High-performance InP/GaAs Based Photonic Integrated Circuits

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Abstract

InP photonic integrated circuits continue to play important roles in realization of modern optical communication systems, optical sensing and free-space communication systems. In this paper, we report on our recent work on InP advanced modulation format tunable transmitters and receivers, as well as 2D optical beam steering InP PICs.

I. INTRODUCTION

InP photonic integrated circuits continue to play important roles in realization of modern optical communication systems, as well as to find new application areas, such are optical sensing and free-space communication. In this paper, we report on our work on advanced modulation format optical tunable transmitter and receiver components, as well as on 2D optical beam steering using PICs.

II. COHERENT OPTICAL RECEIVERS AND TRANSMITTERS

After more than three decades since conception, optical coherent systems are finally a reality. They are being deployed throughout transport optical networks in order to provide more optical bandwidth through existing optical fiber, as well as simplify dealing with the impairments of transmission, given that in most cases, both optical amplitude and phase are being recovered.

Arbitrary vector modulation can be generated using the combination of both amplitude and phase modulation. One popular way to accomplish this task is to use the nested Mach-Zehnder modulator structure shown in Figure 3c. Because this structure assigns the I axis to one MZM and the Q axis to a second MZM, it can modulate the resultant vector to any (I,Q) point in the plane of the I-Q diagram. For QPSK modulation, four equal amplitude (I-Q) points are accessed.

InP Photonic integration and photonic integrated circuits play a prominent role in realization of coherent optical systems. Example devices include modulators and receivers [1],[2], as well as fully integrated transmitter and receiver arrays [3].

Our fully integrated tunable coherent transmitter chip, reported in [4], consists of a widely-tunable sampled-grating DBR (SGDBR) laser monolithically integrated with a nested Mach-Zehnder modulator, as shown in Figure 1 .

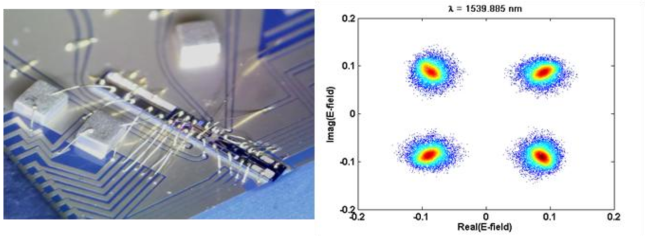

Figure 1 – (left) Photograph of the widely tunable optical transmitter integrated circuit mounted on an Aluminum-Nitride ceramic carrier. (right) A representative constellation diagram from coherent link demonstration using a 20 Gbps QPSK encoded optical signal with 2^{31}-1 PRBS, after DSP post processing. Linear color coding corresponds to symbol density.

The chip was realized using monolithic integration in Indium Phosphide (InP) based on quantum well intermixing. The single-mode SGDBR laser provides 40 nm of tuning around 1550 nm. The signal from the laser is amplified with a semiconductor optical amplifier (SOA), and then split into 4 paths, using a 1x4 multimode interference (MMI) splitter. The light in each path is sent through a static phase adjustment electrode embedded in the S-bend waveguides, which is essential for setting the MZMs in the quadrature state. The high-speed MZMs are formed using 400 μm long quantum-well intermixed (QWI) regions, with a photoluminescence (PL) peak at 1.5μm, utilizing the quantum-confined Stark effect (QCSE) for light absorption. After the light in each of the four arms is modulated, it is recombined in a 4x3MMI, which allows for monitoring of the MZM in the OFF state. Thus, the chip is capable of transmitting a single transverse-electric (TE) polarization QPSK data stream in a compact footprint. The key issue with tunable laser integration for coherent transmitter purposes is that of achieving sufficiently narrow linewidth and low phase noise, and this will remain the area of active research in the near future. Recent progress has been reported using a widely tunable laser with heater electrodes, which reduces the shot noise in the laser cavity [5], as well as through using frequency stabilization based on on-chip integrated monitoring [6].

