



Enhanced Luminescence Studies of Synthesized Ca₂MgSi₂O₇: Ce³⁺ Phosphor

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Abstract

A promising candidate of purple blue $Ca_2MgSi_2O_7$: Ce^{3+} phosphor sample was successfully fashioned via high temperature solid-state reaction technique and characterized in terms of structural, morphological, optical and thermal properties using XRD, FESEM, EDX, FTIR, PL, TL properties including with CIE chromaticity diagram. The results of the powder XRD patterns clearly informed that this sintered crystal structure demonstrates tetragonal crystallography (i.e., akermanite phase structure) with a space group (i.e., P^-42_1m). The average crystallite size (D) is calculated to be about 70nm. The actual formation and absorption of different functional groups was well clarified by FTIR. The PL emission spectra show the 5d-4f allowed transition of Ce^{3+} ions. This phosphor is a promising candidate of long persistent mechanism because the activation energy (i.e., trap depth) of the sintered sample was obtained in the range between (1.27eV-1.69eV). It can also be applicable in high temperature dosimetry applications. The favorable features for applications likewise near UV-LED conversion phosphor, white light emitting diodes (WLEDs), long-persistent afterglow properties, solid-state lighting devices, drug delivery, tissue engineering, bone material, detection of cancer disease, DNA transplantation, and Image processing of computer science etc.

Keywords: XRD; FTIR; Ca,MgSi,O,: Ce³⁺; Tetragonal; WLEDs; Solid-state reaction

Introduction

Commercially, white light is mostly obtained through the combination of blue LED chip and yellow emitting YAG: Ce3+ phosphors [1]. Blue and yellow color is well suitable for the correlated color temperature which plays an important role from the point of view of the generation of white light emission. During experimental observations it has been obtained that the blue color increases the color temperature while on the other hand yellow color decreases the color temperature. In this way, white light is emitted. Compared to various rare-earth ions, Cerium (Ce) and Europium (Eu) ions have often been chosen because of their efficient 5d-4f transitions. For this reason, indeed many Eu-doped and Ce-doped phosphor materials have been extensively investigated as scintillators [2]. Silicates are very better luminescent materials mainly because of their rigid and stable crystal structure. Many of the silicate-based phosphors doped with divalent or trivalent rare earth materials have been preferred for utilized as commercial phosphor in fluorescent lamps & scintillators etc. [3,4]. Silicate based phosphors have been extensively investigated because of their high thermal and chemical stabilities, excellent water-resistance properties, abundant nature, easier synthetization process, cheaper (i.e., low cost) and strong absorption in the near-UV [ultraviolet] region [5-8] and varied luminescence color from blue to yellow region [9]. Due to their special characteristics, they are better than sulfide & aluminate-based phosphors and play a leading role in luminescence field. The akermanite might be considered a probable bone material [10] and tempting bio-ceramic for tissue engineering applications [11]. For PC (i.e., phosphor converted) based WLEDs, rare-earth Ce³⁺ (as an activator ion) have been potentially applied in luminescence materials. The reason behind all this is that the rare-earth Ce³⁺ doped luminescent materials (i.e., phosphor) exhibits very strong intense bands (both excitation & emission spectra) due to the spin allowed (i.e., 5d-4f energy level) transitions between lower energy level (i.e., ground state) to higher energy level (i.e., excited state) of

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 Ce^{3+} ions. Akermanite type structure such as M₂MgSi₂O₇ (where M=Ca, Sr) activated with Eu²⁺ and Dy³⁺ phosphor has displayed quite better long-persisting behavior mechanism and have received continuous attention for their potential uses as white light-emitting diodes (WLEDs) [12-19]. Simultaneously, the results obtained from experimental observations gave a better indication that trivalent Cerium rare-earth ions [Ce3+] could not only be trap centre but also perform as luminescence-centre [20]. In this present investigation, we are informed of a well detailed study regarding the luminescence properties likewise (i.e., structural, morphological, optical and thermal) of Ca₂MgSi₂O₂: Ce³⁺ phosphors which were successfully synthesized by a conventional solidstate reaction technique (basically applied in high temperature treatment). In addition, we have also clearly indicated that Ce3+ ions are responsible for enhancing the long-persisting afterglow characteristics in Ca₂MgSi₂O₇ phosphor and make their valuable contribution. However, Ce³⁺ ions have a tendency to enhance their better luminescent characteristics is found well appropriate as compared to other rare-earth ions. The main intension behind this significant research is to focus on Ca2MgSi2O7: Ce3+ phosphor as a better choice for high temperature dosimetry, favorable WLEDs and long-persistent afterglow applications.

