Radiation-induced plasmons in Si-SiO_2 *

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Abstract The first level plasmons of Si in the pure Si state (corresponding to bonding energy (BE) of 116.95 eV) and in the SiO_2 state (corresponding to BE of 122.0 eV) of Si-SiO_2 prepared by irradiation hard and soft processing were studied with XPS before and after ^{60}Co radiation. The experimental results indicate that there was an interface consisting of the two plasmons, this interface was extended by ^{60}Co radiation, the fractions of the plasmon for Si in the Si-SiO_2 were changed with the variation of radiation dosage, the difference of the change in fraction of plasmons for the two kinds of samples was that the soft varied faster than hard, the change of concentrations in plasmons for both hard and soft Si-SiO_2 irradiated in positive bias field were greater than that in bias-free field. The experimental results are explained from the view point of energy absorbed in form of quantization.
Keywords Plasmon, Si-SiO_2, Radiation dose, Radiation bias field

1 Introduction

One of the most weaknesses of electric devices based on Si-SiO_2 is that the devices may lose their functions because interface states[1] and positive charge[2] are created by ionization radiation in the Si-SiO_2. Over the past years, a number of models have been suggested to explain the origins of interface state and positive charge. However, the oxygen vacancy model, which was proposed by electron spin resonance (ESR) for measurement of point defects[3], is inconsistent with the bond strain gradient model, which was suggested through XPS[4], in the explanation of the damage mechanism in interface. The main reason for this inconsistence is that the Si-SiO_2 interface is complex in nature, particularly for Si-SiO_2 irradiated by radiation.

One significative subject of theory and experiment is to measure plasmons excited by radiation and bias field at Si-SiO_2. The knowledge of plasmon is important for us to understand the features of defects, the ionicity and covalence of interfacial bond, geometric structure and transplant of charge in interface. Moreover, processing improvement efforts on device property may be guided by the information of plasmon.

In this paper, the profile of plasmons, the variations of the plasmons in radiation hard (radiation tolerant) and soft (radiation intolerant) Si-SiO_2, before and after irradiation, have been observed using X-ray photoelectron spectroscopy (XPS). Some view points to explain the experimental results have been suggested.

2 Experimental details

The samples used in the observation were as silicon wafers (p-type $\rho \sim$17 to 27Ω/cm) with <100> surface orientation. Oxides were grown in dry O_2 at 1000°C to a thickness of 68 nm, and annealed in situ in N_2 at 900°C for 30 min, resulting in "radiation hard" samples[5], oxides were grown in the mixture of dry O_2 and 3% HCl gases at 1000°C to a thickness of 67 nm, resulting in a radiation soft samples. Al layers were deposited by electron beams on the two kinds of samples to form Al gate electrodes.

The γ-irradiation was performed at room temperature with a ^{60}Co source of an energy of 1.25 MeV, and the dosage of radiation ranged from 0 to 10^5 Gy (Si). The bias fields during irradiation were 0 and +1 MV/cm. In order to get targets appropriate for XPS measurement, hydrogen peroxide and sulphuric acid solution were employed to remove the Al layer of Ohmic contact before inserting the Si-SiO_2 samples into the XPS cavity.

The Kratos XSAM800 electron spectrometer was used to measure plasmons. An Ar^+ ion beam was used to etch the SiO_2 films. In order to keep the sputtering effect level

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about the same in all samples, each sample was etched with the same Ar^+ beam parameters, i.e. at an energy of 4 keV, identical etching time and beam current, specially for getting profiles[6~12]. The vacuum during the measurement was better than 1.3×10^{-6} Pa. Aluminium radiation was used for excitation, the sweep range was 20 eV, and other measurement parameters, such as reg, step, dwell and scan numbers were the same for every recordation. Spectra were referenced to C at 285.0 eV, and the curve peaks at BE of 116.95 and 122.0 eV were used to resolve the plasmons of Si in the pure Si and in the SiO_2 state[12], respectively. The code DS300X data system software was employed for spectrum's simulation.

