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The influence of deposition gases on the material properties of $Y_2SiO_5: Ce^{3+}$ thin films deposited by pulsed laser deposition (PLD) method

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Abstract

The material properties of $Y_2SiO_5: Ce^{3+}$ thin films have been investigated. The X-ray powder diffraction (XRD) analysis shows that the films are structurally monoclinic with the most prominent diffraction peak of 15.7°. The maximum crystallite size was obtained for samples deposited under oxygen deposition. The PL emission peaks are observed at 423 nm when probed at 370 nm, which can be ascribed to the transition of the electrons from the excited state of 5d to the ground state of 4f. Due to the spin–orbit interactions, the 4f ground state splits into $^2F_{5/2}$ and $^2F_{7/2}$ energy sub-levels. The scanning electron microscopy (SEM) measurement shows a rough and uniform distribution of grains with small agglomerated topographic areas. The energy dispersive spectroscopy (EDS) measurement shows the presence of all elements (Y, Si, O, and Ce). The maximum and minimum absorbance of the visible ultraviolet (UV–vis) spectrum was observed for the thin films deposited under the Argon and vacuum atmospheres with small shifts from Argon to the other depositions. The energy bandgap varies between 3.14 and 4.33 eV. The CIE measurement gives the blue emission band at an emission wavelength of 423 nm. The activation energy was obtained in the range of 0.1733 and 0.1938 eV. The maximum activation energy was obtained under the argon gas deposition.

1. Introduction

The luminescent materials that emit optical radiation (infrared, visible, or ultraviolet light) are sometimes called solid phosphors. The phosphors are widely used in fluorescent lamps, cathode ray tubes (CRT) and X-ray intensifiers [1, 2]. It converts parts of the absorbed energy into electromagnetic radiation that is greater than thermal radiation. When a solid is heated to a temperature of above 600°C, it emits infrared radiation. This condition is observed due to the thermal radiation, not a luminescence phenomenon [3]. Now a days, many researches are concerted on nano-structural phosphors doped with lanthanide ions and transition metal ions. These materials have various optical properties with a range of applications in optoelectrical devices. These compounds can be easily established by doping the rare earth (RE) elements into the single crystal, semiconductor, ceramic or polymer matrix [4]. These RE-doped compounds are the most favorable compounds in the field of optoelectronic and display applications [5–7]. RE-doped phosphors have the characteristics of long-time chemical stability, good illumination which can be applied in industrial processing of displays with a good efficiency and field emission display detector applications [8, 9]. Thin film phosphors are the best solution for the traditional phosphor powder cathode ray tubes. Thin film phosphor exhibits high contrast percentage, high ambient visibility, image resolution, and good heat resistance [10]. Sputtering, thermal evaporation and chemical bath deposition, sanochemical deposition [11] methods are some of the other methods used to deposit thin films of phosphor materials alongside the PLD. The most important parameter of thin film phosphors for the various deposition methods is the deposition at a low substrate temperature. This is due to the use of glass substrates and temperature sensitive phosphor materials. The pulsed laser deposition (PLD) method has been used to deposit thin films with stoichiometrically unique evaporation of target materials, such as complex
superconducting oxides [12]. Therefore, thin film phosphor deposition using PLD is useful to investigate the luminescence and other properties of the phosphor material as we did in our previous papers [13]. Yttrium silicate crystal is a well-known material for hosting rare earth ions such as cerium. Yttrium silicate has a wide band gap of 7.4 eV which can comprehend a large amount of RE ions. It has been used successfully as a host matrix for RE ions due to its thermal and chemical stability, which contributes to the formation of phosphors or scintillating photocathodes. Energy structure of the bandgap of yttrium silicate (Y2SiO5) activated with RE ions such as Ce3+ [14, 15], Tb3+ [14, 16] are widely investigated for different applications. Y2SiO5: Ce3+ has been studied by various researchers for the purpose of scintillation [17, 18]. According to previous studies [14, 19], Y2SiO5: C4+ phosphor is a blue light emitter and many studies have been conducted to investigate luminescence characteristics for lighting industries such as field emission screens (FEDS). However, as far as our knowledge this material has no studied in the thin film form with PLD deposition with the deposition condition we have used. The structure of Y2SiO5 belongs to orthosilicate crystalline structures of (RE2SiO5) [20]. This silicate material has two monoclinic crystalline phase structures which are classified by their synthesis temperatures. These are X1 phase which is synthesized at low temperature (below 1190 °C) and has lower XRD-intensity with a space group of P21/c and X2 phases, synthesizing at high temperature (above 1190 °C) with a space group of B2/c [21]. There are two possible sites of Y3+ in each of these crystalline phases that can be attributed to the different number of coordinations in these phases [21, 22]. Broadband light-emitting materials in the visible spectrum commonly used to sensitize the luminescence of RE ions and the transition of metal ions. Specifically, Ce3+ is a 4f-5d allowable transition that provides effective broadband luminescence. Furthermore, the emission and excitation spectra of Ce3+ ions are very sensitive to the crystallographic site of the host material. Y2SiO5: Ce3+ is a superb phosphorescent material emitting blue light. It is, therefore, crucial to study the optoelectrical and display applications of this material [23, 24].

