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Visible and infrared luminescence properties of Er^{3+}-doped $Sc_2:O_3:LiNbO_3$ crystal fibers

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Abstract

In this work we have made a systematic study of the luminescence properties of $Er:Sc_2O_3:LiNbO_3$ crystal fibers grown by using the LHPG. technique. We present here the main infrared polarized absorption spectra and the polarized emission spectra recorded in the infrared and in the green domains. Fluorescence decay measurements are also reported. The Judd–Ofelt formalism is used to carry out stimulated emission cross-sections and gain spectra.

Keywords: Er; $LiNbO_3$; Eye-safe; Judd–Ofelt

Because of the excellent electrooptic and acoustooptic properties of $LiNbO_3$ and the laser gain presented by the Er^{3+} ion around 1.55 μm in this material, there is presently a renewed interest in the study and the use of $Er^{3+}:LiNbO_3$ for the fabrication of integrated waveguide lasers or amplifiers, waveguide modulators and switches suitable for optical fiber telecommunications [1]. Concurrently, it was shown in the past years that photorefractive damage in $LiNbO_3$ could be prevented by codoping with ZnO, MgO or Sc_2O_3.

So, we present here part of the results of a complete spectroscopic study of Er^{3+}-doped $LiNbO_3$ crystal fibers codoped with Sc_2O_3 and grown by using the (LHPG) technique.

Er^{3+}- and Sc_2O_3-doped $LiNbO_3$ single-crystal fibers with nominal molar concentrations of 1% Er and 1% or 1.5% Sc_2O_3 were grown in air by the LHPG laser heated pedestal growth method. The crystal seed was oriented along the ***a***-axis. After annealing in O_2, the fibers are clear and single domain and have a light-pink color characteristic of Er-doping. We have grown fibers of about 6 cm length and with diameters of about 800 down to 600 μm. The absorption and emission spectra were recorded with standard equipments. The fluorescence rises and decays were measured after various pulsed excitations.

Fig. 1 shows the RT absorption spectra recorded in polarized light for the first three excited states $^4I_{13/2}$, $^4I_{11/2}$ and $^4I_{9/2}$. It appears possible to use current laser diodes to pump Er^{3+} in $LiNbO_3$ at three different frequences and with a comparable absorption cross-section of about 0.5×10^{-20} cm^2.

Using the complete room-temperature absorption spectra (from 440 to 1600 nm), we have calculated the main radiative emission probabilities (A_{ed} and A_{md}), branching ratios β and

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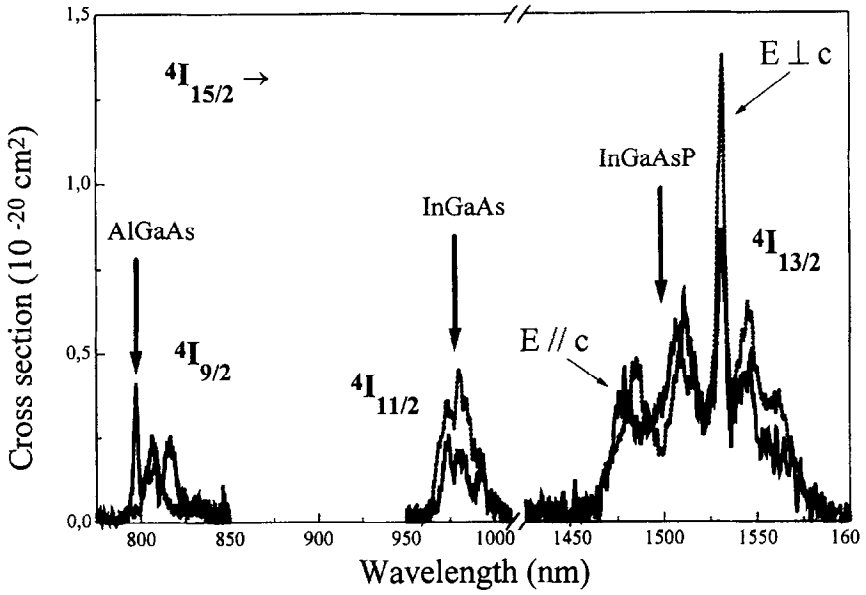

Fig. 1. Infrared RT absorption spectra of a 1%Er:1%Sc_2O_3:$LiNbO_3$ crystal fiber.

