Accurate, high-speed tuning of an ultra-narrow linewidth external cavity laser

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We demonstrate wavelength tuning of a compact external cavity semiconductor laser formed by hybrid integration InP and Si_3N_4 chips. We achieved a scan range covering the C-band with scan resolution of 5 pm providing <13 dBm of output power. Via fast acquisition we demonstrate fast scanning of the wavelength reaching 5 nm within 200 ms.
Keywords: *Tunable laser, External cavity laser, Ultra narrow linewidth, Hybrid integration, Vernier filter, Photonic integration.*

INTRODUCTION

In this work we present the last advancements on tuning external cavity lasers (ECLs) based on a vernier micro ring resonators (MRR). The wavelength of the presented laser can be freely tuned over 100 nm wavelength range, well beyond the C-telecom bandwidth, and similar designs prove to scan at much broader wavelength ranges, yet providing tens of mW of output power [1, 2]. The lasers show great potential in in many applications [3-5]. These MMR Vernier based ECL laser sources are relatively new, and the way of tuning the wavelength is differs significantly from other types of tunable lasers such as well-established laser types like VECSELs, DFB lasers, Littman-Littrow based tunable lasers. Where the wavelength of most of the tunable lasers can be tuned using only 1 or 2 Actuators, exhibiting an almost linear actuation throughout the full wavelength tuning range. The here presented Vernier based actuators (at least 3 actuators) have to cycle through 2π phase shifts between 50 and few hundred times to span the full wavelength range. Therefore tuning of the Vernier based ECLs require high resolution mapping, for high resolution wavelength tuning. In addition the actuator elements have to be fast, in order to scan the wavelength of high speed, full range applications such as Optical Coherence Tomography (OCT).

In this paper we show the obtained results of mapping the laser's characteristics, resulting in a lookup table (LUT). In the second part we push the actuation of the laser to its maximum speed, where we tune the laser over 5 nm range at high speed using a dense LUT, and where we optimize the performance of the laser by a dynamical update of the LUT while scanning the laser. These preliminary results show the potential of the scan speed of the Chilas laser and all MMR based ECLs.

DESIGN

The external cavity laser consists of hybrid integrated indium phosphate (InP) reflective semiconductor optical amplifier (RSOA) and TriPleX silicon nitride (Si_3N_4) external cavity. Here, the RSOA act as gain medium, and feedback is provided by a wavelength selective mirror in the Si_3N_4 photonic integrated circuit (PIC). Wavelength selection is achieved by a vernier filter consisting 2 MRRs. The optical output is interfaced to a polarization maintaining fiber using end face coupling. This commercially available laser source is packaged in a 14-pins butterfly package. The schematic of the laser and its design are shown in Fig. 1.

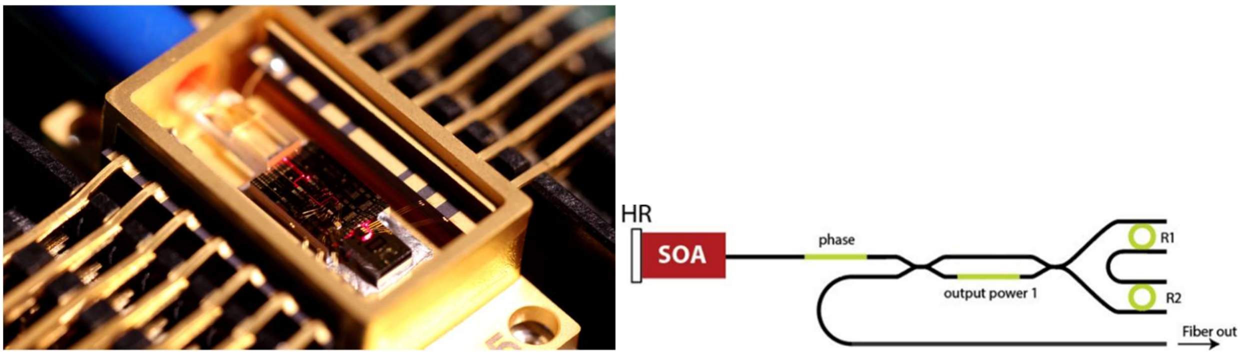

Fig. 1. Photograph and schematic of the Chilas CT3 PIC based external cavity laser module.

The gain section is a reflective semiconductor optical amplifier (RSOA). The RSOA gain section is pumped using an externally driven current. The externally pumped current causes stimulated emission and therefore a high output power of light. The gain section, which has a broad emission band, is coupled to a photonic integrated circuit in the silicon nitride Si_3N_4 realized using TriPleX waveguide technology. TriPleX waveguide technology has the advantage of having extremely low waveguide losses, of ≤ 0.07 dB / cm. The light from the gain section is guided in the Si_3N_4 external cavity through a symmetric Mach-Zehnder interferometer (MZI), and afterwards towards two micro-ring resonators (MRRs) with near-identical but varying circumference length around 1 mm.

