Technical Challenges for 100Gb/s Silicon Photonics Transceivers for Data Center Applications

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Abstract: Silicon photonics based VOAs (variable optical attenuators) have been manufactured for the past several years in quantities of 100,000s per year. How do the lessons of high-volume VOA production apply to 100Gb/s transceivers as the volumes also scale beyond 100k per year?

OCIS codes: (220.0220) Optical Design and Fabrication; (250.5300) Photonic Integrated Circuits; (200.4650) Optical Interconnects

1. Introduction

Variable optical attenuators (VOAs) are widely used in optical networks for amplitude control, network overlay signaling, and transient control. In Optical Add/Drop Multiplexers (OADMs) VOAs are used to set the power of the on ramp channels to match the power of the through channels. VOAs are matched with each channel of an Arrayed Waveguide Filter (Mux). Other VOAs are used for overlay signaling, using a small portion of the optical signal, without impacting the full data transmission. VOAs are also used in of fiber amplifiers and coherent receivers. Data centers use them to improve the performance and reliability of links between data centers.

Mellanox first designed and manufactured silicon photonics (SiP) based VOAs in 2004. The structure of this VOA [1] is silicon-on-insulator (SOI) ridge waveguide integrated with a lateral p-i-n diode as shown in Figure 1(a). The key features of this solid-state device are its MHz bandwidth and submicrosecond response time (Figure 1(d)). Figure 1(c) shows the inside of a packaged VOA.

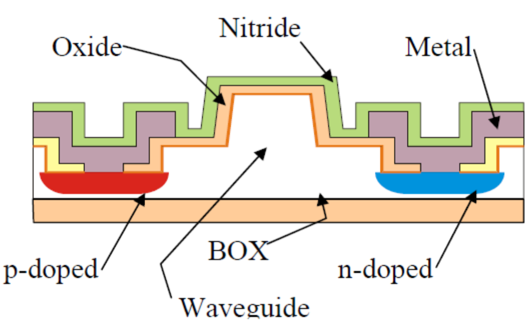

Figure 1(a). Cross-sectional diagram of VOA with forward biased p-i-n diode.

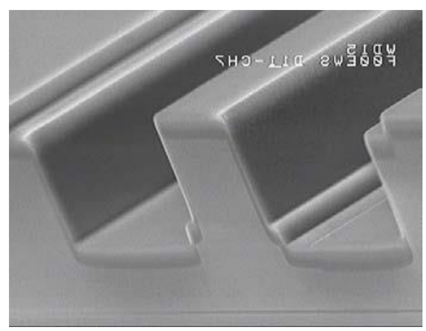

Figure 1(b) SEM view of mode transformer

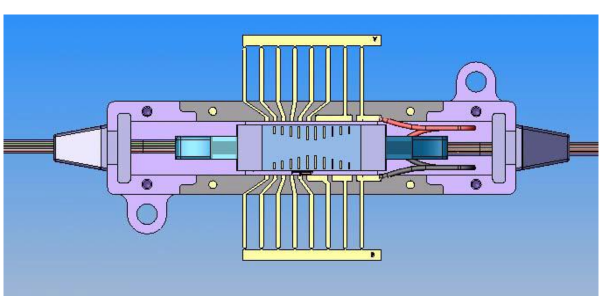

Figure 1(c). Silicon photonic VOA module with the cover removed

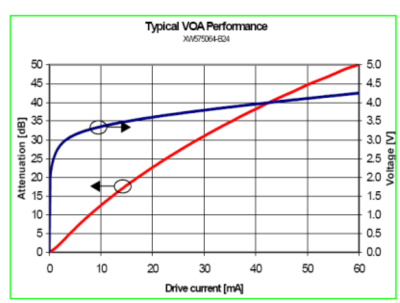

Figure 1(d). Measured VOA performance

Over the last 10 years, this SiP VOA has become the industry favorite for several reasons:

- **Low-cost:** SiPVOAs are more cost effective than MEMs-based, PLC-based, or mechanical VOAs, largely replacing them in many applications.
- **Scale:** the promise of high volume manufacturability with a silicon process has been demonstrated by Mellanox producing millions of units over the past several years.
- **High-speed response time:** the fast opto-electronic response time has expanded the application space for VOAs. SiP VOAs have enabled entirely new, high-volume applications like overlay signaling and transient suppression.
- **Low FIT rate.** Measured field failures has demonstrated a FIT rate of less than 2, far exceeding the reliability requirements of Telecom and data center applications.

