Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 328-329 **A-11-3**

Optical Characterization of Gate Oxide Charging Damage by Photoreflectance Spectroscopy

Masashi Agata, Hideo Wada, Osamu Maida, Koji Eriguchi[1], Akira Fujimoto[2], Takeshi Kanashima and Masanori Okuyama

Area of Materials and Device Physics, Department of Physical Science, Graduate School of Engineering Science, Osaka University, 1-3 Machikaneyama-cho, Toyonaka, Osaka 560-8531, Japan,
Phone:+81-6-6850-6331 Fax:+81-6-6850-6341 e-mal : agata@semi.ee.es.osaka-u.ac.jp
[1]ULSI Process Tech.Dev.Ctr., Matsushita Electronics
19 Nishikujo-Kasugacho, Minami-ku, Kyoto 601-8413, JAPAN
[2]Dept. Electrical Engineering, Wakayama National College of Technology, 77 Noshima, Nadacho, Goboshi 644-0023, Japan

1. Introduction

Recently, much attention has been paid on plasma process for ultra fine fabrication of ultra large-scale integrated circuit (ULSI). In the device performance, charging damage of thin gate oxide during plasma process is important issue as it is exposed in the strong plasma [1]. The above charging damages, inducing-degradation in states at the SiO_2/Si interface and the oxide trapped charge, are characterized by the electrical measurement such as I-V and C-V measurement. However, these techniques are time-consuming and destructive.

Photoreflectance (PR) spectroscopy is contactless and non-destructive technique that can measure the band structure of semiconductor surface or interface. We have reported that the PR spectroscopic method is an easy and promising technique to monitor the plasma-induced damage of Si substrate [2].

In this work, we have applied the PR spectroscopy to monitor the charging damage of Si and compared the obtained results with other electrical characteristics.

2. Analysis of PR Signal Intensity

The PR signal intensity is expressed as the ratio of a small reflectance change induced by modulation light (ΔR) to the reflectance (R), $\Delta R/R$. According to the third derivative theory by Aspnes [3], PR signal intensity is in proportion to the change of square of the surface electric field. When donor or acceptor concentration is homogeneous, the change of square of the surface field is in proportion to the surface potential change, $\Delta\Phi$. Therefore, $\Delta R/R$ is in proportion to $\Delta\Phi$ as follows,

$$\frac{\Delta R}{R} \propto \Delta(E^2) \propto \Delta\Phi. \qquad (1)$$

PR signal intensity should be considered to include the influence of the field distributed inhomogeneously in the space charge region, but these effects are as small as they can be neglected. Thus, we have analyzed the PR signal intensity using eq. (1).

3. Experimental Setup and Samples

Figure 1 shows the experimental setup for the PR measurement used in this study. The surface potential of the sample is modulated by He-Ne laser (632.8 nm, 4.24 W/cm^2) chopped at 100 Hz. Xe discharge lamp as a probe light for measuring the reflectance irradiates the sample. A small reflectance change of the probe light, ΔR is detected through a monochromator by a lock-in amplifier referring to the modulation frequency. All PR measurement was performed in the air at room temperature.

MOS capacitors on n-Si (100) wafers (0.02 Ω cm) were used for all PR measurement. Gate oxide thickness of 4 nm was grown in dry O_2. After Au deposition, Ar plasma treatment was carried out with the DC power at 100 mTorr in the sputtering system to induce charging damage to MOS capacitors.

4. Results and Discussions

Figure 2 shows PR spectra of plasma-exposed sample. The PR signal intensities decrease after the plasma treatment. We can suggest that states at the SiO_2/Si interface generate in plasma-exposed MOS capacitor by induced plasma damage. The states act as recombination-center of photo-generated carrier by modulation light. Therefore, surface potential change, that is proportional to PR signal intensity, decreases. PR signal intensity was also decreased by ion bombardment of plasma. However, PR signal intensities of Si substrate recovered removing oxide layer from plasma-treated MOS structure. Figure 3 shows C-V characteristics of MOS structure before and after plasma treatment. C-V curve distortion reflects state generations at the SiO_2/Si interface. These results show the decrease of PR signal

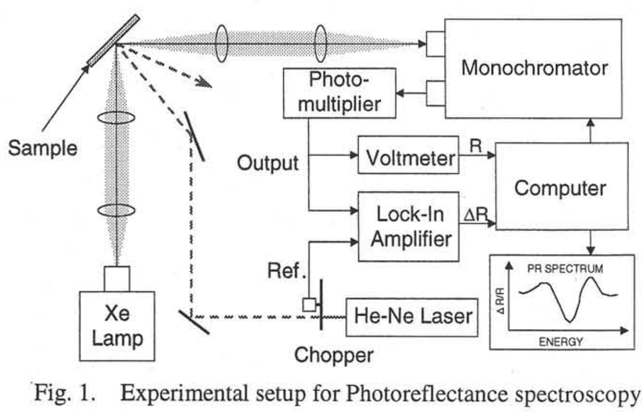

Fig. 1. Experimental setup for Photoreflectance spectroscopy

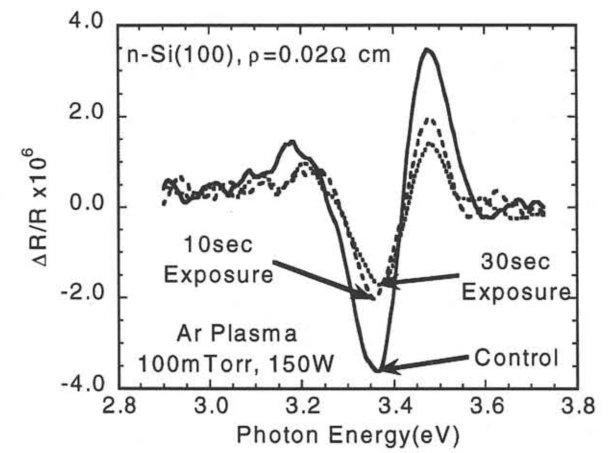

Fig. 2. PR spectra of Si MOS capacitors damaged by Ar DC plasma treatment.

