800 nm narrow linewidth tunable hybrid laser based on a dual microring external cavity

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ABSTRACT

We present a novel hybrid 800 nm laser with a wide tuning range, high optical power and ultra-narrow linewidth with >kHz tuning speeds and a small footprint. Tunable, narrow linewidth hybrid lasers around 800nm serve as an attractive choice for e.g. OCT, LIDAR and atomic transition locking in e.g. atomic clocks. The laser has a microring resonator based optical cavity. The laser has a tuning range of 45 nm and a maximum output power of 5 dBm. The intrinsic linewidth of the laser is measured at 22 kHz.

Keywords: integrated optics, laser, tunable laser, narrow linewidth, lidar, atomic clock, photonic integrated circuit

1. INTRODUCTION

Integrated tunable lasers with a wide tunable range and an ultra-narrow linewidth have a wide variety of applications[1], especially in fields where the device footprint, heat production or scale-up cost have a big impact on the feasibility of the product. This has already enabled the development of applications in the fields of metrology, Lidar and quantum technology[2]. The TripleX® platform is an excellent platform to produce laser cavities[3], as the high refractive index contrast allows for the creation of compact devices, and the large transparency window enables the design of lasers with a wide range of center wavelengths (405-2350 nm). Extending the availability of small, integrated tunable lasers towards lower wavelength than the standard telecom bandwidth will enable the use of these lasers in for example life sciences, quantum computing and sensing[4].

The integrated tunable lasers is realized by hybrid integration of two platforms: a III-V semiconductor based gain section (in this case a GaAs-based semiconductor), and an external cavity based on a photonic integrated circuit (PIC) Vernier filter in the Si_3N_4 TripleX® platform. The Vernier filter consists of two microring resonators, each equipped with a heating element to tune their resonance frequencies. The TripleX® laser cavity also contains a tunable phase section, which tunes the laser cavity length. A Mach-Zehnder interferometer (MZI) inside the cavity functions as a tunable output coupler: it is equipped with a heating element on one of the two interferometer arms that tunes the output coupling efficiency of the cavity. All heaters have a minimum length of 500 µm, which allows for a 2π phase change of the microring resonators over a voltage range of ~12 V. A schematic design layout can be found in Figure 1. The laser includes a negative temperature coefficient thermistor (NTC) – directly mounted on the PIC and close to the gain section for optimal thermal feedback – and is placed inside a 14-pin standard butterfly package with thermo-electric cooler (TEC) to stabilize the cavity temperature. The cavity output is coupled to an optical single mode polarization maintaining fiber with APC connector on the other end. Figure 2 shows an assembled 800 nm laser module, mounted in a LioniX tunable laser controller.

The gain section is a Superlum SOA-380 semiconductor optical amplifier (SOA), with a maximum optical power output of 20 mW. The center wavelength of the SOA is 790 nm and it has a tuning range of >40 nm. The Vernier filter is designed for a free spectral range (FSR) of 50 nm. This FSR is slightly larger than the gain spectrum of the gain chip, allowing tuning over the entire gain spectrum. This large FSR cannot be achieved with a single ring without decreasing the ring radius to a regime that exhibits significant bend losses. Therefore, a Vernier filter, exhibiting two coupled microring resonators with a slightly different resonator length, is used as cavity mirror to provide an FSR of 50 nm. The bus waveguides connecting the microrings are not looped, making sure that the through spectrum of one ring is not fed back into the other ring.

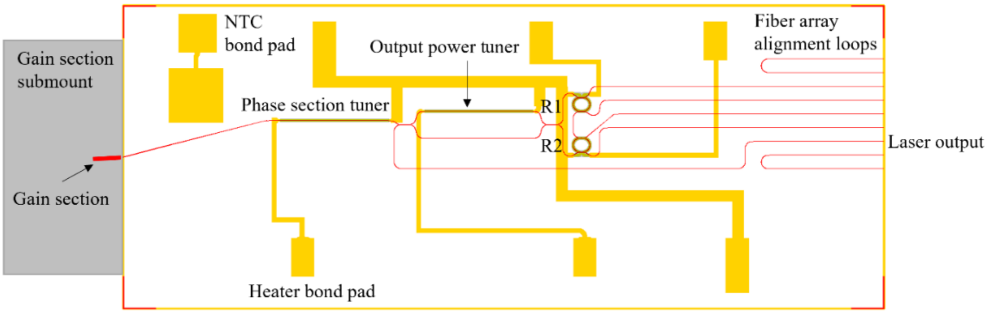


Figure 1. 800nm laser cavity design with Si_3N_4 waveguide layout (red lines) and on-chip metal lead layout (yellow) connecting driving electronics to the heaters. The location of the gain section is given in the grey area to the left. To the right side the laser output and filter drop ports can be connected to a fiber array.

