Positive for Silicon
Si Photonics for Optical Inteconnection

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PETRA
Tohru Mogami
Positive for Si LSI
Digital electronics innovation has changed the world and our societies. This innovation has brought them the IT revolution by using the advanced computer systems, the computer network, Internet, and consumer electronics, since 1970’s. This is mainly based on the Si-LSI.

![Digital Electronics Innovation Timeline](image)

**Main flame (’70s-’80s), ~100M (10^8) Flops**

- Walkman (1979)
- PC6000 (1981)

**Note-PC Mobile Phone (’90s)**

- Digital Video (’90s)
- i-pod (2001)

**Electronic Video (’90s)**

- Mobile Phone (’90s)

**Digital Video (’90s)**

- i-pad (2010)
- i-phone (2007)

**Super-computer Earth Sim.**

- 35 Tera (10^{12}) Flops (2002)

**K comp.**

- 10 Peta (10^{15}) Flops (2012)

**What’s next?**

- Exa-Flops SC
- Smart home Electric appliance
- Smart robots

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The amount of the “Information” which circulates in the world has been expanding more than twice in 2 year since 2006.

In 2010, the amount of the Information exceeding ZB (Zetta Byte) was created in one year.

This mainly comes from the Internet spread and especially picture information, such as digital camera, smart-phone.

The amount of 1 tera-byte is equal to the information of 1000-year newspapers.

The amount of 1 zetta-byte is equal to that of 1 million-year newspapers.
The Internet is a powerful global system of interconnected computer networks. The Internet has enabled new form of human interactions.

- The Internet has enabled new form of things interactions.
- During 2008, the number of things connected to the Internet exceeded the number of people on earth, about 6 billion. These things are houses, cars and animals. By 2020, there will be 50 billion.

More Application on Si

- More applications should be based on Si-LSI, because Si-LSI is a platform to integrate More Than Moore (MTM) tech. & Beyond CMOS (BC) tech.
- Technologies of more applications will be the new functions for LSI’s to add new values for extended LSI world.
Positive for Si Photonics
Si Photonics

- Silicon photonics is the technology to integrate photonic systems which mainly use silicon as optical devices. The silicon is usually patterned with nano-meter precision, into microphotonic devices.

- On-chip OE device
  - Plasmon nanophotodiode
  - Ultra-small PD by novel surface-plasmon effects
  - High-speed & high-sensitivity

- On-chip EO device
  - High-speed ceramic photomodulators
  - Nano-ceramic technology → Transparent ceramic film with high EO coefficient

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Optical interconnect

Optical communication is penetrating from long-haul to short-distance interconnect thanks to larger market.

Optical Interconnect can meet electric devices again by the short distance, thanks to high data transmission.

Telecommunication

km

Between Computers

m

Smaller Distance

between Boards

cm

Larger Market

mm

On-Chip Optical Bus

electrical Signal

Optical Signal

Wavelength

Devision Multiplexing
Why Si photonics?

- Absorption coefficient of Si is very small b/w 1.2-1.6\textmu m. Refractive index of Si is higher than silica.
- Si waveguide has low radiation loss and can size down optical circuits by confinement effect due to higher refractive index of Si.

\[
\text{Radiation Loss [dB]} \propto \frac{1}{(\text{Bending Radius, } R)} \left( \frac{1}{(\text{Relative Ratio of Index, } \Delta)} \right)
\]

T. Horikawa, FOE2013
Light propagation in silicon

Propagation optical modes depend on Effective index and waveguide width.

Lowest optical modes can propagate in WG w/ narrow width.

Effective Index

waveguide Width (nm)

200 300 400 500 600

1.0 1.5 2.0 2.5 3.0

No mode exist

TE lowest mode

TM lowest mode

TE higher mode

Optical field extends to crad around Si waveguide
Key Technology Development
Waveguide by CMOS Technology

- Si waveguide is a optical signal line and is made from SOI(Si on Insulator) layer by dry etching

1. SOI Wafer ➔ 2. Si Patterning ➔ 3. Si Etching ➔ 4. SiO₂ Deposition

Low cost and highly reproducible fabrication by using CMOS process technology
Optical Modulator

- Electrical/Optical Conversion

Phase shift by Index Modulation

Carrier injection (e-, h+) causes Index change

Carrier injection (e-, h+) causes Index change

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Si Fin-MOD

Schematic diagram of Fin-MOD

DC Optical Response

Bench mark
- High performance uniformity
  → No recess process
- Strong optical confinement effect
  → Narrow PN distance
  → Low R
  → High efficiency ($V_{\pi L} = 0.003 \text{ Vcm}$)

Photo-detector

Optical/Electrical Conversion

Absorption Coefficient, $\alpha$ (cm$^{-1}$)

Sensitivity of Ge is larger than Si

![Absorption Graph](graph.png)

- Ge
- Si

- O band
- E band
- S band
- C band

Absorption of signal light

Photocurrent due to Photovoltaic Effect

- N-Ge
- i-Ge
- P-Ge

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PECST Pj (2001-2004) has demonstrated 10 Tbps/cm² throughput density in optical interconnection b/w chip-to-chip by high-performance scaled devices and integration technology.

Throughput (Gbps) vs. 1/Module Area (cm⁻²) diagram showing various interconnect technologies and their performance metrics. Notable points include:
- **LAN/WAN**
  - 300pin-MSA (10Gx1)
  - XFP (10Gx1)
  - POP4 (’05)

- **Inter-Racks**
  - AOC etc.
  - LUXTERA

- **Inter-Boards**
  - PODAvago
  - PETIT2 (NEC ’10)
  - LUXTERA

- **Downscaling**
- **Chip-to-Chip**

- **Application**

- **On-board server**

PECST[@2011] 3.5 Tbps/cm²
PECST[@2012] 6.6 Tbps/cm²
PECST[@2013] 30 Tbps/cm²

Throughput (Gbps) markers:
- 0.1 Gbps/cm²
- 1 Gbps/cm²
- 10 Gbps/cm²
- 100 Gbps/cm²
- 1 Tbps/cm²
- 10 Tbps/cm²

On-board server and other markers indicating various technologies and performance levels.
Positive for Si Bio
A Novel Optical Multiplexed Bio-Photonic-Sensor

- A novel bio-photonic sensing system based on silicon OEIC platform.
- The sensing system comprises an electrical-tracing assisted microring and a sensor microring integrating with an on-chip photodetector. Multiplexing is achieved through an array of microrings and integrated photodetectors.
- The completed system was demonstrated for label-free and multiplexed detection of DNA targets of pathogenic bacteria.

The principle of dual-microring resonators with DNA probes and targets of DNA for bacterial detection.
Silicon Photonic Based Biosensors: The Future of Lab-on-a-Chip Diagnostic Devices

- A palm-size device able to deliver instant diagnostics of our health status
- Silicon photonic biosensors as the most promising candidates for achieving truly point-of-care devices for healthcare diagnostics
- Advantages as miniaturization, clinically-relevant sensitivity, robustness, reliability, potential for mass production at low cost


Light Coupling by Nanogratings

The envisioned LOC platform based on nanophotonic sensors
Summary

- We are positive for silicon.
- We need more high-performance LSI to handle a lot of the environmental data. Therefore, it is necessary to need the advanced Si technology.
- Furthermore, a new kind of Si devices is necessary that we are reliable safely and continue a comfortable living.
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