Article

Thermoluminiscence parameters of Neodymium doped Y_2O_3 Nanophosphors.

Chandrasekhar. M

Asst.Professor, Department of Humanities and Sciences
Chaitanya Bharathi Institute of Technology, Hyderabad, Telangana, India

Citation:
Chandrasekhar . M.

Thermoluminiscence parameters of Neodymium doped Y2O3 Nanophosphors
J.Adv.Sci.Eng&Tech, 1,1,2025, 39-45

Received on
7th July 2024

Revised on
19th September 2024

Accepted on
18th December 2024

Abstract

Neodymium (Nd^{3+}) doped yttrium oxide (Y_2O_3) nanophosphors have emerged as promising materials for various luminescence-based applications, particularly in radiation dosimetry, photonics, and optoelectronic devices. The thermoluminescence (TL) properties of these nanophosphors are of particular interest due to their ability to store and release energy upon thermal stimulation after prior exposure to ionizing radiation. This study provides an in-depth examination of the TL behavior of $Y_2O_3:Nd^{3+}$ nanophosphors, focusing on key parameters such as glow curve characteristics, trap depth energies, frequency factors, and kinetic orders. The glow curves indicates the presence of various trapping levels introduced by Nd^{3+} doping. Using peak shape and deconvolution methods, detailed kinetic parameters are extracted to reveal the underlying recombination processes. The study also compares the TL performance of Nd^{3+}-doped Y_2O_3 with that of other rare-earth doped analogs such as Eu^{3+} and Tb^{3+} to establish the unique advantages of neodymium in enhancing trap depth and luminescence efficiency. Potential applications in low-dose radiation detection, UV dosimetry, and persistent luminescence are discussed in the context of the observed TL characteristics. This review aims to provide a consolidated understanding of the structure-property relationships in $Y_2O_3:Nd^{3+}$ nanophosphors and to guide future developments in designing tailored materials for advanced TL-based applications

Key words : Thermoluminescence (TL), Neodymium-doped Yttrium Oxide , Nanophosphors, Trap Depth Analysis, Radiation Dosimetry

1. Introduction

Thermoluminescence (TL) refers to the emission of light from a material upon heating, following prior exposure to ionizing radiation. This luminescent phenomenon originates from the release of charge carriers that were previously trapped in defect states or impurities within the material's lattice. Nanocrystalline materials are increasingly being explored for their promising luminescent properties, positioning them as potential game-changers in the fields of display and imaging technologies. Modern devices frequently rely on inorganic polycrystalline substances doped with lanthanide or transition metal ions as their primary sources of light emission. With advancements in nanomaterial synthesis, these phosphors have been produced at the nanoscale, enabling direct comparisons with conventional materials and yielding encouraging results.

Among various host matrices, yttrium oxide (Y_2O_3) stands out due to its thermal stability, wide bandgap, and low phonon energy, making it a preferred choice for luminescent applications. Doping Y_2O_3 with rare-earth ions has garnered considerable attention for tuning its luminescent and thermoluminescent properties. Specifically, neodymium (Nd^{3+}) ions, with their unique energy level structure, act as efficient trapping centers capable of storing and subsequently releasing charge carriers upon thermal stimulation. These features render $Y_2O_3:Nd^{3+}$ nanophosphors promising candidates for TL-based radiation detection, storage dosimetry, and optical devices.

2. Synthesis Methods

The synthesis route adopted for nanophosphor fabrication is a critical determinant of their crystallographic structure, defect density, and luminescent efficiency. Solution combustion synthesis (SCS) has emerged as a prominent technique owing to its operational simplicity, economic viability, and capacity to yield highly crystalline nanopowders within a relatively short timeframe. This method involves the preparation of a homogeneous aqueous solution containing metal nitrates, serving as oxidizing agents, and an appropriate organic fuel. Upon thermal activation, the system undergoes an intense exothermic redox reaction, rapidly producing porous $Y_2O_3:Nd^{3+}$ powders with uniform dopant dispersion. Literature evidence indicates that SCS-derived nanophosphors predominantly crystallize in the cubic phase, with average crystallite sizes typically in the range of 18–24 nm. The resultant materials frequently exhibit high surface areas and a notable presence of intrinsic defects, both of which are known to contribute positively to their thermoluminescence (TL) performance.

