Higher gain in 977-nm-pumped $\text{Al}_2\text{O}_3:\text{Er}^{3+}$ integrated optical amplifiers

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Er-doped aluminium oxide ($\text{Al}_2\text{O}_3:\text{Er}^{3+}$) is known to be a good material for active integrated devices, however, in the past it has produced lower net gain compared to other Er-doped glass materials [1,2]. One of the issues potentially affecting the gain in Er-doped amplifiers is the choice of pump wavelength, which is typically either ~980 nm or 1480 nm. The main advantages of 1480-nm pumping are higher pumping efficiency due to a higher number of photons per unit power and similar modal properties to the signal. However, 1480-nm pumping can lead to a lower population inversion because of stimulated emission at the pump wavelength from the $^4\text{I}_{13/2}$ manifold. For this reason lower gain has been predicted theoretically in an $\text{Al}_2\text{O}_3:\text{Er}^{3+}$ amplifier when pumping at 1480 nm [3]. In this paper we experimentally compare pumping at 977 nm and 1480 nm and the influence on gain in an $\text{Al}_2\text{O}_3:\text{Er}^{3+}$ amplifier. We show that significantly higher gain can be achieved when pumping at 977 nm, and a record-high peak gain and gain bandwidth obtains compared to previous results in this material.

$\text{Al}_2\text{O}_3:\text{Er}^{3+}$ straight channel waveguide amplifiers were fabricated on thermally-oxidized silicon substrates by reactive co-sputtering, standard lithography and reactive ion etching [4]. The amplifiers were ~6-cm-long with a waveguide cross section of $1\text{ }\mu\text{m} \times 4\text{ }\mu\text{m}$ and an etch depth of ~70 nm. The waveguide dimensions were selected for single-mode propagation at wavelengths of 977 nm and above, good overlap of pump and signal mode profiles (for both 977-nm and 1480-nm pumping) and strong confinement of the propagating pump and signal within the active region (> 80%). The amplifiers were pumped using either a 977-nm Ti:Sapphire laser or 1480-nm Raman laser. The enhancement of signal light from a tunable laser was measured, and the background losses, which were measured using the moving prism method, were subtracted to determine the internal net gain.

Figure 1 (a) shows the internal net gain versus launched 977-nm and 1480-nm pump power for a 5.4-cm-long amplifier with Er concentration of $1.17 \times 10^{20}\text{ cm}^{-3}$. When pumping at 1480 nm, the amplifier has a threshold pump power of 4 mW and reaches a maximum gain value of 6 dB. When pumping at 977 nm, it has a higher threshold pump power of 7 mW, but a total gain of almost 9 dB is measured. These results support the choice of 977 nm as the pump wavelength in order to maximize the optical gain. For a launched 977-nm pump power of 80 mW, total internal net gain of up to 9.3 dB was measured at 1532 nm and net gain was observed over a wavelength range of 80 nm, inclusive of the critical telecom C-band wavelengths; see Fig. 1 (b). In addition, we have observed net gain per unit length of up to 2.0 dB/cm for an amplifier with slightly higher Er concentration, which is more than double what was reported in a similar material, which was pumped at 1480 nm [1]. From the results reported here, we expect the higher gain is in part due to the selection of pump wavelength, and in part due to other factors, such as reduced gain quenching due to energy-transfer upconversion in our material.

With an optimized waveguide length, a total gain of 24 dB is predicted from a calculation, see Fig. 1 (c), which would place $\text{Al}_2\text{O}_3:\text{Er}^{3+}$ among the most attractive on-chip integrated gain material near 1550 nm.

Fig. 1. (a) Internal net gain at 1533 nm vs. launched pump power for 977-nm and 1480-nm pumping and (b) gain vs. wavelength when pumping at 977 nm in a 5.4-cm-long $\text{Al}_2\text{O}_3:\text{Er}^{3+}$ channel waveguide amplifier. (c) Simulated total internal gain vs. amplifier length for a launched 977 nm pump power of 100 mW.

References

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