# Efficient Compact Tunable Laser for Access Networks using Silicon Ring Resonators

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**Abstract:** A compact external-cavity tunable laser using an InP gain chip and a reflector chip containing silicon ring resonators is demonstrated. We obtain more than 5mW output power with tuning across the C-band.
**OCIS codes:** (140.3600) Lasers, tunable; (130.3120) Integrated optics devices.

## 1. Introduction

The current rapid increase in bandwidth demand has resulted in growing interest in wavelength division multiplexed (WDM) optical access networks, to enable the same level of spectral efficiency in the last mile as is found in core networks. Recent research [1] shows that the best solutions incorporate a tunable transceiver at the optical network unit (ONU), possibly using coherent detection. The key enabling technology for such transceivers is a compact low-cost tunable laser for use in the transmitter and as a local oscillator in a coherent receiver.

The cost requirements preclude the use of large monolithic InP devices or external-cavity lasers using precision-aligned bulk optics. We propose and demonstrate a compact tunable laser that uses a simple InP gain element and an external tunable mirror containing ring resonators fabricated in sub-micron silicon wire waveguides on 8-inch silicon-on-insulator (SOI) substrates. The silicon waveguides have a minimum bend radius orders of magnitude smaller than those made of $SiON/SiO_2$ [2], so the free spectral range of a ring can be much larger, and Vernier tuning over the C-band can be achieved with two rings in silicon compared to three in $SiON/SiO_2$. Furthermore, the thermo-optic coefficient is much higher in silicon, so the required thermal tuning power is greatly reduced. The concept has been demonstrated previously [3], but the efficiency was low, with a maximum power about 2.3mW 120mA above threshold. We exploit recent advances in silicon photonic waveguide technology to incorporate extra functionality and to enable easier more efficient coupling between the gain chip and the waveguides. We obtain 5mW output power despite the use of non-optimized components.

## 2. Experiment

A widely tunable reflector was designed consisting of two ring resonators in Vernier configuration. Two variants were conceived: one in which the ring resonators were placed inside the path of a loop mirror (Figure 1a), one with a Bragg mirror (Figure 1b). For the device with loop mirror, an MMI 3dB splitter was used and the optical signal travels through the ring resonators in both directions in a balanced way. For the device with Bragg mirror, a short etched grating with a wideband reflection around 1550nm is fabricated, and the optical signal makes a double pass through the Vernier rings two times, giving a better wavelength selectivity but also higher loss.

a)

b)

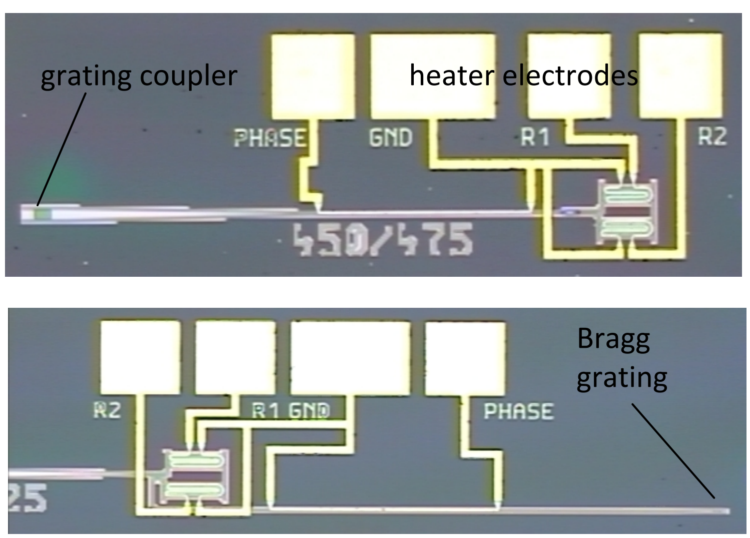


Fig. 1. The two variants of ring resonator reflector: a) loop mirror; b) with etched Bragg mirror.

