Theoretical and Experimental Study of Distributed Bragg Reflector Lasers on SMART Photonics Platform

(Student Paper)

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ABSTRACT

Photonic integrated circuits (PICs) provide the most promising way for tunable semiconductor lasers in reducing their size, weight, power consumption and cost. In this paper, theoretical and experimental research has dedicated on three-electrode Distributed Bragg reflector (DBR) lasers on indium phosphide (InP) PICs. Theory shows that the wavelength tuning could be realized by varying current injections to both DBR grating sections and SOA section. Experiment shows that DBR laser with 750-µm cavity length can be continuously tuned over 1.4 nm with side mode suppression ratio (SMSR) above 40 dB. Moreover, the linewidth of the laser is 4 MHz with 3 mW output power. Since these DBR lasers have been realized in a mature PIC platform following the design rules, which means that they are now available as building blocks in larger-scale PICs.

Keywords: Distributed Bragg reflector lasers, tunable lasers, semiconductor laser, single-mode laser, photonic integrated circuits.

1. INTRODUCTION

Tunable semiconductor lasers attract much interest over the last few decades, due to their extensive applications from fundamental science to ‘real world’ applications, in which fiber optic telecommunication systems , broadband gas sensors and Terahertz emitters have a large demand for them [1]. Photonic integrated circuit (PIC) commercial fabrication platforms have a fast development over the last ten years, which provides an efficient and reliable solution to design and fabricate tunable semiconductor lasers in terms of reducing their size, weight, power consumption and cost. Among all tunable lasers, DBR lasers are single mode lasers with narrow linewidth and modest wavelength tunablity. Their characteristics make them ideal for telecommunication, gas sensor and terahertz generation use, which require a high side mode suppression ratio (SMSR) and a good stability. SMART photonics has released its DBR grating building block in last two years, which gives us the possibility to design the lasers and examine their performances in lab. Since the strongest absorption lines are at 1512, 1514, 1522, 1527, and 1531 nm for ammonia sensing, we have designed a series of DBR lasers aiming at these wavelengths. In this paper, we will focus on one DBR laser with two DBR gratings of equal length on our PICs as an example to show our simulation and experimental results.

2. DESIGN AND SIMULATION

The DBR lasers on our PICs contain three electrodes connecting with the gain section (SOA) and the two DBR grating sections separately. The two gratings work as reflective mirrors to direct back and forth the light generated in the cavity, to form a standing wave. In addition, the laser performance could be controlled by injecting currents through the three electrodes. In order to estimate the threshold current of the lasers, we need to know both the power reflection of the DBR gratings and the gain characteristic of the SOA. In this paper, we focus on the DBR laser with two DBR gratings of equal length 200 µm (Bragg wavelength at 1531 nm), and SOA of length 250 µm, while there are two electrical isolation sections to separate the gratings and SOA.

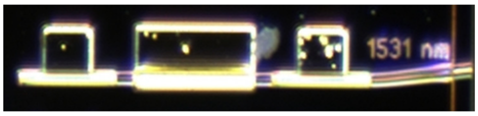

Figure 1. Microscope picture of DBR laser in this paper on PIC

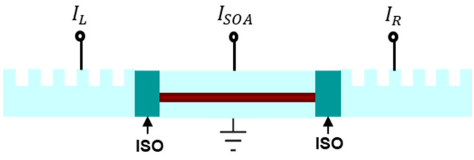

Figure 2. schematic structure of DBR laser (ISO:isolation section)

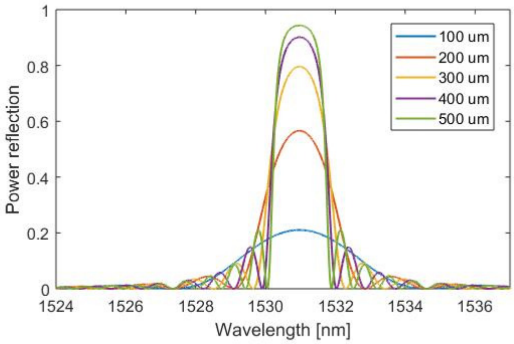

Figure 3. Simulated power reflection of gratings with different lengths

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Fig. 1 demonstrates the microscope picture of the DBR laser on PIC, and Fig. 2 shows the schematic structure corresponding to this laser. The chip will be grounded from its bottom side on our lab setup.

The power reflection of the DBR gratings depends on several parameters, among which include the pitch and length of gratings that we can choose in our design. Moreover, the reflectivity of the gratings could be calculated from the equations shown in [2], and the results are shown in Fig. 3. A 200 µm long grating with Bragg wavelength at 1531 nm reflects around 57% of the light. The relevant parameters are summarized in Table 1.

