Reliable Low-Cost Fabrication of Low-Loss Al_2O_3:Er^{3+} Waveguides With 5.4-dB Optical Gain

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***Abstract*—A reliable and reproducible deposition process for the fabrication of Al_2O_3 waveguides with losses as low as 0.1 dB/cm has been developed. The thin films are grown at ~ 5 nm/min deposition rate and exhibit excellent thickness uniformity within 1% over 50×50 mm^2 area and no detectable OH^- incorporation. For applications of the Al_2O_3 films in compact, integrated optical devices, a high-quality channel waveguide fabrication process is utilized. Planar and channel propagation losses as low as 0.1 and 0.2 dB/cm, respectively, are demonstrated. For the development of active integrated optical functions, the implementation of rare-earth-ion doping is investigated by cosputtering of erbium during the Al_2O_3 layer growth. Dopant levels between 0.2–5 $\times 10^{20}$ cm^{-3} are studied. At Er^{3+} concentrations of interest for optical amplification, a lifetime of the $^4I_{13/2}$ level as long as 7 ms is measured. Gain measurements over 6.4-cm propagation length in a 700-nm-thick Al_2O_3:Er^{3+} channel waveguide result in net optical gain over a 41-nm-wide wavelength range between 1526–1567 nm with a maximum of 5.4 dB at 1533 nm.**

***Index Terms*—Aluminum oxide, erbium, integrated optics, low-loss dielectric waveguide, optical amplifier, reactive cosputtering.**

applications in wavelength-division-multiplexing (WDM) devices and tunable laser sources. Last but not least, the relatively high refractive index, $n \sim 1.65$, allows for the realization of high-contrast channel waveguides with considerably more compact IO circuits compared to implanted waveguides [7], [8] or rare-earth-ion-doped fiber technology [9], [10].

During the past few decades, a number of research groups have investigated and developed Al_2O_3 deposition processes based on different techniques: pulsed laser deposition (PLD) [11], [12], atomic layer deposition (ALD) [13], [14], chemical vapor deposition (CVD) [5], [15]–[17], the sol-gel method [12], [18], [19], sputtering from a dielectric target [20], [21], and reactive cosputtering based on a metallic target [6], [22], [23].

Besides general requirements for thin-film applications in integrated optics, like low propagation loss, uniform growth over a large substrate area, good process reproducibility, and sufficiently high deposition rates, specific demands arising from applications in optically active devices need to be taken into account. For devices based on rare-earth-ion transitions, OH^--free