

Shaping scintillation and UV-VIS-NIR luminescence properties through synergistic lattice disordered engineering and exciton-mediated energy transfer in Pr³⁺-doped Lu_{1.5}Y_{1.5}Al_{5-x}Sc_xO₁₂ (x = 0.0–2.0) garnets

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This study investigated the crystallization behavior, luminescence and scintillation properties of Pr³⁺-doped Lu_{1.5}Y_{1.5}Al_{5-x}Sc_xO₁₂ (0.0, 0.5, 1.0, 1.5, 2.0) garnets, grown using the micro-pulling-down method, to address challenges associated with the substitution of Sc³⁺ for Al³⁺ ions due to their mismatched ionic radii in the same octahedral crystallographic site. A specially engineered crucible with five independent crystallization capillaries was used, which revealed that Sc³⁺ substitution caused localized melt heterogeneity, resulting in non-uniform melt ejection during crystallization. The threshold of Sc³⁺ ions concentration ($x = 1.5$) was identified, beyond which further substitution led to the formation of a garnet/bixbyite-like distorted perovskite hypoeutectic structure. This discovered a novel method for crystallization of hypoeutectic crystal growth by exploiting ionic radii mismatches. Vibrational spectroscopy confirmed that Sc³⁺ ions incorporation disrupted lattice symmetry, increasing structural disorder around Pr³⁺ ions. This structural modification significantly enhanced luminescence, particularly in the visible and near-infrared (NIR) ranges, achieving a sixteenfold increase in NIR luminescence intensity. Synchrotron radiation excitation spectra revealed that the band gap energy progressively decreased with increasing Sc³⁺ ions concentration. This finding provided crucial insights for designing materials based on band gap engineering strategies. A sixfold improvement in scintillation light yield, reaching 11 200 photons per MeV, was observed in the Lu_{1.5}Y_{1.5}Al_{3.5}Sc_{1.5}O₁₂ crystal ($x = 1.5$). The enhancement resulted from a Sc³⁺-mediated energy transfer pathway, which optimized charge carrier dynamics by reducing deep trapping center density by an order of magnitude while preserving shallow traps. The EPR spectroscopy showed that Sc³⁺ incorporation reduced concentration of trace impurities, enhancing scintillation light yield. It also confirmed that F⁺-Pr³⁺ interactions intensified Pr³⁺ emission at 370 nm and identified the 410–420 nm band as originating from F⁺-O⁻ defect pairs. These findings demonstrate that controlled lattice modification through Sc³⁺ incorporation allows for tuning structural and luminescent properties, offering a new approach for the design of advanced scintillators and luminescent materials with improved performance for targeted applications.

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