The threshold current of a laser is defined as the injecting current on the SOA section, when the gain in the laser cavity equals to its cavity loss. Combining the gain curves from the design manual [3], we could estimate the threshold current for the laser in this paper is around 10 mA.

From theory, we know the refractive index of the Bragg gratings will decrease when increasing the current injection to them, due to the free-carrier plasma and band-filling effects. As a result, the wavelength tuning takes place as the Bragg reflection shifts towards shorter wavelength. According to previous research in [4], the carrier concentration in the grating section is normally within the range from $10^{18}/cm^3$ to $10^{19}/cm^3$, which corresponds to maximum around 25 mA current injection to the 200 µm long grating. The simulation result is shown in Fig. 4, which indicates the Bragg wavelength of the grating could be tuned over 10 nm if the thermal effects are not considered.

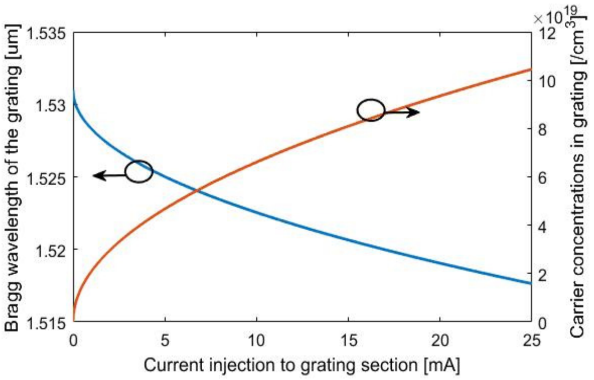

Figure 4. Wavelength tuning by current injection

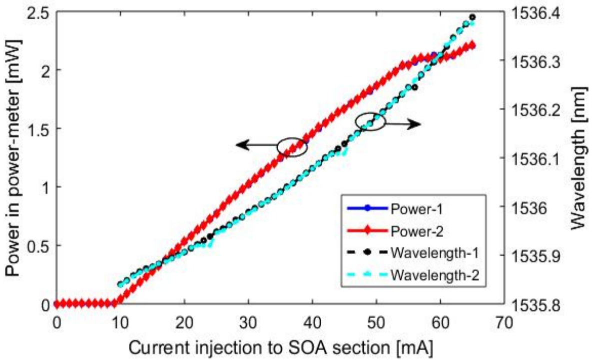

Figure 5. L-I characteristic and wavelength tuning by SOA section

TABLE 1. DESIGN AND SIMULATION PARAMETERS.

Parameter	Symbol	Value	Unit	Parameter	Symbol	Value	Unit
transverse confinement factor[a]	Γ_{xy}	4	%	length of the grating	L	200	µm
coupling coefficient[b]	$\varkappa$	50	cm^{-1}	pitch of the grating	Λ	0.2344	µm
insertion loss[b]	α	2	dB/cm	height of core layer[b]	h	500	nm
electric charge of electron	q	1.602e-19	C	Bragg wavelength	λ_B	1531	nm
current injection efficiency[a]	η_i	70-80	%	width of the grating[b]	w	2	µm
recombination in Q-material[a]	B	0.5e-10	cm^3/s	effective index[b]	n_{eff}	3.266	–

[a] Value taken from [5]

[b] Value taken from [3]

3. EXPERIMENT RESULTS

In this section, we measured the performance of three-section DBR lasers, which included threshold current value, L-I characteristic, wavelength tunability and linewidth. All the measurements performed at 15 °C. Output power and lasing wavelength were measured by Agilent power sensor module (81633A) and Yenista OSA20 respectively.

The L-I characteristic measured from the three-section DBR laser is shown in Figure 4. We obtained the threshold current of 8 mA and the maximum output power in power meter of 2.2 mW at an injection current at 65 mA. Since the output power measured by coupling the light from DBR laser on chip to a lensed fiber, and a 90/10 fiber splitter was used to give 90% output power to power-meter, the estimated coupling loss is 3-5 dB. Therefore, the maximum output power generated from the laser is around 8 mW. From this figure, we could see that the output power of the laser starts to increase slower and become unstable with higher current injection.

There is a wavelength tuning due to current injection above threshold to SOA section, measurement results have been plotted in Fig. 5. It shows that the lasing wavelength of the laser moves towards longer wavelength when increasing the injecting current above the threshold. There observes a 0.55 nm wavelength tuning with current injection in from 10 to 65 mA range. According to theory, the carrier density and the gain of SOA section will clamp at their threshold value with injecting current increasing above the threshold current. Moreover, with higher injecting current, the thermal effects start to affect the laser performance, which result in lasing wavelength moving towards longer wavelengths. Previous research in [6] shows that the lasing wavelength of the laser will increase by 0.1 nm, with every degree temperature increase in active region of the laser.

