VLC PHOTONICS

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Improve your products with photonic integrated circuits

Learn how can you benefit from this technology

Summary

Photonic technologies are enabling multiple applications nowadays, from optical telecommunications to biophotonic devices or precise fibre sensors. Still, optical components tend to be bulky and expensive, and require complex stabilization and adjustments, especially when interfacing with electronics. Embedding some photonic functionalities into an integrated 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 large corporations. Nowadays, generic photonic integration emerges as a new paradigm that provides cost-effective and high-performance miniaturized optical systems for a wide range of applications and markets.

In this white paper we will highlight the advantages of using photonic integrated circuits, and we will give you a brief overview of the new integrated manufacturing models and how can you 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 reduction,
- improved stability,
- increased functionality, and
- reduced assembly, packaging, test and operation costs.

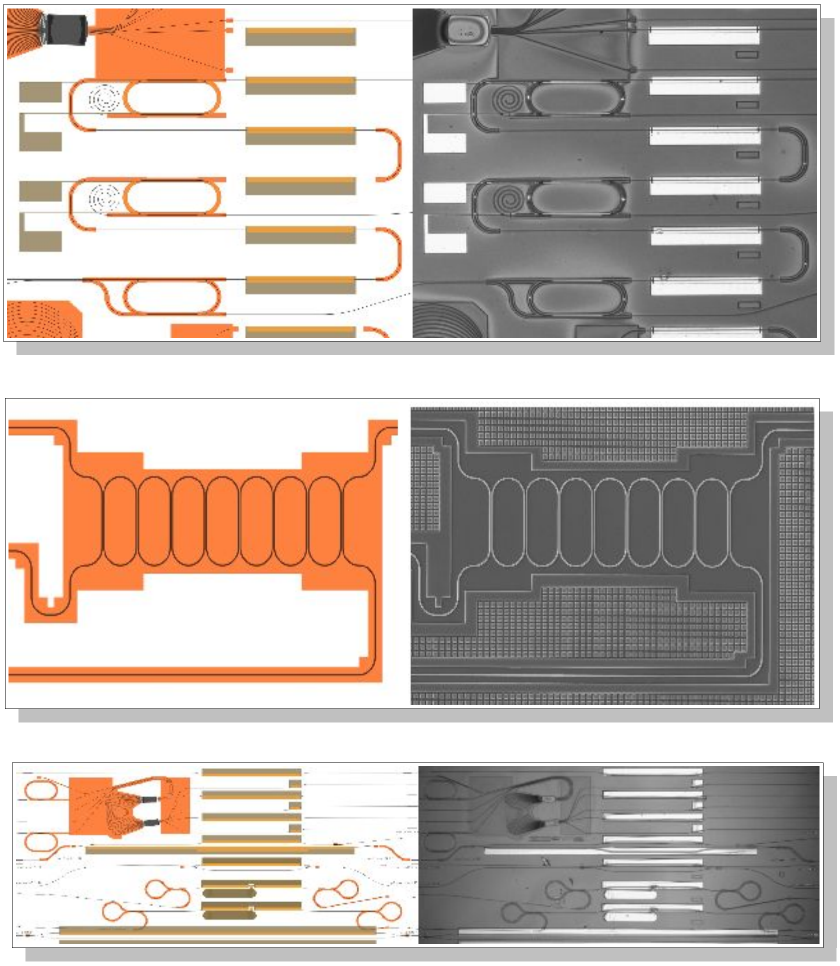


Fig. 1. Illustrative images of photonic design layouts (left) and the corresponding manufactured photonic integrated circuits (right).

Background

What is an ASPIC, and how can it be of any help?

"An ASPIC is an application-oriented chip that integrates various optical components, handling light signals and performing 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 devices, like lasers or photodetectors, 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, due to lower assembly and testing costs,
- aggregation of functionalities, lowering design complexity and increasing scalability, and
- standardization of specifications and processes, resulting in higher product yield and robustness.

"Integrating the photonic functionalities of any product 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 a revenue forecast of $900B for 2012, and with a sustained revenue growth since 2005 of $100B per year[4,5].

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[6], or the commoditization of biophotonic and lab-on-a-chip applications for the medical and sensing markets[5], as can be extracted from Fig. 2.

