Hybrid InP-SiN microring-resonator based tunable laser with high output power and narrow linewidth for high capacity coherent systems

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Abstract: A hybrid InP/SiN tunable laser based on microring resonators exhibiting 40mW fiber-coupled output power and 5kHz linewidth is demonstrated. The device shows performance comparable with commercial external cavity lasers in 90GBd 64QAM coherent system.

1. Introduction

The ever-increasing demand for bandwidth in metro/core and data-center networks has fostered, in recent years, the spreading of coherent detection technology in combination with advanced modulation formats. Indeed, the use of high-order quadrature amplitude modulation (QAM) formats, possibly coupled with probabilistic constellation shaping (PCS), guarantees high spectral efficiencies and constitutes an effective way for overcoming the capacity limitations of deployed networks. Nevertheless, higher order formats call for lower laser phase noise levels, posing very stringent requirements in terms of laser linewidth to minimize impairments from carrier phase recovery [1], and electronically enhanced phase noise for high symbol rate signals transmitted over ultra-long-haul distances [2,3]. In this context, wavelength-tunable narrow linewidth semiconductor lasers are key enabling devices for extending the capacity of optical networks based on dense wavelength division multiplexing (DWDM). While cost-effective integrated tunable laser assemblies (ITLAs) based on distributed feedback (DFB) or distributed Bragg reflector (DBR) lasers arrays are widely used in commercial networks relying on quadrature phase shift keying (QPSK), the linewidth of these sources is typically several hundreds of kHz, limiting their use with more complex modulation formats. Much narrower laser linewidths can be achieved using external cavity lasers (ECLs), allowing to increase photon lifetime by virtue of their long cavity length. Among different ECL configurations, hybrid tunable lasers combining III-V semiconductor gain chips with photonic integrated circuits (PICs) based on microring resonators (MRRs) have received particular attention, owing to their high power capability and compact size. MRR filters, indeed, allow to effectively extend the laser cavity length without increasing the device footprint. PICs for MRR-ECLs are typically implemented on silicon photonics platforms, such as silicon-on-insulator (SOI) [4], silica [5] or TriPleX [6], and fabricated at high yields and low costs in silicon foundries. In addition to these platforms, thick silicon nitride is emerging as a promising alternative for the implementation of high performance PICs. Like silica and TriPleX, thick SiN features very low propagation losses (<0.1 dB/cm), yet its moderate refractive index contrast enables tighter bending radii (<50µm), allowing for more compact devices. Moreover, unlike SOI, SiN waveguides exhibits negligible two-photon absorption, allowing for high power handling capability, which is particularly desirable for integrated nonlinear photonics and ECLs. In the present work, we exploit these properties by building a hybrid high-power tunable laser combining a SiN MRR PIC and a custom InP reflective semiconductor optical amplifier (RSOA). Fundamental device characteristics are presented before demonstrating the ECL performance in a 90 Gbaud 64-QAM coherent transmission system.

2. Device description and characterization

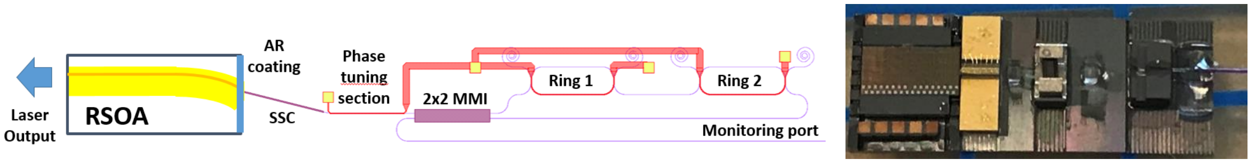

Fig. 1. Schematic representation (left) and micrograph picture (right) of the proposed hybrid InP/SiN MRR-ECL

