InP Photonic Integrated Circuit with On-chip Tunable Laser Source for 2D Optical Beam Steering

Weihua Guo, Pietro R. A. Binetti, Chad Althouse, Leif A. Johansson, and Larry A. Coldren
Department of Electrical and Computer Engineering, University of California Santa Barbara, CA93106, USA
Email: guow@ece.ucsb.edu

Abstract: 2D optical beam steering through an InP photonic integrated circuit with on-chip tunable laser source has been demonstrated for the first time.
OCIS codes: (250.5300) Photonic integrated circuits; (280.3640) Lidar

1. Introduction

Electronically controlled optical beam steering is potentially useful for applications such as free-space optical communication, light detection and ranging (LIDAR), 3D imaging, etc. Several methods have been demonstrated for this purpose such as the phased array for 1D optical beam steering [1], 1D phased array combined with emission gratings for 2D optical beam steering [2]. In [3] we demonstrated an InP photonic integrated circuit (PIC) for 2D optical beam steering using the approach of 1D phased array plus 2nd-order emission grating. Instead of using a single triangle contact to control the phase of the phased array, we use separate contact to control the phase of each channel in the phased array. This increases the number of controls, but does give us more tolerance for fabrication. Also the phase needed is much less because a module of 2π can be used. We have demonstrated 2D optical beam steering with the longitudinal direction controlled by the input wavelength and the lateral direction controlled by the phased array [3]. The tunable laser source used for the beam steering is either an external cavity widely tunable laser or an off-chip sample-grating DBR laser (SG-DBR) [5]. Fiber coupling is used to input to the PIC. It would be ideal to integrate the tunable laser source onto the beam sweeping PIC so that a single PIC can achieve the full function of electronically controlled 2D optical beam steering. In this work we demonstrated the first attempt of such integration: a widely tunable SG-DBR laser is integrated onto the beam sweeping chip.

2. PIC layout, fabrication and measurement

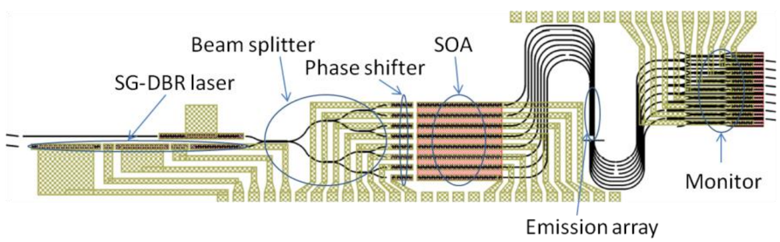

Fig. 1 Layout of the PIC

Fig. 1 shows the layout of the PIC. From left to right, the PIC contains the SG-DBR widely tunable laser, the 1×8 beam splitter consisting of cascaded 1×2 MMIs, 8 phase shifters, 8 semiconductor optical amplifiers (SOA), the emission array consisting of 8 waveguides with buried 2nd-order gratings, and the array of monitors. The waveguide spacing in the emission array is uniformly 5.5 μm. 90° bends are added to make all the channels have the same length as shown in Fig. 1. The detailed structure of the monitors can be found in [4]. These monitors can be used to characterize the phase shifters on-site through monitoring the interference between adjacent channels [4]. To realize the active and passive integration required by the PIC, we use the quantum well intermixing (QWI) technology [3]. The gratings for both the SG-DBR laser and the emission array are patterned by E-beam lithography and etched by a two-step etching process to realize two different etch depths: the laser grating is 70 nm etched into the waveguide core but the emission grating is only 20 nm etched. These gratings are then buried by P-doped InP cladding layers through a blanket regrowth. Deep ridge waveguides (about 5 μm) are used for both the active and passive waveguides for the simplicity of fabrication. The waveguides for the emission array are passive as well. The top of the waveguide is anti-reflection coated by a λ/4-thick SiN_x layer. There is also an aperture opened in the backside contact metal aligned with the emission array. The emission grating scatters the light from the waveguide equally upward and downward. The downward emission is captured by a far-field imaging system which has the ability to record an angle range of 34.8°×26.7° of the far-field with a resolution of 0.1°. The 8 phase shifters are controlled separately by 8 current outputs from a DAC card. The 8 SOAs are biased together by a single voltage source. A variable resistor network connected in series with these SOAs is used to compensate for their series resistance variation so that a single source can still realize uniform current injections into these SOAs. The back mirror, front mirror, gain section and the pre-amplifier SOA of the SG-DBR laser are biased through different current sources. The phase section is left unbiased. So in the tuning demonstrated below only super mode selection is shown. A quasi-continuous tuning can be realized if the back mirror, front mirror and the phase section biases are adjusted in coordination [5]. In the following measurement 100 mA is injected into each SOA of the 8-SOA array. The gain section of the laser is biased at 100 mA as well. The pre-amplifier of the laser is biased at 40 mA. We do notice some unwanted feedback into the laser from the emission gratings due to imperfect control of the duty cycle of the gratings. If we bias the pre-amplifier very hard the laser working would be influenced. Here we select a moderate current of 40 mA to try to minimize the effect. This however reduces the output power of the laser.

