The ionoluminescence characteristics of quartz

O.Vasylchenko, N.Zheltopyatova, V.Zhurenko, O.Kalantaryan, S.Kononenko, V.Muratov, V.Filipenko*

V.Karazin Kharkiv National University,
31 Kurchatov Ave., 61108 Kharkiv, Ukraine
*V.Dokuchaev Kharkiv National Agricultural University,
1 Mazepa Ave., 62483 Kharkiv district, Ukraine

Received January 4, 2010

Experimental study results of silica glass luminescence in optical range under bombardment by molecular hydrogen ions owith energy 420 keV are presented. The effect of H_2^+ dose absorbed in the silica sample on the luminescence spectrum shape has been studied. A calibrating curve for remote control of absorbed dose in the silica glass has been obtained.

Представлены результаты экспериментальных исследований люминесценции кварцевого стекла в оптическом диапазоне при бомбардировке ионами молекулярного водорода с энергией 420 кэВ. Исследовано влияние поглощенной в образце кварца дозы дозы H_2^+ на форму люминесцентных спектров. Получена калибровочная кривая, позволяющая осуществлять дистанционный контроль поглощенной дозы.

1. Introduction

Silica glass parts are used widely in modern devices and assemblies both as insulators and optical elements for diagnostics and microwave radiation transmission as lenses and light guides constituting the optical channel. Physical, chemical, and mechanical properties of this material are changed during particle flux irradiation from thermonuclear plasma. This results from formation, annealing, and establishment of a dynamic equilibrium between different types of radiation-induced defects. Luminescence of silica under irradiation is either an alternative to the defect formation processes, or accompanies those. In this connection, the luminescence spectrum provides an important information on instantaneous dynamic equilibrium of the defect distribution in the solid and is a unique way to remote monitoring of the irradiation process.

The ionoluminescence spectra of quartz are changed essentially during proton irradiation [1]. Based on these data, a novel method was proposed to monitor the proton dose in SiO_2 [2]. This paper presents angular and spectral characteristics of silica luminescence measured during light ion bombardment. For the first time, the dependence of luminescence spectrum shape on relatively low absorption doses up to $1.52 \cdot 10^{10}$ Gy was studied. The results obtained were used to improve the above-mentioned method.

2. Experimental

The ionoluminescence experiments were carried out with the Van der Graaf accelerator using the setup described in details before [1, 2]. The H_2^+ ion beam with 420 keV energy bombarded the silica target at the incidence angle $\alpha = 30°$. The beam diameter after passage through tantalum aperture was 1.5 mm. The beam current density was varied from 0.3 to 30 $\mu A/cm^2$ and was controlled during the experiments. By using a flexible light guide to transmit the optical radiation from the sample, we have pro-

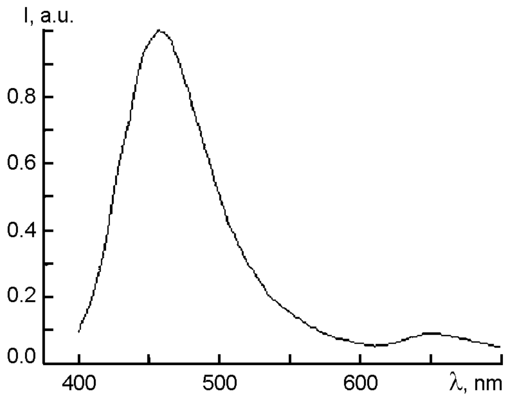

Fig. 1. Luminescence spectrum of unirradiated quartz for 420 keV H_2^+, $\beta = 0°$.

