Optical Waveguide Amplifiers for Heterogeneous Integration in Optical Backplanes

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1. Introduction

Interconnects between electronic cards via their printed circuit board (PCB) backplane have become a bottleneck in high-end systems as a result of the continuous increase of microprocessor clock rates and data transmission rates. Use of optical waveguides in optical backplanes and motherboards is a possible solution, because these are far 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, the feasibility of signal amplification in optical backplanes via integration of Nd³⁺-doped channel waveguide amplifiers is investigated. A maximum 0.21-dB internal net gain is demonstrated in a polymer - tapered Al₂O₃:Nd³⁺ - polymer heterogeneously integrated structure.

2. Optical Backplane and Amplifier Waveguides

Nd³⁺-doped polymer and Al₂O₃ single-mode waveguide amplifiers on Si substrates were investigated at the first optical communication window; similar optical gain of ~2 dB/cm was demonstrated [3, 4]. In Al₂O₃:Nd³⁺ the waveguide geometry was then optimized to a multi-mode, large-core, 8-μm-wide by 3-μm-thick cross section for minimizing the coupling losses to the 6×6 μm² polymer optical backplane waveguides provided by IBM Research - Zurich (Fig. 1). By use of a waveguide structure horizontally tapered down to 2.5 μm (Fig. 2a) in order to increase the pump intensity and heterogeneously coupling this Al₂O₃:Nd³⁺ tapered waveguide amplifier to either one or in between two polymer optical backplane waveguides (Fig. 2b), a maximum gain of 0.87 dB (Fig. 2c) and 0.21 dB, respectively, was demonstrated for light propagating through the complete structures [5]. The coupling losses were 1.33 dB and ~0.5 dB at the first and second interface. This result demonstrates that heterogeneous integration of optical waveguide amplifiers provides a potential solution for compensating losses in optical interconnects.

Fig. 1. Waveguide geometries (from left to right): schematic of the cross section of (a) polymer and (b) Al₂O₃:Nd³⁺ waveguides; (c) optical microscope image of a polymer waveguide and (d) scanning electron microscope image of an Al₂O₃ channel waveguide without upper cladding.
Polymer waveguide from IBM

Al₂O₃:Nd³⁺ waveguide

Signal

I₀

Pump

Signal

I₁

(a)

(b)

(c)

Fig. 2. (a) Top view of an Al₂O₃:Nd³⁺ tapered waveguide; (b) schematic of the demonstration of amplification in optical backplanes by coupling an Al₂O₃:Nd³⁺ waveguide to two polymer waveguides; (c) internal net gain of a polymer waveguide coupled with an Al₂O₃:Nd³⁺ waveguide versus propagation length in the Al₂O₃:Nd³⁺ waveguide for different Nd³⁺ concentrations.

Preliminary investigations of Al₂O₃ waveguide amplifiers for use in future single-mode optical backplanes operating at the second and third optical communication windows have been performed. A net internal optical gain of 5.1 dB [4] and 9.3 dB [6] at 1330 in Al₂O₃:Nd³⁺ and 1530 nm in Al₂O₃:Er³⁺, respectively, was demonstrated for non-optimized waveguide structures in Al₂O₃. In the latter device, high-speed amplification of 170 Gbit/s has been reported [7], demonstrating that rare-earth-ion-doped amplifiers are well suited to provide signal recovery in optical data transmission.

3. Conclusions

Large-core, tapered Al₂O₃:Nd³⁺ channel waveguides have been fabricated and optical amplification at a wavelength of 880 nm has been characterized. Amplification in optical backplanes has been demonstrated by inserting such Al₂O₃:Nd³⁺ channel waveguides in between two polymer waveguides. A maximum 0.21-dB internal net gain has been demonstrated in an Al₂O₃:Nd³⁺ waveguide coupled in between two polymer channel waveguides. The gain can be improved by increasing the pump power and adjusting the waveguide geometry and dopant concentration for the chosen pump power. Use of such rare-earth-ion-doped waveguide amplifiers can provide a solution for compensating the losses occurring in optical interconnects.

4. Acknowledgments

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5. References