White paper v2.0

January, 2013

Miniaturize your optical system into a photonic integrated circuit

Learn how can you benefit from this technology

Summary

Photonic technologies use the light to enable multiple applications nowadays, from optical telecommunications to biomedical diagnostic devices or precise fibre sensors for all kinds of structures. Still, optical components tend to be bulky and expensive, and require precise stabilization and assembly, especially when interfacing with electronics. Embedding some photonic functionalities into an integrated optical chip can simplify a system and dramatically decrease its costs.

However, the cutting edge optical manufacturing technologies enabling such chip integration were traditionally affordable only by very few. Nowadays, generic photonic integration emerges as a new paradigm that provides cost-effective and high-performance miniaturization for a wide range of applications and markets.

In this white paper we highlight the advantages of using photonic integrated circuits, and we give a brief overview of the new generic and fabless manufacturing models and how you can benefit from them.

Fast

Read

Lane

"This white paper presents the benefits of merging several optical devices into a single chip, and the main manufacturing technologies and methods used for that"

Foreground

This paper is mainly addressed to:

- Technology Officers
- R&D Managers
- Product Development Engineers

What will you learn from this paper

You will be introduced to the concept of photonic integration, and understand how it can improve your optical systems through:

- size and weight reduction,
- improved stability and robustness,
- increased functionality and performance, and
- reduced assembly, packaging, test and operation costs.

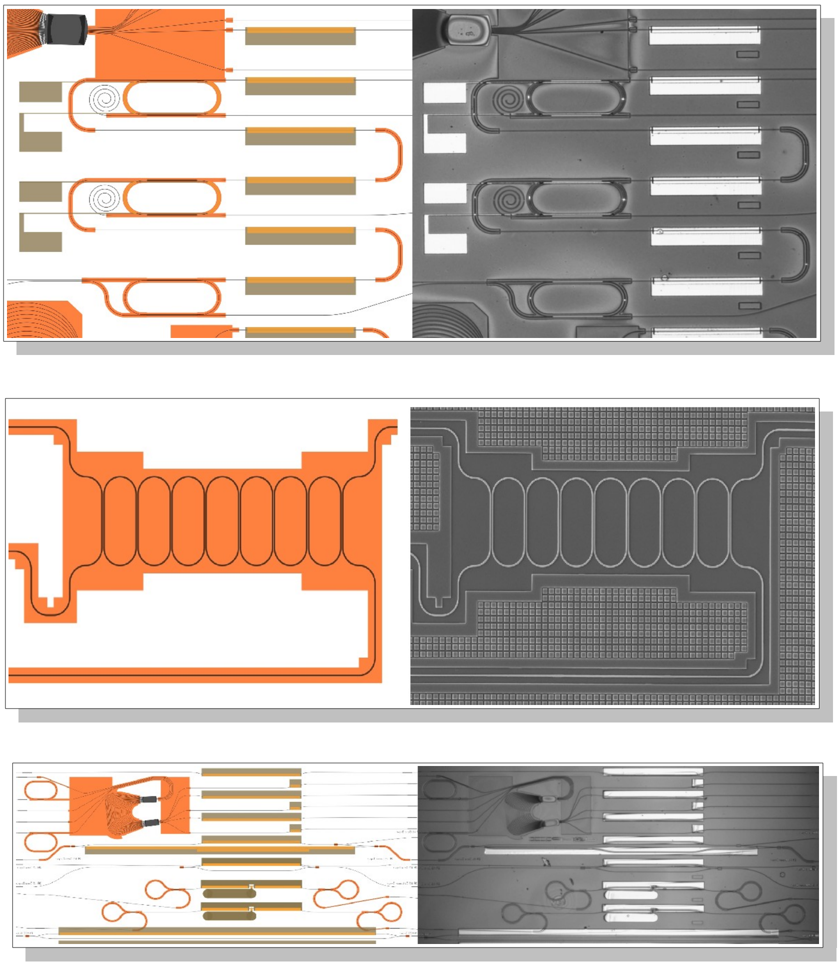


Fig. 1. Illustrative images of photonic design layouts (left) and the corresponding manufactured photonic integrated circuits (right).

Background

What is an ASPIC, and what are its advantages?

"An ASPIC is an application-specific chip that handles light signals, embedding multiple optical components that perform several functions"

An *Application Specific Photonic Integrated Circuit (ASPIC)* is an optical chip designed for a very particular purpose, that allows to generate, manipulate and detect light signals by means of other light and/or electronic signals.

