integrated photonics

make it work
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Photonics: Enabling Technology

In the last few decades there is a broad oriented rising awareness with regard to photonics as an enabling technology. The applications of photonics as an enabling technology are extremely broad and will keep on growing rapidly. Photonics is being regarded not only as supplemental but also as a base technology platform similar to what electronics has become nowadays.

Integrated electronics is already globally used in billions of applications and its functionality is still increasing according to Moore’s law. With similarity Integrated Photonics has emerged as the generic photonic development platform for many future applications. Certainly not to replace electronics but to provide an enormous surplus in capabilities for an extremely wide range of applications.

Technobis Strategy

Our strategy is based on front-end technology development. Technobis group wants to provide total OEM customer satisfaction by offering custom solutions, advanced technologies and quality in design, manufacture, services and support.
An Application Specific Photonic Integrated Circuit (ASPIC) is an optical chip designed for a dedicated purpose. Similar to electronics, ASPICs allows a variety of solutions, all based on a small set of components.

Unlike integrated electronics where silicon is the dominant material, ASPICs have been fabricated on different material platforms having each of them providing advantages and limitations depending on the functions to be integrated. For instance, Silica has desirable properties for passive components like Arrayed Waveguide Gratings (AWGs) while GaAs or InP allow direct integration of active components, i.e. lights sources, detectors, etc.

Although the fabrication process is similar to integrated electronics, there is no dominant device like the transistor. The range of photonic functions include low loss interconnect waveguides, power splitters, optical amplifiers, optical modulators, filters, lasers, detectors, etc.

The versatile ability to replace traditional assemblies of multiple discrete optical or micro-optical components by a single small sized chip, make ASPICs highly favorable for next generation optical systems for benefits in cost reduction, functionality aggregation and standardization of specifications and processes.

Certainly this broad applicable versatility requires the need for standardization to preserve compatibility between the development platforms allowing to integrate the best of worlds to provide the best possible solution available.

In that respect valuable lessons in platform material selection for ASPICs are repeatedly discussed which ultimately will determine the success of the ASPICs industry. For instance, several successes have been achieved in both InP, SOI and TriPleX™ based systems.

As cost and performance may currently prove silicon-based devices preferable, it is certainly the capability of having both passive and active functions combined that proves InP more worthwhile depending on the required system functionality. Moreover, the integration of both electronic circuits with photonics circuits, i.e. hybrid systems, will most likely lead to more applicable development platforms yet to be invented.
Paradigm Shift

ASPIC technology may just as well be moving towards a paradigm shift once it establishes a state where the complexity of optical systems is no longer a major determining factor in optical system development. This shift may very well cause an unpredictably large growth of applications and their markets in the next decades.

As data- and telecommunication needs have been the major driver for some time, other applications fields appear to gain increasing necessity for smaller sized, more affordable and repeatable and reliable performance devices just as well.

Another example of a rapidly growing application area is (Fibre) Optic Sensing. Sensing in general is and shall always be an integral part of a large variety applications in its most wide perspective and remains expressing the need for an increasing improvement of sensing devices.

Photonic Integrated Circuit technology will play a major role in the transition of current conventional systems into next generation optics based systems throughout major technology market segments like Aerospace, Automotive, Medical and Robotics, High-tech Industry, Civil, etc.

For many small and medium enterprises the rising awareness for these needs not only revealed the promising capabilities in the current ASPIC value chain but just as important its shortcomings. Bringing ASPICs to the market requires extensive development steps and associated logistics.

Starting from an idea to have a series production of ASPIC based devices involves sufficient product and technology knowledge, value assessment, photonics integrated system design, chip manufacturing in the foundries, chip testing and prototyping, chip packaging, device integration and interfacing, series production development, and finally implementation.

As the ASPIC technology is in the process of coming loose from its academic roots, some important aspects of the value chain need to be improved, developed or even created in order to get to a valuable supply chain transition.
Time to Market

The need for SME’s to improve time to market for ASPIC based systems is imperative. The current availability of resources like foundries, designers, packagers, still needs maturing for several reasons. Although the first complex ASPICs started to be published in the late 80’s and despite the similarities in chip development complexity, still remaining is a significant difference in research and development methodologies.

The development of ASPICs is obviously very dedicated and focused to its application. As a result there are almost as many technology customizations as applications, often quite similar but different enough to prevent sufficient standardization and subsequently easy transfer from one design to the other.

