850 nm hybrid-integrated tunable laser with Si_3N_4 micro-ring resonator feedback circuits

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Abstract: A novel hybrid integrated tunable laser at 850 nm wavelength has been demonstrated, with a tuning range of >50 nm, an intrinsic linewidth <600 Hz and optical output power of 7.5 dBm.

1. Introduction

Hybrid integrated tuneable lasers are enabling small, scalable, high performance systems in metrology, Lidar, and quantum technologies [1, 2]. However, life science applications are still missing out because they lack a hybrid laser operating at suitable wavelengths.

These types of lasers, so far operating around 1550 nm wavelengths, achieve excellent optical performance – sub kHz linewidth, wide tunability (>100 nm) and high output power (>10 dBm) – from the combination of an active semiconductor gain material and a photonic low-loss silicon nitride external cavity. Due to their high levels of integration, they benefit from increased robustness, stability, scalability, small form factor and low cost.

To widen applicability, especially for the life sciences, there is a need for sources operating at lower wavelengths such as 850nm, where biological tissue and water are relatively transparent. Photonic biosensing, a promising solution to diagnostic and pandemic testing [3,4], benefits most from this water transparency. Additionally, shorter wavelengths will also be more strongly confined to the sensor waveguide surface, improving sensitivity by increasing the light interaction with samples at the waveguide surface. The crucial benefit of a hybrid integrated laser is that it has the possibility to greatly increase the sensitivity due to the unique combination of narrow linewidth with a great tunable wavelength range [5].

Scalable, compact 850 nm lasers are needed for handheld or disposable devices, for example in optical coherence tomography (OCT), a non-invasive ophthalmic and medical imaging technique. Here, lasers that are not only compact but rapidly tuneable are needed for next-generation hand-held systems based on fast image scanning [6].

More generally, the combination of laser sources, modulators and detectors enable fully integrated, photonic modules like sensors and transceivers. Whereas longer wavelengths require expensive semiconductor detectors, 850 nm sources are compatible with low-cost silicon detectors for volume applications.

Existing 850 nm sources are not optimal. On the one side, conventional lasers rely on bulk optical elements that introduce fragility and hamper scalability. On the other side, available scalable solutions, of which the vertical cavity surface emitting laser (VCSEL) is by far the most important, have GHz linewidths which are too wide for many applications, and only a few nm tuning range [7].

To address the combination of these challenging needs head-on we have designed and fabricated – for the first time – a hybrid integrated tuneable laser operating at wavelengths around 850 nm to provide an ultra-narrow intrinsic linewidth below 600 Hz, exceptional tuning range of >50 nm and a high optical power of 7.5 dBm.

2. Design and principles of operation

The hybrid 850 nm laser (see Figure 1) consists of a Superlum SOA-371 semiconductor optical amplifier (SOA) for light generation and a cavity, a wavelength selective Vernier reflector in a TriPleX Si_3N_4 waveguide structure.

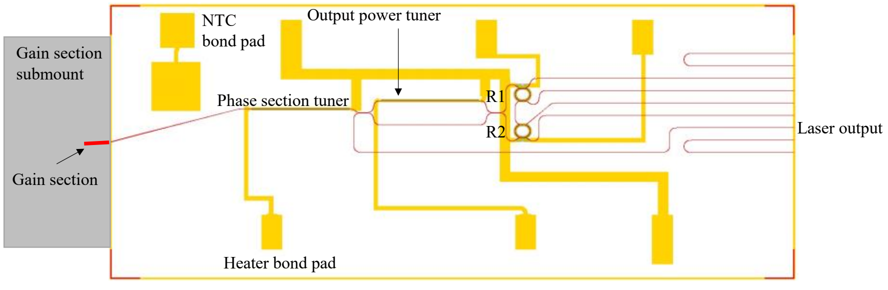
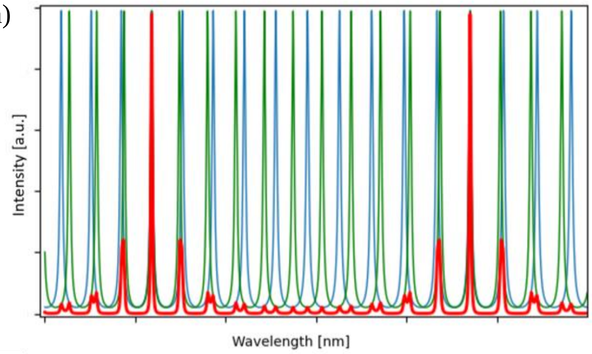


