


 Cite this: *RSC Adv.*, 2025, 15, 34916

## Introduction to the *RSC Advances* themed collection on the photoluminescence of lanthanide-doped phosphor materials

 Ram Sagar Yadav,<sup>\*a</sup> Bryce S. Richards,<sup>b</sup> Joanna Pisarska<sup>c</sup> and Xinyu Ye<sup>d</sup>

DOI: 10.1039/d5ra90094h

rsc.li/rsc-advances

Laser spectroscopy is an essential tool to study the optical properties of the lanthanide-based materials. Lanthanide ions are most stable in a trivalent ion ( $\text{Ln}^{3+}$ ) state, and produce multicolor photoluminescence due to the presence of various distinct energy levels in which some are meta-stable. Each energy level can be excited with a certain excitation wavelength, with the emitted light of lanthanide ions covering emissions in the ultraviolet, visible and near infrared regions. The lanthanide ions also enable upconversion (UC) and downshifting (DS) of the incident photons. The low energy incident photons are converted into a high energy photon in the UC process while the conversion of a high energy photon into a low energy photon is termed as luminescent down-shifting (LDS). The UC process is helpful for measuring the temperature sensing sensitivity of different phosphor materials, as it depends on the fluorescence intensity ratio (FIR) of the two thermally coupled (TC)/non-thermally coupled

(NTC) levels. In these cases, the emission intensity of one level is found to increase while that of the other level decreases when the external temperature of the sample is increased, and *vice versa*. The plot between FIR-based sensitivity and external temperature gives the temperature sensing, which can be examined in other lanthanide-doped phosphor materials. Due to various properties of lanthanide ions, lanthanide-doped phosphor materials can be utilised for different technological applications in various fields, such as display devices, white light emitting diodes (w-LEDs), solar cells, anti-counterfeiting, information storage, optical heating, temperature sensing, and bio-imaging.<sup>1-8</sup>

This themed collection considers the synthesis of lanthanide-doped phosphor materials, and provides insight into the structural and optical properties of these materials, including phosphors, nanoposphors and phosphor composites.

The development of lanthanide luminescence has been summarized in terms of their present, past and future advancements including the practical applications of different lanthanide doped photoluminescent materials in various technological fields (<https://doi.org/10.1039/D3RA00991B>). In one contribution to this series, the photoluminescence activities of rare earth self-activated phosphors are discussed. This activity occurs through

energy transfer between the rare earth ions and niobate/vanadate host materials *via* different processes, such as UC, DS, quantum cutting (QC), *etc.* Their applications in different fields are also discussed (<https://doi.org/10.1039/D3RA00629H>).

Another contribution to the series focuses on the combination of lanthanide ( $\text{Eu}^{3+}$ ) and transition metal ( $\text{Mn}^{4+}$ ) co-doped  $\text{LaAlO}_3$  phosphor, enabling energy transfer between them, which can be used for horticultural lighting purposes (<https://doi.org/10.1039/D3RA03241H>). The role of  $\text{Fe}^{2+}$  ions on  $\text{Er}^{3+}$  doped nanoparticles was also investigated for the use as a sensing material (<https://doi.org/10.1039/D3RA04645A>), and the sonochemically-assisted synthesis of a silver-supported  $\alpha\text{-Fe}_2\text{O}_3$  (SA@Ag@IONC) nanocomposite is highlighted as a better choice to breakdown hazardous dye in wastewater treatment (<https://doi.org/10.1039/D3RA03315E>).  $\text{NaLi}_2\text{PO}_4\text{:Cu(II)}$  and  $\text{NaLi}_2\text{PO}_4\text{:Cu(I)}$  materials are highlighted as good candidates for radiation dosimetry with a wide dose response (<https://doi.org/10.1039/D3RA02498A>), and the synthesis of  $\text{ZrTiO}_4$  nanorods by a solution combustion method is reported alongside the photoluminescence, antibacterial, X-ray/gamma ray absorption, supercapacitor and sensor applications of the nanorods (<https://doi.org/10.1039/D3RA00908D>).

<sup>a</sup>Institute of Science, Banaras Hindu University, Varanasi 221 005, India. E-mail: ramsagaryadav@gmail.com

<sup>b</sup>Institute of Microstructure Technology, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

<sup>c</sup>Institute of Chemistry, University of Silesia, Szkolna 9 Street, Katowice, 40-007, Poland

<sup>d</sup>Faculty of Materials, Metallurgy and Chemistry, Jiangxi University of Science and Technology, Ganzhou, 341000, P. R. China



