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Nanoparticles of $CaSO_4$:Dy as a sensitive TL Material for 100 MeV O^{7+} Swift Heavy Ions

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Abstract. $CaSO_4$:Dy nanoparticles synthesized by chemical co-precipitation method was irradiated with 100 MeV O^{7+} Swift Heavy Ions (SHI) in the fluences range from 1 x 10^{11} to 5 x 10^{12} ion/cm^2. An XRD spectrum shows the orthorhombic phase with crystallite size around 65 nm. The TL dosimetric peak appeared at 554 K which seems to be a deep level trap co-related with good linear dose response. These nanoparticles also revealed the good sensitivity along with low fading (4.3 % for 2 months). Finally, this results suggest that $CaSO_4$:Dy nanoparticles can be used for the ion dosimetry.

INTRODUCTION

Ion beam techniques are very prevailing tools in materials modification technology due to their high flexibility and possibility to control the beam parameters like energy, fluence, beam size and position which in turny used to tailor the materials properties. Low and high energy ion beams have numerous uses mostly in material science, nuclear physics, medical sciences and biological sciences [1]-[3]. Especially, in medical areas, ion beam radio-therapy has grown significantly [4]. Moreover, using carbon SHI irradiation, Thermoluminescence dosimetric areas are achieved in few steps [5][6].

For any nuclear installation system, personal monitoring of radiation workers is a performance-based task of that institution, industries, R & D section etc. and dosimetry is one of the prominent way to detect the ionizing radiation. In the dosimetric field, the use of thermoluminescent (TL) materials is specifically used for the purpose of radiation measurements and requirement of material is showing Z_{eff} values close to biological tissue (i.e. Z_{eff} = 7.4). Therefore, low Z_{eff} phosphor materials (LiF: Mg, Cu, Ti) are strongly recommended due to the smooth response for the radiation energy, but regrettably such materials show a poor sensitivity and fading. So that their performances are not much satisfactory for low radiation doses and, therefore, TL materials with higher values of Z_{eff} i.e. $CaSO_4$ and CaF_2 can be effectively used as a dosimetry [7].

The present study, reports the TL properties of $CaSO_4$:Dy nanoparticles (NPs) for 100 MeV O^{7+} SHI irradiation. Here, $CaSO_4$:Dy NPs chosen for not being an equivalent tissue material, but its wide TLD applications for different ionizing radiations [8-12] and its own quality of easy preparation, high sensitivity, lower cost and simple processing. A method called chemical co-precipitation has been adopted to prepare $CaSO_4$:Dy NPs embedded with Teflon powder and compacted to a very thin pellet to use as a TLD element. Further these TLD elements have been irradiated with 100 MeV O^{7+} and characterized by XRD for structural analysis and TL for dosimetric applications.

EXPERIMENTAL DETAILS

The $CaSO_4$:Dy (1 mol %) NP was prepared by chemical co-precipitation method as already explained in our previous article [9]. Prepared NPs was sintered at 700 °C for 2 hr and the calculated amount of Teflon powder was

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subsequently added and mixed using the pestle mortar. Using hydraulic pellet press machine, ~ 0.05 cm thick pellets were prepared for further irradiation. The pellets were mounted on a hexagonal shaped copper ladder, placed inside the vacuum chamber ($\sim 10^{-6}$ torr), and then irradiated with 100 MeV O^{7+} SHIs at different fluences from 1 X 10^{11} ion/cm^2 to 5 X 10^{12} ion/cm^2. The irradiated $CaSO_4$:Dy NP pellets were examined using the Nucleonix TL reader with the heating rate of (β) = 5 °C/sec.

RESULTS AND DISCUSSION

X-Ray Diffraction Analysis

The XRD spectra of $CaSO_4$:Dy NPs shown in Fig. 1, revealed the orthorhombic phase showed peaks of (200), (012), (220), (202), (212), (311), (103), (032), (400) and (232) which is well agreement with JCPDS data (code 80-0787). Moreover, the crystallite size is estimated from Scherer's formula and found to be ~65 nm.

