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 consist 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 \( \lambda_0=1550 \) 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 π/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 \( \mu \)m. The amplifiers SOA\(_2\) and SOA\(_i\), 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 \( L_4 \) 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 \( L_1 \) to \( L_4 \) at 121.3 mA, 65 mA, 49 mA, and 74 mA respectively. Finally, the length
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 $\mu$m, hence a perimeter of $2\pi \times 85$ $\mu$m each; straight sections between the Sagnac and bent waveguides to the AWG, 1.8 mm each; bent waveguides, 325 $\mu$m each; the AWG optical length is $l_0 + N/2 \cdot \Delta l$ [6], where $l_0 = 500$ $\mu$m 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 $2 \times (1.8 + 2\pi \times 0.085 + 0.325) + 1.5 = 6.7$ 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.

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