Effect of Bi^{3+} and Li^{+} co-doping on the luminescence properties of $\text{Zn}_2\text{TiO}_4\text{:Eu}^{3+}$ nanophosphor for display applications

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Abstract

A novel Li^{+} and Bi^{3+} ions (0.5–2.0 mol%) co-doped $\text{Zn}_2\text{TiO}_4\text{:Eu}^{3+}$ (7 mol%) nanophosphors were synthesised by two step combustion route and its effect on luminescence characteristics are described. Addition of Li^{+} and Bi^{3+} ions does not introduce new luminescence characteristics but affects the intensity of Eu^{3+} related emission. Crystalline structure were characterized by powder X-ray diffraction technique which confirms the formation of a cubic structure and the influence of synthesise conditions on surface morphology was examined by scanning electron microscopic technique. The photoluminescence (PL) properties of Li^{+} and Bi^{3+} ions (0.5–2.0 mol%) co-doped $\text{Zn}_2\text{TiO}_4\text{:Eu}^{3+}$ (7 mol%) show characteristic 4f–4f emissions of Eu^{3+} ions at 578, 592, 613 and 654 nm, also reveals that the small quantity of co-dopant ions was highly effective for charge compensation as well as formation of lattice defects to boost the PL emission. Further, Commission International de l'Eclairage chromaticity and color purity results suggests that, the synthesised phosphor can be used as a red component for production of near ultraviolet based wLEDs, solid state lightning and display applications.

Keywords $\text{Zn}_2\text{TiO}_4\text{:Eu}^{3+}$ · Li^{+} · Bi^{3+} · DRS · Photoluminescence

1 Introduction

Rare earth (RE) based inorganic compounds have attracted researchers owing to their potential applications such as solid state lighting, display devices, finger print sensing etc. Phosphors with properties such as long-standing, better brightness, quick response and good quantum efficiency are very much essential to reach the needs of the devices. Spectroscopic nature of sharp 4f–4f transitions of RE ions undoubtedly leads to ligand dependent luminescence sensitization, large stokes effect which is needed to convert UV or Near UV to visible light [1]. RE electronic transitions (4f–4f) provide long lasting narrow emissions owing to the shielding effect of its 4f-shell electrons. Emission transitions (colour purity, intensity and efficiency) of the RE ions are mainly affected by the kind of host material,

interaction between the host and RE ions, proportion of the dopants concentration and dopant ions distribution and the transfer of energy from the host or sensitizer to the dopant ions. One of the major challenge for the wider use of phosphors, is the suitable inorganic host material, which supports efficient 4f–4f transitions of RE ions [2–4].

RE ions activated titanate nanomaterials are used as a prominent candidates to achieve good excitation, efficient energy transfer, and superior emission. Trivalent RE ions (Eu^{3+} , Tb^{3+} , Sm^{3+} , Er^{3+} , Tm^{3+} , Ho^{3+}) serve as an brilliant luminescent centres in inorganic phosphors owing to their appropriateness of excitation in the ultraviolet, visible and near infrared regions. Among, red emitting Eu^{3+} activated phosphors plays a vital role in photonic device applications [4]. Zn_2TiO_4 belongs to ZnO-TiO_2 family, an important host material among inorganic phosphors due

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its unique characters such as good thermal and chemical stability, low cost, non toxicity, abundance in nature, suitability for doping [5].

It was noticed that, addition of little quantity of co-dopant ions enhances the photoluminescent efficiency of phosphors. In this regard, we used alkali metal ions as co-dopants to synthesise highly luminescent phosphors with better brightness. Also, it was noticed that little quantity of work was reported on the photoluminescence properties of alkali metal ions co-doped with Eu^{3+} ions. Addition of little quantity of codopants into the host material leads to increases the crystallinity, creates more oxygen vacancies and removes the charge imbalance problem, due to its low oxidation states and distinct ionic radii [6–9].

Nowadays development of luminescent nanophosphors with novel properties have gaining abundant interest in the field of display applications, with this connection in the present work, we synthesised Li^+ and Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ phosphors by facile combustion route using lab made ODH as a fuel and obtained results of the prepared phosphor are the potential to be used for real applications in the area of wLEDs, solid state lightening and display applications.