3 Results and discussion

Fig.1 gives a plot of the etch time-normalization area[10], where the normalization area of plasmon for Si in the pure Si state (BE of 116.95 eV) is divided by area at the Si substrate, and the normalization area of plasmon for Si in the SiO_2 state (BE of 122.0 eV)[13,14] is divided by area at the surface of SiO_2. Because the sputter time corresponds to the depth from the surface of SiO_2 to the substrate Si, Fig.1 also shows the profiles of the plasmons. It can be observed in Fig.1, that (1) there exists an interface made of the plasmons in Si-SiO_2,(2) the interface is extended by the actions of radiation. These two points are somewhat like the previous work that the profile consisted of Si in the pure Si state (BE of 99.15 eV) in the SiO_2 state (BE of 1034 eV) and O1s (BE of 531.6 eV).[15,16] Meanwhile, the variational tendency between the former and the latter profiles are the same after radiation. These results may indicate that new interfacial states are not only created in the interface area belong to the unirradiated Si-SiO_2, but they are also generated in the area beyond the interface by γ irradiation[15].

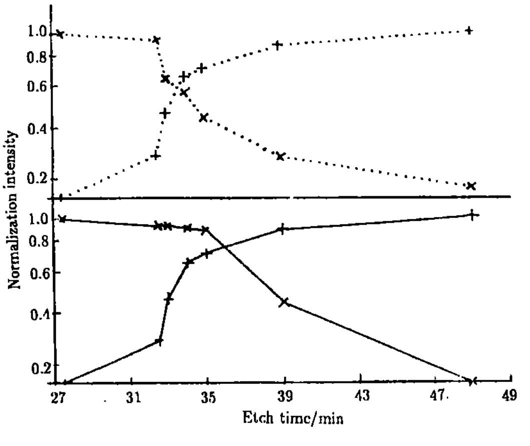

Fig.1 Profiles of etch time-normalization area for plasmons in Si-SiO_2 before and after radiation

The curves (—–) and (······) refer to soft Si-SiO_2 samples unexposed and exposed to 5×10^4 Gy(Si) of ^{60}Co gamma radiation at +1 MV/cm bias field; (+)denotes the normalization area for plasmon of Si in the pure Si state (BE of 1169.95 eV), which is divided by area at the Si substrate and (×) for plasmon of Si in the SiO_2 state (BE of 122.0 eV), which is divided by area at the surface of SiO_2

Fig.2 is the spectra of plasmons at the Si-SiO_2 interface (etch time is 35 min) irradiated at the same bias field. Results in Fig. 2 shows that the fraction of the plasmon for Si in the SiO_2 state (BE of 122.0 eV) increases with radiation dose, obviously. The fractions of the plasmon in soft sample jump as doses rise, while this change of plasmon in the hard Si-SiO_2 is step by step. One plasmon is a quantum of plasmic vibration, and such plasmon can be produced by photon transmitting or reflecting a foil. The plasmons generated by γ rays of ^{60}Co in the Si-SiO_2 interface is just for this reason. Because the nature of soft Si-SiO_2 differs from that of hard, the more energy of γ rays is absorbed by the soft Si-SiO_2 interface below the 1×10^5 Gy (Si) of radiation dose. This difference in the absorbed quantum energy due to oxidation process makes the concentration of valence electron sea[13] in the soft sample be higher than that in the hard one. It is the vibration between entire valence electron sea and ion[13] that constructs the plasmic vibration in Si-SiO_2. When the radiation dose is up to 1×10^5 Gy (Si), the concentrations of plasmons in the soft and in the hard sample are alike. This fact may be utilized to explain why hard samples are tolerant of radiation below certain radiation dose, i.e., it may be said that as long as the fraction of plasmons generated by γ rays is up to an extent (it may correspond to the threshold of radiation tolerant for devices), devices loose functions due to plasmon vibrating excessively.

