Silicon Topography after Low Energy Ar^+ Ion Bombardment

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Abstract

The subject of radiation damage in silicon by plasma and electron beam technique has been investigated for many years. Modification for having particular surface topography is also sometimes desired specially in those experiments that ion interaction with surface is very sensitive to the surface topography. In our previous work in order to study the electron bombardment effect on silicon, we used our new design electron source. In this paper, silicon samples were bombarded by 30 keV argon ions on normal to the surface with doses in the $1\times10^{16} – 2\times10^{17}$ Ar^+/cm^2 range. Topographical changes induced on silicon surface, generation of blisters and evolution of them at different doses observed by atomic force microscopy. Measurement of mean surface height show that for doses greater than 1×10^{17} Ar^+/cm^2 the height decreases because of sputtering.The optical properties of samples after Ar^+ irradiation measured by a UV-Vis-NIR spectrophotometer.

Key Words: Topography, Silicon, Argon ion bombardment, Optical properties

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Introduction

The subject of radiation damage in silicon by plasma and electron and ion beam technique has been investigated for many years [1] which in a special interest have been experimentally studied by authors [2,3]. Application of argon ion bombardment of silicon has been also an important subject in recent years [4-10]. For instance experiments of grazing ion interaction with solid surfaces are very sensitive to the surface topography. The energy and angular distributions of scattered projectiles [1,11] and of electrons emitted from projectiles [12] and surfaces [13] can be modified by the particular surface topography.

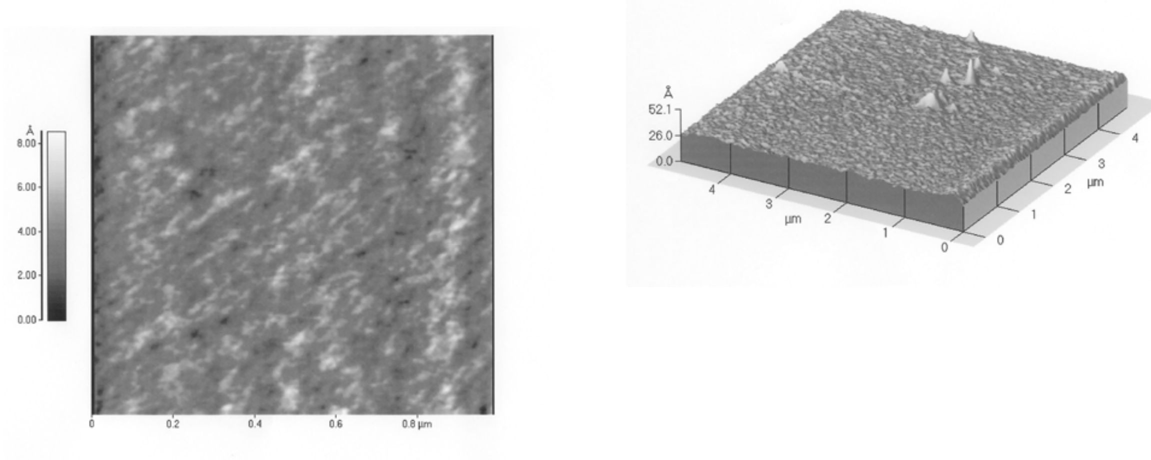
In the case of silicon samples, a moderate bombarding dose (10^{14} ions/cm^2) of medium energy heavy ions is enough for amorphization without producing large topographical changes [14]; for very large doses (10^{18} ions/cm^2), the sputtering process produces remarkable structures such as cones or faceting [14]. At intermediate doses (10^{15}–10^{17} ions/cm^2), formation of blisters, voids and swelling of the surface has been recently reported [14–16]. In this paper we present a study performed with an atomic force microscope (AFM) of the topographical changes induced by argon ion bombardment of Si(1 1 1) surfaces at normal incidence and at intermediate doses. The aim of this work is to characterize the surface topography and to find the optimum point of effective parameters in argon ion bombardment. In addition, the optical properties of samples near silicon band gap region characterized using spectrophotometry.

