Crystal field engineering of Cr^{3+} luminescence in Zn^{2+}/Zr^{4+}-modified $Gd_3Ga_5O_{12}$

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Broadband near-infrared (NIR) emitters are important for applications such as biomedical diagnostics, security, night vision, and non-destructive analysis. Phosphor-converted LEDs (pc-LEDs) are promising NIR sources, but their performance is limited by low quantum efficiency and poor thermal stability. Therefore, the development of materials with tunable, broadband NIR emission remains essential.

In this study, we investigate Cr3+-doped Gd3Ga5O12 (gadolinium gallium garnet, GGG) modified by Zn2+/Zr4+ substitution. Partial replacement of Ga3+ with Zn2+ and Zr4+ alters the crystal field around Cr3+, thereby tuning its luminescence properties.

A series of polycrystalline phosphors with nominal composition Gd3Ga5-2xZnxZrxO12:0.05Cr3+ (x = 0–1) were synthesized via a conventional solid-state reaction method at 1300 °C for 6 h in air. Phase formation were verified using powder X-ray diffraction, confirming successful incorporation of Zn2+ and Zr4+ into the garnet lattice. The optical properties were analyzed by diffuse reflectance spectroscopy, photoluminescence spectroscopy, and luminescence decay analysis.

The results reveal that Zn2+/Zr4+ co-substitution induces a noticeable red shift in both absorption and excitation bands associated with Cr3+ ions, indicating a modification of the crystal field strength. As the substitution level increases, the broadband NIR emission shifts from ~730 nm to ~805 nm under 450 nm excitation. Simultaneously, a significant broadening of the emission band is observed, with the full width at half maximum (FWHM) increasing from approximately 100 nm to 180 nm.

These changes result in enhanced spectral coverage across the NIR region, which is advantageous for broadband NIR applications. The findings demonstrate that cation co-substitution in garnet hosts is an effective approach for tuning Cr3+ luminescence and improving the performance of NIR phosphors for pc-LED technologies.

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