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Single mode tunable lasers are essential components for applications such as classical/quantum communications, sensing and metrology. We report on a monolithically integrated single mode tunable laser with 53 kHz linewidth operating around 1550nm, designed and fabricated in a generic InP integration platform. The laser cavity consists of two ring filters and an asymmetric Mach-Zehnder (MZ) filter, connected via two 1×3 MMI couplers. The laser LIV characteristics, optical output spectra, power spectral density of the phase noise and the tunability map of the laser are presented.

Introduction

Low linewidth and tunable lasers are key components in various applications. Coherent communications rely on low linewidth, frequency stabilized lasers to modulate and de-modulate phase encoded optical signals [1], where the requirement of the spectral stability gets more stringent as the modulation order increases [2, 3]. The laser linewidth affects the transmission rate in both continuous-variable (CV-QKD) [4] and discrete-variable quantum key distribution (DV-QKD) [5]. Low-linewidth and accurate tuning of the wavelength are crucial features for lasers to be used in technologies such as OCT [6], frequency modulated continuous wave LiDAR [7], or quantum sensing, where the lasers are required to precisely match the energy of atomic transitions [8,9].

Improving the spectral output of a monolithically integrated DBR laser using an intra-cavity ring resonator is studied in [10], resulting in a minimum intrinsic linewidth of 63kHz and a side-mode-suppression ratio (SMSR) of more than 60dB. Another example of a monolithically integrated low-linewidth integrated semiconductor DBR laser is demonstrated in [11], reducing the linewidth down to 10kHz by coupling with an extended passive Fabry-Perot resonator, while having a SMSR of 54dB. Further reducing the linewidth of tunable semiconductor lasers through hybrid [12] and heterogeneous [13] integration has been shown, resulting in linewidths on the order of 100Hz. Additionally, lasers with increased wavelength tuning range have been shown using intra-cavity Mach-Zehnder interferometers (MZI) [14], and through selective are growth [15], which are promising components for applications such as optical gas sensing.

Using the vernier effect of multiple cavities with long optical lengths has been shown to result in low linewidth, while increasing the required complexity in accurate and continuous wavelength tuning. Asymmetric MZI filters provide less complexity in wavelength tuning, while compromising the linewidth due to the lower quality factor of the filters. In this work, we report on a novel laser cavity design, which combines two rings and a MZI filter to provide low-linewidth and wide tunability across the C-band. The laser is monolithically integrated in the generic InP platform of Smart Photonics [16], and is able to achieve 53kHz linewidth and 58dB SMSR.

Laser Design

Figure 1(a) shows the schematic of the laser, which consists of a 500µm long semiconductor optical amplifier (SOA) section, connected to two ring/racetrack resonators via 1×3 multi-mode interference (MMI) couplers on both sides. Since each coupler in the cavity is expected to result in additional unwanted reflections and losses,

the choice of using 1×3 MMIs is made to minimize the number of couplers, while ensuring proper connectivity to each filter. One of the rings have an additional coarse-wavelength filter based on an asymmetric MZI, connected through 2×2 MMI couplers.
The laser cavity is designed with a goal of maximizing the photon lifetime, while having sufficient spectral filtering with a high quality-factor to provide single mode output with low linewidth [17]. The ratio between the length of the two ring filters are designed based on their respective comb spectra, and how the peaks of these spectra overlap. The resulting response of the combined filters is simulated and shown in Figure 1 (b). Around the most prominent peak, the two highest neighboring peaks are at a distance of 0.84nm and 1.31nm, each having 5% lower power. The distance between two resonant modes allows the use of an asymmetric MZI filter to provide enough suppression for the neighboring modes around the desired wavelength.

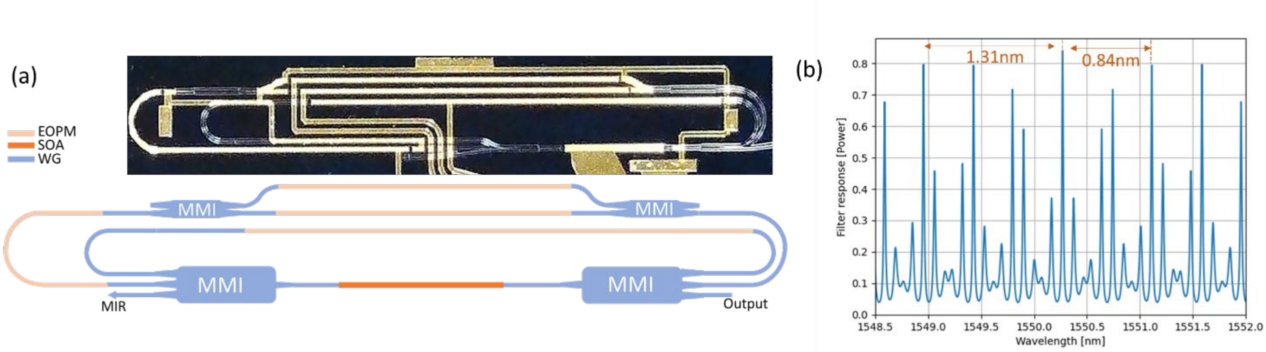

Figure 1- (a) Schematic of the laser (inset: the microscope image of the fabricated chip)
(b) Simulated spectral response of the laser cavity

The two rings, and the asymmetric MZI include electro-optic phase modulator (EOPM) sections in order to control the spectral location of their respective modes. The two ring EOPMs are designed to provide precise control and continuous tuning for the laser emission wavelength across smaller regions, where the asymmetric MZI filter is designed to provide wide tunability across the full emission spectrum of SOA. Fine-tuning of the wavelength through the control of only two voltage signals promises to offer low complexity in the characterization and modeling of the laser wavelength. The third output of the 1×3 MMI on the left-hand side has a multi-mode interference mirror (MIR) to ensure uni-directionality, and the third output of the right-hand side 1×3 MMI is the output of the laser. The laser is fabricated in the generic platform of Smart Photonics and have a 1.2mm^2 footprint. Inset in figure 1(a) shows a microscope image of the fabricated chip including the laser.