An ASPIC may integrate several active optical devices, like lasers or photo-detectors, and passive structures like splitters, couplers, interferometers, filters, or polarization handling elements.

The unique ability to replace the traditional assembly of several discrete optical or micro-optical components by a single miniaturized chip, places ASPICs as the major driver for future optical systems and photonic enabled products[1-5]. Such integration brings the following benefits:

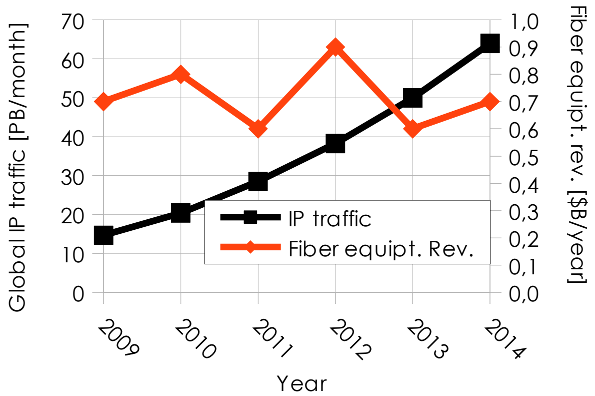
- cost reduction, especially for large volumes (thousands to millions), due to lower packaging and testing costs,
- aggregation of functionalities, lowering design complexity and increasing scalability and yield, and
- decrease in size, volume and weight, with higher robustness and simpler assemblies.

"Integrating the photonic functionalities of a system into an ASPIC reduces its cost, size/weight, and complexity, while improving stability and performance"

Where is photonic integration being applied?

The discipline dealing with the design and manufacturing of ASPICs is known as *Photonic Integration*, and it currently represents a global market with revenues of $75-150M in 2012 and forecasts of $220-900M for 2017 only for silicon photonics [6-7].

Most of the products incorporating an optical module or subassembly can benefit from merging some or most of its optical functionalities into a single ASPIC. This is enabling the aggressive price drop required in optical telecom to sustain IP traffic growth[8], or the commoditization of biophotonic and lab-on-a-chip applications for the medical and sensing markets[9-10], as can be extracted from Fig. 2.



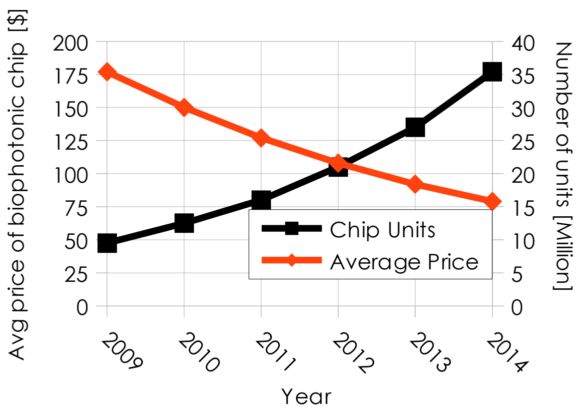


Fig. 2. Trends enabled by photonic integration: Global IP traffic growth requires a drop in optical telecom equipment costs to sustain revenue (left), and the fast decrease in the price of biophotonic chips allows their mass adoption for medical and biological sensing applications (right).

Main Integration Technologies

Overview

Different technologies can be chosen to design and manufacture ASPICs, depending on the suitability of the base material to the application at hand. The most relevant technologies are:

"Several materials can be used to manufacture photonic chips, each with its own features"

- Silicon photonics: Silicon on Insulator[11] (220 nm and 3 µm SOI), and Si based Silica on Silicon[12] (SiO_2, also known as PLC) and Silicon Nitride[13] (SiN and TriPleX)
- III-V photonics: Indium Phosphide[14] (InP), Gallium Arsenide (GaAs) and derivatives.
- Lithium Niobate[15] ($LiNbO_3$) and other more exotic materials.

