GLOSSARY AND DEFINITIONS

- AOC: Active Optical Cable
- APD: Avalanche Photo Diode
- ASP: Average Selling Price
- COBO: Consortium for On-Board Optics
- DC: Data Center
- DML: Directly Modulated Laser
- EEL: Edge-Emitting Laser
- EIC: Electrical IC
- EML: Electro-absorption Modulator Laser
- CAGR: Compound Annual Growth Rate
- HPC: High-Performance Computer
- IC: Integrated Circuit
- InP: Indium Phosphide
- IP: Intellectual Property
- LiDAR: Light Detection And Ranging
- MEMS: Micro Electro Mechanical Systems
- MOS: Metal Oxide Semiconductor
- MSA: Multi Suppliers Agreement
- OEO: Optical Electrical Optical
- OIC: Optical IC
- OXC: Optical Cross-Connect
- PIC: Photonic Integrated Circuit
- ROSA: Receiver Optical Sub-Assembly
- SEL: Surface-Emitting Laser
- SiN: Silicon Nitride
- SiPh: Silicon Photonics
- SOI: Silicon-on-Insulator
- TIA: Transimpedance Amplifier
- TOSA: Transmitter Optical Sub-Assembly
- VC: Venture Capital
- VCSEL: Vertical Cavity Surface-Emitting Lasers
- VOA: Variable Optical Attenuator
- WBG: Wide Band Gap
**GLOSSARY AND DEFINITIONS**

Dedicated to optical communication

<table>
<thead>
<tr>
<th>Fiber</th>
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<tbody>
<tr>
<td>MMF</td>
<td>Multi Mode Fiber</td>
</tr>
<tr>
<td>PSM</td>
<td>Parallel Single Mode</td>
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<tr>
<td>SMF</td>
<td>Single Mode Fiber</td>
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<thead>
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<tbody>
<tr>
<td>NRZ</td>
<td>Non-Return to Zero</td>
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<tr>
<td>PAM</td>
<td>Pulse Amplitude Modulation</td>
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<tr>
<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
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<td>CFP</td>
<td>C Form-Factor Pluggable</td>
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<tr>
<td>QSFP</td>
<td>Quad Small Form-factor Pluggable</td>
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<tr>
<td>SFP</td>
<td>Small Form-Factor Pluggable</td>
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<tr>
<td>CWDM</td>
<td>Coarse Wavelength Division Multiplexing</td>
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<tr>
<td>DWDM</td>
<td>Dense Wavelength Division Multiplexing</td>
</tr>
<tr>
<td>WDM</td>
<td>Wavelength Division Multiplexing</td>
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SCOPE OF THE REPORT (1/2)

Platform

- Silicon photonics
  Courtesy of Luxtera

Modules

- Optical communication
  Including optical transceivers, optical interconnects, co-packaged photonic engines
  Courtesy of Intel

- OCT
  Courtesy of OCTCHIP

- LiDAR
  Courtesy of SiLC

- FOG
  Courtesy of Optics Express

Immunoassays

- Courtesy of Genalyte
SCOPE OF THE REPORT (2/2)

Platforms which are integrated with silicon photonics

- InP
- SiN
- Glass
- Polymer
- Silica PLC
- LiNbO3

- InP is used for commonly lasers.
- SiN is commonly used for waveguides
- SiN is commonly used for interconnects.
- AWG (Silica PLC)
- LiNbO3

A comparison with other platforms is presented in the report.

Devices which are out of scope

- MEMS Matrix Optical Switches

Optical MEMS

3D Tilting MEMS Mirror Matrix

Inputs

Outputs

Courtesy of DiCon Fiberoptics

Yours needs are out of the report’s scope?
Contact us for a custom:
Yole’s market forecast model is based on the matching of several sources:

**Comparison with existing data**
- Monitoring of corporate communication
- Using other market research data
- Yole analysis (consensus or not)

**Comparison with prior Yole reports**
- Recursive improvement of dataset
- Customer feedback

---

### Market

**Volume (in Munits)**

**ASP (in $)**

**Revenue (in $M)**

---

#### Top-to-bottom approach
- Aggregate of market forecasts
  - @ System level

#### Bottom-up approach
- Ecosystem analysis
  - Aggregate of all players’ revenue
    - @ System level

---

### Semiconductor foundry activity

Capacity investments and equipment needs

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### Primary data
- Reverse costing
- Patent analysis
- Annual reports
- Direct interviews

