Reliable fabrication of low-loss Al_2O_3 waveguides for active integrated optics

Feridun Ay, Kerstin Wörhoff, Jonathan Bradley, and Markus Pollnau
Integrated Optical MicroSystems Group, MESA+ Research Institute, University of Twente
P.O. Box 217, 7500 AE Enschede, the Netherlands, e-mail: f.ay@ ewi.utwente.nl

Rare-earth-ion (specifically Er^{3+}) doped Al_2O_3 waveguide layers are promising host materials for applications in active integrated optics including on-chip laser and amplifier structures. In this paper we present results on the fabrication and optical properties of reactively co-sputtered Al_2O_3 waveguide layers. The reproducible deposition process resulted in as-deposited low-loss waveguides (0.3 dB/cm in the near-infrared wavelength range). Furthermore, the Al_2O_3 material fabricated by sputtering techniques is compatible with Si-based integrated optical technology and allows for uniform deposition over a large substrate area.

Although rare-earth-ion doped Al_2O_3 waveguides have already been demonstrated as an attractive material system for integrated optical amplifiers and tunable light sources [1, 2], those previous studies yielded some disadvantages. The propagation losses for Al_2O_3 slab waveguides reported in [1] could be optimized to 0.35 dB/cm, however only after an additional annealing step which reduced the loss of the as-deposited layers being as high as 20 dB/cm. Among the lowest background losses of Al_2O_3:Er waveguides reported so far is the value of ~0.25 dB/cm [2] obtained by reactive co-sputtering based on DC-driven sputtering guns. The main drawback of the applied method turned out to be the poor process stability and reproducibility, which was highly dependent on the exact condition of the sputtering target.

In order to eliminate the above mentioned drawbacks and optimize the material further, we developed an rf-based reactive co-sputtering process, which resulted in stable, target-condition-independent deposition of Al_2O_3 layers with high optical quality. Optimum deposition conditions were obtained by Ar sputtering of an Al target and 5% O_2 flow into a chamber at a pressure of 2 mTorr and an rf power of 200 W. These growth parameters resulted in 5.5 nm/min deposition rate and a dense layer. The optical properties of a 660-nm thick Al_2O_3 layer grown on 8-µm thick thermal oxide were investigated in detail. The refractive index for TE and TM polarized light was measured by prism coupling for wavelengths ranging from 633 nm to 1550 nm with an error of less than 10^{-3}. The resulting refractive-index dispersion curve is shown in Fig. 1(a). Optical loss spectra of the as-grown Al_2O_3 waveguides were measured by the moving prism method. An optical loss value of ~0.3 dB/cm was measured at 1550 nm, see Fig. 1(b). Since this loss value is close to the detection limit of the applied method, waveguide-channel based loss characterization allowing for a significantly lower detection limit is currently under investigation.

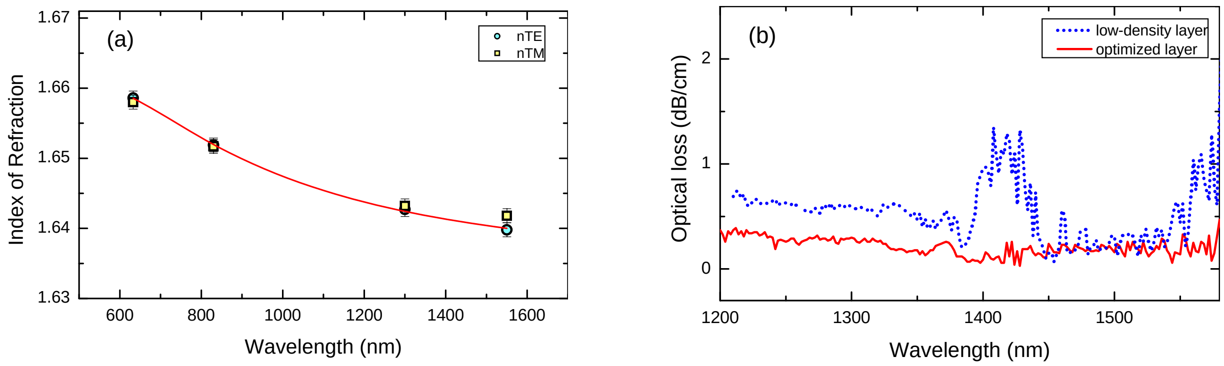

Figure 1: Optical properties of optimized Al_2O_3 layer: refractive index dispersion (a) and optical loss spectrum (b).

Another issue, which is highly important for the operation of rare-earth-ion doped amplifiers and lasers, is the content of OH^- bonds. Although sputter-deposited films yield intrinsically negligible OH^- content, moisture absorption in case of porous, low-density thin films must be avoided. For this purpose we measured the optical loss over a wide wavelength range from 1200-1600 nm for the optimized high-density Al_2O_3 layer and a 695-nm thick Al_2O_3 layer with lower density. In Fig. 1(b) it can be seen that the absorption peak around 1400 nm, which is present in low-density layers and is attributed to OH^- bonds, is absent in our optimized layer.

In conclusion, we have optimized the deposition and optical properties of as-grown Al_2O_3 waveguides which are suited for rare-earth-ion doped active integrated optical devices. Our future research will focus on channel-waveguide optical-gain structures employing this technology.

[1] G.N. van den Hoven, J.A. van der Elsken, A. Polman, C. van Dam, K.W.M. van Uffelen, and M.K. Smit: Absorption and emission cross sections of Er^{3+} in Al_2O_3 waveguides, *Appl. Opt.* **36**, 3338-3341 (1997).

[2] S. Musa, H.J. van Weerden, T.H. Yau, and P.V. Lambeck: Characteristics of Er-doped Al_2O_3 thin films deposited by reactive co-sputtering, *IEEE J. Quantum. Electron.* **36**, 1089-1097 (2000).