Experimental Analysis

Material preparation

A sample with the general structure formula $Ca_2MgSi_2O_7$: Ce^{3+} (CMSC) was successfully fashioned via conventional solid-state synthesis technique. The initial precursor reagents likewise $CaCO_3$ (AR), MgO (AR), SiO₂ (AR) and CeO₂ (AR) with very small quantities of H_3BO_3 (AR) added as flux were utilized in our experiment. The precursor chemical reagents were weighed according to stoichiometrically compositions and mixed homogeneously using CH_3COCH_3 (AR) in an agate mortar & pestle for 2h. The prepare mixture was sintered for 4h under a weak reducing atmosphere (i.e., using activated charcoal) at 1100 °C temperature. In this way, the obtained white powder sample after the cooling down of the programmable furnace and subsequently converted into a super fine powder sample by going through additional grinding process. In an airtight bottle, the final phosphor sample was restored for further structural and optical characterization studies.

The chemical reaction of synthesis process is given as follows: $8CaCO_{3} + 4MgO + 8SiO_{2} * H_{2}O \rightarrow 4Ca_{2}MgSi_{2}O_{7} + 8CO_{2}(\uparrow) + 8H_{2}O(\uparrow) + 3O_{2}(\uparrow) (1)$ $4MgO + 8SiO_{2} * H_{2}O + 2CeO_{2} \rightarrow 4Ca_{2}MgSi_{2}O_{7} : Ce_{3+} + 8CO_{2}(\uparrow) + 8H_{2}O(\uparrow) + 3O_{2}(\uparrow) (2)$

The reaction process involves the chemical decomposition of $CaCO_3$ when the temperature is higher than approximate 950 °C according to following reaction process

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)(\uparrow)(T > 950^{\circ}C)$$
 (3)

Material characterization

For crystal structure and phase identification, X-ray powder diffraction patterns of the synthesized sample was carried out

in an extensive range $(10^{\circ}-80^{\circ})$ of Bragg angle 20 using a Bruker D8 advanced X-ray diffraction measuring instrument with Cu-K α target radiation (λ =1.54056Å). Surface morphology of the sample was examined and EDX analysis performed with the help of SEM (ZEISS model microscope) fitted with EDX. FTIR spectrum was also recorded (Bruker Alpha FTIR Spectroscopy) to identify the vibrational features of the sample. Photoluminescence (PL) data were recorded using with the help of RF- 5301PC SHIMADZU Spectro fluorophotometer. Both Emission and excitation spectra were characterized with the help of a spectral slit width of 1.5nm at room temperature and CIE diagram was recorded using Go-CIE software. The PL decay was recorded with the help of an RCA 931 photomultiplier tube (PMT). The thermoluminescence (TL) data were collected using a TL Reader (Integral- PC Based) Nucleonix TL 1009I.

Result and Discussion

XRD analysis

In sequence to identify the phase structure, crystalline size, lattice constant powder XRD (X-Ray Diffraction) analysis has been recorded. The actual peak position and relative intensity of XRD diffraction patterns (Figure 1) of the synthesized Ce3+ doped Ca₂MgSi₂O₂ phosphor was well clarified and examined to be well agreement with the actual powder XRD pattern with the help of JCPDS PDF file #77-1149 [21] and AMCSD DATA BASE CODE 0008032 [22]. The results of the powder XRD patterns clearly informed that this sintered crystal structure demonstrates tetragonal crystallography (i.e., akermanite phase structure) with a P⁻421m space group (i.e., 113 space number and D³2d space group) as well as cell parameters likewise a =b =7.8071 Å, c = 4.9821 Å & $\alpha = \beta = \gamma = 90^{\circ}$ and the cell volume is 303.663 (Å)³, molar volume 92.619 (m³/mol) as well as density is 2.944 (g/cm³). This crystal structure of sintered sample is an actual member of the melilite group and creates a layered compound. The crystal field symmetry and hence the effect of field on the shifting of emission lines is strongly dependent on the relative contents of these single crystal phase. The average crystallite size (D) was calculated from the XRD pattern with the help of Debye-Scherrer's relation [Eq. 4]:

$$D = K\lambda / \beta Cos\theta$$
 (4)



Figure 1: XRD Pattern of Ca₂MgSi₂O₇: Ce³⁺ Sample.