Platinum resistive heaters elements are placed onto the waveguides. These heaters can be controlled to support high, single-mode output power the tuning of the output wavelength by changing the refractive index of the underlying waveguide with a thermo-optic effect. Two heaters are placed onto the two rings for wavelength tuning, one heater at one arm of the MZI, and a fourth heater is equipped on a bus waveguide inside the cavity to change its phase. To obtain a 2π phase shift tuning at either of the MRR, a voltage close to 14 V is needed. For the other heaters, this value is close to 8 V.

THEORY

The tuning principle is fully derived from the waveguide structure containing the double MRRs and the MZI. The two rings form a Vernier filter with a combined free spectral range (FSR of 100 nm), here the smaller ring has a designed FSR of 1.73 nm and the larger ring a FSR of 1.70 nm. The two MRRs in the structure act as a Vernier filter. Broadband light travelling through the two resonators will emit a single-mode light output. In Fig. 2 the principle of the wavelength tuning of the laser is demonstrated. Fig. 2a depicts an example of ring responses of the two MRRs of a laser. The broadband light coming from the gain section will enter the first ring resonator, ring 1. The wavelength spectrum of light leaving a micro ring resonator is depicted in Fig. 2a. Due to interference between the light in the ring with itself, only wavelengths at the peaks of the spectrum can exit. With two rings, this process is repeated. Due to the small circumference length difference, the spectrum has a small FSR difference, thus the peaks are slightly mismatched. So, the peaks do not match within a certain range and are able to tune to any wavelength within that range, which is called the span. In order to obtain single-mode lasing , the peaks of both rings ought to be moved to the target wavelength, shown in Fig. 2a. Increasing the heat across the waveguide by applying a higher voltage through the leads of the heater will cause a phase shift of the spectrum shown in Fig. 2a, it will shift towards higher wavelengths. Thus, to obtain a lasing peak at the target wavelength, the heaters have to be tuned for a phase shift of ϕ_1 and ϕ_2 for ring 1 and ring 2 respectively. The Vernier response in that situation is given by Fig. 2b, which is the result of a multiplication of the two ring spectra. Here, the side modes are suppressed due to destructive interference within the ring and will die out as they do not reach lasing threshold. Only one wavelength will remain. Part of the light will be guided back to the gain section for feedback to amplify light at that wavelength, and the other part will be coupled outwards to the fiber output.

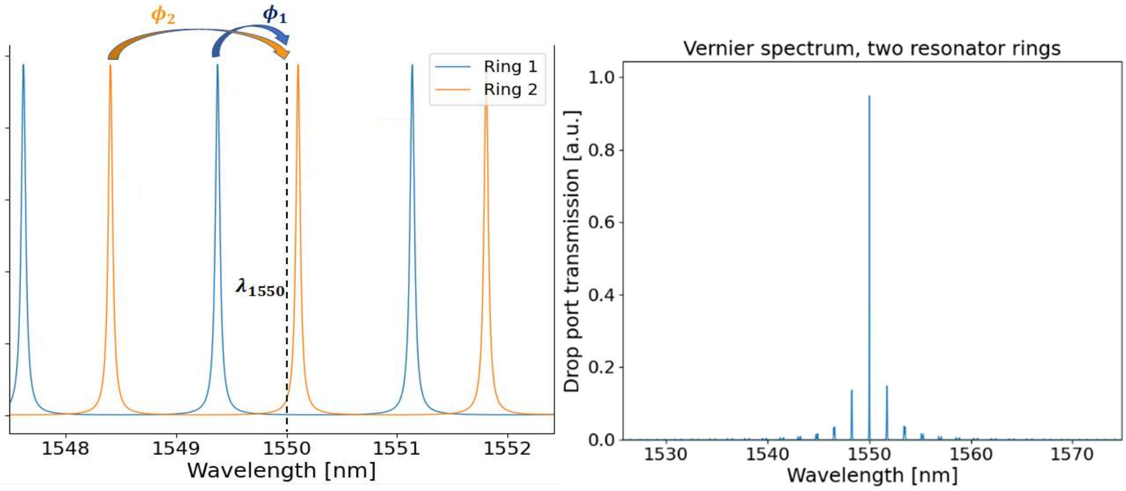

Figure 2. (a): Example demonstrating the ring response and principle of wavelength tuning. The x-axis denotes the output wavelength, and y-axis the transmission. To tune to a specific wavelength (here: 1550 nm), ring 1 and ring 2 needs to be tuned by a phase of ϕ_1 and ϕ_2 specifically. (b): Example of the resulting Vernier response when the rings are aligned at one wavelength (here: 1550 nm).

MAKING THE LOOKUP TABLE (LUT)

The laser system is located inside a 14-pin golden butterfly package and is installed inside the tunable laser controller (TLC). The TLC contains all the necessary hardware to switch on the laser and control the heaters. The optical fiber output of the laser is connected with a 50/50 splitter to measure the output power and the emission spectrum simultaneously. Using a routine a measured dataset is generated, cleaning of the dataset and removal of erroneous data points is done using curve fitting algorithms. This results in a LUT addressing a wavelength range between 1528 nm and 1569 nm, with a resolution of 5 pm. A measurement is performed using another “set-get” routine checking the performance of the LUT systematically Fig. 3a.