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### Secondary data
- Press releases
- Industry organization reports
- Conferences

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### Information Aggregation

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**Preexisting information**
ABOUT THE AUTHORS

Biographies & contacts

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Alexis Debray is a Technology & Market Analyst with the MEMS & Sensors team at Yole Développement, the “More than Moore” market research and strategy consulting company. Prior to Yole, Alexis spent 17 years in Japan, including two years at the University of Tokyo where he studied MEMS technologies, and 15 years at Canon Inc., where he was a Research Engineer. While with Canon, he contributed to works on MEMS devices, linguistic prehension, and terahertz imaging devices. Alexis has also authored various scientific publications and patents. Alexis graduated from ENSICAEN and holds a PhD in Applied Acoustics.
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Jean-Louis Malinge
Jean-Louis Malinge is an accomplished business management executive with extensive experience as a General Manager and CEO in France and the United States. He also serves on numerous Boards of Directors. He has formulated successful strategies to position or reposition numerous businesses, has led numerous acquisition projects, and also managed the creation of a successful joint-venture in Asia. Jean-Louis is currently a Venture Partner with Arch Venture Partners. He is also a Director on the boards of EGIDE Group, POET Technologies, Cailabs and Aeponyx.
Jean-Louis was President & CEO of Kotura from 2004 - 2013, when Kotura was acquired by Mellanox. A global leader in silicon photonics, Kotura designs, manufactures, and markets CMOS optical components that are deployed throughout the communications network.
Formerly, Jean-Louis served as Vice President - Optical Networking Products for Corning, Inc. His other prior experience includes serving as Technology Director with Amphenol and Thompson CSF in France.
Jean-Louis’ academic credentials include an Executive M.B.A. from MIT Sloan School in Boston, Massachusetts. He also holds an Engineering degree from the Institut National des Sciences Appliquées in Rennes, France.
Dr. Eric Mounier, Fellow Analyst

With more than 20 years of experience in MEMS, sensors and photonics applications, markets, and technology analyses, Eric provides deep industry insight into MEMS and photonics current and future trends.

He is a daily contributor to the development of MEMS and photonics activities at Yole, with a large collection of market and technology reports as well as multiple custom consulting projects: business strategy, identification of investments or acquisition targets, due diligences (buy/sell side), market and technology analysis, cost modelling, technology scouting, etc.

Eric has contributed to more than 250 marketing/technological analyses and 80 reports, helping move the MEMS and Si photonics industry forward. Thanks to his extensive knowledge of the MEMS, sensors, and photonics-related industries, Eric is often invited to speak at industry conferences worldwide.

Moreover, he has been interviewed and quoted by leading media throughout the world. Prior to working at Yole, Eric held R&D and Marketing positions at CEA Leti in France. Eric has a Semiconductor Engineering degree and a Ph.-D in Optoelectronics from the National Polytechnic Institute of Grenoble.

Contact: eric.mounier@yole.fr
COMPANIES CITED IN THIS REPORT

WHAT WE GOT RIGHT, WHAT WE GOT WRONG

- The growth of the Si Photonics technology for pluggable optics
- The use of Si Photonics for sensing applications
- The coming of co-packaged switch ASIC
- The involvement of more and more players with many startups

- We under-estimated the use of Si Photonics for coherent transmission
Silicon photonic forecast by application

2019-2025 Forecast

Optical communication is and will remain the most important application of silicon photonics.

Datacenter transceivers
Long haul transceivers
Optical interconnects
Automotive LiDAR

Immunoassay tests
Fiber-optic gyroscope
5G transceivers

2019
$480M

2025
$3.9B

$364M
CAGR 46%

$186M
CAGR 8%

$117M
CAGR 40%

$20M
$22M
$44M
$61M
$18M
$3.6B
• Data center communication is by far the largest market for silicon photonics. Currently more than 40% of Microsoft’s intra data center links use 100G direct-detect technology based on silicon photonics rather than indium phosphide, according to Radha Nagarajan, CTO of InPhi’s Optical Interconnect business (OFC 2018 source).

• There has been a strong decrease in price: a PSM4 100G is today estimated to be $100 and $150 for a CWDM transceiver.
ESTIMATION OF TRANSCEIVER PRICE BREAKDOWN

Explanation of terms
• R&D: Research and Development
• G&A: General and Administrative
• Other transmitter block parts include the Mach-Zehnder interferometer (MZI) driver, clock-and-data recovery chip, optical elements, and assembly.
• Other receiver block parts include transimpedance amplifier (TIA), clock-and-data recovery chip, optical elements, and assembly.