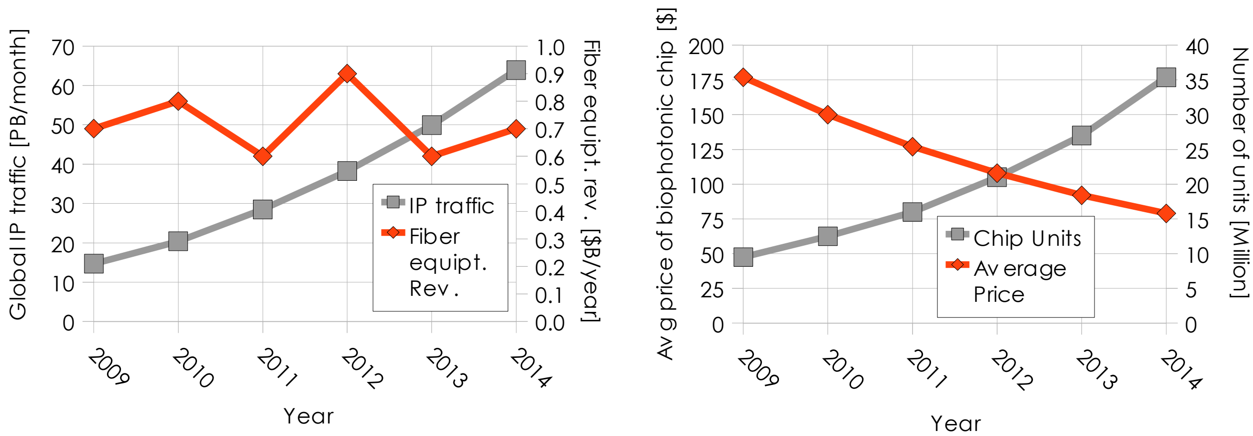


Fig. 2. Trends enabled by photonic integration: Global IP traffic growth requires a drop in optical telecom equipment costs to sustain revenue (left), and the fast decrease in the price of biophotonic chips allows their mass adoption for medical and biological sensing applications (right).

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

Main Integration Technologies

Overview

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

- Silicon photonics: Silicon on Insulator[7] (SOI), Silica on Silicon[8] (SiO_2/Si) and Silicon Nitride[9] (Si_3N_4/SiO_2)
- III-V photonics[10]: Indium Phosphide (InP) and Gallium Arsenide (GaAs)
- Lithium Niobate[11] ($LiNbO_3$)

Characteristics

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

Best Technology Features	SOI	SiO_2/Si	Si_3N_4/SiO_2	InP/GaAs	$LiNbO_3$
Low propagation loss		■	■		
Good coupling to fibers		■	■		■
Good electro-optic effect				■	■
Good thermo-optic effect	■	■	■	■	
Good electro-absorption effect				■	
Light generation / regeneration				■	
Small footprint	■		■	■	
Compatibility with electronics	■				

"In general, Silicon based materials allow for passive devices that are more compatible towards electronic and silica fiber applications"

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"

Component	SOI	SiO_2/Si	Si_3N_4/SiO_2	InP/GaAs	$LiNbO_3$
Waveguide	■	■ ✓	■ ✓	■	■
Y branch coupler	■	■ ✓	■	■	■ ✓
Parallel waveguide coupler	■ ✓	■	■	■	■
MMI coupler	■		■ ✓	■ ✓	
Grating coupler	■ ✓				
Switch		■	■ ✓	■	
Modulator				■	■ ✓
Ring resonator	■ ✓		■ ✓	■	
Arrayed Waveguide Grating	■	■ ✓		■	
Semiconductor Optical Amplifier				■ ✓	
Distributted Bragg Reflector	■			■ ✓	
Laser				■ ✓	
LED				■ ✓	
Photo-detector	■ ✓			■ ✓	

✓ Best match

"Lithium Niobate provides excellent optical coupling and modulation capabilities"

How are these technologies being used?

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: this is known as *monolithic integration*. This goes one step further than the current assembly of micro-optical components in miniaturized photonic systems. By integrating all devices into a single chip, 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[12-14].

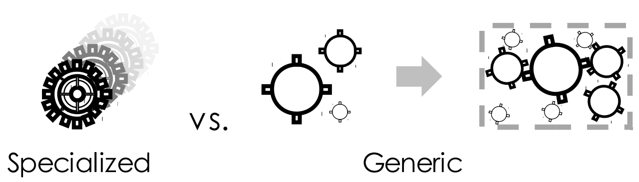
Specialized vs. Generic integration

"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"

ASPIC production has been performed for years using a model known as *specialized integration*, which focuses on the devices rather than the overall 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, photodiodes or power splitters. Then, to produce this very particular device, manufacturing equipment is acquired and a fabrication process is tailored to its development, resulting in optimal 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 manufacturing process.

