Silicon Photonics 2014

The buzz time is over. Now, market drivers & technological developments are both converging to ensure a bright future to Si photonics.
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• **Claire TROADEC, Market & Technology Analyst**
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Companies listed in this report

3S Photonics, Acacia, ADVA, Aifotec, Alcatel Lucent, Altera, Altera, Altis Semiconductor, Amazon, Amicra, Amkor, AML, ams technologies, ASE, Aurrion, Avago Technologies, Bandwidth10, Besi, BinOptics, Cadence, Calient, Caliopa, CEA Leti, Chiral Photonics, Cisco, Cogo, ColorChip, CompassEOS, Corning, CoreOptics, Cray, CyOptics, DAS Photonics, Dell, ebay, EFFECT Photonics, Enablence, ePIXfab, EuroPIC, EVGroup, Facebook, FCI, Ficontec, Finetech, Fraunhofer HHI, Freescale Semiconductor, Fujitsu, Ghent University, IHP Microelectronics, Fujitsu, Georgia Tech, Genalyte, GlobalFoundries, Google, Helios, HP Labs, Huawei, IBM, III-V labs, IME (A*STAR), IMEC, Infinera, Intel, IPKISS, IPT, IQE, JePPIX, Kaim, KAIST, Kotura, Lightwire, LioniX, Luceda, Luxtera, Mellanox, MergeOptics, Micron, Mindspeed, MIT, Mitsubishi Heavy Industries, Molex, Mühlbauer, nanosystec, NeoPhotonics, Newport, NTT, Nvidia, Oclaro, OneChip Photonics, OpSIS, Optocap, Oracle, Palomar, Panasonic, PECST, Phoenix, Photoline Technologies, Ranovus, Rice University, Rockley Photonics, Samtec, Sandia National Labs, Seagate, SEH, Semprius, SET, Sharp, Simgui, Skorpios Technologies, STMicroelectronics, SUN Microsystems, SUSS MicroTec, Synos, TE Connectivity, TEL, Teraxion, Toray, TSMC, Tyndall University, u2t Photonics, UC Berkeley, University of Colorado at Boulder, UCSB, University of Minnesota, University of Southampton, University of Stanford, USConec, VLC Photonics, Wentworth Laboratories, Xilinx, XiO Photonics, Xyratex, Zarlink … and many more.
Why this report?

• Big data is getting bigger by the second. Transporting this level of data around with existing technologies will reach its limit in power consumption, density, weight. Photon will replace electrons and Si photonics will be the platform in the mid term to solve this transition…

• Silicon photonics is an exciting field mixing optics, CMOS, MEMS and 3D stacking technologies. All these technologies converge in Si photonics.

• Across the world, large R&D acquisitions & large R&D programs are being performed, creating IP position for the current players

• Although Silicon photonics is creating a lot of buzz, the market is still modest with estimated sales below $50M today with very few companies actually shipping products to the open market.

• But it is big promises, especially in data centers & HPC that are the big markets that will dwarf all other silicon photonics applications in the near future.

• In order to give clues to this technology and applications, Yole Développement releases this second edition of its 2012 “Silicon Photonics Market & Technologies 2011-2017” report.
Key features of the report

• **Key features:**
  – Description of applications with focus on Data Centers & HPCs.
  – Description of Silicon Photonics building blocks with challenges.
  – Focus on packaging / assembly challenges.
  – Supply chain description for major players.
  – Molex / Luxtera AOC reverse costing analysis.
  – Financial analysis.

• **Integrated photonics:**
  – Integrated photonics regroups three main technologies:
    • Silicon Photonics : focus of this report
    • InP Photonics : not covered in this report but Si Photonics uses InP lasers
    • Dielectric waveguides (Silicon nitrate, Si₃N₄) : not covered in this report but dielectric waveguides have currently larger applications in telecom (splitters, array waveguides) and are gaining more and more attention in biomedical. The wavelengths that can be used are visible & near IR (850nm) and the fabrication tolerance are higher.

➔ In our report, we mostly focus on Silicon Photonics.
What is new compared to 2012 release

• Updated silicon photonics industrial status & supply chain.