Measurement of thermoluminescence (TL) is a common technique for determining ionizing radiation that is known as thermoluminescence. TL is also known as thermally stimulated luminescence (TSL) which is a phenomenon related to the release of photonic energy following exposure to external thermal energy from low to high temperature, and this type is called delayed phosphorescence. In the TL measurement, heat is not the only source of energy for the luminescence to occur. This only causes the release of energy that originally came from another source. TL occurs following heating, when radiative transition (trapping and de-trapping) of the electrons from their metastable state occurs. TL is then released by the result of the trapped and de-trapped electrons and holes (charge carriers) and their combination [25]. If the trapping sites are emptied, the ionized radiation transfers the charges to the pre-existent sites. Consequently, the passage of the charges to the recombination region generates luminescence. The emission observed from the sample during heating up on the interaction of the radiation with matter gives information about the defect levels caused by the interaction of the ionized radiation with the sample [26, 27].

The present study describes the effect of different deposition gases on the luminescent, thermoluminescence, structural, optical and morphological properties of the PLD deposited Y2SiO5: Ce3+ thin-film phosphors. To the best of our knowledge, no research papers have been reported or is under consideration for publication with the deposition condition we have used for the material under investigation for a possible display application.

2. Experimental

Y2SiO5: Ce3+ thin film phosphors deposited from a commercial powder using the PLD method. Nd:YAG with a wavelength of 266 nm was used as a laser source. Base pressure, pulse duration, repetition rate, laser fluence, and substrate-to-target distance were maintained at 5.6 × 10−3 mbar, 8.0 ns, 10 Hz, 10 mJ cm−2, and, 5.0 cm, respectively. Vacuum, oxygen, argon, and nitrogen atmosphere were used as background gases to deposit the thin film on a (100) silicon and glass substrates. The glass substrate was placed together with the silicon substrate in order to characterize the optical property of the thin film phosphor. Before both substrates are ready for deposition, it was washed with distilled water and rinsed. It was also soaked in ethanol and acetone for about 15 min to obtain a clean, dust-free surface. Finally, both the substrates were rinsed with deionized water and dried with nitrogen gas. 11 grams of the commercial powder was used to make the pellet for ablation. A hydraulic pressure of 12.5 Torr was used to make the pellet. It was then annealed at a temperature of 200 °C to remove the moisture and to increase the solidness of the material. The deposition pressure for all the deposition gases was set at 10 mTorr. The following characterization techniques were applied to characterize the material properties of the thin film phosphor: X-ray diffractometer (XRD) operating at a voltage and a current of 40 kV and 40 mA respectively using Cu Kα = 0.154 06 nm was used for phase identification of the crystalline material and provides information on cell size. The scanning electron microscope (SEM) analyzes the topography of the deposition materials. Photoluminescence (PL) operating at room temperature using the
Cary Eclipse fluorescence spectrometer used to achieve the absorption and emission of the material. UV–vis used to study the optical property of the material in the range of 200 to 800 nm. The chromaticity coordinate of the phosphor material was estimated from the International Commission on Illumination (CIE) of 1931 using an excitation wavelength of 370 nm. The TL measurement that is used to study the defect levels of the samples exposed to radiation has been measured at an exposure time of 10 min with a heating rate of 2 °C S⁻¹.

