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New Nondestructive Carrier Profiling for Ion Implanted Si Using Infrared Spectroscopic Ellipsometry

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1. Introduction

The evaluation of carrier or doping concentration profiles have been carried out by using destructive methods such as Spreading resistance profiling(SRP) technique or Secondary ion mass spectrometry (SIMS) measurements. Recently, we have demonstrated the nondestructive method for simultaneous measurements of carrier concentration and layer thickness of epitaxial doped layer by the use of the IR spectroscopic ellipsometry [1]. The method provides accurate carrier concentration over a wide range of concentration; the complex refractive index of doped semiconductor depends on its carrier concentration in the IR range. In this study, we propose a new carrier profiling method for ion implanted Si by extending the method for epitaxial doped layer. This is the first nondestructive carrier profiling method ever reported.

2. Theory

Spectroscopic ellipsometry measures the complex reflection ratio, $\tilde{\rho}$ or ellipsometric angles, Ψ and Δ as a function of wavenumber. These parameters are related to reflection coefficients given by

$$\tilde{\rho} = \tan\Psi e^{j\Delta} \equiv \frac{R^p}{R^s}, \qquad (1)$$

where R^p and R^s are the overall complex-amplitude reflection coefficients of the optical system for the parallel(p) and perpendicular(s) polarizations. For the calculation, we assumed that a carrier profile has the Pearson's type-IV distribution. The carrier profile is approximated by the multiple step function as shown in Fig.1. The implanted region was divided into 200 layers with equal thickness. N_{ci} is the carrier concentration of ith step layer. We use the following complex refractive index of ith step layer $\tilde{n}_i$ since in infrared wavelength, optical properties of the layer are determined by plasma oscillations given by

$$\tilde{n}_i^2 = \epsilon_{opt}\left(1 - \frac{\omega_{pi}^2}{\omega^2 + j\omega\gamma}\right). \qquad (2)$$

Where ϵ_{opt} and γ are high frequency dielectric constant and damping constant for the plasmon, respectively. The plasma frequency ω_{pi} and carrier concentration N_{ci} for the ith step layer are related to

$$\omega_{pi}^2 = \frac{N_{ci}e^2}{m^* \epsilon_{opt}\epsilon_0}, \qquad (3)$$

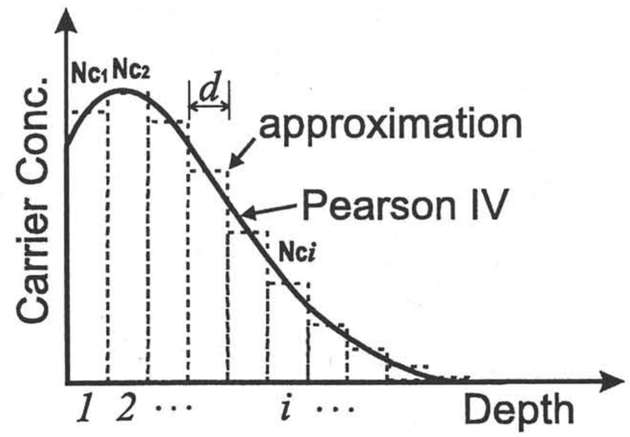

Fig.1 Multilayer approximation of carrier profile.

where e is electronic charge and m^* is effective mass of the free carrier. The complex reflection ratio $\tilde{\rho}$ was calculated with taking into account the multiple reflection from the interfaces. A set of best fitted Pearson IV parameters, the projection range R_p, the deviation ΔR_p, the skewness γ_1, the kurtosis β_2 can be uniquely determined in such a way that the calculated trajectory of $\tilde{\rho}$ are fitted to the measured trajectory of $\tilde{\rho}$ with the use of a steepest descent method.

3. Measurements and Results

We use an FTIR phase modulated ellipsometry is shown in Fig.2 [2]. A sample under measurement is placed between two optical benches of the incident and reflected beam sides. The reflected signal is sensed by a LN_2-cooled photoconductive HgCdTe detector with a spectral range between 860 and $3,400cm^{-1}$ ($11.6 - 2.9\mu m$). The measurement error is less than 0.001 in the real and imaginary part of $\tilde{\rho}$. The samples used in this study are boron implanted Si wafers.

Figure 3 shows the best fitted curve of $\tilde{\rho}$ (—) together with the measured data (o) for the sample in which boron ions were implanted with the energy of 15keV and the dose 2×10^{14}cm^{-2} and annealed in 800°C for 30min.