The powder nanophosphors Y2O3:Nd3+ were prepared by combustion reaction. Neodymium nitrate (99.99% sigma Aldrich), yttrium nitrate (99.99% sigma Aldrich), and Urea (99%, CDH) were used as starting raw materials to prepare Y2O3:Nd3+.The synthesis reaction is [4] (2 - 2x)Y(NO3)3 + 2x Re(NO3) + 5 (NH2)2 CO → (Y1-xREx)2O3 + 5CO + 8N2 + 10H2O Where Re = Rare earth nitrates. A Indigenously developed Thermoluminescence recording system was used for recording TL glow curves. The system is capable of providing linear heating at any desired rate, supported by required software.

3. Structural Characterization

Characterization of the synthesized $Y_2O_3:Nd^{3+}$ nanophosphors is essential for validating their structural integrity and phase purity. X-ray diffraction (XRD) analyses commonly reveal the formation of a pure cubic phase corresponding to Y_2O_3, with diffraction peaks matching standard JCPDS files. The crystallite size, calculated using the Debye-Scherrer formula, confirms the nanocrystalline nature of the material. Complementary morphological studies using scanning electron microscopy (SEM) display agglomerated but porous particles, indicative of rapid combustion-driven synthesis. These morphological traits are critical as they influence the density and accessibility of trapping centers within the material. Furthermore, energy-dispersive X-ray spectroscopy (EDS) and Fourier-transform infrared (FTIR) spectroscopy often accompany XRD and SEM to confirm elemental composition and bonding characteristics.

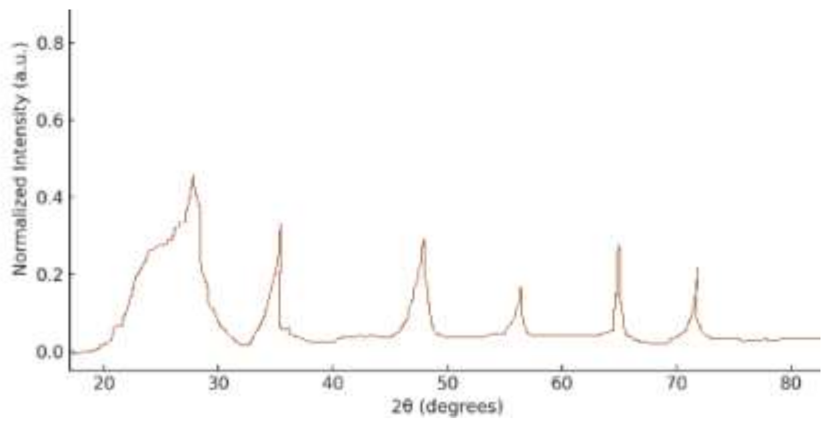

Fig.1. **XRD pattern** for Nd^{3+}-doped Y_2O_3 nanophosphors

4. Thermoluminescence Properties

4.1 Glow Curve Analysis

The TL glow curve of $Y_2O_3:Nd^{3+}$ nanophosphors provides valuable information on the distribution and nature of traps present in the material. Typically, glow curves exhibit two or more prominent peaks, reflecting multiple trap levels. Peaks centered around 587 K and 628 K have been commonly observed, suggesting the presence of discrete trap levels introduced by Nd^{3+} doping. The thermoluminescence (TL) glow curve reveals two distinct glow peaks, with a dominant peak centered at approximately 587K and another peak observed near 623K.

 |

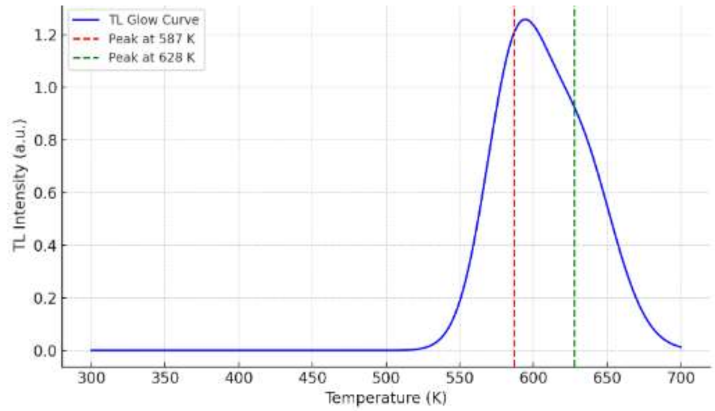

Fig.2.Thermoluminescence (TL) glow curve for Nd^{3+}-doped Y_2O_3 nanophosphors. The peaks at ~587 K and ~628 K represent distinct trap levels

