High-Performance InP Photonic Integrated Circuits

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***Abstract* – We are reviewing recent results in the development of high performance Indium Phosphide photonic integrated circuits for coherent communications applications. Integrated transmitters and receivers for fast wavelength switched applications are presented.**

I. INTRODUCTION

Over the last few years, 100G coherent optical channels have increasingly been deployed for long haul transmission, because they offer improved mitigation of fiber dispersion and non-linearities through post-detection signal processing. These links have typically relied on optimized discrete optical subcomponents to reach the required speed and performance of lasers, modulators and coherent receivers. As 100G coherent is adapted for shorter haul, or LAN applications, low cost, efficient integrated component technologies will be needed. Dynamic networks with increased temporal granularity will also require components compatible with fast wavelength switching and reconfigurability. In this paper we will review recent developments in integrated Indium Phosphide transmitters and coherent receivers, as well as developments using these components for fast and precise wavelength switching applications.

II. INTEGRATED PHOTONIC COMPONENTS FOR COHERENT OPTICAL COMMUNICATIONS LINKS

Future iterations of 100G transceivers will need to meet power and footprint targets significantly improved from current C-form pluggable form factor transceivers. This will require a transition from optimized discrete optical components to photonic integrated circuits (PICs). The Indium Phosphide photonic integration platform is a mature and high performance candidate to implement these PICs [1,2]. Freedom Photonics have recently demonstrated integrated widely tunable transmitters [3,4] and coherent receivers [4,5,6] photonic integrated circuits. Figure 1 shows an overview of Freedom Photonics advanced photonic integrated circuit development for coherent optical communications links. This includes a transmitter including a widely tunable source laser integrated to a QPSK modulator, demonstrated up to 10 GHz QPSK modulation, as well as an integrated polatization diversity coherent optical receiver which integrates a widely tunable LO laser with two sets of I/Q optical receivers with integrated balanced photodetector pairs.

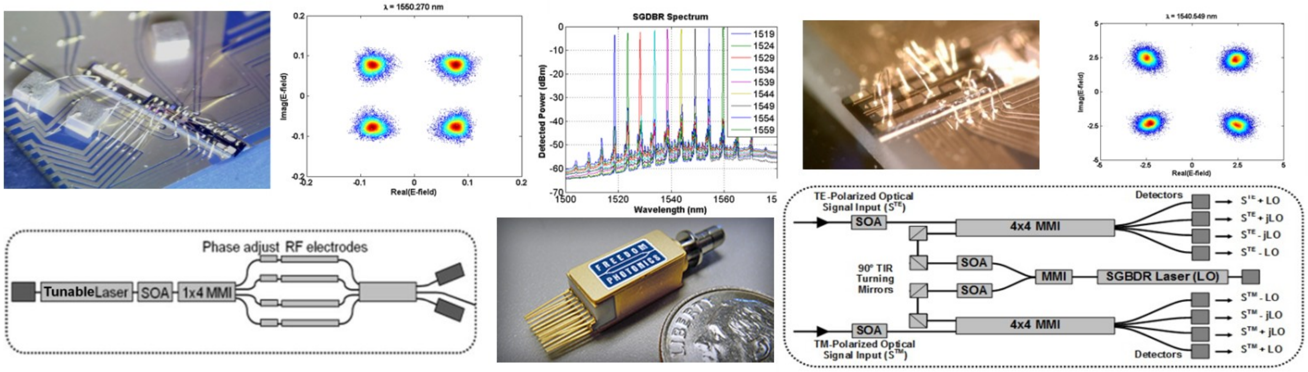

Figure 1 – Overview of Freedom Photonics advanced photonic integrated circuit development for coherent optical communications links. Left: Widely tunable QPSK transmitter compatible with compact TOSA package form with tuning spectra and generated 10 GHz constellation diagram. Right: Integrated polarization diversity coherent receiver with integrated widely tunable C-band LO laser, with received 10 GHz QPSK constellation diagram.