Although a growing trend in the market is tangible, due to this fragmentation current markets are still too small to justify extensive development into a low cost industrial volume manufacturing process, making chip fabrication practically out of reach for many SME’s.

It is the fundamental technology versatility which allows an enormous spread of possibilities that needs the required standardization in order to supply a lateral supported ASPIC technology. Subsequently, the ASPIC value chain appears to illustrate a certain reluctance when it comes to the development of not only follow up processes like packaging and integration but also in the design and prototyping processes of ASPICs.
Generic Photonics Integrated Circuits Fabrication

As a result of this imminent need the consortium Generic Photonic Integrated Circuits Fabrication (GPICSFab) was founded on the initiative of several industrial players, which facilitates a Lean and Asset-Light manufacturing and logistics infrastructure to accelerate the introduction of integrated photonic functionalities. Its mission is to accelerate the introduction of ASPIC functionalities for Integrated Device Manufacturers (IDM) and Original Equipment Manufacturers (OEM) by means of facilitating production and logistics infrastructure using minimal in-house resources and optimizing outsourcing possibilities.

GPICSFab is convinced that the generic fabrication approach will cause a revolution in micro and nano-photonics, just like it did in microelectronics thirty years ago. In Europe, three integration technology platforms are actively introducing the generic foundry concept for the major integration technologies in photonics: JePPiX for InP-based monolithic integration, ePIXfab for silicon photonics and TriPleX™ for low-loss dielectric waveguide technology. GPICSFab concerns itself by selecting and offering those parts of these development platforms which are ready for product development today and offers them to the marketplace.

Given the tremendous impact of photonics as enabling technology for further expansion of high-performance telecom networks, the availability of dedicated ASPICs will enable the development and efficient implementation of advanced systems and instrumentation for a multitude of applications. To maximize its reach GPICSFab aims to collaborate with national and international partners and programs to secure state-of-the-art and world leading photonics integration competences.

GPICSFab provides access to a suite of quality manufacturing and logistics solutions. Instead of having a general ability to subscribe to a Multi Project Wafer (MPW) run once a year, the initiative of GPICSFab now offers SME's accessible and even hybrid options to subscribe to Shared Wafer Runs multiples times a year. This increase in availability of best-in-class methods for volume production will boost speed and reduce costs for the development of ASPIC based systems considerably. With regard to that, one of the important achievements of GPICSFab so far is establishing an agenda for Shared Wafer Runs with an interval period of 3 to 4 months which significantly exceeds current affordable availability of MPWs.

Another important achievement by GPICSFab in the process of standardization, is the initiation of the development of a Generic Package for ASPICs. Packaging is one of the most important steps in bringing ASPICs to the market for which no generic volume process has been established yet. Although photonic packaging researchers have been working on a range of technologies for application across a number of key industry sectors, including telecommunications, medical devices, biotechnology and consumer electronics, many of these research activities are still being performed through industry collaborations with the expectation of growth as photonics becomes the technology of choice for an increasing range of applications.

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Technobis Integrated Photonics Packaging Services

It is because of collaborative initiatives like GPICSFab resulting in progressive insight in market trends, pointing out the necessity of filling gaps in the supply chain of Integrated Photonics.

The increasing potential of integrated photonics requires a baseline in standardization and wide coverage of means to allow the technology to live up to this potential. In that respect these insights have illustrated the need for dedicated ASPIC packaging services, capable of providing mid-range volume production of ASPIC packages.

Progress has to be made rapidly and supply chain processes need to be synchronized with value chain processes. Packaging is the step of integrating ASPIC technology into commercial products. The development and integration of ASPICs requires a high degree of dedication and customization.

Generic Packaging is the preluding solution for supporting the versatility of ASPIC designs, minimizing non-recurring engineering costs, fast prototyping and fast implementations of pre-series production.

Technobis has taken matters in their own hands by founding the new company Technobis ipps. Technobis ipps is presented as a packaging solution provider for integrated photonics by supplying dedicated and mid-range volume packaging services for niche markets for optical instrumentation. With this establishment Technobis ipps aims to add necessary value to the supply chain for efficiently developing ASPICs.

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In the last two years Technobis tft-fos has been increasingly active in evaluating multiple ASPIC designers, manufactures and packagers for a multiplicity of integrated optical devices (see below).

