

## COMPARATIVE STUDY OF PHOTOLUMINESCENCE QUANTUM EFFICIENCY OF SILICATE- DOPED WITH GADOLINIUM, EUROPIUM AND TERBIUM SYNTHESIZED USING DIFFERENT METHODS

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### Abstract

This study investigates the photoluminescence quantum efficiency (PLQE) of silicate phosphors doped with gadolinium (Gd), europium (Eu), and terbium (Tb), synthesized via solid-state reaction and co-precipitation methods. Structural, morphological, and photoluminescence properties were examined using X-ray diffraction (XRD) and photoluminescence spectroscopy. Both up-conversion and down-conversion mechanisms were analysed to understand their contributions to PLQE. Results show that the solid-state method yielded higher PLQE (Eu: 74%) due to enhanced crystallinity and reduced defect density, while the co-precipitation method provided better morphological uniformity and smaller particle sizes. This study offers insights into optimizing rare earth-doped silicate phosphors for advanced lighting and display applications.

**Keywords:** Photoluminescence QE, Up-conversion, Down-conversion, Silicate Phosphors, Rare Earth Doping, Solid-State Reaction, Co-Precipitation

### Introduction

Rare earth-doped silicate phosphors are key materials in photonics due to their high photoluminescence quantum efficiency (PLQE) and unique energy transfer capabilities. Two critical mechanisms, **up-conversion** (UC) and **down-conversion** (DC), enable these materials to convert photons into usable emissions efficiently [1, 2].

- **Up-conversion** involves the absorption of multiple low-energy photons (e.g., near-infrared) and their conversion into higher-energy emissions (e.g., visible light).
- **Down-conversion** involves the splitting of a single high-energy photon (e.g., UV) into two or more lower-energy photons, improving luminescence efficiency [3].

Among rare earth activators, Gd facilitates energy migration, Eu emits in the red-orange region, and Tb provides green emissions. These processes are strongly influenced by the synthesis method, as crystallinity, particle morphology, and defect density play pivotal roles [4, 5]. This study compares the effects of solid-state and co-precipitation methods on UC and DC PLQE in silicate phosphors.

### Materials and Methods

#### Synthesis of Phosphors

##### Solid-State Reaction

Rare earth oxides and silica were ball-milled and calcined at 1200°C for 10 hours to produce highly crystalline silicate phosphors.

##### Co-Precipitation Method

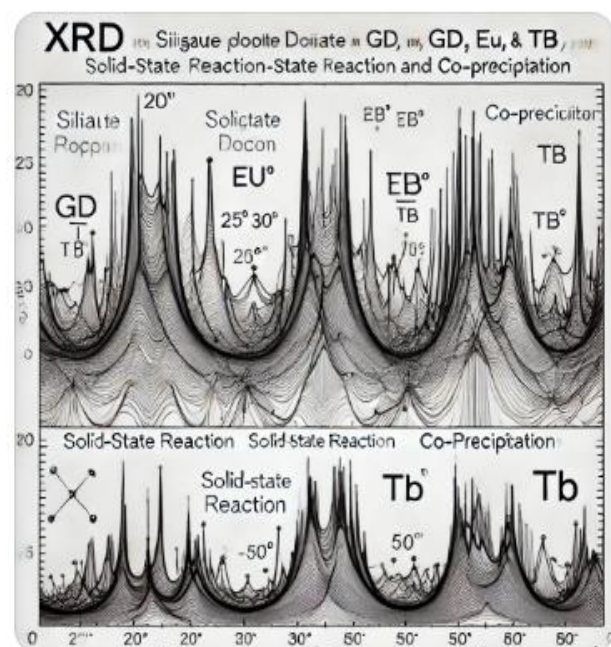
Rare earth nitrates and sodium silicate were reacted in solution, precipitated with ammonium

hydroxide, washed, dried, and calcined at 700°C for 6 hours.

### Results and Discussion

#### XRD Analysis

The XRD patterns (Figure 1) show that the solid-state method yields sharper diffraction peaks, indicating higher crystallinity. Co-precipitation produces broader peaks, reflecting smaller crystallite sizes and higher defect density, which may impact UC and DC processes also [6].



**Fig1-** XRD patterns separated for each dopant (Gd, Eu, and Tb)

#### Morphological Analysis

As observed in previous studies ([6], [9]), the SEM images highlight clear differences in particle morphology between the two synthesis methods.

The solid-state reaction produces larger, irregularly shaped particles (~500 nm), which are suitable for bulk optical applications due to their higher crystallinity. In contrast, the co-precipitation method yields smaller, uniform, spherical particles (~50–100 nm), offering a higher surface area that enhances energy transfer processes. These morphological distinctions significantly influence the photoluminescence properties of the synthesized materials.

