Yb^{3+} and Tm^{3+} doped $KGd_xLu_yY_{1-x-y}(WO_4)_2$ Channel Waveguide Lasers

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Abstract: Channel waveguides with high refractive-index contrast are fabricated in double tungstates. Yb^{3+} lasers with 71% slope efficiency and 418 mW output power are demonstrated. Tm^{3+} lasers at 1843 nm have also been demonstrated.

OCIS codes: (140.3615) Lasers, Ytterbium; (230.7380) Waveguides, channeled

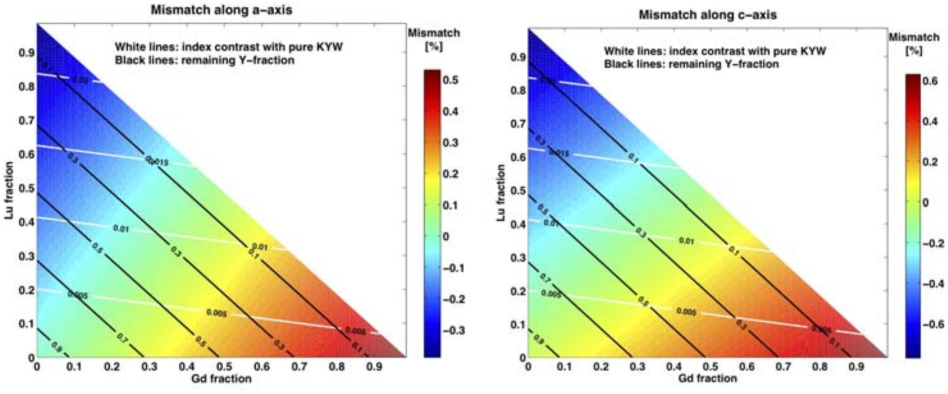
1. Introduction

In the coming years, many applications in photonics will take advantage of miniaturization by on-chip integration of optical components. In most applications, high-performance integrated lasers are required that provide high output power and efficiency, excellent beam quality, broad wavelength selectivity and tunability, ultrashort pulses, ultra-narrow bandwidth, or ultra-low heat generation, potentially by applying a low-cost, straight-forward fabrication process.

The potassium double tungstates $KGd(WO_4)_2$, $KY(WO_4)_2$, and $KLu(WO_4)_2$ are excellent candidates for solid-state lasers [1] because of their high refractive index of ~2.0-2.1 and the large transition cross-sections of rare-earth (RE) ions doped into these hosts. These advantages have been exploited to demonstrate planar [2, 3, 4] and channel [5, 6] waveguide lasers. Co-doping of grown $KY(WO_4)_2$:RE thin films with Gd and Lu ions for lattice matching and enhanced refractive index contrast of up to 7.5×10^{-3} with respect to the undoped $KY(WO_4)_2$ substrate [7] has enabled waveguide lasers with tight pump and laser mode confinement of ~10 μm^2, resulting in excellent slope efficiencies in Yb-doped planar and microstructured channel waveguide lasers of 82.3% [8] and 62% [9], respectively. In this work we demonstrate channel waveguide lasers activated with Yb^{3+} or Tm^{3+} ions.

2. Waveguide Fabrication

The composition of the active layer was chosen to provide the maximum refractive index contrast and simultaneously minimal lattice mismatch with the $KY(WO_4)_2$ substrate. The lattice parameters of the monoclinic layer in the three crystallographic axes were calculated as weighted averages of the lattice parameters of the stoichiometric compositions $KGd(WO_4)_2$, $KLu(WO_4)_2$, and $KYb(WO_4)_2$ and were matched to the parameters of the $KY(WO_4)_2$ substrate, see Fig. 1. In the extreme case, no Y^{3+} was incorporated in the active layer in order to achieve a maximal refractive index contrast of 1.5% between layer and substrate [10]. A $KGd_{0.49}Lu_{0.485}Yb_{0.025}(WO_4)_2$ layer was grown by liquid phase epitaxy onto a (010)-orientated $KY(WO_4)_2$ substrate. Subsequently, the layer was microstructured by Ar^+ beam milling [9] to obtain ridge waveguides along the N_g optical axis. The structure was overgrown by an epitaxial layer of $KY(WO_4)_2$, resulting in buried channel waveguides.



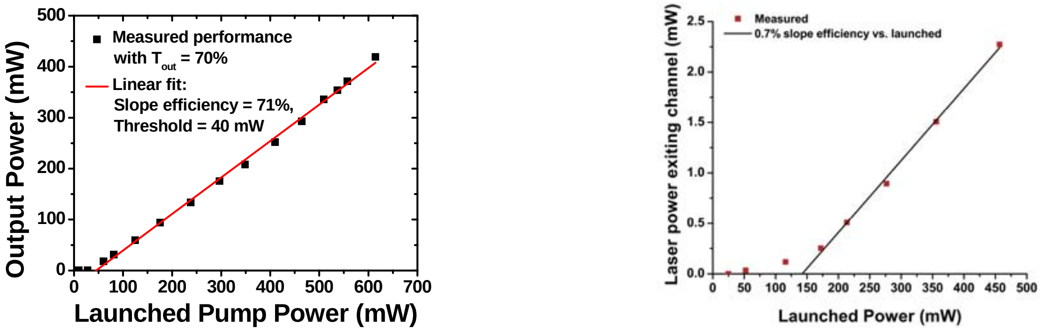
(a) (b)

Fig. 1. Lattice mismatch (color) of $KGd_xLu_yY_{1-x-y}(WO_4)_2$ waveguides with decreasing Y concentration (black lines) on b-oriented $KY(WO_4)_2$ substrates for the lattice the *a*-axis (a) and *c*-axis (b) and resulting refractive-index increase (white lines).

3. Laser Performance

In the case of Yb^{3+}, pump light at 981 nm from a Ti:sapphire laser was end-coupled into the waveguide. The light outcoupled at the other end of the waveguide was collimated and directed to a powermeter or a spectrometer. At the input side a dielectric mirror with a high transmission of 96% for the pump light and a high reflectivity of 99.8% for the laser light was directly butt-coupled to the endfacet. An outcoupling mirror with T_{out} = 70% at 1023 nm was attached to the other side. We obtained a maximum laser output power of 418 mW at 1023 nm, limited only by the available pump power, with a slope efficiency of 71% versus launched pump power; see Fig. 2a. The threshold was 40 mW.

In the case of Tm^{3+}, lower refractive-index contrast and small Tm^{3+} doping of 1at.% was chosen for the first laser tests. pump light at 800 nm from a Ti:sapphire laser was end-coupled into the waveguide. Currently, more than 2 mW of output power at 1843 nm has been achieved. Improvements of pump and laser mode confinement by reducing the Y^{3+} content of the layer as well as higher Tm^{3+} concentration in order to exploit the cross-relaxation typically observed in Tm^{3+} compounds for improving the quantum efficiency of the laser will lead to significantly higher output powers also in this case, and related work is in progress.



(a)

(b)

Fig. 2. Input-output curves of KGd$_x$Lu$_y$Y$_{1-x-y}$(WO$_4$)$_2$ channel waveguide lasers (a) doped with Yb^{3+} at 1023 nm and (b) doped with Tm^{3+} at 1843 nm.

4. Conclusion

The remarkable performance of such rare-earth-ion-doped, microstructured channel waveguide lasers makes them excellent candidates for high-repetition-rate ultrashort-pulse generation on a chip, diode-array side-pumped channel waveguide lasers, and ultra-narrow-linewidth distributed feedback waveguide lasers.

5. References

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