$\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ nanophosphors: its white light emission and photocatalytic activity

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Abstract

The present work involves the synthesis, characterization, photoluminescence and photocatalytic studies of Dy^{3+} (1–11 mol%) doped Bi_2O_3 nanophosphors (NPs) by solution combustion method. The average crystallite size was determined using powder X-ray diffraction, found to be in the range of 15–30 nm. Scanning electron microscopy images shows that the synthesised product is porous and agglomerated. Kubelka–Munk function was used to assess the energy gap of Dy^{3+} doped Bi_2O_3 nanophosphors and it was found to be 2.53–3.00 eV. From the emission spectra, Judd–Ofelt parameters (Ω_2 and Ω_4), transition probabilities (A_T), quantum efficiency (η), luminescence lifetime (τ_f), color chromaticity coordinates (CIE) and correlated color temperature values were estimated and discussed in detail. The CIE chromaticity co-ordinates were close to the National Television Standard Committee standard value of white emission. Using Langmuir–Hinshelwood model, the photocatalytic activity results of Acid Red-88 showed, $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs were potential material for the development of efficient photocatalyst for environmental remediation. The obtained results prove that the $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs synthesised by this method can be potentially used for solid state display and photocatalyst.

Keywords $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ · Photoluminescence · Judd–Ofelt · Color chromaticity coordinates (CIE) · Correlated color temperature (CCT)

1 Introduction

Over the last few decades, the research on efficient and economical nanophosphors (NPs) is a demanding problem for new luminescent materials. Conventional lightning sources suffering from low luminous efficacy and are less sensitive to human eyes. In this regard, phosphors which convert UV or near-UV to visible light plays a vital role in solid state lighting applications [1]. Use of those phosphor materials in light emitting diode (LEDs) was a major step in solid state lighting technology. However, white light emitting diodes (WLEDs) are considered to be the next generation lighting system because of their excellent properties

like high luminous efficiency, low power consumption, environmentally friendly features (nontoxic), reliability and long life [2–4].

Dy^{3+} doped NPs are generally studied due to their potential applications in white light emission as the emission band of Dy^{3+} doped materials exhibit intense blue, yellow and red emission lines at around 480, 580 and 680 nm respectively corresponding to the transitions $^4\text{F}_{9/2} \rightarrow ^6\text{H}_{15/2, 13/2 \text{ and } 11/2}$ [5, 6] and the same is observed in our previous studies in various host materials like $\text{LaAlO}_3:\text{Dy}^{3+}$ [7], $\text{Zn}_2\text{TiO}_4:\text{Dy}^{3+}$ [8], $\text{MgAl}_2\text{O}_4:\text{Dy}^{3+}$ [9], $\text{Mg}_2\text{SiO}_4:\text{Dy}^{3+}$ [10], $\text{MgO}:\text{Dy}^{3+}$ [11] etc. Realization of white light is possible by adjusting the intensity ratio of yellow

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to blue (Y/B). In the emission spectra whenever the Dy^{3+} cation is hosted at a low-symmetry local site, the yellow emission is often dominant and if Dy^{3+} ion is located at a high-symmetry local site, the blue emission becomes stronger [6], and the ratio of these two emission bands varies accordingly with the concentration of Dy^{3+} ions and by selecting a proper host or by varying the composition of host. However the chemical environment surrounding the dopant also has a high impact on these sensible transitions. Therefore the selection of host is a very important factor to explore the luminescence characteristics of Dy^{3+} ions [12].

Moreover, NPs should possess superior physicochemical characteristics, such as long lifetimes, large anti-stokes shifts, high penetration depth, low toxicity, as well as high resistance to photo bleaching [13]. And bismuth is the only heavy metal that is nontoxic which could be easily purified in large quantities. The semiconductors such as Bi_2MoO_6 , BiOX ($X = \text{Cl}, \text{Br}, \text{I}$), BiVO_4 and Bi_2O_3 have high refractive index, excellent visible light absorber, photoluminescence, dielectric permittivity, photoconductivity, large oxygen ion conductivity, and noteworthy photocatalytic activity. [14–17]. Because of these properties, Bi_2O_3 has become an important material for several applications, such as, fuel cells [18], photocatalysts [19–22], gas sensors [23] and electronic components [24]. Another significant characteristic of Bi_2O_3 is its polymorphism, which results in 5 polymorphic forms (α , β , γ , δ and ω) with different structures and properties [25], among them monoclinic α is stable at room temperature and face-centered cubic δ is at high temperature.

