

$\Delta n/\Delta T$  reveals that a small change in lattice temperature (3.75 K) can produce substantial index change ( $1.7959 \times 10^{-4}$ ) and hence considerable wavefront curvature. This suggests that filamentation in OPSLs may prove to be more problematic than in diode structures, whether gain or index guided.<sup>3</sup>

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**Optical Materials, Fabrication and Characterization**

**CWF34**

**Investigation of the Tm → Ho energy transfer and upconversion losses in diode-pumped LiYF<sub>4</sub>**

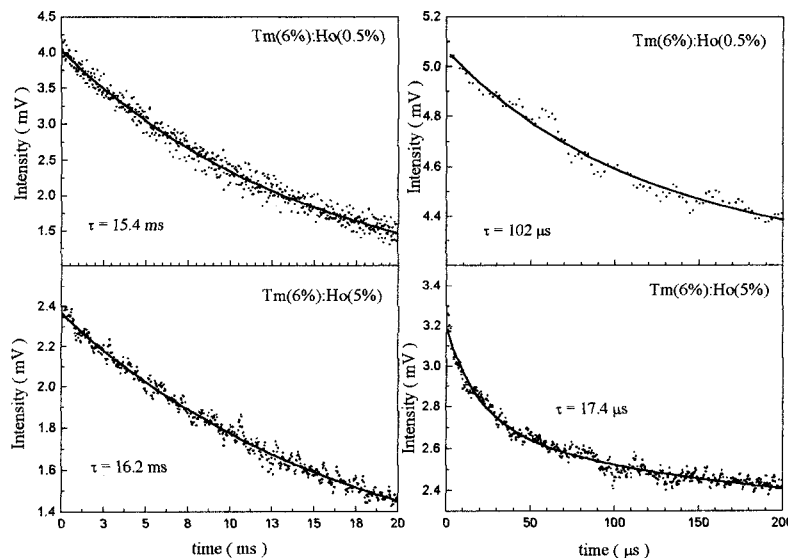
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The Tm:Ho:LiYF<sub>4</sub> is a well-known diode-pumped solid-state laser for cw operation at 2.1 μm.<sup>1,2</sup> The <sup>3</sup>H<sub>4</sub> state of Tm<sup>3+</sup> is directly diode pumped at 792 nm. The population of the <sup>3</sup>F<sub>4</sub> (Tm) donor state can be easily doubled via a cross-relaxation process (<sup>3</sup>H<sub>4</sub>, <sup>3</sup>H<sub>6</sub>) → (<sup>3</sup>F<sub>4</sub>, <sup>3</sup>F<sub>4</sub>) when using Tm concentrations larger than 1%. The energy transfer process occurs from <sup>3</sup>F<sub>4</sub> state to the <sup>5</sup>I<sub>7</sub> upper laser level of Ho.<sup>3</sup> Two types of upconversion processes in the blue, green, and red range of the spectra were observed in this system. These are losses for the 2.1 μm Ho laser operation.

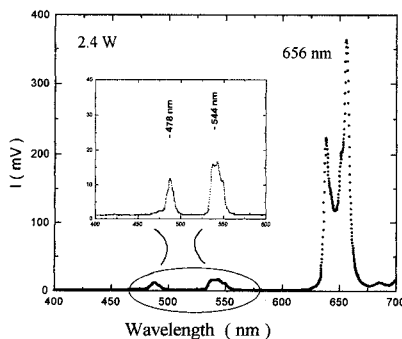
The studied samples were LiYF<sub>4</sub> (YLF) single crystals doped with Tm (x = 1, 3, 5, 10, 20 mol%). Co-doped crystals with Tm(6%) and Ho (y = 0.4, 2, 5 mol%) were also used. The crystals were grown in the Crystal Growth Laboratory of IPEN by Czochralski technique.

The efficiency of the cross-relaxation process and energy transfer step were investigated with use of the excited state dynamics of the <sup>3</sup>H<sub>4</sub> and <sup>3</sup>F<sub>4</sub> Tm states. Figure 1 shows the fluorescence decay time at 1700 nm from the <sup>3</sup>F<sub>4</sub> state for two systems: Tm(6%):Ho(0.4%) and Tm(6%):Ho(5%). The fluorescence transient always shows two time constants; the fastest constant (μs) is related to the energy transfer to Ho ions. The long fluorescence decay (ms) is due to the isolated Tm ions. The same behavior is observed to the <sup>3</sup>H<sub>4</sub> fluorescence decay. From this measurement it was evaluated the cross-relaxation transfer rate for the several Tm concentrations. Also the energy transfer rates to the <sup>5</sup>I<sub>7</sub> upper laser state were evaluated for the co-doped samples.

The system can be also studied with use of a quantitative emission spectroscopy technique



**CWF34 Fig. 1** Fluorescence decay of <sup>3</sup>F<sub>4</sub> (Tm) state under pulsed (10 ns) laser excitation at 463 nm for two systems: Tm(6%):Ho(0.5%) and Tm(6%):Ho(5%) in YLF crystals at 300 K.



**CWF34 Fig. 2** Upconverted spectral emission from Tm(6%):Ho(1%):YLF diode pumped at 796 nm with 2.4 W at 300 K.

that uses calibrated photodetectors. From this measurement it was evaluated the emitted power of each luminescent channel in the range from visible to infrared. The upconversion losses were evaluated from the ratio between the integrated power of upconverted emissions and the absorbed excitation power at 796 nm. Figure 2 shows the upconverted emissions from the Tm (blue and red) and Ho (green) states resulting from excited state absorptions in Tm(6%):Ho(1%) crystal.

The total efficiency of Ho ions excitation could be evaluated with use of the measured ratio between the direct measurement of the 2.1-μm emission and the absorbed pump power.

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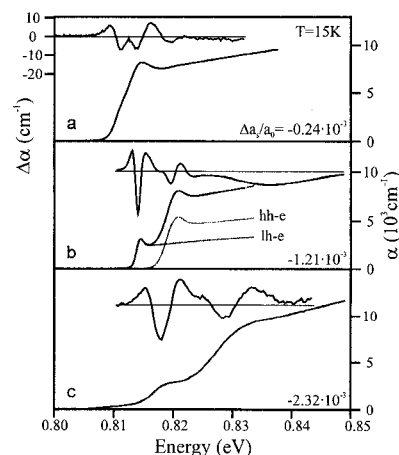
**CWF35**

**Strain and spontaneous ordering of bulk In<sub>1-x</sub>Ga<sub>x</sub>As<sub>y</sub>P<sub>1-y</sub> on (001) n-InP wafers**

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The gap of InGaAsP can be varied over a wide range in the near IR. Spontaneous CuPt ordering has been found to reduce the gap and to split the valence band. In quaternary alloys, however, ordering is rarely observed.<sup>1</sup> High-resolution electroabsorption (EA) spectroscopy that resolves residual strain point to some ordering in InGaAsP alloys, which is supported by transmission electron micrographs.

Strain resulting from small deviations Δx and Δy from the strain-free composition of InGaAsP/InP heterostructures causes splitting of the valence band. The splitting can be resolved in excitonic absorption and electroabsorption spectra at low field and low tempera-



**CWF35 Fig. 1** Absorption and low field electroabsorption spectra of bulk InGaAs/InP at the center of the wafer (a), near its edge (c), and at an intermediate position (b).

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