Monolithic integration of $Al_2O_3:Er^{3+}$ amplifiers in Si_3N_4 technology

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Si_3N_4 platforms have promising features including low waveguide loss (<0.1 dB/cm), wide transparency window (0.4–2.35 μm), and compatibility with CMOS technology [1]. Low-cost and high-performance integration technologies are instrumental for providing active functionalities to the Si_3N_4 platform. Lasers on Si_3N_4 platforms have been realized using hybrid integration of InP [1] and monolithic integration of rare-earth-ion doped Al_2O_3 materials [2]. To independently guide the modes in monolithically integrated Al_2O_3 and Si_3N_4 waveguides, a double-layer platform has been studied in our previous work [3]. This enables to achieve high mode confinement and field intensity in the Al_2O_3 waveguide core, which is beneficial for reducing pump power threshold to obtain net gain of amplifiers. In this paper, we experimentally demonstrate the $Al_2O_3:Er^{3+}$-Si_3N_4 optical amplifiers based on the double-layer monolithic integration. On-chip net gain of ~10 dB is obtained for a 5.9 cm long fully integrated amplifier at the signal wavelength of 1532 nm under pumping at 976.2 nm.

The Si_3N_4 waveguides are fabricated on thermally oxidized silicon wafer (8 μm thick SiO_2) by low pressure chemical vapor deposition (LPCVD), standard lithography and reactive ion etching (RIE) with a CHF_3-O_2 flow. The Si_3N_4 waveguide dimension is 1.4 μm × 200 nm. The Si_3N_4 wafer is cladded by a thin LPCVD SiO_2 film (180–200 nm) after chemical mechanical polishing (CMP). An 820 nm thick $Al_2O_3:Er^{3+}$ layer is then deposited by RF co-sputtering. The Al_2O_3 waveguide has a width of 1.4 μm and is fabricated by the RIE process with a BCl_3-HBr flow. The Al_2O_3 and Si_3N_4 waveguides are coupled by width-tapering the Al_2O_3 waveguide and thickness-tapering the Si_3N_4 waveguide [3] with measured coupler loss of 0.48±0.02 dB at the wavelength of 1306 nm (outside the Er^{3+} absorption band). On-chip 1×2 MMI-based multiplex and demultiplex is employed to combine and split the pump and signal lights [4].

Fig. 1(a) shows the optical image of the integrated amplifier. Red light is from the 633 nm laser launched at the output port and the green light is generated by the energy transfer up-conversion of Er^{3+}. A setup similar to the work of [5], using a lock-in amplifier, is used to measure the signal enhancement (SE) at the wavelength of 1532 nm. Net gain of the integrated amplifier (including the couplers) is calculated by subtracting the absorption loss, propagation loss, and the coupler loss from the SE. The absorption plus propagation losses are measured from the infrared intensity images of the gain spiral [5], which are 0.47, 3.65 and 0.52 dB/cm for the wavelengths of 1306, 1532 and 1640 nm. The incident powers are calibrated by directly connecting the input fibers to the power meters. Fig. 1(b) and (c) show the net gain as a function of the incident pump and signal powers rather than launched powers. Total loss of 19.6 dB is measured at the wavelength of 1640 nm. With known coupler loss and propagation plus absorption loss, the fiber-to-chip coupling plus the MMI loss is extracted to be ~7.8 dB. The loss of the incident power arriving at the coupler at the wavelength of 1532 nm is similar to this value because the MMI enables broadband performance (1460–1640 nm) with limited loss variation (<1 dB). The measurement of launched power can be improved by introducing passive Si_3N_4 reference waveguide in the future works.

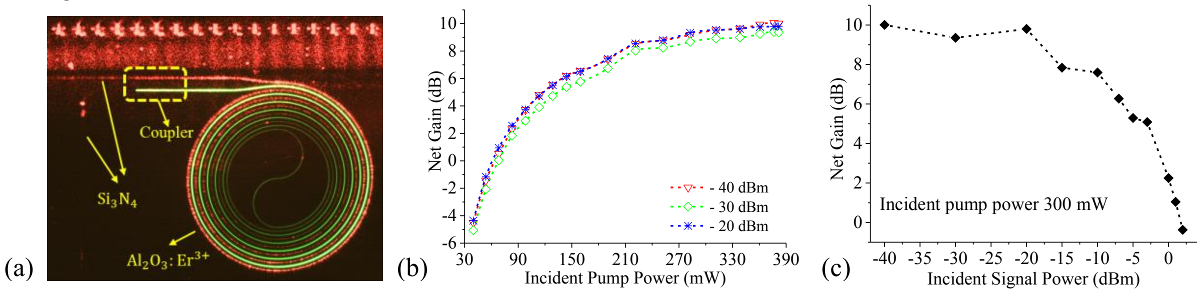

Fig. 1. (a) Optical image of the $Al_2O_3:Er^{3+}$-Si_3N_4 amplifier with launched 976.2 nm and 633 nm wavelengths. Green light is produced by energy transfer up-conversion of Er^{3+}. Net gain under 976.2 nm pumping as a function of (b) incident pump power and (c) incident signal power.

References

[1] D. J. Blumenthal, R. Heideman, D. Geuzebroek, A. Leinse, and C. Roeloffzen, "Silicon Nitride in Silicon Photonics," Proc. IEEE **106**, 2209-2231 (2018).
[2] M. Pollnau and J. D. B. Bradley, "Optically pumped rare-earth-doped Al_2O_3 distributed-feedback lasers on silicon [Invited]," Opt. Express **26**, 24164-24189 (2018).
[3] J. Mu, M. de Goede, M. Dijkstra, and S. M. García-Blanco, "Monolithic Integration of Al_2O_3 and Si_3N_4 for Double-layer Integrated Photonic Chips," in Adv. Photon. 2018, OSA Technical Digest, ITh1I.1.
[4] J. Mu, S. A. Vázquez-Córdova, M. A. Sefunc, Y. S. Yong, and S. M. G. Blanco, "A Low-Loss and Broadband MMI-Based Multi/Demultiplexer in Si_3N_4/SiO_2 Technology," J. Lightwave Technol. **34**, 3603-3609 (2016).
[5] S. A. Vázquez-Córdova, M. Dijkstra, E. H. Bernhardi, F. Ay, K. Wörhoff, J. L. Herek, S. M. García-Blanco, and M. Pollnau, "Erbium-doped Spiral Amplifiers with 20 dB of Net-gain on Silicon," Opt. Express **22**, 25993-26004 (2014).