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Investigation of the effects of Ar plasma etching in Si surface by photoacoustic method*

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Abstract. The effects of Ar plasma treatment on the Si surface were investigated by photoacoustic spectroscopy and atomic force microscopy. We studied the surface structure as a function of plasma experimental parameters to correlate the plasma-surface reaction with surface roughness, surface defects and thermal and electronic transport characteristics. The surface of the Si sample (p-type, 10 kΩcm, 420 μm) was treated with Ar plasma from 2 min to 80 min. Amplitude and phase PA spectra were measured in the energy range from 0.75 to 1.55 eV. The amplitude ratio and phase difference of the photoacoustic signals for Si samples Ar plasma etched and incoming Si samples indicate the existence of two surface energy states (the generation–recombination centers) at 0,81 and 0,99 eV.

1. INTRODUCTION

During the past ten years, photoacoustic (PA) and photothermal science has been successfully applied to study semiconductor materials and microelectronic devices. The induced changes in the sample properties, as a consequence of various microelectronic technology processes, can be detected by the PA effect. The experimental results and theoretical analysis showed a strong dependence of the PA signal on the surface quality of a semiconductor [1, 2 ,3]. The PA signal should generally increase with the extent of damage, in the form of surface electronic states or of lattice disorder in the region near the surface of the semiconductor. In particular, for a mechanically or chemically processed Si wafer, the measured PA signal can be expect to increase or decrease as a consequence of the change in the near surface optical, electronic and carrier transport properties.

Many authors investigated the effects of Ar plasma on the Si surface. Umezu et al [4] investigated the effects of argon and hydrogen plasmas on the structure and electrical properties of the surface of silicon wafers. Surface roughness and defect density were measured by atomic force microscopy and photothermal deflection spectroscopy, respectively. Shin et al [5] investigated the damage distribution in Si surface after low energy (0.5 and 1.0 keV) Ar^+ ion bombardment.

In this work, the effects of Ar plasma treatment of the Si surface were investigated by PA spectroscopy and atomic force microscopy (AFM). We analyzed the PA spectra to obtain the energy distribution of the defect states as a function of plasma experimental parameters to correlate the plasma-surface reaction with surface roughness, surface defects and thermal and electronic transport characteristics.

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2. EXPERIMENTAL RESULTS

The PA spectra were measured as a function of the excitation energy from 0.75 to 1.55 eV, and for the modulation frequency f =10 Hz of the excitation optical beam at room temperature using a standard dual-beam, single-cell PA spectrometer. Typically, all the PA spectra were normalized by the PA signal due to carbon black powder as a reference sample to eliminate the spectral characteristic of the optical source.

The plasma treatment was performed with conventional RF sputtering equipment. The wafer was installed in the target position in the sputtering chamber. The orientation of the Si surface was (100). After introducing 9 mTorr of Ar, 500W RF power was supplied between the target and the ground electrode. The surface of the Si sample (p-type, 10 kΩcm, 420 μm) was treated with Ar plasma from 2 min to 80 min.

An experimental proof of the importance of the surface damage (the recombination and trapping processes) for the PA response is provided by the comparative study. The PA signal has been measured under the same conditions except that in one experiment the excitation light illuminated an intact surface, while in the complementary measurement the surface was Ar plasma treated. Fig. 1 shows one example of investigation of the sputter damage on the Si surface by Ar plasma treated 20 min and 80 min. Fig. 1(a) shows amplitude ratio and Fig. 1(b) phase difference PA spectra for the Si wafer treated with Ar plasma and for an incoming Si wafer.

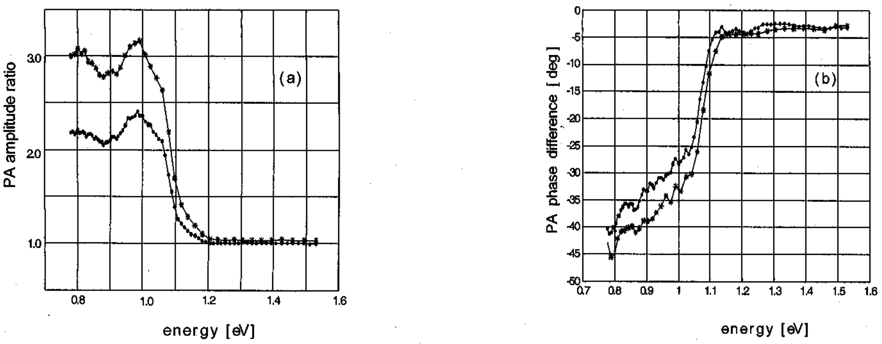


Figure 1. Amplitude ratio (a) and phase difference (b) PA spectra of Si wafer treated with Ar plasma and incoming Si wafer for the modulation frequency 10 Hz: (.) Si surface treated 20 min.; (*) Si surface treated 80 min.