With each run and following ASPIC assessment we learn more and more about the possibilities. Their variations and capabilities in manufacturing processes and the needs of high quality packaging ensure efficient and well performing integrated ASPIC devices for an increasing growth of applications.
Fiber Optic Sensing Applications Opportunities

The increasing demand for applications using this technology tends to sharpen these requirements. As the technology matures, device dimensions, power consumption and costs need to be optimized to serve these increasing application requirements. Based on the current state of technology and its industrialization capabilities, Application Specific Photonics Integrated Circuits is considered to be the most promising technology for the next generation of interrogation devices for fibre optic sensing.

HighTech
High resolution strain sensing.  
Precision stabilization control in vacuum.

Space
High precision sensing.  
High resolution displacement sensing in vacuum.

Automotive
High speed strain sensing.  
Impact deflection analysis on crash dummies and structures.

Aeronautics
High reliability strain sensing. Damage detection and shape monitoring on composit structures.

Medical
Minimal invasive sensing. Steerable needle shape monitoring, vascular pressure sensing.

Nuclear
High endurance sensing.  
Strain sensing in harsh, high temperature and radiated environments.
ASPIC Development Roadmaps

The roadmaps for ASPIC developments regards 4 key performance characteristics where it regards fiber optic sensing devices based on Fibre Bragg Gratings (FBG). These are resolution, sample speed, sensor multiplexing and low cost.

According to this segmentation multiple ASPIC design structures on different materials, including complete opto-electrical subsystems, have been designed, manufactured and evaluated to determine their capabilities and characteristically behavior.

Gator
The Gator chip design consists of a modified Arrayed Waveguide Grating (AWG) and a photodiode at the output of each AWG channel. The AWG is modified such that it operates as a spectrometer (patented technology).

This chip can be used as interposer between a fiber array, and an optical chip. The interposer chip converts the pitch between waveguides to a much smaller pitch of 50 μm. The other side of the interposer chip can be coupled to a second optical chip with matching pitch. The interposer chip function is in particularly useful for the fabrication of ASPIC based hybrid modules.

The first series of Gator chips are manufactured on the InP (Indium Phosphide) platform. By applying strain or a temperature difference to an FBG sensor, the reflected wavelength will change. The reflected light from the FBG is coupled into the chip.

Passive Divider & Interposer
TriPleX™ is a chip platform based on glass. It consists of a layer stack of silicon nitride and silicon oxide deposited on a silicon substrate.

Only passive components can be used on the TriPleX™ platform. An example of a TriPleX™ chip is a passive divider. This design is made such that the incoming fiber will be split into 8 outputs. This chip can be coupled to a fiber array, and serve as a miniaturized fiber splitter.
Ant
The ANT chip is fabricated on InP platform and is an Active Divider device. This design is used as active splitter or active switch. The ANT chip can also be used the other way around as well as combiner of multiple inputs to a single output.

Dragonfly
The dragonfly chip is an InP chip with multiple light sources. The light sources emit a broadband wavelength spectrum of >40 nm (C-Band).

Ladybug
The Ladybug is the crown jewel of our developments today. This ASPIC is specifically designed for extreme high resolution strain and temperature measurements.

Its highly optimized temperature stability ensures this design to readout sub-femtometer wavelength shifts detected by FBG sensors (i.e. for measuring sub-nanostrain / microKelvin variations).
Packaged ASPIC systems

Various ASPIC concepts for FBG interrogator devices have been prototyped and packaged into a working system. Each of these concepts are consecutive prototypes for an extreme high resolution FBG interrogator system.

**KoolMAZE**
The KoolMAZE is an optical device made from Indium Phosphide (InP) and packaged by Heinrich Hertz Institute (HHI). The architecture is designed as a Mach-Zehnder interferometer.

**PimpelMAZE**
The PimpelMAZE is from the same ‘family’ as the KoolMAZE. It is also an InP interferometer and packaged by Tyndall National Institute.

**KuifMAZE**
The KuifMAZE is an optical device made from Silicon on Insulator (SOI) and custom packaged by Tyndall for top coupling.

**PalawanMAZE**
The PalawanMAZE is an optical device made from Indium Phosphide and packaged by Tyndall in an in-house developed package, complete with electronic readout.

The package is designed for low-noise readout and optimal thermal control. The architecture of the device is a Mach-Zehnder interferometer.

**GATOR**
The GATOR is the basic ASPIC based FBG interrogator system (Indium Phosphide) and custom packaged by Tyndall. The package consists of the optical ship and a low-noise an Readout Integrated Circuit (ROIC) for photodiodes.
ASPIC Packaging of Opto-Electric Components

For many components and sub-systems the way they are packaged is imperative with regard to system reliability and costs. Projects where reliability is key (like space projects) tend to opt for fully hermetic packages. Although this generally leads to very high system reliability, it also tends to drastically increase costs.

