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Synthesis of $NaLuF_4:Er^{3+}$, Yb^{3+}, Ce^{3+} nanoparticles and study of photoluminescent properties in C - band

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Abstract. The novel core@shell nanocrystals β-$NaLuF_4$@$NaLuF_4$ co-doped with rare-earth ions Er^{3+}, Yb^{3+}, Ce^{3+} have been synthesized. The nano-particles indicate the intensive lines of anti-Stokes luminescence in the telecommunication C - band of spectrum when pumped at 970-980 nm. The nanoparticles have been characterized by transmission electron microscopy and spectrofluorimetry. The nanoparticles have a size 40-80 nm and possess the intensive photo-luminescence 73 nm bandwidth centered around 1530 nm. The photo-luminescence kinetics of β-$NaLuF_4$: Er^{3+}/ Yb^{3+}/ Ce^{3+} has been studied in IR range of spectrum. We have demonstrated that doping with cerium ions prevents serial stepwise excitation of erbium ions. Consequently, the lifetime of transition in erbium $^4I_{13/2} \rightarrow {}^4I_{15/2}$ has risen up to 6.9 ms. Intensity of 1530 nm line in Er^{3+} ions excited at 980 nm has been increased up to 6 times. Therefore, the nanoparticles are applicable to fabrication of compact waveguide amplifiers for C - band.

Nano-sized phosphor crystals form a new generation of nanomaterials as they possess the unique optical properties attractive for applications in telecommunications technology, integrated optics and photonics. The unique luminescent properties of nanophosphors are the result of successive absorption of photons by ytterbium ions and resonant non-radiative energy transfer to the erbium ions within the matrix of the hexagonal β-$NaLuF_4$ phase inorganic nanocrystal [1]. Figure 2 shows the energy level diagram of the crystal $NaLuF_4$: Er^{3+}/ Yb^{3+}/ Ce^{3+} explaining the down-conversion mechanism of 980 nm radiation. The pump photon at 980 nm is absorbed by the ion Yb^{3+}, transferring the latter into the excited state $^2F_{5/2}$. As a result of non-radiative resonance energy transfer, level $^4I_{13/2}$ of Er^{3+} is populated with the possibility of subsequent excitation of overlying energy states. Ions Ce^{3+} are capable to resettle resonant energy states from Er^{3+} ions above the state $^4I_{13/2}$. Therefore, the cerium ions act as constraints impeding the up-conversion process in the nanoparticle. Thus, the maximum efficiency of nanoparticle excitation is achieved with the following radiative decay at 1530 nm wavelength [2].

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Hexagonal shape nanocrystals have a size distribution in the range 40 - 80 nm (see the inset in Fig. 1). The photoluminescence of nanoparticles has been studied using spectrofluorimeter Fluorolog 3 (HJY, France) under the excitation by semiconductor laser at 977 nm. The luminescence spectra, measured at room temperature, have an intense line in the NIR (see Fig. 1). The utilization of more effective β-$NaLuF_4$ matrix in comparison to β-$NaYF_4$ makes possible to enhance the quantum yield from 2 to 6%. The introduction of cerium ions into the nanocrystal matrix allows to increase the efficiency of transition $^4I_{13/2} \rightarrow {}^4I_{15/2}$ up to 6 times. The transition lifetime is 6.9 ms (see Fig. 3).

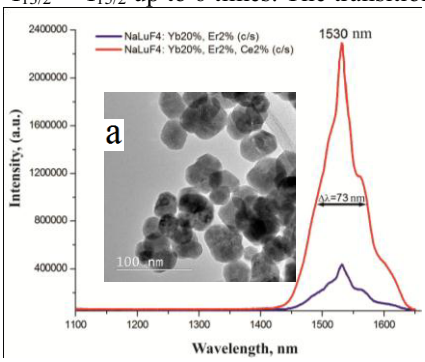

Fig. 1. TEM image (the inset) and the PL spectra of synthesized β-$NaLuF_4$: Er^{3+}, Yb^{3+}, Ce^{3+} and β-$NaLuF_4$: Er^{3+}, Yb^{3+} nanocrystals under excitation at 977 nm.

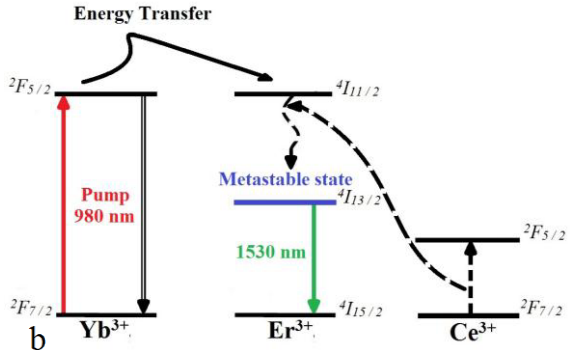

Fig. 2. Schematic energy transfer processes in NaYF4 crystal between Er^{3+}, Yb^{3+} and Ce^{3+}.

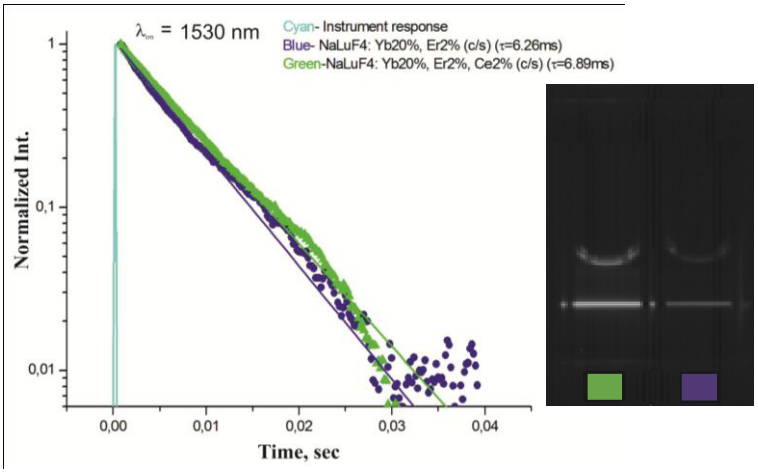

Fig. 3. Kinetics of photoluminescence decay of β-$NaLuF_4$: Er^{3+}, Yb^{3+}, Ce^{3+} and β-$NaLuF_4$: Er^{3+}, Yb^{3+} around 1.5 μm under the excitation at 977 nm. Excitation pulse length duration is 80 μs. The inset demonstrates two cuvettes with nanoparticles dissolved in dichloromethane (CH_2Cl_2) and illuminated by 975 nm laser beam.

Results of the conducted research indicate that the synthesized nanoparticles are a promising platform for fabrication of compact waveguide amplifiers for C - band.

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References

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