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Data partly extracted from System Plus Consulting report Intel 100G PSM4
ETHETNET STANDARDS FOR PLUGGABLE TRANSCEIVERS

Bit rate x Max reach

So far, optical communication has mainly targeted high reach and high bit rates.

- Bit rate is the maximum bit rate in Gb/s as defined in the Ethernet standards and ranges from 10Gb/s to 400Gb/s today.
- Max reach is the maximum distance which attainable and is displayed in meters.
- Electric communication is limited to a few meters.
- Optic communication can reach up to 80km.
- Silicon photonics is targeting the high end in direct detection and coherent detection.
The discrepancy between Cisco VNI and analysts reports:
- ~26% annual traffic growth by Cisco Visual Networking Index
- ~45% annual increase of the aggregate deployed optical transponder capacity over the past decade

Critical disparity
- Global traffic growth of ~45% in contrast to optical interface rates and commercial WDM system scaling at ~20% per year

“Optical networks capacity crunch”
- Optical networks are steering toward fundamental capacity scalability limits in the face of continuing exponential traffic growth, owing to nonlinear Shannon limits of silica optical transmission fiber.

Unlike short-reach links, which we saw have many choices of transmission type, long-reach links (and metro) demand coherent transmission. This is because long fiber routes are expensive to install/obtain, and thus the user wants to push as much information over each fiber as possible.

Incoherent optical communication:
- Information is encoded by changing the amplitude of the light (Turning the light off or on). The receiver simply must measure the intensity of the light to receive the transmitted signal and generally consists of a photodiode.
- This is direct modulation.

Coherent optical communication:
- Signal is encoded in properties of the electric field (phase, or combinations of phase and amplitude). The receiver is therefore more complicated and comes in two flavors:
  - Receivers that don't require a local oscillator (laser): used for differential phase modulation and differential quadrature phase modulation. For these formats, the information is encoded by either changing the phase of the light (1) or not changing the phase (0).
  - Receivers that require a local oscillator (laser): used for modulation formats such as binary phase modulation, quadrature phase modulation, and quadrature amplitude phase modulation (QAM) formats.
  - This requires indirect modulation.
5G RADIO ACCESS NETWORKS (RAN)

5G Network structure

Optimizing the cellular network is complex, whether the topology offers line of sight or not, depending on the density of users, or whether the implementation is feasible or not and so on.

A complete range of solutions exist, going from large macro cells for wide coverage, to femtocell designed to bring coverage to a single household. Depending on the chosen solution, the specifications asked to the hardware vary a lot and so does the technology used inside.

5G networks will be different from current ones, with more signal treatment expected to be done in the cloud (using Cloud-RAN – cloud radio access networks – for example), with the need for a denser line of sight network due to the use of millimeter waves, or with the implementation of new antenna technologies such as active antennas for massive MIMO.

The exact shape of tomorrow’s network is still unknown, but some educated guesses based on current trends and new technologies capabilities are possible.
SILICON PHOTONIC TRANSCEIVERS COMPETITIVE LANDSCAPE

Suppliers
- Substrates
  - soitec
  - Shin-Etsu
  - IQE
  - silex
  - tsmc
  - NXP
  - UN
  - apm
  - skorpios
  - GLOBALFOUNDRIES
  - amf
  - SilTerra
  - TSM
  - Intel
  - Teknion Industries
  - Infineon
  - Partners from RF to Light
  - MACOM
  - Inphi
  - NTT Electronics
  - Cisco
  - ACACIA
  - Infineon
  - NTT Electronics
  - Broadcom

Fab
- Finisar
- IIVI
- II-VI
- InnoLight
- Renesas
- Mellanox
- Fujitsu
- Cisco
- FIT
- NEC
- NTT Electronics
- Sumitomo

Electric components
- III-V lab
- TOWARDZ
- LEONI
- Hwlett Packard Enterprise
- Silicon Photonics
- NeoPhotonics
- Analog Devices
- Hengtong Optical Technologies
- Broadex Technologies Co., Ltd.
- Huawei
- FiberHome
- Juniper Networks
- Intel
- NEC
- Infinera
- Amazon Web Services
- Microsoft Azure
- IBM
- Google
- Facebook
- Ciena

Optical transceivers
- SiPh transceivers
- SiPh platform

Operators
- Hewlett Packard Enterprise
- Intel
- NEC
- Infinera
- Amazon Web Services
- Microsoft Azure
- IBM
- Google
- Facebook
- Ciena
PLAYERS INVOLVED IN CO-PACKAGED OPTICS

**Intel**
- Network switch
- Co-packaged SiPh transceivers

**Barefoot Networks**
- Tofino 2 Switch ASIC
- Using TSMC 7nm foundry

**Cisco**
- Network switch
- Co-packaged SiPh transceivers
- Cisco acquired Luxtera in February 2019.
- Cisco acquired Leaba in March 2016.