Characteristics

"In general, Silicon allows for devices that are very compact and can incorporate some active functionalities, while PLC and SiN have the lowest losses and interface better with fibers"

Each of these materials has its own strengths and limitations, with their main properties highlighted in the following table:

	Thin SOI	Thick SOI	PLC/SiO_2	SiN/TripleX	InP/GaAs	$LiNbO_3$
Low propagation loss		✓	✓✓	✓✓		
Good coupling to fiber		✓	✓✓	✓		✓✓
Good electro-optic effect					✓	✓✓
Good thermo-optic effect	✓✓	✓	✓	✓	✓	
Good electro-absorption effect					✓	
Light generation/regeneration					✓✓	
Small footprint	✓✓	✓		✓	✓	

These features will determine which kind of optical components can be implemented in a practical way and deliver the best performance. The most common functional components available for each technology, along with their most appropriate material matches, are identified below:

"InP/GaAs are the only materials that allow to integrate complex active and passive optical devices with a small footprint"

"Lithium Niobate provides excellent modulation capabilities and good fiber coupling"

	Thin SOI	Thick SOI	PLC/SiO_2	SiN/TripleX	InP/GaAs
Shallow waveguide	✓✓	✓✓		✓	✓✓
Deeply etched waveguide	✓✓	✓✓	✓✓	✓✓	✓✓
Waveguide crossing	✓	✓			✓
Y-Branch splitter	✓		✓✓	✓	✓
Directional coupler	✓✓		✓	✓	
Multimode Interference coupler	✓✓	✓✓		✓	✓✓
Single polarization grating coupler	✓✓				
Polarization splitting grating coupler	✓				
Polarization rotator					✓
Spot-size converter			✓	✓	
Electro-optical modulator					✓
Thermo-optic modulator	✓✓	✓	✓	✓	✓
Carrier injection modulator	✓				✓
Evanescent coupling ring resonator	✓✓			✓	
Arrayed waveguide grating	✓	✓	✓✓		✓✓
Echelle gratings	✓	✓✓	✓✓		✓
Distributed Bragg reflector	✓				✓
Semiconductor optical amplifier					✓✓
Photodiode	✓				✓
Balanced photodiode					✓✓

How is integration being done?

Monolithic integration vs. Micro-optic assemblies

"Choosing the right technology will be the starting point for a successful integration project"

The technologies described before are used to fabricate complete optical devices using only a single material chip: this is known as *monolithic integration*. This goes one step further than the current assembly of micro-optical components in miniature photonic systems.

By integrating all devices into a single substrate, complex assembly, alignment and stabilization processes are avoided, and packaging and testing are greatly simplified. Moreover, it is the only way to scale system complexity when surpassing more than 20-30 optical components into a single package.

The election of the integration material will then determine the capabilities and design rules for the technology platform, making some of them more appropriate for certain applications than others. This is thus a critical step into the integration process and needs to be carefully evaluated[16-17].

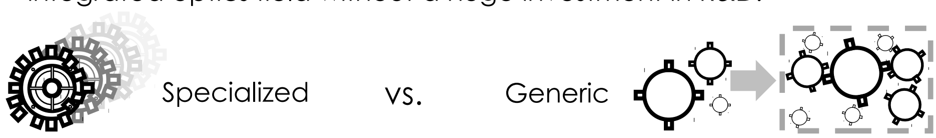
Specialized vs. Generic integration

ASPIC production has been implemented for years using a model known as *specialized integration*, which focuses on single devices rather than a complete optical system. This model is based on a prior identification of specific needs for a certain device and a massive market, like in the case of telecom lasers, photo-diodes or power splitters. To produce this very particular device, a manufacturing facility is set up and a fabrication process is tailored to its development, resulting thus in the best possible performance. This model is only profitable as long as large series of devices –typically hundreds of thousands– are successfully marketed, due to the huge investment required to deploy and operate such a specialized manufacturing process.

"With generic integration, the fabrication process is device-agnostic, providing a general set of building blocks that allows to design ASPICs for a broad range of applications"

On the other hand, *generic integration* focuses on applications rather than devices. Compared to a specialized manufacturing process developed only for a single device, a generic fabrication process makes use of multiple building blocks pre-developed for a generalized manufacturing process. The combination of these can result in several devices enabling very different solutions and markets. Under this model, the number of components to be manufactured does not necessarily need to be huge –starting from tens to hundreds of units – as the fabrication process and costs can be shared amongst many users. Additionally, if required, a generic fabrication process can also be scaled up to transfer production to larger volumes.

Therefore, the *generic integration* model allows a low investment access to custom ASPICs, and opens the door for exploring the integrated optics field without a huge investment in R&D.



What is the current state of the art for ASPICs?

"By making use of the Indium Phosphide and Silicon photonics technologies, most common optical components can already be integrated on a chip"

Similarly to what happened in the last 50 years in the microelectronics industry[18-19], generic integration in photonics is enabling a business model in which design houses without fabrication facilities (*fabless*) make use of generic manufacturing services provided by external foundries.

