Sub-10 kHz Intrinsic Linewidth Extended Cavity DBR laser on InP Generic Foundry Platform

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Abstract: We report an extended-cavity DBR laser with an intrinsic linewidth of 10 kHz and an output power of ~18 mW at an injection current of < 100 mA, on an InP generic foundry platform.

1. Introduction

Integrated semiconductor lasers have become important for various applications ranging from optical communications, optical interconnects [1], light detection [2], metrology and quantum communications [3]. With such applications, semiconductors diode lasers are important, and a key component for photonic industries. Moreover, the lasers spectral purity is characterized by the spectral linewidth, which increases the information, precision, and data rate in optical signal processing. The intrinsic linewidth of lasers is dominated by the amplified spontaneous emission (ASE), and its effect on the semiconductor diode laser can be obtained using the Schawlow-Townes-Henry expression [4,5]. A narrow-linewidth laser can be achieved by increasing the photon lifetime by increasing the cavity length that induced the intrinsic waveguide loss or by increasing the output power of the laser which induced non-linear losses. Therefore, this leads to integrated distributed Bragg grating (DBR) lasers to be intrinsic linewidth limited, typically in the range of a few MHz [6].

To overcome these challenges, a hybrid integration approach between InP-Si_3N_4 photonic circuits was demonstrated which shows an intrinsic linewidth of 40 Hz [7] and a heterogeneous approach of the laser diode on silicon waveguide circuits, which shows the intrinsic linewidth of 220 Hz [8]. However, these approaches have been employed based on two different material platforms which benefit from the low loss of the additional waveguide circuits. Monolithic integration of an extended cavity on an InP generic foundry platform would provide the ultimate solution for fully integrated photonic circuits that are low-cost and scalable. An integrated InP-based DBR laser with 63-kHz intrinsic linewidth was demonstrated using an intracavity resonator on an active generic foundry platform [9]. The generic foundry-based approach ensures the reproducibility, robustness, and consumer demands, which is a pathway to realize scalable photonic circuits. In this work, we realized a fully integrated extended Fabry-Perot resonator coupled with a DBR laser, which shows an intrinsic linewidth of 10 kHz. To our knowledge, this is the lowest value of intrinsic linewidth reported with a generic foundry platform (SMART Photonics).

2. Design and method

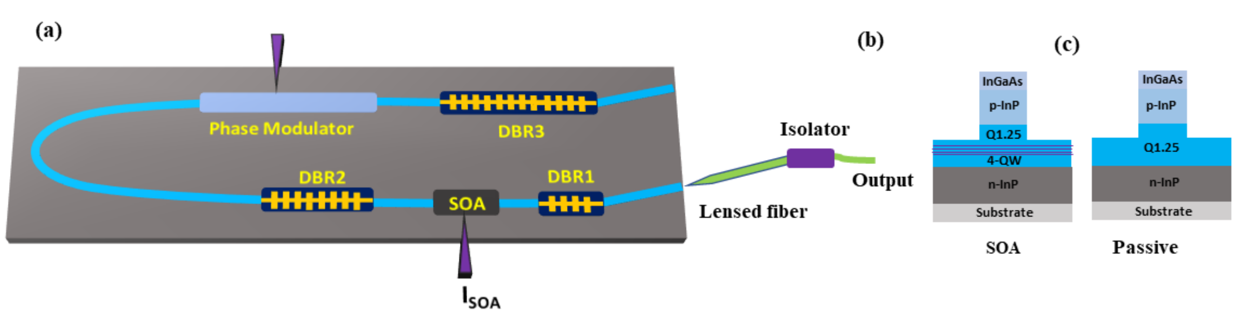

Fig.1 (a) Schematic of DBR laser with an extended cavity on an InP generic foundry platform. Waveguide cross-section (b) of the SOA with four quantum-wells, and (c) of the passive waveguide.

We employ the method of linewidth narrowing of the DBR laser when coupled to extended cavity resonator as described in Ref. [10].