Figure 1 - Cavity chip layout. Waveguides are shown in red, while the thermo-optic tuning elements are shown in grey, with yellow leads.

a)



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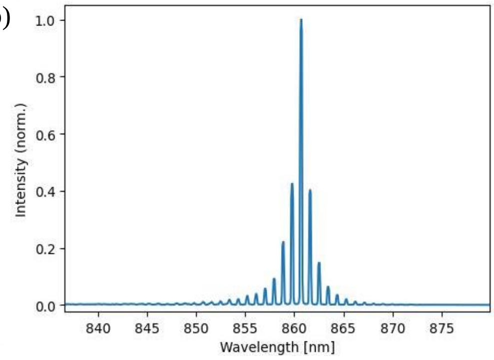

Figure 2 – (a) Example drop port spectra of ring 1 (blue) and ring 2 (green), and their combined Vernier spectrum (red). b) Measured transmission spectrum of the Vernier mirror.

The output light is collected using standard single mode PM fibers. The cavity layout consists of a coupling section to the SOA, a Vernier cavity consisting of two micro-ring resonators (MRRs) with slightly different radius, and a tunable output coupler. Furthermore, thermo-optic tuning elements have been placed to accommodate lasing wavelength tuning. The wavelength is tuned by shifting the MRR resonances, while the output power and stability are optimized with the phase section and output power tuners.

A semiconductor optical amplifier has a gain bandwidth spanning tens of nanometers. Without a wavelength-selective mirror, the laser will lase multimode, or be unstable due to mode hopping. To ensure lasing at a single wavelength in single mode operation, the wavelength filter is attached to the gain section to feed a narrow wavelength range back to it. To allow for a maximum tuning range, the filter should have a free spectral range (FSR) that is larger than the full gain bandwidth of the SOA. This cannot be achieved with a single MRR, since this would require a bending radius in the regime where radiative bending losses dominate. The FSR of each ring is calculated as $\Delta\lambda_{FSR}=\lambda^2/(n_g L)$, where λ is the central wavelength, n_g is the group index of the waveguide, and L is the roundtrip length of the MRR. To increase the filter's FSR, two MRRs are positioned in series with a slight change in circumference. In Figure 2a, simulated drop spectra of the two rings can be seen, along with their combined Vernier spectrum. This Vernier spectrum is calculated by multiplying the two ring spectra, since the rings are connected by a waveguide that is not looped, thus making sure the through spectra of one ring are not being fed back to the other ring.

The reflected wavelength can be tuned over the full gain bandwidth by thermo-optic tuning elements over the rings. A thermo-optic tuning element is placed above a straight section of waveguide to change the cavity's optical path length ($n_g L$), and thus to tune the cavity until standing waves are achieved. A tunable output coupler (Mach-Zehnder Modulator, MZM) is added to adjust the laser output power, and simultaneously the amount of power fed back into the gain section for amplification.

3. Fabrication

The wavelength-selective laser cavity as described in section 2 has been fabricated. Using the TriPleX platform developed by LioniX International for waveguide fabrication [8,9], a waveguide is designed to accommodate for single mode behavior, thereby increasing laser stability. The single-stripe telecom bandwidth spot size converters used in this platform have proven to be a good match for single mode usage at 850 nm wavelength. The waveguide has dimensions of 0.9 µm width by 100 nm height to stay safely in the single mode regime of the waveguide, which has a group index of $n_g = 1.78$ and an effective index of $n_{eff} = 1.53$. For this waveguide cross section, a minimal bending radius where radiative bending losses are below 0.01 dB/cm is calculated to be 60 µm. To tune over the full -3dB cutoff gain bandwidth of the SOAs, the necessary MRR circumferences are calculated as L1 = 450 µm and L2 = 456.2 µm, resulting in a $FSR_{Vernier}$ spanning 50 nm at 850 nm.

To accommodate low-loss coupling to the gain section and fibers, spot size converters are designed. The waveguides are laterally tapered to a width of 220 nm to match the mode field of 780HP single mode fibers. To minimize intra-cavity losses, the waveguide connection to the SOA is optimized for the SOA mode field, by using an inverted taper to a width of 4.6 µm. Furthermore, the SOA is positioned under an angle of 7° on its submount to minimize parasitic reflections on the optical interface. Using refractive indices for the waveguide at the taper end facet and SOA of respectively 1.57 and 3.2, the waveguide angle is calculated to 14.37° for theoretical coupling losses of 0.27dB.

