Noise Reduction of Integrated Laser Source with On-Chip Optical Feedback

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Abstract

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Abstract: Integrated indium phosphide distributed Bragg reflector lasers with on-chip optical feedback were realized and demonstrate a side-mode-suppression-ratio of 45 dB, sub-megahertz laser linewidth and an order of magnitude peak relative intensity noise reduction.
OCIS codes: (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits;

1. Introduction

Narrow linewidth, low noise lasers diodes (LDs) are key components for coherent optical communications and microwave photonics [1, 2]. The linewidth of long cavity distributed feedback (DFB) and distributed Bragg reflector (DBR) lasers have been studied [3-5]. Feedback techniques have been used to improve the signal quality of LDs by suppressing the phase noise as well as amplitude noise. With electrical feedback, the noise of a LD is converted to an electrical signal and fed back in the form of current injection. Although sufficient noise suppression can be achieved [6], the additional electrical components add cost and complexity. Optical feedback can be achieved by capturing a fraction of the output optical power and feeding it back to the laser cavity. This approach is relatively simple and suitable for photonic integration. Owing to the rapid development of photonic integrated circuit (PIC) technology, integrated lasers can be realized monolithically on a single indium phosphide (InP) or with a hybrid integrated platform utilizing an external cavity implementation [7]. The main stream LDs for data communication, however, are constructed with monolithic InP due to the low cost and high yield of this platform.

We have recently reported an integrated InP DBR laser that employs on-chip coherent optical feedback and demonstrates improved linewidth characteristics [8]. In this paper, in addition to reporting additional lasing characteristic measurements and analysis, we report the amplitude noise characteristics, which describe the source of the linewidth reduction. The PIC was realized in an InP-based multi-project-wafer (MPW) run. An order of magnitude reduction of the linewidth as well as 10 dB suppression of the peak relative intensity noise (RIN) were demonstrated.

2. Device Design and Fabrication

As shown in Fig. 1(a) and (b), two types of lasers (Type A and Type B) were implemented. Type A is a conventional DBR laser structure. The gain region was terminated with a high-reflectivity DBR and a 50/50 coupler designed as a broadband partially reflective/partially transmissive mirror. To compare, an optical feedback path was incorporated into the Type B laser whereby a portion of the output signal is tapped using a 50/50 coupler, and fed to the back of the DBR mirror. Fifth-order DBR mirrors based on side-wall-etched gratings were incorporated in order to comply with a minium feature size design rule. The pitch of the grating is 1.2 µm and the fill factor is 0.5. The base width (ridge width) for is 2.4 µm and the lateral corrugation is 0.6 µm, meaning the narrow central region has a width of 1.2 µm. The total length of the DBR is 1.2 mm.

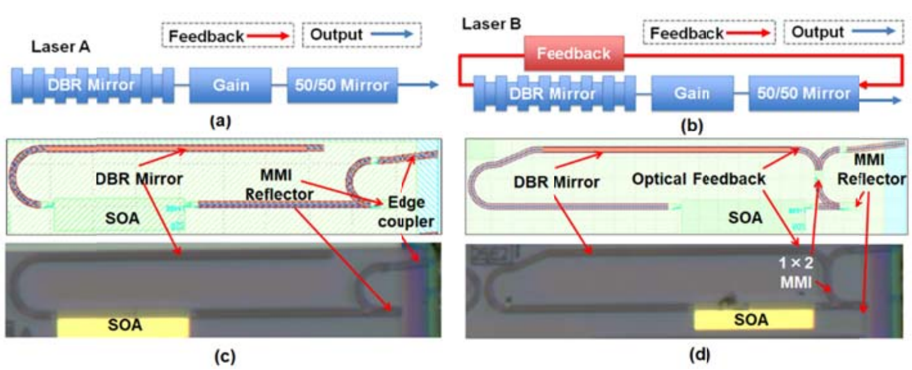

Fig. 1. Schematic of the laser cavity design (a) without (Type A) and (b) with (Type B) optical feedback. (c) Layout (top) and microscope image (bottom) of Type A laser. (d) Layout (top) and microscope image (bottom) of Type B laser.

