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Highly efficient infrared to visible up-conversion emission tuning from red to white in Eu/Yb co-doped $NaYF_4$ phosphor

Trilok K. Pathak [a,b,*], Ashwini Kumar [a,**], L.J.B. Erasmus [a], Anurag Pandey [a], E. Coetsee [a], H.C. Swart [a], R.E. Kroon [a,**]

[a] Department of Physics, University of the Free State, Bloemfontein, South Africa
[b] Department of Physics, [illegible] University, [illegible], India

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ABSTRACT

Eu/Yb co-doped $NaYF_4$ phosphors have been synthesized by the combustion method. The Eu doping was fixed and the effect of Yb doping concentration on the structural, morphological and luminescence properties has been investigated. X-ray diffraction analysis revealed that the phosphors consisted of mixed α- and β-phases, but the β-phase was dominant. All elements of the host and dopants, as well as adventitious C, were detected using X-ray photoelectron spectroscopy. The surface morphology showed a [illegible]-like structure with sharp hexagonal edges. Energy dispersive X-ray spectroscopy spectra proved the formation of the desired materials. The photoluminescence spectra illustrated the optical emission properties of Eu^{3+} in the red region when excited at 394 nm, while, under the same excitation, Yb^{3+} [illegible] emission at 980 nm. The up-conversion (UC) emission of Eu/Yb co-doped $NaYF_4$ produced a white color at the higher concentration of Yb excited by a 980 nm laser, which was made possible by green emission of Er contamination (from Yb source) and blue emission of Eu^{3+} ions. The lifetime of the Eu^{3+} UC luminescence at 615 nm was also affected by the Yb doping concentration. The temperature sensitivity associated with the Er^{3+} peaks at 520 and 542 nm was assessed as a function of temperature and the maximum of 0.0040 K^{-1} occurred at 483 K.

1. Introduction

The study of phosphors which emit visible light upon sequential absorption of two or more low-energy (near infrared, NIR) photons laid the foundation for the new field of up-conversion (UC) nanocrystals [1,2]. This phenomenon, termed UC luminescence, has many potential applications such as solar cells, pH sensors and medical imaging [3–6]. There is a constant demand on developing a white UC phosphor with high efficiency. This work was done to synthesize nanocrystalline Eu/Yb doped $NaYF_4$ using the combustion method and to investigate the effect of Yb concentration on its structure, morphology and luminescence properties (including color). Fluoride materials normally possess a low phonon energy and high refractive index. Furthermore, they exhibit adequate thermal and environmental stability. Therefore, fluoride materials are regarded as excellent host lattices for down-conversion and UC luminescence of lanthanide ions [7–11]. Among the investigated fluorides, $NaYF_4$ has attracted increasing attention in the field of materials science over the past two decades [12–14]. It has three possible modifications: (i) the low-temperature cubic (α) form, (ii) the hexagonal (β) form and (iii) the high-temperature cubic form, depending on the synthesis conditions and methods [15,16]. Zhao et al. [17] observed highest efficiency for UC luminescence from hexagonal $NaYF_4$: Yb/Er material, mainly due to the low phonon energy of the $NaYF_4$ lattice. The rare earth combination Yb/Er has mostly been used to show UC phenomena in different host lattices, whereas less studies have been reported with the Yb/Eu doping combination. However, Eu^{3+} ions have excellent red emitter properties and are famous structural probes [18–24]. Wang et al. [25] observed not only the visible UC luminescence, but also the ultraviolet five-order UC fluorescence of Eu^{3+} in YF_3 nanocrystals by using Yb^{3+} and Tm^{3+} as sensitizers and a 980 nm diode laser as a pump source. In the present study, Eu/Yb doped $NaYF_4$ was synthesized and its UC luminescence and lifetime properties stimulated by a 980 nm diode laser were investigated as a function of Yb concentration, showing that it can act as a white UC phosphor. We have also studied its temperature sensitivity as a function of temperature.

2. Experimental Details

Analytic grade yttrium nitrate hexahydrate $Y(NO_3)_3·6H_2O$ (99.9%), sodium nitrate $NaNO_3$ (99.0%), ammonium fluoride NH_4F (98.0%),

* Correspondence to: T.K. Pathak, Department of Physics, University of the Free State, Bloemfontein, South Africa.
** Corresponding author.
E-mail addresses: [illegible] (T.K. Pathak), [illegible] (A. Kumar), [illegible] (R.E. Kroon).

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