Demonstration of a hybrid III-V/Si multi-wavelength DFB laser for high-bandwidth density I/O applications

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Abstract: We demonstrate a 4-wavelength DFB laser with >8dBm output power per wavelength, <±0.5dB power variations, 140GHz wavelength spacing, and <-140dB/Hz RIN. For data transmission at 64 Gb/s, we obtained comparable performance to a benchtop laser.

1. Introduction

Emerging silicon photonics based optical I/O technology requires multi-wavelength laser sources to support high data rates for advanced optical communication and computing applications [1]. These multi-wavelength lasers are a crucial part of the optical transmitter and will enable improvements in performance, efficiency, cost, and bandwidth scaling. These laser sources can be achieved by combining multiple single wavelength lasers using a wavelength combiner [2], using quantum dot lasers [3], frequency combs [4], or mode-locked lasers [5].

In this paper, we report a single distributed feedback (DFB) laser that produces 4 wavelengths simultaneously with a wavelength spacing of 140 GHz. Therefore, no wavelength combiner or multiplexer is needed to combine wavelengths from individual lasers, saving space and cost. Compared to other multi-wavelength laser sources, the wavelength spacing, and the number of wavelengths can be controlled by design, allowing more efficient use of the total laser power. The hybrid III-V/Si 4-wavelength laser was fabricated in a CMOS compatible process with >8 dBm on-chip power per wavelength and <-140 dB/Hz relative intensity noise (RIN). It can be integrated with other silicon photonic components such as modulators and detectors for high-bandwidth density optical I/O applications.

2. Laser Design and Characterization

The laser was fabricated in Intel's silicon photonics fab [6, 7] and was designed to emit four wavelengths. We designed the DFB laser with 4 quarter-wave phase shift sections corresponding to the 4 wavelengths. The wavelength spacing was controlled through the change in effective index by tapering the waveguide width while keeping the grating pitch constant. The schematic of the laser is shown in Fig. 1, where phase shifts (PS) indicate the defect locations producing the four wavelengths.

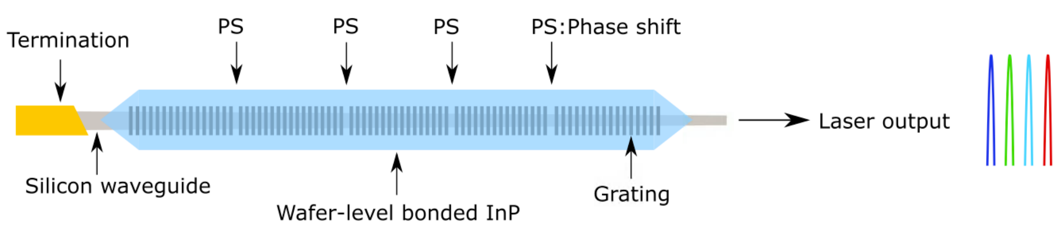


Fig. 1: Schematic of the 4-wavelength hybrid InP/Si DFB laser. The phase shifts (PS) are shown as the defect locations.

Figure 2(a) is the measured L-I curve of the laser showing the threshold current of 20 mA, and the total power of >14 dBm at 200 mA bias. The optical spectrum of the laser is shown in Fig. 2(b), demonstrating four distinct wavelengths [$\lambda_1 - \lambda_4$], separated by 140 GHz. The power difference between the highest and lowest wavelength was measured to be 0.5 dB.

One of the main concerns of quantum-well-based multi-wavelength lasers is the mode-partition noise due to mode-competition between lasing modes [8]. To investigate the intensity noise of this laser, we filtered out individual wavelengths using a tunable optical bandpass filter and measured the RIN for all four wavelengths. Filtered wavelengths are shown in Fig. 3(a), demonstrating close to 50 dB suppression of the other wavelengths. The measured RIN for all four wavelengths is shown in Fig. 3(b) to be <-140 dB/Hz, meeting the RIN requirements for multi-wavelength laser sources [1]. The small peaks seen in Fig. 3(b) at approximately 1.5 GHz, 8 GHz, and 9.5 GHz are due to the four-wave mixing effect in the silicon waveguide. They are more than 30 dB below the main lasing modes, also meeting the MSA requirements [1]. In addition, we measured the frequency noise of each lasing mode of the laser and obtained Lorentzian linewidth of <300 kHz for each of the four wavelengths.

