

Monolithic Integration of WDM Light Source for Silicon Photonics by Cascade of Al₂O₃: Er³⁺ DFB Lasers

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Abstract: We demonstrate a monolithic integration of WDM light source for silicon photonics by cascade of Al₂O₃: Er³⁺ DFB lasers. Simultaneous operation of four channels is achieved with $d\lambda/dT = 15.3 \pm 0.1$ pm/°C temperature dependent wavelength shift.

OCIS codes: (130.0130) Integrated optics; (130.3120) Integrated optics devices; (140.3460) Lasers.

1. Introduction

The development of silicon photonics technology provides a compact and wafer scale solution for optical interconnects in high performance computing systems. In addition, the wavelength division multiplexing (WDM) architecture could enable the utilization of broad optical bandwidth for high traffic data transmission. Several research groups have demonstrated WDM transmitter sources of up to 16 channels by bonding of III-V gain material onto the silicon chip [1-3]. However, these hybrid devices often involve complex fabrication steps with yield challenges and thermal management issues. An alternative solution for on-chip light source is rare earth doped glass on silicon. Monolithic integration of erbium doped aluminum oxide (Al₂O₃: Er³⁺) lasers has been demonstrated in a CMOS compatible process. Quarter phase shift distributed feedback (DFB) Al₂O₃: Er³⁺ lasers have been shown to achieve high power, low noise, and good thermal stability [4]. In this paper, we demonstrate a monolithic WDM source by cascading four Al₂O₃: Er³⁺ DFB lasers. We achieve simultaneous operation of four channels at an average power of -16.9 dBm and > 38.1 dB side mode suppression ratio (SMSR). The temperature dependent wavelength shift ($d\lambda/dT$) is 15.3 ± 0.1 pm/°C across all four channels.

2. Cascaded DFB Lasers

Fig. 1 (a) shows the design of the cascaded DFB structure from the top view. It consists of four DFB lasers cascaded in series with length of each laser $L_{DFB} = 5.5$ mm, distance between each laser $L_{spacing} = 100$ μm, and base period $\Lambda_1 = 490$ nm with 2 nm-subsequent increment ($\Lambda_2 = 492$ nm, $\Lambda_3 = 494$ nm, $\Lambda_4 = 496$ nm). Due to the low emission noise and thermal fluctuation of the erbium laser, this platform allows the close placement of four different channels in series configuration without any significant cross talk. The right output from DFB₁ propagates to the next laser DFB₂, and so on to the right end of the structure. The combined output consists of the WDM of four different wavelengths. From the symmetrical design of the DFB lasers, the same WDM output is obtained at the other end of the structure.

We use the multi-segmented waveguide design to construct the guiding structure [5], as shown in Fig. 1 (b). The waveguide consists of five segments of silicon nitride (SiN_x) structure as the main guiding component, with the periodic perturbation introduced by etching the left-most and right-most segments. These waveguides are fabricated in a CMOS foundry with process described previously [5]. The gain medium is deposited in-house as the final backend step. The dimensions of the waveguide is given by the following, thickness of SiN_x $t = 200$ nm, width of SiN_x $w = 450$ nm, gap of SiN_x $g = 400$ nm, oxide gap of 200 nm, thickness of Al₂O₃: Er³⁺ $t_{AlO} = 1100$ nm. The confinement factor of the pump and signal in the gain layer is calculated to be 89% and 90% respectively, with almost perfect intensity mode overlap (>95%).

We measure the transmission response of the cascaded DFB structure by using a tunable laser, as shown in Fig. 1 (c). The transmission response of each DFB structure is well separated with no cross talk observed. The quarter phase shift induced resonance at each DFB is measured to have Q in the range of 1 to 2 x 10⁵, with the longer wavelength exhibiting higher Q due to being further away from the peak erbium absorption at 1532 nm.

