

Photoluminescence of Eu^{3+} - and Tb^{3+} -Doped Downconversion Phosphor Glasses for Red–Green LED Applications: A Review

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Abstract

Trivalent europium (Eu^{3+}) and terbium (Tb^{3+}) ions are among the most widely studied luminescent activators for red/green downconversion phosphor glasses intended for near-ultraviolet- and blue-excited light-emitting diodes (LEDs). Their intra-configurational 4f–4f transitions give narrow, colour-pure red (Eu^{3+} , ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$, ~ 612 nm) and green (Tb^{3+} , ${}^5\text{D}_4 \rightarrow {}^7\text{F}_5$, ~ 543 nm) emission that is only weakly perturbed by the host lattice, while glass and glass-ceramic hosts offer processing advantages (melt-quenching, fibre drawing, sol–gel synthesis, and high rare-earth solubility) that crystalline ceramic phosphors cannot easily match. This review synthesises twenty-seven research articles on Eu^{3+} - and Tb^{3+} -doped downconversion phosphor glasses and closely related crystalline analogues, organised around the electronic origin of the two ions' emission, the four principal glass host families (phosphate, borate, silicate/germanate, and oxyfluoride/fluoride glass-ceramics), the $\text{Tb}^{3+} \rightarrow \text{Eu}^{3+}$ non-radiative energy-transfer mechanism that underlies essentially all co-doped work, concentration-quenching and compositional tuning of emission colour, tri-ion and multi-ion strategies for white-light generation, and the LED-relevant colorimetric metrics, namely CIE chromaticity, correlated colour temperature, colour rendering index, and photoluminescence quantum yield, by which this literature is ultimately judged. The review concludes by identifying research gaps, most notably incomplete quantum-yield and full colorimetric reporting, sparse thermal/photostability data, and the absence of systematic cross-host comparison, that motivate continued research on $\text{Eu}^{3+}/\text{Tb}^{3+}$ -doped glasses as red/green LED colour converters.

Keywords: Eu^{3+} ; Tb^{3+} ; downconversion phosphor; glass host; energy transfer; photoluminescence; white LED; CIE chromaticity

1. Introduction

The replacement of incandescent and fluorescent lamps by phosphor-converted light-emitting diodes (pc-LEDs) has made the design of efficient, stable, and spectrally tunable luminescent converter materials a central problem in modern solid-state lighting (SSL) research. The conventional white LED, a blue InGaN chip coated with yellow-emitting YAG: Ce^{3+} , suffers from a deficiency of red spectral content, which depresses the colour rendering index (CRI) and pushes the correlated colour temperature (CCT) toward the cold, bluish region of the chromaticity diagram. Overcoming this limitation requires converter materials able to supply red and green emission efficiently under near-UV or blue excitation, ideally from a single chemically and thermally robust host. Trivalent lanthanide ions, particularly Eu^{3+} and Tb^{3+} , have re-emerged as the activators of choice because their shielded 4f–4f transitions give narrow, colour-pure red and green emission lines largely independent of the host lattice.

Glass and glass-ceramic hosts occupy an attractive position among the matrices explored for lanthanide doping. Unlike single-crystal or ceramic phosphors, oxide glasses can be melt-quenched in bulk, drawn into fibres, moulded into arbitrary shapes, or processed through sol–gel and other low-temperature routes, and they tolerate comparatively high rare-earth concentrations without the phase-separation problems that affect many crystalline hosts. The glass network (phosphate, borate, silicate, germanate, or fluoride-containing oxyfluoride) can further be tuned to control phonon energy, chemical durability, and rare-earth solubility. These advantages have driven a large and growing body of work on Eu^{3+} - and Tb^{3+} -doped glasses as red/green downconversion phosphors for LED colour conversion, and for white-light generation when the two ions are combined with a sensitiser or a third activator.

This review synthesises twenty-seven research articles retrieved from the scholarly literature on Eu^{3+} - and Tb^{3+} -doped downconversion phosphor glasses, cited here as [1] through [27]. The literature is organised thematically to reveal the physical and materials-science threads running through the field: the electronic structure underlying Eu^{3+} and Tb^{3+} emission colours (Section 2); the family of glass and glass-ceramic hosts used to accommodate these ions (Section 3); the $\text{Tb}^{3+} \rightarrow \text{Eu}^{3+}$ energy-transfer process common to co-doped systems, together with concentration quenching and compositional tuning (Section 4); tri-ion and multi-ion systems engineered for white light (Section 5); closely related crystalline, non-glass phosphors that provide comparative benchmarks (Section 6); the LED-relevant performance metrics by which this work is judged (Section 7); and the research gaps that emerge from the reviewed literature (Section 8).

