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Remote Monitoring of Silica Absorption Dose by Means of Ionoluminescence

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Abstract

The silica ionluminescence spectra induced by fast proton bombardment were studied. Luminescent radiation angular characteristics were measured. The relation between light intensity and both absorption dose and observation angle was determined. The novel methods for control of proton dose (up to 3×10^{21} particles per cm^3) in quartz were proposed.

Keywords:

ionluminescence, spectrum, silica, absorption dose, light ion, angular characteristic

1. Introduction

The use of silica as insulators and windows in thermonuclear facilities is widespread. The silica grids are one of the main parts of secondary emission radioisotope source of current (SERICS). The properties of silica grid have an influence on operation of this device. Nondestructive monitoring of this property changes is one of the most important tasks of radiation physics.

In thermonuclear reactor silica optic elements are used both for optical diagnostics and for microwave radiation input into chamber as lenses and light guides, which constitute optical channel. Physical, chemical and mechanical properties of these materials are changed during particle flux irradiation from a thermonuclear plasma. It comes out from formation, annealing and establishment of a dynamic equilibrium between different types of defects induced by radiation. Luminescent light of the silica under irradiation is either alternative to the process of defect formation, or accompanying ones. In this connection, a luminescence spectrum includes important information about instantaneous dynamic equilibrium of the defect distribution in the solid and is unique channel of radiation process remote monitoring.

The ionoluminescence spectra of quartz are changed essentially during proton irradiation [1]. Based of these dates the novel method was proposed for monitoring proton dose in SiO_2. The changing of ionoluminescence angular characteristics under ion irradiation in megaelectronvolt region of energy was studied also [2]. The angular and spectral characteristics of silica luminescence during light ion bombardment were studied for improvement of our method.

2. Results

The experiments were carried out using hydrogen ions with energy from 210 to 420 keV. The wavelength range of ionoluminescence study was from 400 to 700 nm. Incident and observation angles were varied from 20° to 70°. Luminescence spectra were studied for absorption dose up to 3×10^{21} particles per cm^3.

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

The first band with maximum near 456 nm was the most intensive. This band was associated with intrinsic silica defects namely E′−centers. Other oxygen deficiency centers could take part in generation of this light. The second band with maximum near 650 nm was situated on the long wave side of the first band. The nonbridging oxygen centers were associated with this band.

Increasing proton dose changed the luminescence spectra. The intensity of the long wave side of the first band increased (see Fig. 1 (b)). The intensity of second band decreased as long as this band become almost indistinguishable at the background of the first band.

For comparison of experimental spectra obtained under different conditions we used normalization of spectra intensities $I(\lambda)$ to spectral intensity maximum of first band (for wave length 456 nm) $I(456)$:

$$I_n(\lambda) = I(\lambda)/I(456),$$

where $I_n(\lambda)$ is normalized spectral intensity for wave

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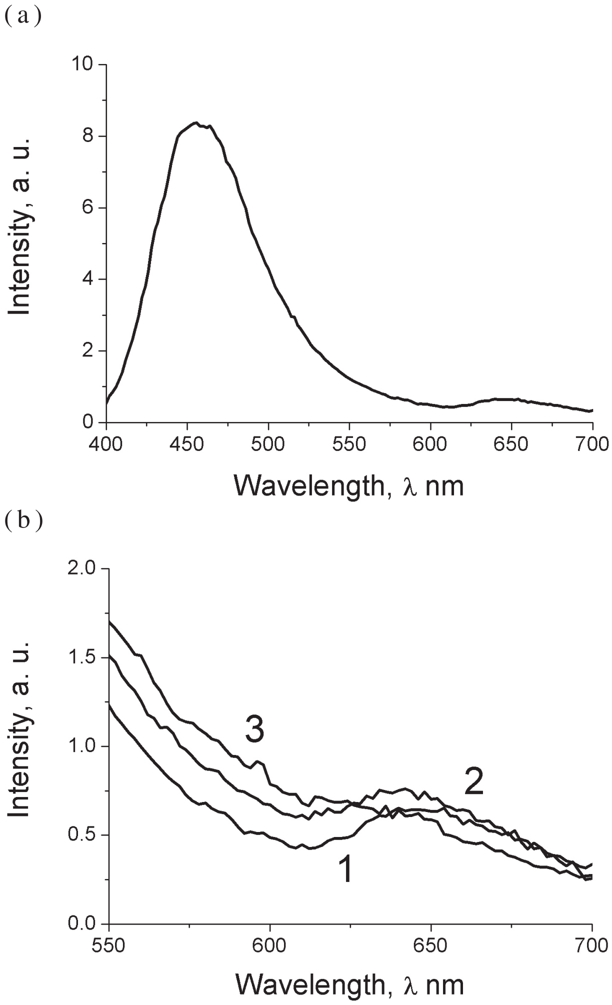

Fig. 1 The ionoluminescence spectra of SiO_2 under proton bombardment, beam energy 420 keV, incidence angle 30°, observation angle 30°:
(a). nonirradiated sample;
(b). 1 - nonirradiated sample, 2 - absorption dose 5×10^{20} particles per cm^3, 3 - absorption dose 3×10^{21} particles per cm^3.

