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Distance-Monitoring of Absorption dose on Materials under Ion Irradiation

KALANTARYAN Oganes V., KONONENKO Sergey I.* and MURATOV Vladimir I.
Kharkov State University, Svobody Sq., 4, 310077, Kharkov, Ukraine

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Abstract

It was obtained that ionluminescence spectra of SiO_2 changed essentially under the proton bombardment. The relation between the light intensity and the implantation dose was determined. The novel method for monitoring proton dose (up to 3×10^{21} particles/cm^3) in quartz was proposed.

Keywords:
ionluminescence, defects, band, silica, irradiation dose, hydrogen

1. Introduction

The powerful flux of the high-energy particles bombards the structural elements inside a thermonuclear reactor during a steady-state fusion [1]. Properties of different materials are well known to change under irradiation. This fact is explained by forming and annealing of the defects of different types and transition to steady-state. [2,3]. These processes increase if the materials are irradiated by ions. The projectile energy is spent for production and annealing of the defects and luminescence generation. The light parameters are determined by projectile characteristics and give the information about absorbed irradiation dose and material properties.

The silica is one of the widely used materials in particular in devices with high irradiation conditions (e.g. as windows or parts of electronic components in space). It is applied as passivating layer while manufacturing of ion implanted semiconductor [4]. Also it was used as the window and guide material for input and output of optical radiation for fusion reactors (see for example [5]). It is necessary to note that the optical properties of silica glass are changed by irradiation essentially [4].

In visible range the luminescence spectra of silica (induced by different sources) consists of two wide bands. The first band maximum lays near 455 nm of wavelength. This radiation is related with one of the intrinsic silica defects, namely, E′-centers [6]. The second band has maximum, which is near 645 nm. Its nature is determined by other intrinsic silica defects which are non-bridging oxygen centers [7]. The optical properties of silica significantly change in the presence of hydrogen in a sample. It was shown in [8] that absorption of light bands with maximums at 4,75 eV and 2,0 eV was decreased essentially by implanted hydrogen. Usually these absorption bands were associated with non-bridging oxygen centers.

In the previous investigations [2,3] the silica luminescence was studied only for irradiation doses less than 10^{18} particles/cm^3 and for a few wavelengths. Note that the samples were preliminarily irradiated by different kinds of the particles and after that the optical radiation was excited in them by ultraviolet sources mostly.

This paper presents the results of experimental study of luminescence spectra during ion bombardment

Corresponding author's e-mail: kononenko@pem.kharkov.ua.

with implanted doses up to 3×10^{21} particles/cm^3, specifically, the relation between ionluminescence spectrum parameters and absorption doses was investigated.

2. Experimental Setup

The setup for a study of the luminescence induced by proton bombardment of the bulk silica samples was described in detail in [9]. The pure silica targets were bombarded by the proton beam with energy of 210–420 keV and current density up to 30 μA/cm^2. The residual gas pressure up to 10^{-4} Pa was maintained in the vacuum chamber by the magnetic-discharge pump. The sample was set at the angle of 30° with respect to the beam (all angles were measured against the perpendicular to the target surface). The face of flexible light guide under the chosen direction collected the silica optical radiation. Quartz condenser projected the light from the back of the light guide on the entrance slit of the grating monochromator. Detection of the luminescence was carried out using the photomultiplier detector in the wavelength range of 400–700 nm.

The observation angle changed from 0° to 60° by of the light guide face. The optical channel of the setup was calibrated by incandescence spectrum-metric lamp. The luminescence spectra were corrected according to the spectral sensitivity and were normalized to the beam current.

3. Results

The typical luminescence spectrum of nonirradiated silica under ion bombardment is shown in Fig. 1 (curve 1).

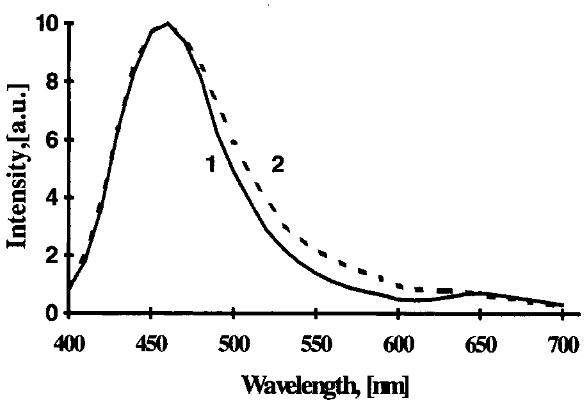

Fig.1 The ionluminescence spectra of SiO_2 under proton bombardment: curve 1 - nonirradiated sample, curve 2 - the sample irradiated with absorbed proton doses of 3×10^{21} particles/cm^{-3}.