An increase in TL intensity for both peaks is evident with the progressive increase in UV irradiation time, indicating enhanced charge carrier trapping and subsequent recombination processes. The symmetry factor of the glow curves was evaluated to gain insight into the kinetic order of the TL processes. The activation energies (E) associated with the first glow peak, estimated using the half-width method, were determined to be 0.762 eV, 0.797 eV, 0.810 eV, and 0.688 eV corresponding to irradiation durations of 5, 10, 15, and 20 minutes, respectively. In the case of the second glow peak, the activation energies were calculated to be 1.51 eV, 1.62 eV, 1.64 eV, and 2.08 eV for the same irradiation intervals. These values suggest the presence of multiple trapping centers with varying thermal stabilities, influenced by the duration of UV exposure.

These glow peaks shift or intensify depending on experimental conditions, such as irradiation dose, heating rate, and dopant concentration. Such thermal peaks are indicative of the material's ability to trap and later release electrons and holes efficiently, which is vital for applications in radiation detection.

4.2 Trap Parameters

The quantitative analysis of TL glow curves yields important trap parameters including the activation energy (trap depth, E) and the frequency factor (s), which characterize the thermal stability and release dynamics of trapped charge carriers. Using peak shape methods and empirical models, trap depths of approximately 1.83 eV and 2.2 eV have been calculated for the glow peaks at 587 K and 628 K, respectively. The corresponding frequency factors are in the range of 10^{15} to 10^{17} s^{-1}, suggesting that these are deep traps with potential for long-term charge storage. Accurate estimation of these parameters is critical for assessing the suitability of the phosphors for dosimetric applications.

Table.1. Thermoluminiscence parameters of Y2O3: Nd3+ Nanophosphors

Glow peak (K)	Trap Depth	Frequency factor (s-1)	Kinetic Order	FWHM (K)
587	1.84	5 x 1015	general	104
628	2.20	3 x 1017	general	119

Table. 2. Comparison of TL properties with dopants

Dopant ion	TL Peak Temperature (K)	Trap depth (eV)	Features
Nd	587	1.84	Deep traps
Eu	560	1.65	Strong red emission
Tb	540	1.70	Green luminiscence
Dy	512	1.55	Persistent after glow

4.3 Kinetic Order

The kinetic order of the TL process reveals the nature of charge carrier recombination mechanisms. $Y_2O_3:Nd^{3+}$ nanophosphors often exhibit general-order kinetics, where both first- and second-order characteristics are present. This suggests that the recombination process involves multiple pathways and may depend on factors such as trap density and re-trapping probability. Understanding the kinetic order aids in the development of theoretical models for predicting TL behavior under varying environmental and irradiation conditions.

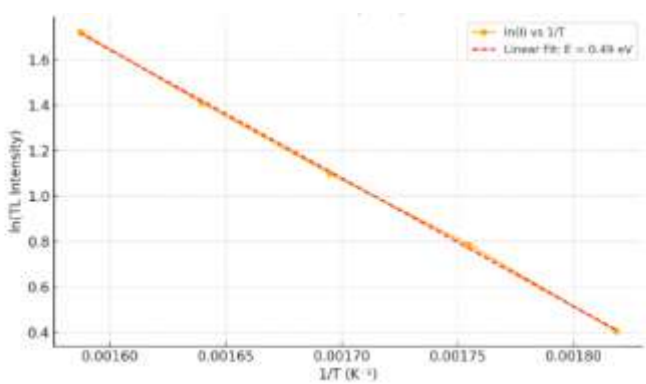

Fig.2. Arrhenius plot for trap depth estimation of Nd^{3+}-doped Y_2O_3 nanophosphors.

5. Influence of Thermal Treatments

Post-synthesis thermal treatments, particularly annealing, play a significant role in optimizing the TL response of nanophosphors. Controlled annealing can enhance the crystallinity, reduce surface-related defects, and influence the distribution of trap states. For instance, increasing the annealing temperature generally results in improved TL intensity due to better lattice ordering and elimination of quenching centers. Although extensive studies exist for Eu^{3+} and Tb^{3+} doped Y_2O_3 systems, which show increased luminescence and TL performance post-annealing, similar effects are expected for Nd^{3+}-doped counterparts. These findings highlight the importance of post-synthesis processing in tuning the functional properties of nanophosphors.