Where is the general meaning of the symbols displayed in the equation such as: D denotes the crystallite size relevant for the (hkl) plane, λ denotes the incident wavelength of X-ray radiation [Cu-K α (0.154nm)], β (in radians) denotes the FWHM (full width at half maximum), and θ denotes relevant Bragg diffraction angle [23]. Sharper and isolated X-ray diffraction peaks likewise 2θ =25.13 (210), 29.19 (201) 31.24 (211), 32.75 (220), 38.64 (102), 44.07 (212) were chosen for crystallite size evaluation. The relevant crystallite size is ~79nm, 76nm, 70nm, 69nm, 66nm, 65nm was evaluated with the help of the Debye-Scherrer's formula respectively and the average crystallite size is obtained ~70nm. We observe that the doping of Ce³⁺ ion did not affect the phase crystal structure in any way.

FESEM analysis

It is absolutely true that the luminescence characteristics of any particles (i.e. Nano or Micro) are clearly defined on the basis of their corresponding specific properties likewise size, shape, size distribution, defects which depending on the morphology of the particles. FESEM images of the sintered Ca₂MgSi₂O₇: Ce³⁺ powder sample is clearly displayed in 2µm range with single magnification (10.00 KX) in Figure 2. FESEM (Field Emission Scanning Electron Microscopy) image clearly indicated that the surface morphology of the particles in prepared sample was not uniform and they were tightly aggregated to each other with different particle size distribution. In addition, due to the high temperature heat treatment some big aggregates are clearly evident in this morphology of the particles.





EDX analysis

For an in-depth analysis of the chemical composition of any powder sample, it has been measured with the help of EDX (Energy Dispersive X-ray Spectroscopy) spectra. It is better utilized as an actual procedure for quantifying & identifying elemental composition of any specimen region as small as a few nanometers. The actual evidence of elements likewise Ca, Mg, Si, O and Ce sharp peaks are clearly present in EDX spectra which preliminary indicates the actual formation of the sample in Figure 3. Along with the clear evidence of rare-earth Cerium ions in their relevant EDX spectrum image. As such, their EDX spectrum showed no emission peaks other than (Ca)calcium, Si (silicon), (O)oxygen, Mg(magnesium) Ce(Cerium). The elements present the actual chemical composition with respect to Weight % and Atomic % also analyzed which is displayed in Table 1.



Figure 3: EDX Spectra of Ca₂MgSi₂O₇: Ce³⁺ Sample.

Table 1: Evidence of expected elements in $Ca_{1.96}MgSi_2O_7$: 0.04Ce³⁺ by weight % and atomic weight %.

No	Elements	Atomic(%)	Weight(%)	
1	ОК	43.19	64.19	
2	Mg K	5.83	5.78	
3	Si K	15.12	12.69	
4	Ca L	27.03	16.02	
5	Ce L	8.83	1.32	
То	tal	100	100	

