Towards integrated channel waveguide lasers in monoclinic double tungstates

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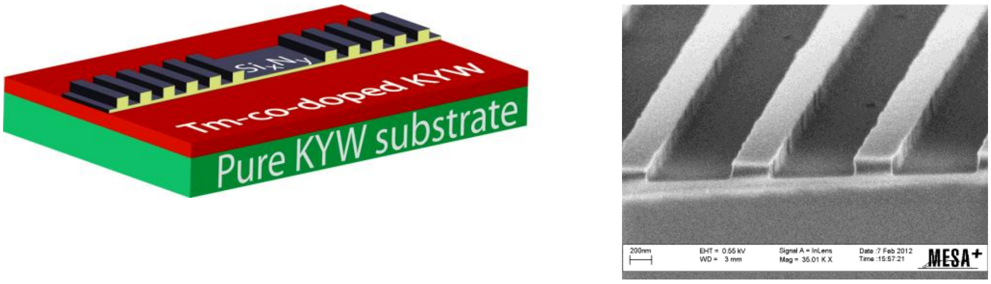
The fabrication of lasers in monoclinic double tungstates has advanced from bulk and planar waveguide lasers toward the recent demonstration of channel waveguide lasers in the 1-μm and 2-μm wavelength regions [1-4]. Not only do these lasers provide a footprint reduction and low thresholds, but also appreciable output powers of several hundreds of milliWatts and slope efficiencies up to 71%. A drawback to these lasers is that the mirrors are not integrated, requiring the rather unstable butt-coupling of mirrors. Further integration of the lasers with on-chip mirrors [5] is naturally the next step towards integrated channel waveguide lasers in this material.

Co-doped layers with different thulium doping levels of 1.5–8at.% and maximum gadolinium and lutetium doping levels, replacing all yttrium to obtain the maximum index contrast with the pure KYW substrate, are grown by liquid-phase epitaxy at 920–923°C. In this way, a refractive-index contrast of up to $\sim 1.9 \times 10^{-2}$ for $E||N_p$ (= transverse-magnetic, TM) polarization at 1950 nm is obtained. The layers are lapped and surface-polished to a laser-grade quality with a planar layer thickness of ~3–4.5 μm. Strip-loaded, corrugated silicon-nitride (Si_xN_y) channel waveguides are patterned as follows: a Si_xN_y layer with a thickness of ~400 nm is deposited onto the thulium-co-doped planar layer by PECVD. A 45-nm-thick chromium mask is subsequently sputtered onto the Si_xN_y layer, followed by the deposition of an electron-beam-compatible resist with a thickness of ~180 nm. A corrugated channel waveguide pattern with a width of 20–30 μm, a periodicity of ~500 nm, and a duty cycle of 50% is written into the e-beam resist using a Raith 150^{TWO} e-beam lithographic system. The channels are aligned such that the light propagates along the N_g optical axis. The pattern is developed and etched into the chromium layer by wet etching. Finally, the pattern is transferred into the Si_xN_y layer by etching 400-nm deep using reactive ion etching. Finally, the chromium mask residue is removed. The resulting grated-waveguide structure is shown in Fig. 1. The characterization of the integrated lasers is ongoing and the results will be reported at the conference.



(a) (b)

Fig. 1. (a) Schematic and (b) SEM picture of a strip-loaded, corrugated, silicon-nitride channel waveguide on a planar thulium-co-doped layer.

In conclusion, Si_xN_y layers have been deposited onto thulium-co-doped double tungstate layers and strip-loaded corrugated channel waveguides have been patterned into them using electron-beam lithography, providing on-chip integrated mirrors in a double tungstate channel waveguide configuration.

References

[1] D. Geskus, S. Aravazhi, K. Wörhoff, and M. Pollnau, "High-power, broadly tunable, and low-quantum-defect $KGd_{1-x}Lu_x(WO_4)_2:Yb^{3+}$ channel waveguide lasers," Opt. Express **18**, 26107 (2010).

[2] W. Bolaños, J. J. Carvajal, X. Mateos, G. S. Murugan, A. Z. Subramanian, J. S. Wilkinson, E. Cantelar, D. Jaque, G. Lifante, M. Aguiló, and F. Díaz, "Mirrorless buried waveguide laser in monoclinic double tungstates fabricated by a novel combination of ion milling and liquid phase epitaxy," Opt. Express **18**, 26937 (2010).

[3] K. van Dalfsen, S. Aravazhi, D. Geskus, K. Wörhoff, and M. Pollnau, "Efficient $KY_{1-x-y}Gd_xLu_y(WO_4)_2:Tm^{3+}$ channel waveguide lasers," Opt. Express **19**, 5277 (2011).

[4] K. van Dalfsen, S. Aravazhi, C. Grivas, S. M. García-Blanco, and M. Pollnau, "Thulium channel waveguide laser in a monoclinic double tungstate with 70% slope efficiency," Opt. Lett. **37**, 887 (2012).

[5] E. H. Bernhardi, H. A. G. M. van Wolferen, L. Agazzi, M. R. H. Khan, C. G. H. Roeloffzen, K. Wörhoff, M. Pollnau, and R. M. de Ridder, "Ultra-narrow-linewidth, single-frequency distributed feedback waveguide laser in $Al_2O_3:Er^{3+}$ on silicon, " Opt. Lett. **35**, 2394 (2010).