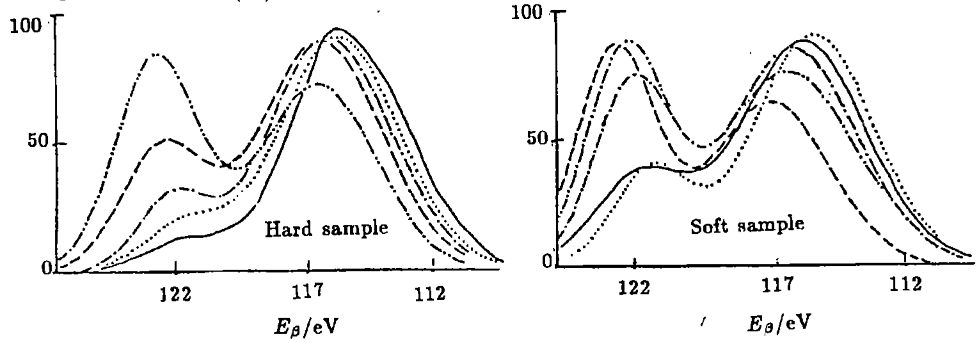

Fig.2 Spectra of plasmons at the Si-SiO_2 interface irradiated at the same bias field
The lines of —, ······, -·-·-, --- and —·— refer, respectively, to samples exposed to 0, 10^3, 10^4, 5×10^4 and 10^5 Gy(Si) of ^{60}Co games irradiation at +1 MV/cm bias field, etch time is 35 min

Having discussed the action of dosage on plasmons, attention should be paid to the influences of bias field on them. Fig.3 is the spectra of plasmons at the Si-SiO_2 interface irradiated at the different bias fields and illustrates that the change of fraction in plasmons for both the hard and soft Si-SiO_2 irradiated in positive bias field are greater than that in bias-free under the condition of the same radiation dose, at the same time, the concentration of plasmon for Si in the SiO_2 state (BE of 122.0 eV) in the soft is higher than that in the hard even if they are irradiated in bias-free field. Si-SiO_2 interface not only absorbs the energy of γ rays, but also can absorb the electric energy to generate plasmons. When Si-SiO_2 is irradiated in

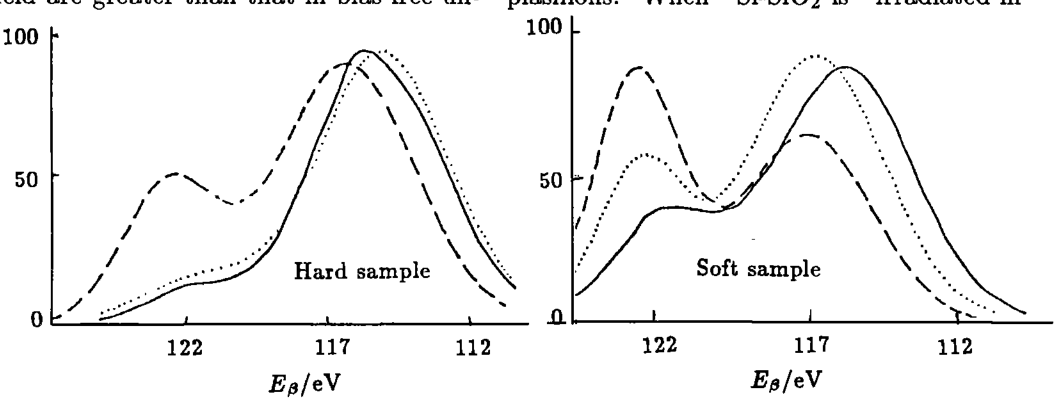

Fig.3 Spectra of plasmons at the Si-SiO_2 interface irradiated at the different bias fields
The curves expressed by —, ······, and --- refer to samples exposed, respectively, to 0, 1×10^5 Gy(Si) at 0 MV/cm bias field and 5×10^4 Gy (Si) at +1 MV/cm, etch time 35 min

positive bias field, there are more vibrations of plasmon for valence electron to positive ions and it is aggravated by positive bias. There is no as such phenomenon in bias-free field, furthermore, the random movement of valence electron to positive ion consumes its energy in free field so that the excited plasmon vibrations vanish.

4 Conclusions

The plasmons excited by radiation and bias field in the Si-SiO_2 interfaces have been measured by XPS, successfully. Experimental results demonstrated that the variation of plasmons with the radiative conditions is more remarkable than those of electronic spectra of Si2p and O1s[17], and the degeneration of the MOS due to it being irradiated may be understood better through such measurement. One important problem to be solved is to seek correspondent relationship between interface states, positive charge in oxide and plasmons.

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