The devices were designed for fabrication on a CMOS line, using 220nm SOI. For the Vernier ring resonators, deep-etched waveguides were used and adiabatic bends were used to reduce cavity losses. Several devices were designed, with the free spectral range of the ring resonators ranging from 300 to 650GHz, corresponding to ring roundtrip lengths of 231 to 107µm. The FSR difference of a Vernier pair was 15 to 50GHz depending on the design. The etched Bragg grating was targeted to give a reflection band of roughly 100nm around 1550nm For coupling to fiber, a high-efficiency grating coupler similar to that described in [4] was fabricated using locally thicker silicon. The grating gives about 70% coupling efficiency at a near-normal incident angle with a 1dB bandwidth of more than 40nm. The devices were fabricated on an 8-inch wafer line, using 193nm DUV lithography. Thermo-optic heaters (Ti/Au) were post-processed for tuning both ring resonators and a phase section. The chip size was 900 by 300µm.

The grating coupler offers several advantages compared to the standard approach of tapered waveguides as spot-size converters. First, the efficiency is very high; second, the alignment tolerance is a relaxed 2µm [4]; third, the chips can be characterized at wafer scale by automated testers with no need for cleaving, prior post-processing. Another advantage, also offered by the Bragg reflector, is broad wavelength selectivity that ensures that lasing only occurs within the C-band. Ring resonators are essentially colorless, so care must be taken to avoid lasing on a different Vernier resonance, especially when the lasing wavelength is close to an edge of the C-band.

For the gain chip, a commercial semiconductor optical amplifier chip was used. It was 500µm long, with one angled AR-coated facet that was coupled to the grating coupler on the reflector chip via a lens. A schematic diagram of our proposed tunable laser assembly is shown in Fig. 2, but the present experiment was performed using separate stages for the SOA chip and the reflector. Conventional manual micrometers were used for alignment, because of the relaxed alignment tolerance offered by the grating couplers . Both variants of reflector chip functioned as designed. We selected a reflector chip with 600/650GHz FSR and Bragg reflector for detailed measurements, since this design gave the best spectral purity.

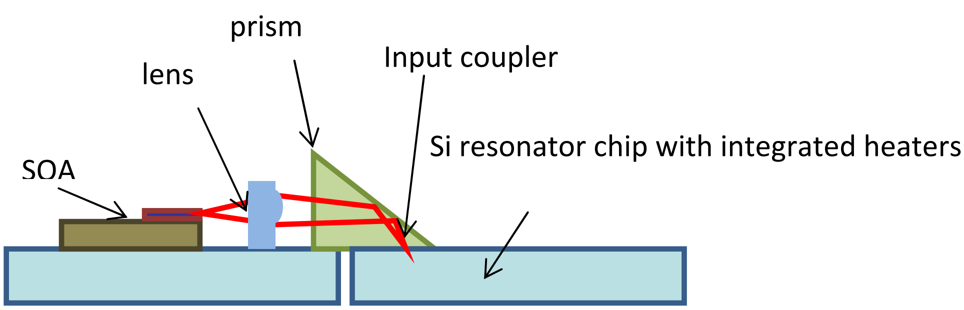


Fig. 2. Schematic diagram of tunable laser assembly with etched grating coupler on the reflector.

## 3. Results

Lasing light was collected from the as-cleaved facet of the gain chip using an angle-cleaved single-mode fiber. By applying heat to one ring, the lasing wavelength could be tuned across the C-band as shown in Fig. 3. The measured side mode suppression ratio was around 20 to 25dB. This value can easily be improved by increasing the finesse of the ring resonators. The tuning power required to generate wavelengths across the band varied from 7 to 45mW, in line with previous results [3].

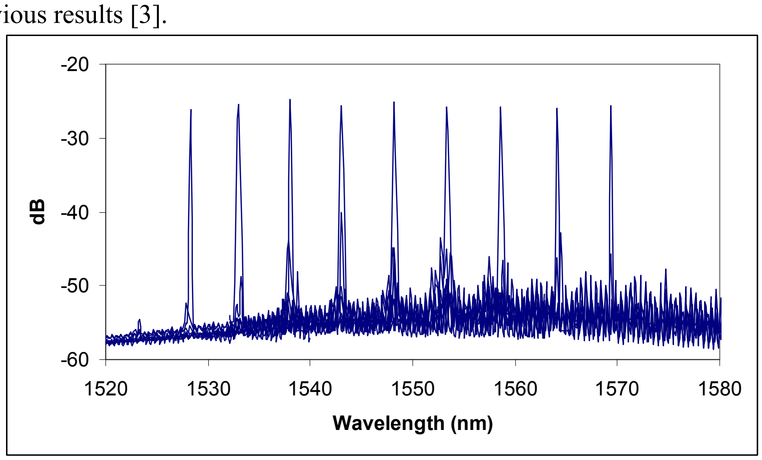


Fig. 3. Superimposed lasing spectra of the tunable laser

 