2. A Highly Manufacturable 100 Gb/s Parallel Single Mode Transceiver for Data Centers

A 100Gb/s SiP transceiver is a much more complicated design than the VOA and the challenge was to incorporate high-speed electronics and opto-electronics in a low-cost package. To accomplish this, the transceiver packaging design took advantage of the lessons learned from the high volume attenuator experience. To be sure, the 100Gb/s transceiver chips have many new internal building blocks, including Franz-Keldysh modulators, echelle grating WDM devices and germanium photo diodes as shown in Figures 2(a) and 2(b) below. The details of these building blocks are described elsewhere [2-6].

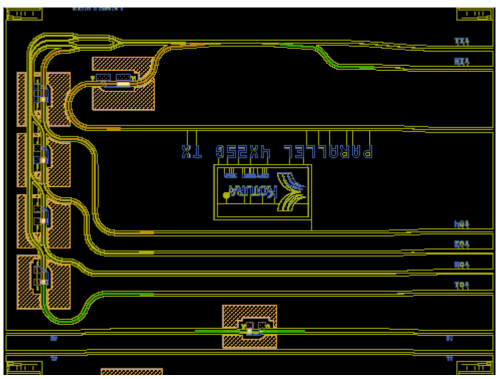

Figure 2(a): Mask layout of SiP Tx with F-K modulators

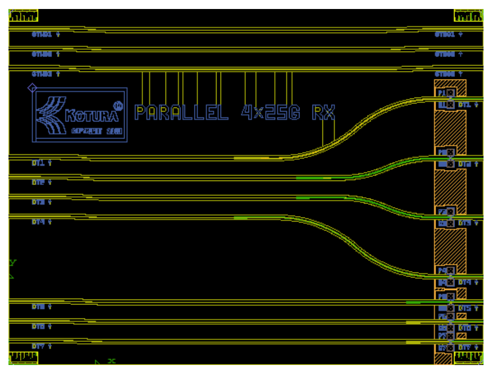

Figure 2(b): Mask layout of SiP Rx with Ge Detectors

Figures 2 (c): Top removed from a 100 Gb/s SiP transceiver; a fully packaged QSFP28 transceiver.

The internal view in Figure 2(c) shows several important similarities to VOA packaging. Both designs employ simple mounting of SiP chips on green PCB boards. Both use non-hermetic packaging. Neither design has expensive “gold bricks” (hermetic subassemblies). Other less obvious similarities are:

a. **Choice of a 3 µm waveguide.** The challenge here was the decision on the size of the waveguide. The older VOA device used 3 µm waveguides as the ideal tradeoff between optical performance and manufacturability; the 100Gb/s designs kept that design choice. 3 µm waveguides transmit both TE and TM modes of light; they have low-loss (less than 0.1 dB per cm); they have low PDL; they can support “sharp bends" at low-loss, enabling efficient optical routing; they have more manufacturing tolerance than smaller waveguides; and 3 µm waveguides match well with the beam profile of a laser.

b. **Low-cost, non-hermetic packaging.** To the best of our knowledge, Mellanox has the first and only 100Gb/s transceiver package which is fully non-hermetic. From the VOA, we learned to design reliable products without the expense of seam sealing and hermetic testing.

c. **Butt coupling of fibers to the chip.** The cheapest and fastest method of fiber attach is to use a fiber block and fiber array. Fiber blocks and fiber arrays are not a new technology and many would call it dull and boring. Widely used for the FTTH market, Mellanox estimates 30-40 million fiber blocks per year are manufactured for PLC splitters. Some SiP transceiver companies have spent years of development on exotic grating couplers, turning mirrors, or adiabatic tapered optical fibers. Mellanox did none of this. Instead we took advantage of the proven method for splitters and VOAs. Attaching a simple fiber block to silicon chips has proven to be a low-cost, highly-reliable process, and scalable to high volumes.

d. **No TOSA, No ROSA**. Usually the laser would be a separate subassembly, hermetically sealed and consisting of an InP laser chip, a ball lens to collimate the beam, an isolator (sometimes double) to prevent back reflections, and another lens. Because the Mellanox design eliminates the need for lenses and isolators, the InP laser can be flip-chip bonded directly on the SiP Tx. Other alignment features enable low-cost passive alignment.

e. **No TEC.** Thermal-electric coolers are often used to extend the operating temperature range of optical devices. Most VOA designs do not require TECs, and a TEC was not used in the transceiver packages. TECs are costly, require additional assembly steps, and consume power.

4. Conclusions

Perhaps the biggest challenge for SiP for data centers is to be able to manufacture a high volume of products at low cost. At Mellanox, VOA packaging techniques are being used to assemble 100Gb/s transceivers, reducing the cost and the manufacturing complexity. The high-volume VOA experience has demonstrated that silicon scales, provides superior performance, and enables low-cost packaging. Reusing these concepts for 100Gb/s transceivers are enabling data centers to cost-effectively scale out their networks.

5. References

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