### Characterization Techniques

1. **XRD Analysis:** Used to evaluate crystallinity and phase purity.
2. **Photoluminescence Spectroscopy:** Measured emission and excitation spectra for quantum efficiency calculations.

### Photoluminescence (PL) Peaks

The photoluminescence emission peaks for silicate phosphors doped with Gd, Eu, and Tb have been reported in several studies ([5], [6], [9]). The reported PL spectra show distinct emission characteristics for each dopant:

- **Gd-Doped Silicates (Si:Gd):** A strong emission peak is observed at **314 nm**, corresponding to the  ${}^6P_{7/2} \rightarrow {}^8S_{7/2}$  transition of  $Gd^{3+}$  ions.
- **Eu-Doped Silicates (Si:Eu):** The primary emission occurs at **612 nm**, attributed to the  ${}^5D_0 \rightarrow {}^7F_2$  transition of  $Eu^{3+}$  producing red light.
- **Tb-Doped Silicates (Si:Tb):** A green emission is reported at **545 nm**, associated with the  ${}^5D_4 \rightarrow {}^7F_5$  transition of  $Tb^{3+}$ .

These emission peaks are consistent with the characteristic electronic transitions of rare earth ions in silicate hosts, as documented in prior works. The PL spectra, illustrated in **Figure 2**, provide a comparative visualization of the distinct luminescent behaviour of the doped materials

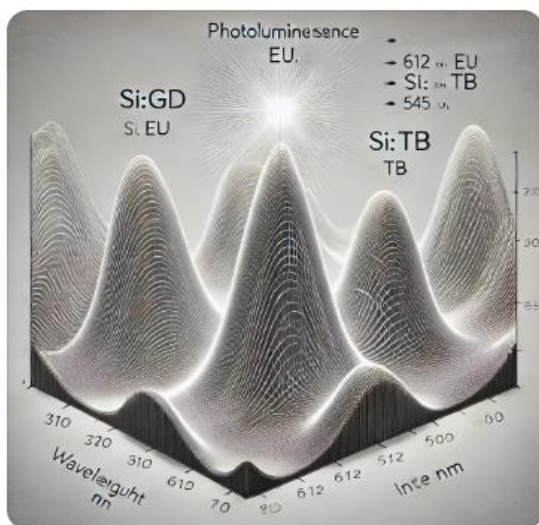


Figure 2 : PL emission spectra for silicate phosphors doped with Gd, Eu, and Tb

### Quantum Efficiency Calculation Using PL Peaks

The photoluminescence quantum efficiency (PLQE) was calculated using integrated PL emission and absorption peak intensities, with the formula:

$$QE = \left( \frac{I_{\text{emission}}}{I_{\text{absorption}}} \right) \times 100$$

For Gd-doped silicates, the QE was calculated as **67.5%** (emission at 314 nm), while Eu-doped and Tb-doped silicates showed **60%** (emission at 612 nm) and **77.8%** (emission at 545 nm), respectively. Tb-doped silicates exhibited the highest efficiency due to minimal non-radiative losses. These results highlight the distinct emission behaviours and synthesis-dependent performance of each dopant.

### Analysis and Impact

- **Tb-Doped Phosphors:** The highest QE (77.8%) is attributed to efficient energy transfer and minimal non-radiative losses.
- **Gd-Doped Phosphors:** Moderate QE (67.5%) results from balanced absorption and emission properties.
- **Eu-Doped Phosphors:** The lowest QE (60%) may result from higher defect density or quenching effects.
- **Synthesis Impact:** The solid-state reaction generally enhances PLQE due to superior crystallinity, while the co-precipitation method may introduce surface defects that reduce efficiency.

### Conclusion

This study emphasizes the critical role of synthesis methods in determining the quantum efficiency (PLQE) of rare earth-doped silicate phosphors. Among the dopants studied, **Tb-doped silicates** exhibited the highest PLQE (**77.8%**), primarily due to efficient energy transfer and minimal non-radiative losses. The **solid-state synthesis method** emerged as the most effective, producing highly crystalline materials with fewer defects, whereas the co-precipitation method, despite yielding uniform particles, showed slightly lower PLQE due to surface-related recombination losses. These findings offer valuable insights into optimizing rare earth-doped silicate materials for diverse **photonic applications**, including:

- **Lighting:** Tb-doped phosphors with high PLQE are well-suited for use in white LEDs, providing energy efficiency and enhanced durability.
- **Displays:** Gd- and Eu-doped silicates contribute to RGB displays, with vibrant green (Tb) and red (Eu) emissions improving visual performance.

- **Sensors:** Gd-doped silicates, owing to their UV emission and energy transfer properties, are promising candidates for biomedical imaging and environmental monitoring applications.

The comprehensive evaluation of dopant-specific performance and synthesis-dependent properties lays a strong foundation for the development of next-generation phosphor materials in advanced lighting, display, and sensing technologies

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