FTIR analysis

The FTIR (Fourier Transform Infra-Red) spectroscopic analysis has been extensively utilized for the investigation of organic & inorganic compounds and identification of absorption bands as well as different functional groups which is clearly present in spectra [24]. In examined Infra-red [IR] spectrum (i.e., v1 symmetric stretching, v2 symmetric bending and v3 asymmetric stretching, v4 asymmetric bending), the absorption bands of silicate groups and various functional groups were clearly evident [25,26]. The IR (Infra-red) spectra of Ca₂MgSi₂O₂: Ce³⁺ phosphor sample in the range between (4000 to 400cm⁻¹) are displayed in Figure 4. The vibration modes of (SiO₂) bands clearly peaked at 496.81 & 634.65cm⁻¹ and tetrahedral Si⁴⁺ sites lie at 687.79, 896.27, 983.54 and 1092.39cm⁻ ¹. The intense band allocated at 896.27, 983.54cm⁻¹ between the range of (800-1000cm⁻¹), because of the (Si-O-Si) asymmetric stretching. In addition, the existence of the (Si-O-Si) vibrational mode, bands centered at 496.81cm⁻¹ respectively [27]. The band peaked at 3546.43cm⁻¹, indicating the vibrational stretching of (O-H) group because of the existence of moisture via atmosphere [28]. The intense band peaked at 478.51cm⁻¹, because of the presence of [Mg-O] vibration mode. At 1678.64cm⁻¹ the vibration band is recorded because of the [Mg2+] ion and bending of the sharp peaks allocated in the region of 896.27 and 794.68cm⁻¹ because of the vibration mode of [Ca²⁺] ion. A typical property of the IR spectrum is the observed influence of the vibration from the doping ions Ce^{3+} in the host lattice crystal structure. The spectrum of sintered sample displays a vibration band at 1678.64 and 1469.32cm⁻¹, which was clearly responsible for Ce^{3+} ions. Such a way, Ce^{3+} ions are expected to substitute Ca^{2+} lattice site in the host crystal lattice ($Ca_2MgSi_2O_7$) because the ionic radii of Ce³⁺ and Ca²⁺ ions are 1.143 and 1.12Å, respectively, and match closely. Ce³⁺ does not replace Mg²⁺ and Si⁴⁺ ions because the ionic radius of Mg²⁺ (0.89Å) & Si⁴⁺ (0.40Å) are far smaller than that of Ce³⁺ ions [29].



Figure 4: FTIR Spectra of Ca₂MgSi₂O₇: Ce³⁺ Sample.

The vibration modes of Mg²⁺ and Ca²⁺ ions peaked at 1678.64 & 1469.32cm⁻¹ respectively. When Ce³⁺ ion enters the host lattice site, it substitutes Ca²⁺ lattice sites which are clearly responsible for distortion in host crystal lattice site. The actual position of Ca²⁺ lattice site was clearly substituted by Ce³⁺ ions and the actual Ca²⁺ is located somewhere else. Therefore, the vibration mode of Ca2+ at 1469.32cm⁻¹ is clearly observed with Ca₂MgSi₂O₇: Ce³⁺ sample. The vibration mode of Mg²⁺ was observed at 1678.64cm⁻¹ which are clearly responsible for the same distortion in the host crystal lattice site. The coordination number of calcium can be shown 6 and 8 [18] in sintered sample. Therefore, [Ca²⁺] lattice sites can occupy two alternative lattice sites, the six coordinated $[Ca^{2+}]$ site $[CaO_{4}]$ (Ca (I) site)] and the eight coordinated $[Ca^{2+}]$ site $[CaO_{\circ} (Ca (II) site)]$. We have also examined that in the crystal lattice sites, Mg²⁺ [MgO₄], and Si⁴⁺ [SiO₄] also exist, other two independent cations sites. Divalent magnesium $[Mg^{2\ast}]$ and tetravalent $[Si^{4\ast}]$ cations occupy in the tetrahedral sites [19,20]. The coordination no. of Cerium ion can be 6, 7, 8, 9 and 10 respectively. When Ce³⁺ ion enters the host crystal lattice site, it will only substitute the original Ca²⁺ lattice sites [17,18,21-23]. Eventually, Ce³⁺ doping ions will clearly acquire two alternative crystal lattice sites [Ce (I) and Ce (II)] with coordination no. of 6 and 8 respectively. After doping, Ce (I) and Ce (II) would be activated into different energy levels, thus resulting in different spectra.

Photoluminescence (PL) analysis

The PL spectra (both excitation & emission) of synthesized sample were characterized in the range between (250-350nm) & (350-500nm) wavelengths at room temperature which are clearly displayed in Figure 5 respectively. Such a way, synthesized Ca₂MgSi₂O₇: Ce³⁺ sample exhibited strong absorption in the UV band and simultaneously emitted a blue light when excited by UV light which relevant to the energy level transitions from the ground state (i.e., lower energy level) to the different crystal field splitting energy levels of 5d state for Ce³⁺ ions. It is known about the Ce³⁺ doping ion that it has only single outer electron and only two spin-orbital splitting 4f energy states via 2F5/2 & 2F7/2. It has a very similar & better stimulated state energy structure as compared to another doping ion likewise Eu²⁺, Dy³⁺, Er³⁺, Gd³⁺ etc. In excitation spectra, at 338nm wavelength, the optimum peak is centered, and someanother spectral peak situated at 282nm. Under 338nm excitation spectra, the sintered sample displays an intense and broad purpleblue emission band at 392nm which is responsible to 5d-4f allowed transition of Ce³⁺ ions from lower energy level (i.e., ground state) to higher energy level (i.e., excited state). This phosphor emits light in the purple-blue region and hence it may be utilized as blue light emitting (LED) phosphor which is very helpful for white light emitting diodes (WLEDs).



