Optical transmission radiation damage and recovery stimulation of DSB: Ce^{3+} inorganic scintillation material

To cite this article: A Borisevich *et al* 2015 *J. Phys.: Conf. Ser.* **587** 012063

Optical transmission radiation damage and recovery stimulation of DSB: Ce^{3+} inorganic scintillation material

A. Borisevich[a], V. Dormenev[b], M. Korjik[a], D. Kozlov[a], V. Mechinsky[a], R. W. Novotny[b]

[a] Institute for Nuclear Problems, Minsk, Belarus
[b] 2nd Physics Institute, Justus-Liebig-University, Giessen, Germany

E-mail: Rainer.Novotny@exp2.physik.uni-giessen.de

Abstract. Recently, a new scintillation material DSB: Ce^{3+} was announced. It can be produced in a form of glass or nano-structured glass ceramics with application of standard glass production technology with successive thermal annealing. When doped with Ce $^{3+}$, material can be applied as scintillator. Light yield of scintillation is near 100 phe/MeV. Un-doped material has a wide optical window from 4.5eV and can be applied to detect Cherenkov light. Temperature dependence of the light yield LY(T) is 0.05% which is 40 times less than in case of PWO. It can be used for detectors tolerant to a temperature variation between -20° to +20°C.
Several samples with dimensions of 15x15x7 mm^3 have been tested for damage effects on the optical transmission under irradiation with γ-quanta. It was found that the induced absorption in the scintillation range depends on the doping concentration and varies in range of 0.5-7 m^{-1}. Spontaneous recovery of induced absorption has fast initial component. Up to 25% of the damaged transmission is recuperated in 6 hours. Afterwards it remains practically constant if the samples are kept in the dark. However, induced absorption is reduced by a factor of 2 by annealing at 50°C and completely removed in a short time when annealing at 100°C. A significant acceleration of the induced absorption recovery is observed by illumination with visible and IR light. This effect is observed for the first time in a Ce-doped scintillation material. It indicates, that radiation induced absorption in DSB: Ce scintillation material can be retained at the acceptable level by stimulation with light in a strong irradiation environment of collider experiments.

1. Introduction

Up to date self-activated scintillation materials like BGO and PWO have found a wide application in detectors at high energy physics experiments. They possess a unique combination of the scintillation and physical properties, including high density, fast response and radiation hardness at least to the electromagnetic part of ionizing radiation. However, heavy materials demonstrate sufficient damage under the hadronic part of the ionizing radiation [1, 2] excluding consideration for high energy experiments at future particle colliders. Ce^{3+} doped scintillation materials are considered to be applied at calorimetric detectors. Among them, LYSO: Ce [3] shows a relatively high resistance to the damage of optical transmission. However, Lu-based crystals indicate after proton irradiation a high level of the radio-luminescence due to induced radio-nuclides and phosphorescence [4]. Therefore, we have paid our attention to medium heavy scintillation materials, particularly to a new scintillation material

Journal of Physics: Conference Series **587** (2015) 012063 doi:10.1088/1742-6596/587/1/012063

DSB: Ce^{3+} [5]. Scintillating glasses, despite their relatively easy and cost effective production, are so far not widely used in high energy experiments due to their poor radiation hardness and low light yield. The Di-silicate of barium (BaO-$2SiO_2$) doped with cerium (DSB: Ce) is one of the new scintillation materials made from binary stoichiometric composition and produced according to glass manufacturing technology with a successive thermal annealing to obtain nano-structuring of the material. In this paper, the first results of measurements of the radiation damage effects and its recovery are presented. For the first time, the effect of stimulated recovery has been observed in Ce-doped inorganic scintillation materials.

2. DSB samples and measurements.

DSB glass samples were provided by Radiation Instruments and New Components (Belarus) to evaluate their radiation hardness to γ-irradiation. The material can be produced as glass or nano-structured glass ceramics using the common production technology accompanied with successive thermal annealing. When doped with Ce^{3+}, it emits scintillation light at a yield of ~100 phe/MeV. Un-doped material has a wide optical window from 4.5eV and can be used as a Cherenkov radiator. The temperature dependence of the light yield LY(T) is on the level of 0.05 % which is 40 times less than in case of $PbWO_4$. Therefore, it becomes tolerant to temperature variation in the wide range of -20°C to +20°C. Therefore, DSB: Ce can be considered to be a prospective material for application in calorimetry. Several samples were irradiated at the Radiation Centre (Justus-Liebig-University Giessen, Germany) using a strong ^{60}Co source at a dose rate of 2Gy/min. Figures 1 and 2 present the transmission spectra of low- (less than 0.1 weight %) and heavy-doped (more than 1 weight %) DSB: Ce, before and after irradiation with γ-rays.

