Photonics-chip integrated large-mode-area high-power CW optical amplifier

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Abstract.
Here, we report on a CMOS-compatible thulium-doped high power continuous wave (CW) optical amplifier, leveraging large mode-area gain waveguides. The amplifier structure combines a silicon nitride waveguide above which a sputtered 1250 nm-thick thulium-doped alumina gain layer is deposited. We demonstrate >220 mW output signal power at center wavelength of 1850 nm inside a 9-cm-long amplifier. Small signal gain of >15 dB is achieved.

1 Introduction

High power optical amplifiers have become increasingly important missing elements as the scale and complexity of photonics integrated circuits grow and the power budgets of micro-photonics systems become more challenging to meet. Recently, several integrated continuous-wave (CW) amplifiers have been demonstrated, based on rare-earth, heterogeneous semiconductor integration or nonlinear parametric gain [1-5]. However, due to the tight mode confinement and accordingly the small optical mode cross-section, the integrated amplifiers have low saturation power and are limited to a few tens of milliwatt output power [1-4]. More recently, an erbium-doped integrated amplifier reached a signal level above 100 mW, however that is at the expense of a complex fabrication method [5].

Here, we demonstrate a CMOS-compatible thulium-doped high saturation power CW amplifier, leveraging large mode-area gain waveguides. The amplifier structure is based on combining a higher index silicon nitride (Si\(_3\)N\(_4\)) waveguiding structure with a lower index top thulium-doped alumina (Tm\(^{3+}\):Al\(_2\)O\(_3\)) gain layer that can provide optical gain to the propagating mode [6]. The 9-cm-long amplifier delivers >220 mW output signal power at a center wavelength of 1850 nm.

2 Results

The amplifier structure combines Si\(_3\)N\(_4\) waveguides with a radio-frequency sputtered 1250 nm-thick Tm\(^{3+}\):Al\(_2\)O\(_3\) gain layer, providing large gain bandwidth (1650nm-2000nm). By designing the dimension of the Si\(_3\)N\(_4\) waveguide, the mode confinement, and its overlap with the gain layer is tailored to achieve low-loss waveguide bends and large optical gain (Fig. 1a-d) [6-8]. Fig. 1e shows amplified spontaneous emission (ASE) from a 9 cm-long amplifier with an estimated Tm\(^{3+}\) concentration of 3.6 \(\times\) 10\(^{20}\) cm\(^{-3}\).

Fig. 1f and Fig. 1g show on-chip net gain and on-chip output signal power as a function of input pump power, respectively, for a CW input signal (1850 nm center wavelength). Amplification with 15 dB net gain at a pump power of <100 mW is obtained for an input seed power of 200 \(\mu\)W (blue curve), before parasitic lasing starts.

Our device supports a large mode area in the range of 10s of \(\mu\)m\(^2\) allowing for high gain saturation power comparable to single-mode fiber based systems. Here, we see that the amplified CW signal reaches >220 mW for an input signal of 40 mW at 300 mW on-chip pump power. As seen in the linear scale (inset of Fig. 1g), no gain saturation is visible and the achievable gain is limited only by the available pump source. The conversion efficiency is >60 % in this case.

3 Conclusion

In summary, we have demonstrated a CMOS-compatible high saturation power optical amplifier with high gain and output power.

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References
Figure 1. 

a. Schematic of amplifier waveguide cross-section with SiN height = 800 nm. The gain film (Al2O3:Tm³⁺) thickness = 1250 nm.

b. Schematic of spiral amplifier waveguide, black sections outline the wide Si3N4 waveguides (width 1000 nm) that confine the mode mostly to the waveguide core. Blue sections indicate narrow waveguide sections (width 300 nm) that will guide the mode with only weak confinement so that most of the optical power propagates in the doped Al2O3 cladding. Color gradient indicates the tapered waveguide sections connecting the wide and narrow waveguides. The area where the doped Al2O3 cladding is deposited is highlighted by the green shaded-area.

c and d. An example of optical mode profiles of signal at wavelength of 1850nm for both 1000nm and 300nm-wide waveguides, respectively.

e. Amplified spontaneous emission (ASE) from the amplifier waveguide.

f. On-chip net gain and g. On-chip output signal power as a function of on-chip input pump power.