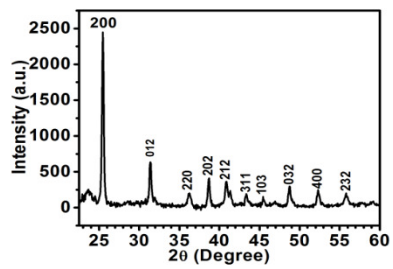
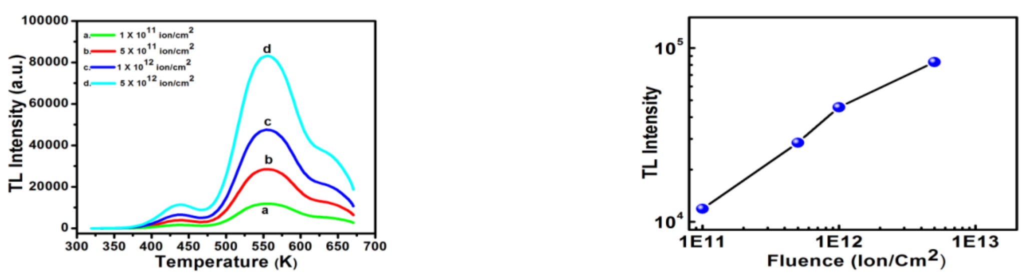


FIGURE 1. XRD spectra of pristine $CaSO_4$:Dy nanoparticles.

Thermoluminescence Properties

TL Glow Curve Analysis TL Linear Response Curve



(a) (b)

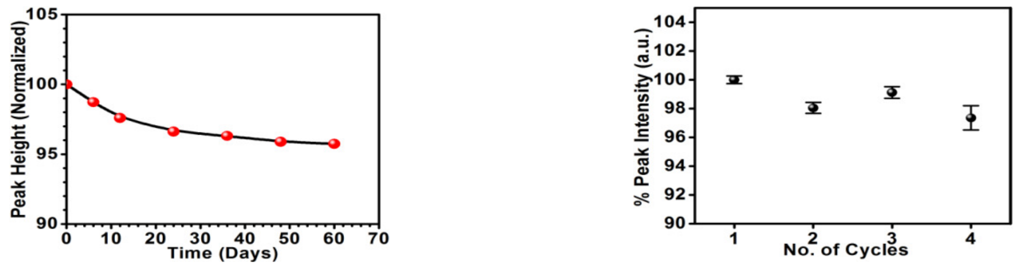
FIGURE 2. (a) TL glow curve of $CaSO_4$:Dy NP irradiated with 100 MeV O^{7+} SHI at different fluences. (b) Linear response of $CaSO_4$:Dy nanoparticles.

The TL glow curve of 100 MeV O^{7+} irradiated $CaSO_4$:Dy NP is shown in Fig. 2.(a). It is observed from the figure that apart from the main dosimetric peak appeared at 554 K, other low intense peaks at 4338 K and 646 K are also observed. The intensity of the peak increase as increase in the fluence from 1 x 10^{11} to 5 x 10^{12} ion/cm^2. These peaks are corresponding to the deeper and shallow traps. The dosimetric peak appeared at 554 K is closely related to the deeper level trap. Response curve of $CaSO_4$:Dy nanoparticles is shown in Fig. 2 (b). It is observed that the linearity maintained from the fluence of 1 x 10^{11} ion/cm^2 to 5 x 10^{12} ion/cm^2 and can effectively been used for the ion dosimetry.

Fading and Repeatability

In the last couple of decade, numerous investigations have been carried out in the pre- and post-irradiation fading of nanoparticles and aim of this study is to record the radiation loses per unit time. In an atmospheric condition, some stored charges in the metastable states can be de-excited and therefore, in day to day contact of the TL dosimeters, some of the signals automatically annealed to a light source or to sunlight. Therefore, fading recorded for $CaSO_4$:Dy nanoparticles irradiated at 5 x 10^{12} ion/cm^2 around 4.3 % (2 months) as shown in Fig. 3 (a).

Repeatability is another important property in the field of radiation dosimetry applications where the measurement cycle can be repeated. Figure 3 (b) shows the consistent repetition occurred for the four measurements and observed that no change in TL sensitivity or glow peak shape even after 4 cycles of reading.



(a) (b)

FIGURE 3. (a) Radiation loss per unit time i.e. fading of $CaSO_4$:Dy NPs. (b) Repeatability curve of $CaSO_4$:Dy NPs.

CONCLUSION

Dy doped calcium sulfate nanoparticles has been synthesized by a simple chemical co-precipitation technique. The orthorhombic structure and ~65 nm crystallite size evaluated by XRD analysis. Dosimetric properties of $CaSO_4$:Dy revealed a three glow curve peak such as 438 K, 554 K, and 646 K respectively and among them, 554 K peak shows a prominent peak which is used for dosimetric purpose. TL linear dose response recorded from the fluence range of 1 X 10^{11} ion/cm^2 to 5 X 10^{12} ion/cm^2 with consistent repeatability with fading of 4.3 %. Therefore, this CaSO4:Dy nanoparticles can effectively been used for the ion dosimetry for the therapeutic applications.

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