Optical Materials 35 (2013) 1179–1183

Contents lists available at SciVerse ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat

Fluorescence emission from CsI(Tl) crystal induced by high-energy carbon ions

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ARTICLE INFO

Article history:
Received 14 November 2012
Received in revised form 3 January 2013
Accepted 7 January 2013
Available online 1 March 2013

Keywords:
High-energy carbon ions
CsI(Tl) crystal
Fluorescence emission
Scintillator detector

ABSTRACT

The fluorescence emission from a CsI(Tl) scintillator crystal induced by high-energy carbon ions with the energy range from 148 AMeV to 207 AMeV has for the first time been investigated at Heavy Ion Research Facility at Lanzhou (HIRFL). In this work, the light output of ultraviolet (around 377 nm) and visible (around 498 nm and 573 nm) bands have been measured. The variations between the fluorescence intensity of each emission component and incident energy are described by linear fitting. The results show that short-wavelength light (ultraviolet band) is conducive to calibrate the CsI(Tl) scintillator detector. Simultaneously, relevant parameters of the different emission components are also introduced.
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1. Introduction

The thallium activated caesium iodide (CsI(Tl)) scintillation crystals are used as detectors in nuclear physics in order to measure the photon and charged nuclear fragment energy, allowing at the same time the charged particle identification. The crystals have the advantages of high light output, little afterglow, sufficient stopping power ($\rho = 4.51$ g/cm^3), large detection area, and low cost. They provide an effective technology for detecting charged particles [1–7], and they have been applied in many large solid angle detection arrays [8–10]. Moreover, the optical and luminescent properties of the CsI(Tl) crystals have drawn considerable concerns, in which it may be interesting to study the absorption and emission spectra and their dependence on different physical quantities by trying to understand the luminescence mechanisms [11–13].

The spectrum studies of the CsI(Tl) crystal are often done at room temperature for photons, electrons and light charged ions like protons and alpha particles. The information on the nature of the luminescent centers and on the energy transport mechanism inside the crystal can be obtained in these studies. The information is precious for both nuclear and material physics. The study of emission spectrum induced by a heavy ion like carbon ion, used in our days in hadron-therapy too, as a function of its incident energy, is an interesting topic for both the development of the nuclear physics detector and the determination of new optical properties of the alkali halides and the consequent applications. It is well known that the light response of a CsI(Tl) crystal shows a non-linear correlation in low energy regime, especially for heavy ions; while the energy dependence of the light output is linear in intermediate energy regime [14–17]. Mastinu et al. have introduced a fitting procedure to the linear relation, and the experimental results also show an excellent linear relationship between the light output and projectile energy [15]. Besides, if the incident particle is an electron or a γ-ray with energies higher than 100 keV, the energy dependence of the light output shows a good approximation as a linear correlation [18,19]. For a given energy, the light output of the CsI(Tl) crystal sensitively depends on the type of the incident particle [20]. For a long time, the fluorescence emission on CsI(Tl) crystal and light-to-energy relation have drawn considerable attentions [21–24]. However, there is a general lack of experimental data at high energies in the literature.

The primary objective of this work is to obtain the fluorescence emission spectra of the CsI(Tl) crystal and the relationship between the light output and the incident energy at high energies. The emission spectra of the CsI(Tl) scintillator crystal were measured in the wavelength range of 300–700 nm. The emphasis will be given to the structure of the emission spectra and the energy dependence of the light output for the characteristic emission bands both in the ultraviolet band and the visible band.

2. Experimental setup

The experiment was performed at the Cancer Therapy Terminal of the Heavy Ion Research Facility at Lanzhou (HIRFL). The upgraded accelerator system of HIRFL consists of Sector Focus Cyclotron (SFC), Separated Sector Cyclotron (SSC), the main Cooling

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http://dx.doi.org/10.1016/j.optmat.2013.01.010

Storage Ring (CSRm), and the experimental Cooling Storage Ring (CSRe) [25,26]. The high-energy carbon ions with energy of 207 AMeV were extracted by CSRm. The energies of 148 AMeV and 179 AMeV were obtained by adding the absorbers (water) and calibrated by using the LISE program [27], and the corresponding uncertainty of the energies is no more than 0.22%. The extraction time of the carbon ions (about 10^7–10^8 ions/pulse) was about 3 s and the beam size was about 15 mm × 15 mm. Fig. 1 shows the energy loss of the carbon ions in the crystal calculated by the SRIM2010 program [28]. In this figure, the beam-energy regime is located in the shadow region, where the energy loss decreases with the increasing of incident energy.

The schematic view of experimental setup is shown in Fig. 2. After penetrating a series of absorbers, the mono-energetic carbon ions from the accelerator impinged on the CsI(Tl) crystal with an incidence angle of 45°. The CsI(Tl) crystal with 5-mm thickness and 4.51-g/cm^3 density was provided by the scintillator group of the Institute of Modern Physics (IMP), Chinese Academy of Sciences, the doping concentration of Tl was chosen as 0.15 mol% since the light output has basically reached saturation at such a doping concentration, which has been tested in an experiment before (see Ref. [29], Annual Report [30] for details). It is noted that the ultraviolet emission peak at about 320 nm of a pure CsI crystal will disappear at such a doping concentration [21]. In addition, the crystal used in our experiment was cut from the center of a big bulk crystal.