We found that the wavelength tuning at a specific injecting current to SOA section could be realized by varying the current injections to both DBR gratings, and the tuning range is the same comparing sweeping the current injection to each DBR grating separately and giving equal current injection to both gratings. Therefore, we measured the wavelength tunability of this DBR laser by sweeping the same current injection to both gratings at different current injection to SOA section. The measurement result shows that this simple DBR laser has a good single mode performance, and it has a 1.4 nm continuous wavelength tuning range with SMSR above 40 dB. The results are plotted in Fig. 6.

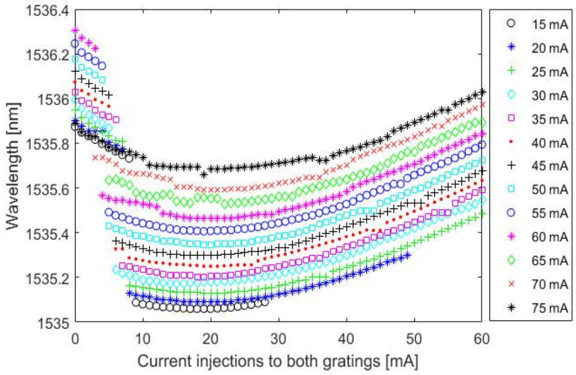

Figure 6. Wavelength tuning with SMSR above 40 dB

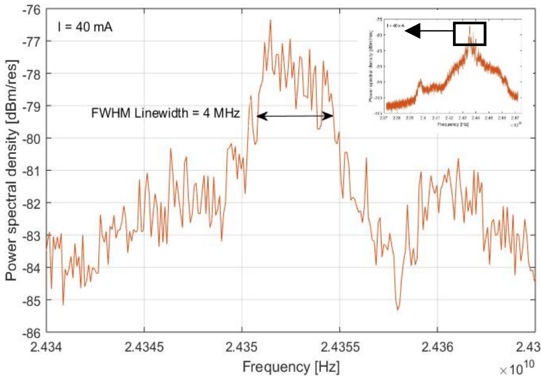

Figure 7. Linewidth measurement result

As shown in Fig. 6, at a specific current injection to SOA section (value shows in legend), the positions of the lasing peaks in the optical spectra move towards shorter wavelengths firstly when increasing the injecting current to both DBR gratings, and then move back to longer wavelengths when the current is above 20 mA to each grating. There should be several reasons resulting in this phenomenon. Firstly, the carrier density in the core layer of the waveguide is saturated when increasing the injecting current, which due to the radiative and Auger recombination. Secondly, the temperature will raise up with higher injecting current, and the thermal effects will take over to tune the wavelength back to longer wavelengths.

The linewidth measurement was done by using heterodyne technique that combining the DBR laser output optical signal with a commercial tunable laser, which has a relatively smaller linewidth of 100 kHz (Agilent 81940A). The frequency difference between these two lasers should stay within both the detecting range of external photodetector (New Focus 1024) and the electrical spectral analyzer (R&S FSV30). The measurement result is shown in Fig. 7, which illustrate that the linewidth of the DBR laser is about 4 MHz with 40 mA current injection to SOA section.

4. CONCLUSIONS

The performance of the DBR laser on SMART Photonics platform has been theoretically and experimentally investigated in this paper. The experimental results mostly meet the expected performance of the lasers. For the three-section DBR laser with 750-µm cavity length, we have observed the maximum output power of 8 mW, continuous wavelength tuning of 1.4 nm with above 40 dB SMSR, and a linewidth of 4 MHz with 3 mW output power. The measurement results show that the DBR lasers on PICs have a good single mode performance and stability, even though there is some limitation of the output power and wavelength tunability. However, the research in this paper shows that we now have building blocks to design tunable lasers for applications such as gas sensing, THz emitters, etc.

REFERENCES

[1] Coldren, Larry A., et al. Tunable semiconductor lasers: A tutorial. Journal of Lightwave Technology, 2004, 22.1: 193.

[2] Kokubun, Yasuo., et al. Encyclopedic handbook of integrated optics. CRC Press, 2005.

[3] Photonic IC design manual. SMART Photonics, 2017.

[4] Bennett, Brian R., et al. Carrier-induced change in refractive index of InP, GaAs and InGaAsP. IEEE Journal of Quantum Electronics, 1990, 26.1: 113-122.

[5] Coldren, Larry A., Scott W. Corzine, and Milan L. Mashanovitch. Diode lasers and photonic integrated circuits. Vol. 218. John Wiley & Sons, 2012.

[6] Sysak, Matthew N., et al. Hybrid silicon laser technology: A thermal perspective. IEEE Journal of Selected Topics in Quantum Electronics 17.6 (2011): 1490-1498.