High-performance $Al_2O_3:Er^{3+}$ integrated optical amplifiers

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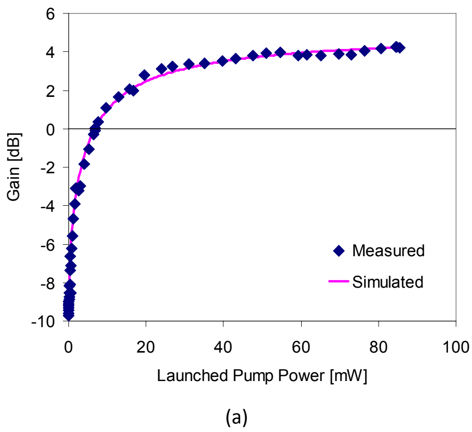
In integrated optics the search continues for active materials which can be integrated with passive materials in a straightforward and low-cost manner. Dielectric Er-doped planar glass waveguiding materials offer broad gain around the critical 1550-nm wavelength range, and the potential for integrated on-chip tunable or short-pulse laser sources. Compared to other such glass materials, $Al_2O_3:Er^{3+}$ has distinct advantages. It possesses a highly broadened emission spectrum for gain over a wider wavelength range. It has a higher refractive index contrast which allows tighter bend radii and more compact devices. Furthermore, it can be deposited on a number of common substrates, including thermally-oxidized Si wafers. This opens the possibility for integration of $Al_2O_3:Er^{3+}$ directly with photonic materials such as Si which are optimized for passive waveguiding functions. Historically, the drawbacks of the material have been the relative fabrication complexity and lower peak gain.

Our research group has addressed both of the aforementioned limitations in order to fully realize the potential of $Al_2O_3:Er^{3+}$ as an active material. In this contribution we present recent results demonstrating the high performance of $Al_2O_3:Er^{3+}$ integrated optical amplifiers.



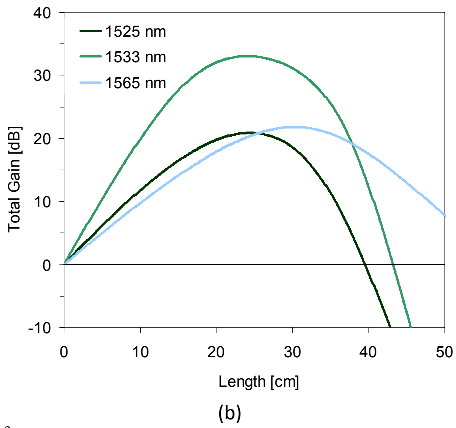


Fig. 1 (a) Net internal gain vs. 977-nm pump power in a 2.1-cm-long $Al_2O_3:Er^{3+}$ amplifier, demonstrating up to 2.0 dB/cm gain; **(b)** predicted total gain vs. length at 1525, 1533, and 1565 nm in compact spiral amplifiers for 100 mW pump power.

Deposition of $Al_2O_3:Er^{3+}$ is carried out by applying a low-cost and straightforward reactive co-sputtering approach [1] and channel waveguides are prepared by reactive ion etching [2]. $Al_2O_3:Er^{3+}$ amplifiers with different Er concentrations have been investigated. Up to 2.0 dB/cm net gain has been demonstrated at 1533 nm for an Er concentration of 2×10^{20} cm^{-3} when pumping at 977 nm (Fig. 1a). Peak total gain of 9.3 dB was also demonstrated in a 5.4-cm amplifier and positive gain was achieved over an 80-nm bandwidth. Using a rate-equation model, up to 33 dB at the peak and >20 dB between 1525-1565 nm is predicted in a 24-cm-long amplifier for a pump power of 100 mW (Fig. 1b). In Er-doped fiber amplifiers, the long excited-state lifetime means transmission at bit rates around 40 Gbit/s is possible. We recently showed open-eye diagrams and only a small power penalty of 1 dB in bit-error-rate measurements for on-chip 40 Gbit/s signal transmission in an integrated $Al_2O_3:Er^{3+}$ amplifier [3]. This result, coupled with the high and broad gain demonstrates that such amplifiers are well-suited to compensating for on-chip losses incurred in high-bit-rate signals. The high gain also indicates that a laser source is possible in a material which can be integrated with passive optical materials such as silicon, providing high functionality on a single chip.

[1] K. Wörhoff, J. D. B. Bradley, F. Ay, D. Geskus, T. Blauwendraat, and M. Pollnau, IEEE J. Quantum Electron. **45** (5), 454-461 (2009).
[2] J. D. B. Bradley, F. Ay, K. Wörhoff, and M. Pollnau, Appl. Phys. B **89** (2-3), 311-318 (2007).
[3] J. D. B. Bradley, M. Gay, J. C. Simon, K. Wörhoff, and M. Pollnau, Conference on Lasers and Electro-Optics Europe 2009, accepted.