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Luminescence of Quartz Crystals Greeted on Neutron-Irradiated Seeds

Mustafakulov A. A., Arzikulov F. F.

Jizzakh Polytechnic Institute, Jizzak, Uzbekistan.
E-mail: asrormustafakulov@gmail.com

Abstract: *The kinetics of the luminescence bands in crystals grown on neutron-irradiated seeds in the temperature range 77–300 K was studied, and the regions of thermal stability of luminescence centers were determined.*

Keywords*:* spectrum, quartz, heat treatment, seed, radiation, neutron, gamma radiation, luminescence, luminescence band.

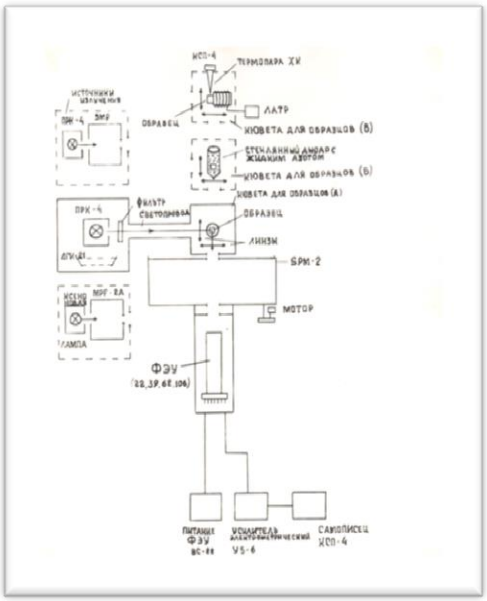
Introduction

It is known that various structural modifications of quartz (SiO_2) and products based on them are widely used in various fields of modern science and technology, electronic and radio engineering industries. The prospect of their development requires the creation of radiation-resistant and radiation-sensitive crystalline materials, and the development of ways of purposefully changing their properties by means of exposure to nuclear radiation. To successfully solve these problems, it is necessary to comprehensively study the mechanisms of creating point defects, radiation-stimulated phase transformations and their role in changing the radiation-optical properties of quartz. This is one of the topical problems of radiation physics of solids.

Research results and discussion

To determine the effect of neutron irradiation on the optical properties of quartz crystals grown on neutron-irradiated seeds and to reveal the nature of structural defects, these crystals were studied after neutron irradiation [1], thermal and photothermal treatments.

Thermal (up to 650 K) and photothermal treatment, recording of photoluminescence (PL) spectra at different temperatures were carried out on a setup [2] based on an SPM-2 monochromator (Pic. 1).



Pic. 1. Schematic of the setup for recording PL spectra and photothermal treatment of samples.

After additional neutron irradiation with a fluence above 10^{17} n / cm^2, the GL spectrum is dominated by bands with maxima at 550 and 660 nm at temperatures above 200 K. Fig. 2 shows the dependence of the intensities of the luminescence bands on the neutron fluence. The intensities of the 550 and 660 nm bands increase up to 10^{19} n / cm^2. A further increase in the dose leads to a decrease in their intensities. In crystals irradiated with a dose of> 10^{20} n / cm^2, the intensity of the 460 nm band predominates in the spectrum.

