CI-7-1(Invited)

Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp819-820

# Optical Interconnection based on Silicon photonics

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## 1. Introduction

Today's advanced information society has reached its present state through the combination of high performance electronic circuits for processing information and large-capacity, high-speed communications networks for transmitting information. This mechanism is supported by silicon integrated electronic circuit technology, which provides high-speed, large-scale integrated circuits (LSIs) and by optical communications technology, which provides large-capacity and high-speed communications. If the advanced information society is to continue to expand, the processing performance of electronic circuits must be improved and optical networks must offer even greater capacities and higher data-transfer speeds. However, higher processing speed consumes larger power, which results in rapid temperature increases and limits the performance of LSIs. Furthermore, the dramatic increase in the power consumed by the huge number of electronic appliances and networks that connect them becomes a serious issue of growing concern from the viewpoint of reducing the load on the global environment.

At present, optical interconnection technology is considered as one way of controlling power consumption while maintaining the trend toward high-performance electronic circuits and appliances. Optical interconnection will provide high-speed, large-capacity data transmission with high energy efficiency between LSIs and those appliances. On the other hand, currently available optical devices are too large to obtain high-density integration and the cost is high.

Silicon (Si) photonics is expected to have the potential to work out a solution. This article describes the technical features of the silicon photonic components and their integration toward the optical interconnections.

## 2. Silicon photonics

Current optical devices consist of optical fibers, wavelength filters, modulators, photodetectors (PDs), lasers, and electronic control circuits. These devices are manufactured as separate components made of various different materials, and since they must be combined and installed as such, it has been difficult to achieve high-density integration. R&D is moving forward to achieve ultrasmall, low-cost optical devices by integrating Si based optical devices with optical devices made from (non-Si) materials that can be handled during the CMOS mass-production process.

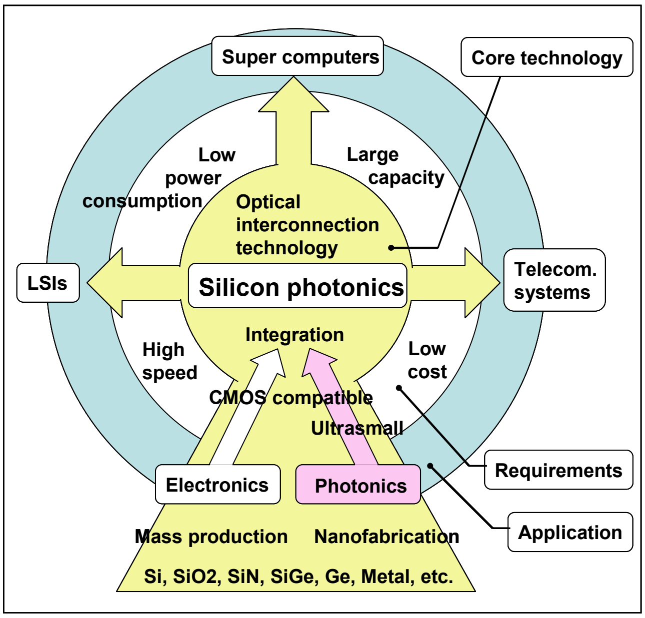


Fig. 1. Concept of Si photonics technology.

Figure 1 shows the concept of Si photonics technology. Si photonics utilizes Si, $SiO_2$, Ge, and other materials having a high affinity to the Si-CMOS fabrication process, and it will have a variety of applications, ranging from LSIs to telecommunications. Optical components made of Si or Ge have many advantages, such as ultrasmall size due to a high optical index. In addition, low cost, and high-density integration will be achieved. This is because Si technology is an industry standard that can provide low-cost, high-performance devices through high-density integration and mass-production techniques. The plan for Si photonics is to replace the various non-Si materials currently used to form optical devices with Si and CMOS- compatible materials and to integrate them monolithically. Silicon photonics enables us to integrate optical and electrical devices on a chip that support optical interconnection at a lower cost. It is also expected to suppress the total power consumption in LSIs and in appliances and their systems through the development of photonic-electronic convergence equipment that consumes less power while achieving even more advanced functionality.

[1] Currently, they belong to NTT Advanced Technology Corporation.