2. Spectroscopic Origin of Eu^{3+} Red and Tb^{3+} Green Emission

The colour purity that makes Eu^{3+} and Tb^{3+} attractive as LED phosphor activators originates in their electronic structure. Eu^{3+} has a $[\text{Xe}]4f^6$ configuration; its emitting $^5\text{D}_0$ level lies well above the $^7\text{F}_j$ ($J = 0-6$) manifold, and because the 4f electrons are shielded from the ligand field by the outer 5s and 5p shells, the $^5\text{D}_j \rightarrow ^7\text{F}_j$ transitions appear as sharp, largely host-independent lines. The two transitions of greatest practical interest are the $^5\text{D}_0 \rightarrow ^7\text{F}_1$ magnetic-dipole transition near 590–595 nm, whose intensity is essentially insensitive to local site symmetry, and the $^5\text{D}_0 \rightarrow ^7\text{F}_2$ electric-dipole transition near 610–615 nm, which is parity-forbidden in a centrosymmetric environment and becomes allowed only when the Eu^{3+} site lacks inversion symmetry. The $^7\text{F}_2/{}^7\text{F}_1$ intensity ratio is therefore a common spectroscopic probe of local symmetry, and because the $^7\text{F}_2$ line dominates in most disordered glass hosts, Eu^{3+} -doped glasses reliably yield colour-pure red emission well matched to the red primary needed for high-CRI white LEDs. Álvarez and co-workers used this asymmetry-ratio argument to show that Eu^{3+} ions occupy low-symmetry sites in a sodium-germanate network, consistent with the reddish-orange emission colour they report [3].

Tb^{3+} , with a $[\text{Xe}]4f^8$ configuration, emits from the $^5\text{D}_4$ level into the $^7\text{F}_j$ ($J = 6-0$) manifold. Unlike Eu^{3+} , Tb^{3+} emission is dominated by a single strong line, the $^5\text{D}_4 \rightarrow ^7\text{F}_5$ transition near 541–545 nm, responsible for the intense green colour of essentially all Tb^{3+} -doped phosphors, regardless of host. Weaker blue ($^5\text{D}_4 \rightarrow ^7\text{F}_6$, ≈ 490 nm), yellow ($^5\text{D}_4 \rightarrow ^7\text{F}_4$, ≈ 585 nm) and orange-red ($^5\text{D}_4 \rightarrow ^7\text{F}_3$, ≈ 620 nm) lines accompany the dominant green line. Zhang and co-workers exploit the combination of the well-isolated Tb^{3+} green line and the Eu^{3+} red lines to demonstrate tunable luminescence across the red–green–white colour space in a single phosphate-glass host for white-LED colour engineering [1], while Nan and co-workers show, in a crystalline YTaO_4 host, that the two lines can be resolved simultaneously under UV excitation with intensities that shift systematically with dopant concentration, a pattern that recurs in essentially every co-doped $\text{Eu}^{3+}/\text{Tb}^{3+}$ system reviewed here [13].

Both ions can be excited directly, into their own weak intra-configurational absorption lines, or indirectly, via a sensitizer or the host lattice itself. Because 4f–4f absorption is parity-forbidden and therefore weak, virtually all practically useful systems instead excite Tb^{3+} into its allowed $4f^8 \rightarrow 4f^7 5d^1$ or $^7\text{F}_6 \rightarrow ^5\text{D}_3/{}^5\text{G}_6$ manifold under near-UV light, followed either by Tb^{3+} green emission or by non-radiative energy transfer to Eu^{3+} (Section 4).

3. Glass and Glass-Ceramic Host Matrices

The choice of glass network shapes the local coordination environment, phonon energy, and hence the non-radiative decay pathways and energy-transfer efficiency available to Eu^{3+} and Tb^{3+} . The reviewed literature spans four broad host families: phosphate-based, borate-based, silicate/germanate, and oxyfluoride or fluoride-containing glass-ceramics.

3.1 Phosphate and Borophosphate Glasses

Phosphate glasses are the most common host family in the surveyed literature, reflecting high rare-earth solubility, low melting temperature, and tunable phonon energy. Zhang and co-workers use a phosphate host for co-doped $\text{Tb}^{3+}/\text{Eu}^{3+}$ with tunable luminescence for W-LEDs [1]; Chen and colleagues embed the ions in glass ceramics containing crystalline $\text{Na}_3\text{Gd}(\text{PO}_4)_2$, combining glass-melt processing with a more ordered local environment [4]; Baoxing and co-workers report concentration- and composition-dependent tunable red/green emission in $\text{Ba}_2\text{P}_2\text{O}_7$ pyrophosphate [11]; Tian and co-workers describe a multicolour phosphate glass useful for both white-LED lighting and X-ray detection [16]; Meejitpaisan and colleagues examine singly- and co-doped phosphosilicate glasses under UV and X-ray excitation for LED and scintillator use [18]; Trápala-

Ramírez and co-workers use calcium–zinc phosphate glass for laser and white-LED applications [19]; Huerta and colleagues extend the family to lithium–aluminium–zinc phosphate, co-doping $\text{Dy}^{3+}/\text{Tb}^{3+}$ and tri-doping $\text{Dy}^{3+}/\text{Tb}^{3+}/\text{Eu}^{3+}$ to access white, yellow, and reddish-orange emission [20]; Chaunwal and co-workers model the energy-transfer mechanism in zinc borophosphate glass for photonic applications [24]; and Hsouna and Bouzidi study white-luminescence generation in Tb^{3+} – Eu^{3+} co-doped phosphate glass [26]. Collectively, this body of work establishes phosphate and borophosphate glasses as the most thoroughly explored and consistently successful host family for $\text{Eu}^{3+}/\text{Tb}^{3+}$ red/green downconversion phosphors.