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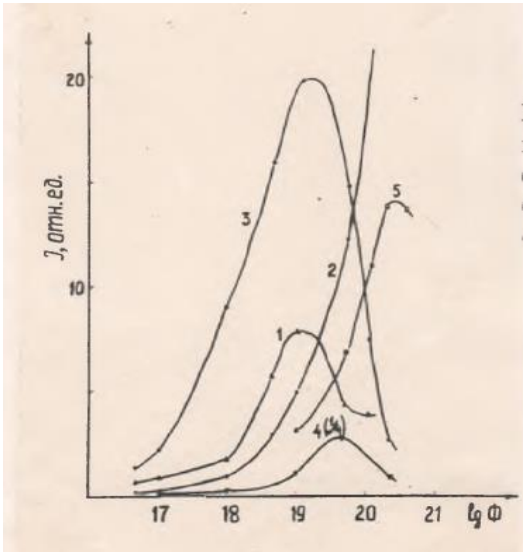
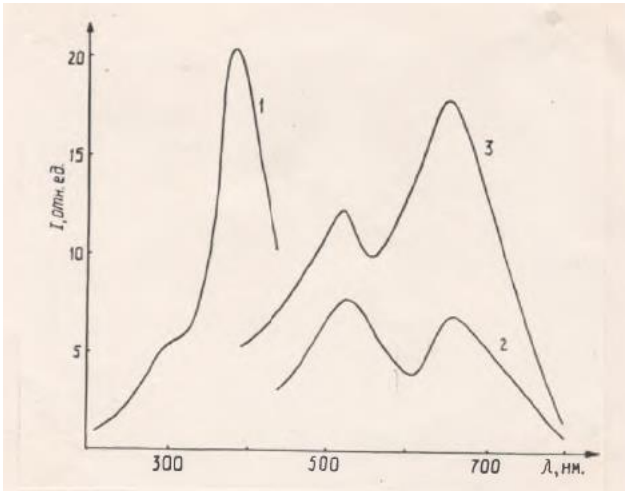


Pic. 2. Dependences of the intensities of the PL bands of 550 (1), 660 (2), 840 nm (4) and gamma-luminescence (GL) (3) 660, 460 nm (5) on the neutron fluence.

Earlier, the 660 nm band was observed in quartz glasses [3] and in quartz crystals irradiated with neutrons with a dose higher than 10^{19} n / cm^2 [4]. It was assumed [2] that the centers of luminescence are nonbridging oxygen atoms (NAC) and they are stabilized only in the glassy phase of quartz. The excitation (SW) (PL) spectra have two bands, at 260 and 620 nm. We found the 660 nm band in crystals irradiated with a neutron fluence of 5 * 10^{16} n / cm^2, when crystal amorphization is practically absent. In SW, one band with a maximum at 315 nm is observed (pic. 3).



Pic. 3. Excitation spectra-1, and luminescence-2 (λw = 315 nm) and 3 (λw = 380 nm) in crystals with an impurity of germanium-Ge.

Red luminescence with a maximum at 680 nm was found in the luminescence spectra of crystals containing Ge impurities, irradiated only with γ - rays [5]. It is excited in the region of 380 nm and is caused by the NAC located at the impurity germanium tetrahedron. The thermal stability of this center and the centers of red luminescence of crystals irradiated with different neutron fluences differ from each other. The above data allow us to make the assumption that the presence of a glassy phase in crystals is not a sufficient condition for the stabilization of NAC, and there are several types of red luminescence centers in quartz [6].

In crystals irradiated above 1020 n / cm2 at (excitation) λw = 260 nm, as in quartz glass, along with the 660 nm band, the 460 nm band is also excited. This result and the disappearance of the 550 nm band at> 1020 n / cm2, the appearance of the 460 nm band belonging to the metamict phase of quartz is in good agreement with the fact that the transition to the metamict phase occurs

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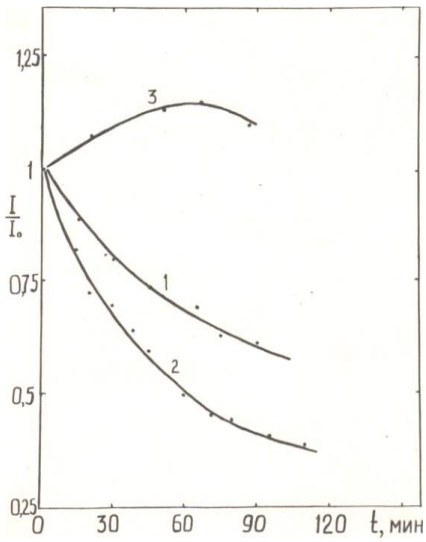
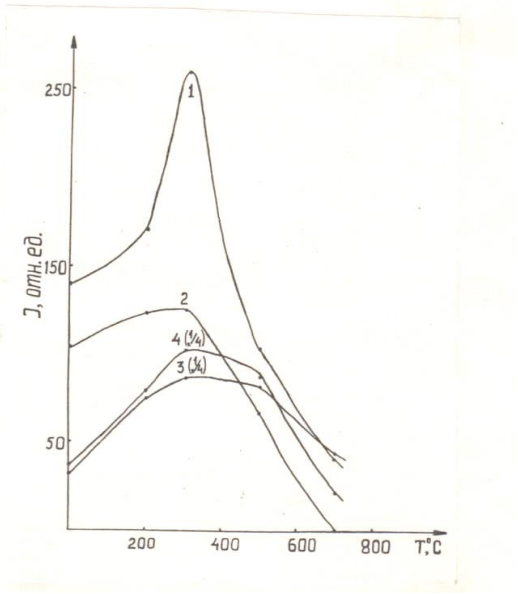
through the β - phase and ends at 2.1020 n / cm2 as in [7]. A study of the PL of crystals in the range 300–720 K at fixed temperatures showed that the intensities of the 550, 660, and 840 nm bands decrease with increasing temperature, and with decreasing temperature, a relative increase in the intensity of the 660 nm band is observed. Under photo-illumination of crystals with λw = 337 nm, the radiation of an argon laser at room temperature with increasing time, a decrease in the intensities of the 550 and 840 nm bands is accompanied by an increase in the intensity of the 660 nm band (pic. 4).