• Updated forecast up to 2024.

• Silicon photonics players’ supply chain description.

• Packaging & assembly challenges.

• Real products case study (reverse engineering & reverse costing).
Rationales for Si photonics

- Silicon photonics involves the use of silicon semiconductors as the medium for optical signals, allowing much faster digital signaling than is currently possible with traditional electron-based semiconductor devices.

- Si photonics offers the advantages of a silicon technology: low cost, higher integration, more functionalities embedded, higher interconnect density. It gives 3 main advantages:
  - **Low power consumption** – in particularly compared to copper-based solutions which is expensive with high electrical consumption.
  - **Reliability** – important for data centres where rack servers life time is 2 years and often replaced.
  - Last but not least, it is **Si technology**, with benefits of functions integration, low manufacturing cost and high density.

- **Back in 2006, VOA have been the first Si photonics products on the market**
  - Today still few Si photonics products are on the market: VOA, AOC and Transceivers from Luxtera, Kotura/Mellanox, Cisco/Lightwire.

- **Over the near term, Si photonics chips will be deployed in high-speed signal transmission systems, which far exceed the capabilities of copper cabling: Data Centers and High Performance Computing (HPC).**
  - As Si photonics evolves and chips become more sophisticated, we expect to see the technology used more in processing tasks such as interconnecting multiple cores within processor chips to boost access to shared cache and busses.
Photonics, semiconductors, MEMS, advanced packaging … all converging to Si photonics!

- Silicon photonics involves the use of silicon semiconductors as the medium for optical signals, allowing much faster digital signaling than it is currently possible with traditional electron-based semiconductor devices.

- It is a disruptive technology to achieve a new breed of monolithic opto-electronic devices in a potential low cost Si process.
  - The ultimate vision is to deliver optical connectivity everywhere, from the network level … to chip-to-chip.

- It is a mix of several technical blocks (optical but also IC for processing, MEMS for packaging…) and involves several core components:
  - First, a **laser** is at the heart of any optical device. Current lasers use indium phosphide to produce coherent infrared laser light.
  - Photons must then be **modulated** to break the light into optical pulses.
  - Optical **waveguides** and other interconnections are necessary to move pulses from one place to another.
  - **Multiplexers** / **Demultiplexers** are used to separate and combine different wavelengths
  - Finally **detectors** convert optical signal into electric signal
Si Photonics
Potential advantages & challenges

**Low Power Consumption**
- Still high for high perf modules (target is fJ/b)
- Impact on reliability

**Silicon technology**
- But no complete integration (laser)
- Packaging issues

**Reliability**
- Telecom standard
- Operation speed vs. InP
- Polarization dependency

- Low environmental footprint
- Low operating costs
- Reduced heat dissipation

- Low manufacturing cost
- Higher density of interconnects
- Higher optical functions integration

- Low error rate
- Spectral efficiency

© 2014
Si photonic products

- First Si photonic products were introduced on the market by Kotura in 2006
- Many more should soon follow!

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Si Photonics Breaking News Overview

More and more announcements

Q4: Integration of photodetector and modulator side-by-side with 90nm CMOS technology

Q4: Faster μ-scale SLM on SOI demonstrated

Q4: Optomechanics switch for all-optical switching

Q4: Wafer scale method to integrate III-V devices with other substrates

Q3: Si Ph on 300mm wafers

03: Kotura partnership with Mindspeed and BinOptics for 100G optical engine

03: ePIXFab launch

03: c-Band tunable Ph laser demonstration

02: plat4M EU project

01: Si Ph with 2.5D interposer

01: Intel to partner with Facebook and Open Compute project to develop Si/Ph connectivity for disaggregated server technology

06: CMOS silicon-photonics transceiver 5 Gbit/s chip-to-chip

06: Acquisition of IPTronics by Mellanox

05: MOSIS teams up with ePIXfab

04: New start-ups

04: 100G CLR4 Alliance

04: official OPSIS closure

03: Multi source agreement

03: IQE & UCSB Team-up

03: IQE & UCSB Team-up

02: $10M of University of Southampton to fund new project

01: PSM4 MSA Group creation to support 100G-400G SMF in Datacenters

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Today, end-users are driving the R&D for optical data centers.
Silicon photonics devices market will grow from less than US$25M in 2013 to more than US$700M in 2024 with a 38% CAGR.

