Ultra-high Gain in an Yb^{3+}-doped Dielectric Waveguide

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Abstract

Thanks to high dopant concentration, large transition cross-sections, and strong light confinement, modal gain of ~1000 dB/cm, comparable to semiconductor optical amplifiers, is demonstrated in a large-refractive-index-contrast $KGd_{0.535}Yb_{0.475}(WO_4)_2$ channel waveguide on a $KY(WO_4)_2$ substrate.

1. Introduction

For optical amplification, typically rare-earth (RE) doped fiber amplifiers (RDFA) or semiconductor optical amplifiers (SOAs) are selected. Despite the weak transition cross-sections of RE ions and their low doping level in silica fibers, resulting in very low gain per unit length, the extremely long interaction lengths realized in fibers can lead to significant overall gain. SOAs can deliver similarly high overall gain as fibers over much shorter distances, which makes them suitable for providing on-chip gain on silicon wafers. Despite the very high material gain in the nano-sized recombination region of a III-V semiconductor, the usual μm-sized confinement of the signal beam results in a very small overlap factor with the active gain region, reducing accordingly the modal gain to several hundred dB/cm. On the other hand, the typical gain per unit length reported so far for RE-doped integrated waveguides has hardly exceeded a few dB/cm, two orders of magnitude less than in SOAs.

Here we report the demonstration of an ultra-high modal gain, ~1000 dB/cm, in a RE-doped waveguide amplifier, comparable to the modal gain reported for SOAs, thus paving the way for applications of on-chip integrated RE-doped amplifiers.

2. High-index-contrast, highly doped double tungstate channel waveguides

The potassium double tungstates $KGd(WO_4)_2$, $KY(WO_4)_2$, and $KLu(WO_4)_2$ have been recognized as excellent host materials for RE-doped lasers [1], partly thanks to the comparatively high transition cross-sections of RE ions in these hosts. In 2006, the first planar $KY(WO_4)_2{:}Yb^{3+}$ waveguide laser on a $KY(WO_4)_2$ substrate was demonstrated [2]. Co-doping the layer with large amounts of optically inert Gd^{3+} and Lu^{3+} ions offers the possibility for lattice matching with the undoped substrate and obtaining a significantly enhanced refractive index contrast, hence improved mode confinement [3]. Microstructuring by Ar^+ beam etching [4] has resulted in channel waveguides (Fig. 1), in which lasing with 418 mW output power at 1023 nm and 71% slope efficiency vs. launched pump power has been demonstrated recently [5]. Replacing Y^{3+} in the layer completely by Gd^{3+} and Yb^{3+} ions results in highly doped channel waveguides with a refractive-index contrast of $>2 \times 10^{-2}$.

3. Ultra-high gain

These novel dielectric micro-structures combine a high dopant concentration, large transition cross-sections, and strong light confinement, all features that are crucial for the achievement of high optical gain, in a single device. When pumping such a $KGd_{0.535}Yb_{0.475}(WO_4)_2$ channel waveguide by launching 932-nm light from a Ti:Sapphire laser via a microscope objective, high inversion of the Yb^{3+} system is obtained. Signal light at the zero-phonon line at 980.6 nm, which is the wavelength of highest absorption and emission cross-section, exhibits a small-signal modal gain of almost 1000 dB/cm (Fig. 2), comparable to the modal gain of typically several hundred dB/cm achieved in SOAs. The mode overlap with the active region is ~75%, indicating an accordingly higher material gain in our material.

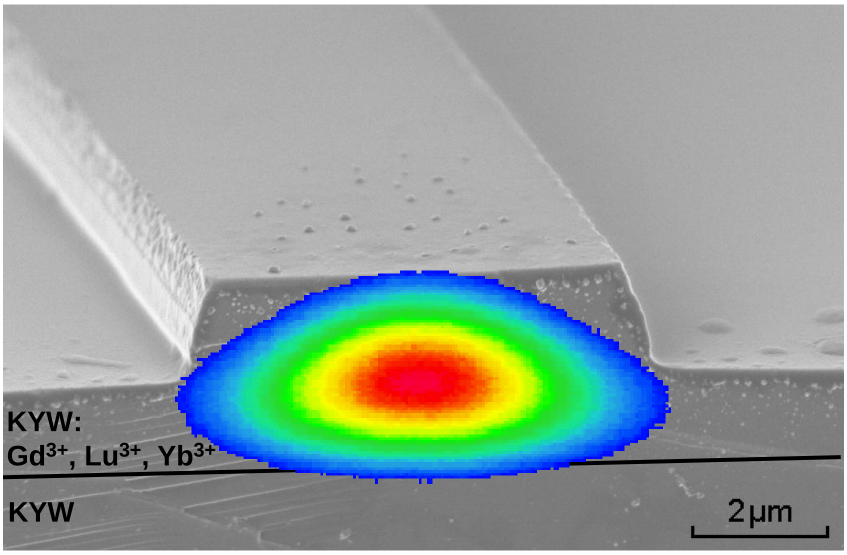

Figure 1. Scanning-electron-microscopy image of a microstructured double tungstate channel waveguide and calculated optical mode confinement.

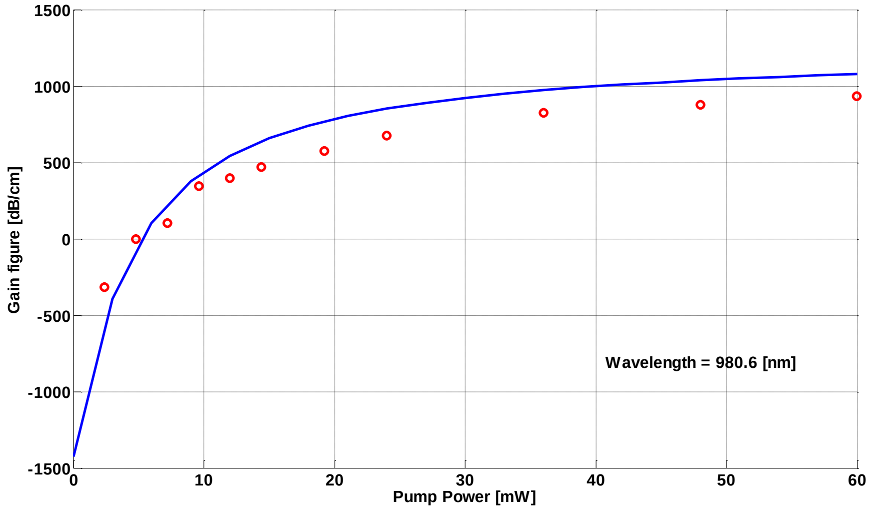

Figure 2. Experimental (dots) and calculated (line) modal gain at 980.6 nm in a $KGd_{0.535}Yb_{0.475}(WO_4)_2$ channel waveguide versus launched pump power at 932 nm.

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