CHARACTERISTIC FEATURES OF THERMOLUMINESCENCE KINETICS IN DOSIMETRIC ALUMINUM OXIDE CRYSTALS

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We have studied the thermoluminescence curves in the 420 nm band (F centers) and the 330 nm band (F + centers) within the temperature range of the dosimetric peak (T_{max} = 450 K) in anion-deficient aluminum oxide crystals. Assuming general-order kinetics, we have analyzed the thermoluminescence decay curves on the rising and falling sides of the dosimetric peak, in samples with different degrees of deep trap filling. We have established differences in the order of the kinetics within different temperature ranges of the dosimetric peak.

Key words: thermally stimulated luminescence, luminescence spectrum, F and F + centers, order of kinetics, deep traps.

Introduction. The thermoluminescence and kinetic properties of anion-deficient aluminum oxide single crystals have been studied in connection with their application for ionizing radiation dosimetry [1–4]. However, so far there has been insufficient study of the nature of the active centers and the mechanism for thermoluminescence (TL) at the dosimetric peak at 450 K. We know [1, 2, 5] that within this peak we observe mainly luminescence of F centers (oxygen vacancies with two trapped electrons) and also a number of thermoluminescence features: a dependence of the intensity of luminescence for the F centers (420 nm) on the heating rate, a decrease in the average activation energy, superlinearity of the dose curve. Establishment of the role played in the indicated processes by deep trapping centers, the thermal ionization of which occurs at 730 K and 880 K, represents important progress. Deep trap filling is connected with the above-indicated characteristics, since it determines the competition for capture of charge carriers in the trap, which are responsible for the dosimetric peak. Data are available [6] indicating that this peak is not an elemental peak and that different luminescence mechanisms can be realized within its temperature range.

We also know [2] that in the TL spectrum of the dosimetric peak there is a 330 nm component due to luminescence of F + centers (oxygen vacancies with one trapped electron). The concentration of F + centers can be varied by exciting the studied crystals with UV light in the absorption band for F centers (210 nm). In this case, the conversion F center \rightarrow F + center occurs and the free electrons generated occupy traps, including deep traps [7, 8].

The aim of this work was to analyze the kinetic parameters of thermoluminescence within the temperature range of the dosimetric peak for irradiated crystals of anion-deficient \(\alpha\)-Al\(_2\)O\(_3\), taking into account the noted characteristics.

Samples and experimental procedure. Samples (diameter 5 mm and thickness 1 mm) of nominally pure anion-deficient single crystals of \(\alpha\)-Al\(_2\)O\(_3\) were grown under strong reducing conditions [1]. For the irradiation, we used a \(\beta\) radiation source based on the \(^{90}\text{Sr} / ^{90}\text{Y}\) isotopes, providing a test dose of 64 mGy at the sample location for 2 min.

The TL curves were recorded using an MUM grating monochromator and an FÉU-39A photomultiplier. The monochromator was used to isolate the luminescence bands of the F and F + centers. The original samples were preannealed up to a temperature of 970 K in order to deplete the dosimetric and deep traps; then they were irradiated with the test dose and heated at a rate of 2 K/sec for recording the dosimetric peak or the isothermal TL decay curves at selected temperatures. Irradiation of the samples by the test dose at room temperature and subsequent recording of the...
thermoluminescence at the dosimetric peak cause insignificant filling of the deep traps [5], which may be neglected. Thus samples with depleted deep traps were considered as depleted in the original samples.

The procedure for varying the filling of the deep traps involved the following. The samples were heated up to a temperature of 650 K, where the traps responsible for the α-Al₂O₃ dosimetric peak are depleted but the deep traps are still able to hold onto the trapped charge carriers. At the indicated temperature, the samples were illuminated by an LD-2 deuterium lamp in the absorption band of the F centers (210 nm) with the aim of filling the deep traps. The degree of filling of the deep traps was varied by changing the UV exposure time. Then the samples were cooled down, irradiated with the test dose from the β source, and the thermoluminescence was recorded with linear heating at the rate indicated above or under isothermal decay conditions for selected temperatures within the range of the dosimetric peak.

Results and discussion. In Fig. 1a, we show the thermoluminescence curves for the studied samples with linear heating in the 420 nm band (F centers) for different degrees of deep trap filling. We see that with an increase in the UV exposure time, the intensity of thermoluminescence at the dosimetric peak increases. This result is quite consistent, since as the deep traps are filled, there is an increase in the number of charge carriers captured by the dosimetric traps, which confirms that interaction occurs between the dosimetric and deep traps [5, 9].

The thermoluminescence curves in the 330 nm band (F⁺ centers) for different UV exposure times are shown in Fig. 1b. The original sample has a low intensity of luminescence for the F⁺ centers, which rapidly increases with UV exposure as a result of the increase in the concentration of F⁺ centers as a result of the conversion F → F⁺. Note the −15 K shift of the temperature of the luminescence maximum toward higher temperature for the F⁺ centers. This suggests that the nature of the thermal activation process leading to excitation of F⁺ centers may be different than for the analogous process for excitation of F centers [8]. Thus within the temperature range of the dosimetric peak, in fact different types of thermal activation processes involving F and F⁺ centers may occur. Accordingly, it is advisable to analyze the thermoluminescence processes at the indicated peak assuming general-order kinetics.

Considering the shift of the temperature of the luminescence maximum for F⁺ centers toward higher temperatures, where we observe a fall-off in the F-center curve, the kinetic parameters were analyzed separately for the rising and falling sides of the dosimetric peak. For the problem at hand, determination of the kinetic parameters by studying the isothermal TL decay curves is the most applicable. Such curves were recorded in the 420 nm band for different UV exposure times within the temperature range for the rising and falling sides of the dosimetric peak. Fig. 2 illustrates the TL decay kinetics for the original samples and after UV excitation. The isothermal holding temperatures were selected on the rising side of the dosimetric peak. We see a regular increase in the TL decay rate as the temperature increases both for the original samples and for the UV-excited samples.

The kinetic parameters were estimated according to the general-order luminescence decay equation [10]:

\[ I(t) = \frac{I_0}{[1 + (b - 1) \rho \alpha t]^{b/(b-1)}} \]  

(1)