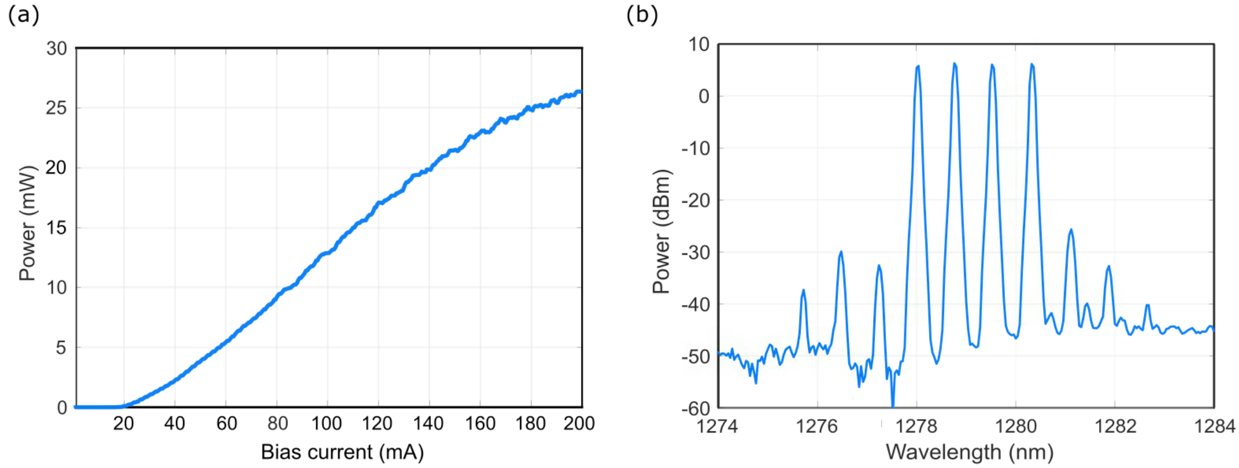


Fig. 2: (a) The total output power of the laser vs. bias current (L-I) curve for all four wavelengths, showing a threshold of 20 mA and total on-chip power of 27 mW at 200mA bias current. (b) The optical spectrum of the laser, showing four wavelengths. All measurements were done at 30 °C.

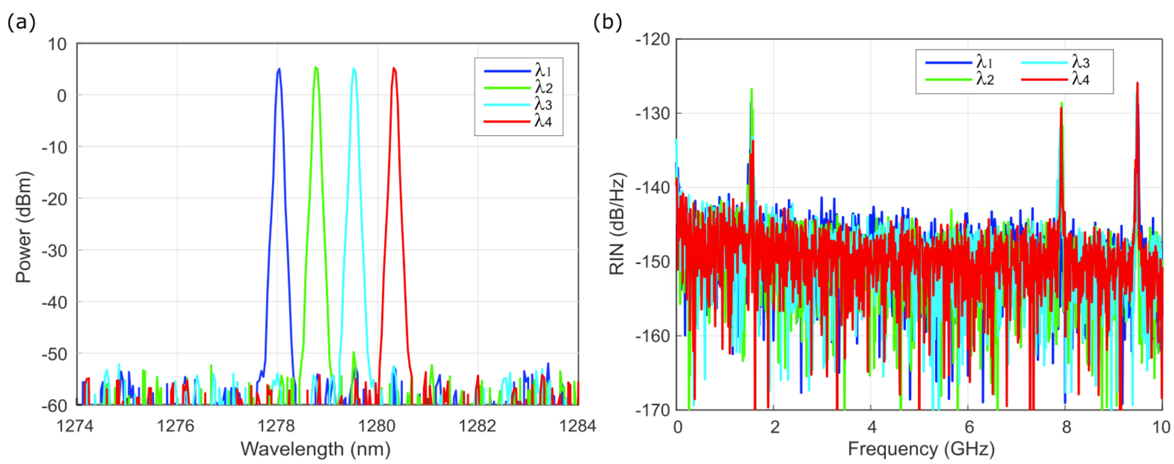


Fig. 3: (a) Filtered spectra of all four wavelengths for RIN measurements. (b) RIN of all four wavelengths up to 10 GHz at 120 mA bias current.

