Multi-wavelength laser based on an Arrayed Waveguide Grating and Sagnac loop reflectors monolithically integrated on InP

P. Muñoz, R. García-Olcina, J.D. Doménech, M. Rius and J. Capmany
Optical & Quantum Comms. Group
iTEAM Research Institute
Univ. Politécnica de Valencia (Spain)
E-mail: pascual@ieee.org

L.R. Chen and C. Habib
Photonics Systems Group
Electrical & Computer Eng. Dept.
McGill University (Canada)
E-mail: lawrence.chen@mcgill.ca

X.J.M. Leijtens, T. de Vries, M.J.R. Heck, L. Augustin, R. Notzel and D. Robbins
Opto-Electronic Devices group
COBRA Research Institute
TU Eindhoven (The Netherlands)
E-mail: x.j.m.leijtens@tue.nl

***Abstract*—In this paper, a multi-wavelength laser monolithically integrated on InP is presented. A linear laser cavity is built between two integrated Sagnac loop reflectors, with an Arrayed Waveguide Grating (AWG) as frequency selective device, and Semiconductor Optical Amplifiers (SOA) as gain sections. The power is out coupled from the cavity using a side diffraction order of the AWG. Simultaneous laser operation is provided for four wavelengths/cavities in the device. The termination of the laser cavities with integrated Sagnac loop reflectors avoids using high reflection coating. Only anti-reflection coating is used in the output facet of the chip.**

I. Introduction

Multi-wavelength lasers monolithically integrated on an Indium Phosphide chip are very relevant devices for optical communications [1]. They usually consists on combinations of Arrayed Waveguide Gratings (AWGs) and Semiconductor Optical Amplifiers (SOAs), and two configurations are mainly used, linear and ring lasers [2]. The linear lasers are assisted by reflectors to provide the needed feedback to the cavity, and they are typically implemented either using High-Reflection (HR) coating at the ending side of the cavity on the chip facet [3], or by means of Distributed Bragg Reflectors (DBR) [4]. Ring lasers do not require HR coating, but the lasing preferred direction cannot always be determined [2]. In this paper we present a multi-wavelength linear laser based on AWGs and SOAs, in which the linear cavity is enclosed by Sagnac loop reflectors, therefore no HR coating is needed. Although HR coating is not a complex process at InP manufacturing, this and other material systems can benefit of this novel configuration.

II. Results

The devices were designed and fabricated on InP active/passive technology, where selective etching and regrowth are used to provide active/passive butt-coupled integration. Full technology details are given in [5], where the layer stack, process flow, waveguide types (deep, shallow) and devices are described. The AWG was designed to work at λ_0=1550 nm, with 2 input and 5 output spectral channels spaced $\Delta\lambda_c$= 1.6 nm. The design is for a cyclic response, FSR=5*1.6=8 nm, and for two diffraction orders [6] to be available at the input/output slab couplers. Hence 50:50 out coupling from the laser cavity can be performed without the need of an additional power splitter, since input waveguides have the same spectral transfer function, as labeled in Fig. 1 as 'FSR out-coup'. The loop reflectors are Sagnac interferometers with a 2x2 MMI coupler [7] that provides a $\pi/2$ phase shift [8] between the two outputs, necessary for total reflection [8]. Although just one waveguide in the Sagnac is used, the other one is terminated in a pigtail/spiral shaped waveguide, Fig. 1, to minimize unwanted reflections due to possible imperfections. The SOA sections have a length of 500 μm. The amplifiers SOA_2 and SOA's L_i, i=1..4, are used to obtain sufficient gain for lasing to occur at each cavity. Additionally, thermo-optic heaters are laid between the SOAs and the Sagnacs, to control the cavity phase. The device was soldered to a copper support and its temperature was kept at 25 C during the measurements. A multi-contact wedge was used to probe the SOA's, and a lensed fiber was aligned with the output waveguide using a nano-positioning stage. Alternate lasing of the 4 available wavelengths was obtained for a SOA_2 bias of 25 mA, and SOA's L_1 to L_4 alternated bias of 75 mA, as shown in Fig. 2-(a). In the present device, for a given SOA L_i, i=1...4, the lasing wavelength can hop between the AWG spectral periods, due to the SOA gain maximum shift with the applied current. This can be prevented if a larger size AWG design, with finer channel bandwidth, is used [2]. With SOA_2 at 25 mA, the threshold currents for alternate lasing are 30 mA, for SOA L_1 and 25 mA for SOA's L_2 to L_4. The Optical Spectrum Analyzer (OSA) peak powers, measured at the wavelengths shown in Fig. 2-(a), for SOA's L_i biased at 75 mA, are 70.795, 141.254, 112.202 and 89.125 mW/0.1 nm respectively. Simultaneous lasing of 4 wavelengths within the same AWG FSR was obtained, as shown in Fig. 2-(b), by biasing SOA_2 at 33.2 mA, and SOA's L_i 1 to 4 at 121.3 mA, 65 mA, 49 mA, and 74 mA respectively. Finally, the length