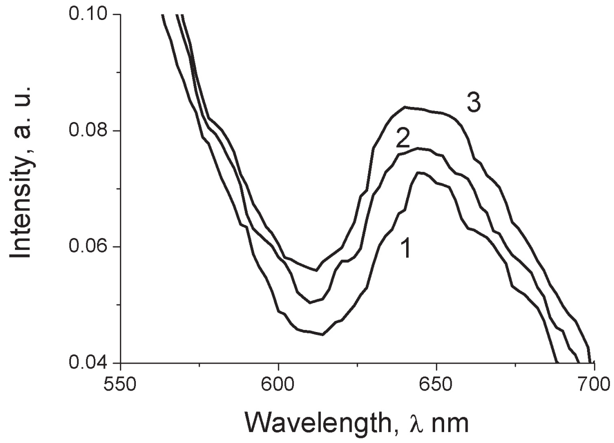

Fig. 2 The ionoluminescence normalized spectra of nonirradiated SiO_2 under proton bombardment, beam energy 420 keV, incidence angle 30°: 1 - observation angle 0°, 2 - observation angle 30°, 3 - observation angle 60°.

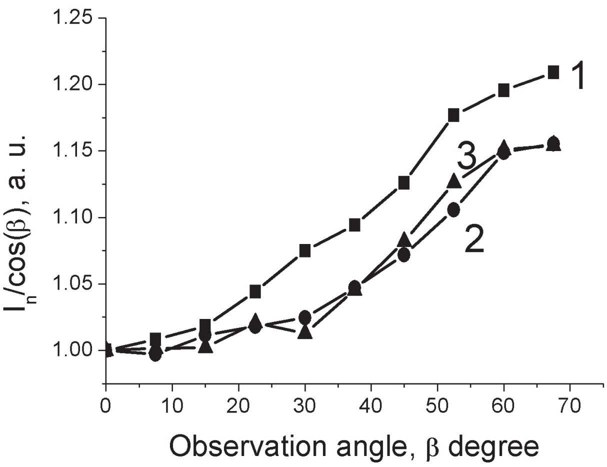

Fig. 3 Angular dependences of the normalized ionoluminescence spectra1 light ($\lambda = 456$ nm) of SiO2 under proton bombardment, beam energy 420 keV, incidence angle 30 (: 1 - nonirradiated sample, 2 - absorption dose 5×10^{20} particles per cm^3, 3 - absorption dose 3×10^{21} particles per cm^3.

length λ. This normalization permits to study changing of spectral shape for different observation angles, incident angles, absorption dose, species and energy of ions.

The nonirradiated silica normalized spectra at different observation angles are shown in Fig.2. The spectra have the main difference in the region, corresponding to second band wavelength location (see Fig. 2). The normalized intensity of second band increased with growth of observation angle. Absorption dose increase changed the ionoluminescence spectrum shape [1]. But when the dose exceeded $\sim 5 \times 10^{20}$ particles per cm^3 the shape of normalized spectra did not depend on observation angle. The similar results were obtained for all species and energy of ions.

The angular characteristics of luminescence in maximum of the first band (456 nm) were studied. We used the technique in detail described in [2]. The spectral intensity $I(\beta)$ was normalized to its value corresponding to observation angle equal 0° (indicatrix maximum $I(0°)$), i.e.

$$I_n(\beta) = I(\beta)/I(0°),$$

where $I_n(\beta)$ is normalized intensity. The dependences measured must follow Lambert law:

$$I = I_0 \cos(\beta),$$

where I is intensity corresponding observation angle β, I_0 is indicatrix maximum corresponding to observation angle 0°. It was reasonably that normalized indicatrix were divided by $\cos(\beta)$.

The luminescence spectral normalized indicatrix taking into account Lambert law is shown on the Fig.3. The parameter for these curves is absorption dose. In the case when the dose exceeds ~ 5×10^{20} particles per cm^3 the normalized indicatrix shape does not change. The similar results were obtained for all species and energy of ions.

3. Discussion

As is shown, the shape of the luminescence spectra depends on both absorption dose of the sample and observation angle. It takes place for doses that not exceed 5×10^{20} particles per cm^3. These effects can be used for remote measurements of sample absorption dose. Dose dependences can be explained by dynamic of intrinsic defect and projectile distributions in bulk of the solid. The first band presence is determined above all by self-trapped exciton decay (see for example [3]). Distance between the formation place and the decay place of the exciton can be quite large; its value can exceed interatomic distances many times [3]. The second band is a result of intrinsic defect non-bridging oxygen center (see for example [3]). The dynamic of both such intrinsic defects and implant hydrogen determine changes in luminescence spectra with absorption dose in silica samples. Such effects can take place in other substances where excitons can be excited (for example, alkali-halogen crystals).

To monitor absorption dose in mentioned above range both spectrum shape and angular characteristic changing can be used. Methods based on measurements of luminescence spectrum shape and angular characteristics can be used as independent techniques, which supplement each other.

For doses more than 5×10^{20} particles per cm^3 the angular characteristics of luminescence are invariable, but spectrum shape changing. In this case, using only changing in the luminescence spectrum shape it is possible to carry out the absorption dose monitoring. Moreover, the invariability of angular characteristics permits to increase of the collecting solid angle for luminescence light. It will increase sensibility of the proposal technique.

4. Conclusion

The new technique for absorption dose monitoring was proposed. This technique based on changes of luminescence spectra and their angular characteristics under ion bombardment.

Methods based on measurements of luminescence spectrum shape and angular characteristics can be used for absorption dose not exceed 5×10^{20} particles per cm^3. These methods can be used as independent techniques, which supplement each other.

For doses more than 5×10^{20} particles per cm^3 using only changes in the luminescence spectrum shape it is possible to carry out the absorption dose monitoring. Sensibility of the method can be increased by means of collecting solid angle increasing.

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