3. Results and discussion

3.1. XRD analysis

Figure 1 shows the XRD diffraction pattern of the thin film deposited at different deposition gases. The diffraction pattern has been observed at 15.7°, 19.9°, 25.06° and 28.65°. All the thin films have the strongest diffraction peak at 15.7° with a Bragg reflection plane of (110). The structures of these thin films formed on the silicon substrate are monoclinic in agreement with the JCPDS data Card No. 742158. The full width at half maximum (FWHM) of the main peak were 0.37°, 0.43°, 0.45° and 0.6° for the deposition gases of oxygen, argon, nitrogen and vacuum, respectively. The corresponding crystallite sizes, calculated using the Scherer’s equation given in equation (1), varies between 14.07 and 22.4 nm.

\[ D = \frac{0.94\lambda}{\beta \cos \theta} \]  

where D is the average crystallite size in nm, λ is the wavelength of the CuKα (0.154 nm), β is the full width at half maximum and θ is the Bragg angle. The highest diffraction peak pattern was observed under oxygen deposition atmosphere. This can imply that a good crystalline thin film is formed in this deposition conditions as compared to the other deposition conditions. The temperature, distance of the substrate from the target has also considerable influence on the development of the thin films by pulsed laser deposition [29]. However, since these parameters are kept fixed; the only significant impact on the growth of the thin film is from the deposition gases. The effect of deposition gases on the crystallite size and FWHM of the deposited thin films are shown in figure 2. From figure 2, the oxygen deposition gas has least value of FWHM and larger crystallite size as compared to the other deposition gases. This can be ascribed to the crystallinity of the thin films at the respective deposition conditions. In the oxygen deposition, oxygen vacancies are small because of the substitution of the background gas (oxygen) in the stoichiometric formation of the resultant compound, which could be a possible reason for the good crystallinity of the thin film in this deposition condition. In the vacuum deposition condition the minor peaks are reduced which might be due to the variation of oxygen vacancies. In the vacuum deposition condition, there is high concentration of oxygen vacancies, when the X-ray photons are interacted with the oxygen vacancies, the photons will be trapped which in turn the diffraction intensity will be very small which can be simply dominated by the relative diffraction peaks from another area of interaction. From the Xrd diffraction peaks, it is possible to calculate the average crystallite size, macrostrain, volume of unit cell, dislocation density, stacking fault probability, and texture coefficient [30] which we can consider it in our future works.

3.2. SEM and EDS analysis

Figure 3 shows the SEM micrographs for thin films deposited under different deposition gases. As clearly seen from the micrographs, the morphology and size of the particle’s changes with varying deposition conditions.
The deposition parameters have a large influence on the plasma plume produced during laser ablation in which the propagating energy and mobility can be controlled by modifying deposition parameters like background gases [31]. When the background gases interact with the plasma plume the kinetic energy, the spatial distribution and the stoichiometry of the ablated particles from the target material changes. As a result, the thin

![Figure 2. Effect of deposition gases on the crystallite size and FWHM of the Y$_2$SiO$_5$: Ce$^{3+}$ thin films.](image)

![Figure 3. SEM micrographs of Y$_2$SiO$_5$: Ce$^{3+}$ thin films deposited at different gases: (a) vacuum (b) nitrogen (c) argon and (d) oxygen.](image)
films will have different deposition rate and morphologies for the altered deposition gases as shown in figure 3. The collision of the atomic species of the deposition gases with the plume can also increase the vibrational energy of the ablated molecular species which can introduce variation of surface composition on the resulting thin films because of the variation in deposition rate \cite{32}. SEM images of thin films with a magnification of x100,000 are shown in figure 3. In all images, particle distribution appears uniform, except for some agglomerations in a particular area. Under the vacuum atmosphere, the particles look small in size as compared to other deposition gases, the distribution of particles over the surface of the substrate appears uniform and smooth regardless of some rarely distributed large particulates (which might be clusters of particles). Under the nitrogen deposition gas, the particle size shows small increment, and clusters of particles are observed similar to the samples deposited under the vacuum condition. Mixtures of small and large sized particles are observed in all deposition conditions. However, under the argon and oxygen deposition conditions the agglomeration of particles is significantly decreased. The possible reason for the increase in agglomeration in vacuum and nitrogen deposition gases atmosphere and the roughness of the films in these background gases is due to the formation of particulates in the plume, which is a distinctive behavior of high pressure laser ablations \cite{33}. The other reason for agglomeration is the condensation of the small clusters of particles removed from the target material in the background gases due to the formation of shock wave in the ablation process, resulting in the formation of large groups and agglomerations on the surface of the thin film.

