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Influence of He^+ long-time irradiation on silica luminescence spectrum

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ABSTRACT

The paper deals with experimental investigation of 420 keV He^+ dose dependence of silica (medium OH-group contents) luminescence. It was founded that experimental spectra were good fitted by two Voigt peaks centered in 2.7 and 1.9 eV. The absorption dose growth influenced on silica ionoluminescence spectra due to increase of radiation defects. We compared the obtained results with 420 keV hydrogen ion irradiation data for the same samples. It was shown that relative intensity of red band correlated with specific energy losses and effective charge of ions in silica. The theoretical simulation of helium ion implantation and intrinsic defect dynamics was performed. The dependence of ionoluminescence intensity on observation angle was measured.

1. Introduction

In recent the increasing interest to new silica based materials (bulk, films, nanostructures and etc.) exposed to irradiation by electrons, neutrons, ions, X-rays etc. is observed. It can be windows in optical channels of thermonuclear devices and facilities, optical fibers, different electronic components in high radiation level environments [1,2].

Radiation change of structure and other irradiation effects should be taken into account for successful operation of silica-based materials. Sometimes radiation-induced modifications in silica can be used to manufacture advanced materials, for example by means of doping impurity elements through ion implantation. The main reason for change of optical properties is formation of optically active defects in a silica glass by radiations [3–5]. Presence of intrinsic defects results in different optical luminescence bands [6,7].

Ion-induced luminescence is an effective technique for detection the dynamic processes of defect formation, modification and annealing in silica matrix [8]. In particular, this technique is widely used to determine the role of hydrogen as an important impurity in the mechanisms of radiation-induced defect formation in «dry» and «wet» silica, especially its ability to passivate dangling bonds [9].

Silica luminescence spectra usually consist of two wide bands in visible wavelength range with maxima near 456 nm (2.7 eV) and 650 nm (1.9 eV) for various ways of excitation. Particularly, it is valid for cathodoluminescence [10,11], luminescence induced by both swift light ions [12–16] and heavy ions [17]. This spectrum structure is associated with silica intrinsic defects such as ODC (oxygen deficiency center) and NBOHC (non-bridging oxygen hole center) respectively [5–7].

There are several ways of NBOHC creation [7]. The first one is breaking of dangling bond accompanied by ODC and NBOHC creation with its subsequent stabilization through restructuring of short-range order. The second one is disruption of hydroxyl group with hydrogen removal from recombination sphere. Destruction of peroxide bonds with its subsequent stabilization is the last one. All these mechanisms can be realized under ion implantation.

The main components of thermonuclear plasma are helium and hydrogen. It should be noted, that influence of inert helium on silica would be different from chemically active hydrogen. The purpose of the paper is experimental investigation of He dose dependence of silica luminescence associated with NBOHCs. To perform comparative analysis with hydrogen ion irradiation data [18] we used the same silica glass samples with medium OH-group contents. We also discussed the results of theoretical simulation of helium ion implantation and NBOHC's dynamics in silica.

2. Experimental procedures

The schematic diagram of the experimental set-up is presented on Fig. 1. The detail description one can find here [19]. The experiments were performed in vacuum chamber with residual gas pressure less than 10^{-4} Pa. We used 420 keV helium ion beam (diameter of the beam was 1.5 mm, Tantalum diaphragm) to