As with coherent transmitters, integration of a widely tunable local oscillator would further benefit the level of integration in coherent receiver PICs. The first implementation of an integrated widely tunable coherent receiver, reported by Freedom Photonics, is shown in Figure 2 [7]. The chip was realized using photonic integration in Indium Phosphide. At the center of the chip is a widely tunable sampled grating distributed Bragg reflector (SGDBR) laser, used as the receiver LO, providing 40 nm tunability and bandwidth coverage. The signal from the LO is split into two identical paths. In each of the two paths, the LO power is amplified with a semiconductor optical amplifier (SOA), before the signal is routed using 2 total internal reflection (TIR) mirrors with a perpendicular waveguide connecting them. The signal from the second TIR mirror is then guided into a 2x4 multimode interference (MMI) hybrid. The receiver chip has two signal input waveguides, which are used to independently couple each of the two demultiplexed polarization data streams from a polarization multiplexed network data stream. The four outputs of each of the hybrids are separated using S-bend waveguides, which terminate in 4 photodiodes. Thus, the chip is capable of simultaneously detecting two independent data streams from a polarization multiplexed QPSK data stream – however, polarization demultiplexing and rotation of the transverse-magnetic (TM) polarization into transverse-electric (TE) has to be performed external to the chip.

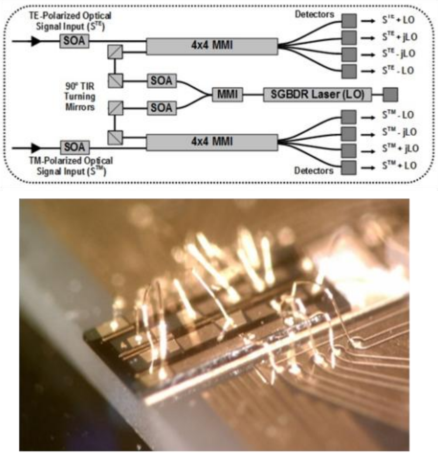

Figure 2 – (top) Schematic of Freedom Photonics' monolithically integrated dual-polarization tunable photonic integrated coherent receiver, including SOAs, MMIs and total internal reflection mirrors and a tunable local oscillator laser (bottom) Photograph of the widely tunable optical receiver integrated circuit mounted on a ceramic carrier [7].

Error-free, 20Gbps (10Gbaud) operation with this chip has been demonstrated. Our more recent work, using a similar device as part of an optical phase locked loop (OPLL) subsystem, for homodyne coherent detection, was reported as an alternative to high power consumption digital signal processing based detection methods. The OPLL was realized using Costa's loop, as shown in Fig.3.

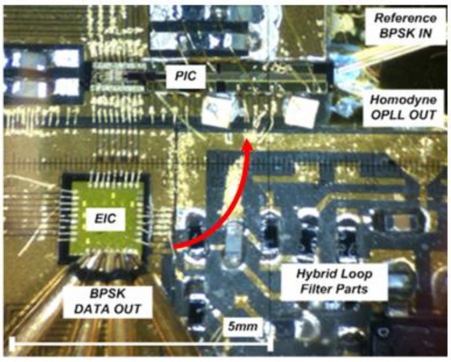

Figure 3 – Photograph of a homodyne optical receiver using an optical phase locked loop based on Costa's loop.

III. PICS FOR 2 DIMENSIONAL BEAM STEERING

Electronically controlled optical beam steering is potentially useful for a number of applications such as LIDAR (light detection and ranging), free space secure laser communication, printing, etc. Various methods have been demonstrated to achieve this goal. One typical method is the optical phased array (OPA) which is used for one-dimensional (1D) optical beam steering .

Recently, we have demonstrated 2D optical beam steering with an InP photonic integrated circuit (PIC) using the scheme of 1D OPA plus wavelength tuning with surface emitting gratings. The PIC used is shown in Figure 4. It consists of an on-chip widely tunable SGDBR laser, followed by a set of 1x2 splitters, forming 8 individual waveguides with an SOA array, and an emission array. On-chip power monitors are integrated as well.

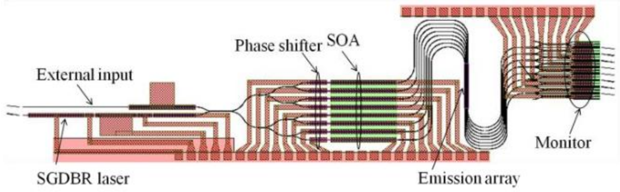

Figure 4 – Layout of the beam-steering photonic integrated circuit, consisting of an on-chip widely tunable SGDBR laser, followed by a set of 1x2 splitters, forming 8 individual waveguides with an SOA array, and an emission array.

Beam steering angle ranges of 5° in longitudinal and 10° in lateral direction have been achieved with this chip.

IV. REFERENCES

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