A histogram which shows the distribution of nanoparticles in all deposition condition is shown in figure 4 with their respective diameters. The average nanoparticle size ($X_{av}$) is 26.66, 26.69, 29.95 and 29.105 nm for vacuum, nitrogen, argon and Oxygen respectively. The average nanoparticle size of all deposition gases is 28.1 nm. The average polydispersity in diameter of the nanoparticles is calculated by equation (2). The calculated average polydispersity of the nanoparticles is 31.6.

$$PD = \left( \frac{\sigma_{av}}{X_{av}} \right)^{100\%}$$

Where $\sigma_{av}$ is the average deviation and $X_{av}$ is the average size of nanoparticles.

Table 1 shows the atomic percentages of the elements for the respective deposition conditions and the powder used to make the pellet for ablation. The cerium (dopant) element has high concentration in the oxygen and argon deposition conditions respectively and lower in the Nitrogen gas deposition condition. The atomic percentage of Si is observed to be high in the thin films which might be due to the silicon substate used to deposit the films. As a result, the atomic percentage of the elements in the thin film and in the powder have significant difference except Ce. Figure 5 shows the energy dispersive spectroscopy (EDS) for the samples deposited under different deposition conditions and the powder used to make the pellet. All the elemental components of the phosphor were detected with their respective weight percent. The plasma plume created during the laser ablation process is strongly directed forward. Consequently, the thickness of the material formed on a substrate could not be uniform and the stoichiometric composition or ratio may vary among deposition conditions. The variation of the weight percentage and atomic percentage of the constituents of the crystalline compound can

![Figure 4. Distribution of nanoparticles.](image-url)
be observed from figure 5 and table 1. When the material is deposited in Nitrogen, the weight and the atomic percentages of the dopant (Ce) reduces considerably. However, the atomic concentration of Ce$^{3+}$ ions increases in the argon and oxygen gas atmospheres.

3.3. UV–vis analysis

UV–vis spectroscopic measurement was taken to determine the optical properties of the thin film materials. Figure 6 represents the absorbance of Y$_2$SiO$_5$:Ce$^{3+}$ thin films as a function of the UV–wavelength. The maximum absorbance spectrum was observed for films grown under the Argon and oxygen deposition.
atmospheres respectively, this can be ascribed to the thickness of the thin films. The optical absorption under the oxygen deposition gas could be due to the increase in roughness and thickness of the surface of the thin film. The minimum optical absorption was observed in vacuum deposition conditions. The thickness of the film deposited on the silicon substrate was calculated by measuring the mass of the substrate before and after deposition respectively, taking the mass difference between the two measurements and plugging in to the mathematical relationship given in equation (3), thin films deposited with argon and vacuum background gas showed maximum and minimum thickness, respectively. The decrease of the absorption value under vacuum deposition conditions could be attributed to the decrease in thickness of the film deposited on the substrate. The optical absorption leaning for the thin film deposited in different deposition gases shows a uniform decrease from the oxygen absorption edge to the vacuum absorption edge as shown in figure 6. The thickness of the thin films has been calculated by equation (3) [34].

\[ X = \frac{(m_2 - m_1)}{\rho A} \]  

Where X is the thickness, \( m_1 \) and \( m_2 \) are the mass of the substrate before and after deposition in grams, \( \rho \) is the density of the silicon in g cm\(^{-3}\). A is the deposition area in cm\(^2\). The estimated thickness of the thin film deposited on the substrate is, \( X = 62, 94, 125 \) and \( 134 \) nm for the thin films deposited in vacuum, nitrogen, oxygen and argon, respectively.

The energy band gap is calculated using Tauc relation [35] which is given by:

\[ (\alpha h\nu)^2 = K(\nu - E_g) \]  

where \( h \) is the plank’s constant, \( \nu \) is the frequency of the incident wave, \( K \) is energy independent constant, \( \alpha \) is absorption coefficient and \( E_g \) is the optical band gap. The optical band gap of the material deposited at different gases which was obtained by extrapolating the \( (\alpha h\nu)^2 \) Vs the \( h\nu \) plots to the energy axis. As we can see from figure 7; the energy band gap varies between 3.14 and 4.33 eV. The thin films deposited at oxygen gas and the Argon has the minimum and maximum bandgap, respectively. The optical band gap decreases from Argon to oxygen deposition conditions. The decrease in optical band gap can be attributed to the improvement in crystalline quality [36].

