Indium Phosphide Photonic Integrated Circuit Transmitter with Integrated Linewidth Narrowing for Laser Communications and Sensing

Brandon Isaac[1*], Bowen Song[2], Sergio Pinna[2], Shamsul Arafin[3], Larry Coldren[1,2], Jonathan Klamkin[2]
[1]Materials Department, University of California, Santa Barbara, California, 93106, USA
[2]Electrical and Computer Engineering Department, University of California, Santa Barbara, California, 93106, USA
*brandonjisaac@ucsb.edu

Abstract: An indium phosphide photonic integrated circuit transmitter with integrated linewidth narrowing capability is demonstrated. Frequency discrimination is achieved with an asymmetric Mach-Zehnder interferometer.

Introduction:

Tunable lasers have enabled significant advancements in communications and sensing applications [1]. Semiconductor diode lasers allow for reduced cost, size, weight, and power making them more widely deployable. Widely tunable semiconductor lasers, however, suffer from larger linewidth compared to short-cavity distributed feedback (DFB) lasers or external cavity lasers, thereby limiting their use in high-performance applications. Also for lidar applications, wide wavelength tuning can be utilized for beamsteering. We present an integrated solution for frequency locking and linewidth reduction of a widely tunable sampled grating distributed Bragg reflector (SGDBR) laser based on an indium phosphide (InP) photonic integrated circuit (PIC) platform that includes active/passive integration and two types of ridge waveguides to enable both low-loss and efficient active devices and sharp-bend-radius passive components. An integrated asymmetric Mach-Zehnder interferometer (AMZI) that taps excess light from the back SGDBR mirror is incorporated for frequency discrimination. The AMZI also includes a phase shifter to apply a frequency chirp. The PIC design and fabrication are discussed, and the components for linewidth narrowing are fully characterized including the laser, the AMZI discriminator, and the chirp phase shifter.

Design and Fabrication:

The PIC transmitter is comprised of an SGDBR laser and frequency discriminator. An external electrical circuit containing linear amplifiers and op-amps can provide the proportional and integral error correction respectively [1,2]. An SGDBR laser consists of a standard DBR laser modified by periodic blanking of the front and back grating mirrors at different sampling periods to produce Vernier-like mirror spectra. The output from the front SGDBR mirror is amplified by a semiconductor optical amplifier (SOA) and coupled off chip through an angled and cleaved facet. The PIC is designed to also alternatively couple light off chip vertically through a total internal reflection turning mirror (TIR), to enable hybrid integration with a silicon photonics optical phased array (OPA) [3]. Power is tapped from the back mirror for the AMZI frequency discriminator, which comprises multimode interference (MMI) couplers and a number of sharp bends. The path length difference of AMZI is designed for a free-spectral range (FSR) = $\frac{c}{n_{eff}\Delta L}$ of 60 GHz. Furthermore, one path contains a phase shifter for frequency chirping so that the laser can be tuned in frequency once it is stabilized. Two high-speed photodiodes (PDs) follow the AMZI for amplitude detection to generate an error signal for a feedback-loop based stabilization circuit. The sensitivity of the discriminator is higher for a smaller FSR, which is inversely proportional to the path length difference. However, increased path length difference leads to higher passive optical loss, which reduces sensitivity. The 60-GHz FSR selected addresses this tradeoff.

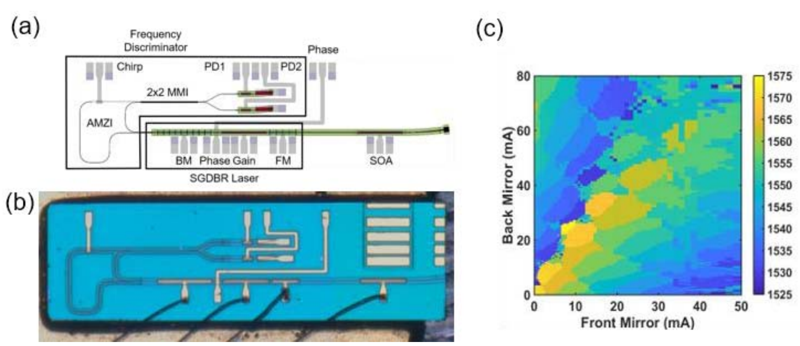

Figure 1 (a) Layout schematic of PIC showing SGDBR laser and frequency discriminator consisting of an AMZI, MMI couplers, and two photodetectors. (b) Microscope image of the fully fabricated PIC mounted on a carrier. (c) Wavelength tuning map of the SGDBR laser.

The PIC transmitter layout and a microscope image of a fabricated chip are shown in Fig. 1. The PIC platform incorporates both surface ridge and deep ridge waveguides to allow for high-performance active components and sharp-bend-radii passive components, respectively. The SGDBR laser was designed for tuning over the wavelength range of 1520-1570 nm. The SGDBR mirrors were tailored for a front-to-back mirror power splitting ratio of 7:1. For active/passive integration, the offset quantum wells were selectively removed. This was followed by formation of SGDBR gratings that were patterned with electron beam lithography and

978-1-5386-6486-5/18/$31.00 ©2018 IEEE

etched with reactive ion etching Next the p-cladding was grown by metalorganic chemical vapor deposition. The remaining process steps were as follows: ridge waveguide formation based on inductively coupled plasma RIE (ICP-RIE) and wet chemical etching with a multi-step process to form both ridge types; device isolation with etching and ion implantation; vias and metal contact formation; sample thinning. A double taper structure was utilized to transition between surface ridge and deep ridge waveguides. The AMZI consists solely of deeply etched waveguides to achieve sharp bends and to reduce the overall footprint.

