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Laser pump power density as a factor controlling up-conversion luminescence quantum yield of lanthanide nanocomplexes

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Introduction

Up-conversion nanoparticles (UCNP) are a class of promising nanomaterials that convert low-frequency light into high-frequency radiation. This unique physical property opens broad prospects for the application of up-conversion nanoparticles in life sciences due to the several advantages of UCNPs over down-conversion NPs. These include greater penetration depth, higher spatial image resolution, as well as the fact that infrared radiation required for up-conversion luminescence (UCL) excitation does not excite autofluorescence of biological tissues.

Objects of the study

Aqueous suspensions of $NaGdF_4$ nanoscale crystalline matrix doped with Yb^{3+} and Er^{3+} ions were the objects of the study. The concentration of samples in the aqueous suspension was 2 g/l. The particles' size in the suspension was 20-30 nm.

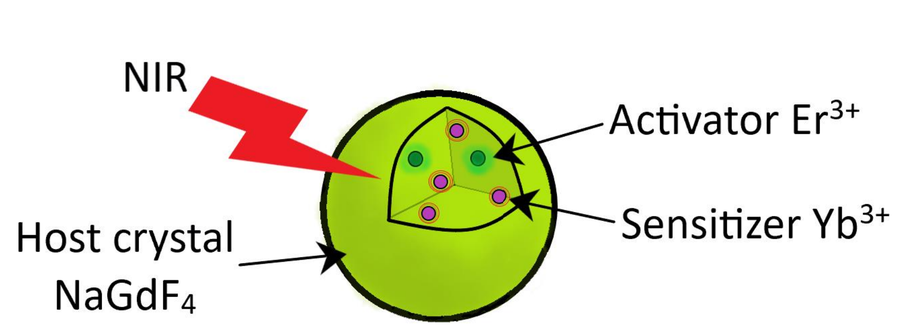

Fig.1. Schematic representation of $NaGdF_4$:Yb^{3+}/Er^{3+}

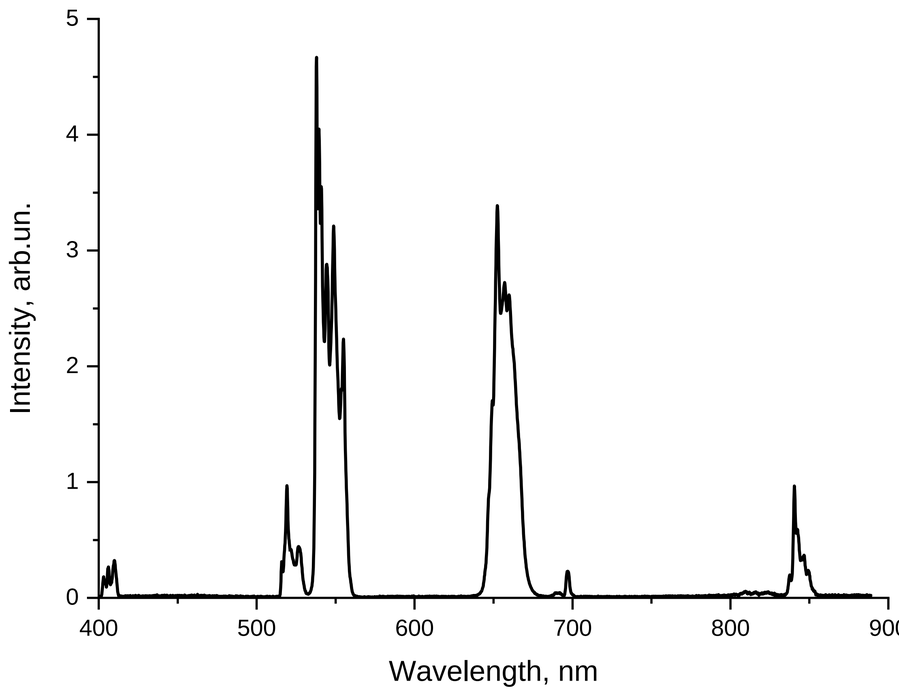

Fig.2. Luminescence spectrum of the $NaGdF_4$:Yb:Er aqueous suspension, concentration 2 g/l.

Methods

To excite the luminescence signal, a laser system based on a pulse laser LQ629-100 and optical parametric oscillator LP603 (Solar, Belarus) was used. The wavelength - 980 nm, the pulse duration - 12 ns, the pulse repetition rate was 100 Hz, and the maximum average power was 330 mW (corresponding to the maximum pulse energy of 3.3 mJ). The laser power was controlled by the Ophir Nova 2 power meter. The spectra were recorded using MVR-80 monochromator (focal length 500 mm, 300 grooves/mm grating) and Horiba Jobin Yvon Synergy BIUV 1024 * 128 CCD camera.

