Broadband and large mode-area on-chip amplifier

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Here, we present work towards a thulium-doped on-chip ultrafast amplifier, leveraging large mode-area gain waveguides with tailored group-velocity dispersion. We demonstrate 10 dB net gain for a broadband signal at 1820 nm inside a 5 cm-long waveguide.

INTRODUCTION

Amplification of ultrafast optical signals is key to a large number of applications in photonics. While ultrashort pulse amplification is well established in optical gain fibers, it is challenging to achieve in photonic-chip integrated waveguides. Recently, several integrated (quasi-)continuous-wave amplifiers have been demonstrated, based on rare-earth, heterogeneous semiconductor integration or nonlinear parametric gain [1-5]. On-chip amplification of ultrafast pulses, however, remains challenging due to the inherently small mode area and high optical nonlinearity in integrated waveguides. Here, we present our recent work towards an on-chip ultrafast amplifier, leveraging large mode-area gain waveguides with tailored group-velocity dispersion (GVD).

RESULTS

The amplifier structure combines silicon nitride (Si_3N_4) waveguides with a radio-frequency sputtered 1100 nm-thick thulium-doped alumina gain layer (Tm^{3+}: Al_2O_3), providing large gain bandwidth (1650nm-2000nm) and supporting sub-100 fs pulses. By designing the dimension of the Si_3N_4 waveguide, the waveguide's GVD, the mode confinement, and its overlap with the gain layer is tailored to achieve stable pulse propagation [6], low-loss waveguide bends and large optical gain (Fig. 1a-d) [7,8]. Fig. 1e shows amplified spontaneous emission (ASE) from a 5 cm-long amplifier characterized by a mode cross-section > 10 µm^2 in the gain section and an estimated Tm^{3+} concentration of 4.0x10^{20}cm^{-3}.

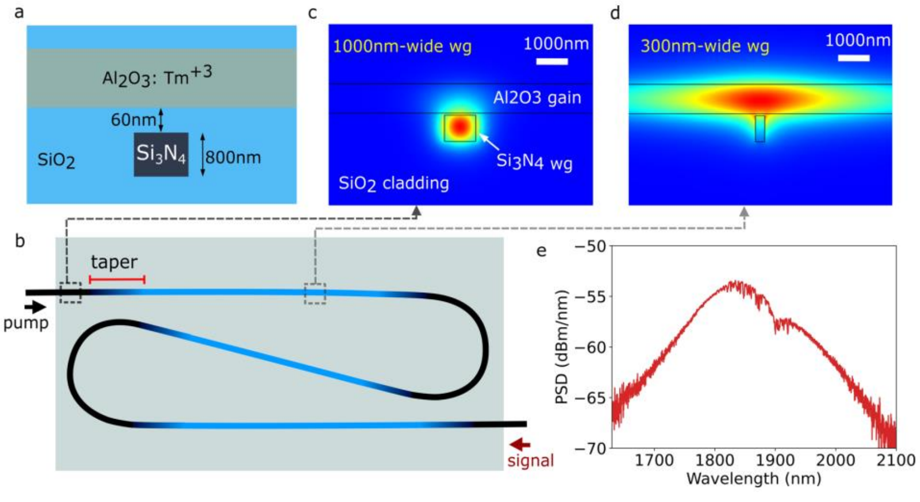

Fig. 1. (a) Schematic of amplifier waveguide cross-section with SiN height= 800 nm. The gain film (Al_2O_3 :Tm^{+3}) thickness= 1100 nm, above which a 1 µm silica layer is deposited for protection and dispersion management. (b) Schematic of spiral amplifier waveguide, black sections outline the wide Si_3N_4 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 Al_2O_3 cladding. Color gradient indicates the tapered waveguide

sections connecting the wide and narrow waveguides. The area where the doped Al_2O_3 cladding is deposited is highlighted by the green shaded-area. (c) and (d) TE mode profiles of signal at wavelength of 1830nm for both 1000nm and 300nm-wide waveguides, respectively. (e) Amplified spontaneous emission (ASE) from the amplifier waveguide.

Fig. 2a shows the on-chip output signal power as a function of input pump power for a pulsed input signal (1820 nm center wavelength, 0.1 mW). Broadband amplification with 10 dB net gain at pump power of 240mW (cf. circle in Fig. 2a) is presented in Fig. 2b.

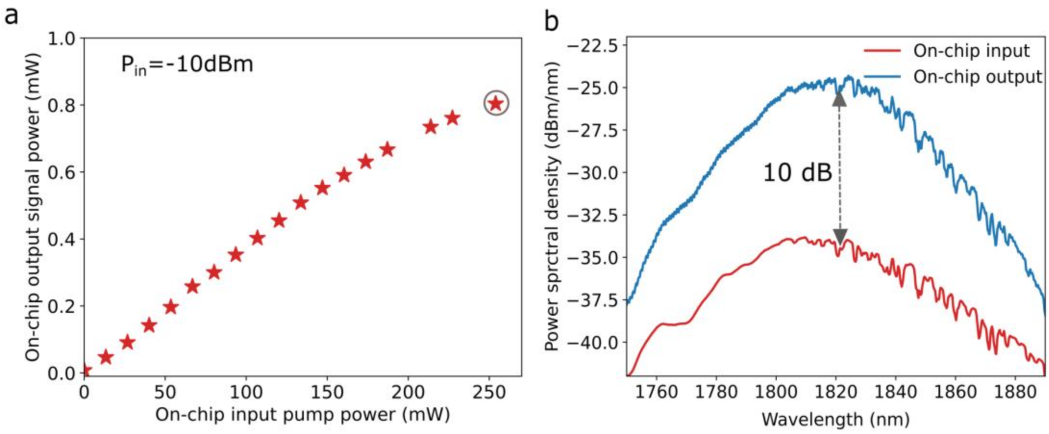

Fig. 2. (a) On-chip output signal pulse power. (b) Optical spectra of the input and output signals.

To summarize, the presented results open a pathway towards on-chip amplification of ultrashort pulses, with potential implications for spectroscopy, ranging or nonlinear mid-infrared light generation [9] in a chip-scale integrated photonic setting.

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