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 certain manufacturing process. The combination of these can result in several end devices enabling very different solutions. Under this model, the number of components to be manufactured does not necessarily need to be huge –typically less than a few hundred– 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 large 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.



"By making use of the Indium Phosphide and Silicon-on-Insulator technologies, most common optical systems can already be integrated"

What is the state of the art for ASPICs?

Similarly to what happened in the last 50 years in the microelectronics industry[15-16], 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[17].

Currently, monolithic integration for SOI[18] and InP[19] relies on mature and well-established fabrication processes, rendering high yield manufacturing platforms for even the most demanding solutions. They will thus be used as an example in the following sections.

What functionalities can be implemented?

An ever growing set of building blocks is available for the InP and SOI platforms, as can be seen below in Figure 3. The use of these blocks allows for the fabrication of multiple devices, granting large freedom to the optical designer for architecting almost any optical system.

In the following pages, two case studies are introduced as an example of successful applications of photonic integration to different optical systems.

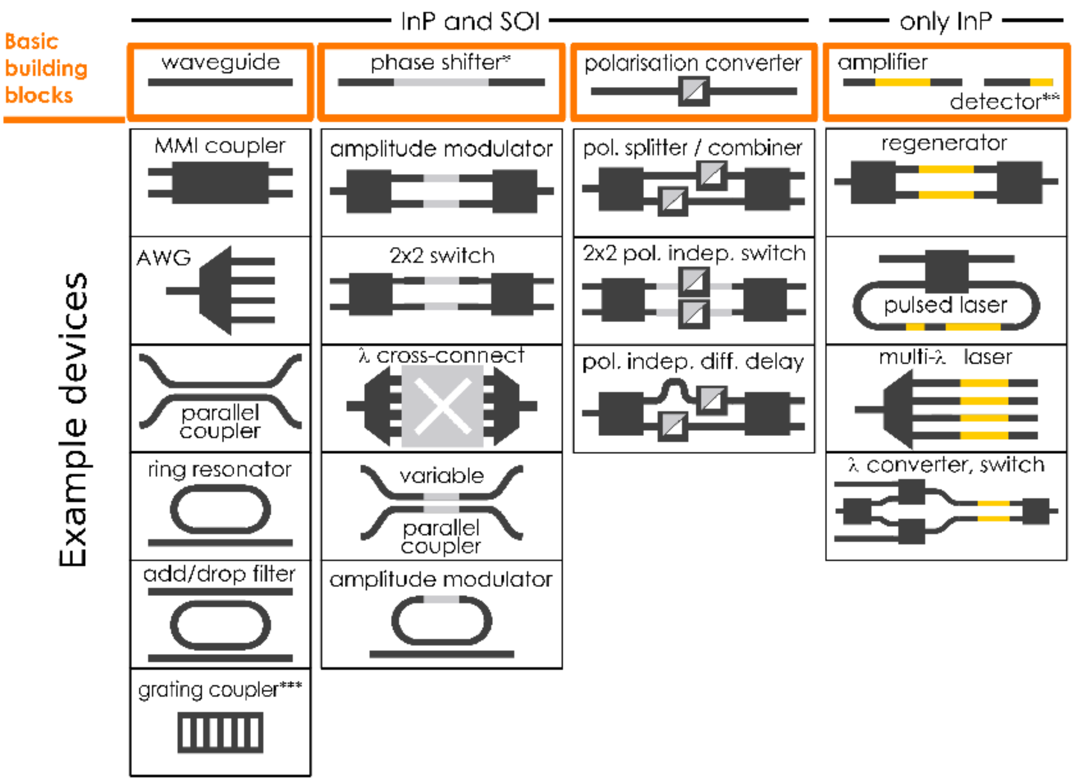


*Fig. 3. InP and SOI building blocks and example devices (adapted from Reference 19). * Phase shifters in InP can use the thermo-optic and electro-optic effects, while in SOI only the thermo-optic. ** Detectors are also possible with SOI. *** Grating coupler can only be implemented in SOI.*

Case Study #1: Stable and compact photonic filtering with ASPICs

Optical filters are used in multiple scenarios, from signal processing to telecom packet processing or biochemical sensing. An integrated optical filter must fulfill the following requirements:

"Custom photonic filtering solutions can be easily designed and prototyped on demand, and for all kinds of applications"