Pic. 4. Dependences of the intensities of the PL bands at 500 nm (1), 840 nm (2). 660 nm (3) from the time of photobleaching in quartz irradiated with neutron fluences of 10^{19} cm^{-2}.

A study of the PL of crystals irradiated with neutron fluences of 10^{19} and 5.10^{19} n / cm^2 at 300 K showed that after annealing in the range 300–600 K, the intensities of the bands increase, and at 600 K, the intensity decreases (Pic. 5).

Comparison of research results with literature data, i.e. works [8-13] on thermo - and phototransformations of surface and bulk paramagnetic E_1 - centers, NAC and radical peroxide in glassy quartz allows us to make the assumption that the centers of luminescence of the 550 nm band are peroxide radicals. The correlation of its intensity with the amount of β - phase and the presence of a luminescence band with similar characteristics in quartz glass [14] suggest that the luminescence centers are located at the boundaries of the α - and β - phases of quartz.



Pic. 5. Dependences of the intensities of the PL bands of 550 nm (1.3) and 660 nm (2.4) on the annealing temperature in irradiated quartz crystals with neutron fluences 10^{19}cm-2-1.2; 5.10^{19} cm-2-3.4.

Based on this, we believe that an increase in the intensity of the 550 nm band to 10^{19} n / cm^2 is due to an increase in the concentration of the β - phase (Pic. 2). Above 10^{19} n / cm^2, a decrease in the number of nuclei is observed due to interaction with each other, which leads to a decrease in the intensity of the 550 nm band. When crystals are heated in the range of 300 - 650 K, as in glassy quartz, an increase in the number of radical peroxides is observed (Pic. 5), and at above 650 K and photoillumination, radical peroxide is transformed into NAC. This leads to an increase in the intensity of the 660 nm band after photothermal exposure.

At present, the nature of the 840 nm band has not been established. It is observed in both pure and impurity neutron-irradiated crystals. The band intensity increases to 5.10^{19} n / cm^2 and then decreases (Pic. 2).

A study of the dependence of the intensity of the GL 840 nm band on the excitation temperature showed that it increases to T = 130 K, and drops sharply at T> 130 K. The excitation spectrum (SW) contains one band with a maximum of ~ 340 nm. These data give reason to believe that the luminescence center is an intrinsic defect in the structure of quartz crystals.

Conclusion

The kinetics of luminescence bands in unirradiated and neutron-irradiated crystals in the temperature range 77 - 300 K was investigated, a new luminescence band with a maximum at 840 nm was found, the dependence of the intensities of the luminescence bands on the dose of neutron seed irradiation and additional neutron irradiation was determined, and the regions of thermal stability of the centers were determined. glow.

Based on the results of studies of the redistribution of the intensities of the photoluminescence bands under illumination (λw = 300 - 340 nm) without heating and with heating in the temperature range of 300 - 720 K, the dependence of the intensities of the luminescence bands on the neutron fluence, it was assumed that the luminescence centers at 550 and 660 nm are respectively, peroxide radicals and non-bridging oxygen atoms located at the interfaces between the α - and β - phases of quartz.

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