1.1 Preparation of Li^+ and Bi^{3+} assisted $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ nanopowders

Red emitting Li^+ and Bi^{3+} (0.5–2.5 mol%) ion compensated $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) powders were synthesised via combustion method using lab made oxalyl dihydrazide (ODH) as a fuel. Zinc nitrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), Titanyl nitrate ($\text{TiO}(\text{NO}_3)_2$), Europium nitrate ($\text{Eu}(\text{NO}_3)_3$), Lithium nitrate (LiNO_3), Bismuth nitrate ($\text{Bi}(\text{NO}_3)_3$) and (ODH; $\text{C}_2\text{H}_6\text{N}_4\text{O}_2$) were used as precursors. Stoichiometric amount of the precursors with suitable quantity of doubled distilled water were mixed in a petri dish using magnetic stirrer for about 5 min and the obtained homogeneous mixture was placed in a preheated furnace maintained at 500 °C. Finally, well grinded powder was calcined at 900 °C for 3 h to get pure cubic Li^+ and Bi^{3+} ions codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanopowders.

2 Result and discussions

The crystalline phase and crystallinity of Li^+ and Bi^{3+} co-doped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphors were investigated by X-ray diffraction and is as shown in Fig. 1a, b. All the obtained peaks observed in the pattern confirms the formation of cubic phase with JCPDS Xard No. 77-14 (space group Fd-3m (No. 227)), no other

Fig. 1 **a** Powder X-ray diffraction patterns of $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%): Li^+ (0.5–2.0 mol%) nanophosphors. **b** Powder X-ray diffraction patterns of $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%): Bi^{3+} (0.5–1.5 mol%) nanophosphors

impurity peaks are observed in the PXRD limit indicates the purity of the prepared sample and reduction in peak intensity was noticed after the addition of co-dopant ions. When dopant ions doped into the host matrix causes expansion of the unit cell resulting in tensile stress and micro strain in the host lattice. Addition of co-dopant ions creates oxygen vacancies in the host lattice, when the concentration of co-dopants increases, substantial number of oxygen vacancies is created in the lattice and these oxygen ions expand the lattice with a decrease in crystal density due to which Li-O / Bi-O bond strength is decreases, which in turn reduces the crystallinity and leads to generate micro strain in the sample.

The crystallite size was calculated using Scherrer's and W–H method for all the prepared phosphors and the calculated values lies within 15–30 nm range, which confirms the formation of Zn_2TiO_4 in the nanometric

region [10]. The X-ray density (dX) was calculated for the prepared powders by using the following equation and found to be 8.54 (g/cm³).

$$dX = ZM/Na^3 \quad (1)$$

where Z: number of Zn₂TiO₄ molecules per unit cell, M: molecular weight, N: Avogadro's number and a: lattice parameter. Also, specific surface area (S) was estimated by the equation

$$S = 6/dXD \quad (2)$$

where dX: X-ray density, D: Crystallite size. Also, from the table it was observed that specific surface area diminishes with the increase of doping concentration which is well agreement with the literature [11–13].

Further, the crystallographic defect with in a crystal structure strongly influences the properties of the material and can be estimated by dislocation density and the micro strain present in the sample, all the obtained values are given in the Tables 1 and 2 [14].

$$\varepsilon = \frac{\beta \cos \theta}{4} \quad (3)$$

$$\delta = \frac{1}{D^2} \quad (4)$$

Figure 2 illustrates the structural investigation of Li⁺ and Bi³⁺ (0.5–2.0%) co-doped Zn₂TiO₄:Eu³⁺ (7 mol%) nanopowder by SEM technique. Obtained SEM pictures indicates that the prepared powder composed of spherical like highly porous particles with different sizes and thickness,

which is a significant character of the materials prepared via solution combustion synthesis [15].