- compactness
- high wavelength accuracy and stability
- very precise reproducibility

The integrated solution:

Depending on the customer's needs, a wide range of filtering solutions can be integrated into an ASPIC (including eventually other additional functionalities). Filters can be designed with custom band pass/rejection responses, tunability ranges and band group delays[20]. For example:

- Integration technology: Silicon-On-Insulator (SOI)
- Size, on chip area: 1x0,05 mm^2 (Real size: -)
- Bandwidth range: from hundreds of MHz to tens of THz
- Bandpass rejection: up to 50 dB
- Group delays: from picoseconds to nanoseconds scale
- No need for hermetic packaging to avoid particle contamination, as opposed to thin-film filters

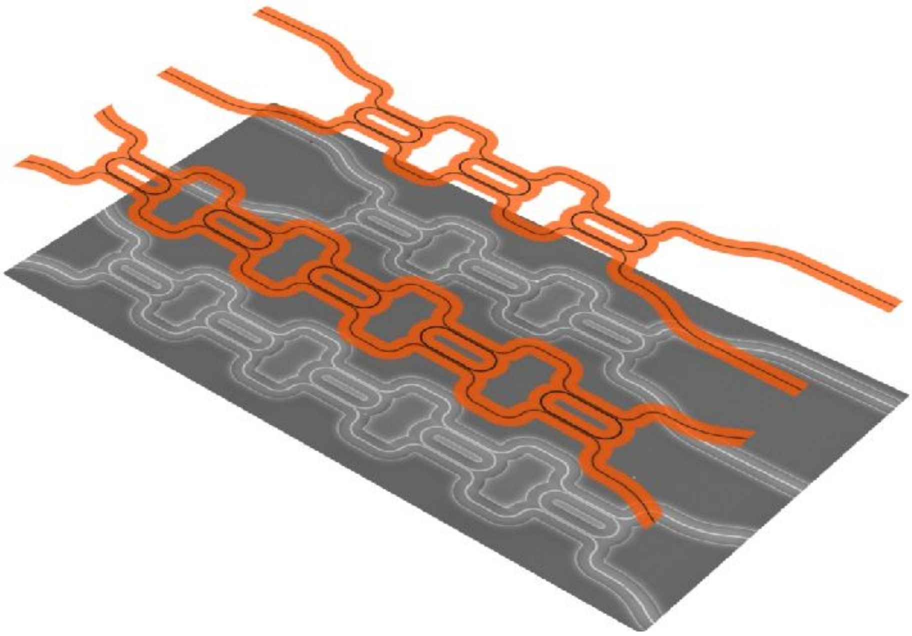


Fig. 4. Design layout (above) and photonic chip (below) of an optical filtering system.

Case Study #2: A single ASPIC replacing a tabletop device

"A bulky laser module composed of 10 discrete optical components could be replaced by a single ASPIC with additional functionality, higher stability and better performance"

A tabletop device made use of a laser system with the following requirements:

- multiple lasing wavelengths
- switchable by external optical signals

The limiting features of such optical module were:

- Size: tabletop of 2 x 1 m^2
- Switching speed: limited to 80 kHz
- Number of simultaneously lasing wavelengths: only 2
- Built with 10 discrete fiber optic components, requiring precise alignment and mechanical stabilization

The integrated solution:

An InP ASPIC was developed[21] to substitute the lasing module in this application, providing the same functionalities and with the following improvements:

- Size: chip with area of 4.5 x 2 mm^2 (Real size: ) (factor $\downarrow 10^5$)
- Switching speed: up to 600 MHz (factor $\uparrow 10^3$)
- Number of simultaneously lasing wavelengths: 4 (factor $\uparrow 2$)
- No alignment or mechanical stabilization required