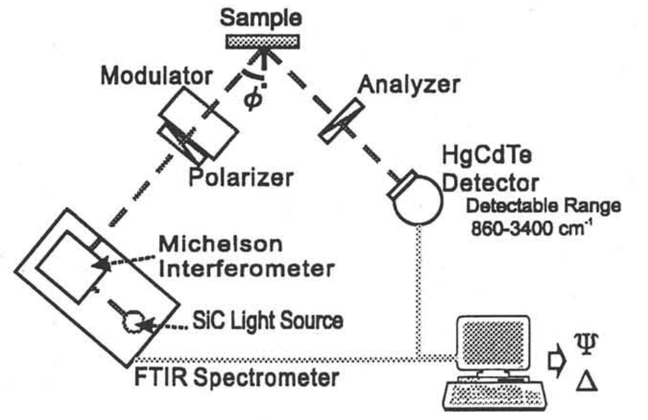

Fig.2 Schematic illustration of IR spectroscopic ellipsometer.

The solid curve and the measured data are plotted from the left to right as the wavenumber increases. The fitted curve is relatively in good agreement with the measured data in the large wavenumber region, through which the Pearson IV parameters; $R_p = 52.4nm$, $\Delta R_p = 53.8nm$, $\gamma_1 = -0.006$ and $\beta_2 = 3.95$ were obtained.

The significant difference in the small wavenumber region is attributed to the neglect of other absorption mechanisms such as interband hole transition in the valence bands.

Figure 4 shows the carrier concentration profile obtained by the new method (—) compared with a result from SRP technique (•). The depth of peak carrier concentration is in good agreement with the result derived from the SRP technique. The peak carrier concentration, however, differs from the SRP result within the error of 50%, which may be due to the error in hole mobility in SRP analysis.

4. Summary

We developed a new method to evaluate the carrier concentration profile of ion implanted Si by employing a contactless and nondestructive infrared spectroscopic ellipsometry. It is demonstrated that the carrier profiles can be correctly measured with the new method by simply assuming the plasma oscillation of free carriers.

References

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2) A. Canillas, E. Pascual and B. Drèvillon: Rev. Sci. Instrum. **64** (1993) 2153.

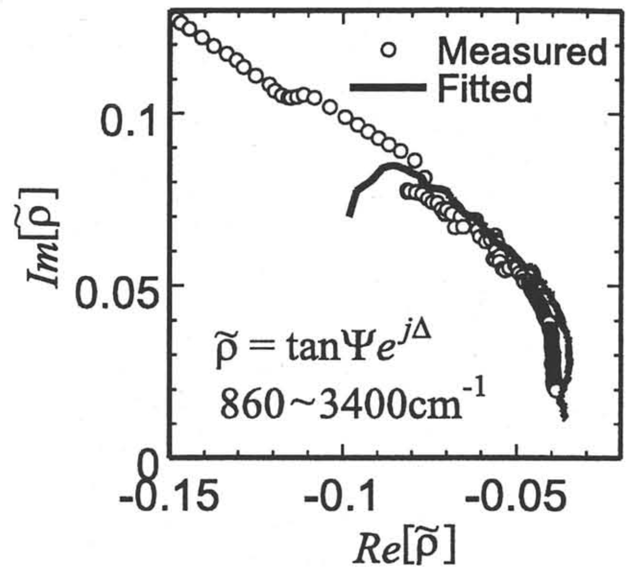

Fig.3 Best fitted $\tilde{\rho}$ (—) together with measured $\tilde{\rho}$ (∘) for B^+ implanted Si.

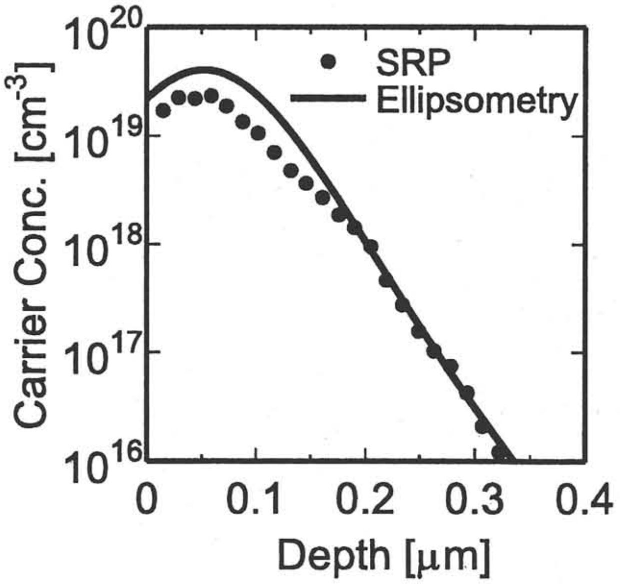

Fig. 4 Obtained carrier profile by using the new optical method (—) compared with the SRP result (•).