Excimer laser cleaning of silicon wafer backside metallic particles

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An excimer laser cleaning system operating at 248 nm was developed to remove micrometer-sized metallic particles from the backside of silicon wafers. Deliberate iron contamination has been performed using iron-oxide particles having a diameter of 0.5–2 μm. The surface photovoltage (SPV) method was used to characterize the cleaning efficiency through the change in diffusion length and iron concentration in the silicon bulk. Following a rapid thermal annealing at 1050 °C for 4 min, the SPV measures diffusion lengths down to 40 μm for the iron-contaminated wafer, corresponding to an iron concentration up to 1.55×10^{13} cm^{-3}. The minimum diffusion length increases to 130 μm after two steam laser cleanings done at a laser fluence below the silicon threshold damage of 200 mJ/cm^2. The iron concentration measured in the bulk of the iron-contaminated wafers is reduced by more than 91%, to a concentration of 1.4×10^{12} cm^{-3}. © *1998 American Vacuum Society.* [S0734-2101(98)51103-7]

I. INTRODUCTION

Particles can be introduced on either side of the wafer surface in many ways during fabrication. Wafer handling was identified as an important source of particles on the backside of wafers.[1,2] These backside particles can result in high metallic concentration in the bulk of silicon.[1,2] Such contamination can affect the reliability and performance of devices by reducing the lifetime of minority carriers,[3] increasing the leakage current at $p-n$ junctions,[4] and lowering the gate-oxide dielectric strength.[5] At present, the iron concentration tolerated in the bulk of silicon is between 10^{10} and 10^{12} cm^{-3}, depending on the technology level.[5]

Backside metallic particles need to be removed before any important thermal steps of the front end in order to avoid the diffusion of metallic contamination into the bulk. Since conventional wet cleaning methods cannot be used at certain process steps, we have developed an excimer laser cleaning system operating at 248 nm to remove backside metallic particles. In this article, we present results which show that the removal of iron-oxide micrometer-sized particles can be performed using the steam excimer laser cleaning technique, resulting in a significant decrease of iron incorporated into the silicon bulk.

II. EXCIMER LASER CLEANING SYSTEM

The *in situ* cleaning method consists of using a 22 ns pulsed KrF excimer laser (248 nm) directed toward the wafer surface, which can be covered by a micrometer-thick liquid film. Two laser cleaning techniques were investigated in this study. In the dry laser cleaning technique no intermediate medium is used. The strong absorption of silicon at the excimer wavelength causes the surface to expand resulting in the removal of particles by momentum transfer.[6,7] In the steam laser cleaning technique a liquid energy transfer medium is condensed on the surface, which is generally water or a mixture of water and alcohol. The laser irradiation is still absorbed by the silicon surface since the water-based liquid film is transparent in the UV region. The heat generated at the liquid/silicon interface will provoke the explosive evaporation of this liquid film, which results in forces high enough to expel the particles from the surface.[6,7]

The experimental setup of the excimer laser cleaning system is shown in Fig. 1. The fluence of the excimer laser can be varied in the range of 0.05–1 J/cm^2 with an estimated error of 10%. The pulsed vapor generator used in the steam cleaning technique consists of a heated (40 °C) nozzle and a container half filled with high-purity deionized water. A nitrogen gas flow is used to carry the water vapor onto the silicon surface, where it will condense. A flow meter and valve system is used to control the thickness of the water film, which is kept around 2 μm in this experiment. After a vapor burst, three laser pulses were triggered at 1 s intervals to assure that all the water had been evaporated. The laser beam is scanned over an area of 50×50 mm^2 whose center corresponds to that of the wafer, using a computer-controlled X-Y stage. The silicon wafer is mounted on the underside of this stage in order to avoid particle redeposition after laser cleaning. The dry and the steam laser cleaning were both performed in clean room air.

