Comparative optical properties and CW laser performance around 1.56 μm of the (Yb^{3+} , Er^{3+}) codoped Y_2SiO_5 and $\text{SrY}_4(\text{SiO}_4)_3\text{O}$ crystals

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I) INTRODUCTION

The research of new laser crystals emitting in the eye safe spectral region around 1.54 μm and presenting better thermomechanical properties and comparable laser efficiencies than the commercially available Yb, Er doped phosphate glasses, have been recently developed. The yttrium orthosilicate Y_2SiO_5 (hereafter noted YSO) has already been reported as a good candidate [1][2]. A further study of various silicate crystals led us to develop an other interesting host: $\text{SrY}_4(\text{SiO}_4)_3\text{O}$ (hereafter noted SYS).

This paper reports the main spectroscopic characterizations and laser experiments carried out on these materials.

II) OPTICAL PROPERTIES OF Yb,Er: YSO AND Yb,Er: SYS.

Crystals doped with various concentrations of Erbium and Ytterbium have been grown by the Czochralski method with good optical quality. YSO is a monoclinic biaxial system [1], while SYS is an hexagonal uniaxial system [3].

Absorption and emission spectra have been recorded at low (10K) and room temperatures for the different polarizations. The resulting absorption and emission cross sections spectra obtained at room temperature around 1.55 μm are shown in Figures 1 and 2. The stimulated emission cross sections have been calculated using the method of reciprocity [4].

It is worth to be noted that these values obtained for YSO and SYS near 1.55 μm are very comparable to the Yb,Er phosphate glasses ($\sigma_e = 8.10^{-21} \text{ cm}^2$ at 1.53 μm).

Figure 1

Figure 2

The 1.55 μm laser emission lies from the $^4\text{I}_{13/2} \rightarrow ^4\text{I}_{15/2}$ transition of Er^{3+} ions, where $^4\text{I}_{15/2}$ is the ground state level. The Erbium doped crystals act thus as a 3 level system in which the emission is significantly reabsorbed. So the Erbium doping level must be low in order to reduce losses. Codoping the crystals with an other ion as Ytterbium is required, in order to increase the pump efficiency. The pumping source (laser or diode) excites the $^2\text{F}_{5/2}$ level of Yb^{3+} ions near 950nm, which transfer to the $^4\text{I}_{11/2}$ level of Er^{3+} ions (Fig.3). The Erbium $^4\text{I}_{13/2}$ level is then populated through a non radiative process from the $^4\text{I}_{11/2}$ level, and produces a radiative emission near 1.55 μm .

This emission is always combined with a green emission due to the $^4\text{S}_{3/2} - ^2\text{H}_{11/2} \rightarrow ^4\text{I}_{15/2}$ transition.

This parasitic phenomena is due to both ESA from the $^4\text{I}_{11/2}$ level and up conversion energy transfer from the $\text{Yb}^{3+} + ^2\text{F}_{5/2} \rightarrow ^2\text{F}_{7/2}$ transition and is favoured when the $^4\text{I}_{11/2}$ has a long fluorescence lifetime. Decay measurements have been performed at room temperature for the $^4\text{I}_{11/2}$ and $^4\text{I}_{13/2}$ levels for Yb,Er:SYS and Yb,Er:YSO and compared with the radiative lifetime calculated using the Judd-Ofelt theory [5].

Figure 3: Yb $\rightarrow$ Er energy transfer process

Material	$\tau_f(^4\text{I}_{11/2})$ μs	$\tau_R(^4\text{I}_{11/2})$ μs	$\tau_f(^4\text{I}_{13/2})$ μs	$\tau_R(^4\text{I}_{13/2})$ μs
Phosphate Glass QE-7S	<1	-	8500	8800
SYS	13	4430	6000	5030
YSO	16	5700	6000	5800

Table I: Calculated radiative and measured fluorescence lifetimes at room temperature

The results, reported in table I show that the non radiative relaxation process from $\text{Er}^{3+} ^4\text{I}_{11/2}$ to $\text{Er}^{3+} ^4\text{I}_{13/2}$ is very important ($\tau_f \ll \tau_R$), which makes efficient the pumping way for Yb-Er: SYS and Yb,Er: YSO. However, the up conversion and/or ESA probabilities leading to green fluorescence may be greater in YSO than in SYS and than in phosphate glass and thus reduce the laser efficiency of these crystals.

III) LASER EXPERIMENTS

Laser tests have been carried out on Yb,Er doped SYS,YSO and phosphate glass (KIGRE QE-7S) rods of 6 mm in diameter and 25 mm in length. The rods end faces were polished flat and parallel, but not AR coated.

