Advanced Photonic Integration and High-Index-Contrast Circuit

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Abstract
We highlight recent advances in advanced photonic integration of reliable densely integrated photonic integrated circuits (PIC) and high-index-contrast photonic lightwave circuits (PLC). The applications and benefits of these devices will be presented.

Introduction
Since the Internet became generally available in the early 1990s, the demand for higher network speed and bandwidth has grown exponentially without any sign of slowing. Much of this growth is driven by the popular and bandwidth hungry video applications where the end user nearly always pays a flat fee for the Internet service. The service provider must develop new technologies that deliver improved systems performance while simultaneously reducing the cost per bit. Among the most forward technologies are advanced photonic integration where large numbers of optical components are integrated onto a single chip. Long in the research and development phase, these technologies are now seeing commercial deployment. We highlight the development and commercial deployment of both the PIC and PLC devices.

Commercial Photonic Integration Circuits
In 1969 Miller [1] first proposed the concept and the merits of photonic integrated circuits. Since then vast amount of efforts and advances have been made [2,3] toward the realization of the PICs, however the introduction of large scale, advanced photonic integration has been particularly slow to develop commercially. In 2004 the world's first digital ROADM based on large scale photonic integrated circuits was introduced into the market. This platform – the Infinera DTN – is based on a transmit and receive Indium Phosphide PICs pair with 10 channels, each running at 10Gbits/s [4]. Figure 1 shows a block diagram of the 100Gbits/s PICs pair. Using this platform, customers were able to add optical capacity in chunks of 100 Gbit/s at a time, taking about the same amount of operational effort to deploy ten times the capacity of a single 10Gbit/s transponder. Since the DTN began shipping it has arrived at the number one position in North America long haul DWDM market [5]. Service providers in this conservative market segment have accepted the PIC approach because it helps them to address the issues they face.

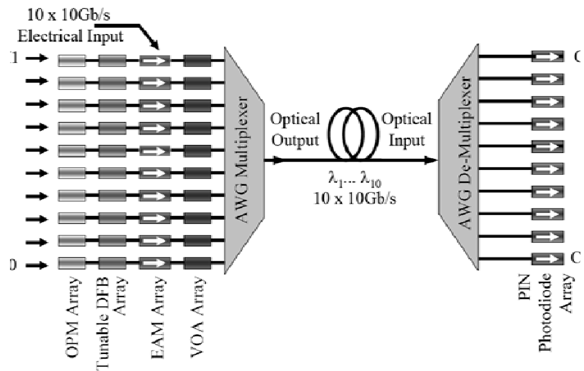

Fig. 1 Block diagram of 100Gbit/s PICs, integrating 10 WDM channels, each operating at 10 Gbits/s, in a single pair of chips.

PIC has a number of advantages over transponder devices assembled from discrete optical components:

1) Reduction of power consumption and size.
Advanced photonic integration allows multiple components that would traditionally each require individual fiber coupled packages to be integrated on a single chip within a single package. This reduces both the size of the package and the power consumption for a given transmission capacity. An integrated design eliminates most of the fiber couplings and their associated splice loss and uncertainties normally found on a transponder card. Consider cooling of packaged components. The 10-channel PIC needs only one thermo-electric cooler (TEC), instead of the 10 that would be needed by single wavelength transponders. These space and power advantages become more prominent as the demand for more dense integration of optical functions in future components involves more complicated modulating and receiving structures [6].

2) Improved reliability.
Integration of optical components into a reliable technology platform such as InP enables comprehensive functionality without compromised reliability. Compared to the discrete component approach, the reduction of fiber couplings and handling in the advanced photonic integration approach allows a more robust assembly process and reduces the amount of failures in fiber coupling to the PIC and splicing between the components. Infinera recently announced over 100 million field hours of PIC operation without a single failure in service.

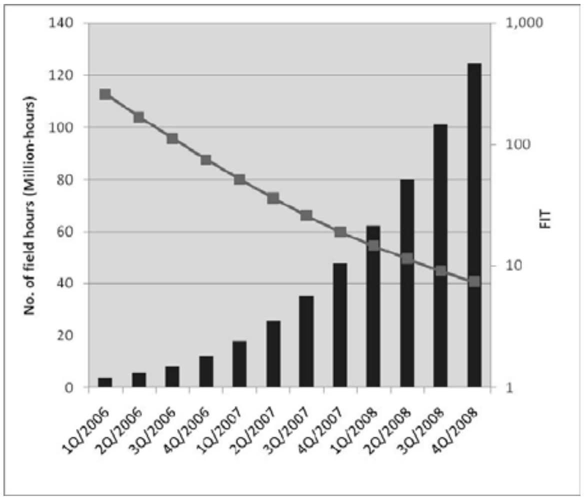

Fig 2. At the end of 2008, there have been 120M+ field hours of PIC operation without failure.

High-Index-Contrast Photonic Lightwave Circuits

Passive integrated optical PLC components offer critical functionality in routing, filtering and signal processing. Dense integration of the PLCs requires waveguides and other circuit elements that behave as optical wires. High-index-contrast materials enable such miniaturization by tightly confining light and allowing it to execute tight bends without loss of total internal reflection. Infinera has developed Hydex, a high-index-contrast material system, that enables orders of magnitude reduction in the size of the optical elements. The operating index contrast region of Hydex is more than an order of magnitude higher than conventional PLCs allowing loss free bends down to about 30 μm in radius. Propagation loss is comparable to the conventional PLCs throughout the C & L bands. Similar to low-index-contrast PLCs, Hydex takes advantage of conventional semiconductor manufacturing tools and processes. However, unlike most conventional PLCs, Hydex circuits are small enough to take advantage of projection stepper lithography, improving feature resolution and circuit fidelity, and increasing wafer throughput and yield. Low loss and compact waveguide arrangements have led to the realization of a number of advanced devices [7] and commercial deployment in telecommunications. We will highlight the process and deployment of these devices in the presentation.

Summary

The commercial deployment of PIC based DTN offers a range of real benefits for the service provider. In many ways, advanced photonic integration follows in the footsteps of electronics integrated circuit evolution, from single-function transistors to large scale integrated circuits. VLSI electronics enabled computing power to become a commodity resource. Similarly, VLSI photonics reduces the cost and power consumption per bit. For the revolution in optical networks to continue, optical transmission capacity must also become a commodity. Advanced photonic integration is essential to service providers to scale capacity and yet achieve practical operational simplicity to sustain this era of explosive growth.

References

1. Miller, S., Bell Sys. Tech. J., 48(7), 2059-2069(1969).
2. Coldren, L., Tutorial Tu.1.A.2., ECOC, Brussels, Belgium, 2008.
3. Doerr, C., OFC/NFOEC(2008), Tutorial OWE3.
4. Welch, D. et al, IEEE JSTQE13(1), pp.22-31,2007.
5. Infinera press release: 'http://www.infinera.com/j7/servlet/NewItem?newItemID=100.
6. Corzine, S. et al., TuX4, IEEE LEOS Ann. Mtg., 2008.
7. Little, B., et al, IEEE Photonics Tech. Lett.(16_, pp2263-2265 (2004)