The present study is focused on investigating physical, structural, optical, photocatalytic and more importantly, photoluminescence properties of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs synthesised via low solution combustion method (LCS) in order to search an alternative materials for commercial WLEDs. LCS technique needs simple setup, gives molecular level of mixing, high degree of homogeneity gives high surface area material in very less time [26].

2 Experimental

2.1 Synthesis

The synthesis of $\text{Bi}_{2-x}\text{O}_3:\text{Dy}_x$ ($x = 0.01\text{--}0.11$) via solution combustion method was made using analytical grade Bismuth nitrate [$\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$: 99.99%, Sigma Aldrich Ltd.], dysprosium nitrate [$\text{Dy}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$: 99.99%, Sigma Aldrich Ltd) as dopant and Urea as fuel. In a cylindrical Petri dish (300 ml), the aqueous solution containing stoichiometric quantity of reactants were taken such that Oxidizer [$\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$] to fuel (urea) ratio is 1 (O/F = 1) [27] and

introduced into a pre heated muffle furnace at temperature of $400 \pm 10^\circ\text{C}$. Thermal dehydration of the reaction mixture takes place and auto-ignites with liberation of gaseous products resulting in the nano powders. Finally, the so-prepared powders were calcined at 600°C for 3 h.

The Photocatalytic Activity experiment was conducted in a reactor by utilizing 125 W mercury vapour lamp as the UV light source ($\lambda = 254\text{ nm}$) at room temperature. Here Acid Red dye 88 (AR-88) was used as a model dye, and the UV light photocatalytic activities of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs were evaluated. In this experiment, 30 mg of synthesized $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs was completely dissolved into 10 ppm of AR-88 dye solution and stirred continuously until it forms a uniform solution. 5 ml of the dye solution was withdrawn every 15 min, and tested by UV–Vis spectrophotometer by means of the typical adsorption band at 510 nm after centrifugation for the computation of the disintegration of dye [28].

2.2 Characterization

Crystal morphology of the synthesised NPs was determined by PXRD using X-ray diffractometer (Shimadzu) (V-50 kV, I-20 mA, $\lambda = 1.541\text{ \AA}$, scan rate of 2° min^{-1}). The surface features are analysed by Hitachi table top SEM (Model TM 3000). Photoluminescence studies are made using Horiba, (model fluorolog-3, xenon-450 W) Spectrofluorimeter at Room Temperature. Fluor Essence™ software is used for spectral analysis. DRS studies of the samples were performed using Shimadzu model UV-2600 in the range 200–800 nm.

3 Results and Discussion

The Powder X-ray diffraction (PXRD) pattern of undoped and Dy^{3+} (1–11 mol%) doped Bi_2O_3 NPs is shown in Fig. 1. All the recorded peaks were indexed to the tetragonal phase of Bi_2O_3 [JCPDS card no. 27-50, Space Group: P-421c (no. 114)], suggesting high purity and crystallinity of the synthesized powders. The average crystallite size (D) was calculated by using Scherer's formula [29]

$$D = \frac{0.9\lambda}{\beta \cos \theta} \quad (1)$$

where ' λ '; wavelength of X-rays, and ' β '; Full width half maxima (FWHM) of XRD peaks. The crystallite sizes of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) samples lies in the range 13–30 nm which indicates that, as doping concentration increases, crystallite size decreases as the addition of Dy^{3+} ions reduces the gap between conduction and valence bands [6].