Two types of sources have been used: a Spectra Physics CW-Ti:Al₂O₃ laser and a Spectra Physics diode laser.

•Ti:Al₂O₃ as a pumping source

The laser cavity consisted of a flat input dichroic mirror, which is highly transmissive at the pump wavelength and highly reflective at the laser wavelength, and output couplers with a 7.5 mm radius of curvature and various reflectivities (from 0.1 % for YSO to 1% and 3% for glass and SYS) at the laser wavelength. The crystals were placed closed to the flat input mirror and the Ti: Sapphire laser beam was focused with a 5cm or 6.5cm focal length lens. The SYS and YSO rods were rotated to find the maximum absorption around 980nm. The Ti:Sapphire laser was then tuned to respectively 970, 971 and 979 nm for Kigre QE-7S, YSO and SYS samples.

A laser emission occurred at 1.576 μ m in Yb,Er:YSO, obtained only with a 99.9% reflection output mirror, and details have been already reported [2]. An other new IR laser emission has been obtained for the first time with the Yb,Er:SYS crystal at 1.554 μ m. The laser threshold was reached for an incident power of about 90mW at 979nm with an 99% reflection output coupler in the α polarization, and the slope efficiency was 0.8%. As a comparison, the slope efficiency of a Yb,Er phosphate glass tested in the same conditions was around 8%, i.e. 10 times more. All the results are gathered in table II.

•Diode pumped experiments

The SDL diode laser used for this experiment delivered up to 1W of output power at wavelengths from 966 to 980 nm with a 3nm spectral bandwidth. The configuration of the cavity was nearly identical to the one's described before.

If Yb,Er: YSO has not shown a laser emission, when it is excited with a diode, Yb,Er:SYS rods exhibit a stimulated emission at 1.554 μ m. Laser threshold was reached for an absorbed pump power of nearly 274mW, and for a maximum absorbed pump power of 670mW, an output power of 1.6 mW was obtained. The slope efficiency was about 0.4% with a 99% reflection output coupler. In the same conditions, we also obtained CW laser action of the Yb,Er phosphate glass (Kigre QE-7) with an absorbed input power of around 36mW and a slope efficiency of about 12% (table II).

pumping source	Material	Length (mm)	dopant cm ⁻³	T _s	λ_D (nm)	α_D (cm ⁻¹)	P _{th.} abs (mW)	Slope effi. %	P _{max} (mW)
Ti:Al ₂ O ₃	YSO Yb 7% Er 0.1%	2.5	1.3 x 10 ²¹ 1.87 x 10 ¹⁹	<1%	971	13.7	200	-	-
Ti:Al ₂ O ₃	SYS Yb 8.5% Er 0.09%	2.5	1.3 x 10 ²¹ 1.4 x 10 ¹⁹	1%	979	19	72	0.8	2.5
				3%	978	19	261	-	1
Ti:Al ₂ O ₃	Glass QE-7 Yb Er	2.5	1.1 x 10 ²¹ 1.1 x 10 ¹⁹ [6] [7]	1%	970	~17	70*	8*	33
				3%	970	17	151	15	55
diode	SYS Yb 8.5% Er 0.09%	2.5	1.3 x 10 ²¹ 1.4 x 10 ¹⁹	1%	980	19	274	0.4	1.6
diode	Glass QE-7SYb Er	2	1.3 x 10 ²¹ 1.3 x 10 ²¹	1%	970	~17	36	12	55

* in fact threshold and slope efficiency given in incident power

Table II

IV) CONCLUSION

Room temperature CW laser emission of Yb,Er: Y₂SiO₅ and Yb,Er: SrY₄(SiO₄)₃O have been demonstrated for the first time at respectively 1.576 μ m and 1.554 μ m. These preliminary laser performance seem still rather disappointed and substantial improvement can be expected. However, the observed green fluorescence coming from the 4S_{3/2} energy level of the Er³⁺ ions, which results mainly from the Yb³⁺→Er³⁺ up conversion energy transfer and excited state absorption from the Erbium 4I_{11/2} energy level, could be responsible of the poor efficiency of Yb,Er: YSO and Yb,Er: SYS.

In this case, the only way to significantly improve the YSO and SYS efficiencies could be to look for an other sensitizer ion than ytterbium, which would not lead to up conversion energy transfer, or even use single doped Erbium crystals. The pumping wavelength could be 800nm or even better near 1540 nm. Further experiments are developed in this way.

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