3.2 Borate and Fluoroborate Glasses

Borate glasses offer good chemical durability, high UV transparency, and low raw-material cost, though their higher phonon energy can promote non-radiative multiphonon relaxation unless compensated by heavy-metal or fluoride modifiers. Loos and co-workers present a systematic, concentration-dependent comparison of energy-transfer efficiency between $\text{Tb}^{3+}/\text{Eu}^{3+}$ -doped borate and fluorozirconate glasses [7], while Kashif and Ratep examine single-, double- and triple-doped $\text{Eu}^{3+}/\text{Tb}^{3+}/\text{Tm}^{3+}$ borate glass under UV excitation, showing that a wide range of emission colours can be accessed within one host by varying which lanthanides are present [12]. Together these studies show borate glasses to be a versatile, if slightly more phonon-lossy, alternative to phosphate hosts.

3.3 Silicate and Germanate Glasses

Silicate and germanate networks generally offer higher chemical and thermal durability than phosphate or borate glasses, at the cost of higher processing temperatures. Álvarez and colleagues report Eu^{3+} - and $\text{Tb}^{3+}/\text{Eu}^{3+}$ -doped sodium germanate glasses producing reddish-orange and greenish-yellow emission, establishing germanate glass as a viable red/green LED-relevant host [3]. Koseva and co-workers report a terbium- and europium-co-doped NaAlSiO_4 nano-glass-ceramic aimed at LED use [6] and a companion study of $\text{Tb}^{3+}/\text{Eu}^{3+}$ -doped Na_2SiO_3 [10], allowing a direct comparison of how adding aluminium to the silicate network affects luminescence intensity and colour purity while holding dopant chemistry constant.

3.4 Oxyfluoride and Fluoride-Containing Glass-Ceramics

This host family combines an oxide glass network with a dispersed fluoride nanocrystalline phase, exploiting the low phonon energy of fluoride environments to suppress non-radiative relaxation and raise quantum efficiency while retaining oxide-glass processability. Lee and co-workers report an oxyfluoride glass co-doped with Eu^{3+} , Tb^{3+} and Tm^{3+} achieving notably high quantum yield as a white-LED colour converter [2]; Klonkowski and colleagues develop an oxyfluoride nano-glass-ceramic co-doped with $\text{Eu}^{3+}/\text{Tb}^{3+}$ aimed at a white LED phosphor [15]; Yu and co-workers report tunable emission and temperature-sensing performance in oxyfluoride borosilicate glass ceramics containing $\text{Eu}^{3+}/\text{Tb}^{3+}$ -doped KY_3F_{10} nanocrystals [27]; Pawlik and co-workers describe SiO_2 – BaF_2 nano-glass-ceramics co-doped with $\text{Tb}^{3+}/\text{Eu}^{3+}$ made by a low-temperature sol–gel route [25]; and Tsyretarova and co-workers report red and green emission from oxide glass-ceramics doped separately with Eu^{3+} and Tb^{3+} [5]. This family generally reports the strongest quantum yields and the clearest evidence of genuine downconversion behaviour among the hosts reviewed.

4. $\text{Tb}^{3+} \rightarrow \text{Eu}^{3+}$ Energy Transfer, Concentration Quenching, and Compositional Tuning

The majority of the reviewed literature concerns not Eu^{3+} or Tb^{3+} individually but their combination in a single host, exploiting non-radiative energy transfer from the Tb^{3+} $^5\text{D}_4$ excited state to the Eu^{3+} $^5\text{D}_j$ manifold to achieve tunable red/green/white emission from a single excitation wavelength and dopant pair. The physical basis is a resonance condition in which the Tb^{3+} $^5\text{D}_4$ level and several higher Eu^{3+} $^5\text{D}_j$ levels lie close enough in energy for non-radiative transfer via an exchange (Dexter-type) mechanism at short donor–acceptor separations, or a dipole–dipole (Förster-type) mechanism at longer range. Zhang and co-workers demonstrate this transfer in phosphate glass: increasing Eu^{3+} concentration at fixed Tb^{3+} concentration progressively quenches the Tb^{3+} green emission while enhancing Eu^{3+} red emission, the classic signature of donor-to-acceptor transfer, and use it to tune emission colour from green through white to red [1]. Lee and co-workers observe an analogous pathway in oxyfluoride glass, additionally incorporating Tm^{3+} as a blue-emitting third ion [2], while Álvarez and colleagues show that the

Tb³⁺/Eu³⁺ emission ratio, and hence perceived colour, can be tuned continuously by composition in sodium germanate glass [3].

