STUDY OF SCINTILLATION STABILITY IN KBR, YAG:CE, CAF_2:EU AND CSI:TL IRRADIATED BY VARIOUS-ENERGY PROTONS *

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Abstract

The luminescence of KBr, YAG:Ce, CaF_2:Eu and CsI:Tl scintillators induced with H_2^+ ion beams in the energy range of 600-2150 keV/u has been systematically measured as a function of irradiation time. The measurements showed that the luminescence of CsI:Tl and YAG:Ce remained constant within the 1-hour continuous irradiation. An initial fast drop of the luminescence on CaF_2:Eu was observed but the light output eventually approached a stable state under constant ion bombardment. We also observed that the light output of KBr initially increased and then degraded gradually with further irradiation. The CsI:Tl screen produced the highest scintillation yield and KBr the lowest.

INTRODUCTION

The wide use of scintillator screens in beam profile measurements and pepper-pot emittance systems has motivated a number of studies [1-4] on the scintillation stability under ion irradiation. The scintillation degradation caused by radiation damages can deteriorate the accuracy of beam width and emittance measurements. The degradation of luminescence can be attributed to many factors, some of which are related to the nature of the scintillator materials, the accumulated fluence, and the energy of bombarding particles. In a previous work [5], we have reported that the scintillation yield of single crystal YAG: Ce was significantly degraded under low-energy (28-58 keV) He^+ irradiation. By using the Birks model, we explained that the decrease of the observed light yield in YAG:Ce is the result of a competition between the creation of luminescence photons and displacement damage defects. The model allows to quantitatively explain how the degradation time depends on the bombarding energy in the low radiation energy range. The degradation of scintillation yield is reduced as the beam energy increases under low-energy bombardments.

In this report, our measurements were focused on investigating the scintillation stability of KBr, YAG:Ce, CaF_2:Eu and CsI:Tl single crystals under H_2^+ irradiation at the energies of 600-2150 keV/u. The scintillation materials and their optical properties [6] are listed in Table 1 together with their manufacturers and dimensional sizes. The choice of these materials was based on their availability and common use as diagnostics in low energy accelerators delivering low intensity beams.

Table 1: The Scintillator Materials under Study

Material	CsI:Tl	CaF_2: Eu	YAG: Ce	KBr
Density (g/cm^3)	4.51	3.18	4.55	2.74
Light yield photons/MeV	55,000	24,000	16,700	----
Thickness (mm)	1	1	1	2
Diameter (mm)	19	19	18	19
Manufacturer	SGC	SGC	MII	ICL

SGC: Saint-Gobain Crystals [7]
MII: Marketech International Inc. [8]
ICL: International Crystal Laboratory [9]

EXPERIMENTAL SETUP

The irradiation experiments were performed at the rare isotope ReAccelerator (ReA) facility of the National Superconducting Cyclotron Laboratory (NSCL) in Michigan State University (MSU). A H_2^+ beam from a stable ion beam injector was accelerated by a room temperature RFQ and the SRF linac, and then delivered to the scintillator target chamber installed in the ReA experimental hall, as shown in Fig. 1. The four different scintillator materials were held on a rotating target wheel inside the chamber under vacuum. A CCD camera (PCO

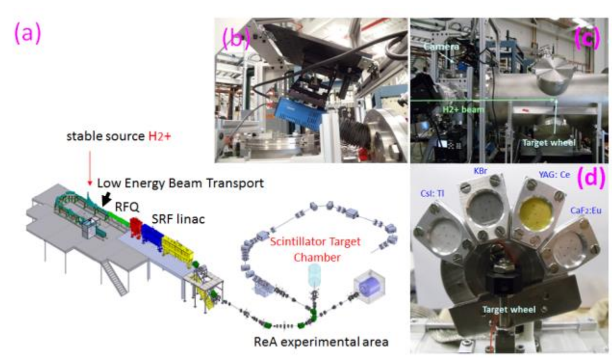

Figure 1: (a) Layout of the beam delivery to the scintillator target chamber in the ReA facility of NSCL. The experimental setup consists of (b) a CCD camera, (c) a target chamber and (d) a target wheel with four different scintillator screens.

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1600) [10] mounted outside of the target chamber was used to record the light emitted from the scintillator screens in time increments of 4 seconds during ion irradiation. The width of the beam spots was about 5 mm and the beam current was not higher than 400 pA in order to prevent sample heating. The light yield for each measurement presented in this report was obtained by integrating the light output in a region of interest which was chosen to be the central brightest region of the irradiated beam spot. To allow the comparison of scintillation yield under varying scintillator materials and beam energies, the light yield was normalized by the beam current and camera exposure time.