A schematic representation of the device design and a picture of the ECL assembly are shown in Fig. 1. The laser consists of the butt coupling of a custom 2-mm-long InP RSOA and a thermally-actuated wavelength selective mirror with 2.7 x 0.45 mm^2 footprint comprised on a 5 x 2.5 mm^2 SiN photonic chip. The RSOA is especially optimized for high output power operation, making use of a slab-coupled optical waveguide (SCOW) configuration featuring a thick under-cladding below an InAlGaAs multiple quantum wells (MQWs) active region. This design allows to increase the RSOA saturation power by reducing the optical mode overlap with the MQWs, although at the expenses of larger laser threshold currents. The InP gain chip is fabricated using semi-insulating buried heterostructure (SIBH) process, where the device active stripe is buried in a high-resistivity thermally conductive material to provide optimal heat sinking and circular optical modes [4]. In addition, the RSOA waveguide part facing the SiN PIC is tilted by 7° with respect to the cleaving direction and the corresponding device facet is anti-reflection coated, in order to minimize optical feedback from the InP-SiN interface. For reduced butt-coupling losses, optical mode matching is achieved by means of a dedicated spot-size converters (SSC), patterned into the 800-nm-thick SiN guiding layer at the edge of the filtering PIC. The latter consists of two racetrack-shaped add-drop MRRs, cascaded within a Sagnac loop reflector based on a 3dB 2x2 multimode interference (MMI) device for maximum reflectivity. The MRRs have slightly different lengths in order to take advantage of Vernier effect for wavelength tuning. Poly-silicon heaters are integrated above the MRRs and phase tuning sections, in order to adjust the PIC filtering function by thermo-optic effect. The MRR lengths and power coupling coefficients are thoroughly dimensioned so that: 1) the target free spectral range (FSR) of the SiN filter exceeds the full width at half-maximum gain bandwidth of the RSOA and 2) side peaks in the filtering function are suppressed by more than 3dB. This ensures stable single-wavelength lasing over the entire gain bandwidth, once the SiN filter is spectrally aligned with one of the Fabry-Perot (FP) modes of the overall laser cavity.

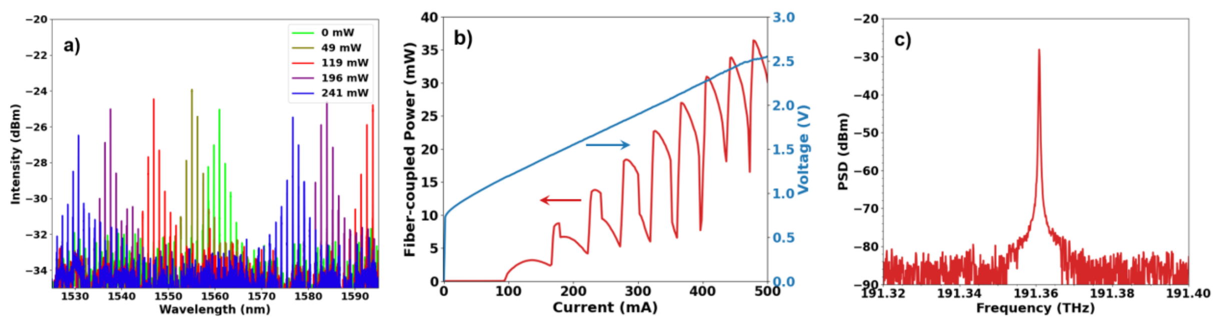

Fig. 2. (a) Single MRR coarse wavelength tuning of the filter PIC. (b) L-I-V curves at 20°C for the assembled hybrid tunable laser, without power applied on the heaters. (c) Optical spectrum of the MRR-ECL at 552mA.

The SiN PIC filtering function and its coarse wavelength tuning by adjusting the heating power on one of the two rings is shown in Fig. 2(a). Around 280mW on a single MRR are required for coarse tuning over the whole filter FSR of 45nm. Fine wavelength tuning and side-mode extinction optimization can be achieved by adjusting heating power on both MRRs simultaneously, as well as on the cavity phase section of the PIC. Both the RSOA and the SiN PIC are mounted on a common micro-optical bench platform in order to assemble the laser cavity and light emitted from the as-cleaved facet of the RSOA is coupled into a single mode fiber (SMF) pigtail using a couple of micro-lenses and an optical isolator in between. Fiber coupling losses are about 1.5dB. The L-I-V characteristics at 20°C of the untuned ECL and the optical spectrum for an RSOA current of 552mA (used for system experiments) are shown in Fig. 2(b)-(c). The device exhibits a threshold current of 95mA and a fiber-coupled output power exceeding 35mW at RSOA currents around 500mA, reaching 40mW at 552mA. The side-mode suppression ratio is above 50dB. The power drops in the L-I curve of the laser are due to mode hops occurring between adjacent FP modes as the effective refractive index in the RSOA changes with injection current. Such mode hops can be avoided by suitably tuning the cavity phase section on the SiN PIC. In terms of output power, to the best of authors' knowledge, such device is one of the best performing MRR-ECL ever reported. Higher output power was only demonstrated in [6] with a larger TriPleX PIC, using two RSOA in the same laser cavity increasing complexity and packaging costs.