3.4. Photoluminescence analysis

The PL emission and excitation of the Y\(_2\)SiO\(_5\) : Ce\(^{3+}\) thin films deposited at different background gases are shown in figure 8. All the thin films were excited at an excitation wavelength of 370 nm. The PL emission spectrum was observed at 423 nm, this is comparable to the emission wavelength reported in [19, 37]. However, Ce\(^{3+}\) ion has different coordination numbers when it occupies two separate lattice sites in the crystalline field of the host material (Y\(^{3+}\)), therefore several emission peaks are hidden under the broadband of Ce\(^{3+}\) emission spectrum. The broadband emission can be decomposed into the constituent emission bands using the Gaussian peak fitting method as shown in figure 9. So, the main PL emission peaks are positioned at 420 and 457 nm which corresponds for the electronic transition of 5d \( \rightarrow \) 4f\(^2\)(\(^{2}F_{7/2}\)) and 5d \( \rightarrow \) 4f\(^1\)(\(^{2}F_{5/2}\)) respectively. The excitation spectrum which was probed at 423 nm shows two peaks at 370 and 332 nm which corresponds to the electronic transition from the valence band to the conduction band (4f \( \rightarrow \) 5d). The electron that revolves around its axis and
orbiting around the nucleus has a doublet character that is observed due to the division of the ground state of Ce$^{3+}$ into $^2F_7/2$ and $^2F_5/2$. The emission bands positioned at 420 and 457 nm corresponds to the blue color. This emission could be attributed to the electron transition of the Ce$^{3+}$ ion from 5d to 4f states. The electronic configuration of cerium (Ce$^{3+}$), consists of one electron in the 4f energy state; When the 4f$^1$ configuration of Ce$^{3+}$ is irradiated with UV radiation, the 4f electron is excited and transferred into the 5d orbit leaving the 4f shell empty. Therefore, the excitation spectrum of the cerium ion gives information on the crystal division of the 5d orbitals, which is the reason for the PL emission centers of 420 and 457 nm. Due to the spin–orbit interactions, the ground state 4f splits into $^2F_5/2$ and $^2F_7/2$ energy sub-levels. When the 4f and 5d states interact, the electron is excited to the 5d state. The electronic transition from 4f to 5d is parity and spin allowed. The interaction between the dopant ions (Ce) and the atoms in the crystalline field of the host material through the surrounding charges is the possible reason for the creation of 4f and 5d energy levels at the positions of the valence and conduction band, respectively. The creation of the energy levels of 4f and 5d could decrease the center of mass of the 5d structures due to the electrostatic interaction that corresponds to the excitation wavelength of 332 nm. The entry of the Ce$^{3+}$ ion into a specific lattice site causes the 5d state to be divided into different sub-states according to the symmetry of the site. If the 5d state is in more than one lattice site, it is very likely to split into several sub-levels. The division of the ground state energy of Ce$^{3+}$ ion into $^2F_7/2$ (parallel) and $^2F_5/2$ (antiparallel) is the possible cause for the doublet characters (rotation of electrons around its

Figure 7. Dependence of $(\alpha_\nu)^2$ on the photon energy $h\nu$ for Y$_2$SiO$_5$:Ce$^{3+}$ thin films deposited at different deposition gases.

Figure 8. Excitation and emission spectra of Y$_2$SiO$_5$:Ce$^{3+}$ thin films.
axis and orbiting the nucleus). Deposition gases play a very important role in the growth of thin films during PLD ablation. During the ablation process, the phenomena that can take place are: the reflection of ions or atoms on the surface of the film, scattering of the incoming atoms from the deposited atoms and the establishment of the arriving particles [41]. High emission and excitation were observed under the oxygen background gas. Since oxygen gas has effective chemical reaction and conversion capabilities when interacting with the ablated particles, molecules and groups are more abundant in the oxygen gas background than other deposition gases [42] which can be attributed to the suppression of oxygen vacancies.