The device schematic is shown in Fig. 1(a). It consists of three DBR mirrors, an active semiconductor optical amplifier (SOA) and a phase modulator. These components are provided by the foundry as a photonic design kit (PDK) with their material platform. The DBR laser is coupled to an extended Fabry-Perot cavity resonator that has length of ~ 8 mm and it consists of a 2-mm long phase modulator. The total length of the extended cavity DBR laser is nearly 9 mm. In order to achieve a low intrinsic linewidth, we thus increased the physical length of the passive waveguide inside the cavity, which has a propagation loss of ~2 dB/cm. The length of the active SOA is 300 µm and it is based on a shallow etched as depicted in Fig. 1(b). The coupling coefficient of the DBR grating is fixed to 50 cm^{-1} and the duty cycle to 0.5 and has an effective index n_{eff} of 3.266 for shallow etched waveguides as depicted in Fig. 1(c). The lengths of DBR1, DBR2, DBR3, are 150 µm, 350 µm, and 700 µm, respectively. The length of the DBR1 was chosen to compromise between output power and linewidth, as higher reflectivity mirrors result in lower linewidth but also low output power. The length/reflectivity of the DBR2 was chosen to maximize the external feedback from the extended cavity. The substrate at the bottom shared the common cathode grounding for the electrical contact for all the devices on this chip. The output waveguide facet of the laser is angled at 8º and coated to minimize back reflections. The chip is mounted on a thermoelectric temperature-controlled stage to prevents thermal drifts. The output light is collected by a lensed fiber and the fiber-to-chip coupling loss is estimated to be ~ 4.5 dB.

3. Results and discussion

The LIV characteristics for this DBR laser is plotted in Fig. 2(a), and it shows a threshold current near 10 mA and a maximum on-chip (fiber-coupled) output power of 18 mW (6.4 mW). The inset curve in Fig. 2(a) shows the optical spectrum with a side-mode suppression ratio (SMSR) of 54 dB at an SOA current of 63 mA. The irregularities in the laser output power are signatures of longitudinal mode hopping, which can be caused by heating of the gain section as the SOA current increases. To overcome these modes hopping, which results in multimode laser emission, the phase section of the extended cavity is actively tuned at a fixed SOA current of ~63 mA. The transition between single mode and multimode regime (drop in output power) is observed on an optical spectrum analyzer (OSA) while sweeping voltage on the phase-section and plotted against the electrical power in Fig. 2(b). We noticed the laser output power and laser wavelength shows a hysteresis behavior, which appears in Fig. 2(b,c). The laser wavelengths were appeared to be red shifted for a one V_π cycle and recovered back afterwards. Therefore, it is possible to align the extended cavity mode to coincide with the mode of the laser main cavity to be operated in a single-mode regime. However, the stability of this laser to be operated in a single-mode regime was limited as it is sensitive to thermal, and electrical drifts. An active feed-back control loop for the SOA current, and phase modulator at fixed temperature is required to improve the laser wavelength stability over a longer duration.

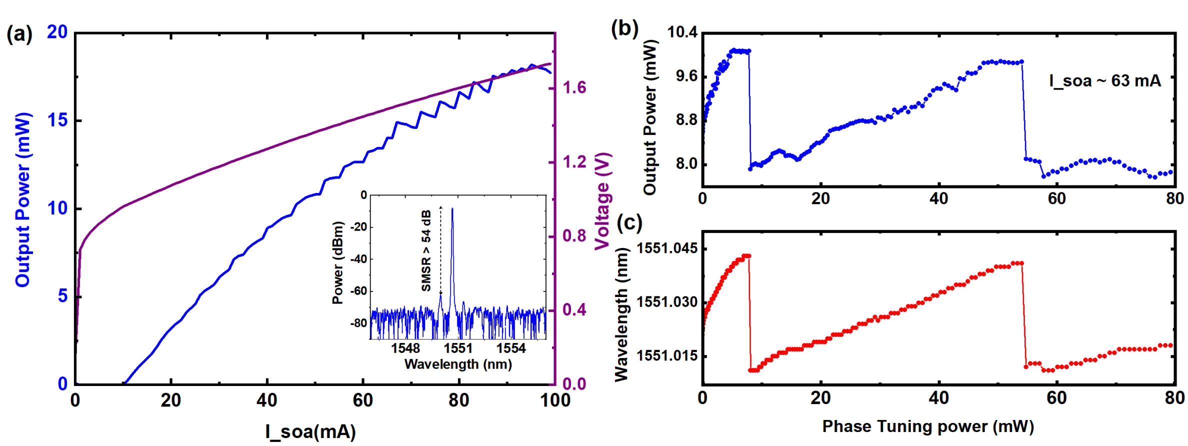

Fig.2 (a) LIV characteristics of the DBR laser with its optical spectrum (inset) showing an SMSR of 54 dB. In parts (b)-(c), the SOA current is fixed (~ 63 mA) while sweeping the phase tuning power. A strong drop of the output power in (b) simultaneously occurs with a mode hopping seen in (c).