Fig. 1 PXRD of Dy^{3+} (1–11 mol%) doped Bi_2O_3 NPs

Scanning Electron Microscopy (SEM) is used to study the topography, texture and surface features of the synthesised nanophosphors. It is a well known fact that for solution combustion derived products, the morphological features depend strongly on the heat and gases which are generated during the complex decomposition of the redox mixture. Figure 2a–f shows the SEM images of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) nanophosphors. The images show highly porous, many agglomerates with an irregular morphology,

large voids, cracks, pores and shape which is the characteristic nature of combustion derived products [30].

To evaluate the energy band gap, the diffuse reflectance spectra (DRS) of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs were carried out and is shown in Fig. 3. The spectra mainly exhibit absorption band at ~ 300 nm which is due to the ligand-to-metal charge transfer (O^{2-} to Dy^{3+}) band and has an absorption band situated at ~ 320 nm which is due to the host. The other absorption bands are due to the electric dipole transition from ground state $^6\text{H}_{15/2}$ to the various excited states such as $^6\text{F}_{7/2}$ and $^6\text{F}_{5/2}$ [31] of the dopant (Dy^{3+}) cations.

Kubelka–Munk relation was adopted to calculate the band gap of the NPs [32],

$$F(R_\infty)h\nu = C(h\nu - E_g)^n \quad (2)$$

where $F(R_\infty)$; Kubelka–Munk function, $h\nu$; photon energy, C ; constant, E_g ; optical energy band gap, n ; constant related with various transitions viz., $n = 1/2$ (direct allowed transition), 2 (indirect allowed transition), 3/2 (direct forbidden transition) and 3 (indirect forbidden transition). As Bi_2O_3 is a direct band gap material, from the extrapolation of the line $[F(R_\infty)h\nu]^2$ to zero (Fig. 4), the E_g of the synthesised NPs was found to be in the range of 2.53–3.00 eV, indicates that the present material can be a promising photocatalyst since it can absorb UV as well as visible region of solar light.

Fig. 2 SEM images of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ **a** 1 mol%, **b** 3 mol%, **c** 5 mol%, **d** 7 mol%, **e** 9 mol% and **f** 11 mol% nanophosphor

Fig. 3 DRS of Dy³⁺ (1–11 mol%) doped Bi₂O₃ NPs

Figure 5 shows the excitation spectra of Bi₂O₃:Dy³⁺ (5 mol%) NPs. The spectrum was taken in the range of 300–450 nm. In the spectra, a band at 306 nm caused by the electron transfer from filled 2p orbital of O²⁻ ions to the vacant 4f orbital of Dy³⁺ ions (O²⁻ → Dy³⁺) known as charge transfer band (CTB) and other excitation characteristic peaks of Dy³⁺ are observed at ~329 (⁶H_{15/2} → ⁶P_{3/2}), 354 (⁶H_{15/2} → ⁶P_{5/2}), 368 (⁶H_{15/2} → ⁴I_{13/2}), 391 (⁶H_{15/2} → ⁴G_{11/2}) and 429 nm (⁶H_{15/2} → ⁴I_{15/2}) [33]. Among these, prominent transition at 354 nm (⁶H_{15/2} → ⁶P_{5/2}) was taken for the studies of emission properties of the NPs, this helps in the fabrication of WLEDs [7].

Figure 6 shows the emission spectra of Bi₂O₃:Dy³⁺ (1–11 mol%) at an excitation wavelength of 354 nm. The spectra consists of three prominent peaks centered at 482, 580 and 673 nm which are due to ⁴F_{9/2} → ⁶H_{15/2}

