A TUNABLE LASER USING LOOP-BACK EXTERNAL CAVITY BASED ON DOUBLE RING RESONATORS

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ABSTRACT
The paper presents a monolithically integrated tunable laser with loop-back external cavity tunable based on double ring resonators. It consists of a gain chip and a double ring resonator structure in a loop-back external cavity, made of silicon photonic waveguides. In the experiment, it measures 40-nm wavelength tuning, > 40 dB side mode suppression ratio (SMSR) and the average output power is approximately -3 dBm.

KEYWORDS
Tunable laser, nano photonics, monolithically integrated, thermal-optics.

INTRODUCTION
Wavelength tunable laser has been widely used in wavelength division multiplexing (WDM) optical communication system, supplying optical signal source. Compared with conventional distributed feedback (DFB) or distributed Bragg reflector (DBR) lasers, tunable lasers reduces the amount of single wavelength lasers, thus makes network system more flexible and lowers the cost. DFB arrays and sampled-grating DBR lasers can provide the function of wavelength tuning, which are compact in fabrication to integrate multiple function elements on one chip [1-2]. The wavelength tuning function can be also realized by various external cavity tunable lasers [3-7]. Although the hybrid integrated tunable lasers, especially microelectromechanical system (MEMS) external cavity tunable lasers [3-6] have advantages on large tuning range and low cost, they suffers mode hopping, frequency chirp, low SMSR, and the stability is limited due to movable part. External cavity tunable lasers with optical circuit and broadband light source provide better stability and can be easily integrated with photonics devices. Micro-size ring resonators are believed to be ideal channel-dropping filters for WDM system, which can be integrated with other photonics circuits [8]. Ring resonator based external cavity semiconductor lasers has been successfully fabricated on one chip using III-V materials [9-10]. On the other side, the high optical transmission loss in III-V waveguides and high cost wafer limit the application for photonic integrated system. With the development of silicon photonic technology [11-12], silicon based wafer has also been applied for realizing the function of external cavity [13-14]. However, it is difficult to integrate this passive external cavity with active gain laser onto a single chip. Besides, complex high-reflection film coating is usually needed in the external cavity to act as mirrors and provide optical feedback. This paper presents a tunable laser with loop-back external cavity tunable based on double ring resonators. MEMS technology is utilized for monolithically integration. It consists of a gain chip as the internal cavity and a double ring resonator structure in the external cavity. The external photonic circuit is made of silicon photonic waveguides. It advances in high SMSR, narrow linewidth and high stability, which results in potential applications such as wavelength division multiplexing (WDM) networks, signal generation and light source integrated in high density optic circuits.

DESIGN AND THEORY
Figure 1 illustrates the schematic of the external cavity tunable laser.

Figure 1: (a) Schematic illustration of the loop-back external cavity tunable laser based on ring resonators. (b) equivalent scheme of the external cavity laser.
A gain chip, which functions as the internal cavity, is bonded to the silicon wafer. It provides wide-spectrum light source, with its right facet anti-reflected. The external cavity consists of a taper waveguide, an optical splitter (50:50), the two rings with slightly different radii, and a U-shape waveguide connecting these two rings. The taper waveguide acts as a mode size convertor, which matches the mode-size of the light emitted from the Si waveguide with that from the gain chip. The optical splitter, the U shape waveguide and the two ring resonators form a loop-back optical circuit. The loop-back silicon photonic circuit not only selects the single lasting wavelength, but also acts as an optical reflector. The light from the gain chip can be returned by the loop-back circuit when the resonance conditions of both rings are satisfied. No high-reflectivity coating films or reflection mirrors are needed. The ring resonators are used as drop filters and single mode wavelength is selected by Vernier effect. Both the straight waveguide and the ring resonator are channel waveguides with 450-nm width and 220-nm height. A cladding layer of 2-μm SiO₂ is deposited on top of the silicon circuit.