Figure 5: Excitation & Emission Spectra of Synthesized Ca₂MgSi₂O₇: Ce³⁺ Sample.

PL decay curve analysis

The PL (Photoluminescence) decay curve of $Ca_2MgSi_2O_7$: Ce^{3+} phosphor sample has displayed in Figure 6 which is irradiated with 254nm light for 2min. During observation, it was found that this sample shows rapid decay process and subsequently also exhibits long-lasting phosphorescence characteristics. Hereby, the intensity

of initial afterglow was so high. The decay times can be evaluated with the help of curve fitting technique and the decay curves are fitted by summing of two exponents, as given below in following mathematical expression:

$$I = A_{1} \exp(-t / \tau_{1}) + A_{2} \exp(-t / \tau_{2})$$
(5)



Figure 6: PL Decay Curves of Ca₂MgSi₂O₇: Ce³⁺ Phosphor.

Where I denote the phosphorescence intensity, A_1 and A_2 are constants, t is time, and τ_1 and τ_2 denotes the decay times for the fast and slow decay exponential components, respectively. The fitting results are given in Table 2.

Table 2: Decay curves for exponential components of $Ca_2MgSi_2O_7:Ce^{3+}$ phosphor.

Phosphors	τ ₁ (s)	$\tau_2(s)$		
Ca ₂ MgSi ₂ O ₇ : Ce ³⁺	38.157	271.654		

CIE color chromaticity diagram

The luminescent color is the most essential and important factor for application of phosphors. This colour coordinate of phosphors were examined based on a clear observation of their emission spectra [24,25]. The CIE diagram of $Ca_2MgSi_2O_7$: Ce^{3+} phosphor is clearly displayed in Figure 7. It is very clear from the calculated colour-chromaticity coordinate that this [X=0.1896, Y=0.1248] co-ordinate represents the blue light emission from the

phosphor. As a result, the colour chromaticity co-ordinate of the luminescent-color emission has been displayed by this phosphor, approaches very close to purple-blue light colour region.



Thermoluminescence (TL) analysis

The phenomenon of TL is related to the process of light emission arising from semiconductors or insulator, either inorganic, crystalline-solid samples. This condition arises when it is heated after being exposed to some irradiation [26]. In such a situation, then the charge carriers likewise holes or electrons are freed. When TL analysis of any phosphor, then the TL glow-curve of that phosphor primly depends on the kinetic (i.e., trapping) parameters which mainly comprise such as [Order of Kinetics b] and [Frequency Factor S] as well as [Activation Energy or Trap Depth] [27]. The peak shape method is a well appropriate method for the determination of kinetic parameters (i.e., trapping parameters) [28].

Correlation between peak shape method and kinetic parameters: To determine the trapping parameters the peak shape method (Figure 8) is being well utilized. This method is an analytical technique which was proposed by Chens, thus also known as Chen's glow curve method [28]. This method is also useful to detect the position of energy levels in the forbidden energy gap and defect centers [29]. Therefore, the complete analysis of glow curve has been done using this method. Figure 8 display the peak shape of glow curve of the sintered sample. In order, T_m denotes maximum value of temperature, T_1 denotes lower (ascending part of glow curve) and T₂ denotes higher (descending part of glow curve) temperature at half the intensity, respectively [30-32] and other kinetic parameters (τ, δ, ω) are originated using these temperatures, where $(T_m - T_1)$ denotes τ , $(T_2 - T_m)$ denotes δ and $(T_2 - T_1)$ denotes ω . With the help of these parameters activation energy, order of kinetics and frequency factor is evaluated.



Figure 8: Determination of Peak Shape Method.

