High power integrated laser for microwave photonics

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Abstract: We present a hybrid integrated laser with two gain sections coupled to one tunable cavity. The resulting laser has a record on-chip power of up to 20.7 dBm and an intrinsic linewidth of 320 Hz.

1. Introduction

Tunable semiconductor lasers with a narrow linewidth have found a wide range of important applications, reaching from coherent communications, remote optical sensing such as Lidar to arising applications such as microwave photonics (MWP). Especially, integrated microwave photonics [1,2] aims to achieve RF-to-RF signal processing in the optical domain with a small footprint while offering wide bandwidths. Recently, we developed a hybrid integrated photonic platform [3] based on active InP components such as gain sections, modulators, and detectors with passive silicon nitride-based TriPleX enabling low loss optical signal processing due to its low propagation losses (< 0.1 dB/cm). The combination of these two platforms enables fully integrated RF-to-RF analog photonic links (APL). The link gain of an APL quadratically depends on the sensitivity of the modulator, responsivity of the photodetector (PD) as well as the optical power at the receiving PD [2]. Therefore, to achieve an efficient APL with a high link gain an optical input power of typically more than 20 dBm is needed. Furthermore, high optical powers can keep the noise figure at a minimum by making the use of additional amplifiers obsolete. However, so far current hybrid as well as heterogeneously integrated lasers lack sufficient optical power to achieve such efficient APLs.

Here, we present, to the best of our knowledge, the first hybrid integrated laser consisting of more than one InP gain sections sharing a common laser mirror. The resulting on-chip power of 20.7 dBm using two gain sections at a pump current of twice 300 mA is the highest optical power of a hybrid integrated laser to date. Furthermore, the laser shows a low intrinsic linewidth of 320 Hz as well as a low relative intensity noise (<-160 dBc/Hz), which should enable future APL with a high link gain and a low noise level.

2. Device design

The scheme and a photograph of the dual-gain section hybrid integrated laser is shown in Fig.1 (a) and (b), respectively. The laser comprises of two InP reflective semiconductor optical amplifier (RSOA) chips and a low-loss TriPleX frequency selective mirror chip. The frequency selective mirror is based on a well-known principle of Vernier mirror with two micro-resonators of slightly different length and, hence, free-spectral ranges of 208 GHz and 215 GHz. To achieve a higher optical output power the mirror chip is coupled to two individual InP RSOAs with a length of 700 µm instead of one [4]. The coupling losses from the InP RSOAs to TriPleX laser cavity are estimated to be about 1 dB. Each of the RSOAs has an individual electrical connection to apply a pump current. On the TriPleX chip, thermo-optic tuners are used to set the frequency selective mirror, to control the phases of the RSOAs within the cavity, two tunable Mach-Zehnder couplers are used to combine both output coupling of the cavity and the power in the output waveguide. The output waveguides are coupled to a fiber array with standard polarization maintaining fibers with a coupling loss of 0.5 dB.

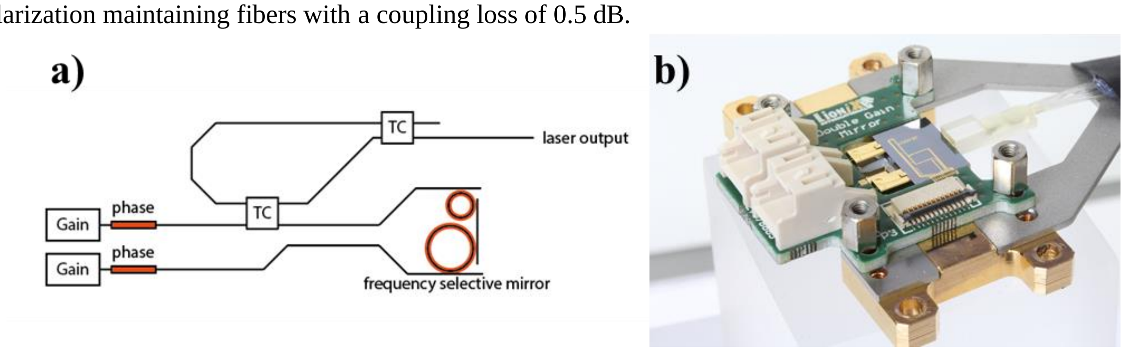

Figure 1 a) Conceptual design of the dual gain laser cavity consisting of a tunable dual-ring cavity, two gain section with phase tuners, and two tunable Mach-Zehnder couplers (TC) to control the output coupling and output power. b) Photograph of the assembled dual gain laser.

3. **Device measurements**

Using this novel design, we achieved a record maximum output power of 20.2 dBm at the fiber output and consequently an on-chip power of 20.7 dBm at a pump current of 300 mA at both RSOAs. The fiber-output power as a function of pump current at each gain section is shown in Fig.2(a) and it can be seen that at pump currents above 300 mA the RSOAs saturate due to insufficient cooling. Note that the output power by using two RSOAs is indeed twice as much when compared to devices with only one RSOA and a similar cavity design, where the maximum obtained optical output power is about 17 dBm. The resulting output power is, to the best of our knowledge, the highest power achieved with any hybrid integrated laser to date. Furthermore, we tuned the frequency selective mirror and measured the achieved output power as a function of wavelength. The results are shown in Fig.2(b) and it can be seen that the wavelength of the laser can be tuned over 100 nm at a -1 dB power drop and a total range of 119 nm from 1468 nm to 1587 nm. Over the whole tuning range, the laser operated at a single mode with a side-mode suppression ratio of more than 50 dB.

