Commercial Photonics

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What are the hurdles to be taken to transfer a photonic concept to a money-making commercial product? In this paper we address a number of these hurdles, and discuss the current situation.

Photonics today

To discuss commercial aspects of photonics, we must first define our scope: what is photonics. In our view, photonics is the area of optics that is described in terms of propagation modes and/or quantum-wise light-matter interaction, rather than in terms of rays and diffraction kernels. Consequently, photonic devices have minimum feature sizes in the order of a wavelength. For low index contrast devices, the size can be somewhat larger. Perhaps the largest photonic device is a single-mode fiber.

Photonic devices are all around us. In fact, the solid-state laser in a CD/DVD player/writer is a photonic device, and these have been sold by the millions for decades. Fiber Bragg Gratings (FBGs) in single-mode fibers are commonly used for structural health monitoring of dikes, bridges, and buildings. Also LEDs, or even solar panels, could be designated as photonic devices. Still, the use of large-scale integration Photonic Integrated Circuits is not wide-spread. The benchmark is more or less set by Infinera, who employs III-V based Wavelength Division Multiplexing (WDM) chips in their telecom systems. The last few years, Arrayed Waveguide Gratings (AWGs) have become commercially available (for example by Gemfire, NTT, Neophotonics, etc.). However, a large breakthrough is yet to come. Why is that?

Large scale photonic integration

As for the integration level, the situation is more or less comparable to electronics. In the analogue era, designers had to make sure that cumulative contributions of noise and distortion remained acceptable. Today, most electronics is digital, and signal processing is the domain of software. Noise has become a highly rare bit-error, and distortion a round-off error. This digitization has lead to larger circuits with more functionality. More important, these circuits can be cascaded and combined to even larger systems.

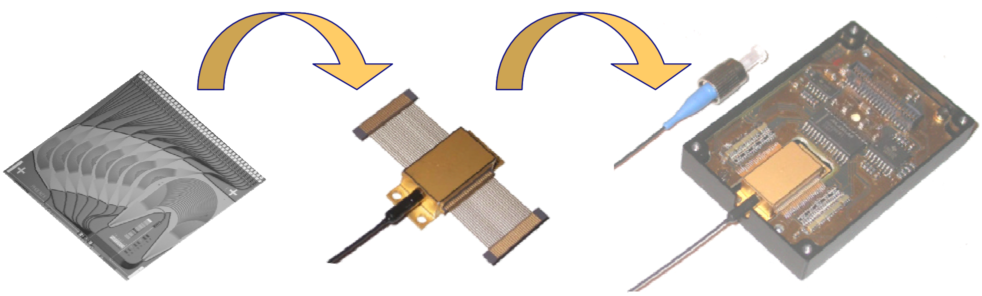

Figure 1: InP-based Optical Channel Monitor consisting of 9AWGs and 40 photodiodes, in a ready-to-use box with RS232 interface and on-board software (ThreeFive Photonics). This was available in 2003!

Photonic circuits, on the other hand, are mainly analogue, in spite of the digital signals processed in telecom applications. The build-up of crosstalk, ASE noise, dispersion and spurious reflections hampers the cascadability of optical devices. Only in truly digital optical systems with full 3R regeneration, cascadability is virtually unlimited. The development of optical memory cells and logic gates [1][2] is a big step forward to cascadability, but quite some work remains to be done. Also sensor applications are usually analogue: the sensor output is an actual value, rather than a digital 'threshold exceeded yes/no'. On a chip with many sensors, a dedicated mini-telecom system is required to address each analogue sensor individually. Here it is again (mainly) the crosstalk of the telecom system that limits the amount of sensors that can be incorporated.

Small scale photonic integration

At the other end of the photonic integration spectrum we have small chips containing only a few components. For telecom applications, that would for example be a detector and a laser, with an optional modulator. Incorporating a multiplexer enables the use of multiple channels. For sensing applications, a ring resonator based sensor with optional coating [3] is a highly useful photonic circuit. Ring-resonator based sensors are commercially available today, even integrated with fluidics, for example by Lionix. In order to be commercially attractive, these 'simple' photonic circuits should be low-cost, preferably down to the level of a consumable, and should be manufactured in large quantities. Recently, programs such as Europic [4] and Paradigm [5] have been initiated to reduce manufacturing costs, and to introduce standardization in photonics. What are the challenges? Let us briefly address the required steps to turn a concept into a high-volume commercial product, specific for photonics.

Design

After conception of the idea we need to make an optimized design. Many mode solver packages and advanced device simulation tools are available today, for example from Phoenix, Photon Design or Apollo Photonics. It is safer to use commercial tools with support and proven track record, than to develop in-house software with potential bugs.

Fabrication

For fabrication, we need a clean room. Two main species of clean room exist:

1. The R&D facility. This is typically a class 1000 or 'dirtier' clean room, with tools being used for a variety of R&D activities. If needed, new processes can be developed, even if this requires hardware modification (i.e. testing a new etching chemistry). Tools may suffer from cross-contamination. If prototyping is successful, small-scale production is an option, up to a few tens of wafers.
2. The high-volume manufacturing facility. This is a class 100 or cleaner, with strict dress codes. Preferably, the production process is automated to such a degree that no people are physically in the clean room at all, except for maintenance. For the stern fab manager, yield and throughput are the reason for living. The facility is operated 24/7 because it costs a fortune.