Therefore, the emission spectrum of the Ce$^{3+}$ ion is positioned at 420 and 457 nm, which are completely in the blue range. The chromaticity coordinates of the Ce$^{3+}$ doped Y$_2$SiO$_5$ phosphor were calculated using the 423 nm emission wavelength, as shown in figure 10 and the corresponding values are in the blue region. This clearly shows that Y$_2$SiO$_5$: Ce$^{3+}$ can be used for blue light emitting applications. Its average chromaticity coordinate is $(x, y) = (0.178, 0.136)$. The results indicated that the corresponding color for all the thin films rests in the blue color region, which are a good candidate for blue light display applications. Nevertheless, the thin films deposited at the oxygen background gas has relatively better emission as shown from the PL graph.
3.5. Thermoluminescence analysis

TL is the stimulated emission of light resulting from the absorption of radiation. The absorbed radiation causes the electrons to move through the crystal lattice. When the sample is heated, the trapped electron returns to its normal position which exists at low energy levels by releasing energy in the process of return. This measurement is effective for biological applications (age determination), dosimetry, geology, analysis of the structure of solid-state defects etc. The main objective of the TL measurement is to exploit the data from the experimental glow curve to calculate the associated parameters (activation energy, frequency factor, kinetic order and form factor) in the energy space related to the luminescence process. The trapping parameters shown in table 3, are related to the TL glow curve which sits in different depth in the band gap (between the conduction and valence bands of the material) \[43\]. The activation energy gives us information about the depth of the trap and measure their energy levels in the band gap. The order of kinetics (b) is mainly related to the mechanism of recombination of the trapping charges with their counterparts. The frequency factor (s) represents the product of the number of times (frequency) the electron heats the potential wall (trap) and the reflection coefficient of the wall as a result of interaction. TL is a very sensitive measurement method that is used to estimate the concentration of luminescent centers in the solid. The TL emission also reveals the levels of defects (traps) created in solids irradiated by a certain energy \[44\]. The TL glow curves of UV irradiated Y\(_2\)SiO\(_5\):Ce\(^{3+}\) thin film grown by different deposition gases are shown in figure 11 and the estimated kinetic and the trapping parameters which are obtained from the glow peak shape are given in tables 2 and 3. The TL glow curve for nitrogen deposition gas was not plotted because the intensity was very small as compared to the other deposition gases which can be ascribed to shallower defect level. We have applied Chen’s peak shape equation \[44\] to find the activation energies from the corresponding parameters (\(\tau\), \(\delta\) and \(\omega\)) that are obtained from the glow curve of the experimental data (figure 11). The value of the parameters is as follow:

\[
\tau = T_M - T_1, \quad \delta = T_2 - T_M, \quad \omega = T_2 - T_1 \quad \text{and} \quad \mu_g = \delta / \omega
\]

Where; \(T_M\) is peak temperature at the maximum TL intensity,
\(T_1, T_2\) are temperatures on either side of \(T_M\), corresponding to the half-maximum intensity and \(\mu_g\) is the geometrical shape factor or symmetry factor.

| Deposition condition | \(T_1\) (°C) | \(T_M\) (°C) | \(T_2\) (°C) | \(\omega\) | \(\tau\) | \(\delta\) | \(\mu_g = \delta / \omega\) |
|----------------------|-------------|-------------|-------------|-------------|-------------|-------------|-----------------|
| Argon                | 50.238      | 120.15      | 164.26      | 114.022     | 69.912      | 44.11       | 0.386 86        |
| Oxygen               | 41.101      | 115.4       | 162.59      | 121.489     | 74.299      | 47.19       | 0.388 43        |
| Vacuum               | 57.23       | 134.4       | 180.088     | 122.858     | 77.17       | 45.69       | 0.371 88        |

Figure 11. Effect of deposition gases on TL intensities of Y\(_2\)SiO\(_5\):Ce\(^{3+}\) thin film phosphors.
The most appropriate chen’s equation to calculate the activation energy is given in equation (6).

\[ E_\alpha = C_\alpha \left( \frac{T^2 - m}{\alpha} \right) - b_\alpha (2KT_m) \]  

(6)

Where \( \alpha \) stands for \( \tau, \delta \) or \( \omega \).

The value of \( C_\alpha \) and \( b_\alpha \) is summarized below:

\[
\begin{align*}
C_\tau &= 1.51 + 3(\mu_g - 0.42); \quad b_\tau = 1.58 + 4.2(\mu_g - 0.42) \\
C_\delta &= 0.976 + 7.3(\mu_g - 0.42); \quad b_\delta = 0 \\
C_\omega &= 2.52 + 10(\mu_g - 0.42); \quad b_\omega = 1
\end{align*}
\]

Theoretically, the system factor \( (\mu_g) \) ranges between 0.42 and 0.52. when the system is closing to 0.42, it is first order kinetics and if the system factor is closing to 0.52, it is second order kinetics. The system factor \( (\mu_g) \) is practically independent of the activation energy \( (E) \) but it strongly depends on the order of the kinetics \( (b) \) [45]. When \( E \) and \( b \) are known, \( S \) can be evaluated by Chen and Kirsh relation [46].