Chen and co-workers extend the picture to a phosphate glass ceramic containing crystalline Na₃Gd(PO₄)₂, showing that the embedded crystalline phase modifies the local coordination environment and the efficiency of Tb³⁺→Eu³⁺ transfer relative to the fully amorphous glass, while red/green tunability and a hint of accessible white light persist [4]. Koseva and colleagues report transfer in both their NaAlSiO₄ [6] and Na₂SiO₃ [10] hosts, with different transfer efficiencies attributed to differences in local field strength and coordination number. Loos and co-workers quantify how transfer efficiency and luminescence output vary with Tb³⁺:Eu³⁺ ratio and total dopant concentration across borate and fluorozirconate glasses [7]; Baoxing and co-workers report an analogous composition- and concentration-dependent transfer in Ba₂P₂O₇ [11]; and Kashif and Ratep show that the presence of Tb³⁺ measurably alters Eu³⁺ emission intensity relative to the singly-doped case in borate glass, consistent with an active transfer channel [12]. Kłonkowski and co-workers [15], Trápala-Ramírez and colleagues [19], Chaunwal and co-workers [24], Hsouna and Bouzidi [26], and Yu and co-workers [27] extend the same mechanistic picture to oxyfluoride, calcium–zinc phosphate, zinc borophosphate, phosphate, and KY₃F₁₀-containing glass-ceramic hosts respectively, with Yu and co-workers additionally showing that the temperature dependence of the Tb³⁺-to-Eu³⁺ intensity ratio can be exploited for optical thermometry.

A closely related, practically important theme is concentration quenching: beyond a certain total rare-earth loading, luminescence intensity decreases with further doping because donor–donor and donor–acceptor separations become short enough that non-radiative cross-relaxation and migration to quenching sites dominate over radiative decay. Loos and co-workers [7] and Baoxing and co-workers [11] both map how luminescence intensity and apparent transfer efficiency evolve with total dopant concentration and Tb³⁺:Eu³⁺ ratio, providing empirical guidance on optimum doping levels. Compositional tuning, whether adjusting the Eu³⁺:Tb³⁺ ratio at fixed total loading [1] or modifying the glass network former itself [6,10], provides a complementary lever for controlling emission colour, and Chaunwal and co-workers' explicit modelling of the critical transfer distance offers one of the more quantitative treatments of how doping levels can be selected predictively to maximise desired emission colour without excessive quenching [24].

5. Multi-Ion Doped Systems for White-Light Generation

While binary Eu³⁺/Tb³⁺ co-doping already permits red-to-green colour tuning and, at intermediate ratios, an approximately white-appearing emission, several studies deliberately add a third lanthanide ion to broaden the colour gamut and improve white-light quality. Lee and co-workers' oxyfluoride glass co-doped with Eu³⁺, Tb³⁺ and Tm³⁺ is the clearest example: Tm³⁺ contributes blue emission that complements the Tb³⁺ green and Eu³⁺ red lines, achieving a notably high overall quantum yield as a white-LED colour converter [2]. Kashif and Ratep similarly compare single, double and triple doping with Eu³⁺, Tb³⁺ and Tm³⁺ in borate glass, providing direct evidence of how progressively adding ions expands the accessible colour space [12].

A second strategy uses dysprosium (Dy³⁺) rather than thulium as the third activator: Huerta and co-workers report Dy³⁺/Tb³⁺ co-doped and Dy³⁺/Tb³⁺/Eu³⁺ tri-doped lithium–aluminium–zinc phosphate glasses, exploiting Dy³⁺ blue (⁴F_{9/2}→⁶H_{15/2}) and yellow (⁴F_{9/2}→⁶H_{13/2}) emission to generate white, yellow or reddish-orange light depending on the dopant combination [20]. Guo and co-workers take a third approach, combining divalent Eu²⁺ with Tb³⁺ and Eu³⁺ in a tri-activated glass synthesised in air, notable because Eu²⁺ is normally stabilised only under reducing conditions, and report that the broad Eu²⁺ 5d–4f emission combines with the sharp Tb³⁺ and Eu³⁺ lines to produce tunable white light, removing the need for specialised reducing-atmosphere furnaces [14]. Across these studies, white-light engineering from Eu³⁺/Tb³⁺-based glasses proves compositionally flexible: a blue- or yellow-emitting third ion (Tm³⁺, Dy³⁺, or Eu²⁺) can be layered onto the base Tb³⁺→Eu³⁺ transfer system across several glass hosts, all converging on the goal of a single-phosphor, single-excitation-wavelength white-light converter.

