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Silicon Surface oxidation and Passivation by Remote Induction-Coupled Oxygen Plasma

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I. Abstract

We report oxygen radical induced oxidation caused by induction-coupled remote plasma of 13.56 MHz radio frequency with mixed gases of O_2 and Ar for passivation of silicon surfaces at a low temperature. Oxidation treatment for 3 min followed by 1.3×10^6 Pa pressure H_2O vapor heat treatment at 260 °C for 3 h increased the minority carrier effective lifetime from 3.3×10^{-5} (bare surface) to 3.3×10^{-4} s. The recombination velocity decreased from 2000 (bare surface) to 100 cm/s. These results indicate a capability of thin oxide formation and effective passivation of silicon surfaces at a low temperature.

II. Experimental

A remote type induction-coupled plasma equipment was constructed, as shown in Fig. 1 [1]. Mixed gases with O_2 and Ar at 2 and 8 sccm, respectively, were introduced to the plasma tube. The gas pressure was 2.0×10^{-2} Pa. Plasma was generated by applying an 13.56 MHz radio frequency RF electric power of 100 W. A mesh plate closed plasma and oxygen radical flew down to the sample. Two substrates of 20 Ωcm n-type silicon with a thickness of 500 μm coated with 100 nm thick thermally grown SiO_2 layers were prepared. The SiO_2 layers at the top surface were removed by 5 % diluted hydrofluoric acid. The first sample was placed directly under the mesh plate. The second sample was placed 5 cm apart from the first one, as shown in Fig. 1. Oxygen radical treatment was conducted for 3 min. The samples were subsequently treated with 1.3×10^6 Pa H_2O vapor at 260 °C for 3 h [2]. The minority carrier effective lifetime τ_{eff} was measured using a 9.35 GHz microwave transmittance measurement system under 635 nm continuous light illumination.

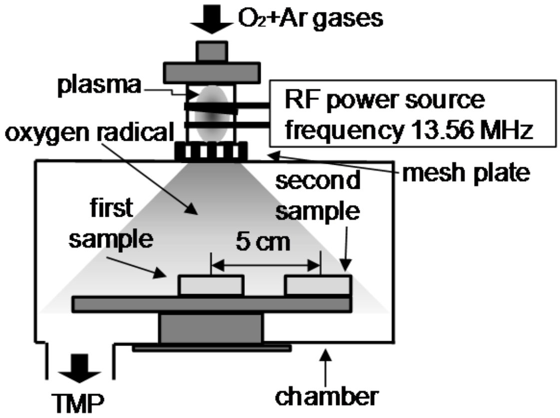

Fig.1: Schematic apparatus for oxygen radical treatment.

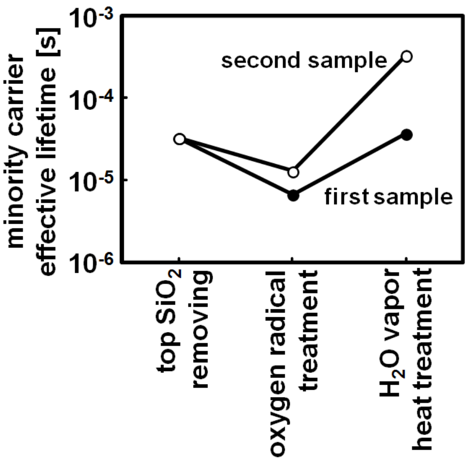

Fig.2: τ_{eff} for samples in the cases of top SiO_2 removing, oxygen radical treatment, and 1.3×10^6 Pa H_2O vapor heat treatment.

III. Results and discussion

Figure 2 shows τ_{eff} for samples in the cases of top SiO_2 removing, oxygen radical treatment, and 1.3×10^6 Pa H_2O vapor heat treatment. τ_{eff} was low of 3.3×10^{-5} s for the top SiO_2 removed sample because the bare silicon surface had a high density of carrier recombination defect sites. τ_{eff} was still low of 6.8×10^{-6} and 1.3×10^{-5} s for the first and second samples. These results indicate that the oxidized top surface by oxygen radical at room temperature had substantial defect sites. 1.3×10^6 Pa H_2O vapor heat treatment at 260 °C for 3 h markedly increased τ_{eff} to 3.3×10^{-4} s for the second sample placed 5 cm apart from the position directly under the mesh plate, as shown in Fig. 2. On the other hand, τ_{eff} was still low of 3.7×10^{-5} s for the first sample placed directly under the mesh plate. The surface recombination velocity at the top surface S_{top} estimated from the experimental τ_{eff} was 2000 cm/s for the initial sample with the top bare surface. Oxygen radical treatment with mixed gases with O_2 and Ar resulted in high S_{top} of 7500 and 11000 cm/s for second and first samples. 1.3×10^6 Pa H_2O vapor heat treatment at 260 °C for 3 h decreased S_{top} to 100 and 900 cm/s for the second and first samples, respectively. We interpret that H_2O vapor heat treatment made Si-O bondings relaxed and the surface stable with thin SiO_2 for the second sample. On the other hand, there was still a high density of recombination defects probably caused by deep ultra violet light irradiation from the plasma for the first sample placed directly under the mesh plate.

References

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[2] T. Sameshima and M.Satoh: Jpn. J. Appl. Phys. 36 (1997) L687.