Experimental Results:

As illustrated in Fig. 1(c), the SGDBR laser demonstrated tuning from 1535-1570 nm. To evaluate the operation of the PIC transmitter, operation was first validated by measuring the laser light-current characteristic by sweeping the laser gain section current and measuring the photocurrent generated in the SOA following the laser and in the PDs (PD-1 and PD-2) as shown in Fig. 1(a). The photocurrent generated in the PDs was lower than expected, and this is attributed to higher than expected passive waveguide and passive component losses. As illustrated in Fig. 2(b), the PD signals were measured as the SGDBR laser phase section current was swept. As expected, the measured signals demonstrate the desired out-of-phase behavior and this measurement effectively tunes the laser. Instead to tune the AMZI filter, which would be performed to dynamically apply a frequency chirp to the stabilized laser, the photocurrent of the PDs was measured while sweeping the chirp phase shifter current (Fig. 2(c)). The inset of Fig. 2(c) shows a

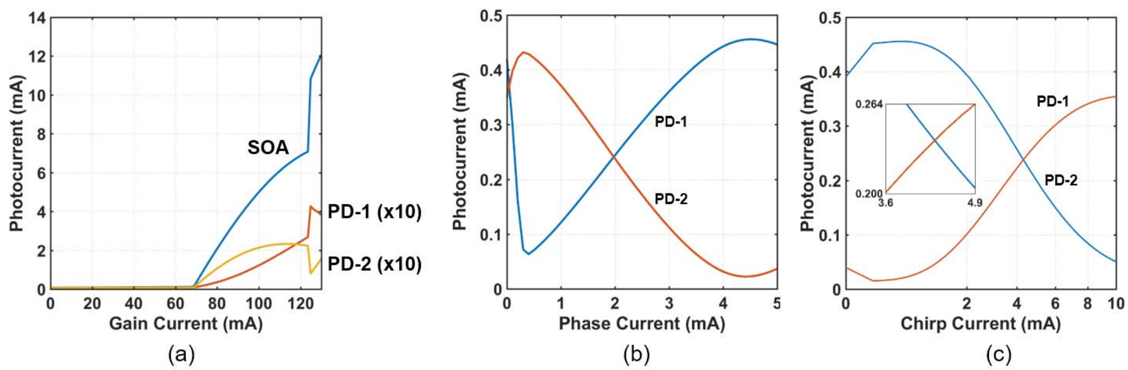

Figure 2 (a) Photocurrent detected out the front and back mirror from the SOA and balanced PDs respectively. (b) Photodetector response of discriminator as the current injected into the phase electrode is swept. (c) Photodetector response of the as the current injected into the chirp electrode in the AMZI is swept. The inset shows the linear region were a tuning efficiency of 4.4 mA/GHz is obtained.

closeup near the crossing point, and a tuning efficiency was estimated in this region to be 4.4 mA/GHz, illustrating the high efficiency attributed to current injection tuning in InP PICs. These measurements demonstrate the functionality of the PIC transmitter with integrated linewidth narrowing and frequency chirp capability. Future work will integrate a locker integrated circuit to demonstrate dynamic wavelength stabilization.

Conclusion:

We proposed and demonstrated an InP PIC transmitter with a widely tunable SGDBR laser and frequency discriminator based on a AMZI. The laser demonstrated 35 nm of wavelength tuning, showing potential for use with OPA-based lidars that utilize wavelength tuning for beamsteering. Locking functionality was demonstrated by measuring the out-of-phase signals generated by the AMZI frequency discriminator using the PDs. Chirp functionality was also demonstrated by first tuning the laser to a specific wavelength and then sweeping the chirp phase shifter current; a chirp efficiency of 4.4 mA/GHz was estimated. Experiments to demonstrate dynamic frequency locking and linewidth narrowing are in progress.

Acknowledgement

The authors acknowledge funding from DARPA AFOSR contract HR0011-16-C-0106 through a subcontract from Lockheed Martin. B. Isaac acknowledges support from the NSF GRFP.

References:

[1] L. Coldren, G. Fish, J. Barton, L. Johansson, C. Coldren, “Tunable Semiconductor Lasers: A Tutorial” Journal of Lightwave Technology 22 (1) 2004

[2] A. Sivananthan, H.Park, M. Lu, J. Parker,E. Bloch, L. Johansson, M. Rodwell, L. Coldren, “Integrated Linewidth Reduction of a Tunable SG-DBR Laser", CLEO (2013)

[3] A. Sivananthan, H. Park, M. Lu, J. Parker,E. Bloch, L. Johansson, M. Rodwell, L. Coldren “Monolithic Linewidth Narrowing of a Tunable SG-DBR Laser" OFC (2013)

[4] B. Song, C. Stagarescu, S. Ristic, A. Behfar, J. Klamkin, “3D integrated hybrid silicon laser,” Optics Express 24(10), 10435-10444 (2016).