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Evaluation of the effectiveness of back-side damage gettering in silicon introduced by a cavitating jet

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Photocapacitance measurements have been performed to evaluate the electrical effectiveness of gettering by back-side damage, introduced by a cavitating jet into silicon wafers. The silicon wafers, which had their back sides damaged previously in localized areas, were intentionally contaminated and subsequently thermally treated to diffuse the contamination through the wafer. The density of deep levels varied between the areas with back-side damage and those without. The results obtained on back-side damaged areas were closer to those on the original starting material. These results confirm that the back-side damage introduced by a cavitating jet can function as gettering sites. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1808499]

Gettering[1,2] to remove unwanted impurities from active device regions is an essential technique in the manufacture of semiconductors. Gettering has been achieved by introducing gettering sites using various techniques, such as polysilicon back coating,[3] solute diffusion,[4] ion implantation and back-side damage introduced by mechanical grinding, shot blasting[5–7] or laser treatment.[8] Unwanted impurities are gathered into the region where gettering sites have been intentionally introduced during subsequent high temperature device processes. In the method presented here, the impacts produced by the collapse of cavitation bubbles are utilized to introduce back-side damage into a silicon wafer. Damage is introduced into the surface region impinged by cavitation impacts. Suitable damage, which would be gettering sites, can be introduced by controlling intensity of cavitation impacts. The cavitation bubbles were caused by a submerged water jet with cavitation, i.e., a cavitating jet, since it is easier to control the intensity of cavitation impacts and the area of formation of bubbles by adjusting hydraulic parameters such as injecting pressure of the water jet than other methods. The intensity of cavitation impacts varies depending on the injecting pressure, standoff distance, and nozzle diameter. Thus, the number of impacts and the magnitude of impacts can be controlled.[9] In the case of the popular technique of shot blasting, both the silicon debris generated from the wafer and the spent abrasive particles, often form additional sources of contamination during subsequent wafer processing. By contrast, in the method using a cavitating jet, additional sources of contamination are not created because this method merely requires water to apply impacts to the surface. It has already been reported that back-side damage required for gettering has been successfully introduced into silicon wafer through the use of a cavitating jet.[10] Also, the effectiveness of gettering by the back-side damage introduced with the cavitating jet was confirmed by observing the surface of the silicon wafer which had been intentionally contaminated and thermally treated.[11] However, the effectiveness of this gettering method on the stabilization of electrical characteristics had not been demonstrated.

In this letter, the electrical effectiveness of gettering by back-side damage introduced with a cavitating jet to getter contamination was demonstrated explicitly, using photocapacitance[12] (PHCAP) measurements. The PHCAP measurement is available for evaluation of the deep levels existing in silicon.[13,14] The PHCAP measurements were performed on areas, both with and without back-side damage, on silicon which had been locally back-side damaged and then intentionally blanket contaminated, with a subsequent thermal treatment. For reference, PHCAP measurements were also performed on fresh starting material which had not been either contaminated or thermally treated.

The cavitating jet apparatus with test section shown in Fig. 1 was used to introduce back-side damage into a silicon wafer. Ion-exchanged water was used as the test liquid. The nozzle used was cylindrical nozzle with 0.8 mm of diameter and 1.2 mm of throat length. The nozzle was fitted into a

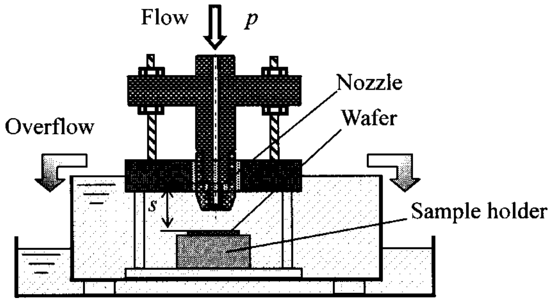

FIG. 1. Test section of the cavitating jet apparatus for introduction of back-side damage. The nozzle was submerged in the water. Pressurized water was injected through the nozzle onto the wafer.