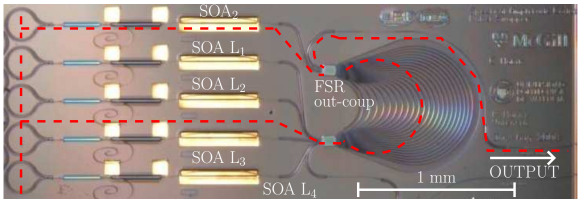


Fig. 1. Device micro graphs, output and SOA's labeled.

of the Fabry-Perot (FP) cavity between the two mirrors was confirmed by means of a 10 pm resolution Optical Spectrum Analyzer. Fig. 3 shows the acquired spectrum for SOA$_2$ and SOA L$_4$ biased at 25 mA and 75 mA respectively. The FP mode spacing averaged amongst five modes yields 51.4 pm, corresponding to a cavity length of 6.7 mm, for a group index of 3.5, marked in Fig. 1 between two Sagnac reflectors with a dashed red line. The length for the SOA$_2$ to SOA L$_4$ cavity is: Sagnac reflectors, ring of 85 μm, hence a perimeter of $2\pi 85$ μm each; straight sections between the Sagnac and bent waveguides to the AWG, 1.8 mm each; bent waveguides, 325 μm each; the AWG optical length is $l_0 + N/2 * \Delta l$ [6], where $l_0 = 500$ μm is the shortest path length, $N = 22$ is the number of arrayed waveguides and $\Delta l = m\lambda_0/n_c$ is the path length increment between consecutive waveguides, with $m = 194$ the AWG diffraction order and $n_c = 3.4$ the propagation effective index in the arms, therefore, AWG path length 1.5 mm; total length 2*(1.8+2π*0.085+0.325)+1.5=6.7 mm.

III. Conclusion

A multi-wavelength laser based on AWGs, SOAs and integrated Sagnac loop reflectors, monolithically integrated on InP, has been demonstrated. The device can be operated either as a discretely tunable or simultaneous four wavelength laser.

Acknowledgments

The authors acknowledge financial support from the European Commission FP6 project 004525 ePIXnet and the Canadian Institute for Photonic Innovations. The devices were fabricated through the InP Photonic Integration Platform JePPIX (coordinator D J Robbins), at the COBRA fab.