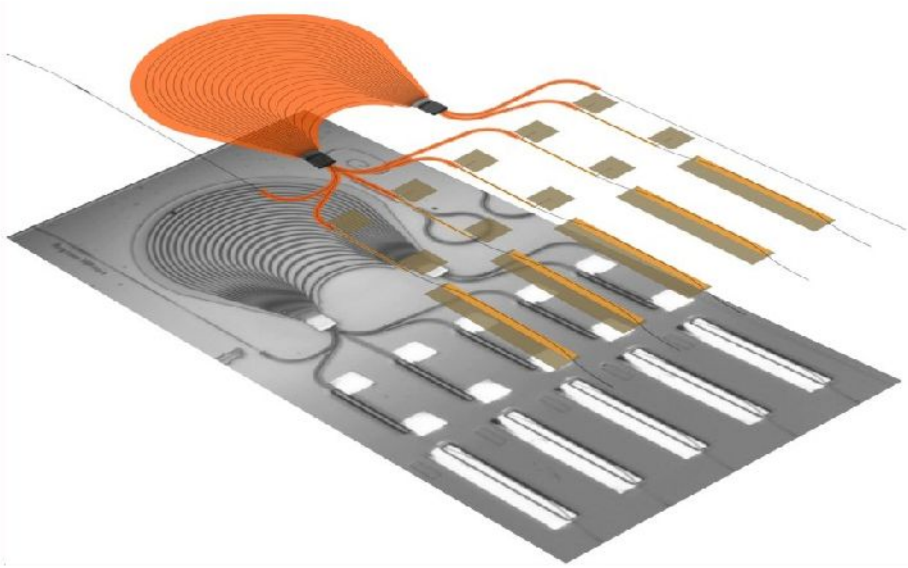


Fig. 5. Design layout (above) and photonic chip (below) of an optically switchable multi-wavelength laser ASPIC[21].

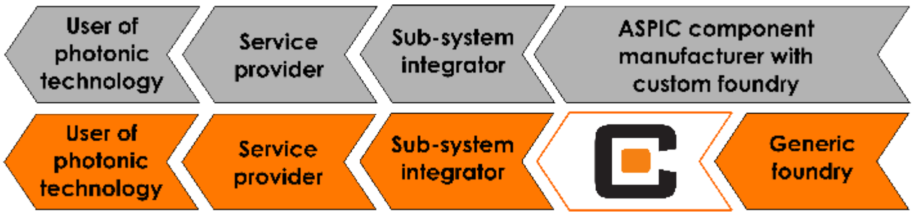


Fig. 6. Traditional ASPIC manufacturer food chain (top) and VLC Photonics food chain (bottom), with fabless operation through generic foundry services.

"At VLC Photonics, we will help you in specifying the system requirements for an integrated optical system, and turn it into a fully manufacturable chip lay out"

VLC Photonics' custom ASPICs

When assembling a product with some optical functionalities, the usual workflow involves different actors. Traditionally, as shown in Figure 6 (top), photonic components have been incorporated into products by sub-system integrators, who serve demand from service 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 boxed product.

At *VLC Photonics* we offer customized ASPICs according to your specifications and needs, by making use of generic integration technologies that enable multiple optical applications and markets. Our ASPIC solutions span the whole integration chain, from initial concept level to mass manufacturing, and even foundry assistance, as shown in Fig. 7.

We provide top-level system design services based on our 10-year long expertise on the field, addressing the requirements and limitations of any optical application to propose a feasible integration solution. Our skills on all current photonic integration technologies distinguish us from other design houses, who are usually focused on only a single material system: this means we are always able to match the optimal technology with the target application (see Fig. 8).

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

We can then perform full ASPIC designs according to the given requirements, supplying the chip lay outs and all the related intellectual property to our customers. Our partnerships with selected foundries allow us to design our ASPICs for manufacturability, assuring higher yields and lowering future development costs.

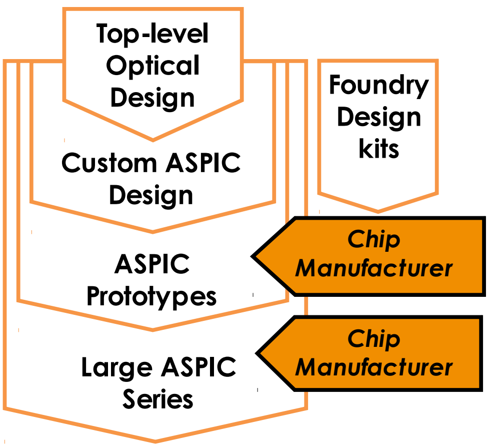


Fig. 7. VLC Photonics services and solutions, spanning the whole product development chain.

Fig. 8. The complete customer orientation of VLC Photonics *allows to optimally serve different markets by selecting the best suited photonic integration solution for each application.*

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

In a next step, we independently coordinate the ASPIC manufacturing process with a selected foundry and, after every successful prototype fabrication, we fully characterize and test the photonic chip before delivery. Additionally, any required certification can be provided through external partners.

Finally, we thoroughly assist you to incorporate the ASPIC into the end product, and work close to you at all stages to ensure the integrated outcome is optimized for your application.