In the design of a Vernier filter, the side modes of the Vernier spectrum should be sufficiently suppressed to avoid undesired mode hopping or multimode lasing. The filters' FSR is determined by the FSR of the individual rings. The side mode suppression is related to the rings' coupling constant κ and the rings' FSR. For these lasers, the coupling constant of the microring resonators was determined using simulations at an optimal value of κ^2=0.07, which is realized by introducing a gap of 500 nm between the bus and ring waveguides. Due to the large tuning range the coupling constant is determined at the center wavelength (800 nm) of the laser and varies significantly for wavelengths at the edges of the tuning range.

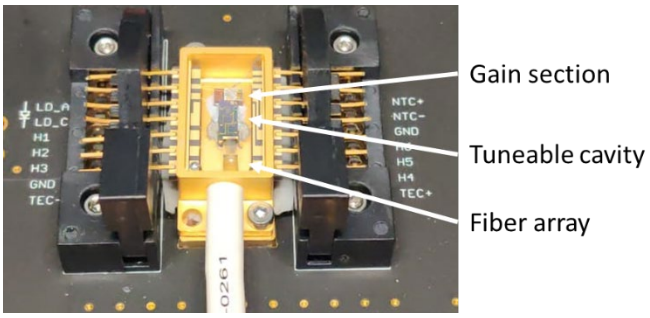


Figure 2. Photo of an assembled laser module, with the 14-pin butterfly package mounted in an in-house developed tunable laser controller. The main parts of the laser are indicated, as described in the text. The image also shows the pinout scheme for the butterfly package, with the phase section heater connected to H1, the output power tuner to H3, and the two microrings R1 and R2 to heaters H5 and H4, respectively.

2. FABRICATION

The tunable laser cavity is fabricated in the patented TripleX® platform, providing waveguides with varying refractive index contrast in a SiO_2/Si_3N_4 material stack. The Si_3N_4 thickness was set at 100 nm, which allows the realization of these cavities in the LioniX 850 nm MPW process. The waveguides were designed for single mode behavior, with a waveguide width of 900 nm. The corresponding minimum bending radius to neglect radiative bend losses is 60 µm, but because of the minimum heater length (to accommodate a full 2π phase change), the minimum fabricated bend radius is 62.7 µm.

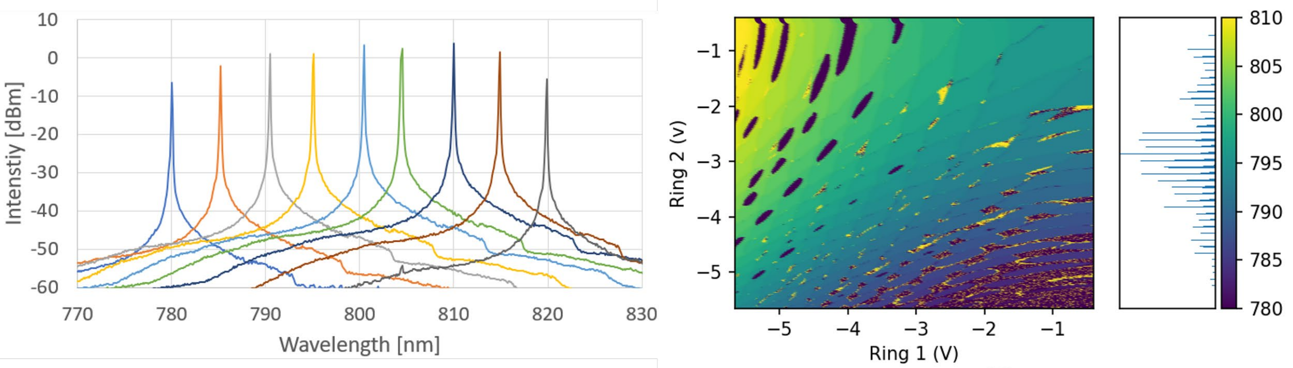
Optimal coupling with the gain section and optical fibers is achieved by introducing spot size converters at the outputs of the TripleX® chip. These are laterally tapered sections, accommodating any variation in the mode size of the fabricated waveguides, gain section or fiber. At the fiber output, the lateral tapers are tapered down to 220 nm, and at the gain section side they are tapered up to a width of 4.6 µm. The optimal width is determined after fabrication by characterizing test waveguide structures that have also been added to the wafer layout, and the chip facets are diced and polished to the correct position in the lateral taper. The theoretical optimal coupling loss at the gain chip side is calculated at 0.3 dB, and at 0.4 dB at the fiber output.