In order to investigate optical response of the prepared material, Diffused Reflectance Studies (DRS) were performed and the obtained results are depicted in Fig. 3. Optical energy gap (E_g) of the Li⁺ (0.5–2.0 mol%), Bi³⁺ (0.5–1.5 mol%) (Inset of Fig. 3) codoped Zn₂TiO₄:Eu³⁺ (7 mol%) nanopowders were estimated from the DRS employing the Kubelka–Munk (KM) method. Energy gap (E_g) values of the prepared material were estimated using the following relation [16].

$$F(R_{\infty})h\nu = A(h\nu - E_g)^n \quad (5)$$

$R_{\infty} = \frac{R_{\text{sample}}}{R_{\text{standard}}}$ and $F(R_{\infty})$ was the K–M function, (where R_{std} 0.973–0.988 for BaSO₄), the standard error in the value of R_{∞} is lies between 0.2 to 0.6 which was defined as:

$$F(R_{\infty}) = \frac{(1 - R_{\infty})^2}{2R_{\infty}} = \frac{k}{s} \quad (6)$$

Here $h\nu$: photon energy, n : nature of the sample transition depends on the kind of transition stimulated by photon. absorption, where $n=2$ for a direct allowed transition, and $n=1/2$ for an indirect allowed transition, A is the constant, The linear part of the curve was extrapolated to $(F(R)h\nu)^2 = 0$ to get the direct band gap energy.

Figure 4 show the characteristic KM plots of Li⁺ (0.5–2.5 mol%) and Bi³⁺ (0.5–1.5 mol%) (co-doped Zn₂TiO₄:Eu³⁺ (7 mol%) nanophosphors. Energy gap

Table 1 Estimated crystallite parameters of Li⁺ ions codoped Zn₂TiO₄:Eu³⁺ nanophosphor

Phosphor Zn ₂ TiO ₄ : Eu ³⁺ _{7 mol%} : Li ⁺ _{x mol%} (mol%)	Crystallite size in nm		Specific surface area 'S' (m ² /g)	Strain (10 ⁻³)	δ
	Scherr's	W–H plot			
0.0	15	20	73.39	2.30	4.4
0.5	18	24	62.28	1.90	3.0
1.0	20	25	56.21	1.80	2.5
1.5	25	28	44.26	1.55	1.6
2.0	27	29	42.26	1.20	1.3

Table 2 Estimated crystallite parameters of Bi³⁺ ions co-doped Zn₂TiO₄:Eu³⁺ nanophosphor

Phosphor Zn ₂ TiO ₄ : Eu ³⁺ _{7 mol%} : Bi ³⁺ _{x mol%} (mol%)	Crystallite size in nm		Specific surface area 'S' (m ² /g)	Strain (10 ⁻³)	δ
	Scherr's	W–H plot			
0.0	15	20	73.39	2.30	4.4
0.5	20	25	60.18	1.78	2.5
1.0	23	27	52.72	1.62	1.8
1.5	24	29	41.36	1.46	1.7

Fig. 2 SEM pictures of Li^+ and Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphors

Fig. 3 Diffused reflectance spectra of $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%); Li^+ (0.5–2.0 mol%) nanophosphors (inset: DRS of $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%); Bi^{3+} (0.5–1.5 mol%) nanophosphors)

Fig. 4 Energy band gap. $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%); Li^+ (0.5–2.0 mol%) nanophosphors (inset: energy band gap. $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%); Bi^{3+} (0.5–1.5 mol%) nanophosphors)

values of the prepared materials increases with Li^+ concentration up to 3.55 eV and then it remains constant at 3.6 eV. This kind of variation in the energy gap values may be due to various factors, structural order–disorder in the host with the incorporation of Li^+ , imbalance of charge and lattice defects [17]. These factors modifies the distribution of energy level and density of states in the host matrix, few factors involves in increasing the energy gap (compressive strain in the host leads to

increase of energy gap) but some other facts such as oxygen vacancies involving in decreasing of energy gap [18]. Also, band gap values of Bi^{3+} (0.5–1.5 mol%) co-doped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphors (Inset of Fig. 4) was estimated and found to be in the range 3.4 to 3.5 eV.

