Highly Efficient $KY(WO_4)_2:Gd^{3+},Lu^{3+},Yb^{3+}$ Channel Waveguide Laser

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Abstract: A double tungstate waveguide with high refractive index contract between layer and substrate is grown and microstructured by Ar beam milling. Channel waveguide lasing with excellent mode confinement, a threshold of 5 mW and slope efficiency of 62% versus launched pump power, and 75 mW output power is demonstrated.

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The monoclinic double tungstate $KY(WO_4)_2$ (KYW) strongly enhances the absorption and emission cross sections of rare-earth ions. In KYW:Yb^{3+}, planar waveguide lasing with 80% slope efficiency was demonstrated [1], however the low Yb^{3+} concentrations of 1-3 at.% induce a refractive index contrast between layer and substrate of only a few $\times10^{-4}$, thus requiring a layer thickness in excess of 10 µm for waveguiding. Structures with better mode confinement were obtained by co-doping the active layer with large amounts of Gd^{3+} and Lu^{3+} ions, thereby increasing the refractive index contrast to $\sim7.5\times10^{-3}$ and leading to few-µm-thin waveguide layers [2]. Such highly co-doped layers have recently enabled planar waveguide lasing with a record-high slope efficiency of 82.3% [3]. Furthermore, the much smaller layer thickness greatly facilitates microstructuring [2]. Recently, channel waveguide lasing was achieved in bulk double tungstates by femtosecond-laser writing of refractive index changes [4], albeit with a rather large mode size and considerable waveguide propagation losses.

Here we demonstrate a channel waveguide laser with an excellent slope efficiency of 62%. A 2.4-µm-thick KYW:(43.3%)Gd^{3+},(15.0%)Lu^{3+},(1.7%)Yb^{3+} layer was grown onto an undoped KYW substrate by liquid phase epitaxy in a $K_2W_2O_7$ solvent [5]. 7-µm-wide rib structures (Fig. 1a) were etched parallel to the N_g optical axis by transferring a lithographic mask of photoresist 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 a pure KYW overlay and endfacets were polished perpendicular to the waveguides. Dielectric mirrors were attached by a fluorinated oil. 981-nm pump light from a continuous-wave Ti:Sapphire laser 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. 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. Figure 1c 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 75 mW. This excellent performance opens possibilities for an integrated crystalline channel waveguide laser with on-chip Bragg gratings as well as a passively SESAM mode-locked channel waveguide laser.

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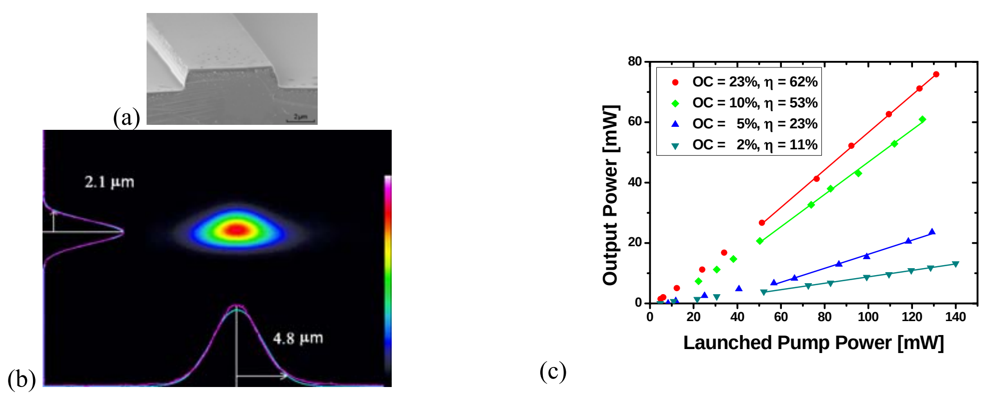

Fig. 1. (a) SEM micrograph of a microstructured KYW:Gd^{3+},Lu^{3+}, Yb^{3+} channel waveguide before overgrowth and (b) measured mode profile of the laser emission (both to scale); (c) measured output power as a function of launched pump power (approx. 99% of the launched pump power was absorbed) for different outcoupling (OC) values.

References

[1] Y. E. Romanyuk, C. N. Borca, M. Pollnau, S. Rivier, V. Petrov, and U. Griebner, "Yb-doped $KY(WO_4)_2$ planar waveguide laser," Opt. Lett. **31**, 53 (2006).

[2] F. Gardillou, Y. E. Romanyuk, C. N. Borca, R. P. Salathé, and M. Pollnau, "Lu, Gd co-doped $KY(WO_4)_2$:Yb epitaxial layers: Towards integrated optics based on $KY(WO_4)_2$," Opt. Lett. **32**, 488 (2007).

[3] D. Geskus, S. Aravazhi, E. Bernhardi, C. Grivas, S. Harkema, K. Hametner, D. Günther, K. Wörhoff, and M. Pollnau, "Low-threshold, highly efficient Gd^{3+}, Lu^{3+} co-doped $KY(WO_4)_2:Yb^{3+}$ planar waveguide lasers," Laser Phys. Lett. **6**, 800 (2009).

[4] F. M. Bain, A. A. Lagatsky, R. R. Thomson, N. D. Psaila, N. V. Kuleshov, A. K. Kar, W. Sibbett, and C. T. A. Brown, "Ultrafast laser inscribed Yb:$KGd(WO_4)_2$ and Yb:$KY(WO_4)_2$ channel waveguide lasers," Opt. Express **17**, 22417 (2009).

[5] R. Solé, V. Nikolov, X. Ruiz, J. Gavaldà, X. Solans, M. Aguiló, and F. Díaz, "Growth of β-$KGd_{1-x}Nd_x(WO_4)_2$ single crystals in $K_2W_2O_7$ solvents," J. Cryst. Growth **169**, 600 (1996).