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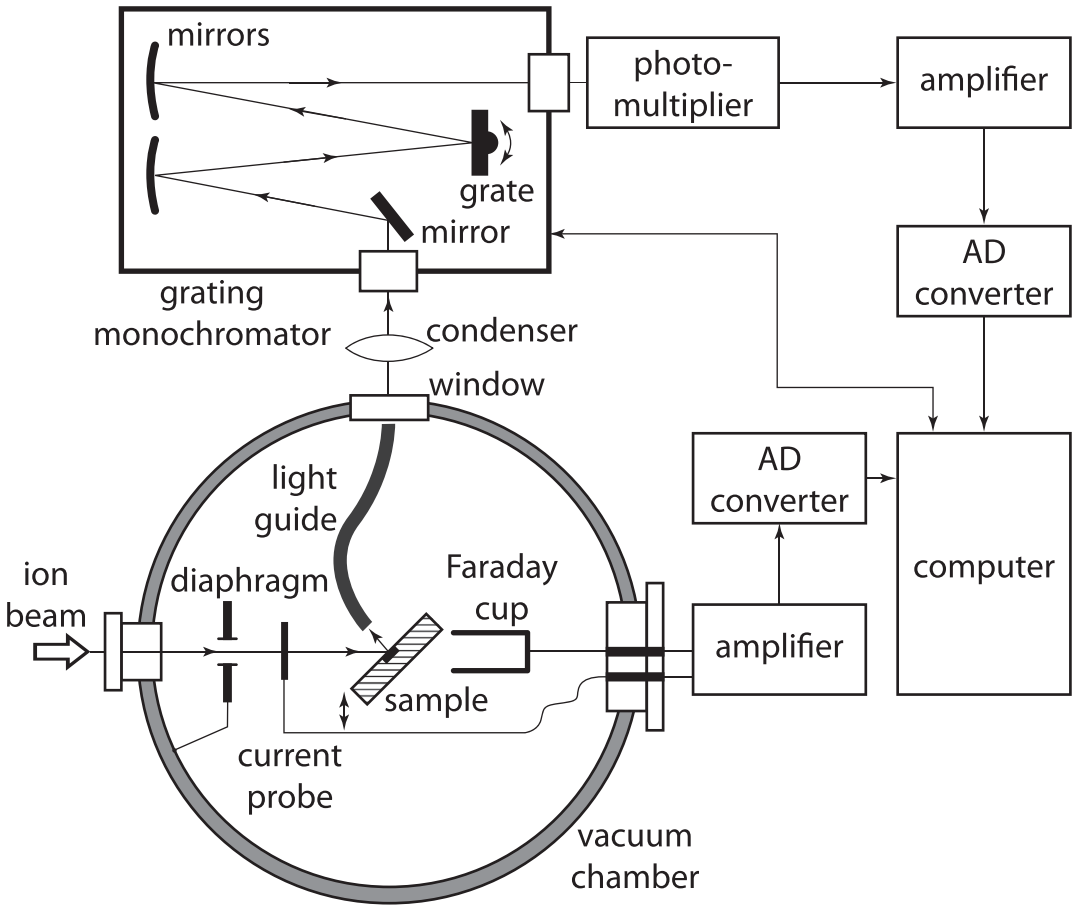

Fig. 1. Schematic diagram of the experimental set-up.

irradiate silica samples up to absorption dose about 2.06×10^{21} - ions per cm^3 (2.99×10^{10} Gy). Projectiles impinged on the target at incident angle of 30°. We performed two irradiation regimes with different beam currents. Current density was up to 0.3 μA per cm^2 during spectral measurements and was controlled by wire current probe. High current beam regime (up to 50 μA per cm^2) was applied to absorption dose accumulation. All experiments were performed at room temperature.

KV-type silica specimens with medium OH-group contents (analogies H-Vitreosil England, 1030 Japan) were exposed to long-time irradiation with Van de Graaf accelerator. The specimens were plane-parallel square silica plates (thickness 1 mm) with polished surfaces.

Observation angle β was varied in the range of 0°–70° and luminescence light was collected by light guide and transmitted through condenser to the entrance window of spectrometric complex. Light analysis was performed by grating monochromator (1200 mm^{-1}) with photomultiplier in the wavelength range of 400–700 nm. The incandescence spectrum-metric lamp was used for calibration procedure to provide correction according to the spectral sensitivity.

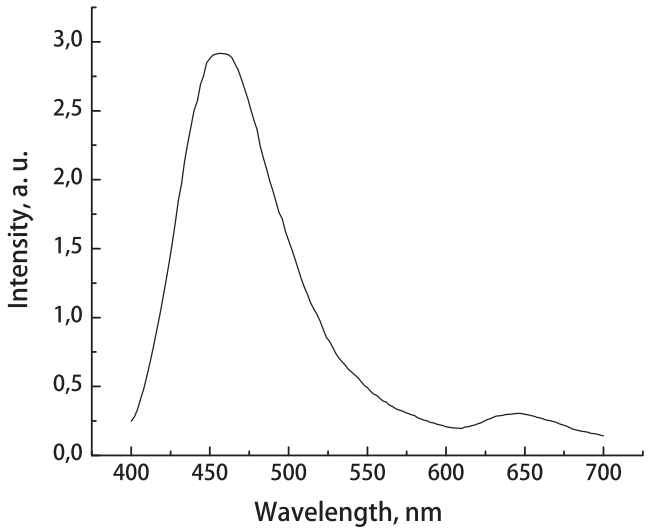

Fig. 2. Typical luminescence spectrum induced by 420 keV He ions from weakly irradiated silica, β = 0°.

3. Results and discussion

Fig. 2 shows ion-induced luminescence spectrum of silica at β = 0°. The two-broad band structure is very similar to the spectra observed for H^+ and H_2^+ irradiation [19,20]. We assumed that ODCs were source for the blue band luminescence radiation (LR) (λ_{max} = 456 nm), while NBOHCs were responsible for the red band light emission (λ_{max} = 645 nm), which agrees well with the results of other authors [6,7]. The same luminescence bands were observed for the whole range of β angles.

For understanding of He-ion passage in silica we carried out the SRIM/TRIM Monte Carlo code simulation [21]. We considered slowing–down process by simulating collision data, trajectories and ion ranges without taking into account subthreshold mechanism of defect formation, annealing of defects (recombination)