Narrow linewidth tunable laser using coupled resonator mirrors

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Abstract: A novel fully integrated tunable single mode hybrid silicon laser is demonstrated. We report a linewidth of 260kHz, which is the lowest reported for a monolithically integrated laser. The side-mode suppression ratio is >40dB.

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

1. Introduction

Narrow linewidth tunable lasers are key components of an optical communication link. Specifically, for next generation coherent systems at 400Gbps and 1Tbps, there is a need for spectrally pure sources to deploy advanced modulation formats and increase spectral efficiency of the optical channel. For example, a 16QAM modulation format requires a laser linewidth <300kHz [1]. Apart from the linewidth requirements, the source also needs to be compact and allow for cost reduction through scaling. This is achieved with monolithic integration of III-V materials for light amplification and silicon photonic waveguides for lower propagation losses and hence higher quality factor laser cavities. Since the entire laser is integrated on a single substrate there is no excess cost involved for alignment or packaging. Several research groups have reported on tunable lasers by bonding III-V materials to silicon-on-insulator (SOI) wafers including molecular bonding [2], benzocyclobutene (BCB) bonding [3].

In this summary, we report a novel hybrid silicon laser using the molecular bonding approach. The laser linewidth is 260kHz or better and the side-mode suppression ratio is >40dB. The tuning range is 29nm; from 1553nm to 1582nm.

2. Device Design

The laser cavity is formed by two pairs of coupled ring resonators. Each pair has a particular circumference leading to a Vernier effect of the mirror loss spectrum. The microscope image and the schematic of the laser are shown in Fig. 1. The circumferences of each pair are 471μm and 513μm respectively. The reflection spectrum of each coupled race-track resonator (CRR) mirror and the composite spectrum are shown in Fig. 2.

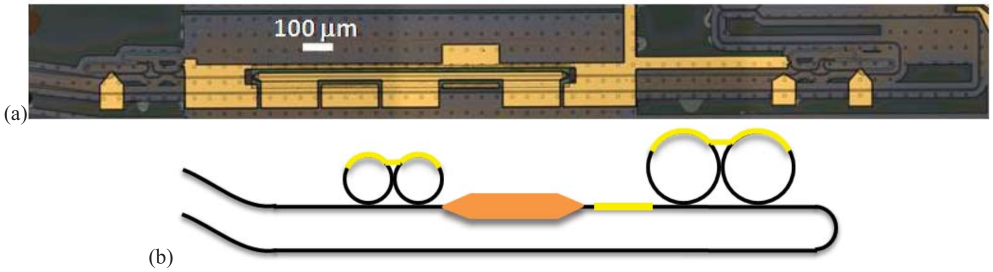

Fig. 1. (a) Microscope image of the hybrid silicon laser. (b) Schematic of the laser showing the design using CRR mirrors. Wavelength tuning is achieved by thermally tuning the waveguides (black lines) underneath the tuners (yellow lines). The orange section is the SOA for gain.

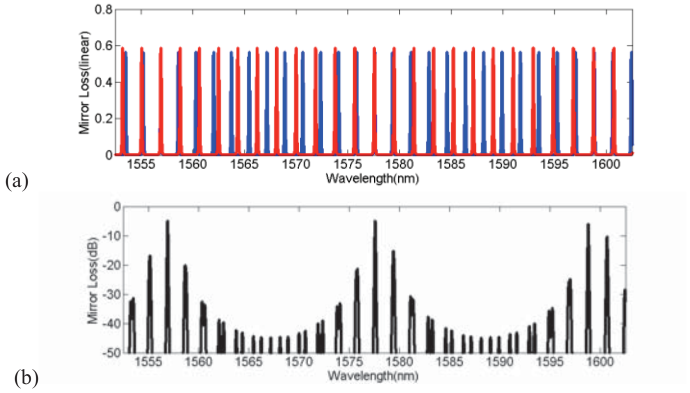

Fig. 2. Reflection spectrum of each CRR mirror (a) and the composite mirror loss spectrum (b) of the laser cavity.

The length of the semiconductor optical amplifier (SOA) is 1040μm including the tapers. The outputs from both sides taper out to a waveguide width of 5μm and terminate at the facet at an angle of 7° to minimize reflections. The use of only directional couplers to form a laser cavity is an important feature to minimize excess mirror loss and improve wall-plug efficiency.

The design of the CRR mirror is different from the traditional design reported so far [4]. This design allows for a larger variation in the coupling coefficients. Fig. 3(a) shows a CRR mirror with the labels for power coupling co-efficient for the three couplers. Regular designs are symmetric and have κ_1 and κ_3 equal and the coupling coefficients are varied to achieve the desired reflection spectrum. In our design we equate κ_1 and κ_2 and this provides a much relaxed tolerance for coupling coefficients at a lower mirror loss. Fig. 3(b-c) show the sum of mirror loss and nearest-mode suppression ratio (figure of merit) achieved for the traditional CRR design and our design respectively. The figure of merit needs to be maximized while keeping the mirror loss lower than the net modal gain. The design point, shown as a red diamond in Fig. 3(c) corresponds to $\kappa_1 = \kappa_2 = 2.25\%$ and $\kappa_3 = 36\%$.