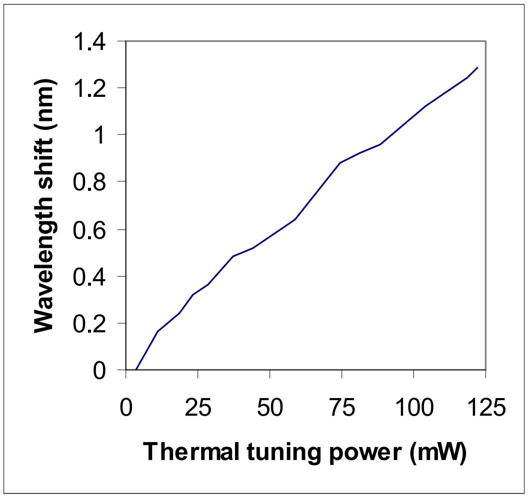


Fig. 4. Fine tuning of an individual lasing peak

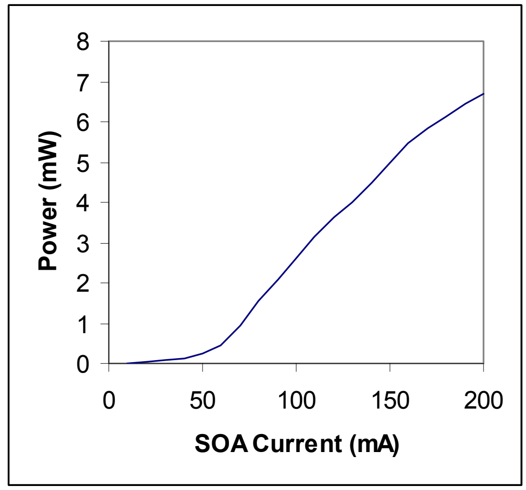


Fig. 5. Laser output power vs SOA current

For fine tuning heat is applied to both rings, roughly equally. Fig. 4 shows fine tuning of one lasing peak versus the total applied heater power. No special structures such as deep trenches were included to reduce the thermal tuning power, and we expect to cut the required by a factor of two by design and by use of a different insulating dielectric under the heaters.

An integrating sphere was used to measure the dependence of output power versus gain-chip injection current, which is shown in Fig.5. The desired output power of 5mW is comfortably achieved, with a slope efficiency around 0.05W/A, more than a factor of two better than previous data [3]. The improved efficiency results from the efficient coupling offered by the grating coupler and the low on-chip loss of the reflector. We note that the SOA chip is not optimized for our application. In particular, the 30% reflectivity of the as-cleaved facet is higher than we would desire, since the net effective reflectivity of the resonator chip, including coupling and on-chip losses, is around 20%. Simulations show that the slope efficiency can be improved by a factor of two by optimizing the facet reflectivity. The threshold is rather high because the SOA that we used is a ridge-waveguide design with a bulk InGaAsP active region. We estimate that an optimized buried-heterostructure gain chip with a multiple-quantum-well active region would have a threshold current around 20mA and an operating current of 50mA for 5mW output.

## 4. Conclusions

We have demonstrated tunable lasing across the entire C-band using a simple InP gain chip coupled to a reflector chip containing ring resonators fabricated in sub-micron SOI. We exploit recent advances in SOI photonics technology, especially efficient grating couplers, to achieve 5mW output power. The output power and slope efficiency are more than double previously reported results for this laser design, and there is a clear path to further improvement. The key components are very inexpensive to manufacture in volume, and the compact external-cavity laser assembly will be a low-cost tunable source or local oscillator with low power consumption for the ONU in next-generation WDM access networks.

## 5. References

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