3. Results

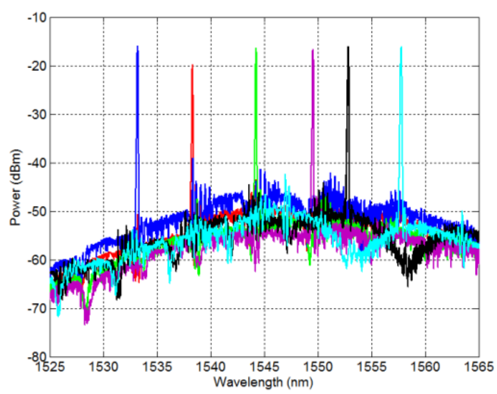

Fig. 2 Super modes of the on-chip SG-DBR laser

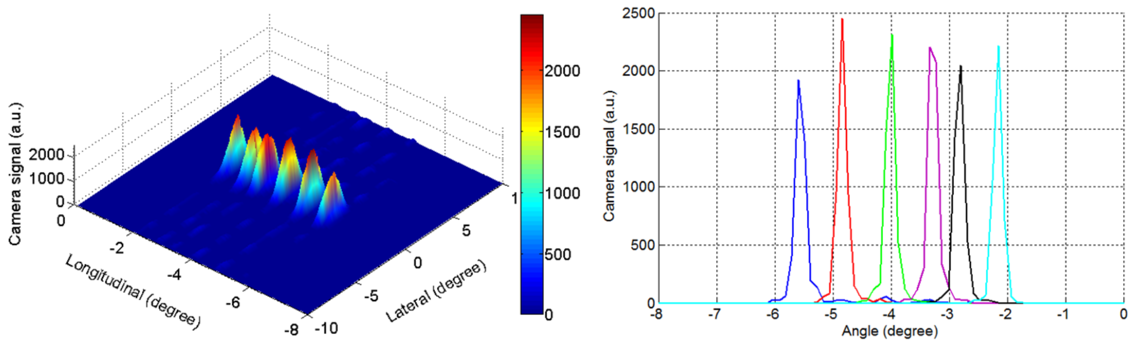

Fig. 3 (a) 3D plot of the far-field pattern for different wavelengths superposed together; (b) far-field across the peak in the longitudinal direction

First the tunable laser is characterized by measuring its super modes. The laser spectrum output through the back mirror coupled by a lensed fiber is shown in Fig. 2. 6 super modes can be seen which corresponds to an expected total tuning range >30 nm [5]. Then for each super mode the far-field pattern is optimized for the lateral angle of 0° by setting the phase shifter currents through the particle swarm optimization algorithm [3]. Each current is varied from 1 to 20 mA. The far-field patterns for different wavelengths are superposed in Fig. 3 (a). The field across the peak in the longitudinal direction is shown in Fig. 3 (b). Very narrow (FWHM about 0.2°) and clean peaks are observed. The peak is narrow due to a long (500 µm) and relatively weakly coupled grating being used. A beam steering efficiency of 0.14°/nm has been observed which corresponds well to our expectation. Then the wavelength is fixed at 1538 nm and the beam is steered to different lateral angles through controlling those phase shifters. The far-field patterns for different angles are superposed in Fig. 4 (a). The field across the peak in the lateral direction is shown in Fig. 4 (b). Because 8 waveguides in the array only span about 40 µm, the far-field in the lateral direction is broad (FWHM about 2°) so the fields overlap with each other as seen from Fig. 4 (b). The waveguide spacing of 5.5 µm determines the 1st-order diffraction peak to be 16° away from the 0th-order peak, which can be clearly seen from Fig. 4 (b). A side-lobe suppression >10 dB around the 0th-order diffraction peak is also realized. Finally we combine the wavelength change with the phase shifter controls to realize a 2D beam steering. The results are shown in Fig. 5. A beam steering angle range longitudinally from -5.6° to -2.1° and laterally from -5° to 5° has been realized.

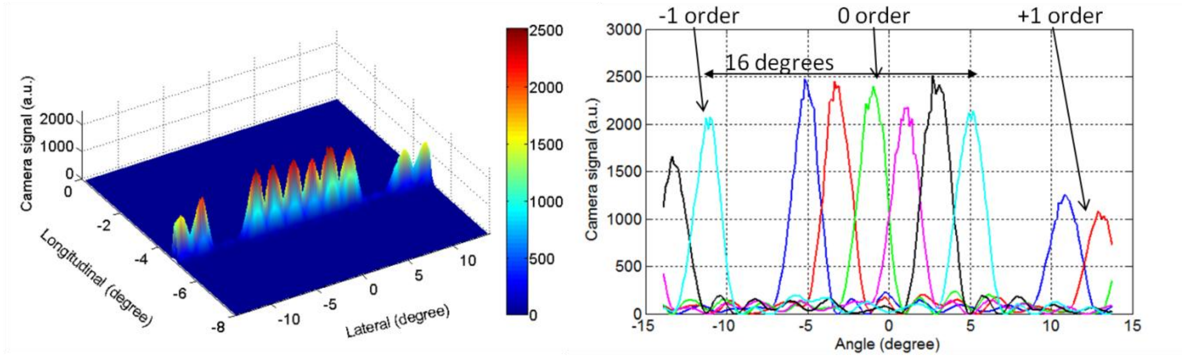

Fig. 4 (a) 3D plot of the far-field pattern for different lateral angles superposed together for the wavelength of 1538 nm; (b) far-field across the peak in the lateral direction