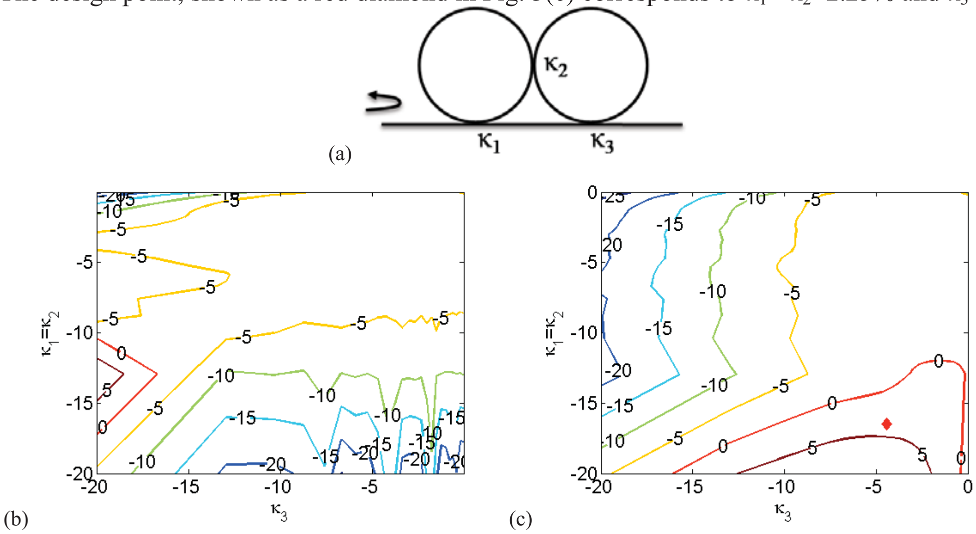

Fig. 3. (a) CRR mirror schematic. Sum of mirror loss and side-mode suppression ratio (figure of merit) (in dB) for the traditional symmetric CRR design (b) and our design (c) for various coupling coefficients $\kappa_1,\kappa_2,\kappa_3$ in dB.

The laser was measured on a temperature controlled stage set at 20°C. The threshold current is 56mA. The output light is coupled into a 2μm lensed fiber and used to measure the optical spectrum and linewidth. The wavelength tuning is achieved using three thermal tuners: one each for tuning the CRR mirrors and one for tuning the cavity modes. Fig. 4(a-b) show the wide tuning range and fine tuning feature of the laser. The side-mode suppression ratio is >40dB in the full span.

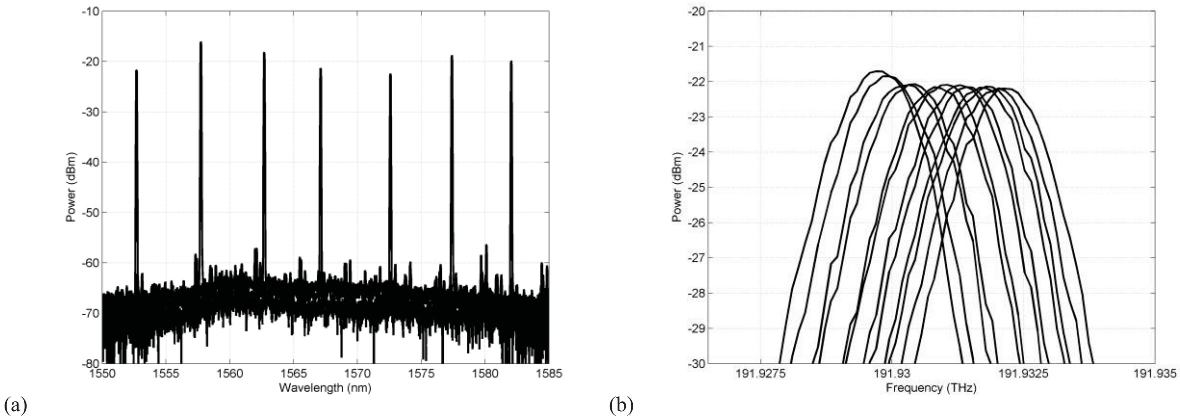

Fig. 4 (a) Coarse tuning between 1553nm and 1582nm. (b) Fine tuning over 25 GHz in steps of ~2GHz.

The linewidth of the laser was measured using a delayed self-homodyne technique using 20km of single mode large effective area fiber (SM-LEAF). The output power of the laser is amplified using an L-band erbium doped fiber amplifier (EDFA) before sending it to the linewidth measurement setup. The linewidth measured at an input current of 195mA and no bias on the heaters is 260kHz, as shown in Fig. 5. The wavelength at this current is 1576.7nm. In the author's knowledge this is the lowest reported for a hybrid laser on a single chip. The linewidths are expected to be lower at higher bias currents and will be shown at the conference. The bias current in this work is limited by the linear regulated power supply.

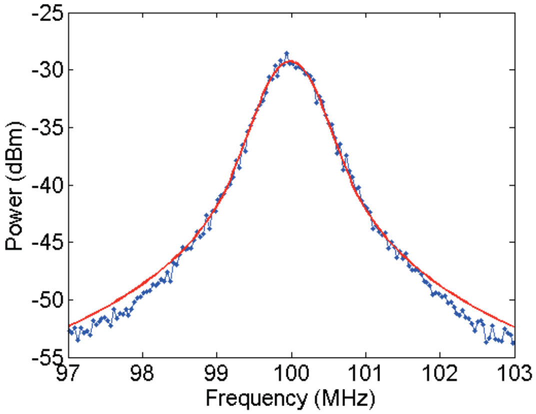

Fig. 5. Self homodyne linewidth measurement (blue dots) and the corresponding loretzian fit (red). The resolution bandwidth is 10kHz.

3. Conclusions

In conclusion we have demonstrated a novel tunable laser on the hybrid silicon platform using coupled ring resonator mirrors. The choice of coupling coefficients allows for relaxed tolerance in designing the couplers for the resonators. The linewidth achieved is better than 260kHz and the coarse tuning range is 29nm. The side-mode suppression ratio is >40dB over the full tuning range.

We acknowledge support from the DARPA EPHI program. We would like to thank Michael Belt for helping with the linewidth measurement setup and thank Prof. Nadir Dagli of UCSB for helpful discussions.

4. References

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