Consequently commercial applications tend to opt for other types of packaging which in turn can lead to reliability issues when the package is not designed to meet the required quality criteria and the packaging is not properly performed. Photonic integrated circuits tend to pose severe requirements with respect to cleanliness and alignment next to the more common environmental sealing, which will have to be satisfied all to lead to an acceptable solution.

The complexity of photonic subsystems and components vary from simple detectors to complex optical systems containing several sensitive components. Almost without exception, a number of strict requirements are posed to photonic systems:

- The components need precise alignment relative to each other and often to an external mechanical reference
- Several electrical connections will have to be made
- During assembly contamination of the optical components shall be avoided
- The system will have to exhibit a high reliability and function flawlessly over a prolonged period in time
- Most miniturized packaging requires a dedicated design for temperature stabilization

Which requirement is most stringent generally depends on the application and exact composition of the components to be packaged but in many cases the costs and efforts associated with proper packaging are largely underestimated. In addition packaging is usually forgotten till the ASPIC has been made, with a non-optimal working device, or even impossible to package device as result.

Integrated photonic circuits generally need to be aligned with one or more optical fibres at micro meter precision, next to this it is common to have thermal stability requirements in the mili kelvin range to obtain the required wavelength stability of the optical circuits. As cleaning afterwards is seldom an option, due care shall be given to packaging and alignment issues well in advance of the actual packaging process to avoid contamination and misalignment issues.

For high frequency applications above 1 GHz the match between package (case, wire bonds, PCB boards,...) and ASPIC is of at most importance.

As customer acceptance is often associated with the pricing of the system and reliability issues are often related to financial risks it is important to work towards solutions which are both highly reliable and affordable. This can only be obtained if the reliability of the package and packaging methods used are taken into account from the early design stages.

It is for this reason that it can be expected that now real life applications of integrated photonic circuits are becoming more common, the importance of reliably and cost effective packaging will increase.

At this moment in time it has led to the start of Technobis ipps, a company which specialises on packaging of integrated photonic circuits.
Currently Available ASPIC Packaging Designs

Palawan Package
The Palawan package is specifically designed by Technobis tft-fos for the Ladybug ASPIC (see previous chapter). It includes a highly ruggedized and thermally stabilized casing and space for small dedicated, extremely low noise electronics for boosting the photodiode signals.

This package is designed for a single channel FBG interrogator ASPIC system and provides several analog photodiode outputs. Although this package is specifically designed for the Ladybug, its generic approach allows usage of other ASPICs.

Generic Package
As more ASPIC designs are developed and manufactured, each of them should have the ability to be packaged at least for assessment and evaluation purposes.

Since designing packages can be as an extensive effort as designing ASPIC themselves Technobis tft-fos has developed a Generic Package for the purpose of ASPIC integration assessment.

This package is designed to accommodate ASPICs different technologies (InP, TriPleXtm, SOI), various dimensions and single or multi-channel fiber channels. The centered placement of the ASPIC utilizes maximum access from three directions for interfacing. Typically two multi-pin connectors and one RF connection interfaces (for GHz speed sampling/modulation).

Over the coming year the features of the Generic Package will be made available in various steps. The design rules of the first set have been released and will be made available through the Phoenix design kit as well. Check the website or contact us for the latest design rules, trials and planning.

Custom Package
The Generic Test Package is intended for evaluation of the functionality and performance of new prototype based Application Specific Photonics Integrated Circuits (ASPICs) and can act as a starting point of the development of a dedicated and custom packaging including front-end electronics.
Timeline & Factsheet

**ASPIC activities**
Since 2008: Jeppix, Paradigm

**ASPIC design support**
Since 2009: Bright Photonics

Technobis ft-fos design since 2013

**First ASPIC**
September 2012

**First full wafer run for Technobis**
June 2014, HHI

**ASPIC test facilities**
Since 2013: Down-flow chamber

**ASPIC test facilities & new building Technobis**
Since 2014: two vibration isolated test chambers

**Multiple ASPIC platforms**
InP, SOI, TriPleX™

**Most foundries**
IME, CEA-LETI, SMART Photonics, HHI, Oclaro

**Packaging & Packaging Design**
Close cooperation with Tyndall
New Business Unit: Technobis ipps (2014)

**IP**
44 chips designs
3 patents pending by Technobis
6 patents pending with Customers