Narrow linewidth hybrid InP-TriPleX photonic integrated tunable laser based on silicon nitride micro-ring resonators

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Abstract: Detailed characterization of a hybrid integrated tunable laser based on micro-ring resonators shows a tuning range of 50 nm with ~40 kHz linewidth. The device demonstrates performance comparable with commercial external cavity lasers in 16QAM coherent system.
OCIS codes: (140.3600) Lasers, tunable; (140.5960) Semiconductor lasers; (160.6030) Silica

1. Introduction

Tunable semiconductor lasers which can provide wide wavelength tuning range, high side-mode suppression ratio (SMSR), high output power, narrow linewidth and fast switching speeds are highly desirable for dense wavelength division multiplexing (DWDM) systems in current core networks and potentially in future optical access networks[1]. In DWDM networks, the use of coherent detection technology combined with advanced modulation formats is employed to achieve higher spectral efficiencies to overcome the capacity limitations of current networks. While quadrature phase shift keying (QPSK) is widely used in commercial optical networks, the use of more advanced modulation formats to increase the spectral efficiency are being investigated. Recent work has presented 256-QAM and 1024-QAM optical systems for access and core network applications [2, 3], however, as the modulation format is increased the laser linewidth requirements become extremely stringent [4]. Among various types of tunable lasers, the external cavity lasers (ECL) can exhibit narrow linewidth due to their long cavity length and indeed recent work [5] has demonstrated an ECL with linewidths below 10 kHz that are suitable for higher order modulation in coherent optical systems. Due to the complexity and footprint of the ECL's, distributed feedback (DFB) laser arrays and distributed Bragg reflector (DBR) type lasers are the preferred tunable laser options for commercial coherent transceivers employing QPSK transmission. However, the linewidth of these devices is typically several hundred kHz [6] which limits their use with higher order modulation formats. A new structure of a micro ring resonator based external cavity laser (MRR-ECL) has recently been developed based on the TriPleX waveguide platform [7-9]. TriPleX, a Si_3N_4 based photonic waveguide platform, has very low optical waveguide losses (<0.1 dB/cm) and has shown its potential for application in a number of fields [10]. The range of applications can be enhanced by hybrid integration of TriPleX with different material platforms, to include increased optical functionality [11], which may make these devices suitable for future coherent transceivers in optical networking applications. In this paper, we initially undertake a detailed characterization to measure the linewidth, relative intensity noise (RIN), tuning range, tuning map, and switching time of the MRR-ECL based on the TriPleX waveguide platform, before demonstrating its performance in a 12.5 Gbaud 16-QAM coherent transmission system for the first time.

2. Device description

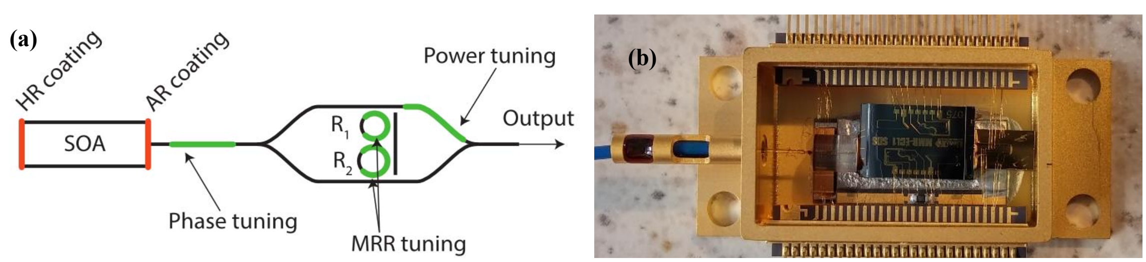

Fig. 1 (a) Schematic diagram of a MRR-ECL [8]. The thermal tuning elements in the external cavity are shown in green color. (b) Photograph of fiber pigtailed hybrid tunable laser in a butterfly package containing a TEC and NTC for thermal control of the narrow linewidth laser cavity.