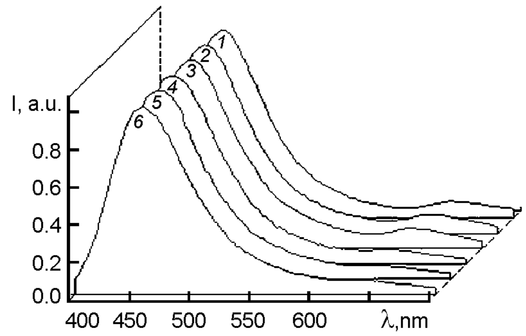

Fig. 2. Silica luminescence spectra for different absorpbed doses (Gy): *1*, unirradiated sample; *2* – $1.52 \cdot 10^{10}$; *3* – $2.07 \cdot 10^{10}$; *4* – $2.97 \cdot 10^{10}$; *5* – $3.86 \cdot 10^{10}$; *6* – $4.31 \cdot 10^{10}$.

vided the independent change of observation angle β in 0 to 60° range at constant α. At any values of β, the radiation was detected from the whole irradiated sample surface. A quartz condenser projected the light from the light guide output on the entrance slit of grating monochromator through a quartz window. The luminescence spectra were measured at room temperature in the wavelength range of 400 to 700 nm. A photomultiplier was used as a light receiver. The optical channel of the setup was calibrated using a spectrometric incandescence lamp. The luminescence spectra were corrected for the spectral sensitivity and normalized to the beam current. All samples were pure silica square plates (side 16 mm and thickness 1 mm) with polished and chemically cleaned surfaces. The residual gas pressure was less than 10^{-4} Pa. The luminescence spectra were treated by the method suggested in previous papers [2–5].

3. Results and discussion

A typical luminescence spectrum induced by H_2^+ ions at the initial irradiation stage of a silica sample is presented in Fig. 1. The spectrum consists of two wide bands with maxima near 456 nm (blue band) and 646 nm (red band). The light yield was proportional to the beam current density. Such double-band shape of the luminescence spectra had been observed not only under ion bombardment with different energy and species [6, 7], but also for other irradiation types, such as electrons [8] or neutrons [9]. Light generation in optical range during ion bombardment occurs on quartz intrinsic defects [7, 10–14]. The most intense blue band is usually connected with *E′* center type of intrinsic silica defects (Si with broken Si–O bond) by decay of self-trapped exciton [11]. Such defects as neutral oxygen vacancy (oxygen deficiency trapping two electrons) [8, 12, 13], twofold coordinated silicon [13], threefold coordinated silicon [10] can be considered as sources of blue band radiation. The red band with 646 nm wavelength maximum is attributed to non-bridging oxygen centers only (see, for example, [14] and references therein).

The experiments have shown that the spectra changed with increasing absorbed dose of H_2^+ ions. The changes in luminescence spectra with the dose growth induced by H_2^+ in quartz are shown in Fig. 2. As the absorbed dose of hydrogen atoms increases, the light intensity of the short wave wing of blue band remain essentially unchanged. The luminescence intensity of the red band decreases and for dose up to $4.35 \cdot 10^{10}$ Gy ($3 \cdot 10^{21}$ particles/cm^3) it becomes almost indistinguishable against the background of long-wave wing of the blue band (456 nm maximum). Perhaps such a dependence is connected with blocking of intrinsic silica defects by hydrogen atoms.

As it was found in a previous work [2], the maximum changes in the spectrum shape was observed near 646 and 606 nm wavelengths for protons. The same feature occurs for H_2^+ ions, too. We defined the *F* value as the ratio of intensity at 646 nm to that at 606 nm. This ratio depends strongly on absorbed dose. The *F* value as a function of absorbed dose is presented in Fig. 3. The resulting curve can be divided into two areas: initial increase up to maximum at $7.83 \cdot 10^9$ Gy dose and slope up to $4.35 \cdot 10^{10}$ Gy dose. It seems that further irradiation can lead to saturation of the curve.

It has been shown first that the absorbed dose dependence is nonmonotonous. Perhaps this is connected with the fact that the process of non-bridge oxygen defect formation in silica predominates over the blocking of these defects by hydrogen at relatively small absorbed doses up to $1.52 \cdot 10^{10}$ Gy. The novel technique proposed before for the remote monitoring of proton absorpbed dose [1–5] could be improved using this work data. The curve in Fig. 3 can be used as the calibrating one to determine the H_2^+ dose absorbed in a silica sample.

