Low-threshold laser in a high-index-contrast double tungstate waveguide

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The potassium double tungstates $\text{KY}(\text{WO}_4)_2$, $\text{KGd}(\text{WO}_4)_2$, and $\text{KLu}(\text{WO}_4)_2$ are recognized as excellent host materials for rare-earth-ion-doped lasers, see Ref. [1] and Refs. therein. Especially $\text{KY}(\text{WO}_4)_2:\text{Yb}^{3+}$, hereafter abbreviated as $\text{KYW}:\text{Yb}^{3+}$, exhibits large absorption and emission cross-sections, a small quantum defect [2], and laser emission with high slope efficiencies. Liquid phase epitaxy (LPE) has been used to grow thin layers of $\text{KYW}:\text{Yb}^{3+}$ onto pure KYW substrates and planar waveguide lasing with slope efficiencies up to 80% has been demonstrated in samples doped with 1.2-2.4% Yb^{3+} [3]. Recently, similar results have been obtained under diode pumping with a monolithic cavity [4]. The main disadvantage of this approach for fabricating integrated devices is the fact that the choice of rather low Yb^{3+} concentration is governed by the need to optimize the laser properties, resulting in a low refractive-index contrast between layer and substrate of only a few $\times 10^{-4}$. This inhibits downscaling the waveguide thickness to 1-2 μm .

Here we report on laser emission from an enhanced-index-contrast waveguide fabricated by co-doping the active layer with Lu and Gd ions. Both, Lu^{3+} and Gd^{3+} possess higher electron densities than Yb^{3+} , thus increasing the refractive index. Simultaneously, this approach provides the possibility for growing lattice-matched layers, as these two ions change the lattice constants of KYW in opposite directions. The active layer was overgrown by an undoped KYW layer (Fig. 1). The buried $\text{KYW}:\text{Lu}^{3+}, \text{Gd}^{3+}, \text{Yb}^{3+}$ layer exhibits a refractive-index contrast of 7.5×10^{-3} [5], thus allowing for a 1.2- μm -thin layer and resulting in a high confinement of pump and laser modes.

Fig. 1 Microscope image (50X) shows endface of buried waveguide

Fig. 2 Laser performance of device

The experimental results were obtained with a 5-mm-long planar waveguide with nominal concentrations of 25.3% Lu^{3+} , 13% Gd^{3+} , and 1.7% Yb^{3+} . The laser cavity was formed by butt-coupling dielectric mirrors to the waveguide endfaces. The incoupling mirror had a reflectance of 99.8% at the laser wavelength, while for the outcoupling mirror reflectances of 98%, 95% and 90% were tested. Two cylindrical lenses were used to adapt the Ti:Sapphire pump mode to the laser mode, resulting in a pump waist of $\sim 30 \mu\text{m}$ in horizontal direction. The highest slope efficiency of 53% was achieved with 10% outcoupling (Fig. 2). The maximum extracted laser power was 60 mW, limited by our attempt to avoid potential damage of the incoupling end-facet by high pump intensity. The laser threshold of 25 mW versus absorbed pump power for 2% outcoupling is low compared to previous experiments [3, 4] and reveals one of the advantages of the high optical confinement obtained by the enhanced index contrast. The emission wavelength varied from 1010 nm to 1040 nm, strongly depending on the alignment, which was probably caused by the etalon effects of the gaps between the mirrors and the endfaces.

These results on lasing of enhanced-index-contrast KYW planar waveguides form the basis for further on-chip integration by implementation of channel waveguides and on-chip resonators.

References

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