**Co-packeted Optics Collaboration (June 2019)**
- Specifications

**Microsoft**

**TSMC**

**PoET Technologies**
- Optical interposers

**Sumitomo Electric**
- Optical interconnection

**Rockley Photonics**
- Integration
- TGA

**Accton**
- Making Partnership Work

**Molex**
- One Company – A World of Innovation

**Samtec**
- Si-fly copper

**Ranovus**
- Co-packaged SiPh transceivers
- Fiber optic connectivity

**IBM**
- Fiber V-groove interconnects

**Senko**
- Co-packaged fine pitch socket interposer

Intel acquired Barefoot Networks in June 2019.
Cisco acquired Luxtera in February 2019.
Cisco acquired Leaba in March 2016.
The continuous increase of data rate could result in a change from pluggable to co-packaged transceivers for network switches.
In March 2020, Intel has demonstrated a network switch using co-packaged optics. The silicon photonic engines are capable of 1.6 Tbps. The switch is expected to achieve 25/6 Tbps with 16 engines and the Tofino2 switch ASIC. Co-packaging is achieved using interposers.

In March 2020, Rockley Photonics, in collaboration with Accton, Molex, and TE Connectivity, have demonstrated a co-packaged optic switch with 6 Tbps with a target of 51.2 Tbps.
Silicon Photonic LiDAR Performances

Recently, silicon photonic LiDAR have shown impressive performances in small packages.

In March 2020, the new iPad includes a LiDAR scanner. This could be a great opportunity for silicon photonics LiDAR.

The silicon photonic LiDAR from Baba Lab/Yokohama University integrates OPA scanning, lasers, modulator, and photodetectors on a single chip.

At CES 2020, SiLC partnered with Varroc Lighting Systems to integrate their FMCW LiDAR into a headlamp.

Also at CES 2020, SiLC demonstrated the operation of their FMCW above 200m being able to measure cross walks at 220m and 2-inch objects at 190m.

In March 2020, the new iPad includes a LiDAR scanner. This could be a great opportunity for silicon photonics LiDAR.
There are initiatives to miniaturise OCT systems to fabrication systems of a chip. However they are still in the R&D phase, financed by the EU.

Envision diagnostic’s Binocular OCT was promising and is finishing clinical studies in the UK on March the 1st 2020.

These are a few examples. But they lack traction especially ophthalmologic applications since cost is not the biggest driver compared to performance.
ROADMAP FOR SILICON PHOTONICS

Data and telecom
- 100G pluggable transceivers using coherent and direct detection
- 400G DR4 transceivers for data centers
- 400ZR coherent transceivers
- Co-packaged optic switch at 25.6 or 51.2Tbps

Automotive
- Photonic FOG
- FMCW LiDAR for ADAS or robo-taxi

Medical
- RFOG
- OCT for ophthalmology or other applications

Consumer
- Immunoassay for point of need
- E-noses in smart white goods
- With volume production in pluggable transceivers, silicon photonics is expanding into new applications: Automotive, medical, and consumer.

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FMCW: Frequency Modulated Continuous Waves
FOG: Fiber Optic Gyroscope
OCT: Optical Computed Tomography
OPA: Optical Phased Array
RFOG: Resonant FOG

Silicon Photonics Market & Technology 2020 | Sample | www.yole.fr | ©2020
YOLE GROUP OF COMPANIES - RELATED REPORTS

Yole Développement

- Optical Transceivers for Datacom & Telecom 2020 (coming soon)
- InP Wafer and Epiwafer 2019 Photonics and RF Applications
- Quantum Technologies 2020
- High-End Inertial Sensors for Defense, Aerospace and Industrial Applications 2020
- LiDAR for Automotive and Industrial Applications 2019

Contact our Sales Team for more information
Intel Silicon Photonic 100G CWDM4 QFSP28 Transceiver

Intel Silicon Photonic 100G PSM4 QFSP28 Transceiver