Highly efficient Gd, Lu co-doped KY(WO4)2:Yb3+ planar waveguide laser

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Summary

Laser operation at 1025 nm with 82.3% slope efficiency and 195 mW output power for 23% outcoupling is reported for $KY(WO_4)_2:Yb^{3+}$ planar waveguides, co-doped with optically inert Gd^{3+} and Lu^{3+} ions. Codoping enhances the refractive index contrast, improves light confinement, and reduces the threshold to 18 mW (1.7% outcoupling).

Introduction

The monoclinic double tungstates $KY(WO_4)_2$, $KGd(WO_4)_2$, and $KLu(WO_4)_2$ are excellent laser host materials and have received a great deal of attention for waveguide lasers over the last years [1]. The $KY(WO_4)_2:Yb^{3+}$ system, hereafter abbreviated as $KYW:Yb^{3+}$, shows a number of useful properties such as large absorption and emission cross sections, broad linewidths, and a small quantum defect compared to other Yb-doped gain media. Layers of $KYW:Yb^{3+}$ with a thickness in excess of 10 µm were grown by liquid phase epitaxy (LPE) on undoped KYW substrates, and planar waveguide lasers were demonstrated with high slope efficiency values of ~80% using an astigmatically compensated Z-shaped cavity configuration [2] and more recently of ~62% by diode pumping using a monolithic cavity [3]. Due to the rather low Yb^{3+} ion concentration in these layers, typically 1-3 at.%, the refractive index contrast between layer and undoped substrate was only a few times ×10-4. This low refractive index contrast inhibits downscaling of the waveguide thickness to a few µm and also significantly challenges micro-structuring and further integrated optical applications, since the mode is only weakly confined to the active region and tends to leak into the substrate.

Here we report on efficient laser emission from an enhanced refractive-indexcontrast waveguide fabricated by co-doping the active layer with high concentrations of Lu^{3+} and Gd^{3+} ions. Both, Lu^{3+} and Gd^{3+} possess higher electron densities than Y^{3+}, thus increasing the refractive index of such a co-doped layer significantly by an order of magnitude to $\sim 7.5\times10^{-3}$ [4], resulting in much tighter pump confinement in these co-doped layers, thereby decreasing the laser threshold significantly.

Experimental

Lattice-matched Lu, Gd codoped KYW:Yb layers with a thickness of 4.6 µm were deposited by LPE and subsequently overgrown by an undoped KYW layer, as shown in Fig. 1. The waveguide endfaces were polished parallel to the N_m optical axis, such that by attaching dielectric mirrors to the endfaces a monolithic cavity along the N_g optical axis was formed. Pump light from a continuous-wave Ti:sapphire laser operating at 981 nm was launched with polarization parallel to the N_m optical axis by two cylindrical lenses

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to adapt the pump mode to the laser mode, resulting in a pump waist of ~30 μm in the horizontal direction.

The laser resonator was formed by attaching a high-reflectivity (HR) mirror to the input face of the waveguide and successively using a set of mirrors with varying transparency values of 1.7%, 5%, 10%, 20%, and 23% as output couplers. The laser output characteristics as a function of absorbed pump power is shown in Fig. 1. The highest slope efficiency of 82.3%, which represents the highest value yet reported for a planar waveguide laser to date, and the maximum extracted laser power of 195 mW for an absorbed pump power of 280 mW were obtained using the 23% outcoupling mirror. We note that further power scaling was not attempted in order to avoid potential damage of the in-coupling endface by the high pump intensity. For the range of output couplers used the laser threshold values obtained were below 32 mW of absorbed pump power, with the lowest being just 18 mW for the 1.7% outcoupling. These low threshold values represent a significant improvement compared to previous experiments [2,3] and are a merit of the high optical confinement achieved by the enhanced refractive index contrast. Optimal laser performance was observed at 1025 nm, although the emission wavelength could be varied from 1000 nm to 1042 nm by slightly changing the alignment, which was probably caused by the etalon effects of the gaps between the mirrors and the waveguide endfaces.

Fig 1. Microscope picture of the polished endface of the buried waveguide; white light was coupled in the waveguide for visualization.

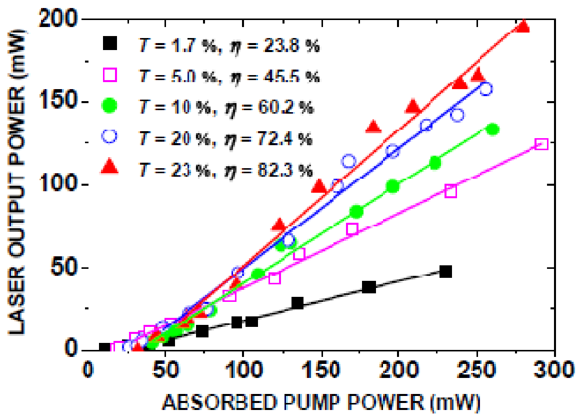

Fig 2. Laser output power as a function of absorbed pump power for various outcoupling mirror transparencies.

Conclusion

Operation of KYW:Lu^{3+},Gd^{3+},Yb^{3+} planar waveguide lasers with a laser threshold low as 18 mW, a slope efficiency of up to 82.3%, and a maximum output power of 195 mW has been demonstrated. In addition to reducing the required threshold pump power significantly, the enhanced refractive index contrast also offers great prospects for realization of micro-structured channel waveguides and, ultimately, opens up a route toward integrated laser resonators.

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