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TL response of Eu activated LiF nanocubes irradiated by 85 MeV carbon ions

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ABSTRACT

Carbon ions were found to be effective for cancer treatment. These heavy ions have a high relative biological effectiveness compared to those of photons. They have higher linear energy transfer and sharper Bragg peak with a very excellent local tumor control. However, the dose of these swift heavy ions needs to be measured with great accuracy. Lithium fluoride (LiF) is a highly sensitive phosphor widely used for radiation dosimetry. In this work Eu activated LiF nanocubes were exposed to 85 MeV C^{6+} ion beam and evaluated for their thermoluminescence (TL) response. Pellet forms of this nanomaterial were exposed to these ions in the fluence range 10^9–10^{13} ions/cm^2. The obtained result shows a prominent TL glow peak at around 320 °C, which is different than that induced by gamma rays. This glow peak exhibits a linear response in the range 10^9–10^{12} ions/cm^2, corresponding to the equivalent absorbed doses 0.273–273 kGy. The absorbed doses, penetration depths and main energy loss were calculated using TRIM code based on the Monte Carlo simulation. The supralinearity function and stopping power in this nanomaterial were also studied. The modification induced in the glow curve structure as a result of changing irradiation type might be utilized to use LiF:Eu nanocubes as a dosimeter for mixed filed radiations. Moreover, the wide linear response of LiF:Eu nanocubes along with the low fading are another imperative results suggesting that this nanomaterial might be a good candidate for carbon ions dosimetry.

1. Introduction

Nanoscale materials with different shapes have been produced and studied by large number of researchers. That is because of their superior optical, electrical, magnetic and mechanical properties. Different nanostructures could be produced and their properties were investigated in more details [1–6]. Moreover, large numbers of these nanostructures were evaluated for different applications. These applications include dosimetry of sparsely and densely ionizing radiations [7–14]. Different thermoluminescent nanostructures were studied in the last few years by different groups. These include $CaSO_4$ nanorods [9], ZnO nano-needle [10], $K_2Ca_2(SO_4)_3$:Eu nanocrystalline [11], $Ba_{0.88}Sr_{0.12}(SO_4)_{99.8\%}$:$Eu_{0.2\%}$ nanophosphor [12], Mg_2SiO_4:Eu^{3+} nanocrystalline [13] and $YAlO_3$:Ni^{2+} nanophosphors [14]. The reported results on these nanostructures showed that they have excellent thermoluminescent (TL) dosimetric properties, particularly their response in a wide span of exposures. However, evaluating these nanostructures for their TL response to C ion beam that recommended for cancer treatment is rarely appeared.

Swift heavy ion beams were recently recognized to be effective in radiotherapy and diagnostic applications [15–17]. These ion beams have superior properties for cancer treatment in comparison with the conventional photons irradiation [18–20]. They have a high relative biological effectiveness compared to those of protons or photons. Moreover, their linear energy transfer (LET) is higher with a sharper Bragg peak. The absorption at the tumor position can be maximized by projecting the penetration depths of those ions [21]. Carbon ions were identified to be the most suitable ions, because they cause a cellular damage of different type than do protons and photons [21]. The linear energy transfer (LET) is large i.e. these ions can deliver a larger mean energy per unit length of their trajectory in the body. This unique property provides high local tumor control when used in radiotherapy. Carbon ions were reported to cleave double-stranded DNA at multiple sites even at low oxygen content, which allows access to hypoxic parts of tumors that would be resistant to low LET

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radiotherapy [22,23]. These ions were also reported by Surdutovich–Solovyov group to induce secondary electrons that are responsible for DNA damage [24]. This group has also studied the energy deposition and DNA damage mechanisms by carbon ion beams [25]. However, for using these ions in radiotherapy application their doses needs to be estimated and measured with great precision and accuracy.

TL dosimeters as sensitive and cheap materials might be a good choice for dose verification, particularly of heavy ions irradiation like C ions. The dose response of such TL materials is different between sparsely ionizing radiation (i.e. X-ray or γ-ray) and densely ionizing radiation (swift heavy ions). This different behavior was reported to occur as a result of different spatial dose distribution, which causes early saturation in the case of densely ionizing radiation [26]. From the other hand several nanostructure materials showed saturations at very high doses [7,8] and thus might be the ultimate choice for ion beam dosimetry, mainly carbon ions. But, these studies were focused on the TL response of high effective atomic number (Z) materials.

Low effective atomic number material with values close to that of biological tissue (7.4) are preferred for radiation dosimetry, particularly in radiotherapy. One of them is lithium fluoride (LiF), which is a well-known highly sensitive material, widely used in radiation dosimetry. The effective atomic number of this material is 8.14, which is close to that of the biological tissue. For better sensitivity LiF needs to be doped with proper impurities like Mg:Mg,Cu,P in LiF single crystals [27]. The nanostructure form of LiF:Mg,Cu,P was produced for the first time by Salah et al. [7]. They have evaluated its TL response to gamma rays in a wide dose range. It was found that this material in nano form is sensitive to gamma rays in the range 0.1 Gy–10 kGy. Recently, other activators were also incorporated in LiF nanostructure [28]. Europium doped one was observed to be the most TL sensitive to gamma rays. Therefore, it is of great importance to evaluate the TL response of LiF:Eu nanostructure to carbon ion in a wide fluence range.

