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Contactless Measurement of Surface Temperature and Surface Potential of Semiconductor by Photoreflectance Spectroscopy

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Surface temperature and surface potential of Si wafers have been measured by photoreflectance(PR) spectroscopy. The surface temperature was obtained in the range from 25℃ to 134℃ within the error of ±0.6℃ from Si transition energy which was calculated from PR spectrum by 3-points method based on 3rd derivative theory. Surface potential was estimated by comparison of experimental PR spectra intensity with theoretical values taking into account photo-induced charge of surface field. The results show that surface potential of Si wafers varies with temperature in the atmosphere.

1.Introduction

Precise controls of surface temperature and surface potential of semiconductor are very important to produce high-quality semiconductor devices. However, it is difficult to measure them accurately, especially during the processing. Photoreflectance(PR) spectroscopy, one of modulation spectroscopy methods, can estimate band structure of semiconductors by measuring reflectance of semiconductor whose surface potential is modulated by optically generated carriers. Owing to need no contact and no destruction of the samples in the PR spectroscopy, the method will be a powerful tool for *in-situ* measurement in the processings such as film deposition and etching.

We have attempted to measure the surface temperature and surface potential without any contact and destruction of samples by using PR spectroscopy method.

2.Theoretical Analysis of PR Spectra

Signal in the PR spectroscopy is expressed as ratio of electric-field-modulated reflectance change(ΔR) induced by photo-irradiation to the reflectance(R), ΔR/R. Since ΔR/R is proportional to the third differentiation of reflectance spectrum, it has extremely sharp shape. The spectrum reflects an energy band structure of semiconductors, and so transition energy can be accurately estimated by 3-points method based on 3rd derivative theory. Surface temperature of Si is determined from temperature-induced shift of the transition energy. Surface potential can be also determined by analyzing of intensity of the PR spectra $|\Delta R/R|$.

Figure 1 shows energy band diagram in the vicinity of the surface with and without light irradiation. The surface potential Ψ_s(=eV_s) decreases with light irradiation for modulation. The variation of Ψ_s expresses as Ψ_m(=eV_m). $|\Delta R/R|$ is in proportion to square of surface electric field[1]. Square of the electric field is also in proportion to variation of surface potential. Consequently, $|\Delta R/R|$ is in proportion to eV_m.

Taking into account the photo-generated current at the Schottky barrier, we derive the equation of the variation of surface potential[2]:

$$V_m=\frac{nkT}{e}\,ln\left[\frac{eP_m\gamma\,(1-R_0)}{A^*T^2h\nu}\,exp\left(\frac{eV_s}{kT}\right)+1\right] \quad (1)$$

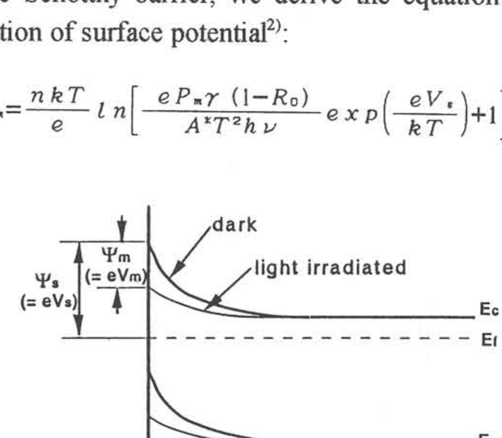


Fig.1. Energy band diagram of semiconductor surface.

where P_m is the light intensity, γ is quantum efficiency of Si, R_0 is reflectivity of Si, $h\nu$ is photon energy for modulation light.

Figures 2 (a) and (b) show the calculated temperature dependence of PR signal intensities as a parameters of modulation light intensity (a) and surface potential (b) from equation (1) under measuring conditions listed in Table I. It is clear that PR signal intensity is strongly depend on the modulation light intensity and Si surface potential. We can estimate the surface potential of Si wafer by fitting experimental data to the theoretical data.

3.Experimental Procedure

Figure 3 shows experimental setup used in this study. (100) oriented n-type Si wafer with resistivity of 0.01 Ω cm was used as a sample. The sample was excited by a 514.5 nm line from an Ar^+ ion laser to modulate the surface field. Xe discharge lamp was used as a probe light source. Sample temperature was controlled by a ceramic heater. PR spectrum was acquired by analyzing reflectance for probe light on Si surface.

