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Light output and decay curve of GSO:Ce under electron, proton, alpha particle and fission fragment excitations

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Abstract

The relationship between the scintillation efficiency and the specific-energy loss as well as the decay curves of the GSO:Ce crystals with the Ce concentrations of 0.25, 0.5, 1.5 and 2.5 mol% have been investigated under the irradiation of high-energy electron, proton, alpha particle and the fission fragment excitation. The relationship observed in the GSO:Ce crystals is found to be independent from the Ce concentration, and is explained in terms of the concept of ionization quenching proposed by Birks. The quenching efficiency B of GSO:Ce is found to be about 0.005 ($\mathrm{g\,cm^{-2}}$/MeV). The measured decay curves showed the independence of the decay curves for excitations of electrons, alpha particles and fission fragments.

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Keywords: GSO scintillator; Specific energy-loss (dE/dx); Scitnillation efficiency; Decay curve

1. Introduction

Among the various types of inorganic scintillators applied heavy ion detection GSO:Ce crystal has been considered a promising candidate, since it shows a sufficiently high-energy resolution, high density and being free from hygroscopicity [1,2]. However, in general, it is well known that the scintillation efficiency in many scintillators tend to be decreased for high specific energy-loss (dE/dx) particles.

Namely, the linearity of light output is lost at high dE/dx region. It was also reported previously that GSO:Ce is also subject to this characteristic [1,2], which is a serious problem for using this

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particular inorganic scintillator as calorimeter for heavy ions.

To investigate the decrease of scitntillation efficiency (dL/dE) of GSO:Ce, we measured light output and decay curve of GSO:Ce crystal with various Ce concentrations for various charged particles (various dE/dx). The high-specific-ionization-density effect on scintillation processes in GSO:Ce, induced by excitations of heavy charged particles, were discussed in the present work.

2. Experimental procedures

All the sample crystals of GSO:Ce investigated in the present work were produced by Hitachi Chemical Co., Ltd. In the process of the crystal growth, the starting materials of Gd_2O_3, SiO_2 and CeO_2 were mixed at stoichiometric composition, and then were crystallized in an iridium crucible in nitrogen atmosphere by Czochralski method. By changing the mixing ratio of CeO_2 in the starting materials, GSO:Ce crystals with four different value concentrations of Ce, 0.25, 0.5, 1.5 and 2.5 mol% (denoted as Gd_2-$x$$SiO_5$: Ce_x, where $x=0.25$, 0.5, 1.5 and 2.5) were prepared for this work. The crystal sizes with $x=0.25$, 0.5, and 1.5 mol% were about $5\times6\times10\,m^3$, and that with $x=2.5$ mol% about $3\times3\times20\,mm^3$.

In order to cover a wide range of dE/dx, fast electrons, protons, alpha particles, and fission fragments were used in the present work. A low dE/dx field of the electrons were generated by converting the 0.662 MeV gamma rays emitted from a ^{137}Cs source to the energetic electrons through Compton scattering and/or photoelectric effect in a GSO:Ce crystal. A slightly high dE/dx field was generated by protons with the Cockcroft-Walton accelerator of Rikkyo University. The proton was produced via ^{3}He(d,p)^{4}He reactions with the 200 keV ^{3}He beam impinging on a D_2 target in a vacuum chamber. The energy of the protons was measured to be 14.4 ± 0.1 MeV at the GSO:Ce crystal position. The 14.4 ± 0.1 MeV protons were degraded to10.8 ± 0.2, 8.0 ± 0.3, 5.2 ± 0.4 and 3.1 ± 0.7 MeV by using aluminum absorbers of 0.5, 0.8, 1.0 and 1.1 mm thick, respectively. A high dE/dx field was generated by 5.5 and 6.1 MeV alpha particles from a ^{241}Am and ^{252}Cf source, respectively. Lastly, an extremely high dE/dx field was generated by fission fragments emitted from a ^{252}Cf source.

The scintillation light outputs of the GSO:Ce crystals were measured with photomultiplier tube (Hamamatsu photonics H1949). The anode signals from the photomultiplier were integrated with an RC circuit in an emitter-follower-type charge sensitive amplifier, whose time constant was about 1 μs. The output pulse was then sent to a linear amplifier (ORTEC 571), whose differential and integral times constants were 1 μs. The amplified pulses were delivered to a multi-channel analyzer for pulse height analysis.

Decay curves of the GSO:Ce scintillation for the electrons, the alpha particles and the fission fragments were measured by using a digital oscilloscope of Tektronix 784A. The scintillation photons were detected with the same photomultiplier. The anode signals were fed to the digital oscilloscope with a 50 Ω impedance termination, where the decay curves were acquired by averaging 10,000 decay signals.

3. Results

Fig. 1 shows the dL/dE values derived for the GSO:Ce crystals with $x=0.25$, 0.5, 1.5 and

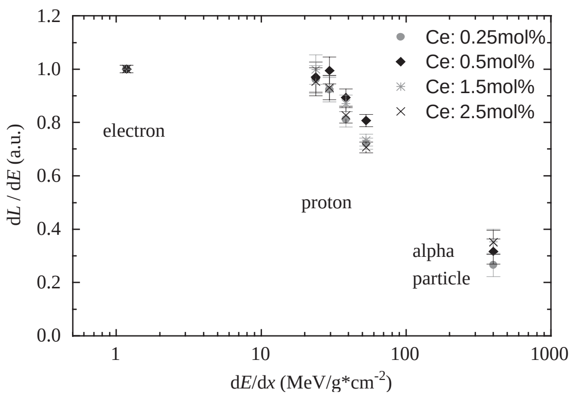

Fig. 1. The dL/dE of GSO:Ce with 0.25, 0.5, 1.5, 2.5 mol% of Ce as a function of dE/dx. Values of dL/dE were normalized to that under electron excitations.