III. EXPERIMENTAL METHODS

The dry and the steam excimer laser cleaning techniques were characterized for the removal of iron-oxide particles

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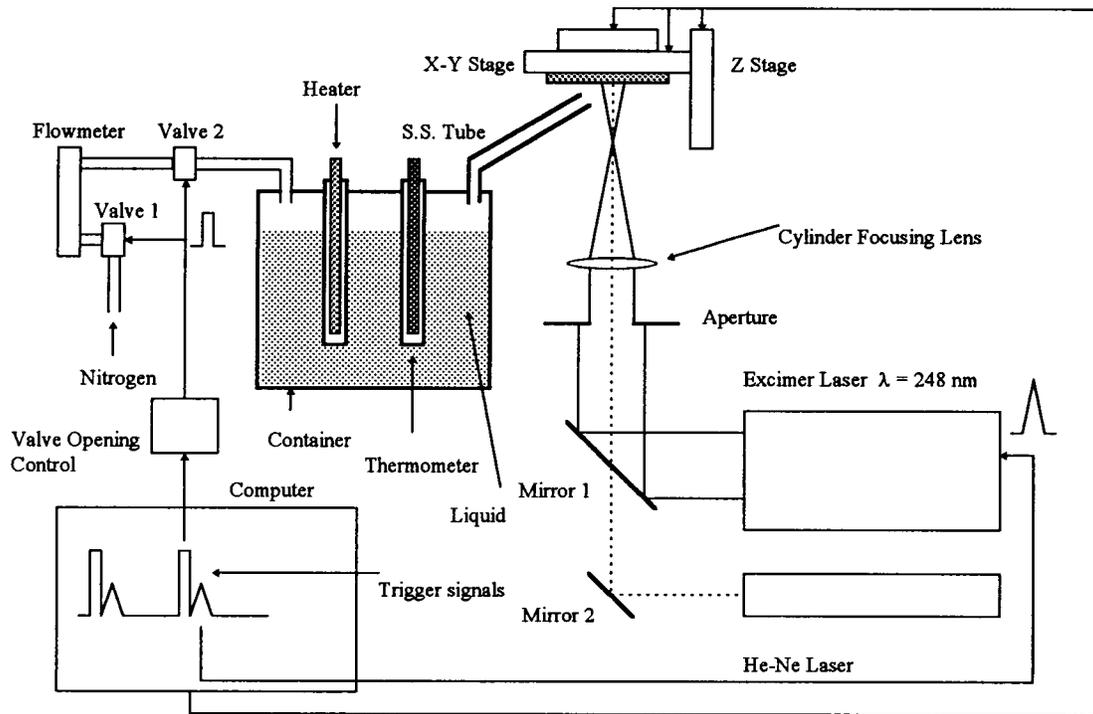
FIG. 1. Experimental setup of the excimer laser cleaning system.

from the front and the backside of the silicon wafer. The Fe_2O_3 (0.5–2 μm) particles were uniformly deposited on either surface in a circular pattern around the wafer center using a particle generator consisting of a nebulizer, a drying tube, a chamber, and an output nozzle. To evaluate the cleaning efficiency on the front surface, a particle counting system (Particle Measuring Systems Inc., SAS 3600) was used to classify particles according to their polystyrene latex sphere spherical equivalents, from 0.1 to 10 μm. Inside the cleaned square area, the surface inspected was a circle of 30 mm in diameter. However, this inspection system cannot be used on the rough backside.

The surface photovoltage (SPV) technique is used to monitor the cleaning efficiency on the backside of the wafer and to provide a comparison with the cleaning efficiency on the frontside. The following method was used. First, the residual surface contamination after cleaning was diffused into the bulk using a rapid thermal annealer (RTA) prior to any SPV measurements. A drive-in step of 4 min at 1050 °C was used to diffuse fast-diffusing metal impurities, such as iron, through the wafer (500 μm for a 100 mm wafer). Minority-carrier diffusion length and lifetime can then be measured from the spectral dependence of the SPV.[8,9] Quantitative metallic contamination information can be obtained in the bulk of silicon since metal impurities strongly affect the minority-carrier diffusion length. Since iron forms Fe–B complexes with boron in *p*-type doped silicon, these complexes can be dissociated thermally, or by illumination at room temperature. A measurement of the diffusion lengths before and after dissociation yields the iron concentration since interstitial iron (Fe_i) is ten times more effective at capturing an electron