In the present work LiF:Eu nanocubes were produced by the chemical precipitation method and evaluated for their TL response to carbon ions. Pellet forms of this nanomaterial were exposed to 85 MeV C^{6+} ion beam in a wide fluence range 10^9–10^{13} ions/cm^2. The obtained TL glow peaks were compared with those induced by gamma rays [28]. The absorbed doses, penetration depths and main energy loss were calculated using TRIM code based on the Monte Carlo simulation [29]. The Supralinearity function and stopping power in this nanomaterial were also studied.

2. Experimental

Europium (Eu) doped LiF nanocrystalline samples were synthesized by the chemical co-precipitation method. They were produced by the method described earlier [28]. Formation of the nanocubes was confirmed by taking SEM images using a field emission scanning electron microscopy (FESEM), JSM-7500 F (JEOL – Japan). For C ion beam irradiation the nano powder samples were prepared in pellets form. The procedure for making pallets and ion beam irradiation was described earlier in more details [8]. The prepared pellets were of 1.38 mm (1380 μm) thickness and 10 mm diameter. They were prepared by taking 100 mg of the sample and 2 mg of Teflon powder. After mixing them together they were put in a die, and applying 0.2 t/cm^2 pressure by a manual hydraulic press. The formed pellets were annealed at 300 °C for 1 h in nitrogen atmosphere. This annealing is useful to anneal out the deformations, if any, due to applied stress. The C ion beam irradiation was carried out using a 16 MV Tandem Van de-Graff-type electrostatic pelletron accelerator at the Inter University Accelerator Center (IUAC), New Delhi, India [30]. The ion beam fluence range is 10^9–10^{13} ions/cm^2. For taking TL of the C ion beam irradiated samples the irradiated surface of the pellet was kept facing upward toward the detector of the Harshaw TLD reader.

3. Results and discussion

Fig. 1 shows SEM images at different magnification of the as synthesized LiF powder. These images show cubic structures with sizes ranging from approximately 20 to 90 nm. This result is similar to that reported earlier [28]. The produced nanostructures have well defined shapes and a good particle size distribution. These images show also that there is no agglomerations or clusters formation in the as produced nanocubes.

Fig. 2 shows TL glow curves of LiF:Eu nanocubes exposed to different fluences of 85 MeV C^{6+} ion beam. The curves a–f are of the samples exposed to the fluences in the range 10^9–10^{13} ions/cm^2. As can be seen in these curves that there is a prominent glow peak at around 320 °C beside three smaller humps at around 125, 200

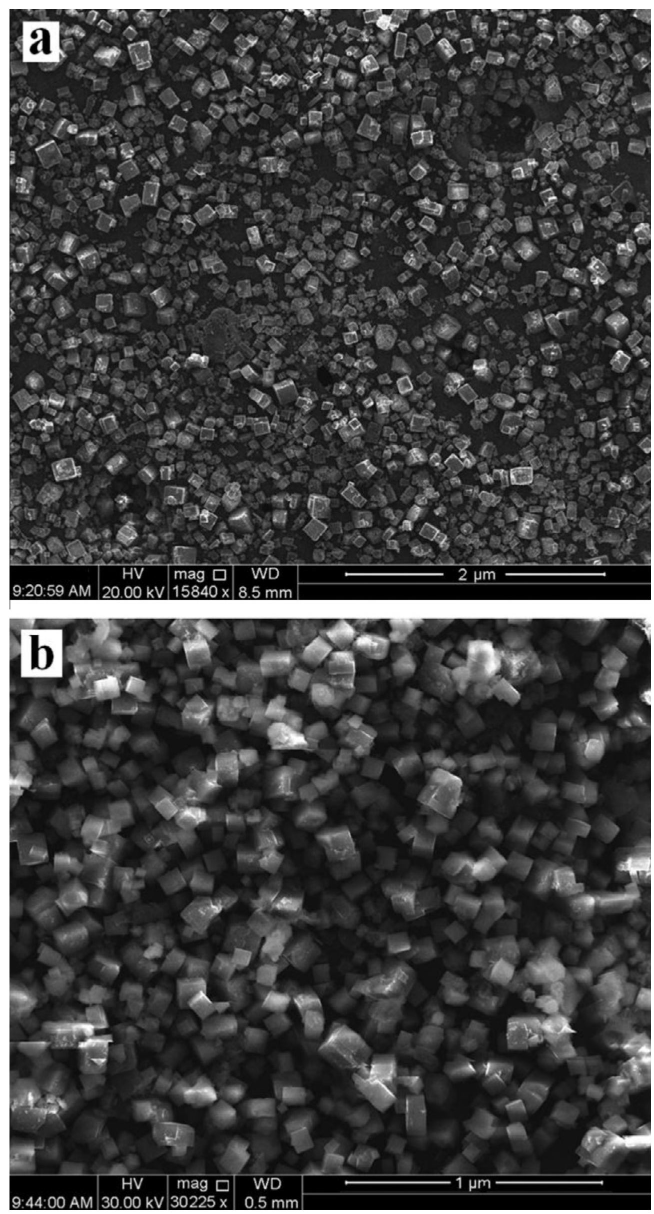

Fig. 1. SEM images at different magnifications of the as-synthesized LiF:Eu nanocubes.