Two heaters are fabricated on top of the two ring resonators, respectively. The tuning of the lasing wavelength is realized by thermal-optics method [15-16]. When applying current to the heaters on top of the ring waveguide, the ring waveguide is heated and the effective refractive index is changed, thus the lasing wavelength is tuned. The tuning range is decided by

\[ \Delta \lambda = FSR_A \cdot \frac{R_A}{R_A - R_B}, \]

where \( R_A \) and \( R_B \) are the radii of the two resonators, respectively. \( FSR_A \) is the mode spacing of ring resonator A. The equivalent scheme of the loop-back external cavity laser is shown in Fig. 1(b).

![Figure 3 SEM images of (a) bonded gain laser chip on the silicon chip; (b) optical splitter; (c) one of two ring resonators.](image)

**RESULTS AND DISCUSSIONS**

Figure 4 shows the reflection spectrum of the external cavity. The channel spacing between two neighboring resonant modes is 1.6 nm (200 GHz), which is determined by the effective refractive index and the radius of the ring gain difference between the main mode and the side mode. High gain difference is preferred to obtain good performance of SMSR. Long cavity length is preferred for achieving both high SMSR and narrow linewidth. It expects the performance of > 40 dB SMSR and < 100 kHz linewidth under the conditions of 4-mm external cavity length and 1.5-db gain difference.

The tunable laser is fabricated on the silicon on insulator (SOI) wafer. Both nano-photonics technology and MEMS technology is utilized for the fabrication of the external cavity tunable laser. Fig. 3(a) shows the top-view SEM image of the gain chip bonded on to the silicon chip. Au/Sn solder layer is used as both bonding and conducting material. A high power gain chip is flip-bonded, with the lasing facet on the bottom, in order to optically couple with the silicon taper waveguide. The gain chip and the silicon photonics chip are well alignment to eliminate misalignment. Fig. 3(b) shows the 50:50 photonics waveguide splitter, which is a key element for the realization of the loop-back optical circuit. Fig. 3(c) shows one of the ring resonators in the optical circuit. The light is coupled into and out from the ring resonator via two straight waveguide. It is connected with another ring resonator with a U-shape waveguide.

![Figure 2: Numerical analysis of SMSR and linewidth of the external cavity tunable laser as a function of external cavity length and the gain difference.](image)
waveguide. It expects a 10-dB mode power difference between the main mode and the adjacent side mode according to the transform matrix method. In experiment, the mode power difference is 1.8 dB measured from the transmission spectrum. The mismatch comes from the limited resolution of optical spectrum analyzer and the unexpected optical transmission loss in the ring waveguides. Nevertheless, as indicated in Fig. 2, 1.8-dB mode power difference guarantees 40 dB SMSR when the external cavity length is above 4 mm.

**Figure 4: Reflective spectrum of the wavelength selection function due to the double ring resonators.**

In experiments, the gain chip works under a constant pumping current of 200 mA. The effective index of one ring resonator is changed by thermal-optics method. The heating current is increased from 0 to 82 mA, while the voltage is increased from 0 to 0.9 V. A serious of single mode wavelength is acquired as Fig. 5 shows. The SMSR varies within the range of 42-45 dB, measured directly from the optical spectrum analyzer. The output power is approximately -3 dBm with 0.4-dB variation. The variation of SMSR and the output power comes from the gain difference within the gain band. The output wavelength is discontinuous with a space of 1.6 nm.

**Figure 5: Experimental results of different lasing wavelengths with in C-band when heater A works.**

CONCLUSIONS

In summary, a monolithically integrated tunable laser with loop-back external cavity is demonstrated. The output wavelength has demonstrated a tuning range of 40 nm with the output power stably maintained at -3 dBm, SMSR of > 40 dB and linewidth of < 100 kHz. The demonstrated tunable laser can be potentially used in WDM systems, signal generation and high density photonic circuits.

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