Conclusions

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

With several integration technologies available already in the market, it is critical to know which is the best solution and platform to implement and manufacture a custom Application Specific Photonic Integrated Circuit (ASPIC).

"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"

Moreover, skilled photonic circuit designers can envision smart combinations of the available building blocks and processes to implement novel or challenging optical systems on chip for multiple applications and markets.

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

Contact

In case you are interested to know more about photonic integration and how you can benefit from it, do not hesitate to contact us:

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References

1. S. Perrin (Heavy Reading), "Photonic Integration: Redefining Optical Cost, Scale & Performance," in Proc. of Optical Expo, Dallas (USA), October, 2008.

2. J.D. Montgomery (ElectroniCast), "Evolutionary path to monolithic transceivers," in Lightwave, pp. 33-36, October, 2005.

3. A. Welrich, "PIC-based transceivers enable cost-effective 1G to 10G PON migration," in Lightwave Online, March, 2010.

4. M. Lebby, "Photonic Integration: What is the Holy Grail?," in Compound Semiconductor, pp. 25-32, October, 2009.

5. Optoelectronics Industry Development Association (OIDA), "Global Optoelectronics Industry Market Report and Forecast", USA, October, 2007.

6. Cisco Systems, "Cisco Visual Networking Index: Forecast and Methodology, 2009-2014," June, 2010.

7. W. Bogaerts et Al., "Nanophotonic waveguides in silicon-on-insulator fabricated with CMOS technology," in Journal of Lightwave Technology, Vol. 23(1), pp. 401-412, January, 2005.

8. C.R. Doerr and K. Okamoto, "Advances in Silica Planar Lightwave Circuits," in Journal of Lightwave Technology, Vol. 24(12), pp. 4763-4789, December, 2006.

9. F. Morichetti et Al., "Box-Shaped Dielectric Waveguides: A New Concept in Integrated Optics?," in Journal of Lightwave Technology, Vol. 25(9), pp. 2579-2589, September, 2007.

10. E. Bente and M. Smit, "Ultrafast InP optical integrated circuits," in Proc. Of the SPIE, Vol. 6124, 612419, 2006.

11. W. Sohler et Al., "Integrated Optical Devices in Lithium Niobate," in Optics & Photonics News, Vol. 19(1), pp. 24-31, 2008.

12. D. Liang and J.E. Bowers, "Photonic integration: Si or InP substrates?," in Electronics Letters, Vol. 45(12), pp. 578-581, June, 2009.

13. D. Liang, G. Roelkens, R. Baets and J.E. Bowers, "Hybrid Integrated Platforms for Silicon Photonics," in Materials, Vol. 3(3), pp. 1782-1802, 2010.

14. R. Soref, "Toward silicon-based longwave integrated optoelectronics (LIO)," in Proc. of the SPIE, Vol. 6898, pp. 689809, 2008.

15. J.T. Macher and D.C. Mowery, "Vertical specialization and industry structure in high technology industries," in Advances in Strategic Management, Vol. 21, pp. 317-356, 2004.

16. C. Brown and G. Linden, "Offshoring in the Semiconductor Industry: A Historical Perspective," in Brookings Trade Forum on Offshoring of White-Collar Work, 2005.

17. European Network of Excellence on Photonic Integrated Circuits and Components (ePIXnet), "Towards a foundry model in micro- and nanophotonics A vision for Europe," 2007.

18. P. Dumon, W. Bogaerts, R. Baets, J.-M. Fedeli and L. Fulbert, "Towards foundry approach for silicon photonics: silicon photonics platform ePIXfab," in Electronics Letters, Vol. 45(12), pp. 581-582, 2009.

19. X.J.M. Leijtens, "JePPIX: the platform for InP-based photonics," in Proc. of the 15th European Conference in Integrated Optics (ECIO), pp. ThG3-1/2, Cambridge, United Kingdom, April 2010.

20. J.D. Domenech, M. Muñoz, J. Capmany, "Experimental demonstration of the longitudinal offset technique for the apodization of coupled resonator optical waveguide devices," in Proc. of the Lasers and Electro-Optics (CLEO) Conference, San Jose, CA, USA, May 2010.

21. P. Muñoz et Al, "Multi-wavelength laser based on an arrayed waveguide grating and Sagnac loop reflectors monolithically integrated on InP," in Proc. of the 15th European Conference in Integrated Optics (ECIO), pp. WeF2, Cambridge, UK, 2010.

✍ NOTES:

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