Tuning Strategy for a Monolithically Integrated Unidirectional Vernier Dual-Ring InP Laser

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Abstract: Wavelength mapping and calibration for a widely tunable laser utilizing Vernier micro-ring resonators are investigated. The laser achieves quasi-continuous tuning through reverse biasing the electro-optic phase sections.

On-chip laser diodes in photonic integrated circuits (PIC) are highly desirable for their small size, light weight, and low power consumption across various applications. InP monolithic generic integration technology enables the creation of extended-cavity widely tunable lasers in a single regrowth step, with passive waveguide, active gain (SOA), and phase sections [1]. This approach exhibits low reflection and loss, and is well-suited for integrating intra-cavity filters such as Mach-Zehnder interferometers (MZI) and micro-ring resonators (MRR) [2]. The tuning process for these filters is accomplished by using electro-optic phase modulators, which offer fast response times, low dissipation, and the ability to enable the Vernier effect.

Based on the Vernier effect and the InP-based generic integration technology, a 74 nm 3-MZI integrated widely tunable laser with dimensions of 4.7 mm × 4.1 mm has been presented [3]. The intrinsic mode hopping induced by the Vernier effect has also been studied, along with a proposed stepwise-scan wavelength calibration process[4]. More recently, a 34 nm dual-MRR integrated widely tunable laser with a much smaller footprint of 2.17 mm × 0.56 mm and its operation of locking to a high-finesse etalon have been demonstrated [5]. Despite the potential benefits of such a compact integrated InP tunable laser as a frequency-agile source in free-running operation, no investigation has been carried out to date regarding the mapping and calibration of its wavelength. This paper presents the demonstration of wavelength tuning for the dual-MRR laser, achieved by scanning all the controllable phase and gain sections. The design incorporates standard building blocks that were pre-defined by the foundry. To map the output wavelength to the input voltages, we developed look-up tables.

The dual-MRR PIC device is fabricated on an n-contact InP substrate with an open-access multi-project wafer (MPW) run. Fig. 1 shows the top view of the implemented sample and schematic layout. The PIC consists of an InGaAsP multi-quantum well (MQW) active SOA in a ring cavity, whereby the two intra-cavity MRRs are coupled to the cavity using 1x2 couplers. A reverse-biased electro-optic phase modulator (EOPM) is included. The two MRRs and EOPM can be reverse-biased to adjust the refractive indices for phase tuning. A broadband mirror (MIR, multimode interference reflector) ensures light propagation in the clockwise direction. While the presented PIC design is almost the same as reported in Ref. [5], it is more compatible with current foundry processes. The MMIs used in this paper are already available to be selected from the building block library as a process development kit (PDK) provided by the foundry. In the experimental testing, the SOA, the MRRs, and the EOPM are directly probed for feeding electrical currents and voltages.

The chip is stabilized at 25°C. Light emitted from the dual-MRR PIC emits is edge-coupled to a lensed single-mode fiber. The reverse-bias voltages applied onto the MRRs and EOPM are controlled from 0 to -10 V, and the SOA is driven from 110 to 140 mA. With an optical spectrum analyzer with a resolution bandwidth of 0.1 nm, the collected peak wavelengths are color-coded, as shown in Fig. 2(a). The EOPM is not biased. Due to the phase dependence on the SOA current, as shown in the tuning maps, an SOA current is first deduced such that a full period of phase tuning is attainable. Figs. 2(b,c) show the measured peak wavelength evolution for one ring as it is biased from 0 V to -10 V in -0.2 V increments. As indicated by the arrows in Figs. 2(b,c), the peak wavelength

Fig. 1. (a) Photo and (b) schematic of the dual-MRR PIC using the blocks for gain (red), phase (blue), and passive (green).