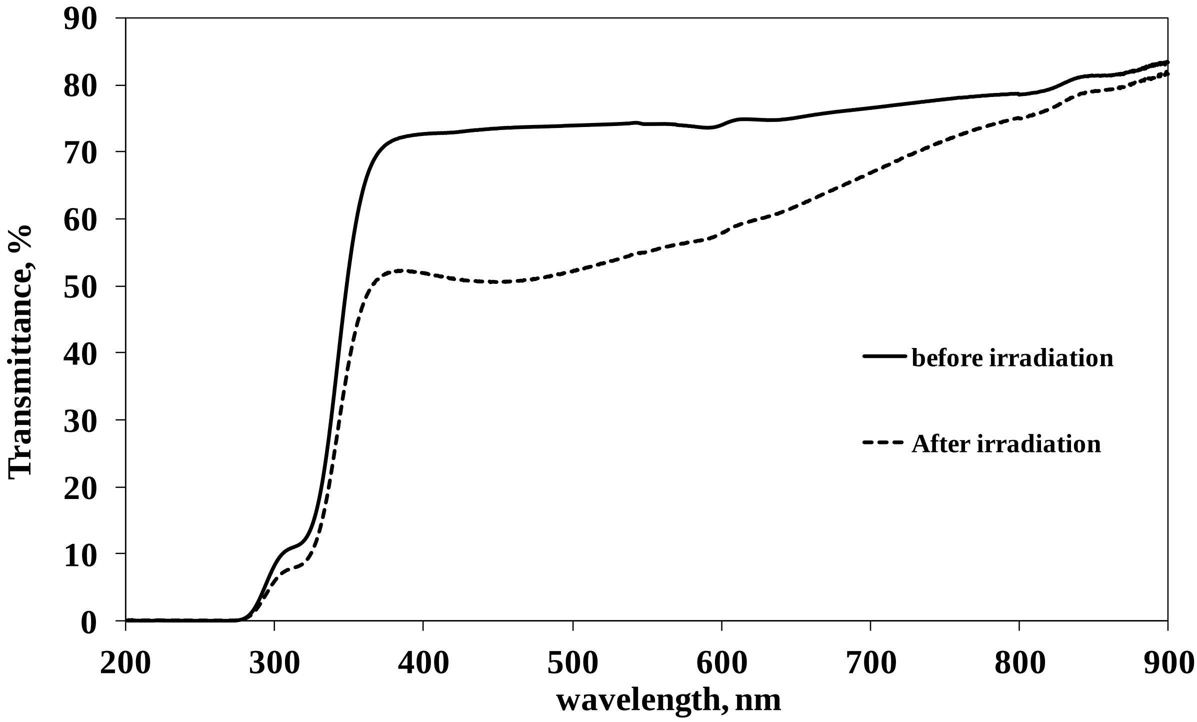

Figure 1. Comparison of the optical transmission spectra measured at room temperature of low-doped DSB: Ce samples before and after irradiation with a ^{60}Co source with an integral dose of 100Gy. The thickness of the sample is 8 mm.

