A Direct Comparison between Heterogeneously Integrated Widely-Tunable Ring-Based Laser Designs

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Abstract: Four ring-based tunable laser structures are firstly demonstrated in the heterogeneous integrated silicon platform. Except for double-sided coupled-ring structure, the other three ones show comparable narrow-linewidth (~200kHz) and output power (~10mW) across entire wide-tuning ranges (~40nm) with high side-mode suppression ratio (>40 dB).

OCIS codes: (140.5960) Semiconductor lasers; (140.3600) Lasers, tunable; (230.4555) Coupled resonators;

1. Introduction

Tunable semiconductor laser sources [1-7] attract lots of attention due to that they are a perfect candidate for dense wavelength division multiplexing (DWDM) communication systems and for a variety of optical sensing applications and systems. Communication systems have recently moved to more complex modulation formats that require higher spectral purity lasers [3], so narrow linewidth, together with wide tunability, have become a focus of research [4, 5]. Wide tunability in semiconductor lasers is commonly achieved by utilizing the Vernier effect. The effect has been utilized both with sampled Bragg grating reflectors and ring resonators. Ring resonators have an advantage as the effective cavity length at ring resonance is significantly enhanced, directly improving linewidth, provided that the utilized waveguide platform offers sufficiently low propagation losses [6]. Recently, by using hybrid package of III-V active layers and passive Si-photonic ring resonator, external cavity tunable laser with state-of-the-art output power, linewidth, and tuning range have been demonstrated [4]. In this work, we firstly demonstrate four different types of widely-tunable ring-resonator laser structures in heterogeneously integrated silicon platform, which should be more compact and better for large scale Si-photonic integration than those of hybrid package tunable lasers with external cavity.

2. Laser topologies

We compare four ring-based laser topologies (see Fig. 1), all of which use ring filters of different circumference in order to make use of the Vernier effect. The first is a ring-bus-ring (RBR) laser that utilizes two ring filters in series in add-drop configuration and two teardrop reflectors. The second is a single-sided coupled-ring resonator (CRR 1x) laser that utilizes a CRR mirror on one side as both reflector and filter, and a teardrop reflector on the other side. The third is a Vernier racetrack laser that utilizes two bus waveguides, one of which has a gain region and phase tuner, and two ring resonators that are coupled to the bus waveguides. The fourth design is a double-sided coupled-ring resonator (CRR 2x) laser that utilizes a CRR mirror on both sides as both reflector and filter. All lasers have resistive heaters overlaying the rings to provide active tuning of the wavelength. Ring circumferences of the RBR laser are 256 µm and 271 µm giving an expected tuning range of 42.1 nm, with power coupling coefficient same for all couplers and equal to 20%. For the CRR 1x laser, the selected circumference values for Ring 1 and Ring 2 were 337 µm and 368 µm respectively, and the selected power coupling coefficient values for K_1, K_2, and K_3 are 2.25%, 2.25%, and 36% respectively. This results with an expected tuning range of 20.4 nm A more detailed description of CRR mirror properties is found in [7]. The Vernier racetrack laser has two rings with circumferences equal to 400 µm and 420 µm with power coupling coefficient of 20% for all couplers. Finally the CRR 2x laser has two pairs of rings, each pair having nominally the same set of radii of 368 µm and 402 µm. The coupling coefficient values for both pairs are equal and same to those on CRR 1x laser. The calculated functions of the passive ring filters are shown in Fig. 2.

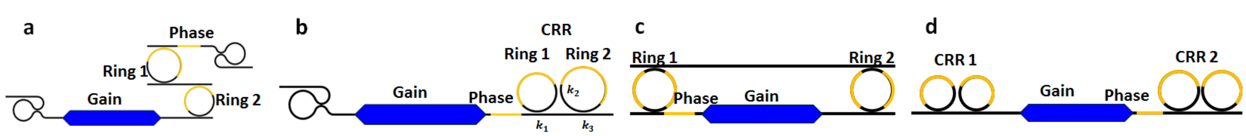

Fig. 1. Four considered widely-tunable ring-based laser designs. Heaters are drawn in yellow: (a) Ring Bus Ring laser (RBR), (b) Single Coupler Ring Resonator laser (CRR 1x), (c) Vernier racetrack laser and (d) Double Coupled Ring Resonator laser (CRR 2x).