Table 1
Radiative emission probabilities (A_{ed} and A_{md}), branching ratios β and radiative lifetimes τ_R for a 1%Er:1%Sc_2O_3:$LiNbO_3$ crystal fiber.

Transitions	λ (nm)	A_{ed} (s^{-1})	A_{md} (s^{-1})	β	τ_R (μs)
$^4I_{13/2} \rightarrow {}^4I_{15/2}$	1544.9	223	127	1	2860
$^4I_{11/2} \rightarrow {}^4I_{15/2}$	991.6	301	0	0.85	2811
$^4I_{13/2}$	2768.5	44	10	0.15	
$^4I_{9/2} \rightarrow {}^4I_{15/2}$	813.3	600	0	0.87	1443
$^4I_{13/2}$	1717.6	85	0	0.12	
$^4I_{11/2}$	4524.9	3	6	0.03	
$^4F_{9/2} \rightarrow {}^4I_{15/2}$	665.2	4668	0	0.92	197
$^4I_{13/2}$	1164.1	254	0	0.05	
$^4I_{11/2}$	2020.6	130	0	0.03	
$^4S_{3/2} \rightarrow {}^4I_{15/2}$	552.1	1907	0	0.66	344
$^4I_{13/2}$	859.1	778	0	0.27	
$^4I_{11/2}$	1245.7	70	0	0.02	
$^4I_{9/2}$	1719.0	149	0	0.05	
$^2H_{11/2} \rightarrow {}^4I_{15/2}$	528.0	23337	0	0.96	41
$^4I_{13/2}$	802.1	420	0	0.02	

radiative lifetimes τ_R by using the Judd–Ofelt (JO) formalism. The calculated JO parameters are: $\Omega_2 = 5.1 \times 10^{-20}$, $\Omega_4 = 2.3 \times 10^{-20}$ and $\Omega_6 = 0.6 \times 10^{-20}$ cm^2. The most important results are shown in Table 1.

The polarized emission spectra were recorded from 500 to 1630 nm after excitation at 488 nm (Ar^+ CW laser). The stimulated emission cross sections were carried out for the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ green transition ($\approx$ 550 nm) and for the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ infrared transition in the eye-safe domain ($\approx$ 1550 nm). Fig. 2 shows the results for the first transition. The maximum is at 551 nm in σ-polarization with $\sigma_{em} \approx 0.54 \times 10^{-20}$ cm^2. The lines are broad which could lead to wavelength tunability. Fig. 3 shows, for the σ polarized infrared emission, the gain spectra obtained with the expression

$$G(\lambda) = \beta\, \sigma_e(\lambda) - (1 - \beta)\, \sigma_a(\lambda),$$

where β is the inverted population rate and σ_e and σ_a the stimulated emission and absorption cross-sections, respectively. According to these spectra, lasing should be obtained first at 1560 nm for a population inversion of about 50%, and, when increasing the pumping power, the laser emission should shift to shorter wavelengths, around 1550 nm and then 1530 nm. At the maximum (1532 nm), in σ-polarization, the stimulated emission cross-section is 1.4×10^{-20} cm^2 which is larger than, for example, in Kigre glass QE-7 (0.8×10^{-20} cm^2) [2] or in Er:YAG (0.5×10^{-20} cm^2) [3].