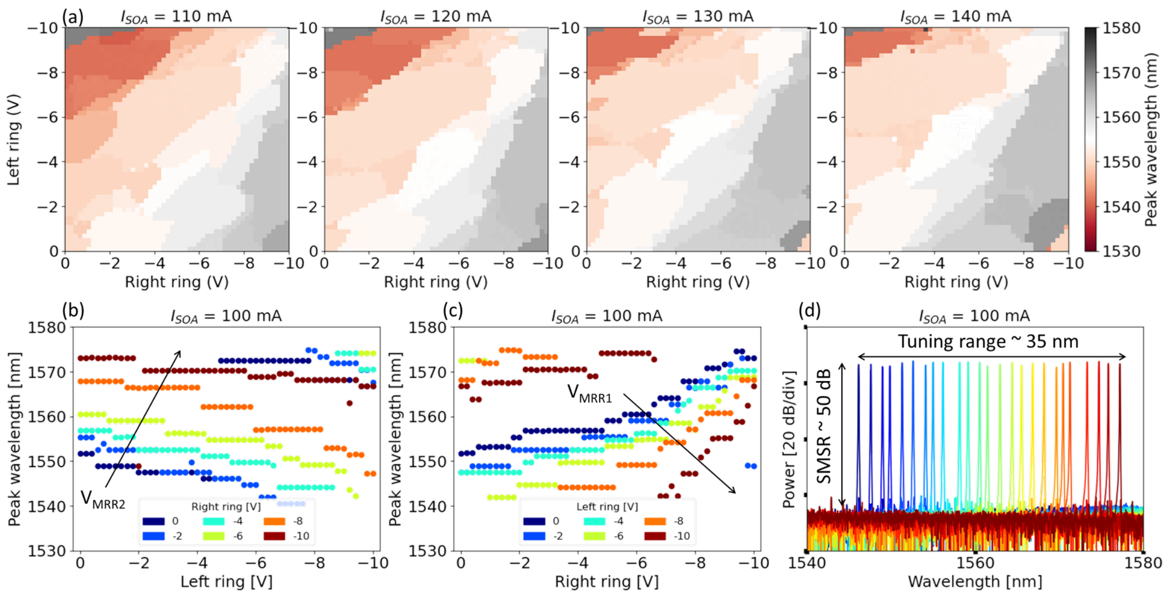

Fig. 2. (a) Wavelength maps for I_{SOA} = 110, 120, 130, and 140 mA. Right ring V_{MRR2} (x-axis). Left ring V_{MRR2} (y-axis). (b) Peak wavelength as function of left ring voltage V_{MRR1}, and (c) of right ring voltage V_{MRR2}. (d) Laser spectra.

decreases as a result of an increase in the reverse-bias left ring voltage (V_{MRR1}) (or a decrease in V_{MRR2}). This is further demonstrated in Fig. 2(a). A reverse-bias voltage of 10 V appears sufficient to cover one period of phase tuning for each MRR. It is evident that mode hopping occurs at 5-7 positions over one period. For dense spectral coverage over a wide tuning range with an optimized SMSR, the V_{EOPM} is fine-tuned. A $\sim$ 35 nm tuning range is presented with $\sim$ 50 dB SMSR in Fig. 2(d). The operating points of the phase sections may not be consistently reproducible, but a quick laser calibration (completed in under two hours) can be reused for approximately 20 hours. While the accuracy of the wavelength with respect to application requirements may be limited, as discussed in Refs. [4, 6], the repeatability can be addressed by using a stabilization scheme [5].

In conclusion, the widely tunable Vernier dual-MRR PIC has been successfully tuned over a $\sim$ 35 nm range using a three-step calibration process. This involves setting the I_{SOA}, then optimizing both MRRs, and fine-tuning the MRRs and EOPM by referring to the calibration map. However, the presence of mode hopping due to the Vernier effect causes non-continuous tuning, and the limited reproducibility of wavelength can pose challenges. Therefore, using a stabilization technique is recommended to ensure a reliable frequency-swept source.

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