3. High-speed data transmission measurements

We performed a high-speed data transmission experiment to benchmark the performance of this laser as a DWDM light source against a commercial benchtop tunable laser. We used a high-speed micro-ring modulator [9] and performed two experiments. In the first experiment, we coupled the output of the laser with all 4 wavelengths into the ring modulator chip as shown in Fig. 4(a). The output from the ring modulator was amplified by an optical amplifier (PDFA), and the modulated wavelength was filtered out using an optical bandpass filter. This configuration represents a practical use-case in a DWDM optical communication link where channel filtering occurs before the optical receiver. In the second experiment, we replaced our multi-wavelength laser with a commercial tunable laser and used the same ring modulator and PDFA in the link as shown in Fig. 4(b). In both cases, we used the same operating conditions for the ring modulator and ensured that the receiver received the same optical power. We drove the ring modulator with 64 Gb/s PRBS data for both the 4-wavelength laser and the tunable laser. As shown in Fig. 5, we measured the eye diagrams and obtained a signal-to-noise ratio (SNR) of 5.9 and extinction ratio (ER) of 4.4 dB with the 4-wavelength laser, and an SNR of 5.8 and ER of 4.3 dB with the tunable laser. Within the measurement uncertainties, we saw no differences in transmitter performance between the two lasers.

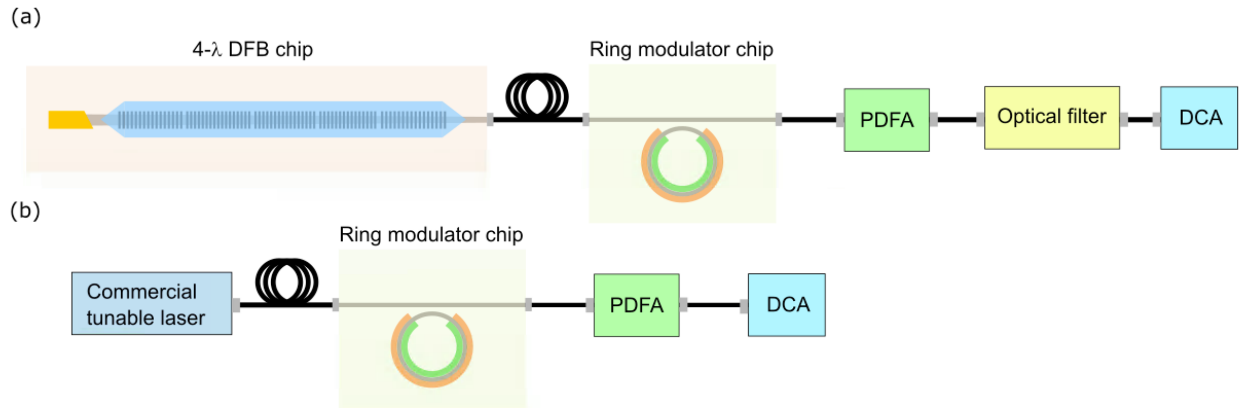
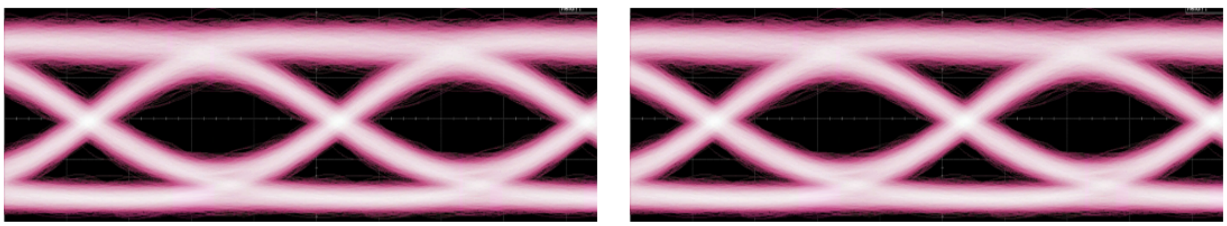


Fig. 4: Schematic of the high-speed data transmission experiment set-up with (a) the 4-wavelength DFB laser, and (b) a commercial tunable laser.



(a) SNR = 5.9, ER = 4.4 dB, Vpp = 1.6 V (b) SNR = 5.8, ER = 4.3 dB, Vpp = 1.6 V

Fig. 5: 64 Gb/s NRZ eye diagrams with (a) single wavelength channel out of the 4-wavelength DFB laser, and (2) the commercial tunable laser under comparable experimental conditions.

4. Conclusion

We have demonstrated a 4-wavelength hybrid III-V/Si DFB laser fabricated in Intel's high-volume silicon photonics fab. We have achieved >14 dBm total output power for all 4 wavelengths with 140 GHz spacing and <±0.5 dB power variations. The laser also shows excellent relative intensity noise of <-140 dB/Hz and Lorentzian linewidth of <300 kHz. In a high-speed data transmission experiment, the 4-wavelength DFB laser showed comparable performance to a commercial benchtop laser. These results indicate that this type of laser is an excellent candidate for multi-wavelength sources targeting low-cost and high-bandwidth density optical I/O applications.

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5. References

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