These initial demonstrations have shown that InP PICs will meet performance requirements for basic QPSK transmission. To reach a performance meeting the demands of next generation 100G systems, A number of improvements are required. Laser linewidth need to be improved. Current multisection tunable lasers suffer from excess wavelength jitter from multiple tuning sections. One option is to incorporate low-noise thermal tuning sections [7]. However, these are not compatible with fast, ns wavelength switching. An alternative approach is to use a fast wavelength locking technique to an integrated wavelength discriminator [8] which has been demonstrated to reach 150 kHz linewidth with maintained ns switching times. Sub-volt drive modulators can be realized in compound semiconductor materials [9,10] which are compatible with Indium Phosphide integration, which will meet stringent power requirements of compact transceiver modules. Reduced receiver insertion loss is achieved through the integration of spot-size converters on the Indium Phosphide receiver PIC, leading to competitive insertion loss [11].

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III. COMPONENT TECHNOLOGY FOR FAST WAVELENGTH SWITCHED APPLICATIONS

To achieve high network utilization in highly dynamic or bursty data traffic, optical packet switching may be required where packets lengths can be as short as 10ns with <10ns guard-bands. In a typical multisection tunable laser, there is a trade-off between switching speed and wavelength accuracy. While switching speeds in the ns rage has been demonstrated, the time to reach sufficient stability for dense WDM (a few GHz) is in the microseconds range [12]. We have developed a transmitter architecture capable of breaking the speed-accuracy trade-off, shown in Figure 2 [12]. This consist of dual SGDBR lasers, each followed by a gating SOA and coupled together in an MMI coupler to form a single optical output. Only one output is active at a time, while the second laser is wavelength tuned to a new destination channel. This not only reduces switching time to ~2ns, as illustrated by Figure 2, but it also eliminates transmission of unwanted spurious wavelengths emitted during laser tuning.

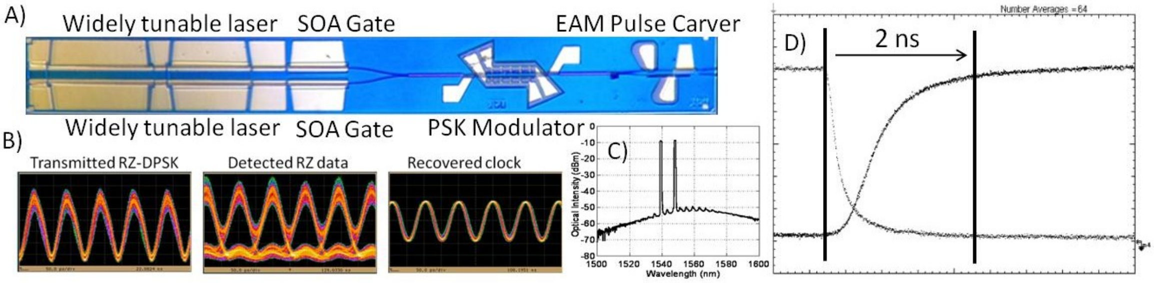
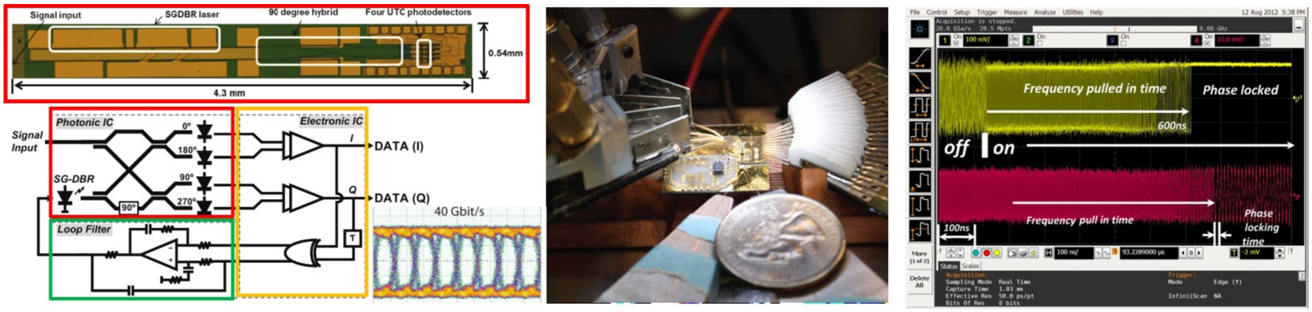


Figure 2: A) Photograph of burst-mode widely tunable RZ-DPSK transmitter. B) Transmitted and demodulated data and clock waveforms. C) Transmitted optical spectrum during cycled wavelength switching. D) <2ns switching time using fast SOA gates.