The fabrication was performed by SMART Photonics through a MPW run. The gain region is an electrically pumped shallow-etched ridge semiconductor optical amplifier (SOA). The length of the SOA is 600 μm for both lasers. The on-chip 50/50 coupler was realized with a two-port multimode interference (MMI) reflector (MIR) [9]. Total internal reflection mirrors were used to terminate the four-port MMI in order to form the two-port device. One port of the MIR was connected to the SOA to terminate the gain region while the other port was used to extract light from the cavity. The layouts and microscope images for both Type A and Type B lasers are shown in Fig. 1(c) and (d). For the altered cavity Type B laser, a 1x2 MMI coupler splits the output of the MIR. One output of the MMI was connected to the back of the DBR mirror to facilitate feedback, and the other port of the MMI was connected to the chip output. Edge couplers, for light extraction, were angled and anti-reflection (AR) coated to reduce facet reflection.

3. Experimental Setup and Measurement Results

Both devices were attached to custom printed circuit boards (PCBs) with heatsinking and wirebonded to facilitate testing (see Fig. 2(a)). The PCB was mounted on a temperature-controlled stage and electrically pumped through a jump wire. Light was coupled off-chip to a lensed single-mode fiber. A fiber isolator was used in order to prevent any unwanted reflection. At 15°C stage temperature, the light-current-voltage (LIV) characteristics were measured and are shown in Fig. 2(b). The threshold currents for Type A and Type B lasers are 75 mA and 43 mA, respectively. The fiber-coupled output power is relatively weak in part because the output coupling is not optimized. The laser spectra are shown in Fig. 3(c) for a pump current of 90 mA for both devices. The measured side mode suppression ratio for the Type A laser was 30 dB. For the Type B laser, that with the optical feedback, the SMSR was 47 dB.

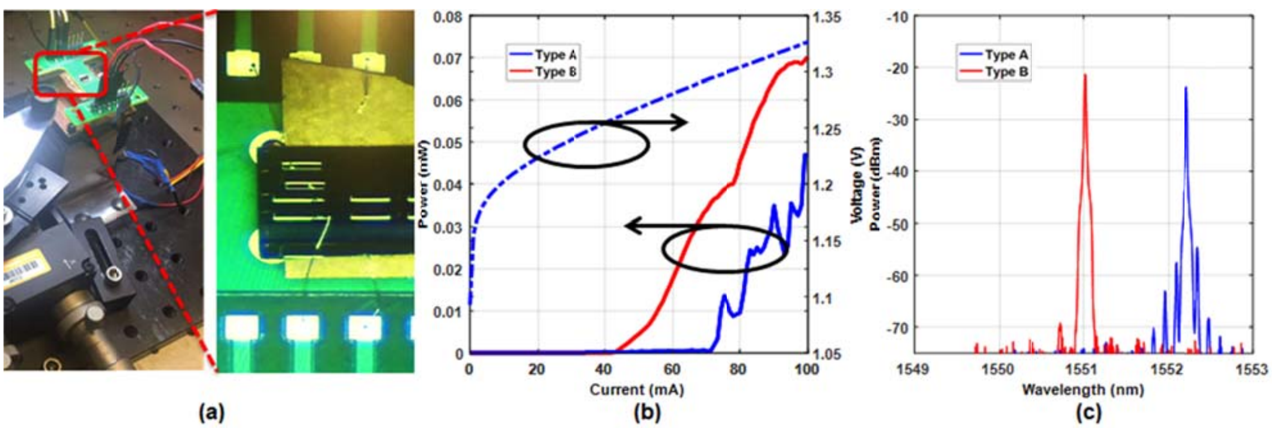

Fig. 2. (a) Experimental set up showing InP laser chip mounted on PCB. (b) LIV measurements for Type A and Type B lasers. (b) Lasing spectra for Type A and Type B lasers.

In order to characterize the amplitude noise of the lasers, the RIN was characterized at different pump current levels for both lasers. An erbium-doped fiber amplifier was used to boost the power of the laser output. Figure 3 (a) shows the output RIN spectrum of the Type A laser at three current levels. Figure 3 (b) shows the peak RIN value as a function of the pump current. The lowest peak RIN measured for the Type A laser was -123 dB/Hz at a pump current of 95 mA. The maximum power shifts with increasing pump current to higher values in accordance with the theoretical relationship between relaxation resonance frequency (f_R) and pump current, as shown in the inset of Fig. 3(b). For the Type B laser, the RIN spectra are shown in Fig. 3(c). Here the RIN spectra were extracted at 20ºC, instead of 15ºC, because otherwise the RIN peak was buried in the measurement noise. As shown in Fig. 3(d), the lowest peak RIN measured for the Type B laser at 20ºC was -131 dB/Hz at 80 mA. At this pumping current, the RIN for the Type A laser was -117 dB/Hz, indicating a more than 10 dB improvement.