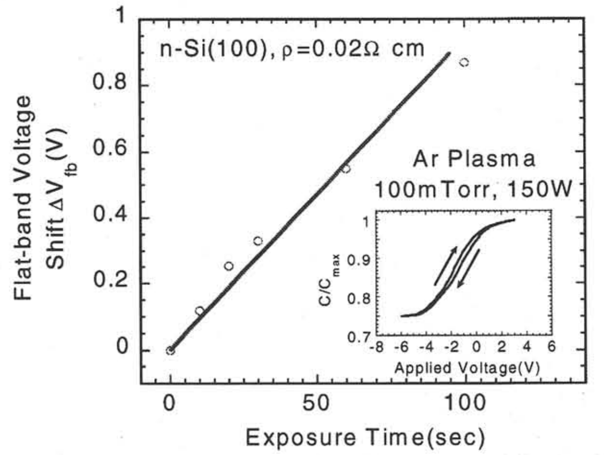

Fig. 4. Ar plasma exposure-time dependence of flat-band voltage shift.

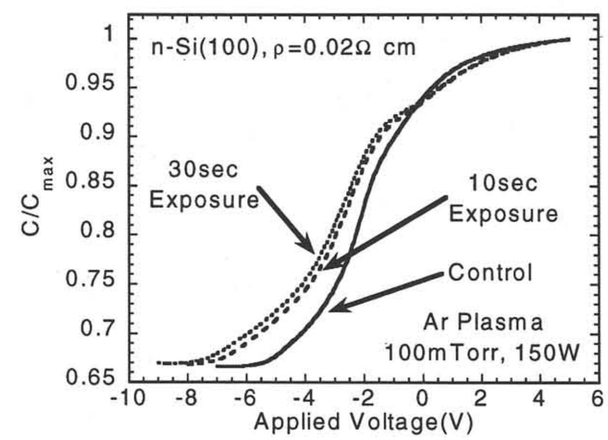

Fig. 3. C-V characteristics of Si MOS capacitors damaged by Ar DC plasma treatment.

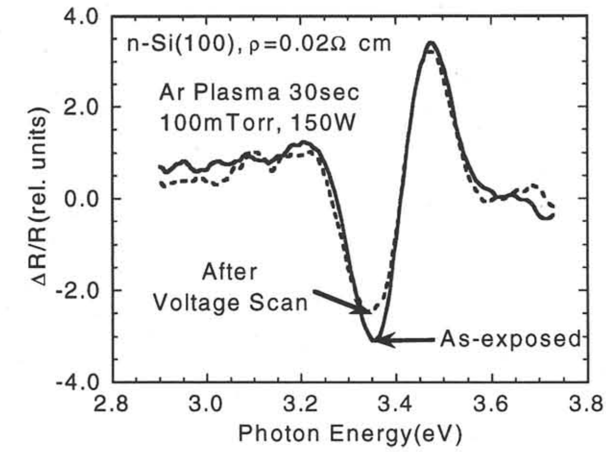

Fig. 5. PR spectra of Si MOS sample damaged by plasma and that after voltage scan.

intensity is due to the plasma-induced defect at the interface of MOS capacitor. Damage induced in Si bulk by plasma treatment didn't cause significant change in PR signal.

The C-V curves of Ar-plasma-exposured sample in increasing and decreasing bias voltage are different. This voltage scan in the C-V measurement produces flat-band voltage shift, ΔV_{fb}. Figure 4 shows exposure-time dependence of flat-band voltage shift calculated from C-V characteristics shown in the inset. If plasma-exposure introduces the charge into oxide layer, the flat band shift stands for detrapping negative charge from oxide layer during the voltage scan. This is because C-V curve shifts to negative voltage when the bias voltage increased. Introducing negative charge into oxide layer of MOS structure brings about higher surface potential. Therefore we suggest that PR signal intensity decreases after the voltage scan to MOS structure. Figure 5 shows PR spectra of plasma-exposured MOS structure before and after the voltage scan. The PR signal intensity decreases by applying the voltage scan. These results show that the decrease of PR signal intensity is the result of negative charge detrapping.

5. Conclusions

Photoreflectance (PR) Spectroscopy has been applied to the characterization of the charging damage on Si MOS capacitor. Plasma exposure decreased PR signal intensity of Si MOS structure and C-V curve distorts after plasma treatment. These results show states at the SiO_2/Si interface affects significantly to PR signal intensity. Furthermore negative charge detrapping can be detected by PR measurements after applying bias. The PR spectroscopic method is confirmed to be useful and contactles technique to characterize the charging damage induced by plasma exposure in Si MOS capacitor.

Reference

[1] H. Shin, K. Noguchi and C. Hu, IEEE Electron Device Lett. Vol. **14**, 509 (1993)

[2] H. Wada, K. Eriguchi, A. Fujimoto, T. Kanashima and M. Okuyama, in Proc. of 1998 International Symposium on P2ID, 152

[3] D. E. Aspnes, Surf. Sci. **37**, 418 (1973)