Experiment

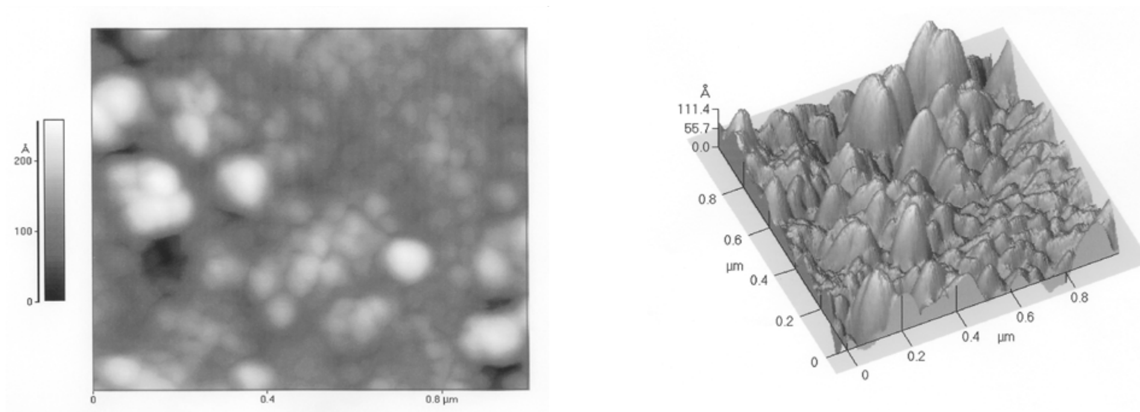
The samples were n-type silicon at (111) direction. Argon ion irradiation was performed at room temperature with doses 1×10^{16}, 3×10^{16}, 5.1×10^{16}, $1\times10^{17}$and 2×10^{17} Ar^+/cm^2 respectively. The ion current density was 24μA/cm^2. For all experiments, the ion energy maintained 30 keV. The irradiation occurred in a high vacuum chamber in ion implanter facility in Plasma Physics Research Center of Islamic Azad University. Topography of the surfaces observed with an AFM (Autoprobe CP working in air) using high aspect ratio conical tip (Ultralever). The stability of the structures observed in the surface was checked by comparing images obtained immediately after the irradiation and, with those obtained many days later. No noticeable changes were detected with time. All the AFM images presented in this paper represent raw data without any image processing. The optical properties of samples were analyzed using Cary 500 UV-Vis_NIR spectrophotometer. This experiment performed at wavelength in the range of 900 to 2000 nanometer for obtaining both reflection and transmition profile.

Results and discussion

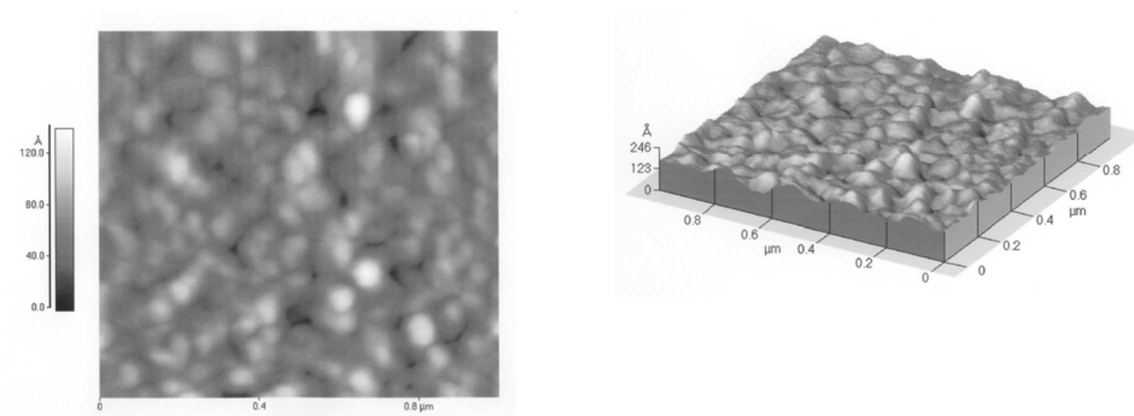
In Fig. 1 we present a set of 2D and 3D images obtained with the AFM after bombarding Si samples with doses ranging from 1×10^{16} to 2×10^{17}ions/ cm2 with 30 keV Ar^+ ions. We observe that a non-irradiated sample had a flat surface with a roughness lower than 5 A. This characteristic remains up a critical dose Dc of about 1×10^{17} ions/cm^2, where dome like structures appears. By increasing the dose, the bumps start to merge together to form a bigger one that breaks at 2×10^{17}ions/cm2. The mechanism responsible for these features is blistering formation resulting from the inner pressure exerted by the implanted Ar gas that has low mobility in silicon (14, 15).



(a)



(b)



(c)

Fig1. AFM 3D images for Si(1 1 1) surfaces modified by bombardment with 30 keV Ar. The irradiation doses are (a) 1×10^{16}, (b) 1×10^{17}, (c) 2×10^{17}.