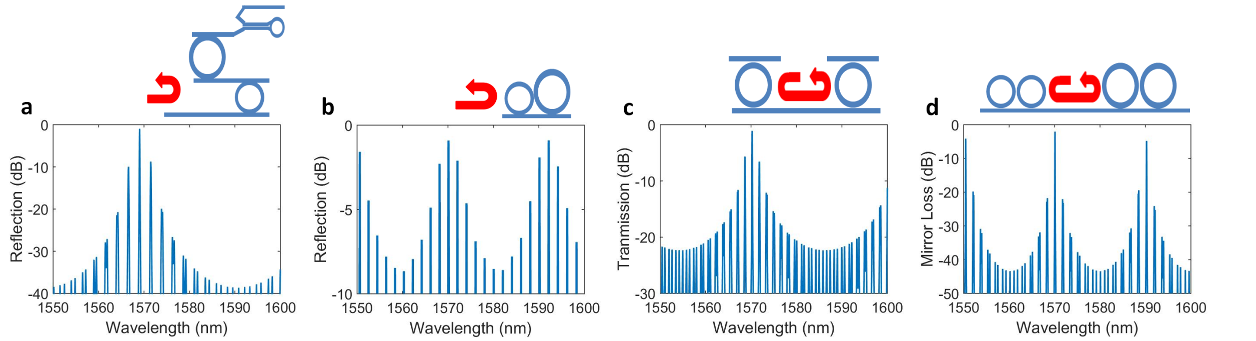

Fig. 2. Synthesized spectra of all the considered ring structures. (a) Ring Bus Ring laser (RBR), (b) Single Coupler Ring Resonator laser (CRR 1x), (c) Vernier racetrack laser and (d) Double Coupled Ring Resonator laser (CRR 2x).

3. Measurements

Optical photos of the laser types are shown in Fig. 3. Wavelength tuning for lasers vs. ring heater power are compared in Fig. 4. The RBR laser had a tuning range of 42 nm, the CRR 1x laser had a tuning range of 21 nm, the Vernier racetrack laser had a tuning range of 47 nm and the theoretical tuning range of CRR 2x laser is 19 nm. We do not show 2D tuning map for CRR 2x laser due to unpredictable tuning performance that we address in next section. The maximum measured double-sided output power was 7.7 mW for the RBR laser, 10.5 mW for the CRR 1x laser laser, 12.7 mW for the Vernier racetrack laser, and 14.2 mW for the CRR 2x laser. The output powers were measured using an integrating sphere. The RBR lasers have >40 dB side mode suppression ratio (SMRS), while all other designs have >45 dB SMSR across their tuning ranges.

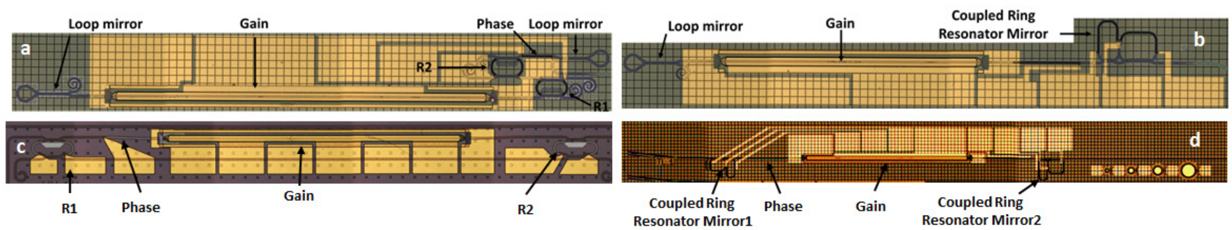

Fig. 3. Optical image of the completed lasers : (a) Ring Bus Ring laser, (b) Single Coupler Ring Resonator laser (CRR 1x), (c) Vernier racetrack laser and (d) Double Coupled Ring Resonator laser (CRR 2x).

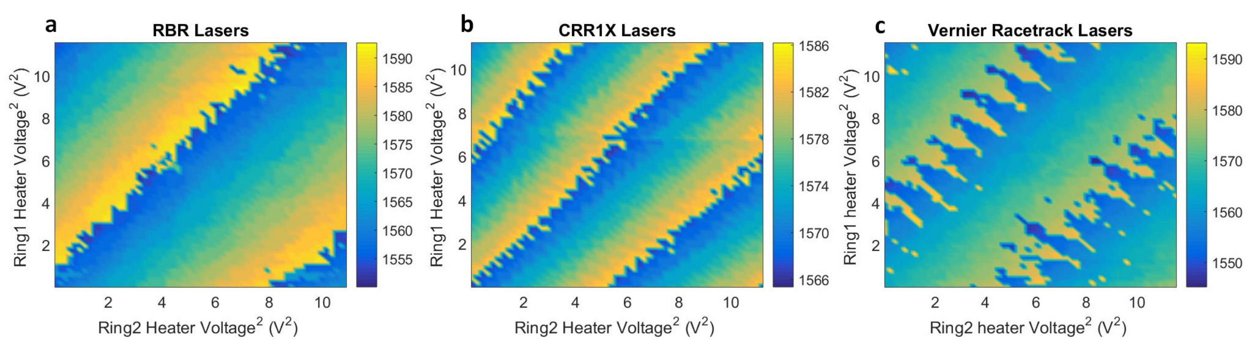

Fig. 4. Plot of peak wavelength vs. ring tuning voltage squared for (a) RBR laser, (b) CRR 1x laser, and (c) Vernier racetrack laser. We do not show the CRR 2x laser tuning performance due to unpredictability.