than Fe–B complexes.[10,11] The iron concentration can be obtained from Fe $(cm^{-3}) = 1.1 \times 10^{16}$ $(1/L_{aft}^2 - 1/L_{bef}^2)$ where L_{bef} and L_{aft} refer to diffusion lengths before and after pair dissociation.[10,11] In this experiment, the iron concentration was measured at nine points on the wafer using the optical Fe–B pairs dissociation station of our SPV system.
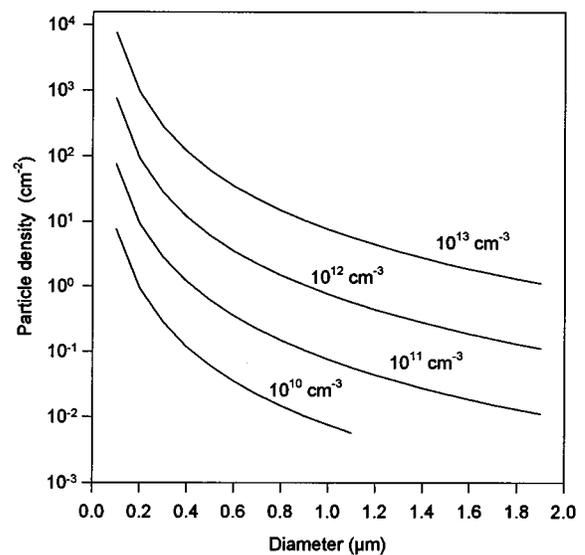
FIG. 2. Number of Fe_2O_3 particles of a determined diameter necessary to introduce a given metal concentration into a 100 mm wafer (thickness of 500 μm).
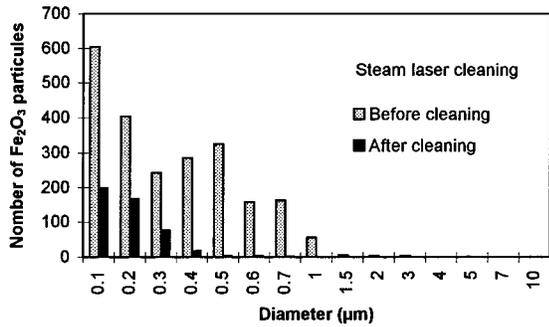
FIG. 3. Number of Fe_2O_3 particles on the front surface, as a function of their diameter, before and after two consecutive steam laser cleanings at a fluence of 200 mJ/cm^2.

IV. RESULTS AND DISCUSSION

Particle maps were obtained on the contaminated front-side before and after cleaning. The excimer laser cleaning was done at different laser fluences in order to determine a high cleaning efficiency window. Only particles with a diameter equal to and above 0.3 μm will be considered in this study since smaller particles do not contribute significantly to the introduction of metallic contamination into the bulk.

Indeed, as shown in Fig. 2, the density of 0.1 and 0.2 μm Fe_2O_3 particles necessary to introduce a given metal concentration into a 100 mm wafer (the wafer thickness is 500 μm) is very high compared to 0.3 μm and larger particles. The particle densities shown in Fig. 2 are underestimated since we assumed a complete diffusion of iron from the Fe_2O_3 particles into the bulk during the RTA step.

Using a fluence of 350 mJ/cm^2, just below the silicon threshold damage, the dry laser cleaning technique was found to be inefficient for the removal of iron-oxide particles. The particle density ($\geqslant 0.3$ μm) is reduced from 373 to 310 cm^{-2} after cleaning. Only particles with a diameter of 0.5 μm and above are removed with some efficiency. The dry laser cleaning technique was discarded at this point and no SPV measurements were performed.