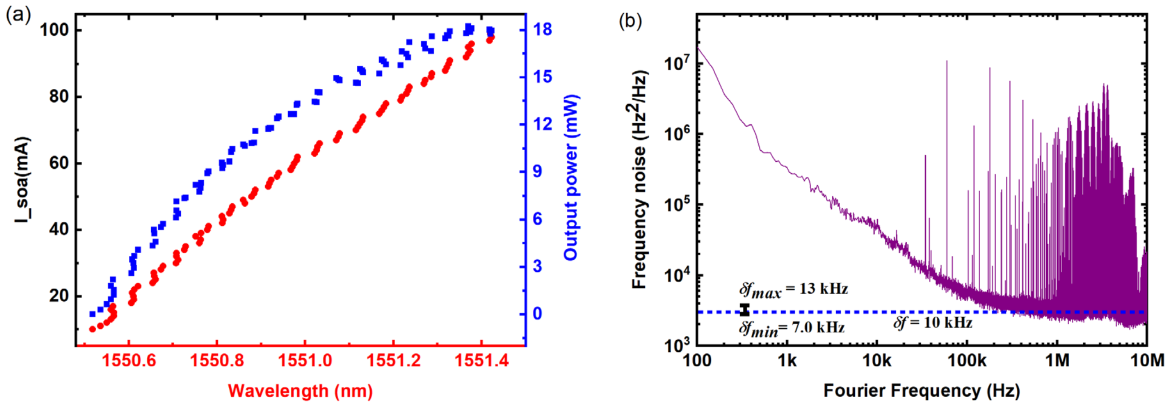

Fig. 3(a) The DBR laser wavelengths as a function of SOA injection current (stepping of 1 mA) with phase modulator unbiased. The right-hand side of the plot shows the on-chip optical power that is accounting for the fiber-to-chip coupling loss of ~4.5 dB. (b) Frequency noise PSD spectrum (averaged 20 samples) of the DBR laser obtained at an injection current of ~53 mA with phase modulator unbiased.

Fig. 3(a) above shows the relation of the output power with emission wavelengths, which are red-shifted as the SOA current increases (stepping of 1 mA) due to heating of the active gain section. Therefore, mode-hopping is observed over large range of the longitudinal modes of the laser cavity and simultaneously the highest peak power value corresponds to laser emission wavelength that is aligned with external cavity modes. Therefore, it is possible to operate the extended cavity DBR laser in a single-mode regime and at specific wavelength as shown in Fig. 3(a), while controlling the injection current in the SOA.

We obtain the frequency noise power spectral density (FN-PSD) using a commercial frequency noise analyzer (High-Finesse, LWA-1k-1550) at an SOA current of 53 mA as shown in Fig. 3(b). We observe a best fit of white-noise frequency value of about 3180 Hz^2/Hz, which corresponds to an intrinsic linewidth value about ~10 kHz. Moreover, we obtain the uncertainty in the intrinsic linewidth as 10±3 kHz as illustrated by error-bar in Fig. 3(b). The frequency noise of the laser is attributed to intense spurious peaks that originate from the current driving source of SOA (Keithley, 2401).

4. Conclusion

We have demonstrated an extended cavity DBR laser with an intrinsic linewidth of 10 kHz on InP-based generic foundry platform. This is the lowest reported linewidth for monolithically integrated InP-based DBR laser, to our knowledge. The device generates an on-chip output power of ~18 mW at the current injection of < 100 mA and has a threshold current to be around 10 mA. This work paves the way towards monolithically integrated quantum key distribution on InP platform [3].

5. Acknowledgments

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6. References

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