Synthesis and TL/OSL properties of CaSiO$_3$:Ce biomaterial

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**Abstract**

The polycrystalline CaSiO$_3$:xCe ($x=0.001, 0.002, 0.005$) biomaterials were prepared by using solid state diffusion (SSD) method. The structure of CaSiO$_3$:Ce phosphor was confirmed by X-ray diffraction technique. Moreover, photoluminescence (PL), thermoluminescence (TL) and optically stimulated luminescence (OSL) properties were studied. The TL glow curves consist overlapping peaks in temperature range 40–450 °C. The peak shape method was adopted for the calculation of the kinetic parameters such as activation energy, frequency factor and shape factor. The OSL sensitivity of CaSiO$_3$:Ce phosphor was 2.8 time than that of OSL sensitivity of Al$_2$O$_3$:C (BARC) phosphor. The minimum detectable dose (MDD) was found to be 43.6 μGy corresponding to 3σ background.

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**1. Introduction**

The Rare Earth (RE) doped silicate base host such as CaSiO$_3$, BaSiO$_3$ and SrSiO$_3$ are widely used for white LED applications [1–5]. These are best host for luminescence because of their excellent chemical and thermal stability [6,7]. However, CaSiO$_3$ host is widely used as a biomaterial for bone related surgical applications [8].

TL and OSL techniques are essential to real-time dosimeters for checking, absorbed doses delivered to patients [9]. But as compared to TL technique, OSL is becoming more popular in radiation dosimetry [10]. The OSL technique is used for personnel dosimetry only after the development of crystalline Al$_2$O$_3$:C.

In the present work, we developed CaSiO$_3$:Ce phosphor and it is promising alternative to Al$_2$O$_3$:C phosphor. Because effective atomic number of CaSiO$_3$:Ce ($Z_{eff}=15.3$) is nearly same with higher OSL sensitivity as compared to Al$_2$O$_3$:C phosphor ($Z_{eff}=11.28$). This phosphor synthesized by using SSD method and also first time reported the TL/OSL properties of CaSiO$_3$:Ce biomaterial for radiation dosimetry.

**2. Experimental**

SSD method was employed to synthesized Ca$_{1-x}$SiO$_3$:Ce ($x=0.001, 0.002, 0.005$) phosphors. High purity starting materials such as calcium nitrate Ca (NO$_3$)$_3$, silicic acid (SiO$_2$) and cerium nitrate (Ce (NO$_3$)$_3$) were used. These materials were mixed in china clay basin with small amount of acetone was added. This mixture was heated on hot plate at 100 °C for 30 min after that sample was placed in muffle furnace at 300 °C for 2 h, 600 °C for 2 h, 800 °C for 3 h and 950 °C for 6 h with intermediate grinding. Phase purity of CaSiO$_3$:Ce sample was checked by means of powder X-ray diffraction (XRD) using a Rigaku miniflex II diffractometer with Cu Ka ($\lambda=1.5405 \text{ Å}$) operated at 5 kV. All TL/OSL measurements were carried out using an automatic Risø TL/OSL-DA-15 reader system at (BARC) Mumbai. Irradiations of all the samples were performed using a $^{90}$Sr/$^{90}$Y $\beta$ source in-housed in RISO TL/OSL Reader. The activity of the source was 40 mCi and the dose rate was 20 mGy/s. PL and PL excitation spectra were measured on (Hitachi F-7000) fluorescence spectrophotometer with a 450 W xenon lamp, in the range 200–600 nm, with spectral slit width of 1 nm and PMT voltage at 700 V at room temperature.

**3. Results and discussion**

**3.1. X-Ray diffraction patterns**

The XRD pattern of the Ca$_{0.995}$SiO$_3$:0.005Ce phosphor was represent in Fig. 1. The pattern well matched with ICDD file Card No-01-075-1396. The structure of CaSiO$_3$:Ce was monoclinic system, space group was $P2_1/a$ (14) and lattice parameters were $a=15.4090$, $b=7.3220$, $c=7.0630$ Å, $\alpha=90$, $\beta=95.3$, $\gamma=90$ [11]. Moreover the XRD patterns reflect that the addition of doping does not seem to have effect on lattice.
3.2. Thermoluminescence

TL glow curve of Ca(1−x)SiO2:xCe (x=0.001, 0.002 and 0.005) phosphor under β irradiation (100 mGy) was shown in Fig. 2 and observed that TL glow curve consist overlapping peaks in temperature range 40–450 °C.

The TL glow curve was deconvoluted by using peak fit software [10] and figure of merits (FOM) was found to be 0.0188. The kinetics parameters were calculated by using peak shape method [12,13]. The TL glow curve of Ca(0.998)SiO3:0.002Ce phosphor was composed three peaks, first peak (P1) at 195 °C, second (P2) at 259 °C and third (P3) at 409 °C as shown in Fig. 2(A). The activation energy for peaks P1, P2 and P3 were found to be 0.742 eV, 1.319 eV and 2.603 eV respectively, frequency factor was found to be 1.51 × 10^17 s^−1, 6.59 × 10^11 s^−1 and 4.29 × 10^18 s^−1 respectively and shape factor was found to be 0.50, 0.49 and 0.50 respectively.

3.3. Optically stimulated luminescence

3.3.1. CW-OSL (Continuous wave-OSL)

The CW-OSL response of Ca(0.998)SiO3:0.002Ce phosphor under β irradiation (100 mGy) was shown in Fig. 3. The OSL sensitivity of CaSiO3:Ce phosphor was compared with OSL sensitivity of α-Al2O3:C (BARC) phosphor and found to be 2.8 time than that of OSL sensitivity of α-Al2O3:C (BARC) phosphor. Reusability is one of the most important properties any dosimetric material should possess [14]. From inside Fig. 3 show reusability study of CaSiO3:Ce phosphor under β irradiation and observed that phosphor can be reused for 10 cycles without change in the OSL output. The MDD was found to be 43.6 μGy corresponding to 3σ background.

Fig. 1. XRD pattern of the Ca_{0.995}SiO_{3:0.005}Ce phosphor along with standard ICDD-01-075-1396.

Fig. 2. (A) TL glow curve of Ca_{1−x}SiO_{2:xCe} (x=0.001, 0.002 and 0.005) phosphor under β irradiation and (B) TL deconvolution curve of Ca_{0.998}SiO_{3:0.002}Ce phosphor.

Fig. 3. CW-OSL response of Ca_{0.998}SiO_{3:0.002}Ce phosphor under β irradiation and compared with α-Al2O3:C (BARC) phosphor.
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