Intra-Cavity Coherently Combining of DBR Lasers on an InP Generic Foundry Platform

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We report an intra-cavity coherent combining of two DBR lasers with on-chip power of ~9.5 mW at the injection current of 42 mA in both gain sections simultaneously. The combined DBR laser operates in a single mode regime with a side-mode suppression ratio of 36 dB on an InP generic foundry platform.

Keywords: *Integrated optics, Integrated lasers, Indium Phosphide*

INTRODUCTION

Integrated semiconductor lasers are an essential component to miniaturize or scale photonic technologies [1, 2]. The maximum power of a single DBR laser is limited due to heating of the active gain region with increasing current density. Therefore, coherent beam combination (CBC) of integrated DBR lasers diodes can overcome these limitations by distributing the power across a larger active area, and thus provides a path for scaling the optical power. CBC laser systems have traditionally been made from bulky optical components such as optical fibers, lenses, external cavities, and diffraction gratings on a free-space optical bench [3,4]. These components do not provide a scalable and cost-effective solution. In contrast, integration of such components on a chip would provide a scalable, miniaturized, and cost-effective solution. A chip-based CBC laser system has been demonstrated using a hybrid InP-Si_3N_4 technology [5]. However, this demonstration requires hybrid integration of two different dies, which adds to the fabrication, and packaging complexity. Thus, it does not provide a cost-effective solution. In this work, we report for the first time a monolithically integrated intracavity CBC based on two DBR lasers on an InP generic foundry platform.

DEVICE DESIGN AND EXPERIMENTAL RESULTS

We employ CBC of two DBR lasers by adding a common intra-cavity 50:50 MMI splitter as sketched in Fig.1. The DBR lasers are combined in a way that feedback is equally distributed over both arms from the DBR1 mirror. Furthermore, both DBR lasers are coherently combined when the constructive interference occurs at the output port that is in the lower arm of the MMI ports. Consequently, the upper arm of MMI ports goes into destructive interference of two laser beams and it can be monitored by an incorporated photodiode. The InP circuit was fabricated via a multi-project wafer (MPW) run at SMART Photonics with components that are part of the default process design kit (PDK). The upper and the lower arms of the laser cavity consist of DBR mirrors, SOAs, and phase-shifters. The lengths of DBR1, PhS1, SOA1, and DBR3 are 100 µm, 400 µm, 500 µm, and 300 µm respectively and total cavity length in upper/lower arm is about 2.3 mm. The other components in the lower arm are identical compared to the upper arm. More details about the waveguide cross-section and SOA component are provided in the Ref [2]. The coupling coefficient of the DBR grating is fixed to 50 cm^{-1}. All active components (DBRs, SOAs, PhS, and PD) can be electrically driven through a common cathode ground at the n-substrate at the backside of the chip.

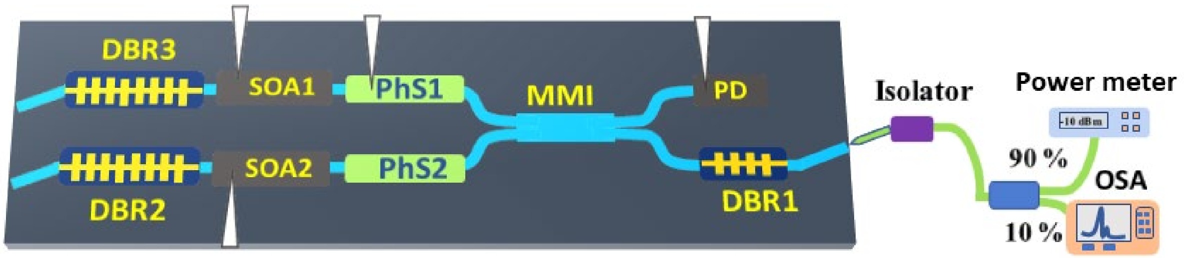

Fig. 1. Schematic of the chip and experimental set-up. SOA: semiconductor optical amplifier, DBR: distributed Bragg reflector, PhS: phase shifter, PD: photodiode, OSA: optical spectrum analyzer.

The output of the waveguide facet of the laser is angled at 7° and anti-refection coated to minimize back reflection. The chip is mounted on a temperature-controlled stage. The laser output is collected by a lensed fiber with coupling loss of ~4.5 dB. The L-I curves and photocurrent response of individual and combined DBR lasers are plotted in Fig. 2(a-d) and output power is corrected for the fiber-to-chip insertion loss. The threshold current of individual and combined DBR lasers are observed to be 30 mA and 20 mA, respectively.