The laser linewidths were measured using the delayed self-heterodyne method with 10 km of fiber in one arm and an acousto-optic modulator with 100 MHz of frequency shift in the other arm. We quote the Lorentzian linewidth calculated from -20 dB points. We show the measurements in Fig. 5. All the measured configurations have linewidths in the 200 kHz range, with best results of 150 kHz. For the case of CRR 2x laser, in some certain lasing wavelengths its measured linewidth can be as narrow as 196 kHz, however, the stable single-mode lasing performance can't be sustained across the whole theoretical tuning range.

4. CRR 2x performance

The tuning performance of CRR 2x structure is unpredictable. For optimal performance of a CRR structure with rings of equal length it is necessary to tightly control both the dimensions and the group velocity refractive index so their resonances match, but the required control surpasses the typical semiconductor process variations. Even in case of such superior process control, slight gradients in temperature due to thermal crosstalk or non-symmetric layout can result with rings being off resonance resulting with reduced reflectivity and splitting of the reflection peak (Fig. 6). In theory each individual ring can independently be tuned to correct both for process tolerances and temperature crosstalk, but this results in 5-dimensional tuning space (4 rings and phase) which severely complicates the tuning of such structures. Due to this we do not recommend the CRR 2x as a widely-tunable laser design.

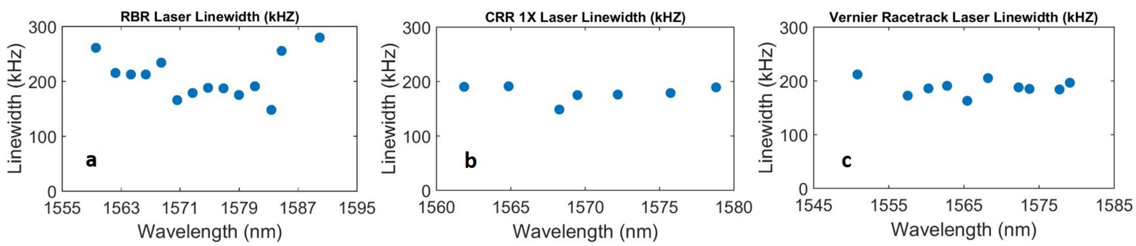

Fig. 5. Plot of measured linewidths for (a) RBR laser, (b) CRR 1x laser, and (c) Vernier racetrack laser. We do not show the CRR 2x laser tuning performance due to unpredictability.

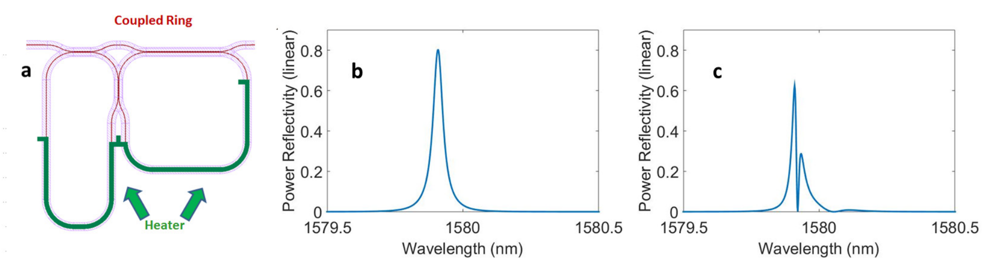

Fig. 6. (a) Mask layout for CRR structure with rings of equal length, (b) Reflection performance of aligned CRR mirror with rings of equal length, and (c) Reflection performance of aligned CRR mirror with rings of equal length when there is a temperature difference of 2 °C between them.

5. Conclusions

We have compared four ring-based widely-tunable laser designs realized in heterogeneous integrated silicon platform and have shown wide tuning performance and narrow linewidth across the whole tuning range. The linewidth of all considered designs is around 200 kHz with best results down to 150 kHz.

A tolerance sensitivity study of all four ring-based designs will be presented along with experimental comparisons of the four designs at the conference.

6. References

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7. Acknowledgements

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