Currently, monolithic integration for SOI[20] and InP[21] relies on mature and well-established fabrication processes, rendering high yield manufacturing platforms for even the most demanding markets. They will thus be used as an example in the following sections.

What functionalities can be implemented?

An ever growing set of building blocks and predefined subsystems is available for the InP and SOI platforms, as can be seen below in Figure 3. These building blocks are either offered by the foundries through design kits, or developed by design houses under proprietary libraries, and they can be directly plugged into more complex chip designs.

In our website, multiple case studies are introduced in one-pagers as an example of successful applications of photonic integration to different optical systems.

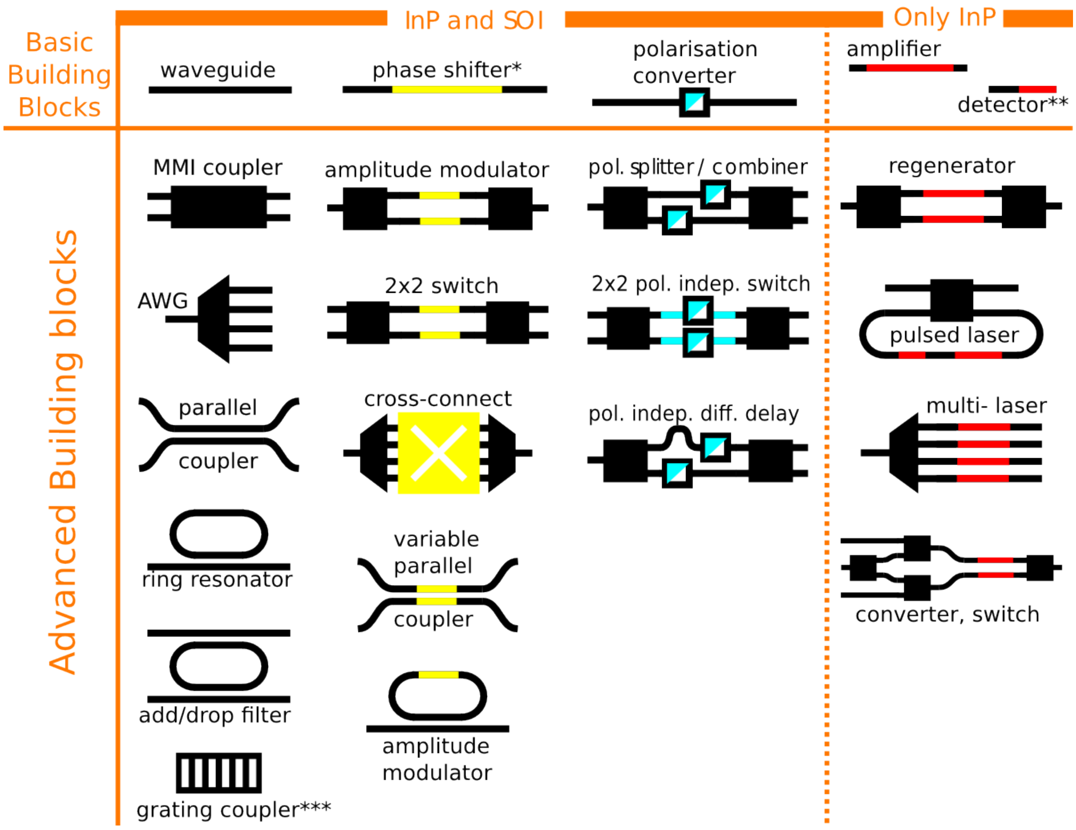


*Fig. 3. InP and SOI building blocks and example devices (adapted from Ref. 21). * Phase shifters in InP can use thermo-optic and electro-optic effects, while in SOI only thermo-optic. ** Detectors are also possible in SOI. *** Grating couplers can only be implemented in SOI.*

VLC Photonics' custom ASPICs

When assembling a product with some optical functionalities, the usual work flow involves different actors. Traditionally, as shown in Figure 6 (top), photonic components have been incorporated into assemblies by sub-system integrators, who serve demand from module or system providers at the request of the end users. Sub-system integrators are usually OEM manufacturers that make use of one or several specific photonic components from different manufacturers, and assemble them together into a single product.