A coupling constant $\kappa^2 = 0.05$ and a gap of 0.8 µm between the straight and ring waveguide to accommodate for sufficient side mode suppression of the Vernier filter.

4. Characterization

To characterize the laser, the Vernier spectrum, the gain chip's spontaneous emission spectrum and the laser tuning range are measured. In Figure 2b, the passive Vernier spectrum of the optical cavity is shown. As can be seen, its central resonance is at 861 nm, with a side mode suppression of almost 60%.

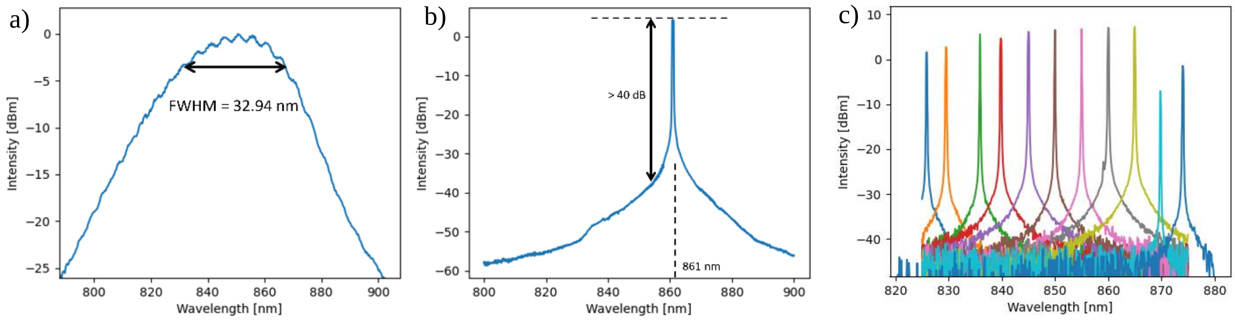

Figure 3 – (a) Measured spontaneous emission spectrum of 850 nm SOA. b) Single lasing peak at 861 nm wavelength, with > 40 dB SNR. c) Full tuning range of the laser, ranging from 825 nm to 875 nm.

To estimate the limits of the laser's tuning range, its spontaneous emission spectrum is measured. The gain section is driven at a power of 90 mA, and the spectrum, shown in Figure 3A, is measured using an optical fiber (PM 780-HP) connected to a spectrometer with a resolution of 0.1nm. The spectrum in Figure 3a. The -3dB gain bandwidth is 32.94 nm wide, with a central wavelength at 850 nm.

A single lasing mode at 861 nm is shown in Figure 3b, using a gain section current of 90 mA and heater voltages of 0V. The spectrum is measured using a spectral optical analyzer (Ando AQ-6315E) with a resolution of 0.1 nm. The lasing spectrum reveals a signal to noise ratio (SNR) of >40 dB. The maximum output power from a power meter (Thorlabs PM100D) at 861 nm is measured to be 7.5dBm. Using a delayed self-heterodyne measurement setup, the intrinsic linewidth of the laser is found to be <600 Hz.

To determine the full tuning range of the laser and the complete operation principle, electrical power is applied to the MRR, output coupler and phase section thermo-optic elements. A dedicated software package has been developed by LioniX International in which the relationships between the MRR tuning elements can be set automatically to provide lasing conditions for a target wavelength. To optimize the output power and feedback into the gain section, the phase section and output power tuning voltages are optimized manually.

To demonstrate the tuning range of this hybrid integrated laser, in Figure 3c different laser wavelengths are shown with a spacing of about 5nm. The full tuning range of the laser spans from 825 nm to 875 nm, thus achieving a tuning range of >50 nm around the gain section's central 850 nm wavelength. This bandwidth is wider than the FWHM of the gain section's spontaneous emission spectrum.

5. Conclusion

To conclude, for the first time a hybrid-integrated tunable laser is realized at wavelengths around 850 nm. A maximum output power of 7.5 dBm is measured using a SOA pump current of 90 mA. Its tuning range spans 50 nm symmetrically around its central wavelength of 850 nm. The laser output has a signal to noise ratio of >40 dBm and an ultra-narrow intrinsic linewidth <600 Hz. This unique combination of characteristics at the 850 nm wavelength range allows this laser to become the perfect solution as the laser source for small-sized, scalable life science photonic solutions in application areas like biosensing and OCT.

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