Efficient Tm^{3+} lasers in double tungstate channel waveguides

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Abstract
Gd^{3+}(29.5%)-Lu^{3+}(29.0%)-Tm^{3+}(1.5%) co-doped KY(WO$_4$)$_2$ layers were grown onto KY(WO$_4$)$_2$ substrates by liquid-phase epitaxy and microstructured by Ar$^+$-beam milling. Laser experiments with butt-coupled dielectric mirrors demonstrated maximum output powers of 149 mW and slope efficiencies of 31.5% when pumping at 794 nm. The lowest threshold was 7 mW.

1. Introduction

The enormous potential of the monoclinic potassium double tungstates [1] for creating compact lasers has previously been demonstrated in Yb^{3+}-doped KY(WO$_4$)$_2$ (= KYW:Yb^{3+}) [2] and Gd^{3+}, Lu^{3+} co-doped KYW:Yb^{3+} [3] thin films, with planar and channel waveguide lasers achieving slope efficiencies as high as 82.3% [4] and 71% [5], respectively, output powers of several hundreds of milliwatts, and low thresholds. In Tm^{3+}-doped KYW, planar and channel waveguide lasers have been demonstrated with maximum output powers of 32 mW and slope efficiencies of 13% [6,7]. The higher slope efficiencies of Yb^{3+}-based lasers are partially due to the smaller quantum defect between pump and laser wavelength and the absence of detrimental upconversion processes in Yb^{3+}. Here we report, for the first time, an efficient channel waveguide laser in a double tungstate, operating at 2 μm [8].

2. Waveguide fabrication

A co-doped layer of KY$_{0.4}$Gd$_{0.295}$Lu$_{0.29}$Tm$_{0.015}$(WO$_4$)$_2$ with a thickness of several tens of micrometers was grown onto a pure, (010)-orientated, laser-grade polished KYW substrate by liquid-phase epitaxy in a K$_2$W$_2$O$_7$ solvent at 920-923°C. The layer was polished to a thickness of 6.6 μm with laser-grade surface uniformity. A photoresist mask was deposited onto the layer and patterned. Ar$^+$-beam milling [9] at an acceleration voltage of 350 eV, resulting in an etch rate of 3 nm/min., was applied to the sample to produce ridge-type channel waveguides along the N_g optical axis with widths of 7.5–12.5 μm and an etch depth of 1.5 μm. Afterwards the channel waveguides were overgrown with a pure KYW cladding. After overgrowth, the samples were diced and end-face polished to a length of 8.4 mm.

3. Results and discussion

Laser experiments were carried out at pump wavelengths of 794 nm (TM, E∥N$_p$) and 802 nm (TE, E∥N$_m$). Ti:Sapphire pump light was coupled into the channels by use of cylindrical lenses with focal lengths of 40 mm and 10 mm in horizontal and vertical direction, respectively. Dielectric mirrors with reflectivities of 99.99% (HR), 98%, and 92% at 1900–2100 nm and high transmission at 790–810 nm were butt-coupled to the waveguide ends using index-matching fluid. Different mirror combinations of HR & 98%, HR & 92%, and twice 92% reflectivity were tested. The laser output power was outcoupled from the other waveguide end and measured after passing through a RG1000 high-pass filter to block residual unabsorbed pump power. For the configuration with two 8% outcoupling mirrors, the laser output power was also measured at the incoupling side, see Fig. 1. A spectrometer was used to determine the lasing wavelength. Cavity losses at the laser wavelength were determined by measuring the relaxation-oscillation frequency as a function of pump power.

The laser operated at 1930 nm for an outcoupling degree of 2%. Higher outcoupling efficiencies of 8% and 2 × 8% resulted in the laser wavelength shifting to shorter wavelengths of 1906 nm and 1846 nm, respectively. When pumping at 794 nm (TM, E∥N_p), a slope efficiency as high as 31.5% and a maximum output power of 149 mW were measured for two mirrors with an outcoupling efficiency of 8% (Fig. 2a). When pumping at 802 nm (TE, E∥N_m), the output power and slope efficiency decreased to 76 mW and 17.0%, respectively (Fig. 2b). A zoom-in on the threshold region is shown in Fig. 2c. A low threshold of ~7 mW of absorbed pump power was achieved, which will facilitate future diode pumping. The upper limit for the waveguide propagation loss was determined to be 0.11±0.04 dB/cm.
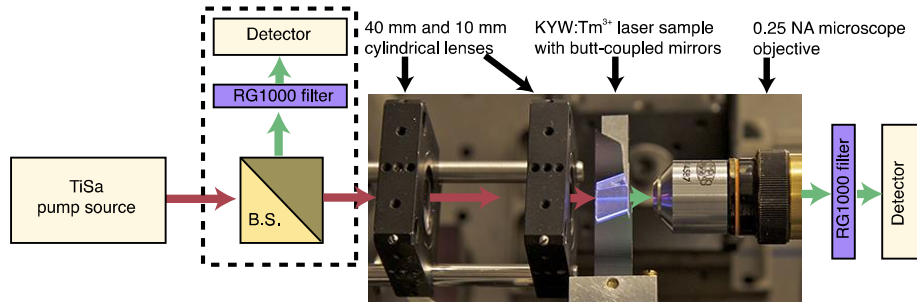

Figure 1. Schematic of the experimental setup. The elements enclosed by the dashed line were only used with the double 8% outcoupling mirror configuration. The blue streak of luminescence visualizes the position of the channel waveguide.
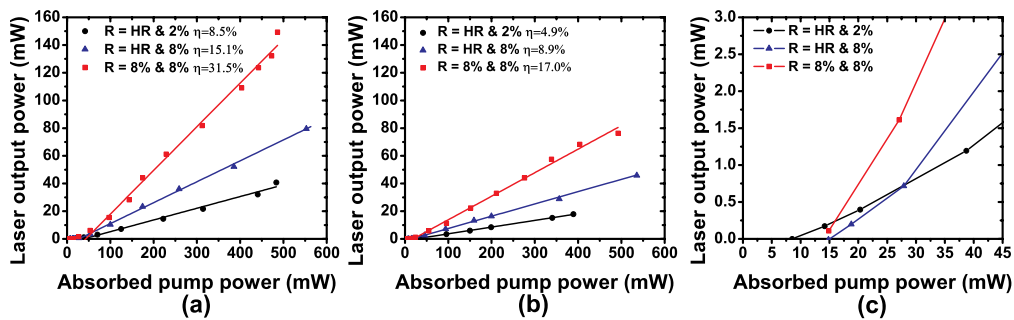

Figure 2. Laser output power versus absorbed pump power for two different pump wavelengths and polarizations: (a) pumped at 794 nm in TM polarization (E∥N_p); (b) pumped at 802 nm in TE polarization (E∥N_m); (c) zoom-in on the threshold region when pumped at 794 nm in TM polarization (E∥N_p).

Acknowledgement

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