Spectroscopic and laser properties of Tm$^{3+}$ ions in fluoride crystals and ceramics.

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Abstract— Fluoride crystals and ceramics doped with Tm$^{3+}$ ions were developed and spectroscopic and laser properties in 2 μm spectral region were investigated. Slope efficiency about 20% was demonstrated in 2 μm spectral region under 790 nm laser diode pumping.

Keywords—fluoride crystals, fluoride ceramics, thulium, mid IR lasers.

I. INTRODUCTION

Thulium doped materials are of great interest for development of efficient 2 mm diode pumped lasers due to effective cross relaxation mechanism taking place under convenient 790 nm pumping into $^3H_4$ electronic level. Such cross relaxation results in doubling of excitation at $^3F_4$ level with following lasing to ground state at ~1.9 μm. This allows to obtain efficient oscillations despite large difference in pump and laser photon energy (quantum defect). The efficiency of cross relaxation is known to depend strongly on distance between the interacting ions. From this point of view fluorides have an advantage due to tendency to formation of clustered optical centers especially for relatively high doping concentrations.

II. SPECTROSCOPIC PROPERTIES OF Tm$^{3+}$ IONS IN DIFFERENT MATRIXES.

The CaF$_2$(59%)-SrF$_2$(38%):Tm$^{3+}$(3%), CaF$_2$:Tm$^{3+}$ (2%) and BaF$_2$(66%)-SrF$_2$(31%):Tm$^{3+}$(3%) fluoride crystals were synthesized and two last samples were also hot formed to obtain ceramics of similar composition. The spectroscopic properties of Tm$^{3+}$ were investigated and found that for used sufficiently high thulium concentrations these properties are mostly determined by the clustered Tm$^{3+}$ optical centers. The maximums of absorption and fluorescence spectra for thulium ions were measured to have shift to longer wavelengths in Ca-Sr-Ba row as shown in Fig.1. The measured lifetimes of Tm$^{3+}$ ions at 2 μm $^3F_4$-$^3H_4$ transition in investigated fluorides were rather long about 22 ms for CaF$_2$, 16 ms for Ba-Sr and 8 ms for Ca-Sr samples. Thulium concentration increase from 2% to 4% in CaF$_2$ sample did not result in strong shortening of fluorescence lifetime.

III. LASER PROPERTIES OF Tm$^{3+}$ IONS IN DIFFERENT MATRIXES.

Laser properties were studied under 790 nm pumping with commercial laser diode which fitted rather well second absorption maximum of Tm$^{3+}$ ions in the studied crystals and ceramics. The best result of 23% slope efficiency with respect to absorbed power was obtained for CaF$_2$:Tm$^{3+}$ ceramics. BaF$_2$-SrF$_2$ single crystal and ceramics have demonstrated slightly lower efficiency of 17% and 16.5% respectively. The estimated optical losses calculated from laser oscillations threshold in single crystals and ceramics were very similar and did not exceed the value of 0.05. Using the Lyot filter the tuning of oscillation wavelength within 1880-2000 nm range was obtained the broadest being for Ba-Sr solid solution as presented in Fig.2.

Thus thulium doped fluoride materials based on simple fluorides and their solid solutions seem to be perspective materials for development of efficient broadly tunable 2 μm lasers.

Fig.1 Fluorescence spectra of Tm$^{3+}$ ions in different fluorides.

Fig.2 Tuning curves of Tm$^{3+}$ ions in different fluorides.