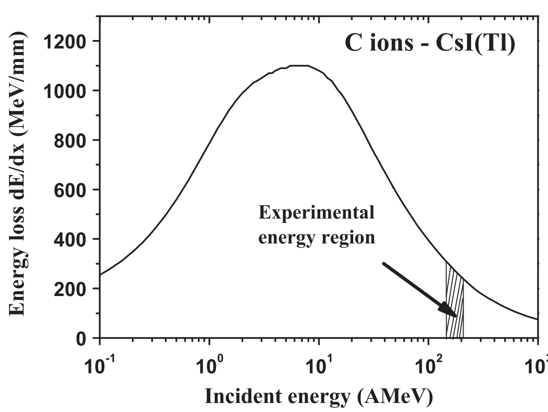

Fig. 1. Energy loss of the carbon ions in CsI(Tl) crystal. The shadow region is the range of the selected energy in the present work.

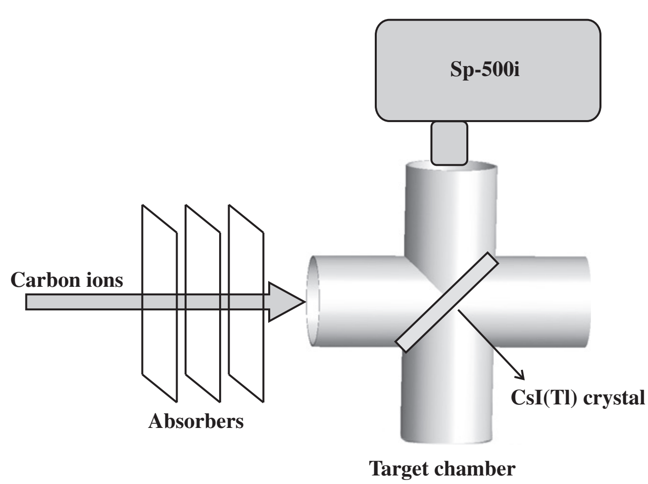

Fig. 2. Experimental setup. The CsI(Tl) crystal and the spectrometer was positioned at 45° and 90° with respect to the incident ion beam, respectively.

A Spectrapro-500i (Sp-500i) monochromator with a 500-mm focal length produced by Acton Research Corporation (ARC) and coupled with a CCD (charge coupled device), was employed in the experiment. The Sp-500i was mounted at 90° with respect to the incident beam to collect and record fluorescence signals. During the experiment, the grating of the Sp-500i was selected as 150 g/mm with the blaze wavelength of 500 nm and the resolution of 0.05 nm at 435.8 nm. The dispersion is 1.7 nm/mm. The effective scanning range is from 185 nm to far infrared. The accuracy is ±0.2 nm. The time of exposure is set as 10 s. All the measurements were performed at room temperature.

3. Results and discussion

Fig. 3a and b shows typical fluorescence emission spectrum in the wavelength range of 300–700 nm for 179 AMeV carbon ions with flux of 10^7–10^8 ions/pulse impinging on the CsI(Tl) crystal. After the correction of efficiencies of the grating and the CCD, the measured spectrum was normalized to the number of incident carbon ions. At room temperature, the emission spectrum of a CsI(Tl) crystal excited by charged ions is dominated by a broad yellow band, centered about 550 nm [18]. In the present work, however, the fluorescence spectrum contains two emission bands: the ultraviolet band with central wavelength at 377 nm and the visible band with central wavelengths at 498 nm and 573 nm. The ion-induced ultraviolet band, which was seldom reported in the literatures before, is attributed to the electronic transitions from trigonal and tetragonal Jahn–Teller minima of the triplet relaxed excited state of Tl^+ [23]. As a comparison, the fluorescence emission spectrum from the same CsI(Tl) crystal induced by X-rays with

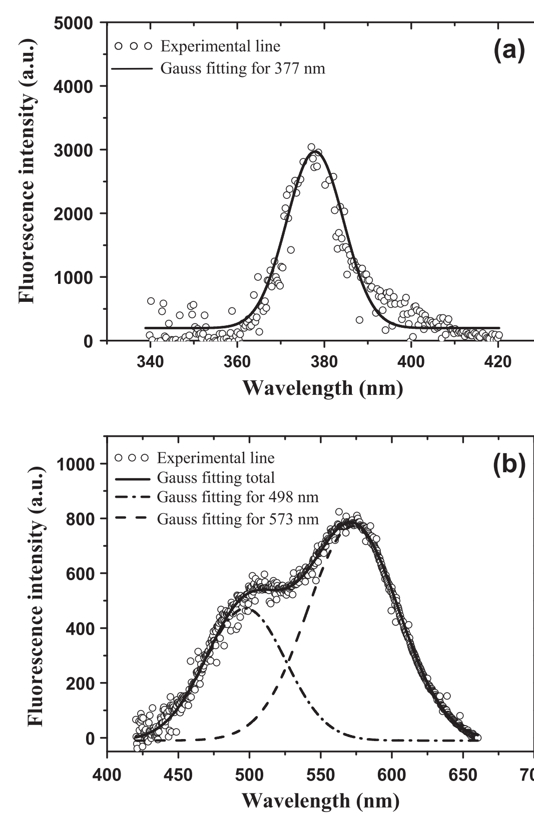

Fig. 3. Fluorescence emission spectrum measured during 179 AMeV carbon ions impacting on a CsI(Tl) crystal. (a) 377 nm emission. (b) 573 nm and 498 nm emission.

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