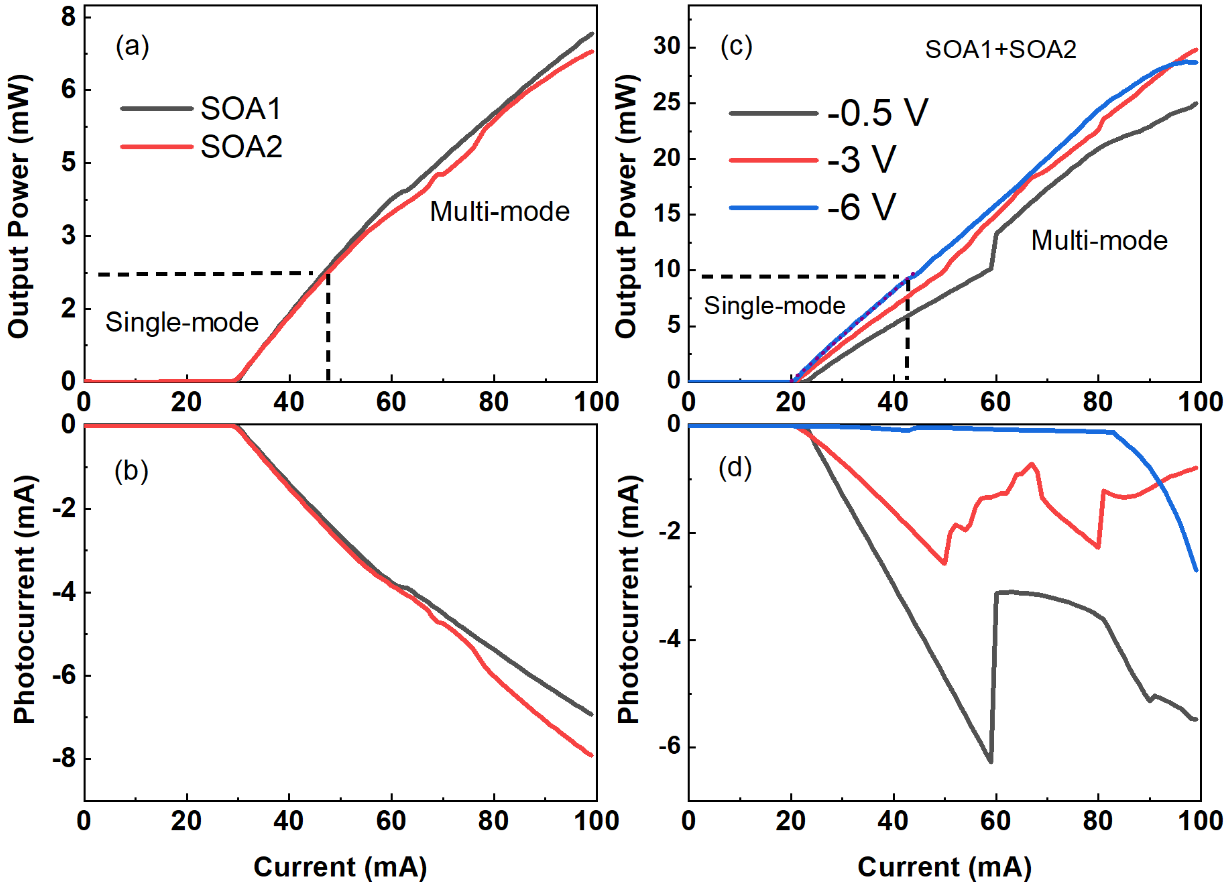

Fig. 2(a-b) L-I curve and photocurrent response of the individual DBR laser with only one SOA driven at a time. (c-d) L-I curves and photocurrent response with both SOA1 and SOA2 driven simultaneously with a pre-selected voltage on one of the phase shifters, which shows the increase in output power and decrease in photocurrent because of constructive and destructive interference in the corresponding MMI ports.

To coherently combine the DBR lasers using an intra-cavity MMI splitter, the voltage of one of the phase shifters was tuned at three different values which increases the output power as shown in Fig. 2(c). This plot is obtained by varying the currents of SOA1 and SOA2 simultaneously with pre-selected voltages on one of the phase-shifters. The maximum output power is observed when the constructive interference occurs at -6V on the phase-shifter and the modes of the two parallel laser cavities are aligned. Consequently, photocurrent is reduced because of destructive interference in the corresponding MMI port as plotted in Fig. 2(d). Hence, both cavities are aligned with an MMI port connected to the feedback mirror DBR1 and all power exits at the same MMI port. Thus, the threshold current of the combined DBR lasers is reduced due to lower internal loss inside the cavity. Moreover, the photocurrent increases with the SOA current in the individual operation of the DBR laser in Fig. 2(b) as expected without any combining effect where the equal power simply splits in both arms of the MMI ports. The individual DBR lasers account for at least ~6 dB extra internal loss for one round-trip. Hence, the output power of the combined laser is expected to be 4 times higher than that of an individual DBR laser operation. We also reported the slope efficiency which is inversely proportional to the internal cavity losses [6]. Hence, we obtained the slope efficiencies from the L-I curves in the individual and combined DBR lasers which are 122 mW/A and 410 mW/A, respectively. Therefore, we report a combining efficiency of ~ 84 % at 42 mA in both SOA on an integrated chip.

