Demonstration of Athermally Synchronized Distributed Feedback Laser with Microring Filter

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Abstract: We demonstrate an athermally synchronized distributed feedback laser cascaded with microring filters on a silicon photonic platform, with >10dB extinction ratio and a synchronized wavelength shift of 0.02 nm/ °C from 20 to 50 °C.

OCIS codes: (130.3120) Integrated optics devices; (140.3500) Lasers, erbium; (130.7408) Wavelength filtering devices.

With an increasing demand for bandwidth, optical interconnects based on silicon photonic technology have been extensively studied to overcome the limits of electrical interconnects [1, 2]. In an optical interconnect circuit, microring resonators (MRR) are commonly used as multiplexers within wavelength division multiplexing (WDM) systems. However, the resonant wavelength of the MRR should be matched to the laser wavelength at all operating temperatures. Although the wavelength of the MRR can be controlled by using thermal tuning [3], the power consumption to align the wavelengths of many MRRs is significant in a high-channel count WDM system. To overcome this problem, the MRR resonant wavelength can be matched to the laser wavelength and have the same thermal wavelength shift as the laser source, therefore, achieving system-level temperature control-free operation without the need for additional tuning power.

Prior to this work, on-chip lasers have been demonstrated using rare-earth elements doped in Al_2O_3 as gain media [4, 5]. The low thermo-optic coefficient of Al_2O_3 enables lasing operation over a wide temperature range. Furthermore, compare to III-V material systems [6], laser cavities that utilize Al_2O_3 can have a similar overall thermal response as other Si_3N_4 devices on the chip such as a MRR filter [7]. This makes it possible to achieve a control-free operation WDM system consisting of a laser source and a wavelength filter over a wide temperature range. In this paper, we demonstrate a distributed feedback (DFB) laser cascaded with Si_3N_4 MRRs on the same chip and show that the system is athermal. We achieve >10 dB power extinction ratio (between matched laser-MRR channel and unmatched channel) from 20 to 50 °C due to a laser-MRR synchronized wavelength shift of 0.02 nm/°C.

The waveguide cross-section of the DFB laser is shown at the top of Fig. 1(a). The width and gap of the Si_3N_4 pieces are selected to be 600 nm and 400 nm respectively to provide high mode confinements for both 980 nm pump and 1550 nm signal modes within the $Al_2O_3{:}Er^{3+}$ film. The height of each Si_3N_4 piece is 200 nm. The gap between the Si_3N_4 and Al_2O_3 layers is 200 nm. An 1100 nm thick $Al_2O_3{:}Er^{3+}$ film is deposited on top via reactive co-sputtering. The DFB cavity is formed by adding Si_3N_4 pieces alongside the waveguide with width of 400 nm, duty cycle of 0.5, and period of 487 nm. The total length of the DFB laser is 2 cm. At the end of the DFB, a transition is designed to adiabatically couple the mode from DFB gain waveguide into a double layer Si_3N_4 waveguide, which is coupled to the double layer Si_3N_4 MRRs. The MRR waveguide has a width of 1 µm, and a height of 200 nm for each layer, with 100 nm oxide gap in between. The fabrication process of the wafer is reported in [8]. In order to ensure DFB and MRR wavelength matching, 16 MRRs with diameters ranging from 90 µm to 90.36 µm are placed along the Si_3N_4 waveguide. The drop ports of the MRRs are used to couple out the laser signal. The characterization setup of the on-chip system is shown in Fig. 1(b). A 980 nm pump source together with a polarization controller is used to couple the

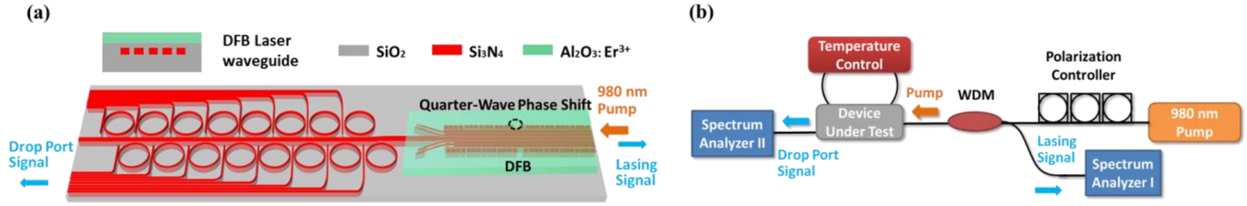

Figure 1 (a) Sketch of the system, including DFB laser cascaded with Si_3N_4 MRRs, and cross section of the laser gain waveguide (not to scale). **(b)** Characterization setup: 980 nm laser diode pump source together with polarization controller to ensure the fundamental TE mode is coupled into the $Al_2O_3{:}Er^{3+}$ DFB laser. Optical spectrum analyzers I and II are used to monitor the DFB laser output and MRR drop port signal, respectively. Temperature control feedback loop is used to modify and monitor the temperature of the system.

pump signal into the fundamental TE mode of the laser gain waveguide. An external WDM is used to couple out the lasing signal from the pump side of the DFB for analysis. Optical spectrum analyzers I and II are used to monitor the signal from the DFB laser and the MRRs, respectively. TEC temperature control with a feedback loop is implemented to modify, monitor and stabilize the operating temperature of the system.