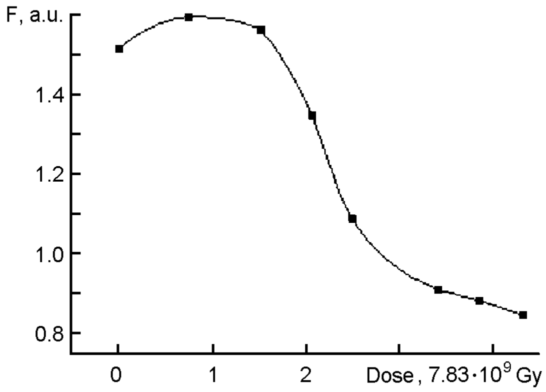

Fig. 3. *F* value as a function of absorbed dose (calibrating curve).

4. Conclusion

The study of silica irradiation with molecular hydrogen ions of several hundred keV energy has shown that the luminescence spectra are changed during the bombardment. This result allows to extend the application sphere of our remote monitoring method of absorbed dose for protons in silica to the case of H_2^+ ions. The wavelength areas of maximum spectra changing have been defined and the absorbed dose calibrating curve has been obtained. This procedure enabled to carry out remote monitoring of H_2^+ dose absorbed in silica.

References

1. O.V.Kalantaryan, S.I.Kononenko, V.I.Muratov, *J.Plasma Fusion Res.Ser.*, **3**, 274 (2000).
2. S.I.Kononenko, O.V.Kalantaryan, V.I.Muratov, V.P.Zhurenko, *Nucl.Instr.and Meth.in Phys.Res.B*, **246**, 340 (2006).
3. S.I.Kononenko, O.V.Kalantaryan, V.I.Muratov, *Functional Materials*, **10**, 656 (2003).
4. S.Kononenko, O.Kalantaryan, V.Muratov, C.Namba, in: Joint Meeting of 14th Int. Toki Conference on Plasma Physics and Controlled Nuclear Fusion, Toki, Japan, October 5-8 (2004), p.120.
5. S.I.Kononenko, O.V.Kalantaryan, V.I.Muratov et al., *Rad.Meas.*, **42**, 751 (2007).
6. F.Jaque, P.Townsend, *Nucl.Instr.and Meth., Phys. Res.*, **182/183**, 781 (1981).
7. T.Tanabe, A.Omori, M.Fujiwara, *J.Nucl. Mater.*, **258–263**, 1914 (1998).
8. A.Morono, E.R.Hodgson, *J.Nucl.Mater.*, **258–263**, 1889 (1998).
9. F.Sato, T.Iida, Y.Oyama, F.Maekawa, Y.Ikeda, *J.Nucl.Mater.*, **258–263**, 1897 (1998).
10. A.N.Trukhin, *Nucl.Instr.and Meth.B Phys. Res.*, **91**, 334 (1994).
11. F.Pio, M.Guzzi, M.Martini, *Phys.State Sol. (b)*, **159**, 577 (1990).
12. J.P.Duraud, F.Jollet, Y.Langevin, E.Dooryhee, *Nucl.Instr.and Meth.B Phys. Res.*, **32**, 248 (1988).
13. L.N.Skuja, A.N.Streletsky, A.B.Pakovich, *Sol. State Commun.*, **50**, 1069 (1984).
14. L.N.Skuja, A.R.Silin, *Phys.State Sol.(a)*, **70**, 43 (1982).

Характеристики іонолюмінесценції кварцу

О.І.Васильченко, Н.О.Желтопятова, В.П.Журенко, О.В.Калантарян, С.І.Кононенко, В.ІМуратов, В.Є.Філіпенко

Представлено результати експериментальних досліджень люмінесценції кварцового скла в оптичному діапазоні при бомбардуванні іонами молекулярного водню енергією 420 кеВ. Досліджено вплив поглиненої кварцевим зразком дози H_2^+ на форму люмінесцентних спектрів. Отримано калібрувальну криву, яка дає можливість здійснювати дистанційний контроль поглиненої дози.