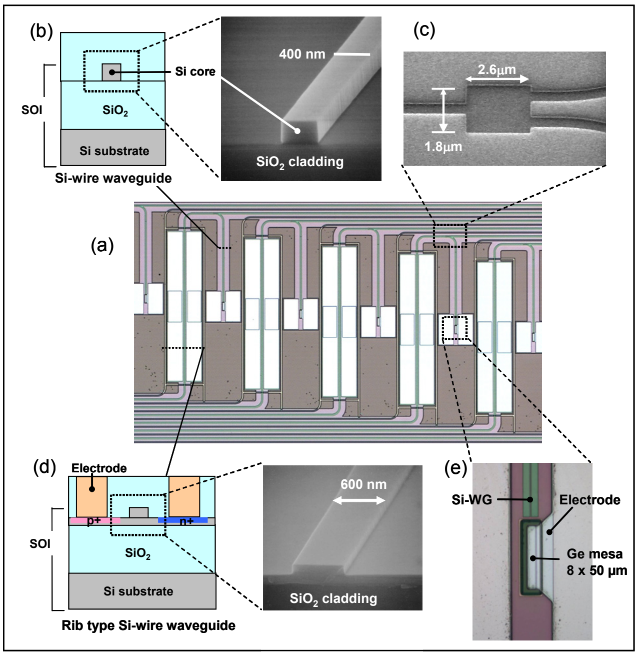


Fig. 2. Integrated Si photonic components.
(a) Microphotograph of integrated device; (b) cross section of Si-WG; (c) MMI optical branch; (d) Rib WG with p-i-n structure; (e) Ge photodetector connected to Si-WG

## 3. Silicon optical components and their integration

Si optical components consist of very compact Si wire waveguides (WGs), which are composed of a Si core and $SiO_2$ cladding on a SOI wafer.[Fig.2(b)] The core size is only 200 x 400 nm and a bending radius as small as 5 micrometers is available. Improvement of nanofabrication technology enables us to decrease light propagation loss in the WGs below about 2 dB/cm, which is low enough to apply them to actual use.

Various passive components, such as branches and wavelength filters, based on Si WGs have already been developed[1,2]. Dynamic components, such as variable optical attenuators (VOAs) and germanium (Ge) PDs with p-i-n structures, have also recently been demonstrated[3].

Integrating those components, while maintaining their performance, is the next important challenge. Fig. 2(a) shows an example of monolithically integrated devices[4]. Si VOAs and Ge PDs are combined with Si WGs. Figs.2(c) and (d) show the very compact 1x2 branch and a VOA based on a rib WG with a p-i-n structure, respectively. The propagated optical power is attenuated due to the carrier absorption when the carriers are injected into the WG, and the VOA shows a response time as fast as a few nanoseconds. Fig. 2(e) shows the Ge PD connected to the Si WG. Ge is formed by selective epitaxial growth and its size is only 80 x 100 micrometers. Responsivity is 0.8 A/W and the response speed is as fast as a few gigaherz. These components indicate the same high performance as they are fabricated individually.

Integration of electrical and optical circuits, or photonic-electronic convergence, is the next step. At present, electro-optical fusion on Si is being pursued throughout the world. Two types of approaches have been developed. One is to fabricate a Si electrical chip and a Si optical chips as separate components and them bond together. The other is monolithic integration of both electrical and optical circuits on a same chip by using a CMOS compatible process. In 2006, Japan launched a national project devoted to research on optical wiring for application to electronic circuit systems, and good results have already been obtained.[5] The year 2010 saw the start of a new program[6] devoted in research on optical interconnection for application to on-chip data centers. In the USA, Si photonics is viewed as a technology for achieving super-high-performance computer systems, and work is moving forward as a national policy centered on the public DARPA program[7]. A few laboratories have proved that the second approach is feasible. They have shown that optical and electronic circuits can be formed on the same silicon substrate by using a silicon CMOS process[8,9]. These results will promote efforts to achieve supercomputing systems by constructing optical interconnections between LSIs, boards and appliances.

Elsewhere Si photonics foundry services have been launched to support developments up to the commercialization level. In this way, competition in Si photonics R&D is intensifying throughout the world in a wide variety of technical areas ranging from basic technologies to system development.

## 4. Conclusions

Optical interconnection technology based on Si photonics will become indispensable for state-of-the-art supercomputers and is expected to be commoditized and incorporated into all kinds of information appliances. Si photonics will have a ripple effect that should lead not only to improvements in electrical circuits but also to optical circuits and an overall drop in cost and power consumption.


## Acknowledgements

The Ge film-growth process was carried out at the Wada Laboratory, University of Tokyo. The authors thank all concerned for their assistance in this research. They also thank Prof. Kazumi Wada and Associate Prof. Yasuhiko Ishikawa for their useful suggestions and discussions.


## References


[1] T.Tsuchizawa et.al., IEEE JSTQE, **11**, 1, (2005) 232.
[2] W. Bogaerts dt.al., IEEE J. Sel. Top. Quant. Electron. **12** (2006) 1394.
[3] S.Park et.al, IEICE TRANS. ELECTRON, **E91-C**, 2 (2008) 181.
[4] S. Park et.al., Optics Express, **18**, 8 (2010) 8412.
[5] K. Ohashi et.al., Proceedings of the IEEE, **97**, 7, (2009) 1186.
[6] http://www.pecst.org/outline.html.
[7] K. Raj et.al., Proc. of SPIE **7607** (2010) 760702-1.
[8] T. Pinguet et.al. *Group Four Photonics* (2008) FB-1.
[9] S. Assefa et.al. IEEE JSTQE, **16**, 5 (2010) 1376.