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Characterization of Surface Potential of Si-SiO_2 Interface by Photoreflectance Spectroscopy

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We have attempted to characterize Si-SiO_2 interface by photorefrectance(PR) spectroscopy. Si PR signal intensity was reduced by forming SiO_2 layer on the surface, but was enhanced by applying dc electric field to the Si-SiO_2 interface. Surface potential of Si estimated from modulation light intensity dependence of PR signal intensity decreased with increasing SiO_2 layer thickness on Si surface. The experimental results suggest that reduction of PR signal intensity of Si with SiO_2 layer was partially caused by decrease of Si surface potential.

1. Introduction

Photorefrectance(PR) spectroscopy is a contactless and nondestructive method to estimate band structure of semiconductors accurately, through the measurement of field-induced-change of the reflectance of a semiconductor whose surface potential is modulated by optically generated carriers.[1] The PR method can be applied to the sample placed into plasma reaction chamber because of this method was not affected by sample ambient. We have measured surface temperature and surface potential of Si nondestructively by using this method succesfully.[2] However, PR signal intensity was weakened by forming SiO_2 layer on Si surface and no PR spectra was able to be obtained if SiO_2 layer thickness was over 100Å. Therefore it was difficult to measure surface temperature and surface potential of Si-SiO_2 structure. The reduction of PR signal intensity prevented to apply this method to characterization of Si surface and interface.

In this paper, we characterize Si-SiO_2 interface by PR method and show that the PR signal intensity enhanced by applying electric field to the interface and the surface potential of Si decreased with increasing SiO_2 layer thickness on Si wafer.

2. PR spectrum measurement

Figure 1 shows energy band diagram in the vicinity of the Si-SiO_2 interface with and without light irradiation. Surface potential of Si ϕ_s $(=eV_s)$ decreases with light irradiation for modulation as photo-generated holes accumulate at the interface. The signal in PR spectroscopy is expressed as the ratio of reflectance change induced by photo-irradiation to the reflectance.

Figure 2 shows experimental setup of PR measurement. n-type Si wafer with resistivity of 0.01 Ω cm was used as a sample. SiO_2 layer was formed on Si surface by thermal oxidation in an O_2 ambient. The sample was excited by Ar^+ ion laser to modulate surface electric field and irradiated simultaneously by Xe discharge lamp as a probe light for measuring of surface reflectance. The

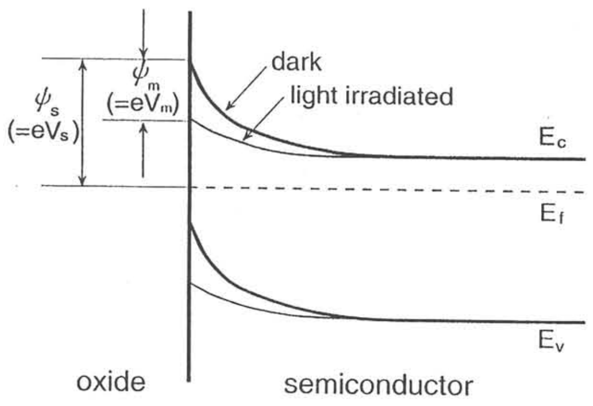

Fig.1 Energy band profile of semiconductor interface with and without light irradiation.

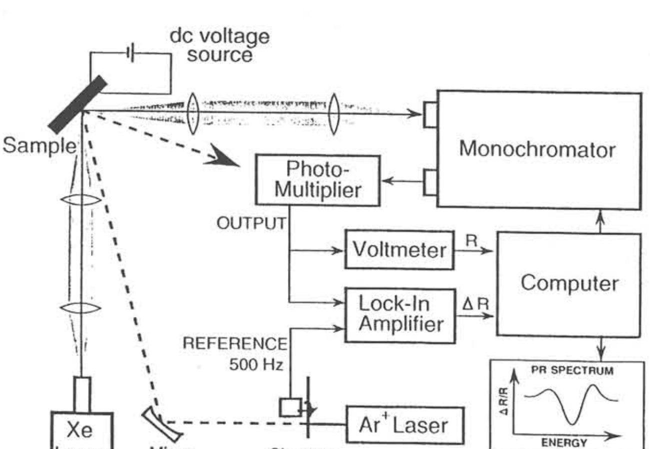

Fig.2 Experimental setup of PR spectroscopy.

sample was measured in the atmosphere. PR spectrum was obtained by the ratio of reflectance change to the reflectance for probe light .