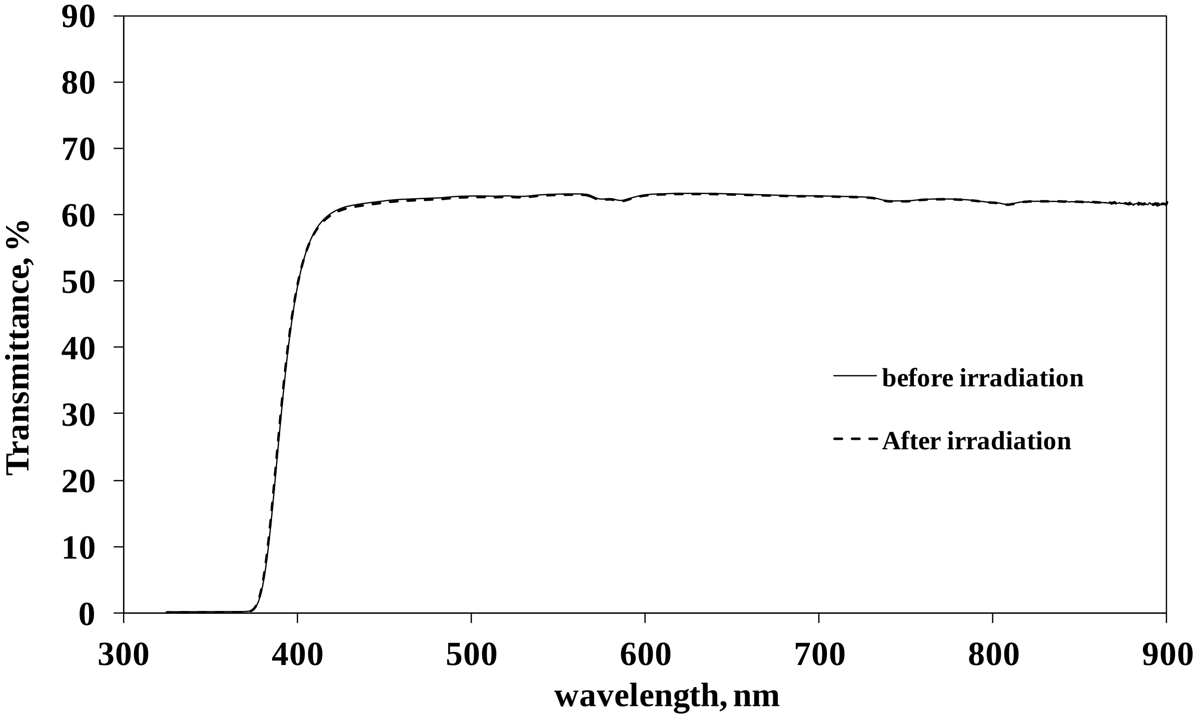

Figure 2. Comparison of optical transmission spectra measured at room temperature of a heavy-doped DSB: Ce sample before and after irradiation with a ^{60}Co source with an integral dose of 100Gy. The thickness of the sample is 4.45mm.

The low-doped sample shows several color centers peaking near 450nm and 650nm, respectively, whereas heavy-doped DSB samples show an extremely high radiation hardness against γ-irradiation.

3. Spontaneous and stimulated recovery of the gamma irradiation induced optical absorption

The effect of stimulated recovery of the radiation damage has been observed so far in self-activated scintillation material, namely $PbWO_4$ [6]. It was suggested that Ce-doped scintillation materials, due to the presence of cerium ions with a high capture cross-section of free carriers, should show fast recombination of color centers, especially created due to shallow traps. However, our study shows that even at high concentration of Ce^{3+} in the inorganic material, spontaneous recovery of the induced absorption is a relatively slow process. Figure 3 shows spontaneous recovery at room temperature of the normalized radiation induced coefficient of a heavy-doped DSB: Ce sample. Fast recovery is observed only in the initial. Only up to 25% of the reduced optical transmission is recuperated after 6 hours. Afterwards, the value of induced absorption remains practically constant if the samples are kept in the dark. However, induced absorption is decreased by a factor of two due to annealing at 50°C and completely removed by a short annealing phase at 100°C. It appears that the fast component of the recovery is due to recombination of color centers with cerium ions. However, annealing of the majority of the color centers above room temperature and their slow spontaneous recombination at room temperature indicate deep traps which only weakly interact with cerium ions. Therefore, recombination can be significantly enhanced by illumination with external optical photons.

