Single-mode and multi-mode DBR lasers using InP-Si_3N_4/SiO_2 integration

(Student paper)

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ABSTRACT

We propose to highlight the versatility of the integration of InP and Si_3N_4 platforms by presenting two hybrid lasers. Our first laser reaches a narrow optical linewidth of 5.6 kHz at 1546 nm, with a continuous tuning range of 12.7 GHz and a 65 dB side-mode suppression ratio. Then, we report preliminary work on another integrated multimode laser which presents 48 optical lines in a 10 dB bandwidth, spaced 1.19 GHz apart. Such integrated sources present low consumption, compact and affordable solutions for LiDAR, coherent communication transmissions or spectroscopy.

Keywords: Distributed Bragg reflector lasers, hybrid lasers, narrow linewidth, comb source

1. INTRODUCTION

The integration of lasers is a key leverage for a growing number of applications. Telecommunications, LiDAR, or microwave generation take profit of low cost, compactness and power saving integrated sources. However solutions based on monolithic InP integration are limited by their cavity length due to the propagation losses. They are not adapted to narrow linewidth single mode laser or low repetition rate mode-locked laser fabrication.

One possibility to integrate high-performance lasers is to extend the III-V gain chip cavity by butt-coupling a passive chip with low propagation losses [1]-[4]. We report here two hybrid lasers composed of an InP Reflective Semiconductor Optical Amplifier (R-SOA) with a silicon nitride (Si_3N_4) Bragg grating. Thanks to the maturity of the silicon platform, the propagation losses of the Si_3N_4 waveguides are very low. Consequently, the cavity length can be adapted to the targeted application. We emphasize in this abstract the flexibility of this hybridization. After describing the key fabrication steps of low loss Si_3N_4 waveguide, we present a single mode laser made of a short passive cavity and a narrow Bragg filter. Then, we will demonstrate a multimode laser composed of a longer passive cavity with a broad Bragg filter.

2. FABRICATION OF LOW LOSS PASSIVE WAVEGUIDES

The passive chip process begins by a 8-µm thermal oxidation of the 200-mm diameter silicon substrate. Then the stoichiometric Si_3N_4 90-nm thin film is deposited by low pressure chemical vapour deposition (LPCVD). We define the waveguide by Deep Ultra Violet (DUV) lithography with a width of 2.9 µm. These dimensions of the waveguide enable a low confinement of the propagating mode over the core of the waveguide, leading to the lowest propagation losses and avoiding nonlinearity in the passive waveguide. It implies to monitor carefully the quality of the Si_3N_4 and the SiO_2. Thus we apply to the wafer a 3-hour annealing at 1200°C in oxygen atmosphere. It is a key step to purify the wafer from hydrogen. Next we encapsulate the waveguides with a SiO_2 thermally grown on a silicon wafer. Finally, clean optical facets are formed by deep etching down to the silicon. To turn the large wafer on several tens of chips, it is partially sawed by its rear side to release the chips.

We finally measure very low losses around 2 dB/m, which is a typical value in the top foundries [5]. Such performances easily open the road to very long cavity.

3. NARROW LINEWIDTH SINGLE MODE DBR

Our narrow linewidth single-mode DBR laser is using the design already presented in [3] for which we reduced the waveguide losses and improved the mode matching with the R-SOA. The R-SOA, built in our laboratory, is based on a SIBH structure, with an asymmetric optical confinement. This 1 mm-long component provides a gain centred on 1.55 µm strong enough (around 20 dB) to compensate the losses form a long external butt-coupled cavity.

To close the cavity, we choose to butt-couple a Si_3N_4 Bragg grating, which doesn't require a thermal control unlike ring filters with Vernier effect. The bandwidth has to be narrow enough to insure the single mode operation. Thus, we designed a high order Bragg grating allowing a low contrast effective refractive index, despite fabrication constraints. Every 5.797 µm, we increase the waveguide width from 2.9 µm to 3.7 µm to construct a 264x400 nm tooth. With a circulator, we measure its reflectivity spectrum (Fig. 2). The FWHM bandwidth is about 17.5 GHz (140 pm).

By using a dynamical alignment setup, we butt-coupled the two components to obtain the hybrid laser. Computing the overlap between the modes of two components gives a minimal loss estimate of 0.7 dB. By monitoring the optical power and the spectrum during a current sweep (not shown here), we noted a 55 mA threshold and a maximal output power of 6 mW in the fiber, which corresponds to 15 mW at the on-chip output port. During the current sweep, the R-SOA is slightly heating, thus the wavelength laser steadily increases until the laser undergoes mode hopping since the Bragg filter bandwidth is constant. We measure a typical laser spectrum before a mode hopping in Fig. 2, which permits to easily see the side modes and measure a 17.5 GHz FSR, and a 65 dB side-mode suppression ratio (SMSR). In the same time, we record a continuous tuning range of 12.7 GHz (102 pm), which is suitable with LiDAR applications.

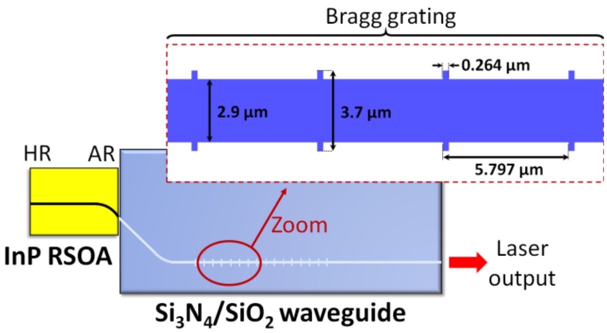

Figure 1. Schematic of the hybrid cavity. The 21th order Bragg grating is made of regular tooth aside the Si_3N_4/SiO_2 waveguide.