6. Crystalline and Non-Glass Eu³⁺/Tb³⁺ Phosphor Systems: Comparative Context

Several closely related studies of crystalline, non-glass Eu³⁺/Tb³⁺ co-doped phosphors illuminate host-independent aspects of the Tb³⁺→Eu³⁺ transfer mechanism and provide useful performance benchmarks. Ma and co-workers report a Ba₂La_{2.85–x}Tb_{0.15}Eu_x(SiO₄)₃F multicolour phosphor with tunable green-to-red emission relevant to near-UV LEDs [8]; Boriboon

reports Eu^{3+} - and Tb^{3+} -doped bulk GaN, an unusual wide-bandgap-semiconductor host, yielding three distinguishable colours and addressing the historical 'yellow gap' in nitride emitters [9]; Nan and co-workers synthesise $\text{Tb}^{3+}/\text{Eu}^{3+}$ co-doped YTbO_4 via sol-gel combustion, reporting UV-excited red/green emission with LED and WLED prospects [13]; Yano and co-workers use a combinatorial, microplate-reader-based screening approach to optimise green-emitting $\text{YBO}_3:\text{Ce}^{3+}, \text{Tb}^{3+}$ and red-emitting $\text{YBO}_3:\text{Ce}^{3+}, \text{Tb}^{3+}, \text{Eu}^{3+}$ phosphors [21]; and Xia and co-workers report host-composition-dependent tunable multicolour emission in single-phase $\text{Ba}_2(\text{Ln}_{1-u}\text{Tb}_u)(\text{BO}_3)_2\text{Cl}:\text{Eu}$ phosphors [22]. This literature confirms that $\text{Tb}^{3+} \rightarrow \text{Eu}^{3+}$ transfer is a general property of the ion pair rather than an artefact peculiar to disordered glass networks, while indicating that crystalline hosts can sometimes achieve sharper spectral features and more systematic compositional optimisation, as illustrated by Yano and co-workers' combinatorial approach [21].

Two further sources are themselves broader reviews rather than primary research. Erol and co-workers survey lanthanide-doped luminescent glasses for SSL broadly, identifying quantum efficiency, thermal stability, and colour rendering as the three performance axes along which the field's progress should be judged [17]; Yasaka and Kaewkhao provide a complementary, somewhat earlier review of luminescence from lanthanide-doped glasses and their applications [23]. Read against the primary-research literature summarised above, these reviews confirm that the $\text{Eu}^{3+}/\text{Tb}^{3+}$ red/green downconversion phosphor glass sub-field, while extensive, represents one well-developed branch of the larger lanthanide-doped luminescent glass literature.

7. LED-Relevant Performance Metrics: CIE Chromaticity, CCT, CRI and Quantum Yield

The practical value of any $\text{Eu}^{3+}/\text{Tb}^{3+}$ -doped downconversion phosphor glass for LED applications is judged against a small set of standard photometric and colorimetric metrics: CIE 1931 chromaticity coordinates, correlated colour temperature (CCT) when the emission approximates white light, colour rendering index (CRI), and internal or external photoluminescence quantum yield (QY). The reviewed literature varies considerably in how thoroughly these are reported. Quantum yield receives its most explicit, quantitative treatment in Lee and co-workers' oxyfluoride study, which reports a notably high QY for the $\text{Eu}^{3+}/\text{Tb}^{3+}/\text{Tm}^{3+}$ composition as direct evidence of suitability for a robust white-LED colour converter [2]. Tian and co-workers similarly frame their multicolour phosphate glass as having potential for white-LED lighting while also demonstrating X-ray detection capability [16].

CIE chromaticity tuning, showing that emission colour coordinates move systematically across the diagram with composition or excitation conditions, is reported, at least qualitatively, in essentially all co-doped studies reviewed in Section 4, since demonstrating colour tunability is typically their central experimental claim. Zhang and co-workers [1], Trápala-Ramírez and colleagues [19], and Huerta and co-workers [20] explicitly connect their results to W-LED terminology. Meejitpaisan and co-workers extend the excitation-source dimension of this metric space by comparing UV- and X-ray-excited luminescence in the same phosphosilicate composition [18], while Yu and co-workers' temperature-sensing application of the $\text{Eu}^{3+}/\text{Tb}^{3+}$ intensity ratio represents a related but distinct performance metric, optical thermometric sensitivity, deriving from the same underlying energy-transfer physics exploited for colour tuning [27].

Several studies report photoluminescence spectra and energy-transfer evidence without explicit CIE, CCT, or CRI values, reflecting a more materials-chemistry-oriented rather than device-engineering focus, notably the concentration-quenching and mechanism-oriented studies of Loos and co-workers [7], Baoxing and co-workers [11], and Chaunwal and co-workers [24]. This uneven reporting of device-relevant metrics is itself a notable feature of the corpus and is discussed further in Section 8. Across the reviewed literature, phosphate-family glasses dominate numerically, essentially every co-doped study reports the same qualitative $\text{Tb}^{3+} \rightarrow \text{Eu}^{3+}$ transfer signature regardless of host, and explicit quantum-yield figures are reported in only a minority of studies, most clearly in [2], despite quantum yield being arguably the single most important metric for judging commercial phosphor viability.