Surface potential of Si $\phi_s(=eV_s)$ can be estimated by fitting the experimental modulation light intensity dependence of the PR signal intensity to the theoretical data, reported previously.[2] Transition energy of Si can be also calculated from PR spectra by the 3-point method based on 3rd derivative theory.

3. Result and Discussion

3.1 PR spectra under dc electric field

Figure 3 shows an example of PR spectra of Si wafer with various thickness of SiO_2 layer. Typical PR spectra are confirmed clearly around energy of 3.4 eV. Transition energy calculated from these spectra agrees with L-point transition energy of Si. Though SiO_2 layer absorbs modulation light and probe light very little, the PR signal intensities of Si decrease with increasing SiO_2 layer thickness. The PR spectrum was not observed from Si-SiO_2 structure with SiO_2 thickness over 100Å.

Figure 4 illustrate the sample structure for PR spectrum measurement of Si-SiO_2 structure with dc bias voltage. A semitransparent electrode of Au layer was deposited on the SiO_2 layer and electrode of Au-Sb layer was also deposited on another side by vacuum evaporation. dc bias voltage was applied by these electrodes. Excitation and probe lights were introduced through the semitransparent electrode to measure the PR spectrum. Figure 5 shows PR spectra from Si-SiO_2 structure with dc bias voltage. The thickness of SiO_2 layer was 60Å. The PR signal intensity drastically increased when dc bias voltage was applied to negative direction. The negative bias voltage increases surface potential of Si with SiO_2 layer. Taking into account the photo-generated current at the Schottky barrier, the PR spectrum intensity increased with surface potential of a sample.[3] It is supposed that the enhancement of PR signal intensity is caused by the increment of surface potential of Si.

Figure 6 shows the bias voltage dependence of the peak to peak value of PR spectrum in Si-SiO_2 structure (SiO_2:60 Å). The signal intensity increased sharply with increasing bias voltage toward negative direction and saturated at bias voltage of around -1 V. This phenomena suggests that the dc bias voltages increase the Si surface potential which is decreased by forming of SiO_2 layer on it. When the dc voltage reached -1 V, the PR signal intensity was enhanced by the factor of three to the non-biased signal. At the applied voltage beyond -1 V, the saturated intensity was determined by modulation light intensity according to the theory.[3]

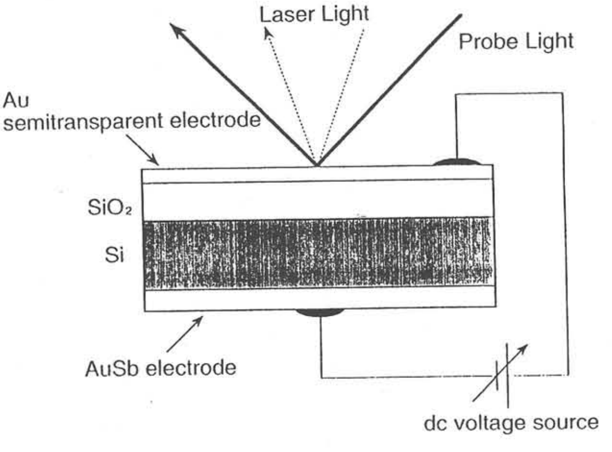

Fig.4 Configuration of Si-SiO_2 structure for increasing electric field at the interface.

