Integrated Waveguide Amplifiers for Optical Backplanes

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Abstract: Amplifier performance of Nd^{3+}-doped polymer and Al_2O_3 channel waveguides at 880 nm is investigated. Tapered amplifiers are embedded between optical backplane waveguides, and a maximum 0.21 dB net gain is demonstrated.

1. Introduction

As a result of continuous increase of data transmission rates, interconnects between electronic cards via their printed circuit board (PCB) backplane have become a bottleneck in high-end systems. Use of optical waveguides in optical backplanes and motherboards is a possible solution, because these are less sensitive to electromagnetic interference than electrical interconnects and offer the potential of a much larger capacity.

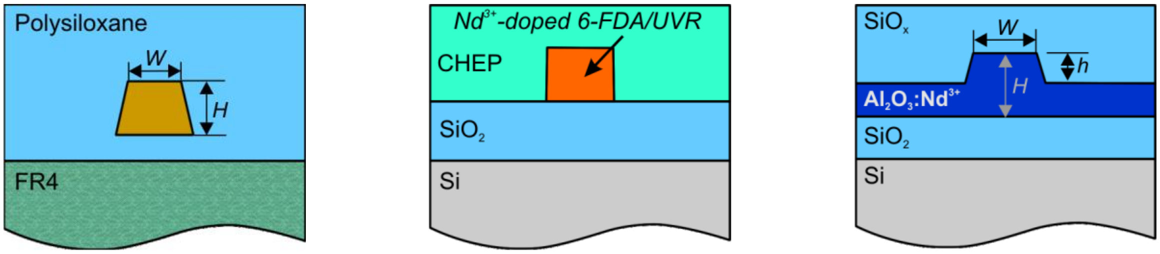
Polymers are promising as a waveguide material in this application due to their low cost and ease of fabrication. Recently, a 12-channel card-to-card optical interconnect link with embedded polymer waveguides and optical signal generation by a diode laser operating at 850 nm (due to the maturity of VCSEL technology at this wavelength) with data transmission up to 10 Gb/s per channel has been reported [1]. Investigations on the optical power budget for polymer-waveguide-based high-speed links via optical backplanes indicate that signal recovery by optical amplification to compensate the optical losses arising due to waveguide materials, signal routing, and input/output coupling is necessary [2].

In this work we investigate the feasibility of using Nd^{3+}-doped polymer and $Al_2O_3:Nd^{3+}$ channel waveguides as amplifiers for optical backplanes. Optical amplification in both materials is analyzed and demonstrator device performance is reported [3].

2. Optical Backplane and Amplifier Waveguides

As the optical backplane waveguide, a polysiloxane-based polymer [4] with the geometry shown in Fig. 1 (a) was fabricated. The refractive indices of the waveguide core and cladding at 850 nm are 1.515 and 1.479, respectively. The minimum thickness (H) of the core layer that can be achieved by spin-coating is ~5-6 µm, while the smallest channel width (W) is ~5-6 µm. The unpolarized propagation loss at 880 nm measured in a 6×6-μm^2 multimode channel waveguide by the cut-back method was 0.34 ± 0.09 dB/cm.

Using a polymer also as host material for waveguide amplifiers was considered first. Active layers were realized by encapsulating rare-earth ions with organic fluorinated ligands to form stable complexes and doping these into a fluorinated polymer host [5]. A neodymium complex, $Nd(TTA)_3phen$ (TTA = thenoyltrifluoroacetone, phen = 1,10-phenanthroline), was synthesized and doped into the fluorinated host 6-FDA/epoxy (6-FDA-fluorinated-dianhydride). The resulting channel waveguide cross-section structure is given in Fig. 1(b).



(a) (b) (c)

Fig. 1. Waveguide cross sections of (a) polymer waveguides embedded in FR4 substrate, (b) 5×5-μm^2 Nd^{3+}-complex- doped polymer channel waveguides, and (c) Nd^{3+}-doped Al_2O_3 waveguides.

As a second waveguide amplifier medium we focused on Al_2O_3, which has been shown to be an excellent host material due to its low loss, good mechanical stability, and – compared to other amorphous dielectric materials – high refractive index (n = 1.66 at λ = 633 nm) [6]. The latter enables more compact waveguide cross-sections and, thus, higher pump intensities, reducing pump-power requirements and allowing high integration density. Furthermore, the compatibility of Al_2O_3 with Si-based technology allows for direct integration with silicon photonic circuits [7]. A general waveguide structure used for channel amplifiers is depicted in Fig. 1(c). We consider two different types of waveguide geometries, single-mode structures of 0.6-µm thickness (H) and width of ~2.0 µm as well as larger-mode structures with a layer thickness of ~3 µm.

3. Optical Gain Investigation

Optical gain was experimentally investigated using a pump-probe method. Small-signal gain of Nd^{3+}-complex-doped polymer channel waveguide amplifiers at 840-950 and $Al_2O_3:Nd^{3+}$ channel waveguide amplifiers at 845-940 were measured. A Ti:Sapphire laser was used as the signal source, while an external-cavity diode laser operating at 800 nm was applied as the pump source.