Fig. 4 Energy band gap of Dy³⁺ (1–11 mol%) doped Bi₂O₃ NPs

(blue), ⁴F_{9/2} → ⁶H_{13/2} (yellow) and ⁴F_{9/2} → ⁶H_{11/2} (red) transitions respectively. Among these, ⁴F_{9/2} → ⁶H_{13/2} transition is hypersensitive electric dipole transition and ⁴F_{9/2} → ⁶H_{15/2} transition is less sensitive magnetic dipole transition. The intensity of Electric dipole transition strongly depends on host and is affected by the crystal field environment, and the intensity is high when compared to the magnetic dipole transition representing the asymmetric nature of the NPs [34, 35]. As it can be observed from the spectra, these emissions are broad which may be due to the non-removal of degeneracy and accessibility of more number of Stark levels for ⁴F_{9/2} and ⁶H_j levels. Here, the crystal-field splitting components of Dy³⁺ ions are observed and is in accordance with the Kramer's doublets, (2J + 1)/2, where J—the angular momentum of the electrons. Hence, Bi₂O₃:Dy³⁺ NPs exhibit a bright yellow emission at 580 nm [33]. Only a little quantity of the Dy³⁺ ions occupy Bi²⁺ substitution sites and the excess Dy³⁺ ions may be precipitated into clusters or appeared as oxide phase to yield optimum strain relief. However, oxide phase was not observed in PXRD confirms Dy³⁺ ions occupy Bi²⁺ sites effectively in the host lattice [36]. The possible defect reaction was represented in the following way:

where 'Dy'_{Bi}' means 'Dy' occupying the site normally occupied by a 'Bi²⁺', due to replacement by 'Dy'; 'V''_O' was the 'O²⁻' vacancy, 'Bi^x_{Bi}' represents the rest bismuth atoms in the lattice of Bi₂O₃, and 'O^x_O' was the oxygen in the host lattice [37].

Figure 7 shows the variation of PL intensity with Dy³⁺ ions concentration and it is observed that the PL intensity increases with the concentration of Dy³⁺ ions up

Fig. 5 Excitation spectrum of Bi₂O₃:Dy³⁺ (5 mol%) NPs

Fig. 6 Emission spectra of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) (excited at 354 nm)

Fig. 7 Variation of PL intensity with Dy^{3+} concentration

to 3 mol% and there after decreases which is due to concentration quenching. This can be explained as follows, (a) when the doping concentration was increased, the excitation migration due to resonance between the activators is increased, and thus the excitation energy reaches quenching centers, and (b) the activators are paired and were changed to quenching centers. Due to these two aspects concentration quenching is taking place. Also, may be at higher concentrations, cross-relaxation process happens between Dy^{3+} – Dy^{3+} pairs [38], and this mechanism resulting from resonance energy transfer between neighbouring Dy^{3+} ions. From energy match rule, the probable cross-relaxation channels (CRC1, CRC2 and CRC3) for Dy^{3+} ions were responsible for depopulation of $^4\text{F}_{9/2}$ level [39].

Forster resonance energy transfer (FRET or FET) was established based on classical dipole–dipole interactions between the donor and the acceptor. However, in Dexter mechanism energy transfer was a short-range phenomenon ($\leq 10 \text{ \AA}$) that decreases with e^{-R} and the critical distance (R_c) between donors (activators) and acceptors (quenching site) in the Bi_2O_3 phosphor was found to be $17.38 \text{ \AA}$ as calculated by using Blasse, clearly show that the mechanism of exchange interaction was ineffective [40, 41].

Also, the non-radiative energy transfer among neighbouring Dy^{3+} ions may due to the radiation re-absorption, exchange interaction, or a multipole–multipole interaction and is accountable for concentration quenching. Hence, the critical distance (R_c) between two Dy^{3+} ions can be calculated according to Blasse [42] as:

$$R_c \approx 2 \left[\frac{3V}{4\pi CN} \right]^{1/3} \quad (4)$$

where $C=0.03$, the critical dopant concentration; $N=4$, the number of Bi ion in the unit cell and $V=330.16 \text{ \AA}^3$, the volume of the unit cell. By using these values, the critical distance was found to be $17.38 \text{ \AA}$. From the obtained value of R_c which is greater than $5 \text{ \AA}$, it is clear that the exchange interaction is no more effective, but the multipole–multipole interaction is prevailing and is the main cause for quenching.

As per Van-Uitert, the type of interaction involved in the energy transfer between Dy^{3+} ions can be determined by the equation [43]:

$$\frac{I}{x} = k \left[1 + \beta(x)^{Q/3} \right]^{-1} \quad (5)$$

where 'x'; activator concentration, 'k' and 'β' are the constants for the given host, and $Q=3$ (exchange interaction), 6 (dipole–dipole), 8 (dipole–quadrupole) and 10 (quadrupole–quadrupole) interactions respectively. Figure 8 shows the plot of $\log(x)$ versus $\log(I/x)$ with the slope = -1.16618 . Using the above equation the value of Q is ~ 3.498 which was close to 3, indicates that the concentration quenching was due to exchange interactions [44].