RESULTS AND DISCUSSION

The initial beam spot observed from KBr, YAG:Ce, CaF_2:Eu and CsI:Tl under the same irradiation energy is compared in Fig. 2. Among the investigated materials, CsI:Tl produced the highest light yield and KBr produced the lowest. Due to the different light sensitivity for the materials under ion bombardment, the beam current was adjusted for each scintillator material to avoid blurring of the beam spot images due to photon scattering inside the crystal.

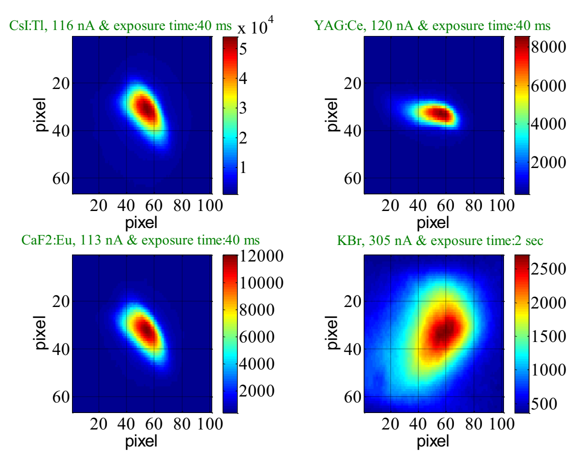

Figure 2: The initial beam spot image on CsI:Tl, CaF_2:Eu, YAG:Ce and KBr under H_2^+ irradiation at the beam energy of 2150 keV/u.

In Fig. 3, the scintillation response for CsI:Tl and YAG:Ce materials is shown as a function of irradiation time. In the investigated beam energy range of 600-2150 keV/u with less than 400 pA of beam current, a constant light output is observed from these two screens during 1-hour irradiation. The stable light yield suggests that the transparency loss of the scintillation photons inside the irradiated scintillators is negligible in the energy range and low radiation fluence of this study.

On the other hand, M. García-Muñoz et al. [11] have reported scintillation degradation of YAG:Ce during the irradiation of the deuterium ions and α-particles with the energies of 0.47-3MeV and the beam current of 30-60 nA. In addition, our previous study [5] showed that the YAG:Ce scintillator will rapidly degrade under He^+ irradiation at the beam energies of 28-58 keV and beam current of 100-500 pA. Thus it is important to note that the scintillation deterioration caused by radiation damages can be significant under low-energy or high-fluence irradiation.

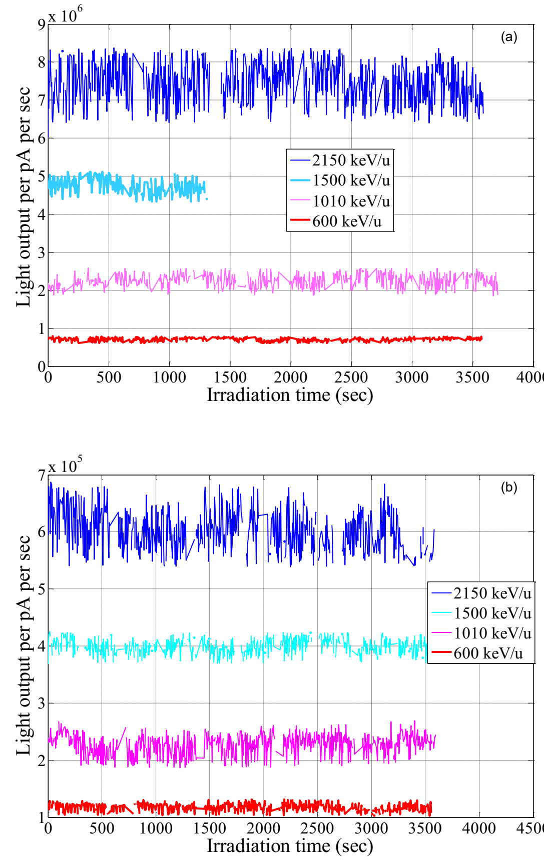

Figure 3: Light yield of (a) CsI:Tl and (b) YAG:Ce as a function of irradiation time at H_2^+ beam energies of 600-2150 keV/u.

Figure 4 shows the luminescence intensity of CaF_2:Eu as a function of irradiation time at the H_2^+ beam energies of 600-2150 keV/u. The light yield of CaF_2:Eu significantly drops in the beginning of irradiation and then approaches constant luminescence as irradiation continues. Figure 4 also shows that the initial degradation of CaF_2:Eu luminescence caused by irradiation cannot be recovered through a 10-minute radiation break. One of the suspected causes for a rapid initial decay in CaF_2:Eu luminescence may be due to a change of the charge state of the luminescence centers by energy transfer in CaF_2:Eu [12].

