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

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**OCIS codes:** (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits;

## 1. Introduction

Coherent optical communication is attractive for higher spectral efficiency and superior tolerance to dispersion effects and fiber nonlinearities [1]. Owing to the rapid development of photonics integrated circuit (PIC) technology, optical coherent systems can be realized on a single indium phosphide (InP) chip demonstrating small footprint, low power consumption and high yield [2]. One of the key elements for a single-chip coherent system is a low-phase-noise integrated laser. An effective phase noise suppression of the of the laser source can simultaneously reduce receiver complexity and cost, while reducing power consumption by simplifying the required receiver digital signal processing. Various approaches have been proposed to reduce the phase noise of the integrated laser such as optical-phase-locked-loop [3] and coherent optical feedback schemes [4]. Among the two solutions, optical feedback is often more desirable due to the simpler monolithic fabrication process of the laser source.

In this work, we report the phase noise reduction of an integrated InP distributed-Bragg-reflector (DBR) laser by using on-chip coherent optical feedback. The PIC was realized in a multi-project-wafer (MPW) run and demonstrates an order of magnitude reduction of the linewidth.

## 2. Device Design and Fabrication

In order to evaluate the impact of optical feedback on linewidth, two type of lasers (Type A and Type B) were designed as shown in Fig. 1 (a) and (b). Type A is a conventional DBR laser, where the laser cavity consists of a high-reflectivity DBR and a 50/50 coupler designed as a broadband partially reflective/partially transmissive mirror. The type B laser is similar but also incorporates a path for optical feedback whereby some light from the 50/50 coupler is fed to the back of the DBR mirror.

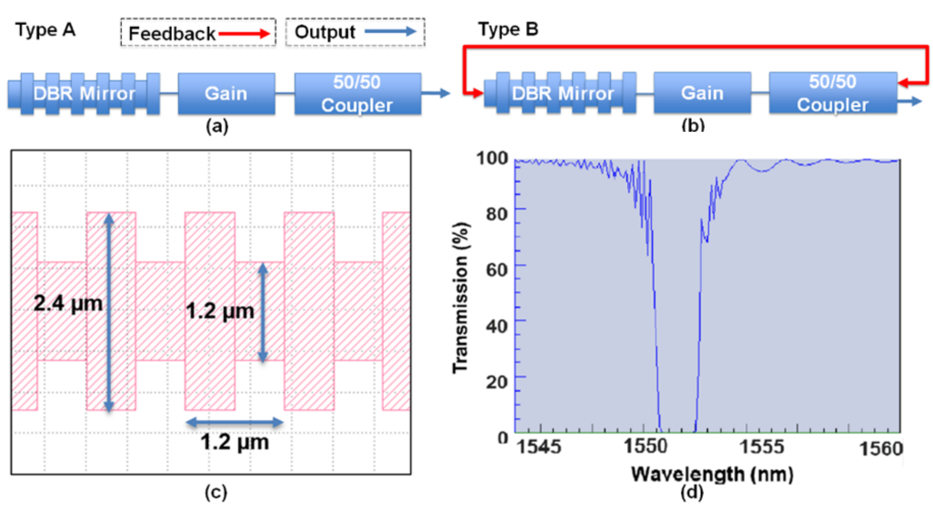


Fig. 1. (a) Schematic of the laser cavity design (a) without (Type A) and (b) (Type B) with optical feedback. (c) Layout of the side-wall-etched DBR. (d) Simulated transmission spectrum of the DBR mirror.

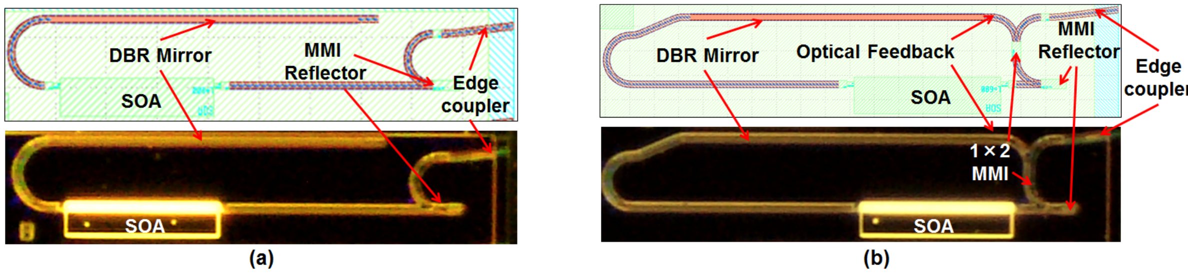


Fig. 2. (a) Layout (top) and microscope image (bottom) of Type A laser. (b) Layout (top) and microscope image (bottom) of Type B laser.

