Abstract: Laser operation was achieved in microstructured channel waveguides of KY(WO₄)₂:Gd³⁺, Lu³⁺, Yb³⁺, resulting in a threshold of only 5 mW, a slope efficiency of 62% versus launched pump power, and 76 mW output power.

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

1. Introduction

The monoclinic double tungstate KY(WO₄)₂ (KYW) has been recognized as an excellent laser material, see Ref. [1] and Refs. therein. KYW strongly enhances the absorption and emission cross sections of rare-earth ions. In KYW:Yb³⁺, planar waveguide lasing with 80% slope efficiency was demonstrated [2], however the low Yb³⁺ concentrations of 1-3 at.% induce a refractive index contrast between layer and substrate of only a few ×10⁻⁴, thus requiring a layer thickness in excess of 10 μm for single-mode waveguiding. Improved mode confinement was obtained by co-doping the active layer with large amounts of Gd³⁺ and Lu³⁺ ions, thereby increasing the refractive index contrast to ~7.5×10⁻³ and leading to few-μm-thin waveguide layers [3]. Such highly co-doped layers have recently enabled planar waveguide lasing with a record-high slope efficiency of 82.3% [4]. Furthermore, the much smaller layer thickness greatly facilitates microstructuring [3]. Channel waveguide lasing was previously achieved in bulk double tungstates by femtosecond-laser writing of refractive index changes [5], although the rather large mode size and considerable waveguide propagation losses diminished the laser efficiency. Here we demonstrate a microstructured channel waveguide laser with low loss and excellent mode confinement, resulting in a slope efficiency of 62% [6].

2. Device fabrication and laser experiments

By liquid phase epitaxy in a K₂W₂O₇ solvent [7], a 2.4-μm-thick KYW:(43.3%)Gd³⁺,(15.0%)Lu³⁺,(1.7%)Yb³⁺ layer was grown onto an undoped KYW substrate. 7-μm-wide rib structures (Fig. 1a) were etched parallel to the N directors optical axis by transferring a lithographic mask of photoresist (Fujifilm OiR 908/35) to a depth of 1.4 μm into the active layer by Ar beam milling with an etch rate of 3 nm/min. The rib structures were overgrown by an undoped KYW overlay and endfacets were polished perpendicular to the waveguides. Dielectric mirrors were attached by use of a fluorinated oil. A continuous-wave Ti:Sapphire pump laser at 981 nm was coupled into a channel waveguide by a ×16 microscope objective. The outcoupled laser light with beam radii of 4.8 μm × 2.1 μm (Fig. 1b) was collimated by a ×20 microscope objective. A grating was used to separate the residual transmitted pump light from the laser emission. A schematic of the experimental setup is shown in Fig. 2a.

At the laser wavelength near 1028 nm the incoupling mirror had a reflectivity of 99.8%, while for the outcoupling mirror transparencies of 2%, 5%, 10%, and 23% were tested. Fig. 2b shows the laser output power as a function of launched pump power. Laser oscillation commenced at a launched pump power as low as 4.5 mW. A slope efficiency of 62% was measured for 23% outcoupling efficiency. The maximum output power was 76 mW.

When analyzing the obtained slope efficiencies versus output coupling according to the theory for laser devices exhibiting reabsorption [2] an intracavity roundtrip loss of 11% is derived. This value includes the waveguide propagation losses and losses occurring due to butt-coupling of the mirror substrates to the endfacets. Therefore, the value of 11%, equalling 0.34 dB/cm, is the upper limit for the propagation loss at 1028 nm in the microstructured channel waveguide.
3. Conclusions

We have demonstrated, to the best of our knowledge, the first microstructured double tungstate channel waveguide laser. Excellent control over the lateral waveguide dimensions results in tight confinement of pump and laser mode. Combination with the high absorption and emission cross-sections present in Yb$^{3+}$-doped double tungstates and the tight confinement makes it an attractive high-gain laser device.

In the future, replacing the butt-coupled mirrors with an on-chip integrated cavity by etching Bragg reflectors or a distributed-feedback grating into the channel waveguide [7] or employing a ring-resonator configuration will make the device more robust and environmentally stable, such that real-world applications can seriously be envisaged.

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4. References