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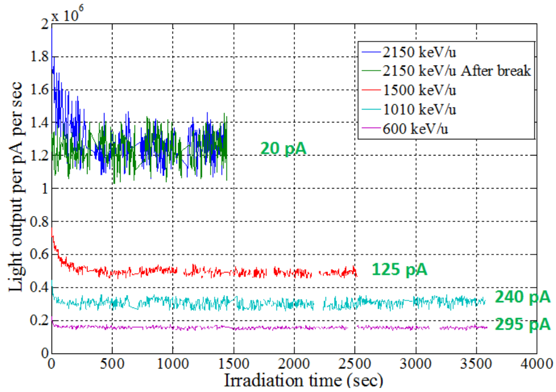

Figure 4: Light yield of CaF_2:Eu as a function of irradiation time at H_2^+ beam energies of 600-2150 keV/u. For 2150 keV/u, after 24-min irradiation (blue curve), a 10-min break was applied and followed by 24 minutes of the second-time irradiation (green curve).

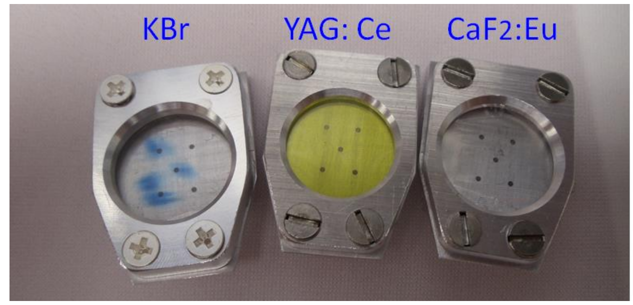

Figure 6: The KBr, YAG:Ce and CaF_2:Eu samples after ion irradiation. The KBr crystal shows damaged spots in blue colour.

The scintillation yield of KBr irradiated with H_2^+ ions at the beam energies of 600-2150 keV/u is plotted as a function of irradiation in Fig. 5. Among the investigated scintillators, the KBr is the only scintillator material that shows a relatively fast increase in the light yield in the beginning of H_2^+ irradiation, followed by a gradually decay. Since there is a region where luminescence intensity of KBr increases as a function of irradiation time, it indicates that the centers responsible for KBr luminescence are created by ion bombardment. Indeed, when the KBr sample was examined after irradiation, it was found that the irradiated areas on the KBr sample turned blue, as shown in Fig. 6, which adds evidence that color centers were created in the crystal during irradiation. It is known that F-centers in KBr can produce a band of optical absorption around 600 nm [13]; thus the blue color appeared on the irradiated spots demonstrates the F-center formation. The combination of F-centers with V-centers would be responsible for KBr luminescence [14].

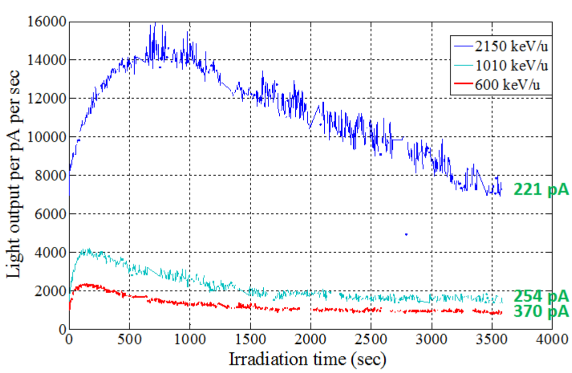

Figure 5: Light yield of KBr as a function of irradiation time at H_2^+ beam energies of 600-2150 keV/u.

CONCLUSION

KBr, YAG:Ce, CaF_2:Eu and CsI:Tl scintillator materials were investigated under H_2^+ irradiation for the beam energies from 600 to 2150 keV/u. CsI:Tl is the most sensitive material among all the investigated scintillators. The luminescence of YAG:Ce and CsI:Tl exhibits a stable behaviour under the beam energy and total particle fluence used for this measurements. For CaF_2:Eu scintillator, scintillation degradation at the beginning of irradiation was observed but then a constant luminescence during consequent irradiation was measured. Due to the radiation with bombarding ions, the KBr material shows noticeably radiation damages on the sample and an unstable behaviour in the light yield. The results of this study are essential for choosing a suitable scintillator screen to achieve precise beam width and emittance measurements at the rare isotope ReAccelerator facility. Further analysis and discussion will be presented in a future publication.

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