[a)] Electronic mail: kumano@abe.mech.tohoku.ac.jp nozzle holder and submerged in the test liquid. The water, stored in header tank, was pressurized using a diaphragm pump and directed vertically at the surface of silicon wafer at room temperature. The silicon wafer was attached by vacuum to a sample holder in the water. The intensity of impacts, produced by collapse of cavitation bubbles, was controlled by adjusting the injecting pressure of the jet, p, and standoff distance, s, defined as the distance from the upstream corner to the surface of the sample. The level of the water in test section was kept constant using an over-flow weir. The samples used here were prepared from p-type, Czochralski silicon wafer with a (100) surface orientation and a thickness of 525 μm. The wafer was sawn into 18×20 mm samples along the $\{110\}$ direction. The introduction of back-side damage was performed under the conditions of $p=2.5$ MPa and $s=15$ mm. Required damage can be introduced into silicon wafer under this condition. The back-side surface of the sample was subjected to the cavitating jet for 10 min. The back-side damage was introduced in an annular region, which is typical damaged region of a cavitating jet. In order to compare the characteristics of the regions with and without back-side damage in the same sample, back-side damage was confined to the annular region. After treatment to introduce back-side damage, the sample was subjected to a conventional cleaning process and then dipped into HF solution to remove the native oxide layer. Contamination was intentionally introduced by immersing the sample into a 50 mg/l solution of $Cu(NO_3)_2$, followed by spin-drying for 60 s. The sample was thermally treated for 1 h, at 1373 K, in wet O_2 to diffuse the Cu contamination from the surface into the bulk of the sample. This thermal treatment was sufficient to diffuse Cu right through the sample to reach the gettering sites on back-side surface. After thermal treatment, the oxide layer grown on the surface was entirely removed by dipping in 49% HF solution for 1 min.

For the PHCAP measurements, Schottky diodes were fabricated with Ti on the areas of the sample, both with and without back-side damage. A 300 nm film of Ti was sputtered onto the sample at room temperature, at a pressure of 0.7 Pa. The Ti was then patterned into ϕ 500 μm spot electrodes by wet etching. The PHCAP measurements were carried out using the constant capacitance method[15] at 40 K, at which temperature shallow levels are thermally ionized. When Schottky diode is illuminated with the monochromatic light, electrons or holes trapped in deep levels are emitted into conduction band or valence band if incident photon energy is larger than the photoionization energy of these deep levels. The space charge is modified and, in consequence, the capacitance of the diode also changes. In the PHCAP measurement with constant capacitance method, the capacitance of the diode is kept constant by automatic control of the bias voltage and this bias voltage, corresponding to the change of space charge, is recorded instead of the capacitance value.

Figure 2 shows the PHCAP spectrum of fresh starting material, which has not been contaminated or thermally treated. V_{dark} and V_{light} are the bias voltages to hold the diode capacitance constant in the dark and under illumination, respectively. At each incident photon energy, V_{dark} and V_{light} were measured after filling deep levels with holes by applying a forward bias to the diode. V_{light} is almost constant below 0.65 eV. However, changes are observed with incident photon energy above 0.65 eV. This demonstrates the existence of a threshold photon energy, at which the ion density begins to increase with increasing photon energy, at 0.65 eV above the valence band ($E_v+0.65$ eV), where E_v is the energy of valence band. The PHCAP spectra of the sample intentionally contaminated and thermally treated are shown in Fig. 3. The deep level at $E_v+0.59$ eV and $E_v+0.65$ eV can be clearly observed in the spectrum of the back-side damaged region shown in Fig. 3(a). The deep level at $E_v+0.65$ eV is the same as that existing in the starting material.

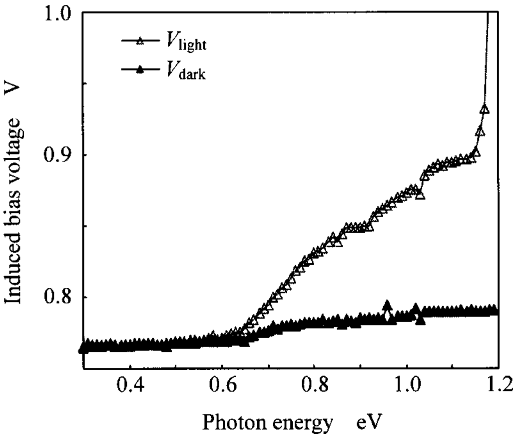

FIG. 2. PHCAP spectrum of fresh starting material with nonintentional contamination and nonthermal treatment, and which is not also treated by the cavitating jet to introduce back-side damage.