Lanthanide doped phosphor materials have been widely investigated by different groups of researchers in this collection. Initially, the DS photoluminescence of  $\text{Eu}^{2+}$ ,  $\text{Ce}^{3+}$ ,  $\text{Eu}^{3+}$ ,  $\text{Tb}^{3+}$ ,  $\text{Dy}^{3+}$ ,  $\text{Ho}^{3+}$ ,  $\text{Tm}^{3+}$  and  $\text{Pr}^{3+}$  doped phosphor materials have been investigated in detail. The structure and morphology of the phosphor materials were modified *via* the incorporation of alkali as well as alkaline earth metal ions. These properties were also modified through the incorporation of transition metal ions. These processes are highly favourable for improving the photoluminescence intensity of the phosphor materials. The photoluminescence intensity of a  $\text{Eu}^{3+}$  doped  $\text{ZnGa}_2\text{O}_4$  phosphor was improved significantly *via* doping with  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions, which leads to the production of bright tunable photoluminescence (<https://doi.org/10.1039/D3RA03215A>). Energy transfer has been reported in the  $\text{Dy}^{3+}/\text{Eu}^{3+}$  co-doped  $\text{Na}_4\text{Ca}_4\text{Si}_6\text{O}_{18}$  phosphors in which the energy transfer takes place from  $\text{Dy}^{3+}$  to  $\text{Eu}^{3+}$  ions, which also produces colour-tunable photoluminescence (<https://doi.org/10.1039/D3RA03229A>). Energy transfer has also been studied in the  $\text{Tm}^{3+}/\text{Tb}^{3+}/\text{Eu}^{3+}$  co-doped  $\text{Sr}_4\text{Nb}_2\text{O}_9$  phosphors, which leads to the production of colour tunable luminescence due to energy transfer from  $\text{Tm}^{3+}$  to  $\text{Tb}^{3+}$  and  $\text{Eu}^{3+}$  ions. Lifetime analysis also supports an efficient energy transfer from  $\text{Tm}^{3+}$  to  $\text{Tb}^{3+}$  and  $\text{Eu}^{3+}$  ions (<https://doi.org/10.1039/D3RA05519A>).

Finally, researchers have studied the UC process in different lanthanide doped phosphor materials in detail. The UC process has been studied in  $\text{Tm}^{3+}$ ;  $\text{Yb}^{3+}$

co-doped  $\text{Zn}_2\text{TiO}_4$  phosphors using a solid-state reaction route. The phosphor produces an intense blue colour due to  ${}^1\text{G}_4 \rightarrow {}^3\text{H}_6$  transition under 980 nm excitation, which finds its applications in anti-counterfeiting fields (<https://doi.org/10.1039/D3RA03238H>). Enhancement in the photoacoustic and green UC emissions of the  $\text{Er}^{3+}/\text{Yb}^{3+}$  co-doped  $\text{Gd}_2\text{O}_3$  phosphor has been achieved using  $\text{Mg}^{2+}/\text{Zn}^{2+}$  ions under 980 nm excitation (<https://doi.org/10.1039/D3RA03041E>). This phosphor is also useful for the detection of fingerprints and security applications. The  $\text{Er}^{3+}/\text{Yb}^{3+}$  co-doped  $\text{NaZr}_2(\text{PO}_4)_3$  material gives intense green UC with a good FIR under 980 nm excitation, which is useful for temperature sensing applications (<https://doi.org/10.1039/D3RA02126B>).

We thank all colleagues who participated in this special collection for their enlightening scientific contributions.

## Conflicts of interest

There are no conflicts of interest to declare.

## References

- 1 X. Huang, Red phosphor converts white LEDs, *Nat. Photon.*, 2014, **8**, 748–749.
- 2 G. S. He, L.-S. Tan, Q. Zheng and P. N. Prasad, Multiphoton absorbing materials: Molecular designs, characterizations, and applications, *Chem. Rev.*, 2008, **108**, 1245–1330.
- 3 X. Cheng, J. Zhou, J. Yue, Y. Wei, C. Gao, X. Xie and L. Huang, Recent development in sensitizers for

lanthanide-doped upconversion luminescence, *Chem. Rev.*, 2022, **122**, 15998–16050.

- 4 Y. Xie, Y. Song, G. Sun, P. Hu, A. Bednarkiewicz and L. Sun, Lanthanide-doped heterostructured nanocomposites toward advanced optical anti-counterfeiting and information storage, *Light Sci. Appl.*, 2022, **11**, 150.
- 5 R. S. Yadav, Monika, S. B. Rai and S. J. Dhoble, Recent advances on morphological changes in chemically engineered rare earth doped phosphor materials, *Prog. Solid State Chem.*, 2020, **57**, 100267.
- 6 H. Daicho, T. Iwasaki, K. Enomoto, Y. Sasaki, Y. Maeno, Y. Shinomiya, S. Aoyagi, E. Nishibori, M. Sakata, H. Sawa, S. Matsuishi and H. Hosono, A novel phosphor for glareless white light-emitting diodes, *Nat. Commun.*, 2012, **3**, 1132.
- 7 E. I. Madirov, S. V. Kuznetsov, V. A. Konyushkin, D. Busko, B. S. Richards and A. Turshatov, Pushing the limits: Down-converting  $\text{Er}^{3+}$ -doped  $\text{BaF}_2$  single crystals with photoluminescence quantum yield surpassing 100%, *Adv. Optical Mater.*, 2024, **12**, 2303094.
- 8 S. P. Tiwari, S. K. Maurya, R. S. Yadav, A. Kumar, V. Kumar, M. F. Joubert and H. C. Swart, Future prospects of fluoride based upconversion nanoparticles for emerging applications in biomedical and energy harvesting, *J. Vac. Sc. Technol. B*, 2018, **36**, 060801.