The measured and simulated internal net gain versus propagation length in two types of channel waveguides with various Nd^{3+} concentrations are given in Fig. 2. For Nd^{3+}-complex-doped 6-FDA/UVR samples, a maximum gain of 2.7 dB and 2.8 dB was demonstrated at 873 nm with Nd^{3+} concentrations of 0.3 and 0.6×10^{20} cm^{-3}, respectively, for a launched pump power of 25 mW, see Fig. 2(a). As depicted in Fig. 2(b), a peak gain of 3.0 dB at 880 nm was obtained in 3.0- and 4.1-cm-long Al_2O_3 waveguides with Nd^{3+} concentrations of 1.13×10^{20} $cm^{-3}$and 0.65×10^{20} cm^{-3}, respectively, at a launched pump power of 45 mW.

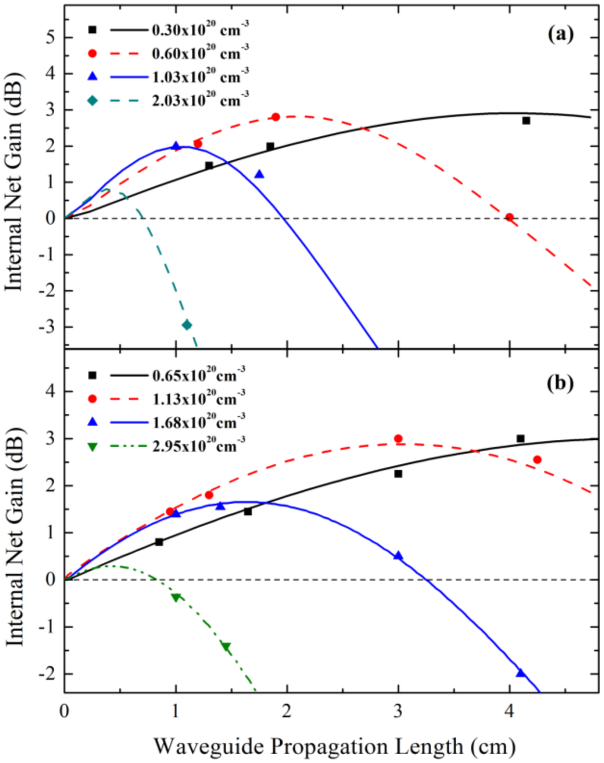


Fig. 2. Measured (dots) and calculated (lines) internal net gain versus propagation length of (a) Nd^{3+}-complex-doped 6-FDA/UVR channel waveguides at 873 nm and (b) $Al_2O_3:Nd^{3+}$ channel waveguides at 880 nm for a launched pump power of 25 mW and 45 mW, respectively.

The gain performance of both materials is similar and each can potentially be optimized for use in optical backplanes. However, Al_2O_3 is preferable to the polymer host due to its better damage threshold at high pump intensity and long-term stability, while we have observed degradation in the polymer structure depending on the absorbed pump power [8]. Therefore, we focus on $Al_2O_3:Nd^{3+}$ waveguide amplifiers to be further optimized for potential integration in optical backplanes.

4. Amplifier Integration

$Al_2O_3:Nd^{3+}$ waveguides were designed to be directly coupled between two polymer waveguides in order to test the performance of waveguide amplifiers in optical backplanes, as depicted in Fig. 3. This approach aimed at demonstrating the feasibility of the concept rather than as a final device geometry.

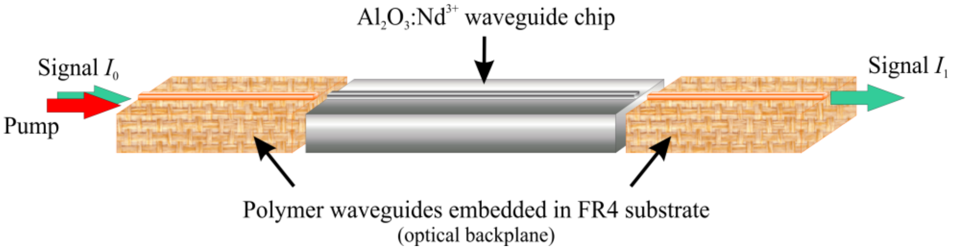


Fig. 3. Schematic of the demonstration of amplification in optical backplanes by coupling an $Al_2O_3:Nd^{3+}$ sample between two polymer waveguide samples.

A peak gain of 3 dB at 880 nm in $Al_2O_3:Nd^{3+}$ amplifiers was achieved in single-mode small-core waveguides. Large geometrical cross sections are favorable for the envisaged application, because the currently developed optical backplanes consist of transverse multi-mode waveguides. The coupling configuration in Fig. 3 was formed and a total net gain of 0.21 dB was measured in a 4-cm-long $Al_2O_3:Nd^{3+}$ with a Nd^{3+} concentration of 0.50×10^{20} cm^{-3} [30]. The total net gain can be further increased by increasing the pump power.

5. Conclusion

The feasibility of using Nd^{3+}-doped polymer and $Al_2O_3:Nd^{3+}$ channel waveguides as amplifiers for possible applications in optical backplanes has been investigated and the latter has been chosen for implementation of an amplifier structure embedded between two polymer waveguides of an optical backplane. A maximum 0.21-dB net gain has been demonstrated in a structure consisting of an $Al_2O_3:Nd^{3+}$ waveguide coupled between two polymer channel waveguides. The gain can be further improved by increasing the pump power, and the wavelength of amplification can be adjusted by doping other rare-earth ions. Therefore, a solution for compensating optical losses in optical interconnects has been provided.

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6. References

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