Order of kinetics [b]: For glow-curve peak, this parameter can be evaluated with the help of geometric shape factor) $[\mu_g]$ determination from the following mathematical form as below:

$$\mu_{g} = \delta / \omega = (T_{2} - T_{m}) / (T_{2} - T_{1})$$
(6)

Where T_m represents the prominent peak temperature and $T_1 \& T_2$ denotes temperatures at half intensity on the ascending and descending orders of the glow-curve peak, respectively and $[\omega=T_2-T_1]$ and $[\delta=T_2-T_m]$ represents the high-temperature halfwidth. The geometric shape factor is a key part of TL glow-curve peak which is to differentiate between Ist and IInd order kinetics. The mathematical value of geometric shape factor $[\mu_g=0.39-0.42]$ represents for the Ist order kinetics and $[\mu_g=0.49-0.52]$ denotes for the IInd order kinetics as well as for the mixed order kinetics also represent as $[\mu_g=0.43-0.48]$ [29-33].

a) Activation energy (E) or (Trap Depth): The trapped electron needs some amount of energy to free itself, also known as activation energy (i.e., trap depth) which is required to liberate an electron to the conduction band from defects centre [34]. The value of trap-depth (i.e., activation energy) can be evaluated with the help of the following mathematical equation as mentioned, which is valid for any kinetics (i.e., first, second and mixed order-kinetics).

$$E_{\alpha} = C_{\alpha} \left(\frac{KT_m^2}{\alpha} \right) - b_{\alpha} \left(2kT_m \right)^{(7)}$$

 $C_{\alpha} \& b_{\alpha}$ (where α indicates: τ, δ, ω) are determined with the help of the following mathematical equation, which is valid for any general order kinetics [35,36].

$$C_{r} = \left[1.51 + 3(\mu_{g} - 0.42)\right], b_{r} = \left[1.58 + 4.2(\mu_{g} - 0.42)\right] (8)$$

$$C_{\delta} = \left[0.976 + 7.3(\mu_{g} - 0.42)\right], b_{\delta} = 0 (9)$$

$$C_{\omega} = \left[2.52 + 10.2(\mu_{g} - 0.42)\right], b_{\omega} = 1.0 (10)$$

b) Frequency factor (s⁻¹): This kinetic parameter is one of the most significant parameters which are used for sample

characterization process [37]. This trapping-parameter is calculated by substituting the previously evaluated values of order of kinetics [b] and activation energy [E] in the mathematical equation (as mentioned):

$$\frac{\beta E}{KT_m^2} = S \left[1 + (b-1)\frac{2kT_m}{E} \right] \exp\left(\frac{-E}{KT_m}\right)$$
⁽¹¹⁾

Where k denotes Boltzmann constant, E represents activation energy & b denotes an order of kinetics, T_m represents the prominent temperature of glow-curve peak position, and β (i.e., at present work 5 °Cs⁻¹) represents the heating rate of the any material sample [38-40].

TL kinetic parameters of $Ca_2MgSi_2O_7$: Ce^{3+} phosphor with different UV exposure: For clarity, the TL glow curves of synthesized $Ca_2MgSi_2O_7$: Ce^{3+} sample for different UV radiation doses at a fixed heating rate of 5 °Cs⁻¹ are shown in Figure 9. The maximum & minimum TL glow curve peaks were obtained at 109.19 °C temperature. In all glow curve peaks, no important modification in peak position was clearly observed with different UV radiation. It is significant to notice that the fixed and appropriate do-pant concentration is utilized. Simultaneously, it is a potential approach to responsible for optimizing TL efficiency & reforms sensitivity as well as dose-linearity for an exclusive UV-irradiation type and can be highly utilized for high temperature dosimetry applications [41]. Figure 9 displays the TL glow curve of synthesized $Ca_2MgSi_2O_7$: Ce^{3+} sample for 5,10,15,20 and 25min UV irradiation. The synthesized micro particles have displayed that the peak intensities approximately between 3684.6-6954.7 units and the peak position was centered at 109.19 °C with single glow curve peaks. TL intensity increases with increasing UV irradiation time. The optimum TL intensity for 15min UV exposure time was obtained at least one single trap clearly evidence in sintered phosphor. However, being able to recognize the actual nature of the trap is still a challenging task in a difficult process. In the meantime, the TL glow curves play a significant role in providing some beneficial information for the decay process. In this case, the position of the TL peak is associated with the initial concentration of trapped carriers and the change in initial concentration necessarily changes Tm. The released carriers are retrapped before they recombine, giving rise to a delay in the luminescence emission and a spreading of the emission over a wider temperature range [42] (Table 3). The Geometric shape factor (μ_{a}) lies between (0.52-0.57) which displays the second order kinetics which clearly supports the probability of re-trapping released charge carriers before recombination process. The trap depth (i.e., activation energy) was calculated in the range between (1.27-1.69 eV) and frequency factor also as $(4.03 \times 10^7 - 6.8 \times 10^7 \text{ s}^{-1})$. So, on this basis we can say that this phosphor exhibits very high persistency but it can be considered as the value of trap depth is widespread range from 0.50eV to 1.50eV. According to Sakai and Mashangva [43,44] research reports, they have reported that a very appropriate trap depth (0.65~0.75eV) is very necessary for phosphors to display long persistency phenomenon [45-49]. So, we suggest that this phosphor is well suitable for long lasting phosphor.