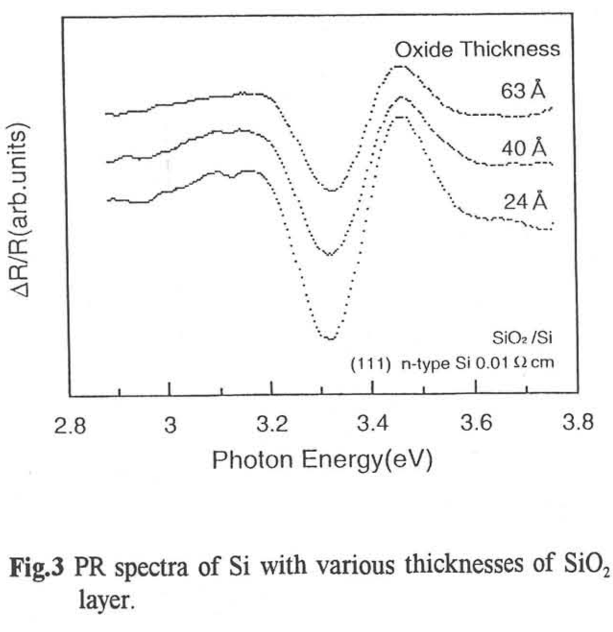

Fig.3 PR spectra of Si with various thicknesses of SiO_2 layer.

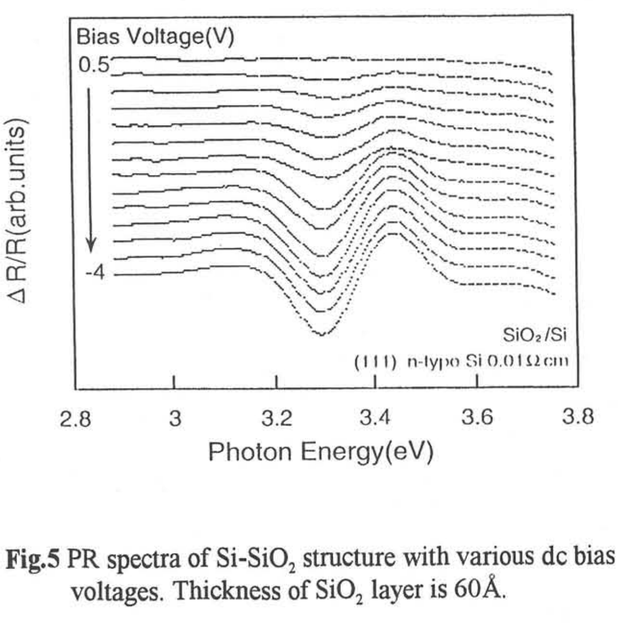

Fig.5 PR spectra of Si-SiO_2 structure with various dc bias voltages. Thickness of SiO_2 layer is 60Å.

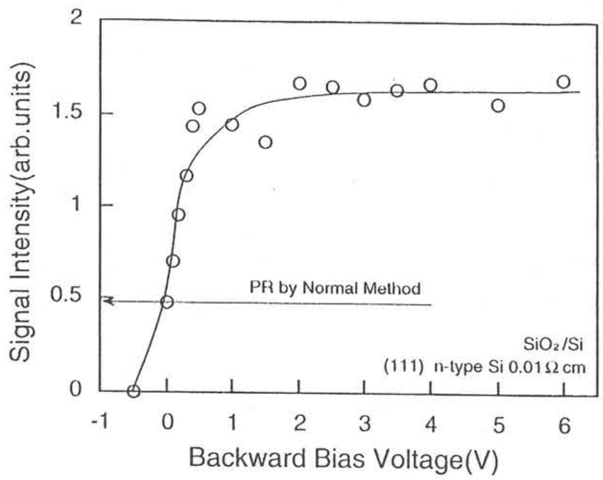

Fig.6 PR signal intensity as a function of applied bias voltage.