Power density

Due to their unique energy levels structure, enabling up-conversion process, UCNP show non-linear dependence of UCL intensity on power density of excitation radiation. Such specific behaviour of UCL intensity may be explained in terms of two competing processes: linear decay (LD) of metastable intermediate energy level and process of energy transfer up-conversion (ETU). The observed non-linear UCL dependence means similar behaviour of quantum yield (QY) under pump power density changes.

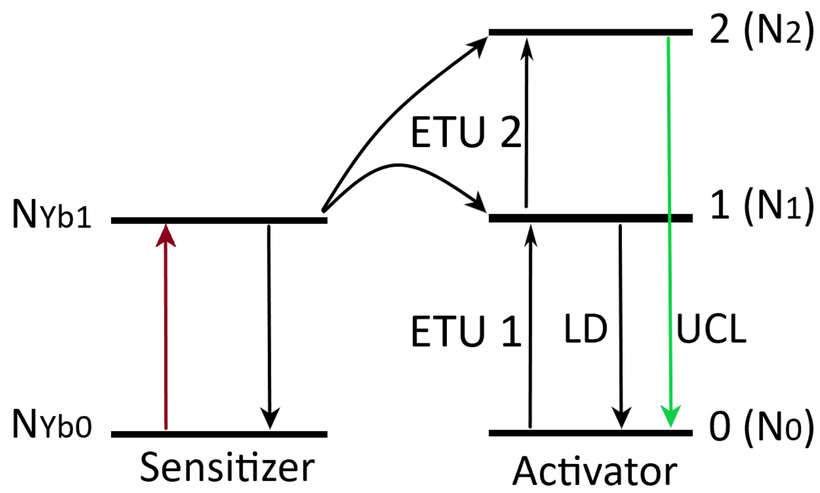

Fig.3. Schematic representation of Yb^{3+} and Er^{3+} energy levels and proposed UCL mechanism

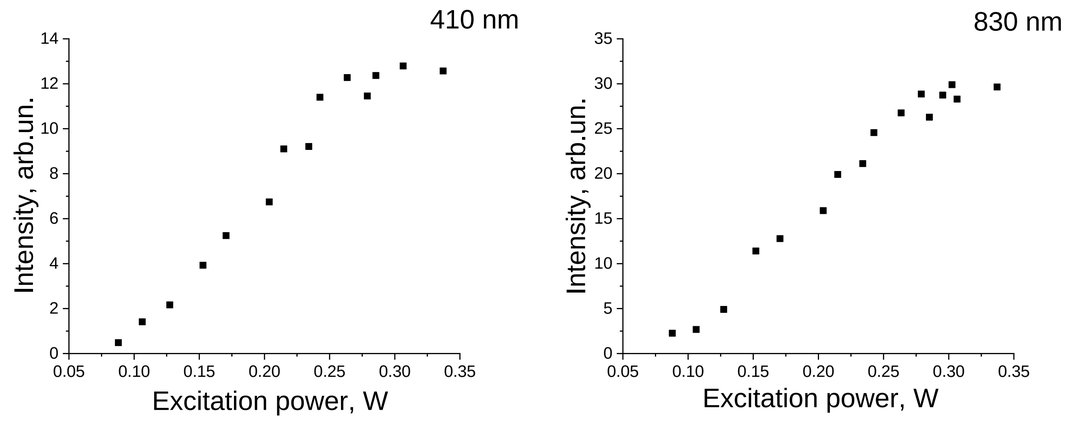

Fig.4. UCL intensity dependence (band in the region of 410 nm on the left, in the region of 830 nm on the right) on the laser power.

Conclusion

- The dominant UCL mechanism at powers of 0.15-0.22 W is the linear decay (LD) of the activator intermediate level 1 and energy transfer from the sensitizer to the.
- When the pump power increases up to 0.23 W, the rate of non-radiative energy transfers increases, resulting in the process of up-conversion photon emission domination, which occurs due to the photon transition from the state 2 to the ground one.
- At a radiation power of 0.25-0.28 W, the mechanism of luminescence due to the transition of the activator ion from the ground state to the metastable state 1 (ETU1) and the subsequent transition to state 2 (ETU2) is dominating.

Acknowledgments

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