Figure 9: TL glow Curves of Synthesized Phosphor with Different UV Irradiation Time.

UV min	HTR	Т ₁ (°С)	Т _m (°С)	T ₂ (°C)	τ	δ	ω	μ= δ/ω	E(eV)	Frequency Factor (S ⁻¹)
5	5 °Cs ⁻¹	95.24	109.19	125.16	13.95	15.97	29.92	0.53	1.39	4.8X10 ⁷
10	5 °Cs ⁻¹	97.38	109.19	121.78	11.81	12.59	24.4	0.52	1.66	6.8X10 ⁷
15	5 °Cs ⁻¹	97.38	109.19	125.16	11.81	15.97	27.78	0.57	1.69	7.1X10 ⁷
20	5 °Cs ⁻¹	95.24	109.19	125.16	13.95	15.97	29.92	0.53	1.39	4.8X10 ⁷
25	5 °Cs ⁻¹	93.65	109.19	127.21	15.56	18.02	33.56	0.54	1.27	4.03X10 ⁷

 Table 3: Evaluated TL Kinetic Parameters of Synthesized Ca2MgSi2O7: Ce3+ Phosphor.

Conclusion

In brief, purple blue Ca₂MgSi₂O₂: Ce³⁺ phosphor was well synthesized via high temperature solid-state reaction technique. The XRD patterns were well clarified and clearly matched through JCPDS PDF File #77-1149. The average crystallite size (D) was obtained ~70nm. XRD results also show that the synthesized phosphor is crystalline with a single phase. The PL emission spectra, purple-blue emission peak, observed at 392nm due to 5d-4f allowed transition from Ce³⁺ ions The CIE chromaticity co-ordinates located in the purple-blue color region; hence the synthesized phosphor might be very useful in blue component of WLED's trichromatic phosphors and has potential applications in solid-state lighting (SSL) devices and WLEDs. It is very clear from TL spectra that second order kinetics which supports the probability of retrapping released charge carriers before recombination process and the trap depth (i.e., activation energy) of the synthesized sample was obtained in the range between (1.27-1.69eV). This phosphor is suitable for long lasting phosphor, novel TL material and high temperature dosimetry applications because it exhibits very high persistency.

Application

The favorable features for applications likewise near UV-LED conversion phosphor, white light emitting diodes (WLEDs), long-persistent afterglow properties, solid-state lighting (SSL) devices, biomedical research such as drug delivery, tissue engineering, bone material, detection of cancer disease, DNA transplantation, and Image processing of computer science etc.

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Conflict of Interest

The authors declare that no conflict or any economic interest exists in our present research work.

Authors Contribution

This work was carried out in collaboration between both authors. Author Dr. Shashank Sharma undertakes the manuscript designed and conducted the entire experiments & characterization studies, collected and analyzed the research data, and prepared the entire manuscript draft as well as supervised the resultsdiscussion. Similarly, author Dr. Sanjay Kumar Dubey has properly checked the spelling mistake, punctuation, grammatical error, conceptualization, writing, review, editing and helped in sample preparation. Both authors read and approved the final manuscript.

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