In order to select the MRR whose response matches with the DFB laser wavelength, the drop ports of 16 MRRs are tested. The optical power of the matched MRR (channel 1) and the two nearby MRRs (channel 2 and 3) are recorded while altering the chip temperature (Fig. 2(a)). More than 10 dB power extinction between channel 1 and nearby channels is observed within the temperature range from 20 to 50 ^{o}C showing athermal operation in this range. As the temperature is set beyond 50 ^{o}C, the power in channel 1 drops by more than 5dB, due to the wavelength mismatch between the MRR and the DFB, shown in Fig. 2(b). The spectrums from the laser (monitored by spectrum analyzer I) and from the channel 1 MRR drop port (monitored by spectrum analyzer II) are shown in Fig. 2(c) and (d), respectively, at different temperatures. A 0.2 nm wavelength shift is observed in each for a 10 ^{o}C temperature change. To further characterize the system, the passive response of the DFB laser cavity together with the MRR is obtained by measuring the transmission spectrum using an Agilent tunable laser. Fig. 2(e) shows the response of the DFB cavity with the channel 1 output at different temperatures. The system resonance peaks around 1547 nm and 1557 nm are contributed by the response of the MRR. Around 1552 nm, there is no resonance peak in the system since the response of the MRR cancels with the DFB lasing response. For comparison, the passive response of the DFB cavity together with the channel 3 MRR, which is not matching, is shown in Fig. 2(f). At each temperature, 3 orders of resonance are observed instead of 2. Furthermore, a wavelength shift of 0.2 nm is observed for a 10 ^{o}C temperature change, which matches the lasing wavelength change.

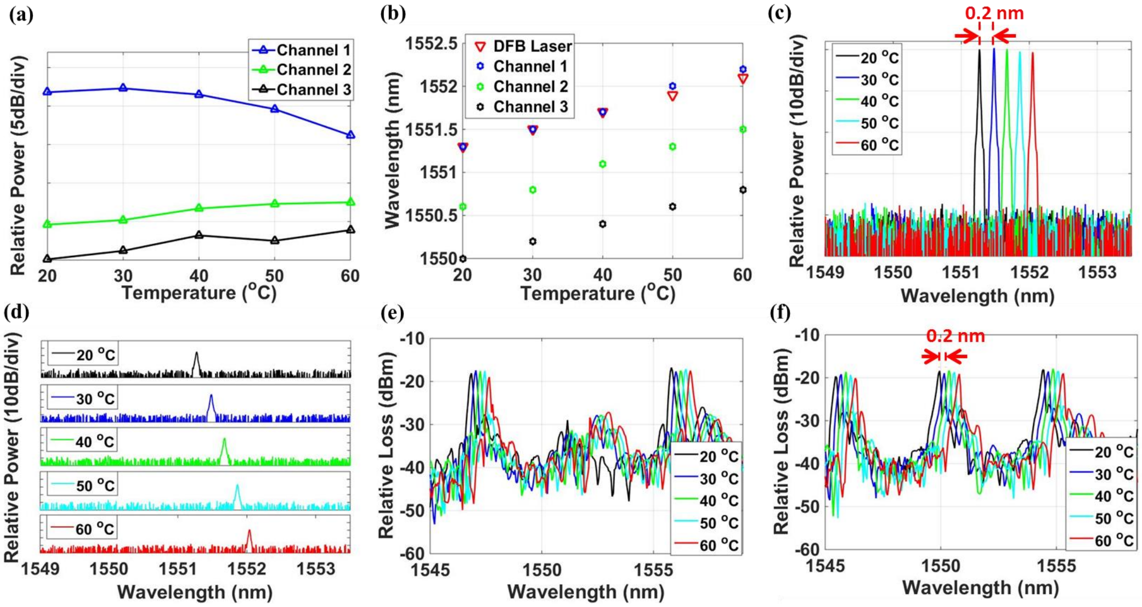

Figure 2 (a) Drop port power comparison between matched MRR (channel 1) and two nearby channels (channel 2 and 3) at different temperatures. **(b)** Resonant wavelength of DFB cavity and three channels. **(c)** Lasing spectrum monitored by spectrum analyzer I. **(d)** Channel 1 drop port spectrum monitored by spectrum analyzer II **(e)** and **(f)** Passive response of DFB together with channel 1 and 3 respectively

In conclusion, we have demonstrated an athermally synchronized operation of an integrated DFB laser cascaded with Si_3N_4 MRRs over a temperature range from 20 to 50 ^{o}C within a silicon photonic platform. A power extinction ratio of >10 dB between matched and unmatched channels is achieved, and a synchronized wavelength shift of 0.02 nm/^{o}C is reported.

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