4. Results and Discussions

4.1. Surface temperature

Figure 4 shows PR spectra of Si wafer within temperature range from 25℃ to 134℃. The spectrum position moves to lower energy side with increasing temperature. Transition energy was calculated from the spectra. Figure 5 shows the transition energy as a function of temperature. The transition energy decreases linearly with increasing temperature and is expressed by

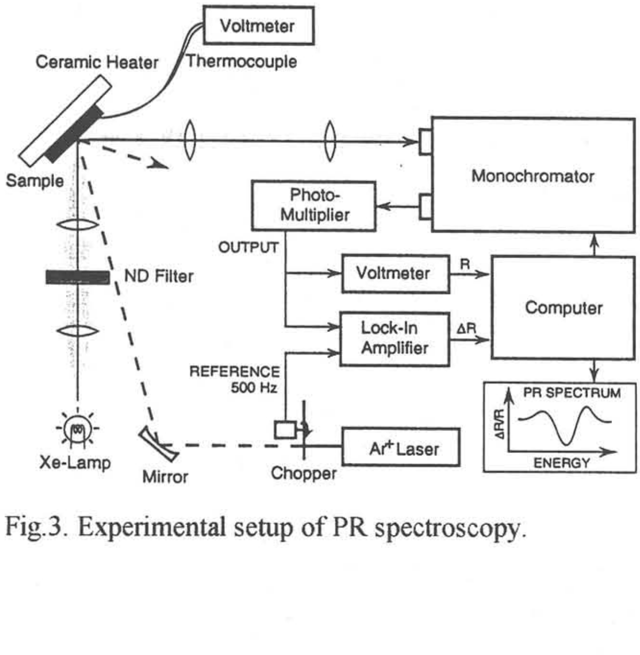
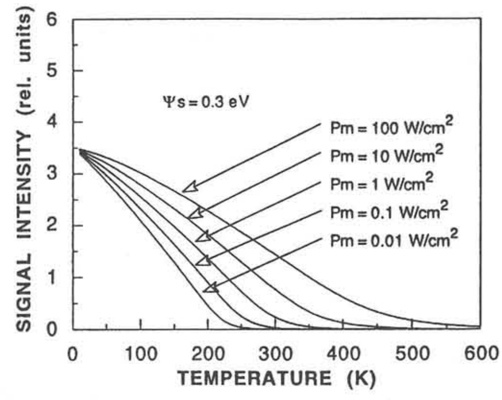
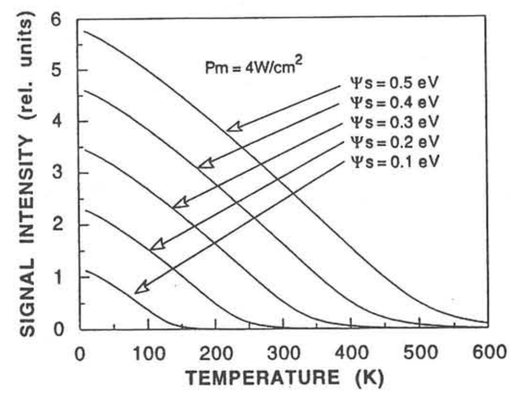


Fig.3. Experimental setup of PR spectroscopy.



(a)



(b)

Fig.2. Temperature dependence of PR signal intensity as a parameter of P_m (a) and surface potential (b).

Table I. Measuring conditions of PR spectra.

Modulation light intensity	P_m	4	W/cm^2
Reflectivity	R_0	0.4	
Photon energy	$h\nu$	2.54	eV
Quantum efficiency	η	0.5	

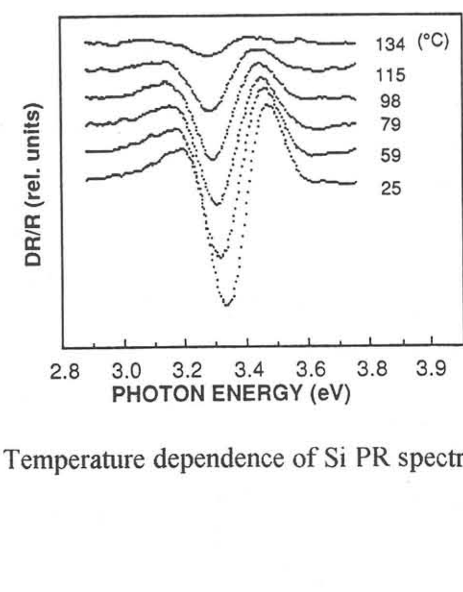


Fig.4. Temperature dependence of Si PR spectra.

$$E_g=3.3972-5.03\times 10^{-4}\times T(℃)\pm 3\times 10^{-4} \qquad (2).$$

By using this relation, we can estimate the surface temperature of Si wafer within the error of ±0.6℃.

