obtained without surface damage.

A thin film material can be removed from a substrate surface due to laser ablation. Typically UV laser ablation is carried out with one laser pulse or with a succession of laser pulses.

In Table 1 is given general irradiation condition we have used for the cleaning tests.

To estimate from microscope investigation of the irradiated surface the cleaning effect on the silicon wafer a comparative study was realized about laser radiation effects on the silicon wafer. In figure 1 it is given a microscope image of the silicon wafer surface with mirror quality surface irradiated at 2.6×10^7 W/cm^2. This laser intensity is a little bit lower than the calculated melting temperature of the silicon [1, 2].

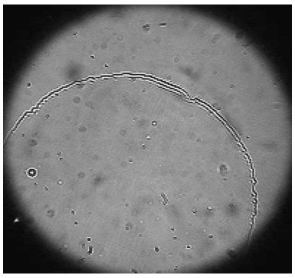

Fig. 1. Silicon wafer surface irradiated at 2.6×10^7 W/cm^2 (λ = 248 nm).

In the irradiated region the silicon surface has still a mirror quality, only after a number of more than 50 laser pulses melting appear for this laser intensity.

A good cleaning of the silicon wafer was considered to be obtained in cases for which the microscope image of the irradiated region looks like the unirradiated mirror quality silicon.

An analysis of laser removal of photorezist film from the surface of silicon wafer was realized for different laser intensities and number of pulses. An interesting sequence of images is given in figure 2 for 0.17 J/cm^2 respectively 0.6×10^7 W/cm^2 and different number of pulses (1, 7, 13, 18 pulses, respectively) (Fig.1). The incident laser intensity is much lower than the melting threshold of the silicon substrate [1,2].

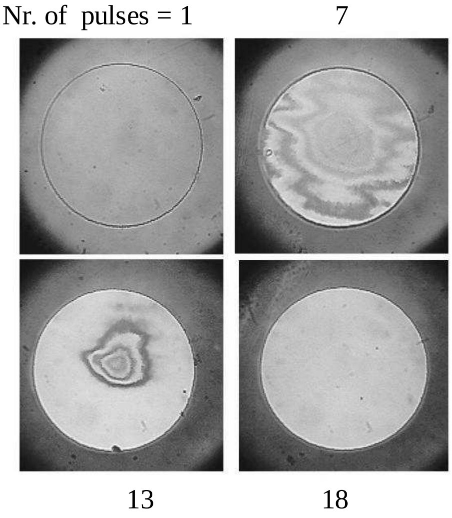

Fig. 2. Silicon wafer covered with photoresist (10-12 μm thickness) thin film irradiated (λ = 248 nm) at 0.6×10^7W/cm^2 and 1, 7, 13, 18 pulses respectively.

The thickness of the photoresist layer was between (10 – 12) μm. Cleaning effect is considered to be obtained for 18 pulses. For 13 pulses a partial cleaning of the substrate is realized.

For a greater number of pulses the substrate is at the beginning still undamaged, but the border of the irradiated region became double or triple, because material in the neighboring region is affected.

For a 2 μm photoresist layer the evolution of the effects induced in the irradiation region is given in figure 3, for the same irradiation conditions. The numbers of subsequent laser pulses were 1, 5, 10, and 15 (from left to right) (Fig. 2).

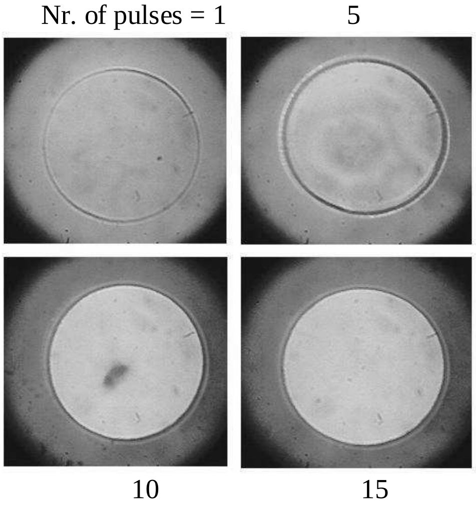

Fig. 3. Silicon wafer covered with photoresist thin film (2 μm) irradiated (λ = 248 nm) at $0.6x10^7$ W/cm^2 and 1,5,10,15 pulses, respectively.

Cleaning effect is obtained for 12-13 laser pulses. It is to be noticed that the difference in number of pulses for removing the photorezist layers with different thickness is low. It can be considered that material removal appears only after a number of pulses due to film buckling [3]. But in front of the irradiated region a visible light due to emission of the ablated ionized material can be seen for a number of pulses approximately equal to the number of pulses needed for thin film removal.

In case of a photoresist thin film with the thickness of about 0.3 μm, the uniformity in intensity of the irradiation spot is more important. A tattering effect is obtained in the irradiated region. In spite of the fact that the thickness of the covering material is much lower a complete cleaning in the irradiated region is obtained for a greater number of pulses, more than 100.

By growing the incident laser energy, respectively irradiation intensity, the cleaning effect can be obtained for a lower number of pulses, even for 1 laser pulse. So, for a 10 μm thickness of the photorezist layer for an intensity of 0.6×10^7 W/cm^2 the needed number of laser pulses for complete removal of the film is between 12 and 20. For an intensity of 8.9×10^7 W/cm^2 there are needed 1-5 laser pulses. The drawback of using high incident energies is that the resulted incident intensities can be higher than the melting threshold of the silicon and the substrate can be affected (damaged).

In case of surface irradiation with laser of 313 nm wavelengths and fluency less than 0.07 J/cm^2, cleaning effect can be obtained only after hundreds of laser pulses action. A sequence of images reflecting the evolution of the laser induced effects is given in Fig. 4.

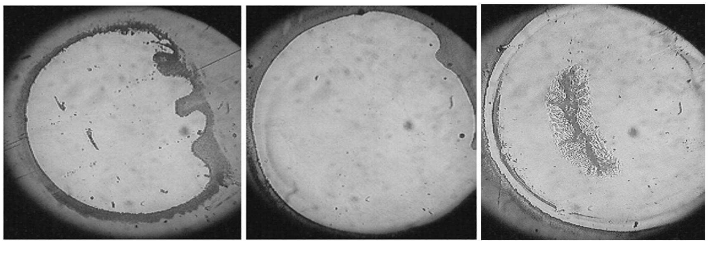

Fig. 4. Silicon wafer covered with photoresist thin film irradiated with 313 nm laser radiation (200, 2400, 4800 pulses, from left to right).

A complete removal of the photo resist layer is obtained for approximately 2400 pulses. For a greater numbers of pulses substrate melting is induced.

In conclusion photoresist laser cleaning in the laser irradiation area was evidenced to depend on the incident laser energy and on the number of incident laser pulses, but also on laser beam pulse length.

In case of 248 nm, 30 ns laser beam, a clean trace after laser irradiation was obtained in an interval from an incident laser intensity of 0.6×10^7 W/cm^2 to 6.93×10^7 W/cm^2 for multipulse action. As higher the laser intensity the trace becomes larger with a double or triple border. Also surface cleaning was obtained for a larger intensity but for a smaller number of pulses.

In case of 313 nm, 7 ns laser beam for a comparable laser intensity a much greater number of pulses is needed to obtain the complete removal of the photoresist layer, for the same laser intensities.

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