The self-heterodyne method was used to extract the laser linewidth for phase noise evaluation. The beat note was captured with a photodetector and the output signal was input to an electrical spectrum analyzer (ESA). The ESA spectra for both devices are shown in Fig. 3(e) and Lorentzian data fits are shown in Fig. 3(f). The linewidth for the Type A laser is 14 MHz and that for the Type B laser is 0.8 MHz. The RIN reduction qualitatively explains the linewidth reduction.

4. Conclusions

InP-based integrated DBR lasers with and without on-chip optical feedback were fabricated and characterized. The amplitude and phase noise were extracted for both devices. At the same pump current, the peak RIN value for the Type A laser is 10 dB higher than the Type B laser, indicating that optical feedback clearly improves the amplitude noise performance of a DBR laser. The linewidth of both lasers was measured using the self-heterodyne technique. With on-chip optical feedback, the linewidth was reduced to 0.8 MHz, corresponding to an order of magnitude improvement. On-chip feedback with monolithic InP PICs is promising for coherent optical communications.

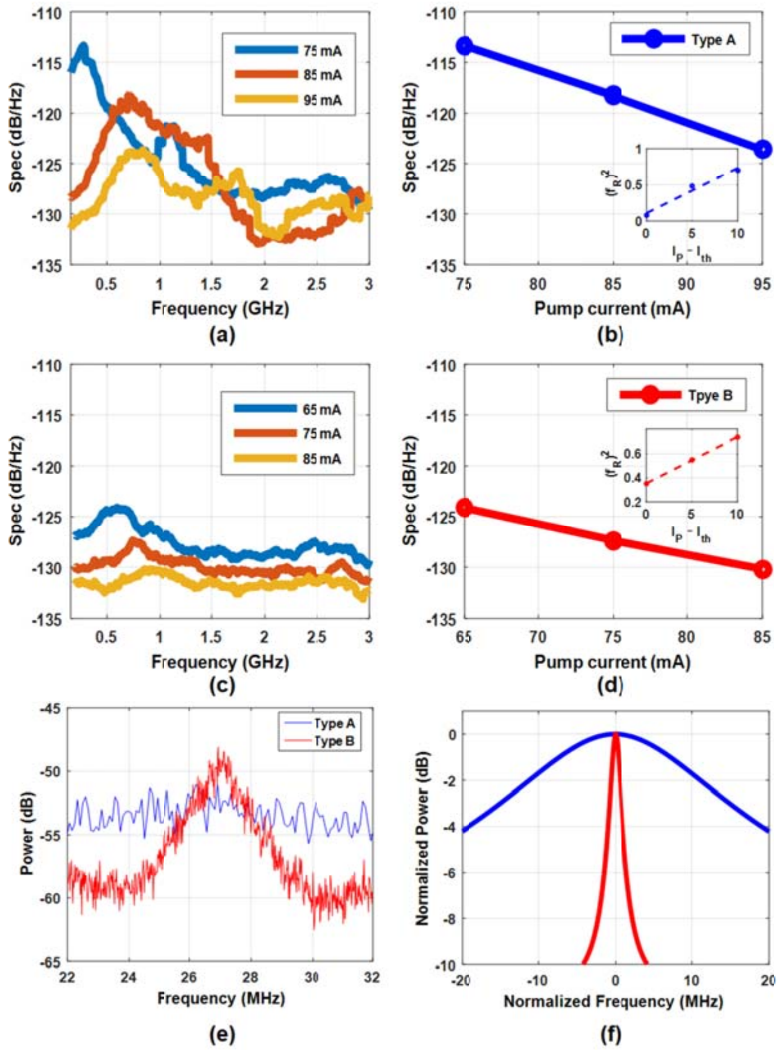

Fig. 3. RIN spectra at various current levels for (a) Type A laser and (b) peak RIN versus pump current (IP) and relaxation resonance frequency square (fR2) with respect to pump current less threshold current (inset). RIN spectrum for (c) Type B and (d) peak RIN versus pump current. (e) The output spectrum of the photodetector showing the beat note of the self-heterodyne measurement for Type A and Type B. (f) FWHM of the Lorentzian fit spectra for Type A and Type B lasers.

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