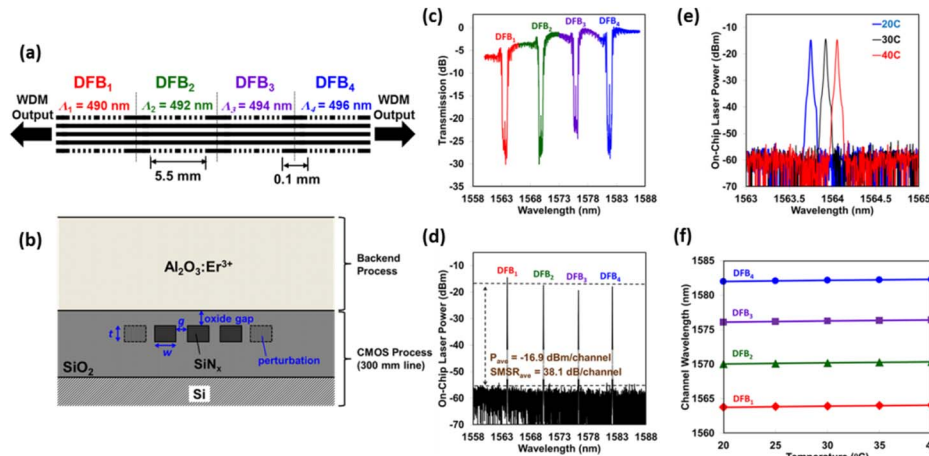


Fig. 1. (a) Top view of cascade of four DFB lasers design. (b) Cross sectional view of multi-segmented waveguide design. The fabrication process is CMOS compatible, with the deposition of Al₂O₃:Er³⁺ film as the last backend step. (c) Transmission measurement of the cascaded DFB structure at zero pump power. (d) Emission spectrum of cascaded DFB lasers with on-chip pump power of 190 mW. (e) Spectrum of the first channel of cascaded DFB lasers at temperature 20°C, 30°C, and 40°C. (f) All four channel wavelengths at varying temperatures from 20°C – 40°C. The channels exhibit temperature dependent shift is $d\lambda/dT = 15.3 \pm 0.1$ pm/°C.

The cascaded DFB lasers are pumped by using two laser diodes at 978 nm and 976 nm from both sides. The on-chip pump powers of the 978 nm and 976 nm diodes are 120 mW and 70 mW, respectively. The cascaded laser output is measured by using Optical Spectrum Analyzer (OSA) on both sides. The output is monitored using two optical spectrum analyzers (OSA) on both sides. We obtain laser wavelengths centered at 1563.92 nm, 1570.20 nm, 1576.28 nm, and 1582.16 nm, slightly higher than the passive transmission measurement due to local heating by pump absorption. The peak output powers obtained in the left (and right) OSA for the four DFBs are as follows: -17.7 dBm (-17.4 dBm), -20.4 dBm (-20.2 dBm), -22.1 dBm (-22.6 dBm), -19.1 dBm (-24.0 dBm). The average power is -16.9 dBm with >38.1 dB SMSR. Fig. 1 (d) shows the spectrum of the cascaded DFB lasers. The uniformity of the output power can be improved by a careful design of the grating strength and ratio of the pump power.

We perform a temperature dependent test of the lasers by placing the chip on a TEC. The TEC temperature can be adjusted from 20°C to 40°C by varying the current level. Fig. 1 (e) shows the spectrum of the first channel at temperatures of 20°C, 30°C, and 40°C. No significant change of the output power has been observed at varying temperatures, demonstrating thermal stability of the monolithic erbium-doped gain medium. Fig. 1 (f) shows the wavelengths of all four channels at varying temperature. A nearly uniform temperature dependent shift of $d\lambda/dT = 15.3 \pm 0.1$ pm/°C is observed for all the channels.

3. Summary

We demonstrate monolithic integration of a WDM light source in a silicon photonics platform by cascade of Al₂O₃:Er³⁺ DFB lasers. Simultaneous operation of four channels has been achieved with an average power of -16.9 dBm (> 38.1 dB SMSR), and a small temperature dependent shift $d\lambda/dT = 15.3 \pm 0.1$ pm/°C.

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4. References

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