Figure 9 shows the schematic representation of energy level diagram of Dy^{3+} ions from which the luminescence property of the prepared NPs can be analysed. Dy^{3+} ions absorb the energy and get excited to the excited states from the ground state, following which part of the electrons gets depopulated into the $^4\text{F}_{9/2}$ level giving rise to nonradiative (NR) transitions. From $^4\text{F}_{9/2}$, the Dy^{3+} ions depopulate giving rise to the three major characteristic emissions leading to blue ($^6\text{H}_{15/2}$), yellow ($^6\text{H}_{13/2}$) and red

Fig. 8 Relation between $\log(x)$ and $\log(I/x)$ (x ; activator concentration) in $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) NPs

Fig. 9 Energy level diagram of Dy^{3+} ions showing the states involved in luminescence process and transition probabilities

($^6\text{H}_{11/2}$) transitions at 482 nm, 580 nm and 673 nm respectively [45].

The total radiative transition probability (A_T), radiative lifetime (τ_r) and the luminescence quantum efficiency (η) are calculated using the following equations [46]:

$$A_T(\psi J) = \sum_{\psi' J'} A_R(\psi' J' - \psi J) \quad (6)$$

$$\tau_r(\psi' J') = \frac{1}{A_R(\psi J)} \quad (7)$$

$$\eta = \frac{A_R}{A_R + A_{NR}} = \frac{A_R}{A_T} \quad (8)$$

Table 1 gives the results of J–O intensity parameters (Ω_2 and Ω_4) and radiative properties of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ nanophosphors that are calculated from the emission spectra. From the results it was clear that, Ω_2 and Ω_4 were observed to be comparatively high due to the fact that the samples generally possess higher fraction of the rare earth ions on the surface of the nano crystals compared to the bulk counterparts [47]. The parameter Ω_2 is related to the short range impact in the vicinity of the rare earth Dy^{3+} ion and Ω_4 is related to the long range impact [48]. A_R and τ_r were calculated from the emission spectra. The quantum efficiency (η) was calculated as per Eq. (8) and found equal to 74.8%. The increase in quantum efficiency indicates the better applicability for display devices. It was observed that $^4\text{F}_{9/2} \rightarrow ^6\text{H}_{13/2}$ transition of Dy^{3+} doped Bi_2O_3 NPs dominates the intensity emitted by the NPs in the emission spectra. The results infer that the current NPs can be utilized for white light emitting display devices [49].

Figure 10a shows the Commission International De l'Eclairage (CIE) chromaticity coordinates for $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) NPs. The chromaticity coordinates depends on both asymmetric ratio, on emission levels and are towards white region. The CIE coordinates were obtained from following equations [50]

$$x = \frac{X}{X + Y + Z} \quad (9)$$

$$y = \frac{Y}{X + Y + Z} \quad (10)$$

Table 1 J–O intensity parameters and radiative properties of Dy^{3+} doped Bi_2O_3 NPs

Phosphor $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (mol%)	J–O intensity Parameters (10^{-20} cm^2)		Transitions	$A_R (\text{s}^{-1})$	$A_{NR} (\text{s}^{-1})$	$A_T (\text{s}^{-1})$	$\tau_r (\text{ms})$	$\eta (\%)$
	Ω_2	Ω_4						
1	0.375309	0.389079	$^4\text{F}_{9/2} \rightarrow ^6\text{H}_{15/2}$	65.188	21.961	87.149	11.4745	74.8
3	0.342964	0.524237	$^4\text{F}_{9/2} \rightarrow ^6\text{H}_{13/2}$	59.570	20.068	79.638	12.5567	74.8
5	0.371157	0.389723	$^4\text{F}_{9/2} \rightarrow ^6\text{H}_{11/2}$	64.466	21.718	86.184	11.6029	74.8
7	0.342767	0.522853		59.535	20.057	79.592	12.5639	74.8
9	0.346098	0.525968		60.114	20.252	80.366	12.4430	74.8
11	0.374792	0.39057		65.098	21.931	87.029	11.4904	74.8