To investigate the photoluminescence properties of Li^+ and Bi^{3+} co-doped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ phosphor, the excitation spectra is recorded by monitoring emission at 612 nm

Fig. 5 Excitation spectra of Li^+ , Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) (emission at 612 nm)

Fig. 6 Emission spectra of Li^+ , Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) (Excited at 395 nm)

and the obtained spectra is as shown in the Fig. 5. From the Fig. 5 it was noticed that both Li^+ and Bi^{3+} co-doped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ phosphor indicates similar type of excitation peaks with variation in intensity only. The spectra consists of broad and sharp narrow peaks, the peak situated at 311 nm is due to the charge transfer band (CTB). In the present case CTB is due to transfer of an electron from the filled $\text{O}2\text{-(}2p6\text{)}$ ligand orbital to the empty states of $4f$ orbital of Eu^{3+} . The peaks at 360 nm (${}^7\text{F}_0 \rightarrow {}^5\text{G}_3$), 382 nm (${}^7\text{F}_0 \rightarrow {}^5\text{G}_4$) and 395 nm (${}^7\text{F}_0 \rightarrow {}^5\text{D}_3$) were due to absorption transitions of Eu^{3+} ions, and these transitions clearly indicate that the prepared material is a suitable candidate for blue and near-UV excited red phosphor.

PL emission spectra of Li^+ and Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ nanophosphor excited under the wavelength of 395 nm is as shown in Fig. 6. In our earlier research work,

luminescence studies of $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (1–11 mol%) nanophosphor proved that 7 mol% Eu^{3+} doped sample show highest intensity [10], thus in the present study, it was taken as optimum concentration for Li^+ and Bi^{3+} codoping.

Luminescence spectra of lithium co-doped with $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphors shown in inset of Fig. 6 (Left), indicates that there is no considerable change in the peak position but the relative intensities of peaks changed significantly with addition of Li^+ . Emission spectra consists of four groups of intense peaks associated with transitions ${}^5\text{D}_0 \rightarrow {}^7\text{F}_j$ of Eu^{3+} ions lying in the range between 550 nm to 770 nm, peaks observed at 578, 592, 613 and 654 nm which were attributed to transitions ${}^5\text{D}_0 \rightarrow {}^7\text{F}_0$, ${}^5\text{D}_0 \rightarrow {}^7\text{F}_1$, ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$ and ${}^5\text{D}_0 \rightarrow {}^7\text{F}_3$ respectively. Among, ${}^5\text{D}_0 \rightarrow {}^7\text{F}_0$ transition may not be observed in various cases due to parity conservation rule which kind of unusual characteristic is mainly due to the existence of strong interaction of interstitial oxygen with Eu^{3+} ions, the transition ${}^5\text{D}_0 \rightarrow {}^7\text{F}_1$ is originated from magnetic dipole transitions (independent of symmetry and occupation of Eu^{3+} site in the host) whereas the ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$ peaks originate from electric dipole transitions which is hyper sensitive to the crystal environment [19]. In particular, the ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$ characteristic red emission transition at 613 nm is the dominant which is due to occupation of site without an inverse center (forced electric dipole (FED)). Figure 6 (Inset right) shows the luminescent spectra of Bi^{3+} codoped with $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphors. Also noticed that addition of Bi^{3+} ions in the phosphor enhances the luminescence intensity multiple times without disturbing peak position as in the case of Li^+ codoped samples and the corresponding, variation of emission intensity with the codopants was shown in Fig. 7

2.1 Effect of codopants

It was noticed that, PL peak positions are independent of co-dopant (Li , Bi^{3+}) concentrations, but the relative luminescent intensity is significantly influenced with the addition of $\text{Li}^+/\text{Bi}^{3+}$ ions (~three fold/six fold) compared to the Eu^{3+} doped Zn_2TiO_4 nanophosphor. Enhanced intensity in the emission is due to the charge compensation assisted by the $\text{Li}^+/\text{Bi}^{3+}$ ions in the host matrix. Charge compensation provides superior chemical stability and enhances the quality of the crystal which has a considerable effect on the increasing of emission intensities in the co-doped phosphors. Emission intensity increases with addition of $\text{Li}^+/\text{Bi}^{3+}$ concentration up to 1.5/1.0 mol% and thereafter intensity reduces which is attributed to concentration quenching [20]. Moreover, at higher $\text{Li}^+/\text{Bi}^{3+}$ concentration, excess of oxygen vacancies may be produced which leads to decrease of luminescence intensity. In the present work codopants acts as a sensitizer which provides effective

Fig. 7 Emission Intensity of Li^+ , Bi^{3+} codopants with concentration

transfer of energy from host to activators due to the well matching of charge transfer states and the schematic diagram is illustrated in the Fig. 8.