8. Comparative Summary of the Reviewed Literature

Table 1 consolidates the host chemistry, dopant combination, reported emission colour, and stated application relevance of the twenty-seven reviewed sources, providing a single overview of the field. Phosphate-family glasses dominate the corpus

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Ref.	Host system	Dopant ions	Reported emission	Stated application
[1]	Phosphate glass	Tb^{3+} , Eu^{3+}	Green–white–red tunable	W-LED
[2]	Oxyfluoride glass	Eu^{3+} , Tb^{3+} , Tm^{3+}	White (high QY)	White-LED converter
[3]	Na germanate glass	Eu^{3+} , Tb^{3+}/Eu^{3+}	Reddish-orange / greenish-yellow	LED phosphor
[4]	Phosphate glass ceramic	Eu^{3+} , Tb^{3+}	Red/green, possible white	LED, possible WLED
[5]	Oxide glass-ceramic	Eu^{3+} , Tb^{3+} (separate)	Red / green	LED
[6]	NaAlSiO ₄ nano-glass-ceramic	Tb^{3+} , Eu^{3+}	Red/green	LED application
[7]	Borate & fluorozirconate glass	Tb^{3+} , Eu^{3+}	Concentration-tunable	LED-relevant
[8]	Crystalline silicate-fluoride	Eu^{3+} , Tb^{3+}	Green–red tunable	n-UV LED
[9]	Bulk GaN	Eu^{3+} , Tb^{3+}	Three colours	Red/green LED
[10]	Na ₂ SiO ₃ glass	Tb^{3+} , Eu^{3+}	Red/green	LED application
[11]	Ba ₂ P ₂ O ₇ phosphor	Tb^{3+} , Eu^{3+}	Tunable red/green	LED colour tuning
[12]	Borate glass	Eu^{3+} , Tb^{3+} , Tm^{3+}	Multiple colours	UV-excited phosphor
[13]	Crystalline YTaO ₄	Tb^{3+} , Eu^{3+}	Red/green	LED/WLED prospects
[14]	Glass (air-synthesised)	Eu^{2+} , Tb^{3+} , Eu^{3+}	Tunable white	White light
[15]	Oxyfluoride nano-glass-ceramic	Eu^{3+} , Tb^{3+}	White phosphor	LED use
[16]	Phosphate glass	Multicolour (Eu/Tb family)	Multicolour	White-LED, X-ray detector
[17]	Review (multiple hosts)	Various lanthanides	n/a	SSL, general
[18]	Phosphosilicate glass	Eu^{3+} , Tb^{3+}	Red/green	LED, scintillator
[19]	Ca–Zn phosphate glass	Tb^{3+} , Eu^{3+}	Tunable	Laser, white LED
[20]	Li–Al–Zn phosphate glass	Dy^{3+}/Tb^{3+} , $Dy^{3+}/Tb^{3+}/Eu^{3+}$	White/yellow/reddish-orange	Colour-tunable lighting
[21]	Crystalline YBO ₃	Ce^{3+} , Tb^{3+} / + Eu^{3+}	Green / red	Phosphor design methodology
[22]	Crystalline borate-chloride	Tb^{3+} , Eu^{3+}	Multicolour	Multicolour phosphor
[23]	Review (lanthanide glasses)	Various lanthanides	n/a	General lighting
[24]	Zinc borophosphate glass	Tb^{3+} , Eu^{3+}	Tunable	Photonic applications
[25]	SiO ₂ –BaF ₂ nano-glass-ceramic	Tb^{3+} , Eu^{3+}	Red/green	LED-relevant phosphor
[26]	Phosphate glass	Tb^{3+} , Eu^{3+}	White	Lighting
[27]	Oxyfluoride borosilicate ceramic	Eu^{3+} , Tb^{3+}	Tunable, temperature-dependent	LED colour tuning, sensing

Table 1. Comparative summary of reviewed Eu^{3+}/Tb^{3+} downconversion phosphor literature.

9. Research Gaps and Future Directions

Several gaps emerge from this synthesis. First, quantitative photoluminescence quantum yield, the metric most directly predictive of a phosphor's usefulness in a real LED package, is reported explicitly in only a small fraction of the reviewed studies, with Lee and co-workers' oxyfluoride glass [2] one of the few sources to report a specific, high QY figure; systematic quantum-yield benchmarking across the phosphate, borate, silicate/germanate and oxyfluoride families would allow a more direct, device-relevant comparison than the qualitative colour-tuning data that dominates the corpus.

Second, full LED-package-level colorimetric characterisation, namely CIE 1931 coordinates under standard blue or near-UV excitation, CCT, and CRI measured under conditions representative of an actual LED die, is reported only partially and inconsistently, even among studies that explicitly invoke W-LED terminology [1,19,20]. Third, thermal and photostability data, critical given that LED junction temperatures can reach 100–150 °C under prolonged high-flux irradiation, are largely absent, with Yu and co-workers' temperature-dependent intensity-ratio study providing only partial, incidental thermal-response information [27]. Fourth, direct, controlled cross-host comparisons of energy-transfer efficiency, quantum yield, and

colour-tuning range using matched dopant concentrations and identical protocols are rare; most comparative insight in this review had to be assembled indirectly by juxtaposing separate studies, such as Koseva and co-workers' NaAlSiO₄ versus Na₂SiO₃ results [6,10] or Loos and co-workers' internal borate-versus-fluorozirconate comparison [7].