A second requirement is fast clock recovery. Many electronic methods require >100ns of preambles to align data and clock. This is not compatible with 10ns packets. The RZ-D(Q)PSK modulation format is a very attractive modulation format as the clock information is transmitted with the data encoded in the optical envelope, such that the need for clock recovery and alignment is eliminated. The transmitter shown in Figure 2 incorporated both a PSK data encoder as well as an EAM pulse-carver for the generation of RZ-DPSK modulation format. Generated and demodulated waveforms are shown in Figure 2. The combination with fast gated SOAs and dual laser architecture makes this transmitter an ideal candidate for packet switching applications.



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Acquisition is stopped.
20.0 GSa/s   20.5 Mpts
Acquisition:
Sampling Mode   Real Time
Capture Time    1.03 ms
Effective Res   50.0 ps/pt
Bits Of Res     8 bits
Trigger:
Mode            Edge (↑)
InfiniiScan     NA
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Figure 3: Left: Schematic of phase-locked Costa's loop receiver with picture of integrated coherent receiver PIC and demodulated 40Gbps eye diagram. Center: Relative size of integrated coherent receiver. Right: Fast switching performance with ns loop acquisition demonstrated.

Fast coherent receivers may similarly be required for these applications. Figure 3 shows a fast phase-locked coherent receiver for PSK modulation, extendable to QPSK. This receiver has been demonstrated PSK demodulation up to 40 GHz data rates [13,14]. A fast Costa's loop is capable of recovering the optical carrier for direct data demodulation with locking times in the ns range. The loop bandwidth is around 1.1GHz in this loop configuration, allowing potential acquisition times of less than 10ns.

REFERENCES

[1] B. Mason, M. Larson, Y. Akulova, and S. Kalluri. Indium Phosphide and Related Materials (IPRM), 2013 International Conference on, pp. 1-2. IEEE, 2013.
[2] M.L. Masanovic, L.A. Johansson, J.S. Barton, W. Guo, M. Lu, and L.A. Coldren, Proc. CLEO Pacific Rim 2013, paper no. TuN1-2, Kyoto, 2013.
[3] S.B. Estrella, L.A. Johansson, M.L. Mašanović, J.A. Thomas, and J.S. Barton, IEEE Photon. Technol. Lett,. 25(7), pp. 641-643, 2013.
[4] L. A. Johansson, M. L. Mashanovitch, S. B. Estrella, J.A. Thomas, S. S. Kumar, and J. S. Barton, ICSOS 2012, paper #9-3, Corsica, France.
[5] S.B. Estrella, L.A. Johansson, M.L. Masanovic, J.A. Thomas, J.S. Barton, IEEE Photon. Technol. Lett,. 24(5), pp. 365 - 367
[6] M.L. Masanovic, *at al,* Proc. OFC/NOEFC, paper no. OThY1, Los Angeles, CA (March 6-11, 2011).
[7] M. Larson, Y Feng, P-C Koh, X Huang, M Moewe, A Semakov, A Patwardhan et al. In Optical Fiber Communication Conference, pp. OTh3I-4. 2013.
[8] A. Sivananthan, H. Park, M. Lu, J.S. Parker, E. Bloch, L.A. Johansson, M.J. Rodwell, and L.A. Coldren, Proc. CLEO 2013, CTu1L.2, San Jose, CA, 2013
[9] Selim Dogru and Nadir Dagli, CLEO: Science and Innovations, paper STu1G, San Jose, California June 8-13, 2014.
[10] Selim Dogru and Nadir Dagli, Integrated Photonics Research, Silicon and Nanophotonics, paper IW3A, San Diego, California, July 13-17, 2014.
[11] S. Farwell, P Aivaliotis, Y Qian, P Bromley, R Griggs, J Hoe, C Smith, and S Jones. In Optical Fiber Communication Conference, pp. W1I-6. 2014.
[12] L.A. Johansson, M.L. Mašanović, J.S. Barton, 2010 IEEE Avionics, Fiber- Optics and Photonics Technology Conference (AVFOP), pp 23-24, 4-6 Oct. 2010
[13] L.A. Coldren, M. Lu, H. Park, E. Bloch, J.S. Parker, L.A. Johansson, and M.J. Rodwell, In Optical Fiber Communication Conf, OTh3H.5, 2013.
[14] M. Lu, *et al*, Journal of Lightwave Technol, 31, (13), pp. 2244-2253, July 1, 2013.