"At VLC Photonics, we will help you in specifying the requirements to integrate your optical system, and turn it into a fully manufacturable chip layout"

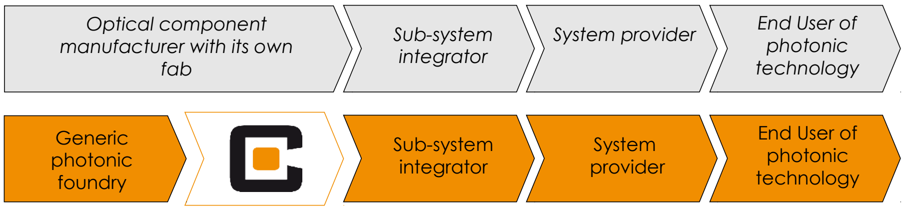


Fig. 6. Traditional photonic manufacturing food chain (top) and generic integration food chain (bottom), showing fabless design house operation.

At *VLC Photonics* we can develop custom ASPICs that adapt to your specific needs and requirements. Our solutions can span the whole integration process, from the initial system concept to chip design, prototyping and mass manufacturing, working also closely with foundries to assist them with their design kits, as shown in Fig. 7.

Our optical system and photonic design expertise is based on our +10 year long expertise on the field, being able to offer an optimal approach to any integration project and quickly react to your requests in no time. Our experience with all current photonic integration technologies and major foundries distinguish us from other design houses, who are usually focused on only a single material system or attached to a specific foundry. We thus are able to match the best technology and foundry with your target application, guaranteeing an optimal chip implementation (see Fig. 8).

"We outsource chip manufacture to industry-proven foundries, while characterization and testing remains in-house. This model allows us to guarantee the highest yield and to take on large series and small prototype runs alike"

We are also able to fully characterize and test any manufactured ASPIC at our facilities, through automated optical setups in clean vaults, ensuring that the delivered chips fully comply with your requirements, and that the foundry performed as specified.

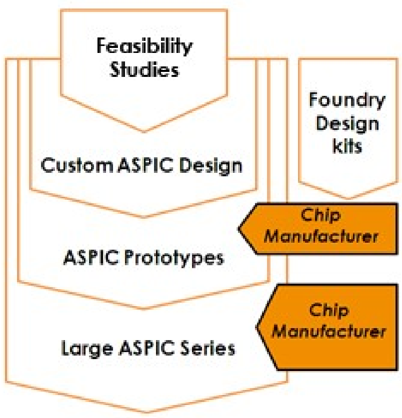


Fig. 7. VLC Photonics services and solutions, spanning the whole product development chain.

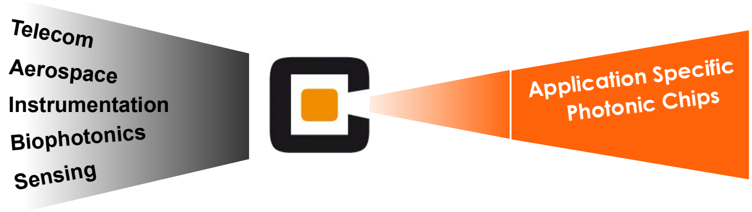


Fig. 8. The complete customer orientation of VLC Photonics *allows to serve different markets by developing a custom photonic solution optimized for each application.*

We are able to offer additional services too, like packaging or optoelectronic integration, through our extensive network of partners.

"No matter what your end market is, photonic integration can help in reducing costs and increasing functionality and performance"

Moreover, total confidentiality is always maintained with our customers, protecting all developments with non-disclosure agreements, and acting as a confidentiality firewall among customer and foundry if needed. Proper design protection is always in place, and any IP developed for our customers always remain their property.

Finally, we always work close to you at all stages to ensure that the outcome of any photonic integration project is exactly what you need and it is optimized for your end application.

Conclusions

Photonic integration can impact any optical system by reducing its complexity and cost, while providing superior and sometimes unique features and scalability.

"The technical know-how and design expertise on any technology will guarantee the best outcome for any photonic integration project. VCL Photonics can provide both, boosting your optical applications to new heights"

With several integration technologies are available in the market, it is critical to know which is the best material platform and foundry to manufacture a custom Application Specific Photonic Integrated Circuit (ASPIC), to optimally match the application at hand.

Photonic design houses can provide valuable insight on the most appropriate implementation and manufacturing of an integrated optical system, and greatly reduce the cost, time and risk for any integration project.

VLC Photonics wants to be your partner for all your optical integration needs, from initial R&D consulting to the later design, prototyping and product development. We put all our expertise and optical know-how at your disposal, to ensure an easy and successful outcome in any photonic integration project.

Contact

If you want to know more about photonic integration and how you can benefit from it, do not hesitate to contact us:

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✍ NOTES:

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