

Er³⁺ and Nd³⁺ doped Al₂O₃ amplifiers on a silicon chip

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Dielectric Er³⁺- and Nd³⁺-doped waveguide materials offer broad gain in the third [1], second, and first telecommunication windows. Rare-earth-ion-doped Al₂O₃ has broad emission spectra for gain over a wider wavelength range, a high refractive index contrast which allows tighter bend radii and more compact devices, and can be deposited on a number of common substrates, including thermally oxidized Si wafers. This opens the possibility for integration of Al₂O₃ directly with photonic materials which are optimized for passive waveguiding functions. In this contribution we present recent results demonstrating the high performance of Er³⁺- and Nd³⁺-doped Al₂O₃ integrated optical amplifiers.

Rare-earth-ion-doped Al₂O₃ layers were deposited onto thermally oxidized Si wafers by reactive co-sputtering [2] and channel waveguides were microstructured by chlorine-based reactive ion etching [3]. We developed Al₂O₃:Er³⁺ amplifiers with up to 2.0 dB/cm net gain at 1533 nm and gain over an 80-nm bandwidth [4], among others enabling loss-less power splitters over the entire telecom C-band [5], and demonstrated 170-Gbit/s signal transmission in an integrated Al₂O₃:Er³⁺ amplifier [6]. In Al₂O₃:Nd³⁺ amplifiers, net gain of 6.3 dB/cm at 1064 nm and 1.93 dB/cm at 1330 nm, as well as in the range 865-930 nm with a peak gain of 1.57 dB/cm at 880 nm was obtained [7].

Monolithic integration of Al₂O₃:Er³⁺ amplifiers with passive silicon-on-insulator waveguides was demonstrated and a signal enhancement of >7 dB at 1533 nm wavelength was obtained [8]. The straightforward wafer-scale fabrication process allows for parallel integration of multiple amplifier and laser sections with silicon or other photonic circuits on a chip. Furthermore, a solution for compensating losses in optical interconnects is provided [9]. Large-core Al₂O₃:Nd³⁺ channel waveguide amplifiers were tested in combination with passive polymer waveguides. Coupling between the two waveguide types was optimized and tapering the Al₂O₃:Nd³⁺ waveguide improved the pump intensity in the active region. 0.21 dB net gain at 880 nm was demonstrated in a structure with an Al₂O₃:Nd³⁺ waveguide coupled between two polymer waveguides.

In spectroscopic investigations, the influence of energy migration and energy-transfer upconversion (ETU) among neighboring Er³⁺ ions on luminescence decay in Al₂O₃:Er³⁺ was investigated [10]. We observed a fast quenching process induced by, e.g., active ion pairs and clusters, undesired impurities, or host material defects such as voids. This process was verified by pump-absorption experiments, but was not revealed by any particular signature in the luminescence decay curves. This result highlights the fact that spectroscopic processes can be – and in many cases probably are – present in optical materials, although these processes are invisible in any kind of luminescence measurements, because they do not lead to the emission of a photon. On the other hand, we show that these processes strongly affect device performance as an amplifier.

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