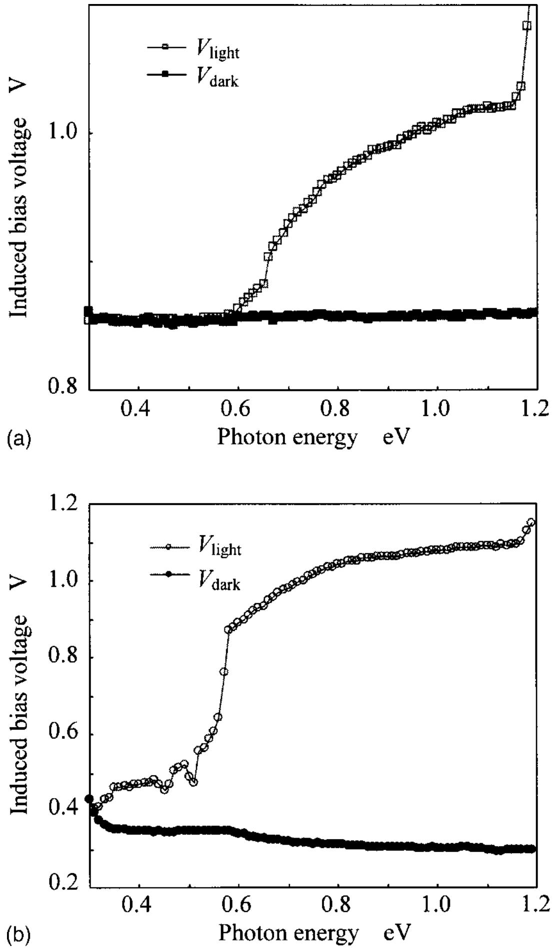

FIG. 3. PHCAP spectrum of the region (a) with back-side damage, and (b) without back-side damage of the silicon wafer, which are intentionally contaminated with $Cu(NO_3)_2$ solution and subsequently thermally treated.

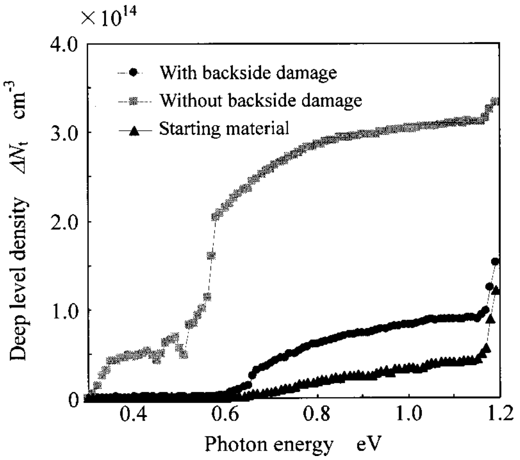

FIG. 4. Deep level density as a function of excitation photon energy of the wafer partly introduced back-side damage and the starting material. Back-side damaged wafer was intentionally contaminated and subsequently thermally treated.

In contrast, in the case of the region without back-side damage, shown in Fig. 3(b), a deep level is apparent, other than that associated with back-side damage, and photoinduced bias voltage, ΔV_{ph} $(=V_{\mathrm{light}}-V_{\mathrm{dark}})$, is increased. Figure 4 shows the deep level density, ΔN_t, calculated by

$$\Delta N_t = \frac{2C^2}{q\varepsilon A^2}\Delta V_{\mathrm{ph}}, \qquad (1)$$

where C is the constant capacitance value, q is the elementary charge, ε is the dielectric constant of Si, and A is the area of diode used for measurement. Although the deep level density of the region without back-side damage is considerably larger than that of starting material, the deep level density in the region with back-side damage is closer to that of starting material. This means that the intentional Cu contamination was eliminated from the surface in the region with back-side damage.

In order to evaluate the effectiveness of gettering by back-side damage introduced into a silicon wafer with a cavitating jet, PHCAP measurements were carried out on a sample, which had previously been locally back-side damaged and then intentionally contaminated and thermally annealed. The density of deep levels in the region with back-side damage was closer to that of starting material. The electrical effectiveness of gettering by back-side damage introduced with the cavitating jet was thus demonstrated.

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