Characterization Results

Figure 2(a) shows the LIV characteristics of the fabricated laser, measured at 17 °C. The threshold current is at 38mA. The output power from the laser, coupled out using a lensed fiber is measured as 0.4mW for a pump current of 120mA.
The figure 2(b) shows the output spectrum of the laser, operated at 17C with a 92mA SOA current. The cavity side-modes are 0.84nm and 1.32nm away from the main emission peak, in agreement with the cavity simulations. The side-mode-suppression ratio of both peaks are more than 58dB. There are two additional peaks around the center wavelength, resulting from relaxation oscillations at a frequency of 3.6GHz.

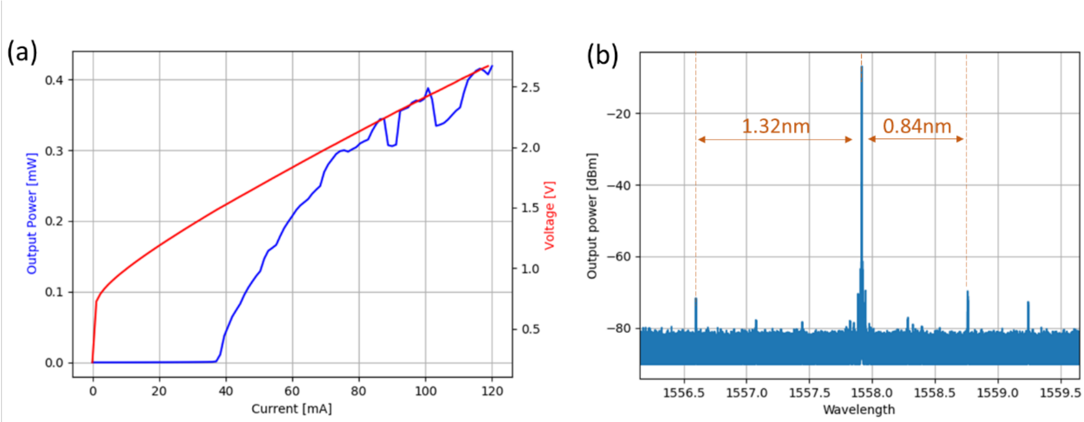

Figure 2 – (a) LIV characteristics and (b) the output spectrum of the laser

The figure 3(a) shows the frequency noise power spectral density of the laser operating at 79mA SOA current. The white noise level is measured by averaging the region of the spectrum shown in green between 20MHz-80MHz, indicating to a 53kHz intrinsic linewidth. The β-separation line shown in orange is defined as $\beta_{sep}(f) = 8\ \ln(2)\, f/\pi^2$ [18]. The effective linewidth starts to increase for observation times more than 8µs, determined by the where the frequency noise crosses the β-separation line, which is around 125 KHz.

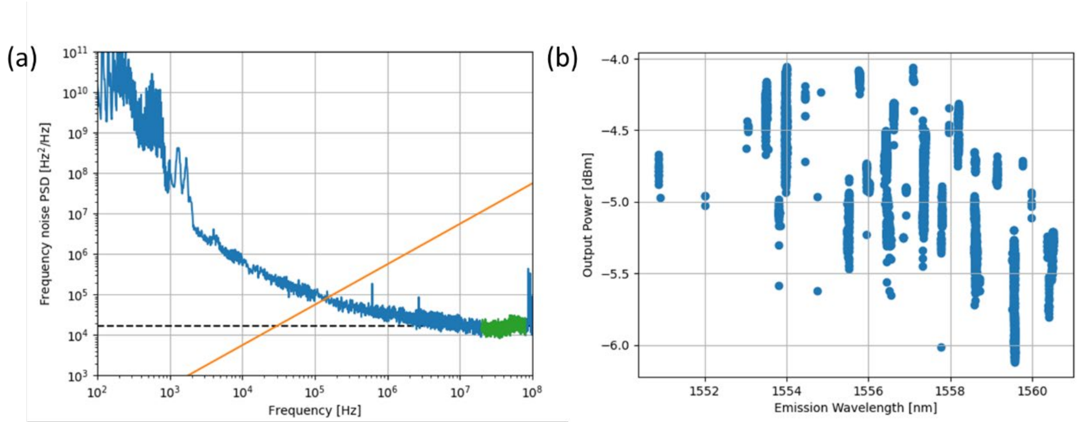

Figure 3- (a) Frequency noise power spectral density of the laser. (b) Various operating wavelengths with the corresponding fiber-coupled optical powers

The figure 3(b) shows the measured single mode emission wavelength and output power of the laser while the bias voltages on the EOPMs of both rings are scanned between 0V and -6V with a resolution of 0.1V. The SOA current and the bias voltage on the MZI filter are kept constant at 79mA and 0V respectively. By controlling the bias of the two ring EOPMs, the laser wavelength can be shifted over a range of 10nm, while the output power staying within a range of 2dB around -5dBm. Changing the bias voltage on the MZI arms is expected to provide larger wavelength tuning range.

Conclusion & Outlook

A monolithically integrated low-linewidth and tunable laser with a novel cavity design is presented. The initial results show 53kHz linewidth with 58dB SMSR, and around 10nm of tuning range with a power stability of ~2dB. Complete investigation of the tuning range requires simultaneous tuning of the MZI filter and the ring cavities and is planned in future experiments.

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