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The structure of the device is schematically shown in Fig. 1(a). The pigtailed hybrid laser assembly has two optimized optical interfaces: the InP coupled to the TriPleX photonic integrated circuit (PIC), forming the hybrid tunable laser cavity; and the TriPleX PIC coupled to the polarisation maintaining (PM) fiber output. The InP based semiconductor optical amplifier (SOA) has a high reflective (HR) coated back-facet to reduce cavity losses, and a low reflectivity front facet to impose lasing on the external TriPleX cavity. The TriPleX waveguide circuit consists of two cascaded MRRs with slightly different radii, exploiting the Vernier effect to achieve wavelength tuning. The radii as well as the power coupling coefficients of the MRRs are chosen such that the free spectral range (FSR) of the mirror exceeds the 3 dB gain bandwidth of the SOA thereby suppressing the spectral side peaks of the mirror response to avoid lasing at undesired side modes. The result is a highly frequency selective feedback mirror enforcing single-frequency operation. The low propagation loss of the TriPleX waveguides allows for high quality resonators, resulting in several cm's of effective optical path length inside the cavity. In addition, by optimized on-chip spot-size convertors [10], very efficient coupling to a range of mode fields ranging from standard SM fiber (10 microns) to the modes of the InP gain section (3 microns) is achieved, resulting in low loss chip-to-chip coupling (<1dB) between the InP and the TriPleX. The resulting laser cavity has a large cavity photon lifetime enabling narrow spectral linewidth performance compared to typical DFB/DBR lasers. The device is subsequently packaged in a fiber pigtailed butterfly package (as shown in Fig 1(b)) containing a thermistor and thermoelectric cooler (TEC) for accurate thermal control of the device.

3. Laser characterization

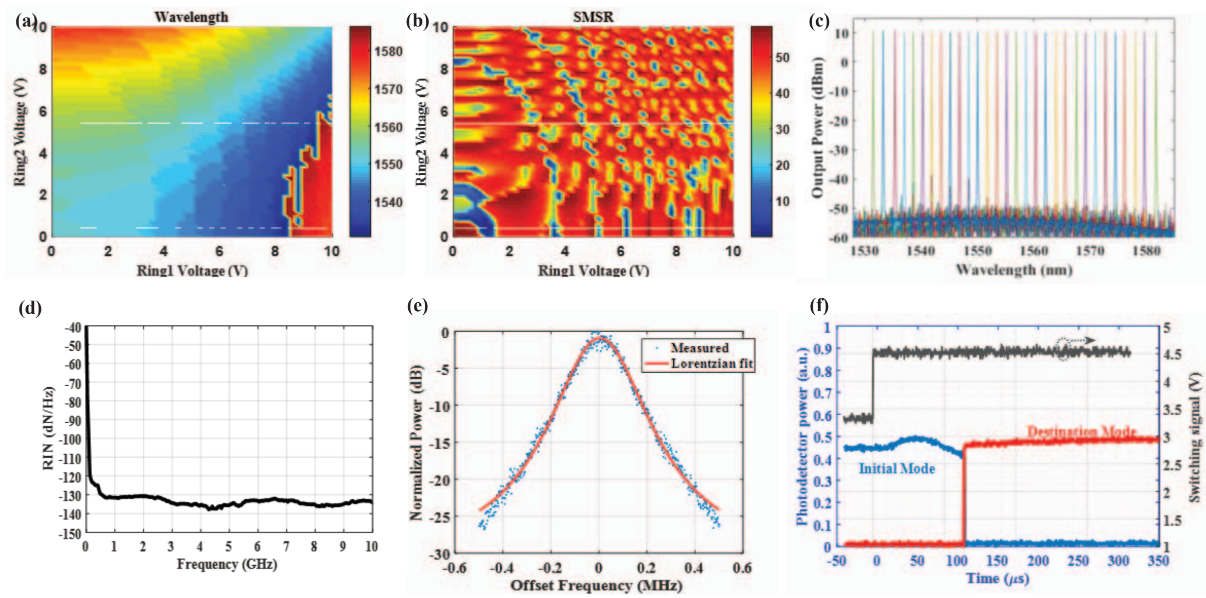

Fig. 2 (a) Tuning map of the wavelength versus voltage on the ring sections. (b) SMSR versus voltage on the ring sections. (c) superimposed laser spectra. (d) Relative intensity noise (e) Linewidth measurement and the corresponding lorentz fitting curve (f) Laser switching times