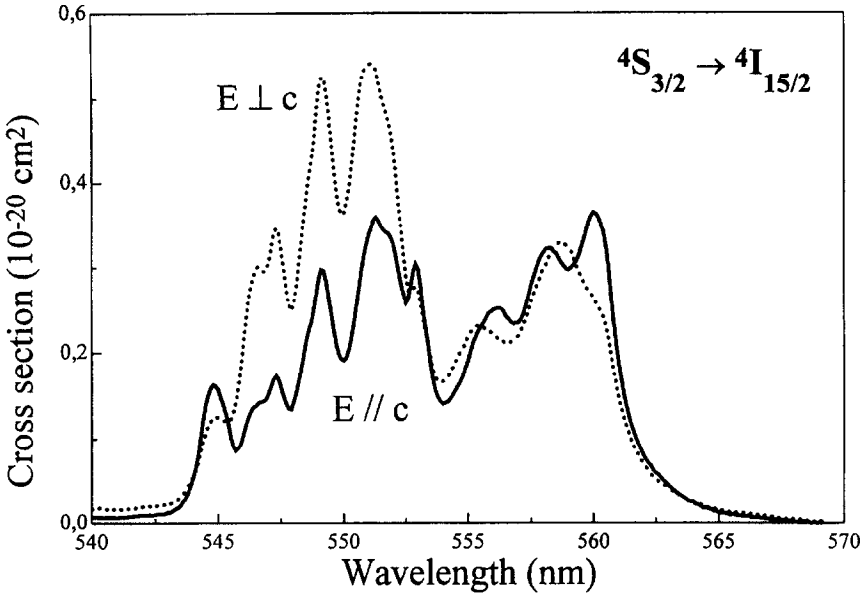

Fig. 2. RT polarized emission spectra ($^4S_{3/2} \rightarrow {}^4I_{15/2}$) of a 1%Er:1% Sc_2O_3:$LiNbO_3$ crystal fiber after excitation at 488 nm.

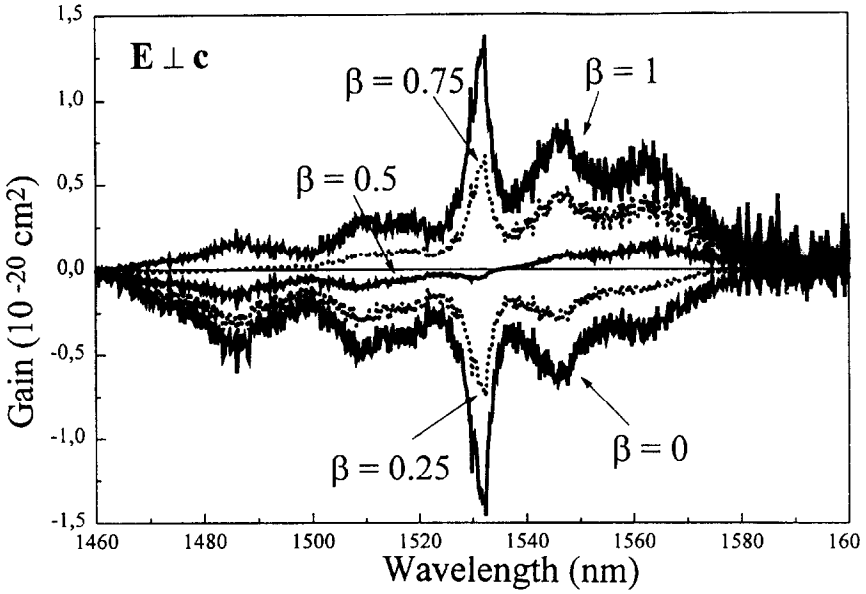

Fig. 3. σ-polarized infrared gain spectra ($^4I_{13/2} \leftrightarrow {}^4I_{15/2}$) of a 1%Er:1%$Sc_2O_3$:$LiNbO_3$ crystal fiber.

The fluorescence decays were measured after direct and indirect excitations. The $^4I_{13/2}$ fluorescence lifetime is the same as the calculated radiative lifetime ($\tau_R \approx 2.9$ ms), which means a fluorescence quantum efficiency is close to unity. The $^4I_{11/2}$ fluorescence lifetime is rather long (215 μs) for diode pumping at 800 or 980 nm, but Ce^{3+}-codoping could be used to reduce this value [4]. The lifetime

of $^4S_{3/2}$ is shorter ($\tau_R \approx 25$ μs) than in Er : $YLiF_4$ but it is larger than in Er : TAG, two systems which already lased in the green domain. Growing thinner fibers (with less than 100 μm diameter) and using energy confinement could be interesting to measure the laser efficiencies, especially in this green domain.

References

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