References

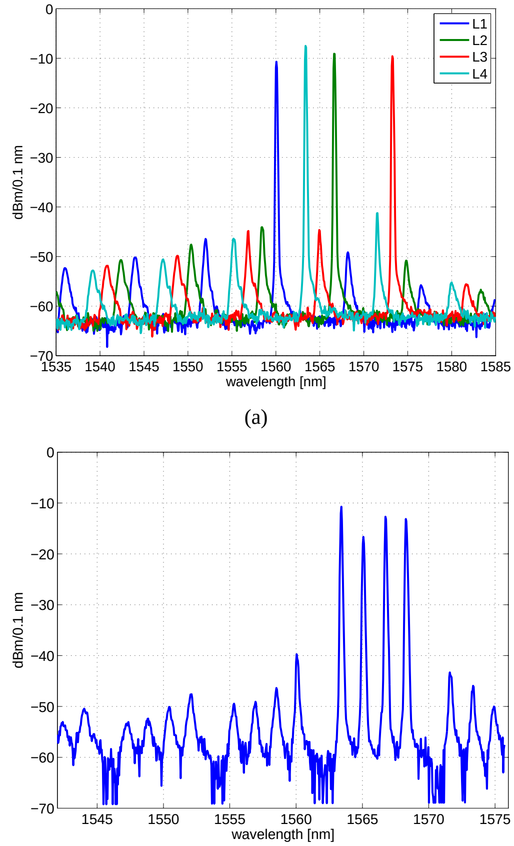
[1] D. Welch, F. Kish, S. Melle, R. Nagarajan, M. Kato, C. Joyner, J. Pleumeekers, R. Schneider, J. Back, A. Dentai, V. Dominic, P. Evans, M. Kauffman, D. Lambert, S. Hurtt, A. Mathur, M. Mitchell, M. Missey, S. Murthy, A. Nilsson, R. Salvatore, M. Van Leeuwen, J. Webjorn, M. Ziari, S. Grubb, D. Perkins, M. Reffle, and D. Mehuys, "Large-scale inp photonic integrated circuits: Enabling efficient scaling of optical transport networks," *IEEE J. Sel. Topics Quantum Electron.*, vol. 13, no. 1, pp. 22–31, Jan.-feb. 2007.

[2] J. den Besten, "Integration of multiwavelength lasers with fast electro-optical modulators," Ph.D. dissertation, TU Eindhoven, 2004.

[3] A. La Porta, M. Heck, X. Leijtens, L. Augustin, T. d. Vries, E. Smalbrugge, Y. Oei, R. Notzel, R. Gaudino, D. Robbins, and M. Smit, "Monolithic awg-based discretely tunable laser with nanosecond switching speed," in *Proc. LEOS Annual Meeting*, 2008, p. CThM3.

[4] L. Coldren, "Monolithic tunable diode lasers," *IEEE J. Sel. Topics Quantum Electron.*, vol. 6, no. 6, pp. 988–999, Nov/Dec 2000.

[5] E. Bente and M. Smit, "Ultrafast InP optical integrated circuits," in *Proc. of SPIE*, vol. 6124, 2006, p. 612419.



(a)

(b)

Fig. 2. (a) Alternate lasing and (b) simultaneous 4 laser operation

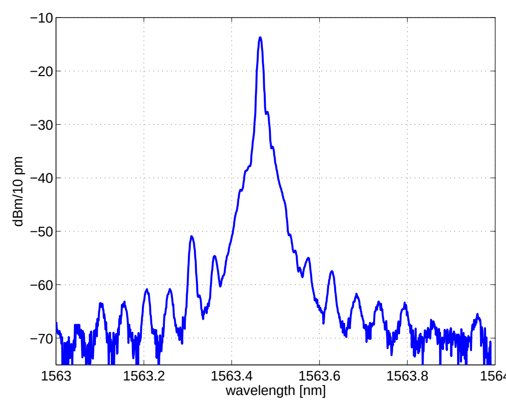


Fig. 3. 10 pm OSA resolution laser spectrum trace.

[6] P. Munoz, D. Pastor, and J. Capmany, "Modeling and design of arrayed waveguide gratings," *J. Lightw. Technol.*, vol. 20, no. 4, pp. 661–674, 2002.

[7] L. Soldano and E. Pennings, "Optical multi-mode interference devices based on self-imaging: principles and applications," *J. Lightw. Technol.*, vol. 13, no. 4, pp. 615–627, Apr 1995.

[8] B. Saleh and M. Teich, *Fundamentals of Photonics*, 2nd ed. Wiley, 2007, ch. 2.