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Kinetics of luminescence and charge transfer after impacts of neutrons, heating and gamma-quanta on LuAG:Pr crystals for thermoluminescent dosimetry

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ABSTRACT

The purpose of this work was to study the possibility of using the expired scintillation detectors as thermoluminescent dosimeters after exposure to high-energy irradiation and thermal annealing. The LuAG:Pr single crystals were irradiated by fast neutrons to the fluency of 10^{17} cm^{-2} in WW-reactor to generate structural defects and then heat-treated at 610 K to fade the color centers. Then they were subjected to ^{60}Co gamma-irradiation to various doses to 2.6 kGy to study the kinetics of charge carrier accumulation in neutron-induced color centers. The conclusion was made that after neutron irradiation and heat treatment, the decrease by ~50 % in the intensity of the 310 nm gamma-exited luminescence band of Pr^{3+} under a gamma-dose of 770 Gy is associated with capture of holes by the Pr^{3+} with conversion to Pr^{4+} centers, and capture of electrons by the defect F^+ and F_2^+ centers. Thermal glow measurements in the temperature range of 300–605 K showed the presence of an isolated peak at 440 K, which intensity increases linearly with increasing gamma-dose from 19 to 70.4 Gy due to the release of charge carriers from traps. With the increase in the dose rate of gamma-irradiation from 0.064 to 1.1 Gy/s the intensity of this dosimetric peak also increases linearly. At this the accumulated light sum keeps unchanged for 5 h at 305 K. Obtained results show their usefulness for thermoluminescent dosimetry.

1. Introduction

Scintillation optical materials for high-sensitive detectors are used in computed tomography, positron emission tomography, high-energy physics, security systems, etc. They are characterized by such criteria as high luminescence efficiency, fast response, and stability at high radiation doses (Dujardin et al., 2018; Bilki, 2015; Hu et al., 2018, 2019; Zhang et al., 2014; Elftmann et al., 2015; Lecoq, 2009). Due to fast and effective $5d\rightarrow4f$ transitions, Ce^{3+} and Pr^{3+} have become one of the most promising activators. Therefore yttrium aluminum $Y_3Al_5O_{12}$ (YAG) and lutetium aluminum $Lu_3Al_5O_{12}$ (LuAG) garnet crystals doped with Ce^{3+} and Pr^{3+} are investigated intensively (Chewpraditkul et al., 2009; Nikl and Yoshikawa, 2015). In this regard, single crystals of LuAG:Pr attract great attention for their use in scintillators (Lecoq, 2009; Pauwels et al., 2013) due to their high density (6.7 g/cm^3), fast response (~20 ns), high light output (~20,000 ph/MeV), three times higher than the light output of $Bi_4Ge_3O_{12}$ (BGO) (Nikl et al., 2005; Ogino et al., 2006).

One of the criteria for a scintillator quality is the radiation stability of the optical response, when exposed to ionizing and displacing radiation in the required (for specific applications) range of intensities and doses. The radiation stability of crystals is controlled by radiation-induced fast electron processes (the population of existing traps by charge carriers) and slow lattice processes (the creation of additional defects, both neutral and filled with charge carriers).

Boron carbide is considered as promising compounds for increasing the sensitivity of neutron detectors, and recently the detectors based on B_4C for recording "cold", "hot" and "fast" neutrons in order to improve the safety of nuclear reactors has been studied [see the general literature presented in (Mirzayev et al., 2018a, 2019a)]. In the works (Mirzayev et al., 2019a, 2019b, 2020) B_4C crystals were irradiated with a ^{60}Co source (dose rate 0.27 Gy/s) with several absorbed doses from 48.5 to 194 kGy and studied: formation of defects and determination of the concentration of color centers (Mirzayev et al., 2019a); temperature dependences of the kinetics of weight, specific heat capacity and oxidation rate with the formation of the B_2O_3 phase and two deep energy levels (Mirzayev et al., 2019b); amorphization of B_4C compounds

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