Spectroscopy and Ultra-narrow-linewidth Lasing in Rare-earth-doped Amorphous Al_2O_3 Waveguides on a Silicon Chip

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Highlights

Despite a strong fluorescence-quenching process that affects a significant fraction of erbium or ytterbium ions in amorphous Al_2O_3, channel waveguide lasers with 1.7 kHz linewidth at 1.5 µm or 55 mW output power at 1.0 µm, stable microwave beat-frequency generation, and intra-laser-cavity optical sensing is demonstrated on a silicon chip.

Abstract

Miniaturization and on-chip integration of high-performance light sources have become major issues in integrated optics. While semiconductor amplifiers and lasers have emerged as the most-preferred choice, spatial and temporal gain-patterning effects evoked by the large refractive-index changes that are accompanied with electron-hole-pair excitation limit their performance in several respects. We demonstrate that rare-earth-doped dielectric materials provide a viable alternative to semiconductors.

We have developed low-propagation-loss, rare-earth-ion-doped Al_2O_3 layers directly deposited onto thermally oxidized silicon chips by reactive co-sputtering [1]. Especially in $Al_2O_3:Er^{3+}$, a fast lifetime-quenching process [2] induced by, e.g., energy-transfer upconversion (ETU) among active ion pairs and clusters, undesired impurities, or host material defects such as voids, that is not revealed by any particular signature in the luminescence decay curves because of negligible emission by the quenched ions under quasi-CW excitation, limits the amplifier performance at 1.53 µm to 2 dB/cm [3], see Fig 1(a). Nevertheless, this gain is higher than the propagation losses of typically 0.2 dB/cm in micro-structured channel waveguides, thereby allowing for efficient lasing. Bragg gratings inscribed into the SiO_2 top cladding by laser interference lithography and reactive ion etching, in combination with a $\lambda/4$ phase shift induced by adiabatic widening of the waveguide, enabled distributed-feedback (DFB) lasers at 1.5 µm with ultra-narrow linewidths down to 1.7 kHz in $Al_2O_3:Er^{3+}$ [4] and lasers at 1.0 µm with up to 55 mW of output power and 67% slope efficiency versus launched pump power in $Al_2O_3:Yb^{3+}$ [5], see Fig. 1(b). By fabricating two phase-shift regions, see Fig. 1(c), dual-wavelength lasers and highly stable microwave beat-frequency generation at a frequency of ~15 GHz were obtained [6]. When perturbing the environment of one of the two phase shifts by a glass sphere attached to the cantilever of an atomic-force microscope, we demonstrated intra-laser-cavity optical sensing of nano-particles down to a size of 500 nm [7].

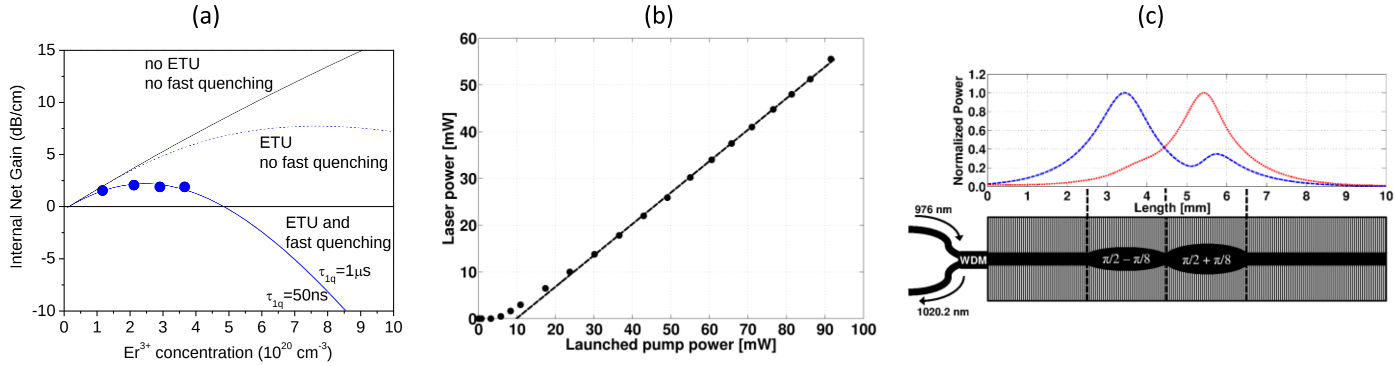

Figure 1. (a) Internal net gain versus erbium concentration i) without parasitic quenching effects, under ii) de-excitation by ETU only and iii) de-excitation by ETU and the fast quenching process. (b) Input-output curve of the $Al_2O_3:Yb^{3+}$ DFB channel waveguide laser. (c) Dual-phase-shifted DFB cavity layout and laser mode intensities.

References

[1] K. Wörhoff, J.D.B. Bradley, F. Ay, D. Geskus, T.P. Blauwendraat, M. Pollnau, IEEE J. Quantum Electron. 45 (2009) 454-461.

[2] L. Agazzi, K. Wörhoff, M. Pollnau, J. Phys. Chem. C 117 (2013) 6759-6776.

[3] J.D.B. Bradley, L. Agazzi, D. Geskus, F. Ay, K. Wörhoff, M. Pollnau, J. Opt. Soc. Am. B 27 (2010) 187-196.

[4] E.H. Bernhardi, H.A.G.M. van Wolferen, L. Agazzi, M.R.H. Khan, C.G.H. Roeloffzen, K. Wörhoff, M. Pollnau, R.M. de Ridder, Opt. Lett. 35 (2010) 2394-2396.

[5] E.H. Bernhardi, H.A.G.M. van Wolferen, K. Wörhoff, R.M. de Ridder, and M. Pollnau, Opt. Lett. 36 (2011), 603-605.

[6] E.H. Bernhardi, M.R.H. Khan, C.G.H. Roeloffzen, H.A.G.M. van Wolferen, K. Wörhoff, R.M. de Ridder, M. Pollnau, Opt. Lett. 37 (2012) 181-183.

[7] E.H. Bernhardi, K.O. van der Werf, A.J.F. Hollink, K. Wörhoff, R.M. de Ridder, V. Subramaniam, M. Pollnau, Laser Photonics Rev. 7 (2013) 589-595.