Integrated Al_2O_3:Er^{3+} DFB Laser for Temperature Control Free Operation with Silicon Nitride Ring Filter

Purnawirman,[1] E. Shah Hosseini,[1] M. Moresco,[1] Z. Su,[1] E. Timurdogan,[1] A. Baldycheva,[1] J. D. B. Bradley,[1] J. Sun,[1]
T. Adam,[2] G. Leake,[2] D. Coolbaugh,[2] and M. R. Watts[1]
[1]Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA
[2]College of Nanoscale Science and Engineering, University at Albany, 257 Fuller Road, Albany, New York 12203, USA
Author e-mail address: purna@mit.edu

Abstract: We demonstrate almost synchronized temperature dependent wavelength shift of Al_2O_3:Er^{3+} DFB laser (2.57 GHz/^{o}C) and Si_3N_4 ring filter (2.47 GHz/^{o}C), which makes it possible for on-chip transceiver operation without temperature control.
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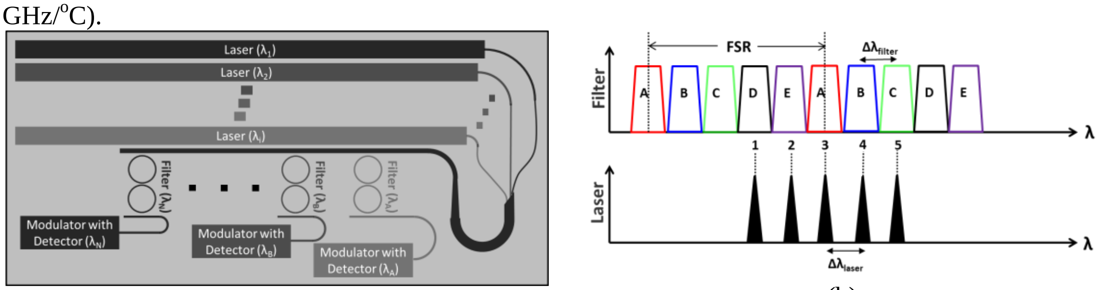
1. Introduction

Temperature insensitive operation of optical interconnects has been actively investigated in recent years[1, 2]. Erbium-doped aluminum oxide laser (Al_2O_3:Er^{3+}) and silicon nitride (Si_3N_4) filter are promising components for optical transceiver. Both have demonstrated CMOS compatibility and excellent thermal properties [3]. In addition, Al_2O_3:Er^{3+} laser have been shown to achieve ultra-narrow linewidth [4] and high power [5] in distributed feedback (DFB) configuration. By using multiple DFB lasers and ring filters with equal channel spacing ($\Delta\lambda_{laser}$= $\Delta\lambda_{filter}$), we propose an optical transceiver scheme as shown in Fig. 1. The outputs from N number of regularly spaced lasers are combined into one waveguide. This waveguide is then passed through N filters with each output proceed to the modulator and detector for that wavelength. If the channels span across entire free spectral range (FSR), then there would be a one-to-one correspondence of the laser and the filter. Furthermore, a temperature control free operation is possible since both Al_2O_3:Er^{3+} lasers and Si_3N_4 filters have small and almost equal thermal characteristics.

In this paper, we demonstrate Al_2O_3:Er^{3+} DFB laser integrated with Si_3N_4 photonics platform. We obtain a 115-GHz Si_3N_4 ring filter with 30 µm bend radius and maximum uncooled output power of 0.18 mW in the DFB laser. The measured temperature dependent wavelength shift of the laser (2.57 GHz/^{o}C) is comparable to the ring filter (2.47 GHz/^{o}C).



(a) (b)

Fig. 1. (a) Conceptual diagram of the proposed Al_2O_3:Er^{3+} lasers and Si_3N_4 filters-based optical transceiver. (b) Schematic responses of drop ports and laser outputs from five filters and DFB lasers, respectively. If the wavelength spacing is equal ($\Delta\lambda_{laser}$= $\Delta\lambda_{filter}$), there would be a one-to-one correspondence of the laser and the filter, e.g. 1 to D, 2 to E, 3 to A, 4 to B, and 5 to C.

2. Design and fabrication

The filter measured in this paper consists of two PECVD Si_3N_4 rings (radius R = 30 µm), both at the same thicknesses of 200 nm and widths of 1 µm. The nitride layers are separated by 100 nm SiO_2. The filter is coupled symmetrically from both sides by bus waveguides made from two Si_3N_4 waveguides of widths 1 µm at equal gap distances of 200 nm.

