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CMM6 1530

Er^{3+} absorption and optical gain in Al_2O_3 waveguides

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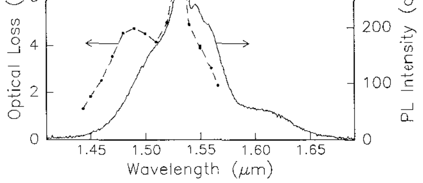
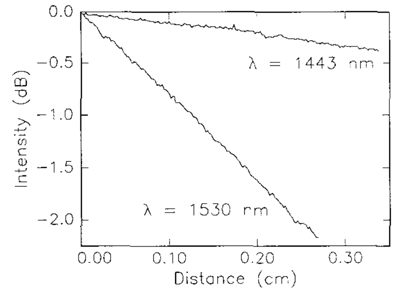
Planar Al_2O_3 waveguides were fabricated by sputter deposition of Al_2O_3 onto a thermally oxidized silicon (100) substrate. A SiO_2 layer was deposited on top of this as a cladding. The nominal layer thickness of 6 μm thermal SiO_2, 0.60 μm Al_2O_3 and 1.35 μm top SiO_2 result in singlemode planar waveguide films at 1.5 μm. Annealing of these films at 825°C was performed to achieve a low optical loss of 0.35 dB/cm.[1] Preceding the deposition of the top cladding, 2×10^{16} Er/cm^2 was implanted into the Al_2O_3 film at 1.35 MeV, with the sample held at 77 K. Using Rutherford backscattering spectrometry, an Al_2O_3 layer thickness of 430 nm and a Gaussian Erbium concentration profile at a depth of 250 nm (full width at half maximum, 135 nm) were measured. The Erbium peak concentration is 1.4 at.%. Upon excitation with an Ar-ion laser the film shows intense room temperature photoluminescence around 1.53 μm due to intra-4*f* transitions in Er^{3+} (Fig. 1, solid line). The luminescence lifetime is 4.5 ms. Earlier work characterizing the photoluminescence properties of similar Er-implanted Al_2O_3 films show that high concentrations of optically active Erbium are attainable without strong concentration quenching effects.[2] However, cooperative upconversion was observed in films with an Erbium concentration of 3.6 at.%.

Optical absorption was measured by coupling light from a tunable external cavity laser into the Er-implanted Al_2O_3 waveguide film using a high index prism. A second prism was employed to couple the light out of the film and onto a germanium detector. Figure 2 shows the detector signal as a function of the distance between the two prisms for two different wavelengths. From the slope of the data the optical loss was determined. Figure 1 shows the optical loss (dashed line) as a function of wavelength. Both emission and absorption are due to Erbium^{3+} on the basis of the spectral shapes. From the dashed line, the Er^{3+} absorption cross section may be derived using the overlap between the optical mode and Erbium profile, assuming that all of the Erbium is optically active. This yields cross sections of 4.2×10^{21} cm^2 at 1.53 μm and 2.1×10^{21} cm^2 at the typical pump wavelength of 1.48 μm.

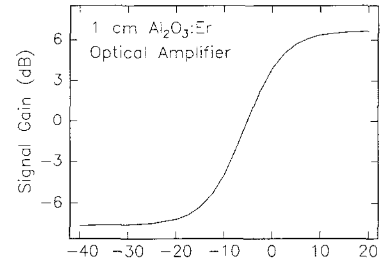
Using these results the gain performance of a 1-cm-long Er-implanted Al_2O_3 waveguide was calculated. Figure 3 shows the predicted signal gain versus pump power for a pump source at 1.48 μm and a −40-dBm signal at 1.53 μm. The waveguide parameters are the same as above, with a lateral confinement made by etching 3-μm ridges into the Al_2O_3. The model used for the calculation is based on a quasi two-level system for the Er^{3+} ion. The rate equations were solved numerically and no approximations were made. Neglecting possible upconversion effects, the calculations predict that 6 dB/cm optical gain is achievable in a 1-cm waveguide at a modest pump power of 10 dBm. Similar calculations on a 5-cm waveguide show a total gain of 30-dB for a pump power of 15 dBm. Measurements of optical gain in these waveguides are forthcoming.



CMM6 Fig. 1. Optical loss (dashed line) as a function of wavelength for an Er-implanted Al_2O_3 planar waveguide film. For comparison, the emission spectrum of the same sample is shown (solid line). The sample was implanted with 2×10^{16} Er/cm^2 at 1.35 MeV (peak concentration), 1.4 at.%) and annealed at 825°C.



CMM6 Fig. 2. Prism coupling measurement of the light intensity in an Er-implanted Al_2O_3 planar waveguide film as a function of the change in distance between the two prisms. The data are shown for two different wavelengths.



CMM6 Fig. 3. Optical gain vs pump power calculated for a 1-cm-long Er-implanted Al_2O_3 ridge waveguide. The Er fluence was $2 \times 10^{16} \times$ Er/cm^2 (peak concentration: 1.4 at.%). The input signal was −40 dBm at 1.53 μm and the pump wavelength was 1.48 μm.

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CMM7 1545

A diode-pumped, first window optical fibre amplifier providing up to +12 dBm of output

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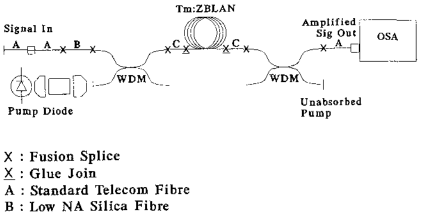
The thulium ion is one of great interest when it is doped within fluorozirconate glass due to the number of transitions available for stimulated emission. One such transition is the $^3F_4$ to $^3H_6$ transition at 0.8 μm. This is of interest as it lies within the first window for optical communication. There is growing interest in the use of this window for local area networks, passive optical networks, or supervisory systems. Small signal amplification of up to 23 dB has been reported for this transition in a thulium-doped fluoride fibre using a Ti:sapphire laser as the pump source.[1] We report here the first diodepumped operation of this optical amplifier. An intrinsic small signall gain in excess of 30 dB was achieved. With a launched 807-nm signal power of −10 dBm, intrinsic gain of 21 dB was observed, producing amplified output powers of +11 dBm. An intrinsic gain of greater than 20 dB was observed for signals over the spectral range of 802 nm to 810 nm. The greatest amplified output power obtained for this system was 12.8 dBm for 30 mW of launched diode pump power.

The experimental configuration used is shown in Fig. 1. The entire system was fibre-connectorised using fusion splices for silica-silica joins and glue splices for fluoride silica joins. The system started and ended with standard 1.3 μm telecommunications fibre. WDM couplers, optimised for 780 nm and 815 nm operation, were used at both ends to combine and split the pump and signal light. Undoped silica fibre was used to optimise coupling from the large-core telecommunications fibre down to the small-core fluoride fibre, and back again to the out-



CMM7 Fig. 1. Experimental setup.