The transition $^3\text{P}_1 \rightarrow ^1\text{S}_0$ of Bi^{3+} ions effectively transfer the energy from $\text{Bi}^{3+} - \text{Eu}^{3+}$ in the material enhances the PL intensity by multiple times than that of Li^+ co-doped samples [21].

Vanuitert's equation was utilised to examine the kind of interaction involved in the process of energy transfer.

$$\frac{I}{X} = k [1 + \beta(X)^{Q/3}]^{-1} \quad (7)$$

where I be the emission intensity, X be the dopant concentration, I/X be the emission intensity per dopants (X), β and k be the constants. From the above equation, $Q=3$ indicates the transfer of energy among the nearest neighbour ions, while $Q=6, 8$ and 10 for dipole-dipole ($d-d$), $d-q$ and $q-q$ interactions respectively. Above equation can be written as by assuming that $\beta(X)^{Q/3} \gg 1$

$$\log \left(\frac{I}{X} \right) = K' - \frac{Q}{3} \log X \quad (K' = \log K - \log \beta) \quad (8)$$

Fig. 8 Probable mechanism of charge transfer process from sensitizer to activators in Li^+ , Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}(7 \text{ mol}\%)$ nanophosphor

The multipolar character (Q) was calculated using the above equation (Fig. 9). The Q Value for Li^+ and Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ nanophosphor is found to be 6.27 and 6.66 respectively which are ~ 6 indicates that concentration quenching in Li^+ and Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ nanophosphor occurred due to $d-d$ interaction. Thus addition of the codopants into $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ nanophosphor did not change the quenching mechanism.

Figure 9 indicates the energy level diagram of prepared phosphors which represents the probable mechanism involved in the luminescence process. Excitation is due to transferring the valence band electrons to the CTB or by jumping to the higher levels of Eu^{3+} . excitation at 311 and 395 nm attributed to charge transfer and direct excitation respectively, After this process, excited electrons were jumped into lower level ($^5\text{D}_0$), which is non radiative transition and then depopulated to the lower levels by radiative transitions $^5\text{D}_0 \rightarrow ^7\text{F}_0$, $^5\text{D}_0 \rightarrow ^7\text{F}_1$, $^5\text{D}_0 \rightarrow ^7\text{F}_2$ and $^5\text{D}_0 \rightarrow ^7\text{F}_3$ results in 593, 615, 652 and 700 nm emissions respectively.

In order to describe the emitted colour of the synthesised Li^+ and $\text{Bi}^{3+}(0.5-2.0\%)$ activated $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}(7 \text{ mol}\%)$ phosphors, it is very much essential to study the color coordinates on a standard Commission International d'Eclairage (CIE) 1931 chromaticity diagram. The chromaticity coordinates

Fig. 9 The energy level diagram of Li^+ and Bi^{3+} ions showing the states involved in the luminescence process

(x , y) of the synthesised phosphors were estimated from PL data, the obtained values are located in the red region of the CIE diagram Fig. 10a, b and the corresponding (X , Y) details listed in the Table 3, the values indicate that the synthesised phosphor can be used as a red component in the fabrication of white LEDs and display applications [22, 23]. Correlated Color Temperature (CCT) was evaluated (by transforming the (x , y) coordinates to (U' , V') to characterise the quality of emission from photoemitters (Fig. 11a, b),

$$U' = \frac{4x}{-2x + 12y + 3} \quad (9)$$

$$V' = \frac{9y}{-2x + 12y + 3} \quad (10)$$

Also, theoretically CCT values were calculated using McCamy empirical formula $\text{CCT} = -437n^3 + 3601n^2 - 6861n + 5514.31$, where $n = (x - x_c)/(y - y_c)$ and chromaticity epicenter is at $x_c = 0.3320$ and $y_c = 0.1858$. CCT was found to be 2460 K and 3792 K for Li^+ and Bi^{3+} (0.5–2.0%) activated $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) phosphors and the calculated CCT values are given in the Table 4.