The optical properties of bombarded samples tested by using double beam Varian Cary 500 UV-Vis-NIR Spectrophotometry, in both transmission and specular reflectance mode.Figures 2 and 3 show transmission and reflection measurements in terms of wavelength respectively.

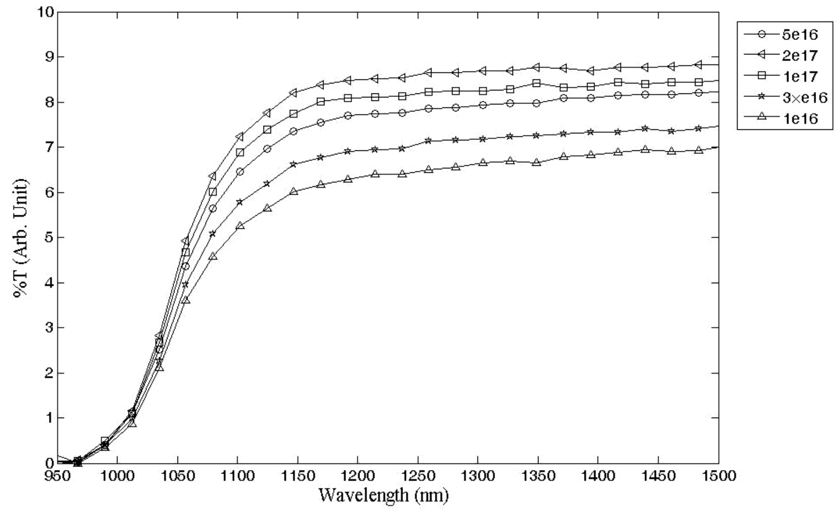


Fig2. Transmition versus Wavelength for samples irradiated at different doses.

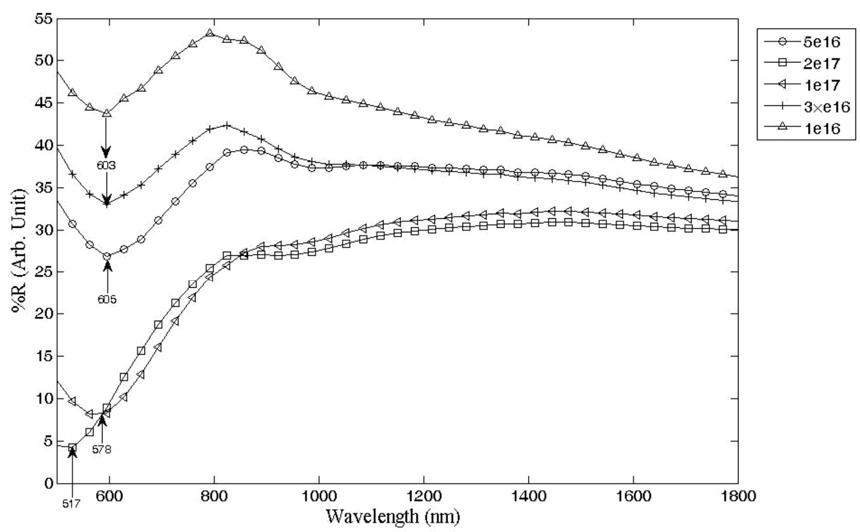


Fig3. Reflection versus Wavelength for samples irradiated at different doses.
R-no1=5.1×10^{16} R-no2=2×10^{17}, R-no3=1×10^{17} , R-no4=3×10^{16}, R-no5=1×10^{16}

Transmission curves and its dependencies to the wave lengths confirming that we have created structural defects close to the fundamental band gap absorption. The reflection measurement performed at shorter wavelength using SR accessory (fig3). In figure 3, we can see the absorption edge to compare the amount of curve shifting at increasing dose. When the dose of argon incident ions increase, the minimum point of reflection curves happen in higher photon energy. It may caused by creation of electron trapping levels in silicon samples. These defects levels play an essential role for this optical behavior.

Conclusions

In this work we have characterized the topographic changes produced by 30 keVAr bombardment on Si(111) surfaces. The features observed can be interpreted in terms of sputtering and implantation of low mobility Ar gas. The implanted ions initially produce swelling of the surface without major external topographic changes, and then roughening and erosion by blistering formation. The optical properties' measurements show that for the wavelength greater than 1000 nm by increasing the argon ion dose, transmittance enhances. In contrast to this for lower wavelength in reflection profile it can be concluded that by increasing of argon ion dose, absorption increase.

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