6. Comparative Studies with Other Dopants

Comparative analyses with other rare-earth dopants in the Y_2O_3 matrix help in benchmarking the TL efficiency of Nd^{3+} doping. For example, Eu^{3+}-doped Y_2O_3 is well-known for its sharp red emission and excellent TL sensitivity, making it a preferred choice for TL dosimetry. Tb^{3+}-doped variants exhibit green emission and a comparable TL glow curve structure. Nd^{3+} doping, on the other hand, introduces different trap depths and energy level transitions that enable broader and more stable TL emissions. Such unique characteristics position Nd^{3+} as a versatile dopant with potential applications in multi-spectral dosimetry and photonic devices.

7. Applications and Future Prospects

The unique thermoluminescent features of Y_2O_3:Nd^{3+} nanophosphors make them suitable for a range of high-impact applications:

- **Radiation Dosimetry**: The presence of deep and thermally stable traps allows for precise measurement of ionizing radiation doses over extended periods, with minimal fading.
- **Optoelectronic Devices**: The strong luminescence and stability of Nd^{3+}-activated Y_2O_3 nanophosphors make them suitable candidates for use in LEDs and flat-panel displays.
- **Photonic and Laser Technologies**: Nd^{3+} ions offer energy level transitions that are exploitable in laser gain media and optical amplifiers.

Looking forward, future research should aim to refine synthesis parameters for better control over morphology and crystallinity, investigate co-doping with other rare-earth ions to modulate trap characteristics, and conduct in-depth studies on thermal treatment regimes to fine-tune TL response. These efforts will not only enhance our understanding of TL mechanisms but also facilitate the development of application-specific phosphor materials.

 |

8. Conclusions

Nd3+ doped Y2O3 phosphors, has been successfully prepared via combustion method. The TL property of Y2O3:Nd3+ has been investigated for different UV radiations at 8°C/min and it was found the TL glow curve is maximum for 25 min radiation

References

1. Jayaramaiah, J. R., Lakshminarasappa, B. N., & Nagabhushana, B. M. (2011). Thermoluminescence studies of solution combustion synthesized Y_2O_3:Nd^{3+} nanophosphor. *Materials Chemistry and Physics*, 130(1-2), 175–178
2. Murthy, S., & Nagabhushana, B. M. (2014). Effect of calcination temperature on structural, photoluminescence, and thermoluminescence properties of Y_2O_3:Eu^{3+}.
3. Dubey, V., Kaur, J., & Agrawal, S. (2015). Effect of europium concentration on photoluminescence and thermoluminescence behavior of Y_2O_3:Eu^{3+} phosphor. *Research on Chemical Intermediates*, 41(7), 4727–4739
4. Delice, S., IŞIK, M., & Hasanlı, N. (2019). Low temperature thermoluminescence behaviour of Y_2O_3 nanoparticles. *Journal of Rare Earths*, 37(1), 19–23.
5. Rzepka, A., et al. (2007). Growth and characterization of Nd, Yb–yttrium oxide nanopowders obtained by sol-gel method , *Crystal Research and Technology* 42(12):1314-1319
6. Tiwari, R., et al. (2013). Thermoluminescence studies of UV-irradiated Y_2O_3:Eu^{3+} doped phosphor. *Research on Chemical Intermediates*, 39(10), 3919–3923
7. Deshmukh, P., et al. (2016). Effect of charge transfer band on luminescence properties of Yb doped Y_2O_3 nanoparticles for blue-far yellow emission.
8. Tiwari, R., et al. (2015). Effect of europium concentration on photoluminescence and thermoluminescence behavior of Y_2O_3:Eu^{3+} phosphor. *Research on Chemical Intermediates*, 41(7), 4727–4739.
9. Dubey, V., et al. (2013). Thermoluminescence studies of UV-irradiated Y_2O_3:Eu^{3+} doped phosphor. *Research on Chemical Intermediates*, 39(10), 3919–3923.
10. Rzepka, A., et al. (2007). Growth and characterization of Nd, Yb–yttrium oxide nanopowders obtained by sol-gel method. 2 (7), 167-178