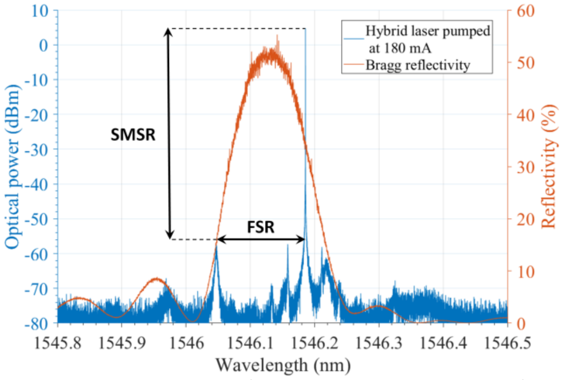

Figure 2. Optical spectrum of a hybrid laser (blue) and of the Bragg reflexion (orange). The side peaks located at 1546.16 nm and 1546.21 nm are measurement artifacts due to APEX optical spectrum analyzer.

By using a self delayed heterodyne setup, we measure the frequency noise of our hybrid laser. We deduce a 5.6 kHz lorentzian linewidth, which we compare with others works in Table 1. One should note that our cavity optical length (around 9 mm) is smaller than competitors, leading to a larger linewidth (see Table 1). For our next components, we plan to increase the cavity length and expect to reduce the linewidth below 1 kHz.

TABLE 1. Linewidth comparison for different configurations

Sructure	**L_{Bragg}**	**P_{out} (mW)**	**Linewidth (kHz)**	**References**
Bragg III-V + Si_3N_4	6.5 mm	6	5.6	Our work
Bragg III-V/Si	15 mm,	37	1	Huang et al. OPTICA 2019 [6]
Bragg III-V/Si	20 mm	24	0.32	Xiang et al. OL 2019 [1]
Ring III-V + Si_3N_4	not applicable	13	0.29	Fan et al. CLEO 2017 [2]
Ring III-V/Si	not applicable	3	0.22	Tran et al. JSTQE 2019 [7]
Ring III-V + PLC (SiO_2)	not applicable	10	2.7	Verdier et al. ECOC 2017 [4]

4. MULTIMODE DBR

The objective of this demonstration based on the same technological platforms is to realize a mode-locked laser with repetition rate in the microwave range. As in the previous experiment, we use the same R-SOA, but here we add in the Si_3N_4 chip a 77 mm delay before a broad Bragg grating at the end (Fig. 3) to fabricate a multimode laser. To reduce the constraints for the lithography process, we choose to create the Bragg grating by using $3\lambda/(4n_{eff})$ long-teeth instead of the standard $\lambda/(4n_{eff})$ length (n_{eff} is the effective refractive index of the mode). Its performance is slightly deteriorated, but as shown in Fig.4, our 1.5 mm-long Bragg grating has still a 95 GHz FWHM-bandwidth.

When aligning the R-SOA and the passive chip, we obtain a very multimode laser. Within a 10 dB bandwidth (measured to 436 pm), we count 48 optical lines which results in an optical comb with a 1.19 GHz repetition rate. It corresponds to an effective optical cavity length of 12.6 cm.

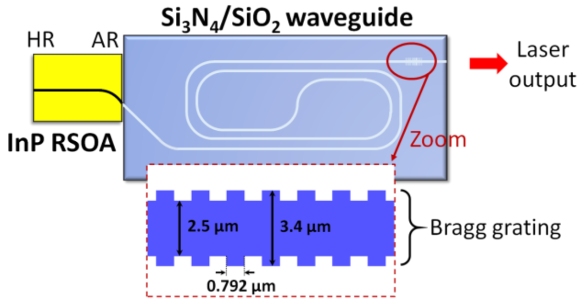

Figure 3. Schematic of the multimode hybrid cavity.

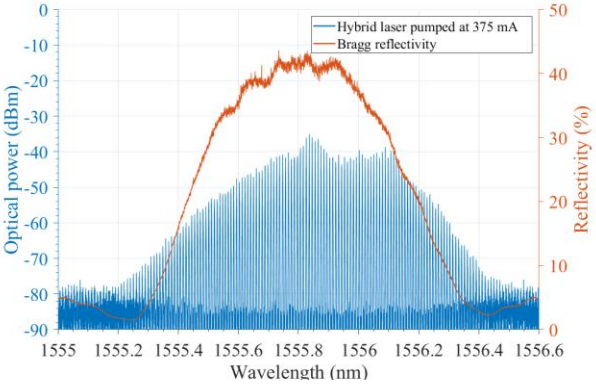

Figure 4. Optical spectrum of a hybrid laser (blue) and of the Bragg reflexion (orange).

The next step of this study will be to investigate the coherence of the peaks and the possibilities of passive or active mode-locking. It is a promising configuration, since it has very few elements and no saturable absorber. Furthermore, it can be tuned by adjusting the cavity length and working on the Bragg filter so as to obtain a specific repetition rate. Moreover it's worth pointing out this work is one of the very few that proposes a mode-locked laser by using the Si_3N_4 platform. Others integrated solutions are based either on monolithic or III-V/Si solutions [8], [9].

5. CONCLUSIONS

We demonstrated the flexibility of the hybridization between the InP and Si_3N_4 platforms. The striking advantage of this concept is to use the low losses of Si_3N_4 (2 dB/m in our devices), which enable the increasing of the cavity lengths. The main challenge is to control the coupling between the two components. We presented a single mode laser based on the butt coupling between a R-SOA and narrow Bragg grating, which presents 5.6 kHz linewidth. We demonstrated preliminary works on a multimode laser, which can become a compact and an affordable solution to mobile spectroscopic analysis and microwave signal generation.

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