Most clean rooms are not rigidly type 1 or 2, but certainly tend to either of the two. Combining R&D and production is a dangerous mix, since R&D activities will undoubtedly interfere with production, or even render the yield of the next production batch to zero.

Figure 2: fiber-to-the home brings photonics to the end-consumer, opening possibilities for high-volume photonic applications.. The picture shows fiber installation construction works, and was taken in Eindhoven, 2007.

The last decade, a third option has come up: the foundry. This is again comparable to the electronics industry, where many companies have dedicated themselves to either design or manufacturing. For photonics, economic exploitation of a foundry is more difficult because the volumes are (still) lower, but foundry services have become available for the main material systems: IMEC and CEA-LETI for Silicon-On-Insulator (SOI), GCS, CIP and CST for III-Vs and Lionix for dielectrics. Multi-project wafers services are available in the Epixfab (SOI) and Jeppix (III-V) frameworks. We believe that the availability of foundry services is the key to commercial success for photonics.

Wafers

Outsourcing wafer fabrication is common practice already. Even many companies who have fabs do not make their own wafers, but leave this to specialists at external suppliers. Obviously, for a fabless company that is the only route.

Testing

In order to make testing low-cost, it is preferably done on-wafer rather than on-chip. An attractive enabling concept is the Vertical Grating Coupler (VGC) [6], which allows for a vertical optical coupling to in-plane waveguide devices, so that optical circuits can be characterized fast and effectively prior to wafer dicing.

Packaging

The photonic circuit must be connected to at least one source and detector. We identify three main possibilities:

1. Sources and detectors are part of the integrated circuit. Sources are only possible in III-Vs (yet?). III-V chips are relatively expensive, but not to a show-stopping level. Of more concern is the fact that, in applications that require one or more high-performance lasers, the circuit yield will be determined by the laser yield.
2. Sources and detectors are hybridly coupled, and can be tested before being applied to the photonic circuit. Alignment, mounting and achieving high coupling efficiency are difficult, but several groups are working on the subject.
3. The circuit is connected to a fiber. Here we face again alignment and mounting issues, though the previously mentioned VGCs can be enabler to reduce packaging costs. In the framework of Epixpack, VGC-based packaging is offered for prototyping. Fiber-chip assemblies with lensed fibers, commercially offered by for example Optocap, CIP and Flextronics, are generally in the several 100 EUR range and up, depending on the specs.

Packaging costs are typically in the order of 80% of the total product costs. This fact is now becoming commonly accepted in the photonics community, and it is of show-stopping importance to get that level down. The use of VGCs or spot size converters is essential to relax the alignment tolerances.

Interrogation

Remarkably, many groups work on sensor applications, and publish their results with Optical Spectrum Analyzer (OSA) data. However, and OSA is a highly expensive instrument. In order to increase the use of photonic sensors and FBGs, the development of low-cost interrogation systems is essential. Still, only few publications on the subject exist [8]. The issue of interrogation does not yet get the attention it deserves!

Conclusions

Photonics is commercially successful today, however, the level of integration seems to be limited to several tens of non-trivial* components until truly digital photonics has matured to a commercial level. High-volume photonics does not need that high integration level to be commercially attractive. Some must-haves for realization are available, in particular design software, wafer suppliers and foundry services. Other issues remain to be solved, in particular low-cost packaging (chip-chip or fiber-chip) and sensor interrogators.

References

[1] Dorren, H.J.S., Hill, M.T., Liu, Y., Calabretta, N., Srivatsa, A., Huijskens, F.M., de Waardt, H., Khoe, G.D.: Optical packet switching and buffering by using all-optical signal processing methods. Journal of Lightwave Technology 21, 2-12 (2003).

[2] Berrettini, G., Simi, A., Malacarne, A., BogoniL, A.: Poti: Ultrafast integrable and reconfigurable XNOR, AND, NOR, and NOT photonic logic gate. IEEE, Photonics Technology Letters 18, 917-919 (2006).

[3] N.A. Yebo, P.Lommens, Z.Hens, R. Baets, "An integrated optical ethanol vapor sensor based on a silicon-on-insulator microring resonator coated with a porous ZnO film ," Optics Express, vol. 18, No 11, 11859-11866, 2010.

[4] http://www.europic.org/

[5] http://cordis.europa.eu/fetch?CALLER=PROJ_ICT&ACTION=D&CAT=PROJ&RCN=95444

[6] G. Roelkens. D. Vermeulen, F. van Laere, S. Selvaraja, S. Scheerlinck, D. Taillaert, W. Bogaerts, P. Dumon and R. Baets: Briding the Gap Between Nanophotonic Waveguide Circuits and Single Mode Optical Fibers using Diffractive Grating Structures, Journal of Nanoscience and Nanotechnology, vol. 10, 1551-1562, 2010.

[7] Hui Su and Xu Guang Huang: A novel fiber Bragg grating Interrogating sensor system based on AWG demultiplexing, Optics Communications 275, 196-200, 2007.

[8] Y.H. Huang, Chao Lu, P.K.A.Wai, H.Y. Tam, H.Y: Fast FBG sensor interrogation system using vertical cavity surface emitting laser source, OECC 2009, July 13-17, pp. 1-2, 2007.

** A non-trivial component is described by an S-matrix which does not consist of only zeros and ones for ideal performance*

Companies are listed for illustration purpose only. The author makes no statements about the quality of their delivered products or services. Competition exists, the reader is encouraged to search him/herself.