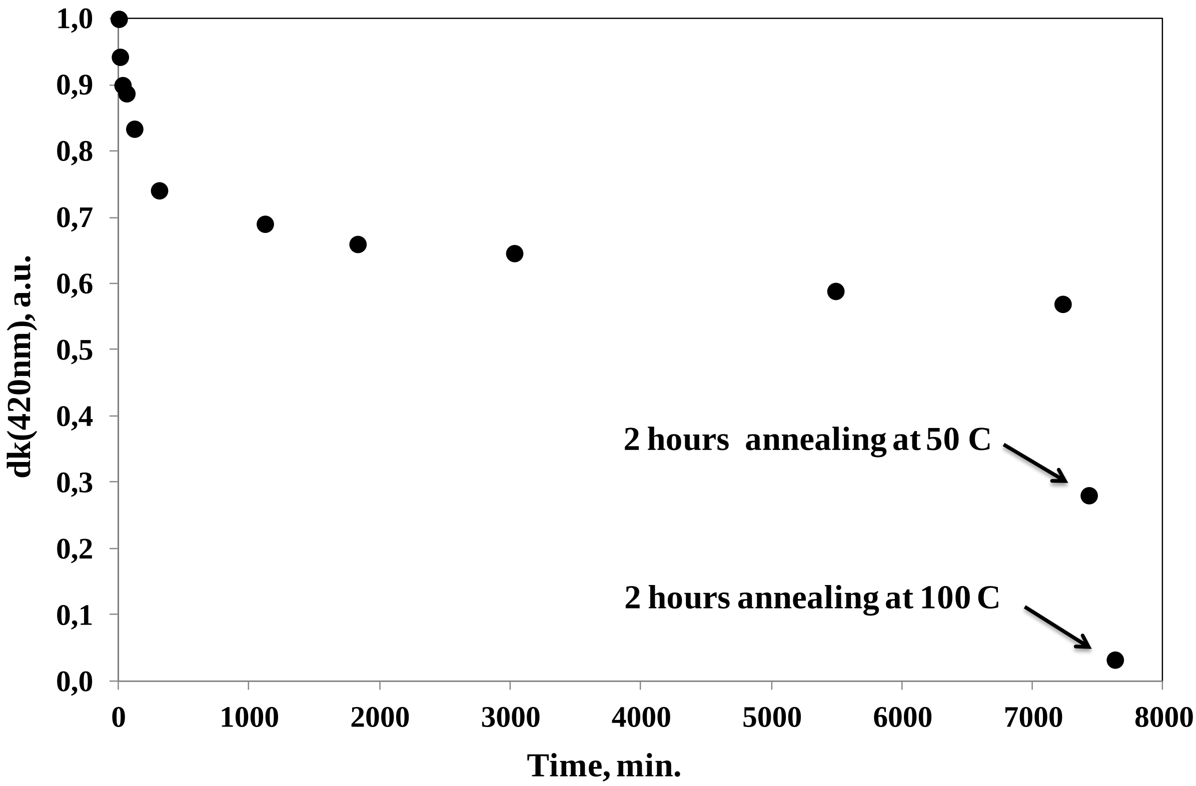

Figure 3: Spontaneous recovery at room temperature recovery of the normalized radiation induced coefficient at 420nm wavelength of a heavy-doped DSB: Ce sample after 500Gy of absorbed dose.

There are two mechanisms initiated by the photons: 1) ionization of color centers and 2) transport of the captured electron from the ground state of the color center to the radiating level or center. The first process depends on the energy width of the conduction band and the position of the ground state of the color center in the forbidden zone and may be initiated in a wide spectral region from UV to visible light. In Ce-doped material, ionization may be effective since electrons released from color centers can be captured by cerium ions preventing their re-capturing by other traps. The second type of process is an intra-center resonant transition among color centers or between a color center and a cerium ion. Due to the lower energy difference $E_f \sim E_{TA}$ even infrared (IR) photons can initiate the mechanism . Figure 4 illustrates the impact of light illumination on the recovery of the induced absorption coefficient in a heavy-doped DSB: Ce sample at room temperature.

The effect is achieved by the injection of photons of selected wavelengths with an intensity of 2 to $9 \cdot 10^{16}$ photons/s into the sample wrapped in a reflector foil. However, the time constants of the recovery progressively increase shifting towards the IR range. Stimulated relaxation provides relaxation within a wide spectral region. As expected, illumination with blue light, which can cause even ionization of the color centers, leads to the fastest recuperation. The observed results confirm that radiation induced absorption in cerium doped scintillation materials also can be promptly recuperated using stimulated recovery with optical photons.