The steam laser cleaning technique was found to be efficient for the removal of iron-oxide particles using laser fluence between 150 and 200 mJ/cm^2. Surface damage occurs for laser fluences higher than 200 mJ/cm^2. The number of Fe_2O_3 particles before and after two consecutive steam laser cleanings at a laser fluence of 200 mJ/cm^2 are given in Fig. 3. The removal of Fe_2O_3 particles is efficient since the density of particles with a diameter of 0.3 μm and above is reduced from 176 to 15 cm^{-2}. Note that 0.1 and 0.2 μm
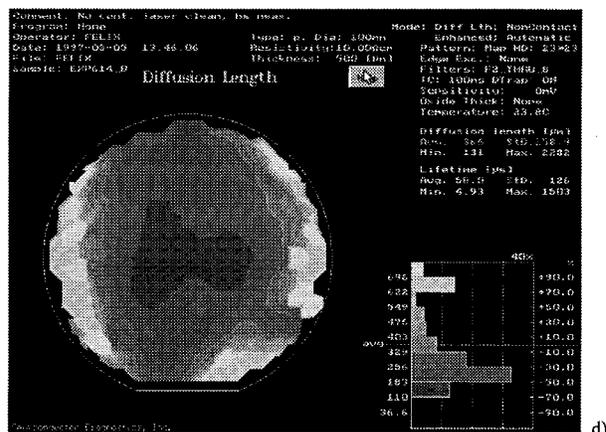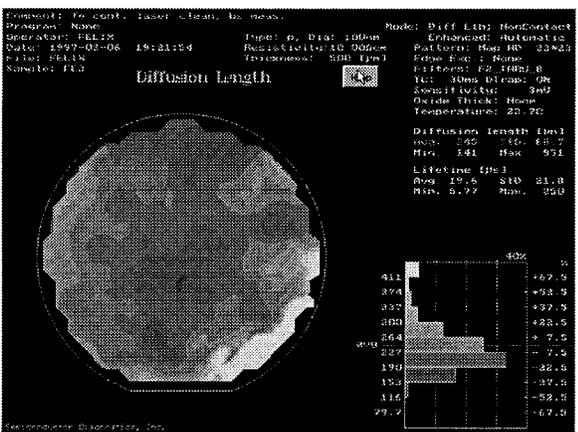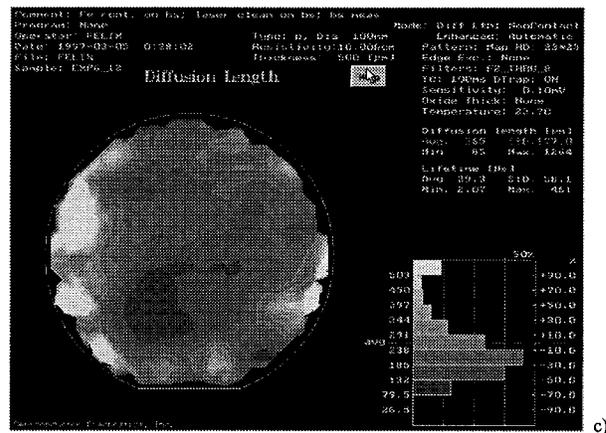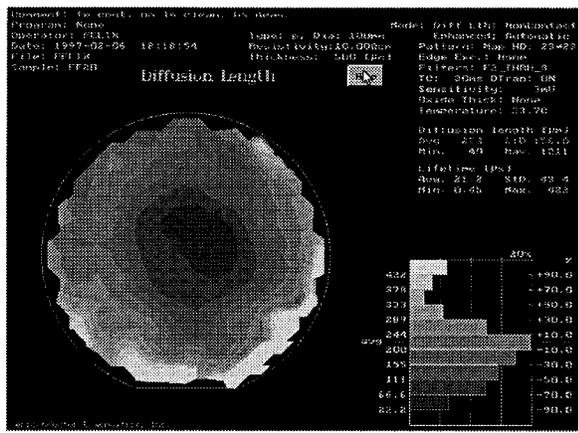
FIG. 4. (a) Diffusion length map of a wafer contaminated on the frontside only; (b) diffusion length map of a wafer contaminated on the frontside and laser cleaned at a fluence of 200 mJ/cm^2; (c) diffusion length map of a wafer contaminated on the backside and laser cleaned at a fluence of 200 mJ/cm^2; and (d) diffusion length map of wafer that was laser cleaned only at a fluence of 200 mJ/cm^2 (reference wafer).