The DFB laser waveguide (Fig. 2. (a)) consists of five segments [6] of 200 nm LPCVD Si_3N_4 core buried in silicon dioxide (SiO_2), a 200 nm SiO_2 gap between Si_3N_4 and 1.1 µm Al2O3:Er3+ film. The multi-segmented Si_3N_4 waveguide was designed with the following parameters: thickness t = 200 nm, width w = 600 nm, and gap g = 400 nm. The intensity distribution of the fundamental TE mode at pump and signal wavelengths is shown in Fig. 2. (b). The confinement factors in the active medium for pump and signal wavelengths were calculated to be 73% and 79%, respectively. These modes have almost perfect overlap factor (99%) in Al_2O_3:Er^{3+}. The DFB cavity consists of grating across the entire gain region, with the grating formed by periodic additional side pieces with w_{DFB} = 300 nm and g_{DFB} = 550 nm. The total length of the DFB is L_{DFB} = 20 mm. The quarter-wave phase shift of the DFB was designed to be slightly off from the center of the cavity (0.4 L_{DFB}) so as to ensure lasing out of a single facet. Fig. 2. (c) shows the top view of the DFB structure.

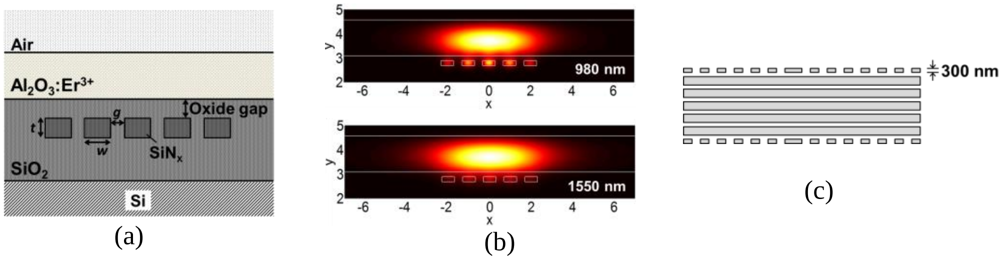


Fig. 2. (a) Schematic of the five-segment waveguide design. (b) The calculated intensity of fundamental TE mode at 980 nm (pump) and 1550 nm (signal). (c) Top view of the DFB laser structure.

3. Measurement results

The DFB laser was pumped by using two 978 nm diode lasers. We obtained maximum uncooled on-chip power of P_{max} = 0.18 mW and slope efficiency of η = 2.7%. The threshold pump power is P_{th} = 14 mW. The DFB output is centered around 1565 nm. On the other hand, the ring filter has 3dB bandwidth of 114 GHz at 1567 nm.

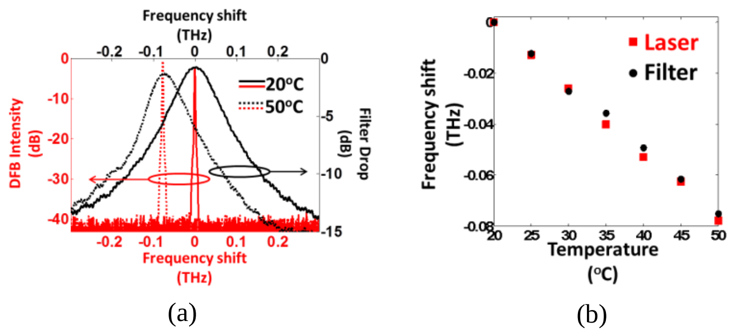


Fig. 3. (a) The spectra of $Al_2O_3:Er^{3+}$ DFB laser outputs and Si_3N_4 ring filter drop responses at 20°C and 50°C. (b) Plot of frequency shift of the laser and filter at various temperatures.

We measured the spectra of the DFB outputs and drop responses at various temperatures. In Fig. 3. (a), we aligned the laser and filter spectra plot at 20°C. The temperature dependent frequency shifts are then compared at 50°C. The frequency change is almost synchronized, demonstrating the potential for on-chip optical transmitter operation without temperature control. A finer measurement of the frequency shifts at various temperature points is shown in Fig. 3. (b). The fitting of the frequency shift of the $Al_2O_3:Er^{3+}$ laser (2.57 GHz/°C) is measured to be within 4% difference from the Si_3N_4 ring filter (2.47 GHz/°C).

4. Conclusions

We proposed a temperature control free optical transceiver by using $Al_2O_3:Er^{3+}$ DFB laser and Si_3N_4 ring filter. The temperature dependent frequency shift of the laser is shown to be almost synchronous with the ring filter over temperature range of 20°C to 50°C.

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