Fifth, the tri-ion and multi-ion white-light literature, spanning Tm³⁺-, Dy³⁺-, and Eu²⁺-based strategies [2,12,14,20], has not been extended to a systematic comparison of which third-ion strategy best balances CRI, CCT stability, and quantum yield. Finally, high-throughput compositional screening methods such as Yano and co-workers' combinatorial, microplate-reader-based approach [21], demonstrated for crystalline YBO₃ phosphors, have not been applied to any glass-host system reviewed here, suggesting that adapting such methods to glass-melt or sol-gel synthesis could substantially accelerate compositional optimisation that is currently performed one composition at a time.

10. Conclusion

This review has synthesised twenty-seven research articles on Eu³⁺- and Tb³⁺-doped downconversion phosphor glasses and closely related crystalline analogues, organised around the electronic-structure basis of Eu³⁺ red and Tb³⁺ green emission, the four principal glass host families used in the field, the Tb³⁺→Eu³⁺ energy-transfer mechanism common to essentially all co-doped work, concentration-quenching and compositional-tuning behaviour, tri-ion and multi-ion white-light strategies, comparative crystalline systems, and the LED-relevant colorimetric and quantum-yield metrics by which this literature is ultimately judged. The reviewed corpus establishes the robustness of the Tb³⁺→Eu³⁺ transfer mechanism across essentially every host chemistry examined, and the practical viability of phosphate and oxyfluoride glass hosts in particular, while also revealing what remains open, most notably incomplete reporting of quantum yield, full LED colorimetric parameters, and thermal/photostability data. Addressing these gaps through systematic, device-oriented, and cross-host comparative studies would substantially strengthen the case for Eu³⁺/Tb³⁺-doped downconversion phosphor glasses as practical, single-phosphor red/green (and white) colour converters for next-generation solid-state lighting.

References

- [1] Zhang, Y., Liu, J., Li, P., Wu, Y., Sun, K., Fang, Q., & Zhu, W. (2025). Characteristics and tunable luminescence of a phosphate glass doped with terbium and europium for W-LEDs. *Ceramics International*, 51(17), 24080–24088.
- [2] Lee, H., Lee, J., Shinozaki, K., & Chung, W. J. (2022). Eu³⁺-Tb³⁺-Tm³⁺ co-doped oxyfluoride glass with high quantum yield for a robust white LED color converter. *Optical Materials*.
- [3] Álvarez, E., Zayas, M. E., Alvarado-Rivera, J., Félix-Domínguez, F., Duarte-Zamorano, R. P., & Caldiño, U. (2014). New reddish-orange and greenish-yellow light emitting phosphors: Eu³⁺ and Tb³⁺/Eu³⁺ in sodium germanate glass. *Journal of Luminescence*, 153, 320–325.
- [4] Chen, X., Zhang, H., Jia, W., Zou, X., & Su, C. (2021). Luminescence properties and energy transfer of Eu³⁺/Tb³⁺ co-doped glass ceramics containing Na₃Gd(PO₄)₂. *Journal of the Chinese Chemical Society*.
- [5] Tsyretarova, S. Y., Kozhevnikova, N. M., Eremina, N. S., & Mokrousov, G. M. (2015). Red and green phosphors glow on the basis of oxide glass-ceramics doped with Eu³⁺ and Tb³⁺. *Key Engineering Materials*, 670, 107–111.
- [6] Koseva, I., Tzvetkov, P., Ivanov, P., Yordanova, A., & Nikolov, V. (2017). Terbium and europium co-doped NaAlSiO₄ nano glass-ceramics for LED application. *Optik*, 145, 435–440.
- [7] Loos, S., Mungra, M., Ahrens, B., Leonard, R. L., Evans, A. W., Johnson, J. A., Steudel, F., & Schweizer, S. (2017). Concentration-dependent luminescence and energy transfer in Tb³⁺/Eu³⁺ doped borate and fluoro-zirconate glasses. *Journal of Luminescence*.
- [8] Ma, X., Liao, L., Guo, Q., Liu, H., Zhou, T., & Mei, L. (2018). Luminescence properties and energy transfer investigations of Ba₂La_{2.85-x}Tb_{0.15}Eu_x(SiO₄)₃F multicolor phosphor. *RSC Advances*, 8, 26425–26433.
- [9] Boriboon, A. (2022). Closing the yellow gap with Eu- and Tb-doped GaN: One luminescent host resulting in three colours. *Scientific Reports*.
- [10] Koseva, I., Tzvetkov, P., Ivanov, P., Yordanova, A., & Nikolov, V. (2018). Some investigations on Tb³⁺ and Eu³⁺ doped Na₂SiO₃ as a material for LED application. *Optik*.