The packaged laser was mounted on a PCB and the temperature was set at 23 °C using the TEC. The threshold current of the device was measured to be 13 mA and Fig. 2 (a)-(b) show the tuning map and side mode supression ratio of the tunable laser as a function of the injected voltage on the two ring resonators. The current on the SOA was kept at 70 mA throughout the measurements in Fig. 2(a) and (b). Coarse tuning can be achieved by adjusting the voltage to either of the rings independently and more precise wavelength tuning can be achived by using both rings together. The device has a tuning range of more than 50 nm with a SMSR in excess of 50 dB across all wavelengths. High output power can be attained by increasing the current into the SOA to greater than 200 mA, and using the two power tuning sections to optimize output power. Fig.2 (c) shows the superimposed spectra of the laser covering the whole C-band from 1530 nm to 1580 nm with an output power of 10 dBm on each wavelength achieved with the higher current applied to the SOA. The RIN was measured to be less -130 dB/Hz at 70mA current to the SOA as shown in Fig. 2(d) and the linewidth measurement was then undertaken by using the self delayed heterodyne method with 12 km single mode fiber in one arm, a phase modulator with a 2 GHz RF signal applied in the other arm, and a photodiode and spectrum analyser to measure the signal. As presented in Fig.2 (e) the full spectral width at 20dB down from the peak is around 780 kHz, which corrresponds to a laser linewidth of 39 kHz with an injection current of 70 mA to the SOA and no voltage applied to the ring resonators. Finally, the tuning time of the laser was measured by applying a 100 Hz clock signal to one ring section to switch the laser between two adjacent modes, filtering out each mode with a 0.2 nm bandwidth optical bandpass filter, and then measuring the detetcted power in each wavelength as a function of time with a real time scope. Fig.2 (f) shows the received power on the initial wavelength and wavelength the laser is switched to, indicating it takes about 100 microseconds after the clock edge for the thermal tuning of the ring to induce the wavelength switch [12], but the actual switch between wavelengths occur on a sub microsecond time scale.

4. Transmission Experiment

In order to evaluate the performance of the TriPleX based MRR-ECL in an optical coherent system, the laser was utilized in a coherent setup as the signal source tuned to 1550 nm and was modulated with 16-QAM data at 12.5-Gbaud using an optical "I-Q" modulator. The optical modulator was driven by electrical signals generated from an arbitrary waveform generator (AWG) which operated at 25 GSa/s. The modulated optical signal was then passed through a 3 dB splitter with one arm sent to the OSA for measuring the OSNR, and the other passed into the coherent optical receiver and captured by a real-time oscilloscope sampling at 50 GSa/s. The required DSP functionality was performed offline. The performance of the MRR-ECL in terms of BER versus OSNR was verified to be comparable to a commercial ECL laser (Keysight N7711A) as shown in Fig.3 (a), and the constellation diagram of the 12.5 Gbaud 16-QAM signal at an OSNR of 19 dB is presented in Fig. 3(b). Fig. 3(b) also shows the constellation diagram of a 12.5 Gbaud 32-QAM signal achieved with the MRR-ECL which presents a BER of 10^{-3}. These results indicate the excellent performance of this tunable laser in a coherent optical communication system.

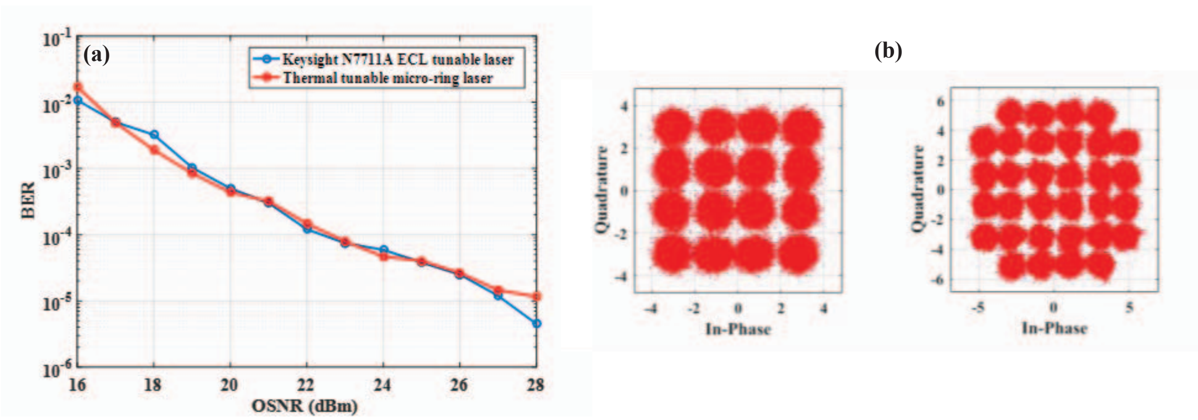

Fig. 3 (a) BER versus OSNR curve for 16 QAM data signal at 12.5 Gbaud (b) constellation diagram for 12.5 Gbaud16-QAM at OSNR of 19 dBm and 12.5 Gbaud 32-QAM at a BER of 10^{-3}

5. Conclusion

In this paper, detailed characterization of a hybrid InP-TriPleX integrated tunable laser based on silicon nitride micro ring resonators has been presented. A tuning range of around 50 nm with high output power (>10 dBm), high SMSR (>50 dB), and narrow linewidth of around 40 kHz makes this a promising device for use in coherent communication systems employing higher order modulation formats; especially given the ease of integration of the PIC. Furthermore, the µs switching speed indicates its suitability for use in coherent systems employing burst mode operation.

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6. References

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