Highly Efficient Near-Infrared To Visible Photon Upconversion In Bulk And Nanocrystalline $NaYF_4:Er^{3+},Yb^{3+}$

J. F. Suyver, A. Aebischer, J. Grimm, S. Heer, K. W. Krämer and H. U. Güdel

Department of Chemistry and Biochemistry, University of Bern, Freiestrasse 3, 3000 Bern 9, Switzerland. E-mail: suyver@iac.unibe.ch

Photon upconversion entails the sequential absorption of two or more near-infrared excitation photons and the subsequent emission of a photon of higher energy, typically in the visible range of the spectrum. Due to the prerequisite of multi-photon absorption, all upconversion emission bands have a non-linear behaviour as a function of the excitation power used [1]. As a result, the applicability of these phosphors in a future device will depend strongly on the available excitation power.

The $NaYF_4$ host-lattice has been recognized since the early 1970's as being one of the most suitable for near-infrared to visible photon upconversion. Specifically, micrometer-sized $NaYF_4$ powder co-doped with the rare earth ions Yb^{3+} and Er^{3+} (resulting in mainly green and red upconversion emission under 980 nm excitation) is among the most efficient photon upconversion materials known [2]. The syntheses of efficiently upconverting $NaYF_4:Er^{3+},Yb^{3+}$ bulk powders [2] and nanocrystals [4] are now understood.

A set of typical emission spectra for bulk $NaYF_4:Er^{3+},Yb^{3+}$ is shown in Fig. 1 as a function of the excitation power. Even though in the high-power limit the infrared emission is still the dominant spectral feature, the visible emission amounts to nearly 50 % of all the infrared photons absorbed. Thus showing clearly the very high efficiencies that are obtainable with this phosphor. From a detailed study of the upconversion characteristics, such as the temperature- and power dependence as well as the excitation spectra, the precise efficiency as well as the underlying energy transfer mechanisms were determined [3]. The most important energy transfer and luminescent processes are depicted in Fig. 2.

Nanocrystals of upconverting $NaYF_4:Er^{3+},Yb^{3+}$, with an average particle diameter of ~15 nm can be transparently dispersed in several organic solvents. These solutions show intense visible upconversion emission under infrared excitation [4]. The similarities and differences between the nanocrystalline and bulk systems will be addressed.

[1] F. Auzel, Chem. Rev. **104**, 139 (2004).
[2] K. W. Krämer *et al.*, Chem. Mater. **16**, 1244 (2004).
[3] J. F. Suyver *et al.*, Submitted to Phys. Rev. B (2004).
[4] S. Heer *et al.*, Submitted to Adv. Mater. (2004).

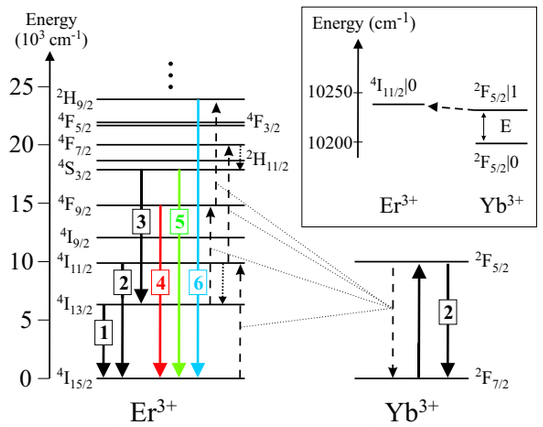

Figure 1: Room temperature emission spectra of $NaYF_4:Er^{3+},Yb^{3+}$ powders for excitation densities of (a) 1 W/cm^2, (b) 10 W/cm^2, and (c) ~60 W/cm^2. Excited at 10238 cm^{-1} (arrow). The electronic transitions responsible for the six major emission bands are identified in Fig. 2.

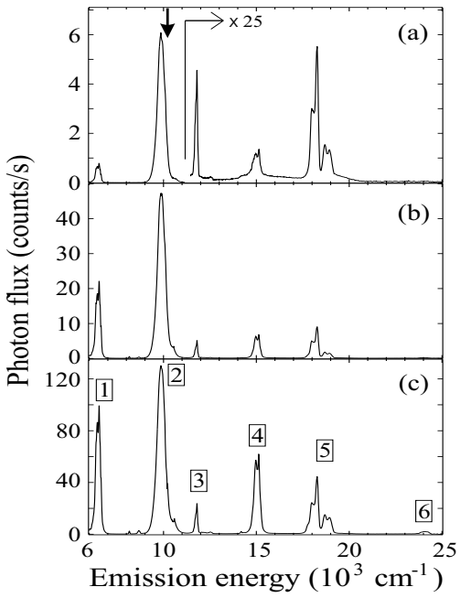

Figure 2: The Er^{3+} and Yb^{3+} related energy levels in $NaYF_4:Er^{3+},Yb^{3+}$ together with the most important luminescent processes (drawn arrows), upconversion processes (set of dashed arrows) and multiphonon relaxations (dotted arrows).