3. Experimental results

In this section, we conduct experiments to measure the MRR-ECL linewidth and compare its performance with a commercial ITLA laser source in a Back-to-Back (B2B) configuration. The experimental setup for linewidth measurement is depicted in Fig. 3(a). A 14.5dBm signal at the output of the MRR-ECL is split to two signals with a

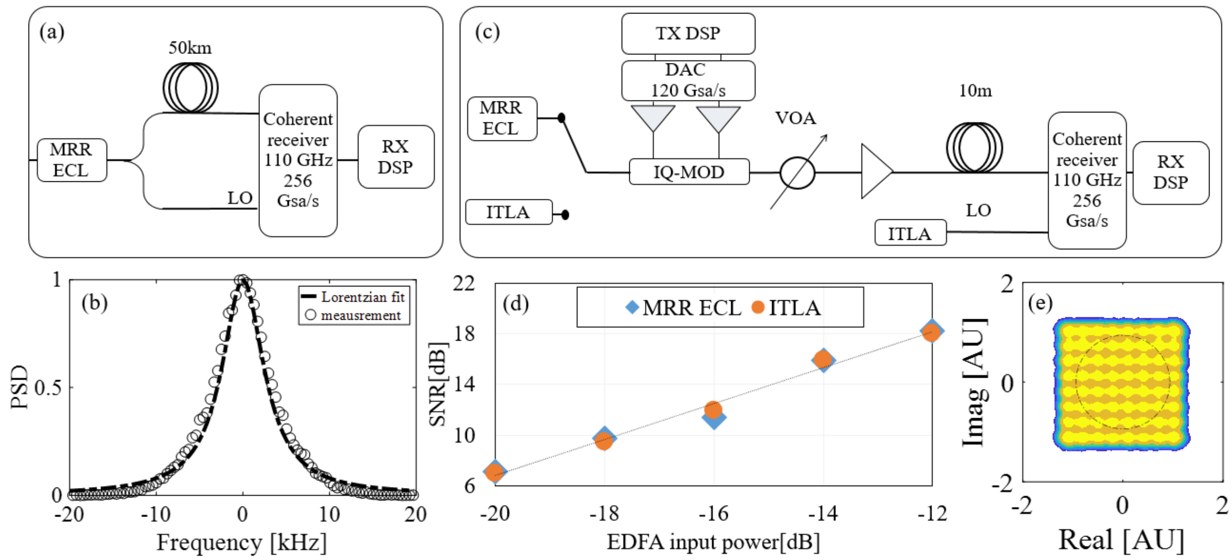

Fig.3(a): Experimental setup for linewidth measurement; (b) Normalized frequency noise PSD at 552mA RSOA current with 5kHz linewidth Lorentzian fit; (c) Experimental setup for laser comparison in coherent system; (d) Numerical SNR distribution as a function of EDFA input power for the MRR-ECL and the commercial ITLA; (e) Received 64QAM constellation diagram.

3-dB coupler, the first is directly sent to the coherent receiver while the second one propagates over 50km of SSMF for decorrelation. At the receiver, electrical waveforms are sampled with a 110 GHz bandwidth high speed sampling scope operating at 256 GSa/s. Offline digital signal processing (DSP) is performed on the received streams. After resampling, the phase component of a single polarization trace is analyzed at different values of laser current. Fig. 3(b) shows the normalized frequency noise PSD at 552mA as well as its corresponding Lorentzian fit with 5kHz linewidth. To compare the performance of the MRR-ECL with a commercial ITLA, we use the experimental setup in Fig. 3(c). A 4-channel high speed CMOS DAC operating at 120 GSa/s is used to generate 64QAM sequences at 90GBd with root-raised cosine (RRC) pulse-shaping (roll-off 0.1). The DACs' outputs are then amplified using driver amplifiers with 43 GHz 3-dB bandwidth followed by a Lithium-Niobate IQ modulator having about 35GHz 3-dB bandwidth. For both configurations, the optical carrier is generated at 191.360 THz and the optical output power is set at 14dBm. Signal power is then adjusted using a variable optical attenuator (VOA) before being amplified by an EDFA. We used the same receiver as in Fig. 3(a) and processed data offline using the DSP chain used in [7]. We performed B2B experiment and Fig. 3(d) shows the measured SNR as a function of EDFA input power. We observe that the MRR-ECL provides very similar performance to that of the ITLA, for any output SNR up to 18dB. Fig. 3(e) finally depicts a received 64QAM constellation diagram, illustrating that our hybrid InP-SiN tunable laser is compliant with high symbol rates and high constellation orders coherent communications

4. Conclusion

In this paper, a novel hybrid integrated tunable laser based on a high-power InP RSOA and thick SiN microring resonators has been presented. Its tuning range of around 45nm, high output power in excess of 40mW, high SMSR (>50dB), and narrow linewidth of around 5kHz make this device particularly promising for use in coherent communication systems employing high order modulation formats and high symbol rates over long haul distances.

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3. References

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