Fig. 10 **a** CIE chromaticity diagram of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs and **b** CCT diagram of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs

Correlated color temperature (CCT) was estimated by Planckian locus, which is a small portion of the (x, y) chromaticity diagram and the points were located outside the Planckian locus (Fig. 10b). As the coordinates are outside the locus for a given light source, CCT can be used to define the color temperature of it. By using the following equations [51], CCT was found to be 5629 K by transforming coordinates (x, y) of the light source to (U' , V'). Hence the synthesised NP is a promising candidate for WLEDs and Display applications.

$$U' = \frac{4x}{-2x + 12y + 3} \quad (11)$$

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

Acid Red-88(AR-88) was an azo dye has intense red colour, was used to dye cotton textiles and used for photocatalytic studies in the present case. The PCA of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) were analysed for the decolorization of AR-88 in aqueous solution under UV light irradiation for time duration of 60 min. The UV visible absorption spectra of the dye for various concentrations of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ (1–11 mol%) was shown in Fig. 11a–f. To know about the response kinetics of AR-88 Dye decolorization, the Langmuir–Hinshelwood model was adopted which follows the equation, $\ln(C/C_0) = kt + a$, where, k; reaction rate constant, C_0 ; preliminary attention of AR-88, C; attention of AR-88 on the response time t [52]. Figure 12 shows the plot of $\ln(C/C_0)$ photo decolorization of all catalysts $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ under UV light irradiation. As the doping concentration increases, the photo decolorization efficiency decreases and after 60 min irradiation it was found that the photo decolorization efficiency was maximum for 7 mol% (Fig. 13). This might be due to the fact that, at 7 mol% Dy^{3+} ions on the host Bi_2O_3 behave as electron trapper to detach the electron–hole pairs which is much needed for PCA [53]. At other molar concentrations, there is decrease in the degradation of dyes which may occur due to the blockage and hindering of light particles blocking the surface of the material. Also at higher concentration, multiple trapping of charge carrier was observed which may increase the possibility of recombination of electron–hole pair therefore; fewer charge carriers will reach the surface to initiate the degradation of the dye. This leads to less PCA efficiency at other molar concentrations [54].

4 Conclusions

The present $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ nanophosphors were prepared by solution combustion method and the PXRD patterns confirm that the synthesized samples exhibit tetragonal structure with crystallite size in the range 13–30 nm. Porous nature of the prepared nanophosphors was confirmed by SEM images. The bands in the range 300–400 nm in DRS correspond to the ligand to metal charge transfer (O^{2-} to Bi^{2+} or O^{2-} to Dy^{3+}). The phosphors upon exciting comparably low energy at 354 nm, electronic transitions $^4\text{F}_{9/2} \rightarrow ^6\text{H}_j$ ($j=15/2, 13/2, 11/2$) corresponding to characteristic emission peaks of f–f transitions of Dy^{3+} cations results in white emission as confirmed by CIE chromaticity diagram. The obtained average value of CCT (5629 K) and CIE lie in white region and J–O intensity parameters signify that $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ is a promising material for solid state displays, ceramic color pigments and wLED applications. Photocatalytic activity of the NPs show the enhanced activity in the

Fig. 11 Absorption spectra of Acid Red-88 (AR-88) with $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs catalysts under UV light irradiation

degradation of AR-88 dye under UV light irradiation was attributed to the effective separation of charge carriers since it has large oxygen ion conductivity and excellent

visible light absorber. All the above results indicating that the prepared material is highly useful for multiple applications.

Fig. 12 Plot of $\ln(C/C_0)$ photo decolorization of all catalysts $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs under UV light irradiation

Fig. 13 Percentage decolorization rate of $\text{Bi}_2\text{O}_3:\text{Dy}^{3+}$ NPs

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author (Prashantha S.C.) states that there is no conflict of interest.

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