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

(7)

Where \( \beta \) is the linear heating rate, \( b \) is the order of kinetics and \( \Delta m = \frac{2KT_m}{E} \). Shenker and Chen [47] and Kivits and Hagebeuk [48] tested the accuracy of these methods of calculating \( E \). They concluded that the methods give trap depths at 5% close to the real value. Using equations (6) and (7), the corresponding activation energy and the frequency factor are summarized in table 3. As can be seen from tables 2 and 3 the value of the kinetic factor approaches that of the first order kinetics (0.42), as a result, the value of \( C_\alpha \) and \( b_\alpha \) \( (\alpha = \tau, \delta \) and \( \omega \) have been used to calculate the corresponding activation energies.

The average activation energy ranges between 0.1733 and 0.1938 eV. Maximum activation energy was obtained under the argon deposition gas. This can be ascribed to the existence of maximum defect level on the argon deposited thin film as compared to the other thin films deposited at different gases.

4. Conclusion

The \( Y_2SiO_5:Ce^{3+} \) thin films have been deposited at different background gases to characterize their luminescence, thermoluminescence, optical, morphological and structural properties. The material is structurally monoclinic with a prominent diffraction peak of 15.7°. Relatively, good crystalline thin film has been obtained at oxygen deposition gas, which can be due to the suppression of oxygen deficiency by the background gas. From the SEM measurements, the thin films have different textures and topographies. The collision of the deposition gas with the plume increases the vibrational energy of the eliminated molecular species and induces a variation of the composition during the formation of the thin films. The crystallite size of the particles has increased from vacuum to oxygen deposition condition. Agglomeration was observed due to the condensation of the shock wave formation introduced at the surface of the thin film. The average diameter of the nanoparticles is 28.1 nm. From the EDS measurements, all constituent elements were detected with their respective atomic weight. Maximum and minimum UV absorbance was noticed at argon and vacuum respectively. Thickness and roughness of thin films play an important role in increasing and decreasing the absorbance value of thin films. All the thin films were probed at an excitation wave length of 370 nm. The corresponding emission spectrum was observed at 420 and 457 nm by deconvoluting the broad PL emission into its constituents. Due to the spin–orbit interactions, the ground state 4f alienated into \( ^2f_5/2 \) and \( ^2f_7/2 \) sub-energy levels. From the CIE measurement, all the color coordinates of the thin films are in the region blue. Maximum TL emission was observed at 393.15, 388.4 and 407.4 K for Argon, Oxygen and vacuum respectively. The activation energy ranges between 0.1733 and 0.1938 eV.

### Table 3. Calculation of trap parameters and order of kinetics for UV-irradiated \( Y_2SiO_5:Ce^{3+} \) thin film phosphor.

| Deposition condition | \( T_m \) (K) | Order of kinetics \( \mu_g \) (b) | \( E_r \) | \( E_i \) | \( E_g \) | \( E_m \) | Frequency factor \((S^{-1})\) |
|---------------------|--------------|-------------------------------|--------|--------|--------|--------|-------------------|
| Argon               | 393.15       | 0.386                         | 0.1727 | 0.2212 | 0.1875 | 0.1938 | \( 1.16 \times 10^3 \) |
| Oxygen              | 388.4        | 0.388                         | 0.1522 | 0.2050 | 0.1686 | 0.1752 | \( 6.56 \times 10^2 \) |
| Vacuum              | 407.4        | 0.371                         | 0.1579 | 0.1952 | 0.1668 | 0.1733 | \( 4.30 \times 10^2 \) |

### Notes:

- \( E_r \), \( E_i \), \( E_g \), and \( E_m \) represent the corresponding emission spectrum.
- \( \alpha \), \( \beta \), and \( \gamma \) are system factors.
- \( C_\alpha \), \( b_\alpha \), \( C_\beta \), \( b_\beta \), \( C_\omega \), and \( b_\omega \) are constants.
- \( \Delta m \) is the change in the order of kinetics.
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