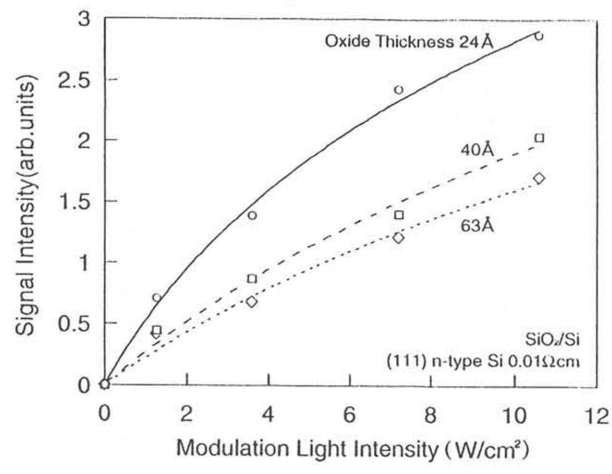

Fig.7 Modulation light intensity dependence of PR signal intensity. Solid line and broken lines show theoretical curves.

3.2 Surface potential of Si with SiO_2 layer

The surface potentials of Si-SiO_2 structure were estimated by modulation light intensity dependence of the PR signal intensity. Figure 7 shows the modulation light intensity dependence of the PR signal intensity with various thicknesses of SiO_2 layer. Solid line and broken lines show theoretical curves fitted by least mean squares method to the data. We can obtain the surface potentials of Si with SiO_2 layer from the fitted curves.

Figure 8 shows estimated surface potential of Si with various thicknesses of SiO_2 layer. The estimated surface potential of Si decreases gradually from 0.43 eV to 0.38 eV with increasing the thickness of SiO_2 layer from 24 Å to 63 Å. The tendency of the results agrees with the above discussion. We suppose that the reduction of surface potential of Si wafer by forming SiO_2 layer was caused by trap charge on the Si-SiO_2 interface, fixed oxide charge in the SiO_2 layer, or increase of the voltage applied to SiO_2 layer.

From these results, the decreasing surface potential of Si may cause to decrease PR signal intensity of Si with SiO_2 layer.

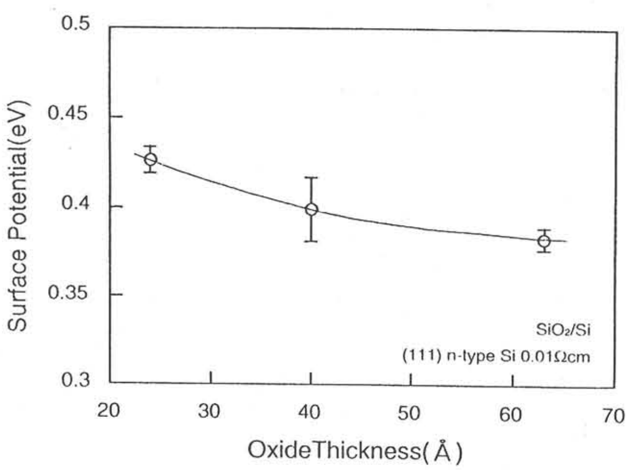

Fig.8 SiO_2 thickness dependence of Si surface potential.

4. Conclusions

We have characterized Si-SiO_2 interface by photorefrectance(PR) spectroscopy. Si PR signal intensity was weakened by forming SiO_2 layer on the surface, but was enhanced by applying dc electric field to the Si-SiO_2 interface. Si surface potential of Si-SiO_2 structure estimated from modulation light intensity dependence of PR signal intensity decreased with increasing SiO_2 layer thickness. These results are consistent each other and suggest that diminution of surface potential of Si caused to decrease PR signal intensity of Si with SiO_2 layer partially.

By analyzing PR spectra of Si-SiO_2 structure, the quality of Si-SiO2 interface and/or SiO2 layer will be characterized with no contact and no destruction. This method can be used to analyze early stage of Si oxidation process and also applied *in-situ* monitoring of semiconductor manufacturing process such as growth and oxidation process even in a plasma reaction chamber.

Acknowledgment

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