- Emerging optical data centers from big Internet companies (Google, Facebook …) will be triggering the market grow in 2018 (see following slides).
# CHIPS

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Acacia (US)</td>
<td>Advanced modulation technology with high speed optics and electronics. Target telecom applications at 100Gb/s.</td>
</tr>
<tr>
<td>Aurrion (US)</td>
<td>Has developed a process to make multiple lasers on a wafer. Target 400Gb/s.</td>
</tr>
<tr>
<td>Avago (US)</td>
<td>Move in Si photonics through the acquisition of CyOptics for 40/100 Gb/s telecom and datacom technology.</td>
</tr>
<tr>
<td>BinOptics (US)</td>
<td>InP-based microphotronics technology for laser sources.</td>
</tr>
<tr>
<td>ColorChip (US)</td>
<td>40G and 100Gb high speed transceivers and passive devices based on ion-exchange glass technology.</td>
</tr>
<tr>
<td>Ranovus (CAN)</td>
<td>Innovative Quantum Dot Multi-Wavelength Laser technology for potential low-cost optical transceivers for data center applications.</td>
</tr>
<tr>
<td>Skorpios (US)</td>
<td>Focus on integrated optical devices based on CMOS. Has demonstrated CMOS tunable laser for data center and coherent long haul systems for 100Gb/s+.</td>
</tr>
<tr>
<td>Teraxion (CAN)</td>
<td>Long haul, metro coherent receiver using Si photonic. 3x smaller compared to competition.</td>
</tr>
</tbody>
</table>

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# DESIGN

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luceda Photonics (Be)</td>
<td>Design solutions for Si photonics.</td>
</tr>
<tr>
<td>IPtronics (Mellanox, US)</td>
<td>Modulator driver design</td>
</tr>
</tbody>
</table>
Examples of Supply Chain (extract)

IBM Supply Chain

Intel Supply Chain

KOTURA Supply Chain

LUXTERA Supply Chain

ORACLE Supply Chain

etc …
Molex AOC cost analysis Process flow

Process flow (bonding 1/2)

- Laser assembly
- Wire bonding
- Adhesive deposition
- Optical elements report
- Indium preform report

Physical analysis

Connector / QSFP+

Silicon photonic die:
- Passives: CMOS Die
- Optical fibers
- Waveguide: SMF
- Electrical connections
- Laser: Glued onto the substrate

Fiber coupling

MEMS laser source module:
- Laser: silicon waveguide, gold waveguide
- Electrical connections: wire bonding to the AOC
- Metallization: metal solder
- Preform: gold on chip
- Laser diode: ball jointed, parallel orientation

Sealing

The lid is sealed by KOH. The angle of 54.7 degrees is typical of the anisotropic etching of silicon.

The lid and the MEMS are sealed by a gold solder. A seed layer in Ti is deposited.

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~US$1B transaction value in Si photonics!

Can you stay Zen?

2013 Si Photonics Transactions ~US$1B

2013 Si Photonics revenues < US$30M

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Yole activities in MEMS

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(1) Our Terms and Conditions of Sale are available at www.yole.fr/Terms_and_Conditions_of_Sale.aspx
The present document is valid 24 months after its publishing date: June 23rd, 2014

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<td>30056</td>
</tr>
<tr>
<td>BIC or SWIFT code:</td>
<td>CCFRFRPP</td>
</tr>
<tr>
<td>Account n°:</td>
<td>0170 200 1565 87</td>
</tr>
<tr>
<td>Account holder:</td>
<td>Yole Développement</td>
</tr>
<tr>
<td>Address:</td>
<td>Lyon - France</td>
</tr>
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9. **GOVERNING LAW AND JURISDICTION**

9.1. Any dispute arising out of or linked to these Terms and Conditions shall be settled by the French Commercial Courts of Lyon, which shall have exclusive jurisdiction upon such issues.

9.2. French law shall govern the relation between the Buyer and the Seller, in accordance with these Terms and Conditions.