3. MEASUREMENTS

3.1 Tunable range

The wavelength(s) supported by the Vernier filter can be tuned using the two heaters on top of these rings. However, especially when tuning over a larger wavelength range, the phase section (controlling the cavity length) and the output coupling of the cavity also influence the ability to lock on a wavelength and can influence the output power of the laser at a specific wavelength. Figure 3A) shows full wavelength spectra of the tunable laser at several different settings of the Vernier filter, with the phase section and tunable output coupler optimized for the highest laser output. At the lasers' center wavelength of 800 nm, an output power of 5 dBm was measured using a Thorlabs PM100 photodiode for the 400-1100 nm range. The side-mode suppression ratio (SMSR) of the laser was also determined, and a minimum SMSR of -40 dB was measured at the center wavelength (λ=800 nm).

For rapid tuning, the laser has to be calibrated by measuring a full wavelength map of the laser as function of the Vernier filter settings, and the phase section and tunable output coupler voltages. An example of such a calibration map is shown in Figure 3B). This map was measured for a tunable laser controller developed by Insight Photonics Solutions, Inc. and shows the laser output wavelength when the heaters on the microrings are swept in the range over a 5 V range. With this voltage range the rings cannot be tuned over the full 2π phase shift, so the full wavelength range has not been mapped. The phase section and tunable output couple were kept at a constant voltage during this measurement, causing the appearance of a series of 'gaps' in the spectrum. Currently, the wavelength mapping does not include fine-tuning of the phase section and output coupler voltages, causing these gaps because the laser starts hopping between several wavelengths and no stable wavelength can be measured.



(A) (B)

Figure 3. (A) Full spectrum scan of the 800 nm tunable laser for several different settings of the Vernier filter. The spectral resolution is 0.05 nm, and evidence of side bands is present at a value of -40 dBm for the center wavelength. (B) Wavelength map of the same butterfly-assembled laser, used as a calibration map for a tunable laser controller developed by Insight Photonic Solutions, Inc.

3.2 Thermal stability

Laser output power was measured over a 24-hour period at several different wavelengths in the 790-810 nm range, to determine the thermal stability of the laser. For these measurements the butterfly module temperature was actively controlled using the NTC on the TripleX® chip and the TEC inside the butterfly package, keeping the package temperature at a constant 25°C. The driving current of the gain chip was kept at a constant value of 130 mA during the experiment. Before starting the measurement, the laser was allowed to settle for 30 minutes. The maximum wavelength drift measured at λ=792 nm was 0.8 pm/24h. For the majority of the wavelengths the drift was <0.4 pm/24h, with a minimum drift of 0.1 pm/24h at the center wavelength λ=800 nm.

3.3 Linewidth

To determine the linewidth of the laser, the noise power spectral density of the tunable laser was measured using a delayed self-heterodyne setup. For this measurement, the laser was operated at a wavelength of 802 nm using a gain chip current of 90 mA. The resulting frequency noise spectrum is shown in Figure 4, and shows a white noise level of 7 kHz. The intrinsic linewidth (FWHM) of the laser can be estimated [5] using the formula FWHM= $\pi \cdot h_0 = \pi \cdot 7$ kHz = 22 kHz, with h_0 the white noise level.

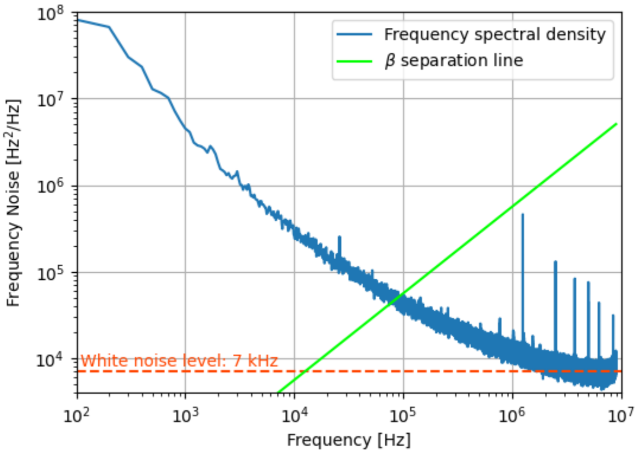


Figure 4. Frequency noise spectral density of the laser for a fixed output wavelength of 802 nm. The green line indicates the β separation line, given by $\boldsymbol{S_{\delta\nu}(f) = 8\ln(2)\, f/\pi^2}$, with $\boldsymbol{S_{\delta\nu}}$ the frequency noise and $\boldsymbol{f}$ the frequency.

4. CONCLUSIONS

An integrated tunable laser has been developed for the 780-820 nm tuning range, with an ultra-narrow linewidth of 22 kHz and an output power of up to 5 dBm at the center wavelength. By actively controlling the module temperature, a thermal stability can be achieved of down to 0.1 pm/24h, and the side mode suppression ratio (SMSR) of the laser is >40 dB. Work continues on improving the driving electronics and the procedures for wavelength calibration, including the phase section and output coupler settings. This will enable easy, rapid wavelength tuning by simply recalling the correct heater settings for a specific wavelength.

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