TABLE I. Iron concentration (10^{11} cm^{-3}) measured at the center of the wafers shown in Fig. 4.

Fe$_2$O$_3$ contaminated	Laser cleaned	Iron concentration (10^{11} cm^{-3})
Frontside	No	155
Frontside	Yes	11
Backside	Yes	14
No	Yes	8

Fe$_2$O$_3$ particles are removed with some efficiency.

Diffusion length maps were measured on three different iron-oxide-contaminated wafers. The first wafer was contaminated on the frontside and no laser cleaning was done. The second and third wafers were, respectively, contaminated on the front- and on the backside. The contaminated surface of these two wafers were laser cleaned twice at a fluence of 200 mJ/cm^2. A fourth wafer (or reference wafer) was also laser cleaned, but no Fe$_2$O$_3$ particles were deposited on its surface prior to cleaning. The iron concentration was also measured at the center of all these wafers.

The diffusion length maps are shown in Fig. 4 for the removal of Fe$_2$O$_3$ particles. The frontside contaminated but not the laser cleaned wafer is shown in Fig. 4(a). The area of low diffusion length (dark region) corresponds to the Fe$_2$O$_3$ particle contaminated area. The minimum diffusion length measured on this wafer is of 40 μm. The iron concentration measured at the wafer center is given in Table I and is 1.55×10^{13} cm^{-3}. The Fe$_2$O$_3$ particles introduce a significant iron concentration in the bulk after a drive-in step since the average initial diffusion length before contamination is around 300 μm corresponding to an iron concentration below 10^{11} cm^{-3}.

The comparison between the contaminated but not cleaned wafer [Fig. 4(a)] with the frontside contaminated and laser cleaned wafer [Fig. 4(b)] shows an increase from 40 to 141 μm in the minimum diffusion length. We can also see from Table I that the iron concentration measured at the center of these two wafers is reduced by 93% after laser cleaning, resulting in a final iron concentration of 11×10^{11} cm^{-3}. The Fe$_2$O$_3$ particles are simply ejected from the polished surface during laser cleaning, resulting in a higher diffusion length and lower iron concentration.

A similar result was obtained for the laser cleaning of the Fe$_2$O$_3$ from the wafer backside. The diffusion length map of the backside contaminated and laser cleaned wafer is shown in Fig. 4(c). The minimum diffusion length near the wafer center (contaminated region) is of 126 μm. The rough backside does not seem to influence the laser cleaning efficiency since the minimum diffusion length obtained after the laser cleaning of the contaminated frontside wafer is of the same order of magnitude (141 μm). The low diffusion region close to the wafer center in Fig. 4(c) can be attributed to the introduction of metallic contamination during wafer manipulation. This region cannot be caused by the Fe$_2$O$_3$ particles since none of them were deposited in this area.

The diffusion length map of the reference wafer is shown

in Fig. 4(d). Even though this wafer was not contaminated, the minimum diffusion length after laser cleaning is 131 μm and the iron concentration at the wafer center (Table I) is 8 $\times 10^{11}$ cm^{-3}. These numbers are of the same order of magnitude as the one we obtained after the laser cleaning of the frontside and the backside contaminated wafers. We conclude that the cleaning efficiency is only limited by the current laser cleaning system setup. The deionized water used during the steam excimer laser cleaning left some metallic contamination on the wafer surface. In order to achieve iron concentration as low as 10^{10} cm^{-3} after laser cleaning, higher-purity deionized water and wafers characterized by a level of iron concentration below 10^{10} cm^{-3} should be used.

V. CONCLUSION

The removal of micrometer-sized particles from the wafer backside can be achieved using the steam excimer laser cleaning technique. In the deliberately contaminated wafers with iron-oxide particles, an increase of about a 100 μm in the diffusion length was obtained after the laser cleaning. The final iron concentration was decreased significantly from 1×10^{13} to 1×10^{12} cm^{-3}.

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