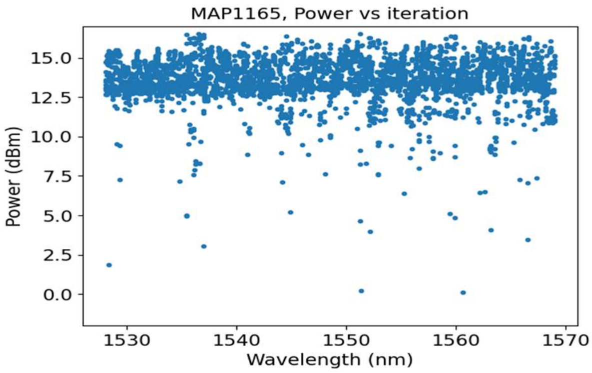

Fig. 3, Graph of power as a function of wavelength for more than 3700 points with a single-mode wavelength output between 1528 and 1569 nm. In this example we obtain an wavelength accuracy of ~ 90% (90% is both single mode, inside the same ring resonance, and above 10 dBm), The majority of the solutions provide a output power between 13 and 16 dBm.

FAST WAVELENGTH TUNING OF THE EXTERNAL CAVITY LASER.

In order to achieve fast tuning a part of the LUT is loaded into a small EEPROM memory cell inside the tunable laser controller (TLC) avoiding any PC to TLC communication related timing issues. The LUT elements are send to the heater drivers of the laser using a local running routine with an interval time of 200 us per element. In this way the system cycles through the full set of 1000 preloaded laser configurations within a total cycle time of 200 ms, while covering 5 nm wavelength range. To measure the emission wavelength of the laser a tunable filter is used for fast acquisition of the wavelength. This tunable filter provides both power as wavelength information at a very high sampling speed. Both the tuning of the laser, and the tunable filter are synchronized to each other. The software interface has a sampling is well below the 200 us interval time, and therefore allows updating of individual heater settings in the LUT while continuously running the scanning laser routine. This dynamical updating of heater settings allows maximization of the output power for each individual entry of the LUT. This results in a fairly flat output power of the laser while scanning as presented in Fig. 4.

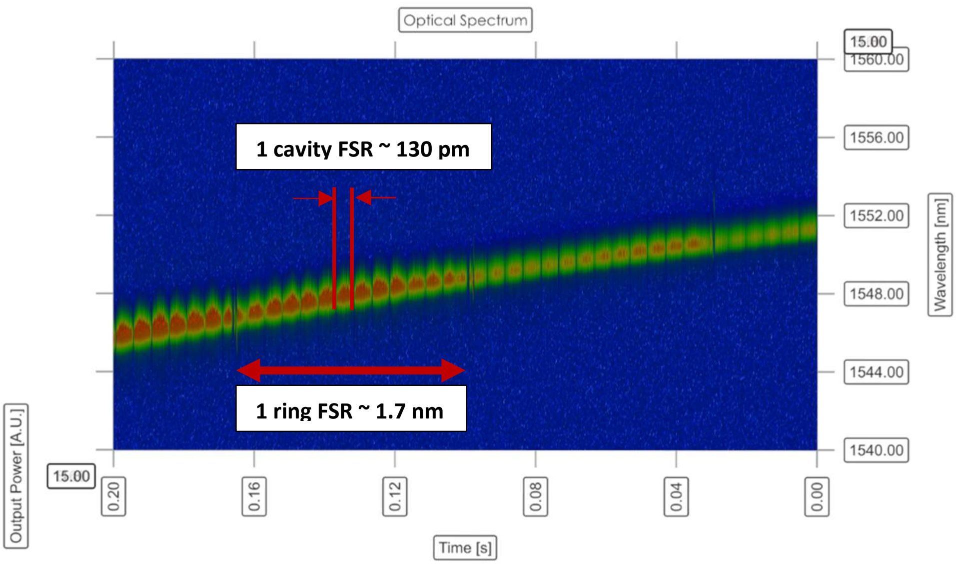

Figure 4, Output power as function of wavelength.

When looking at the results of fast scanning, we can indicate clear patterns, the fine patterns originate from the laser scanning through the cavity FSR with an interval of ~130 pm, we assume this scan is modehop-free. The larger patterns correspond to the FSRs of the rings, being ~1.7 nm. Here the "dark" spots originate from the 2π phase jumps the laser has to make, and therefore is not optimally tuned during a few milliseconds. Ongoing efforts are made to improve the tuning algorithms, and improve the acquisition speeds.

CONCLUSIONS

We have demonstrated high accurate wavelength setting of an vernier based ECL, providing a LUT of 50 nm and a resolution of 5 pm. Measurements show <90% setting accuracy within 10 pm resolution, and power levels between 13 and 16 dBm. Using the combination of fast scanning and fast spectral acquisition of the laser we demonstrate 5 nm wavelength tuning of the laser within 200 ms. Based on these results we anticipate to scan the full telecom C-band within 1 second using our off the shelf tunable laser source.

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