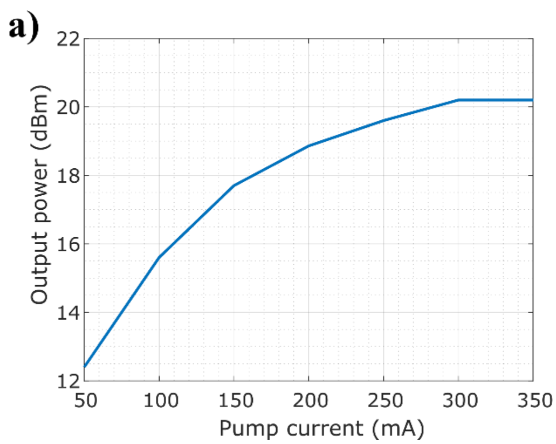

Figure 2 a) Fiber-output power as a function of pump current at each gain section. Gain saturation is reached at pump currents of 300 mA. b) Fiber-output power as a function of laser wavelengths. At a -1 dB drop in output power a tuning range of 100 nm is reached.

The frequency noise of the laser shown in Fig 3 (a) was measured using a linewidth analyzer (HighFinesse LWA-1k) up to a frequency of 20 MHz. Note that for this measurement the heaters were inactive due to noise induced by the heater drivers, while both gain sections were driven with a pump current of 100 mA. It can be seen that the white noise floor reaches a level of 10 $Hz/Hz^{1/2}$ corresponding to an intrinsic Lorentzian linewidth of the laser of around 320 Hz, which is comparable to low intrinsic linewidths reported earlier using hybrid integration [5]. To show that a low noise figure in an APL is to be expected using this laser, we measured its relative intensity noise (RIN) using a high-speed detector and an electrical spectrum analyzer up to a frequency of 25 GHz. The RIN measurement is shown in Fig 2 (b) and it can be seen that the RIN (shown in blue) is well below -160 dBc/Hz over the whole measurement range and for most of the frequencies at a level as low as -170 dBc/Hz. Additionally, we show the relative system noise (RIN and shot noise) shown in red as a comparison to the RIN.

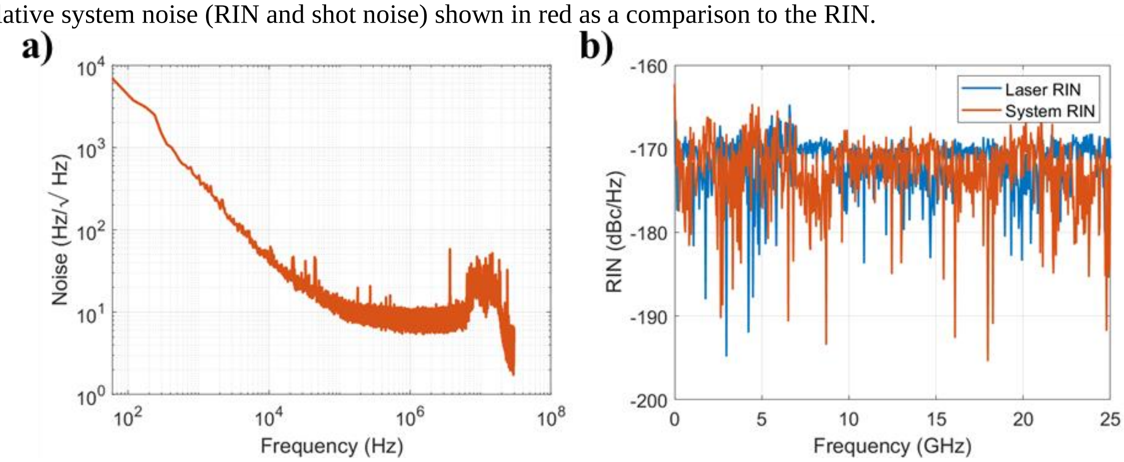

Figure 3 a) Frequency noise measurement of the dual-gain laser showing a intrinsic linewidth of 300 Hz. b) Measured relative intensity noise (RIN) of the laser and the system for frequencies up to 25 GHz.

4. Conclusions

In conclusion, we demonstrated for the first time a hybrid integrated laser with two gain sections coupled to a single cavity. The laser shows a record high on-chip optical power of 20.7 dBm, while still being tunable over nearly 120 nm and showing a high SMSR of more than 50 dB. Due to the low-loss of the cavity waveguides the laser shows an intrinsic Lorentzian linewidth of 320 Hz and a low RIN of less than -165 dBc/Hz. The high output power of this laser and its low RIN are ideal to achieve an efficient link gain in an APL, while simultaneously having a low noise figure. In future devices the output power of this laser can even be improved by improving the thermal management of the RSOA or as well by simply adding more ROSA units to the device.

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