Standard DBR gratings were not available in the MPW foundry offering, therefore 5$^{th}$-order DBR mirrors based on side-wall-etched gratings were designed. The layout of the gratings as well as the simulated transmission spectrum of the DBR mirror are shown in Fig. 1 (c) and (d), respectively. The corrugation pitch is 1.2 µm with a fill factor of 0.5. The base width for this grating is 2.4 µm and the lateral corrugation depth is 0.6 µm. The total number of periods is 1000.

The lasers chip was fabricated by SMART Photonics through a MPW foundry offering. The gain region is an electrically pumped semiconductor optical amplifier (SOA), which is defined with a shallow-etched ridge structure. The length of the SOA is 600 µm for both lasers. The metal pads, shown in Fig. 2 (a), are P-contacts while the N-contact is made on the bottom of the chip. The 50% mirror is realized with a 2-port multimode interference reflector (MIR) [5]. One port of the MIR is connected to the SOA while the other is connected to the chip output through an edge coupler. The altered cavity layout for the Type B laser is shown in Fig. 2 (b). A 1x2 multimode interference (MMI) coupler splits the output of the MIR. One output of the MMI is connected to the back of the DBR mirror to provide optical feedback, and the other of the MMI is connected to the chip output. To reduce unwanted back reflection, all edge couplers are angled with respect to the chip edge and anti-reflection coatings are applied to the facets.

## 3. Experimental Setup and Measurement Results

For the laser characterization, both devices were mounted on a temperature-controlled stage and electrically pumped using pin probes. Light was coupled off-chip through the edge coupler to lensed single-mode fiber (SMF) followed by an optical isolator, in order to prevent any unwanted reflection. In order to stabilize measurements, the stage temperature was kept at 10°C. The light-current-voltage (LIV) characteristics are shown in Fig. 3 (a). The threshold currents for Type A and Type B lasers is 73 mA and 50 mA, respectively. The output power is relatively weak in part because the output coupling is not optimized. The laser spectra are shown in Fig. 3(b) for a pump current of 85 mA for both devices. The measured side mode suppression ratio (SMSR) is greater than 35 dB for both Type A and Type B lasers.

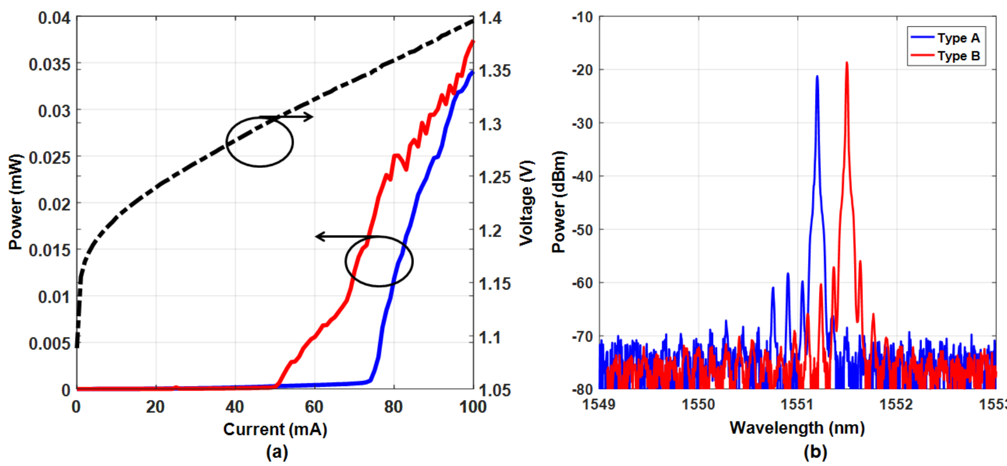


Fig. 3. (a) LIV characteristics and (b) optical spectra for Type A and Type B lasers.