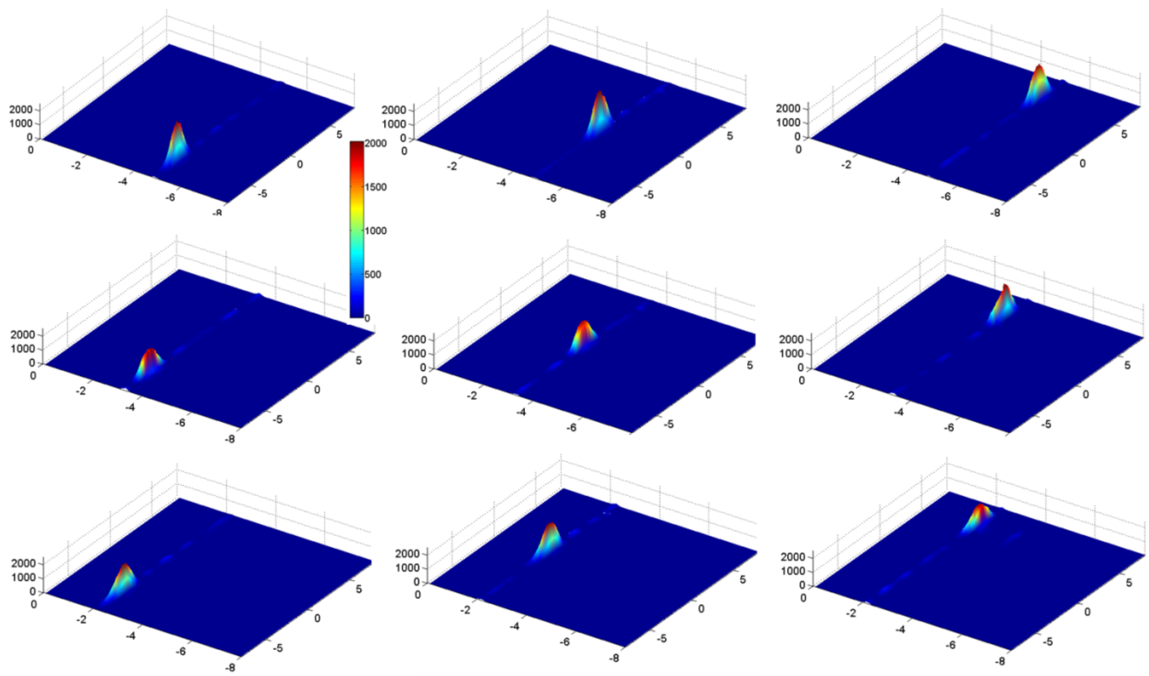

Fig. 5 2D optical beam steering: wavelength controlling the longitudinal direction (vertical in the plot) and phase shifters controlling the lateral direction (horizontal in the plot)

4. Summary

In summary 2D optical beam steering from an InP PIC with integrated on-chip tunable laser source has been demonstrated. Beam steering angle range of 3.5° in the longitudinal direction and 10° in the lateral direction has been realized.

5. Reference

[1] P. F. McManamon, T. A. Dorschner, D. L. Corkum, L. J. Friedman, D. S. Hobbs, M. Holz, S. Liberman, H. Q. Nguyen, D. P. Resler, R. C. Sharp, and E. A. Watson, “Optical phased array technology,” Proc. IEEE **84**, 268-298 (1996) .

[2] K. V. Acoleyen, W. Bogaerts, J. Jagerska, N. L. Thomas, R. Houdre, and R. Baets, “Off-chip beam steering with a one-dimensional optical phased array on silicon-on-insulater,” Opt. Lett. **34**, 1477-1479 (2009).

[3] W. H. Guo, P. R. Binetti, C. Althouse, A. Bhardwaj, J. K. Doylend, H. P. M. M. Ambrosius, L. A. Johansson, and L. A. Coldren, “InP photonic integrated circuit for 2D optical beam steering,” Post-deadline paper, IEEE Photonics 2011 (IPC11), 2011.

[4] W. H. Guo, P. R. Binetti, C. Althouse, H. P. M. M. Ambrosius, L. A. Johansson, and L. A. Coldren, “InP photonic integrated circuit with on-chip monitors for optical beam steering,” MA6, ISLC2012, San Diego, CA, USA (2012).

[5] L. A. Coldren, “Monolithic tunable diode lasers,” IEEE J. Sel. Topics Quantum Electron. **6**, 988-999 (2000).