Such spectra were observed earlier for pure silica when excitation of different type was applied. The most intensive (the first) band had maximum at 460 nm . Its presence was associated with defects of E′-center (the break of the short-life bond between Si and O). The second band had the maximum at 650 nm and was situated on the long wave side of the first band. The radiation in this band was associated with non-bridging oxygen centers.

The ionluminescence spectra changed when the proton dose increased. The intensity of the long wave side of the first band grew (see Fig. 1, curve 2). The intensity of the short wave side and position of the maximum did not change. As the result of full width on half-maximum (FWHM) increased from 500 nm (nonirradiated silica) to 508 nm (for the dose ~3×10^{21} particles/cm^3). The ratio of intensities in the point with wavelength of $\lambda = 620$ nm to those in the first band maximum increased from $5{,}6 \times 10^{-2}$ to $7{,}3 \times 10^{-2}$. The intensity of the second band decreased and became almost indistinguishable at the background of the first band. These results were obtained for proton energy of 210 keV.

4. Discussion

The changes in spectrum depended on the implanting dose strongly. These effects can be used for the monitoring of absorption proton dose. The most significant changes of spectra with the growth of dose were observed at the wavelength of 650 nm. The ionluminescence intensity at the wavelength 650 nm was a sum of the longwave side radiation of the first band and the radiation maximum of the second band. The intensity of the first band in this point increased with dose growth but the maximum magnitude of the second band decreased. As the result, the intensity at 650 nm decreased because the rate of the second process was higher that of the first process. The measurement of changes of intensity at this wavelength allows monitoring the absorbed dose. So, we can determine the implantation dose on the basis of the analysis of the light intensity growth at 620 nm because the light yield of the first band in this point changed most significantly.

However, we think that efficiency of this method can be improved using the ratio of luminescence intensity at 650 nm to that at 620 nm. In this case the method becomes more sensitive because the first value increases and the second value decreases. Moreover, these wavelengths are close to each other; thus, an

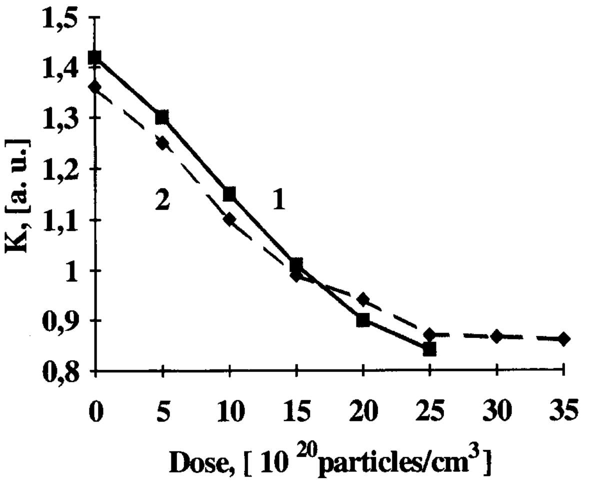

Fig. 2 The proton dose dependence of the coefficient *K*: curve 1 - the proton energy was 420 keV; curve 2 - the proton energy was 210 keV.

influence of optical channel dispersion on the measurements is negligible.

It was obtained that the dependence of the ratio of the luminescence intensities at 650 nm to that at 620 nm (coefficient ***R***) upon the absorption dose had similar behavior for studied proton energy and the different observation angles. We calculated the coefficient $\boldsymbol{K} = \boldsymbol{R}/\boldsymbol{l}$, where $\boldsymbol{l}$ was the mean path of proton in SiO_2 and plotted the curves of dose dependence of ***K*** for different energies of particles (see Fig. 2). The energy loss data was taken from [10] and quartz density from [11]. The magnitude of ***K*** depended only on the proton density in silica sample but was practically independent of projectile energy and observation angles (see Fig. 2).

The expecting high particle flux of the LHD project is up to 10^{17} particles/cm^2 s [12]. In this case, dose up to 3×10^{21} particles/cm^3 will be accumulated during the irradiation time equal to 3×10^4 s.

5. Conclusions

It was obtained that the ionluminescence spectra of SiO_2 changed under the proton bombardment. The relation between light intensity and implantation dose up to 3×10^{21} particles/cm^3 was determined. The novel method for monitoring the proton dose in quartz was proposed.

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