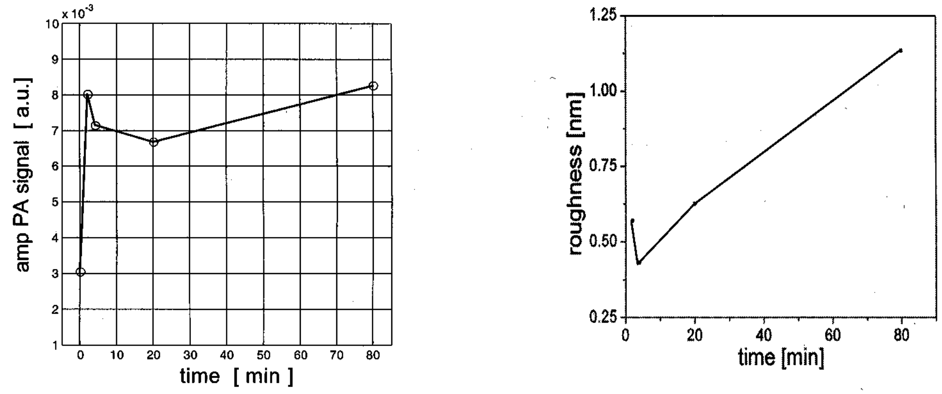
Investigation of sputter damage in Si surface by Ar plasma was also made by atomic force microscope (AFM). AFM micrographs for Si wafer surface of untreated and treated with Ar plasma for different time (from 2 to 80 min) were measured.

3. ANALYZE OF EXPERIMENTAL RESULTS

The PA spectra of incoming Si wafer are analogous to the optical absorption spectra near the energy gap. On the other side, the PA spectra of Ar plasma treated Si wafer with surface damage shows the significant difference. The level of the PA signal is about 20 to 30% higher in comparison to the PA signal of incoming Si wafer and the spectral characteristic is different. The amplitude PA signal of Si wafer with sputter damage surface is higher because the reflectivity of this sample is smaller and the absorption in the surface region is higher. In this case, as a consequence of the sputter damage, a great numbers of carrier traps exist in the surface region leading to a higher surface recombination velocity.

It is possible to see that for energy greater than 1.2 eV, the amplitude ratio and phase difference of the PA signal are not a function of the Ar etching process. In this energy region the fundamental absorption, i.e., the valent-conduction band transitions are dominant. Here, the sputter damage (the surface defect states) has small influence on the PA signal. However, for energy smaller than 1.2 eV, the amplitude ratio and phase difference of the PA signal changed drastically. The amplitude ratio and phase difference increase with increasing process time. Also, the amplitude ratio and phase difference of the PA signals indicate the existence of two small peaks in the spectra (the generation–recombination centers) at 0,81 and 0,99 eV. These curves show the energy distribution of the surface energy states below the energy gap of the semiconductor.

The Ar plasma spattering changes the surface defect density of the Si samples. This is clear from Fig. 2 (a) where the PA amplitude vs processing time (for 1.15 eV and 10Hz) of the Si wafer with Ar plasma is shown. The surface roughness was measured using the AFM (Fig. 2(b)). The height profile measuring for the Si wafer surface treated with Ar plasma for 80 min, shows the average roughness (Ra) of 1.15 nm, while the average roughness of the incoming Si wafer is 0.55 nm. These AFM results are in agreement with those obtained by Umezu et al [4].



(a) (b)

Figure 2. (a) PA amplitude vs processing time (for 1.15 eV and 10Hz) of the Si wafer with Ar plasma; (b) AFM measured roughness of Si wafer treated with Ar plasma vs process time.

4. CONCLUSION

The surface of Si samples (p-type, 10 kΩcm, 420 μm) was treated with Ar plasma from 2 min to 80 min. Amplitude and phase PA spectra were measured in the energy range from 0.75 to 1.55 eV and for the modulation frequency of 10 Hz. The amplitude ratio of the PA signals indicate the existence of two maximum in the energy spectrum near the valence and conduction bands (the generation–recombination centers) at 0,81 and 0,99 eV.

AFM results show that due to the Ar plasma treatment of the Si surface its roughness did not substantially increase with increasing process time, while the PA spectra show that the density of surface defect in samples treated by Ar plasma increases with the processing time.

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