The self-heterodyne method was used to extract the laser linewidth information. The output optical power was amplified to 6 dBm with an erbium-doped fiber amplifier (EDFA) before being input to the heterodyne setup. The EDFA was set with a fixed pump current (100 mA) for all measurements. The acousto-optic modulator resonant frequency for the heterodyne measurements was 27 MHz. For the Type A laser, a 10 km SMF delay was used, corresponding to a linewidth measurements resolution of 30 kHz. Since the estimated linewidth for the Type B laser was narrower, a 25 km SMF delay was used, corresponding to a linewidth resolution of 12 kHz. The beat note was recorded by a photodetector and the output signal was sent to an electrical spectrum analyzer (ESA) to extract the laser linewidth.

Figure 4 (a) shows the output spectrum of the delayed self-heterodyne measurement for Type A and Type B lasers with pumping current of 80 mA and 75 mA, respectively. As shown in Fig. 4 (b) and (c), a Lorentzian fit was applied to precisely evaluate the laser linewidth. The fitted spectra were plotted in normalized frequency and power in order to better appreciate the effect of the optical feedback. As shown in Fig. 4 (d), the 3-dB beat bandwidth for the Type A laser (blue) is approximately 28 MHz and approximately 1.6 MHz for the Type B laser. Such values correspond laser linewidths of approximately 14 MHz and 800 KHz, respectively, thus demonstrating a significant linewidth reduction by way of optical feedback.

## 4. Conclusion

InP-based integrated DBR lasers with and without on-chip optical feedback were fabricated and characterized. Both devices show a SMSR greater than 35 dB. The linewidth of both lasers was measured using the self-heterodyne technique. Experimental measurements show 14 MHz linewidth for the device without optical feedback. The introduction of on-chip optical feedback demonstrated a linewidth reduction to 800 KHz, signifying an order of magnitude improvement. This is promising for coherent optical communication applications.

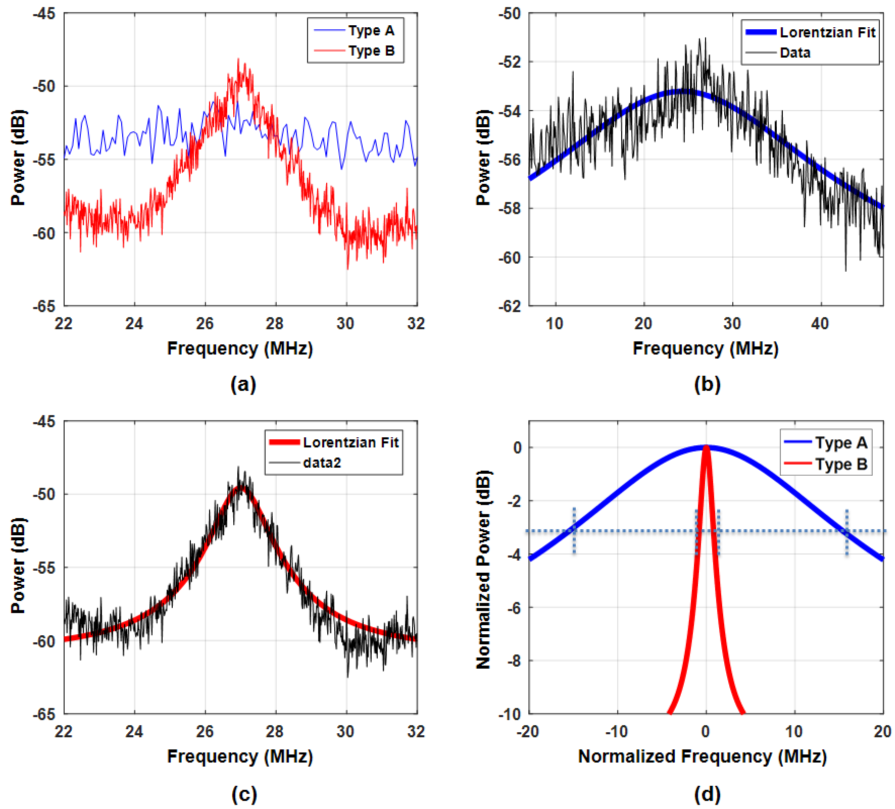


Fig. 4. (a) The output spectrum of the photodetector showing the beat note of the self-heterodyne measurement for Type A and Type B lasers. A Lorentzian fit applied for (b) Type A and (c) Type B. (d) FWHM of the Lorentzian fit spectra for Type A and Type B lasers.

## 5. Acknowledgment

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