

Influence of double aliovalent codoping on the luminescence of YAG:Ce scintillator

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The radiation detectors for future high-luminosity particle physics experiments require scintillators that combine a fast scintillation response, sufficient light yield, and radiation hardness. Ce-doped gadolinium aluminum gallium garnet (GAGG:Ce) is currently considered a state-of-the-art garnet scintillator offering exclusively high light yield. However, the presence of gallium in the host lattice requires the growth of GAGG:Ce single crystals using iridium crucibles, which significantly increases production costs.

Ce-doped yttrium aluminum garnet (YAG:Ce) is a mature material and can be grown using tungsten or molybdenum crucibles, thus being a cost-effective alternative [1]. However, YAG:Ce performance as a scintillator suffers from carrier trapping, resulting in slow scintillation decay components.

Aliovalent codoping with Mg²⁺ or Ca²⁺ ions has been shown as an effective way to improve the scintillation properties of Ce-doped garnets [2]. However, neither Mg- nor Ca-codoping is capable of improving the balance between fast decay and high light output up to the level sufficient for many important applications.

In this work, we investigate the influence of combined Mg and Ca codoping on the scintillation performance of Ce-doped YAG single crystals using time-resolved photoluminescence (PL), cathodoluminescence (CL), and transient absorption measurements performed over a temperature range from 78 to 750 K. The crystals codoped with different amounts of Mg and Ca were studied under two qualitatively different excitation conditions. In CL experiments, multiple electron–hole pairs are generated in the crystal bulk, excitation transfer to emitting centers is important, and cerium in both valence states, Ce³⁺ and Ce⁴⁺, can be excited. Meanwhile, under photoexcitation, only Ce ions are selectively excited to specific Ce³⁺ levels.

The results show that Mg²⁺ and Ca²⁺ codoping have distinct influences on the scintillation performance. Magnesium codoping causes a slight acceleration of the luminescence decay at a moderate conversion of Ce³⁺ to Ce⁴⁺. It also reduces the influence of shallow electron traps, as evidenced by enhanced low-temperature PL intensity. Ca-codoping results in a strong acceleration of luminescence kinetics. Calcium promotes a substantial conversion of Ce³⁺ to Ce⁴⁺, suppresses electron trapping by directing electrons toward nonradiative recombination centers, and modifies the local Ce environment, reducing the thermal depopulation barrier from 0.8 to 0.36 eV.

The study demonstrates that double codoping with Mg²⁺ and Ca²⁺ provides an effective means to tailor YAG:Ce scintillation performance for specific applications by balancing light yield and temporal response.

[1] O. Sidletskiy et al., “Garnet Crystal Growth in Non-precious Metal Crucibles”, *Engineering of Scintillation Materials and Radiation Technologies, Springer Proceedings in Physics* 227, pp. 83-95, (2019).

[2] O. Sidletskiy et al., “Progress in fast-timing Ce-doped garnet scintillators by complex codoping with divalent cations”, *Materials Research Bulletin*, **184**, 113283 (2025).