- [11] Baoxing, W., Qiang, R., Ou, H., & Xiulan, W. (2017). Luminescence properties and energy transfer in Tb³⁺ and Eu³⁺ co-doped Ba₂P₂O₇ phosphors. RSC Advances.
- [12] Kashif, I., & Ratep, A. (2023). Various color light emission from single, double, and triple Eu³⁺/Tb³⁺/Tm³⁺ doped borate glass excited by UV light. Journal of Fluorescence.
- [13] Nan, S., Hong, F., Xu, H., Dou, J., Liu, G., Dong, X., Wang, J., & Yu, W. (2020). Luminescence properties and energy transfer of Tb³⁺, Eu³⁺ co-doped YTaO₄ phosphors obtained via sol-gel combustion process. Journal of Materials Science: Materials in Electronics.
- [14] Guo, H., Teng, L., & Wei, R. (2019). Tunable white light and energy transfer of Eu²⁺-Tb³⁺-Eu³⁺ tri-activated glasses synthesized in air. Journal of the American Ceramic Society.
- [15] Kłonkowski, A. M., Wicz, W., Ryl, J., Szczodrowski, K., & Wileńska, D. (2017). A white phosphor based on oxyfluoride nano-glass-ceramics co-doped with Eu³⁺ and Tb³⁺: Energy transfer study. Journal of Alloys and Compounds.
- [16] Tian, S., Shi, Z., Sun, Y.-H., Zhang, P., Wu, S. Y., Chen, D., Xiong, P., Qian, Q., & Yang, Z. (2022). Multicolor phosphate glasses for potential white LED lighting and X-ray detections. Laser & Photonics Reviews, 16(9), 2200020.
- [17] Erol, E., Vahedigharehchopogh, N., Kırışlı, O., & Ersundu, M. Ç. (2021). Recent progress in lanthanide-doped luminescent glasses for solid-state lighting applications: A review. Journal of Physics: Condensed Matter, 33(48).
- [18] Meejitpaisan, P., Doddaji, R., Kothan, S., Kim, H. J., & Minnam Reddy, V. R. (2025). UV light and X-ray induced luminescence properties of Eu³⁺ and Tb³⁺ single-doped and double-doped phosphosilicate glasses for LED and scintillator applications. Materials Research Bulletin, 182, 113295.
- [19] Trápala-Ramírez, A. U., Gálvez-Sandoval, J. L. N., Lira, A., Camarillo, I., & Alvarez-Ramos, E. (2019). Calcium-zinc phosphate glasses activated with Tb³⁺/Eu³⁺ for laser and white LED applications. Journal of Luminescence, 215, 116621.
- [20] Huerta, E. F., Meza-Rocha, A. N., Lozada-Morales, R., & Speghini, A. (2020). White, yellow and reddish-orange light generation in lithium-aluminum-zinc phosphate glasses co-doped with Dy³⁺/Tb³⁺ and tri-doped with Dy³⁺/Tb³⁺/Eu³⁺. Journal of Luminescence, 220, 116882.
- [21] Yano, K., Takeshita, S., Iso, Y., & Isobe, T. (2017). Combinatorial optimization of the atomic compositions for green-emitting YBO₃:Ce³⁺, Tb³⁺ and red-emitting YBO₃:Ce³⁺, Tb³⁺, Eu³⁺ phosphors using a microplate reader. RSC Advances, 7, 19379–19385.
- [22] Xia, Z., Zhuang, J., Meijerink, A., & Jing, X. (2013). Host composition dependent tunable multicolor emission in the single-phase Ba₂(Ln_{1-x}Tb_x)(BO₃)₂Cl:Eu phosphors. Dalton Transactions, 42, 10609–10615.
- [23] Yasaka, P., & Kaewkhao, J. (2015). Luminescence from lanthanides-doped glasses and applications: A review. 2015 International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering.
- [24] Chaunwal, R. C., Fanai, A. L., Upreti, D. K., & Mishra, H. (2025). Tunable luminescence and energy transfer mechanism in Tb³⁺/Eu³⁺ doped zinc boro-phosphate glasses for photonic applications. Journal of Molecular Structure, 1343, 142931.
- [25] Pawlik, N., Szpikowska-Sroka, B., Goryczka, T., Pietrasik, E., & Pisarski, W. A. (2022). Luminescence of SiO₂-BaF₂:Tb³⁺, Eu³⁺ nano-glass-ceramics made from sol-gel method at low temperature. Nanomaterials, 12(2), 259.
- [26] Hsouna, N., & Bouzidi, C. (2022). White luminescence and energy transfer studies in Tb³⁺-Eu³⁺ co-doped phosphate glasses. Solid State Sciences, 134, 107053.
- [27] Yu, B., Zheng, B., Xia, H., Wang, J., Song, H., & Chen, B. (2021). Tunable emission and temperature sensing performance in novel oxyfluoride borosilicate glass ceramics containing Eu³⁺/Tb³⁺: KY₃F₁₀ nanocrystals. Ceramics International, 47(7), 9668–9678.

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