We have also reported the optical spectra of combined case of the DBR lasers in the regime where single mode operation in Fig. 3(a) changes to multimode regime in Fig. 3(b). Fig. 3(a) shows that the side-mode suppression ratio (SMSR) of 36 dB at 42 mA current in both SOA simultaneously. The multimode regime in the Fig. 3(b) is observed due to the amplification of the side longitudinal modes at the higher current ~ 45 mA in both SOA.

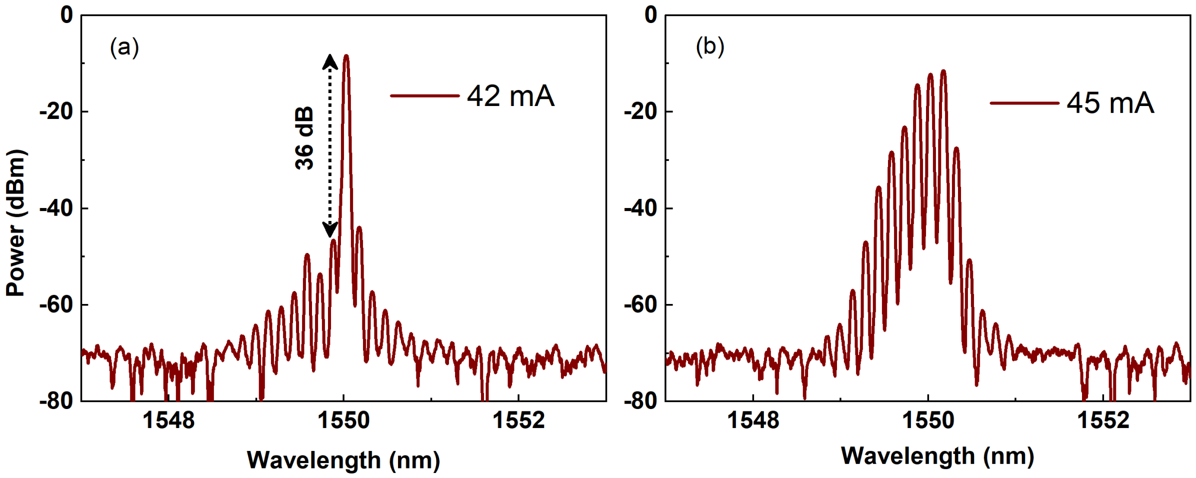

Fig. 3 Optical spectra in combining case at -6V on one of the phase shifters. (a) single mode regime with side-mode suppression ratio of 36 dB (b) multimode regime is observed due to amplification of side longitudnal modes. The current values were denoted in both SOA at the same time.

DISCUSSION

We noticed that the passband of the DBR grating mirror is much wider than the free-spectral range of the laser cavities. Therefore, many side modes get amplified as injection current increases. The measured output power in the single-mode regime is limited in this paper but shows the potential to obtain a higher power up to 28 mW on a single chip. However, this limitation can be further improved by designing narrower grating mirrors which can suppress the side modes amplification at the higher injection current. Besides, one can implement an imbalance length of two DBR lasers to circumvent such multimode behavior at the higher current [7]. Moreover, the combining efficiency of ~ 84 % in this work is limited by the differences in total cavity losses in the lower and upper arm of the MMI ports. In addition, we notice that the combining efficiency is reduced over time. Thus, output power is reduced due to the phase error that may be caused by spontaneous emission or environmental temperature variation. Therefore, a feedback control circuit is required to maintain the output power using an on-chip photocurrent electrical signal to correct the phase-error to maintain the output power at a desired value.

CONCLUSION

We demonstrated the intra-cavity CBC of the DBR lasers which emits an on-chip power of ~9.5 mW (~ 3.35 mW in the fiber) at 42 mA in both SOAs with SMSR of 36 dB. This is based on fully monolithic approach and can be further scaled to more DBR lasers which increases the output power linearly with the number of arms coherently combined. This work will pave the way for higher power lasers by circuit design techniques, using generic integration platforms, which can e.g., improve the bit error rate in optical communications.

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