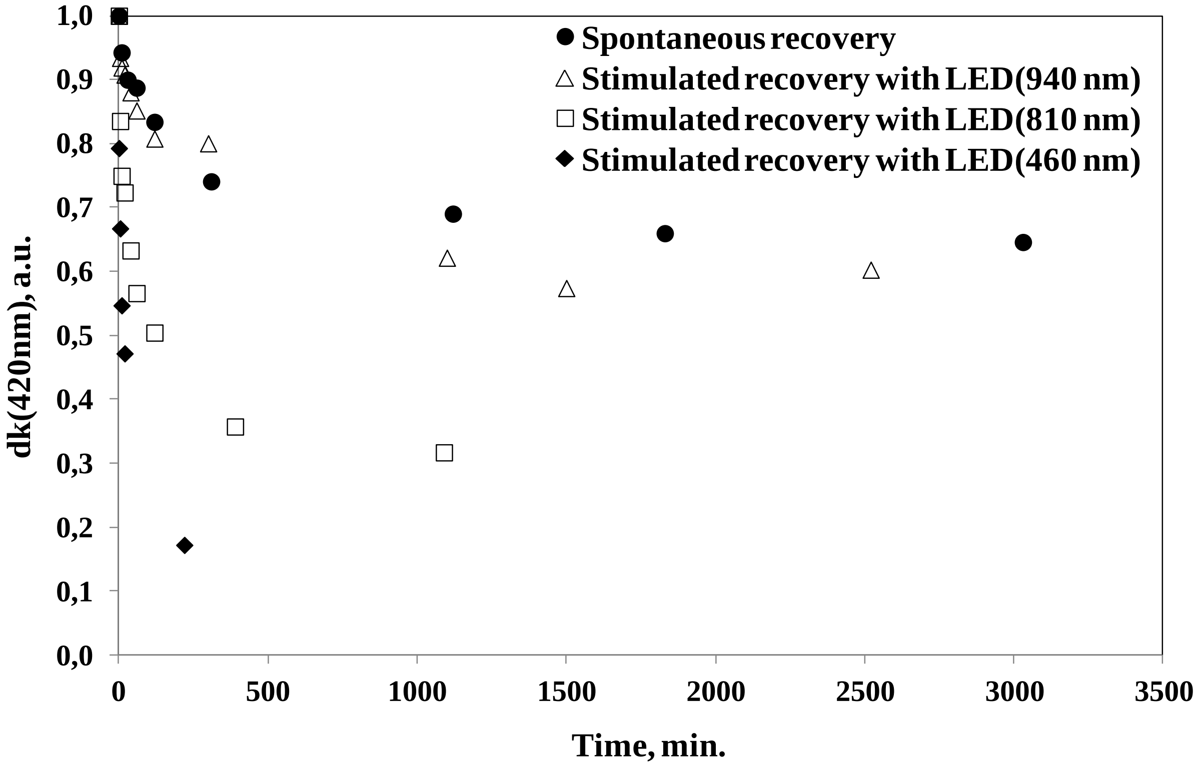

Figure 4. Stimulated recovery of the normalized radiation induced coefficient at 420nm for a heavy-doped DSB: Ce sample after an integral dose of 500Gy using optical photons of selected wavelengths measured at room temperature.

4. Conclusions

The radiation damage of new DSB: Ce scintillating glass quantified by the change of the optical transmission was investigated. It was found that heavy-doped glasses show a extremely high radiation resistance. It was observed for the first time that the radiation damage in Ce-doped scintillators can be recuperated by illuminating the samples with optical photons.

Acknowledgement

The authors thank Radiation Instruments and New Components LLC (Belarus) for providing the samples.

References

[1] E. Auffray, A. Barysevich, A. Fedorov, M. Korjik, M. Koschan, M. Lucchini, V. Mechinski, C.L. Melcher, A. Voitovich, Radiation damage of LSO crystals under γ- and 24 GeV protons irradiation. Nuclear Instr. and Meth. in Physics Res. **A721** (2013) pp.76-82.

[2] E. Auffray , M. Korjik, A. , Experimental Study of Lead Tungstate Scintillator Proton-Induced Damage and Recovery. IEEE Trans. on Nucl. Sci, **59** (2012) pp. 2219-2223.

[3] J. Chen, L. Zhang, R.-Y. Zhu, Large size LSO and LYSO crystal scintillators for future high-energy physics and nuclear physics experiments. Nuclear Instr. and Meth. in Phys. Res.

A572 (2007) pp.218-224.

[4] E. Auffray, A. Fedorov, M. Korjik, M. Lucchini, V. Mechinski, N. Naumenko, A. Voitovich, Radiation Damage of Oxy-Orthosilicate Scintillation Crystals Under Gamma and High Energy Proton Irradiation. IEEE Trans. on Nucl. Sci. **61** (2014) pp. 495-500.

[5] Baker Hughes International Information, 2013.

[6] A. Borisevich, V. Dormenev, T. Kuske, M. Korjik, S. Lugert, V. Mechinski, O. Missevitch, R. W. Novotny, A. Fedorov, Stimulated recovery of the optical transmission of $PbWO_4$ scintillation crystals for electromagnetic calorimeters after radiation damage. Nucl. Instr. and Meth. in Physics Res. **A623** (2010) pp. 1082-1085.