4.2. Surface Potential

By simplification of the coefficients, equation (1) is rewritten as a function of modulation light intensity

$$|\Delta R/R|=C_1 ln(C_2 P_m+1) \qquad (3)$$

where C_1 is a constant and $C_2=e\gamma\,(1-R_0)/A^*T^2h\nu\times\exp(eV_s/kT)$. The coefficient C_2 is a function of temperature and surface potential. We can determined C_2 by measuring PR spectra intensities under various temperature. Figure 6 shows temperature dependence of C_2. Circles show the experimental data and dotted lines show theoretical curves. There are discrepancies between the data and the curves, which are attributed to change of the surface potential Ψ_s. By fitting the experimental data to the theoretical data, the surface potentials are estimated. Figure 7 shows the surface potential of Si wafer in the atmosphere under various temperature. The surface potential increases with temperature below 355K and decreased above it. This variation of surface potential may be caused by adsorption and/or desorption of ionic molecules on Si surface..

5.Conclusions

We have proposed contactless and nondestructive characterization method of surface temperature and surface potential of Si wafer by PR spectroscopy. The accuracy of temperature measurement was ± 0.6℃ in the temperature range from 25℃ to 134℃. The surface potential was estimated from PR spectra intensity under various temperature of Si wafer by fitting them to theoretical results. It is shown that the surface potential of Si varies with it's temperature in the atmosphere.

By applying this method to semiconductor manufacturing process, we'll be able to measure the distributions of surface temperature and surface potential of semiconductors even in the plasma reaction chamber or crystal growth chamber. In addition, this method can be effectively applied to analysis of the reaction mechanism of semiconductor surface during growth process and etching process.

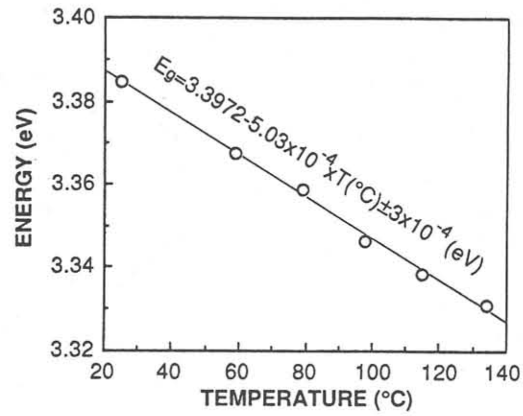


Fig.5. Temperature dependence of Si transition energy.

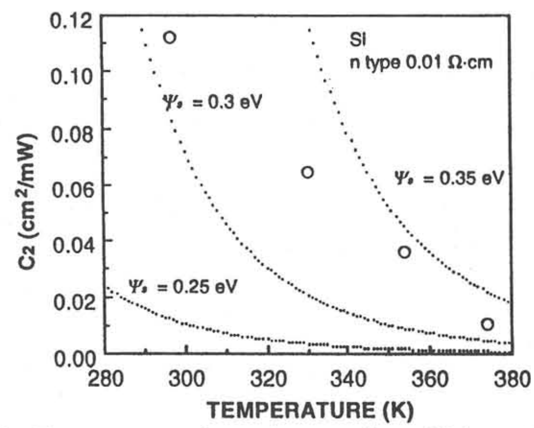


Fig.6. Temperature dependence of coefficient C_2 of equation (3) as a parameter of Ψ_s. Open circles show experimental data.

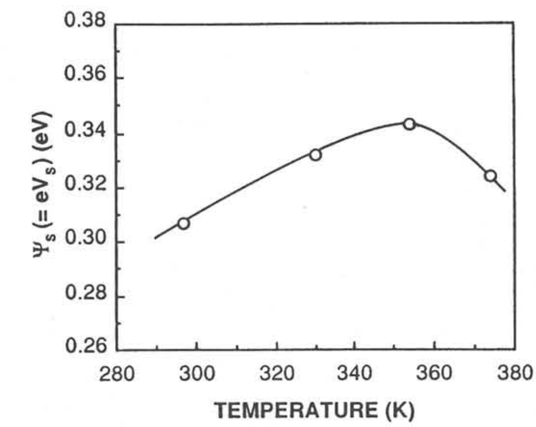


Fig.7. Surface potential Ψ_s as a function of temperature.

Acknowledgment

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