Further, evaluation of color purity (CP) and dominant wavelength provides other way to describe the position of a prepared phosphor on the CIE diagram. In the present work, Fred Schubert method was used to calculate the effect of Li^+ on the CP of the material using the relation [24].

$$\text{color purity} = \frac{\sqrt{(x_s - x_{ee})^2 + (y_s - y_{ee})^2}}{\sqrt{(x_d - x_{ee})^2 + (y_d - y_{ee})^2}} \times 100\% \quad (11)$$

Fig. 10 **a** CIE diagram of Li^+ codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphor. **b** CIE diagram of Bi^{3+} codoped $\text{Zn}_2\text{TiO}_4:\text{Eu}^{3+}$ (7 mol%) nanophosphor

Table 3 CIE and CCT parameters of Li⁺ ions codoped Zn₂TiO₄:Eu³⁺ nanophosphor

Phosphor	Concentration (mol%)	CIE coordinates		CCT coordinate		CCT (K)
		X	Y	U'	V'	
Zn ₂ TiO ₄ : Eu ³⁺ (7 mol%) : Li ⁺ x mol%	0.5	0.6364	0.3630	0.4185	0.5371	2194
	1.0	0.6437	0.3558	0.4303	0.5353	2403
	1.5	0.6524	0.3471	0.4453	0.5331	2731
	2.0	0.6469	0.3527	0.4357	0.5345	2513

Fig. 11 **a** Correlated color temperature diagram of Li⁺ codoped Zn₂TiO₄:Eu³⁺ (7 mol%) nanophosphor. **b** Correlated color temperature diagram of Bi³⁺ codoped Zn₂TiO₄:Eu³⁺ (7 mol%) nanophosphor**Table 4** CIE and CCT parameters of Bi³⁺ ions codoped Zn₂TiO₄:Eu³⁺ nanophosphor

Phosphor	Concentration (mol%)	CIE coordinates		CCT Coordinate		CCT
		X	Y	U'	V'	
Zn ₂ TiO ₄ : Eu ³⁺ (7 mol%) : Bi ³⁺ x mol%	0.5	0.6724	0.3255	0.4819	0.5210	3645
	1.0	0.6751	0.3294	0.4820	0.5291	3792
	1.5	0.6715	0.3278	0.4815	0.5191	3692

where (x_s, y_s), chromaticity coordinates of the sample point, (x_{ee}, y_{ee}) equal energy point which is equal to (0.33, 0.33), and (x_d, y_d) are the dominant wavelength point, calculated from connecting line intersection between equal energy and sample point [25]. CP of the prepared samples is found to be in the range of 85%. Thus, the obtained results such as enhanced PL emission and high CP show that, prepared phosphors can be a promising material for display solid state lightening applications.

3 Conclusions

The effect of Li⁺ and Bi³⁺ ions codoping on luminescence properties of Zn₂TiO₄:Eu³⁺ (7 mol%) nanophosphor was studied. Addition of these elements as a codopants enhances the luminescence intensity of the Zn₂TiO₄:Eu³⁺ (7 mol%) phosphor with better crystallinity and charge compensation. The PL studies of Li⁺ and Bi³⁺ ions (0.5–2.0 mol%) co-doped Zn₂TiO₄:Eu³⁺ (7 mol%) phosphors indicates characteristic 4f–4f emissions of Eu³⁺ ions also observed that addition of small quantity of codopant ions effectively enhances the PL emission intensity. Incorporation of Bi³⁺ (1 mol%) and Li⁺ (1.5 mol%) enhances the luminance intensity of Zn₂TiO₄:Eu³⁺ (7 mol%) phosphor with ~ six fold and ~ three fold respectively. The chromaticity coordinates (x, y) of the synthesised phosphors were estimated from PL data and the obtained values are located in the red region of the CIE diagram and CP of the prepared samples is found to be in the range of 85%. The above results suggest that, the prepared material can be used as a red component for production of NUV based wLEDs, solid state lightning and display applications.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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