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Si Nano-photonics for LSI on-chip optical interconnection

Kenichi Nishi[1],Junichi Fujikata[1], Hirohito Yamada[1], Tsutomu Ishi[1], Masafumi Nakada[1], Koichi Nose[2], Masayuki Mizuno[2], Muneo Fukaishi[2], Yutaka Urino[3] and Keishi Ohashi[1]

[1]NEC Corporation, Fundamental and Environmental Research Laboratories
34, Miyukigaoka, Tsukuba, Ibaraki 305-8501, Japan
Phone: +81-298-1589 E-mail: k-nishi@cj.jp.nec.com
[2]NEC Corporation, System Devices Research Laboratories
[3]NEC Corporation, System Platform Research Laboratories

1. Introduction

As the scaling of modern LSI technology proceeds, the number of integrated transistors in LSI increases correspondingly. This results in a drastic increase in the amount of transmitted signals within a chip and consequent increase in the number of global wires. Conventional electrical wiring will soon face the fact that this increase in wiring will push up the LSI fabrication cost, with high frequency and high transfer rate operations becoming more and more difficult due to jitter/timing/electro-magnetic interference problems. One candidate for solving such expected problems is to use optical wiring within a LSI chip: that is LSI on-chip optical interconnection. Optical interconnections have advantages compared to electrical wiring such as low power loss at high frequencies, low crosstalk between wires, and electromagnetic compatibility [1, 2]. Recent progresses in optical technology is now making such LSI on-chip interconnections more realistic[3]. Si-nanophotonics is a key technology for realizing such optical components on a LSI chip, where essential optical components can be fabricated with Si CMOS-compatible device processes and the sizes of the components around the micron to mm size with nano-meter-scale precisions[4]. Here, basic optical components used to build such on-chip optical interconnection are introduced: nano-photodiodes (PDs) and opto-electronic (OE) conversion devices as well as optical waveguides and other passive optical components. Also advanced circuit designs for high-speed clock distribution with nano-PDs are discussed.

2. Concept of LSI on-chip interconnection

Basic structure

On-chip optical interconnections can be utilized in several ways for sending/receiving data signals within a LSI chip. For example, optical clock distribution and on-chip optical bus are representative targets. There, advantages of optical data transmission can be positively utilized, such as high-speed data transfer and wavelength division multiplexing.

Optical clock distribution, which is illustrated in Fig.1, utilizes several PDs connected to optical waveguide branches. Fundamental clock signals are delivered from an optical light source, which is located outside the LSI chip. In this arrangement, the clock frequency corresponds to a

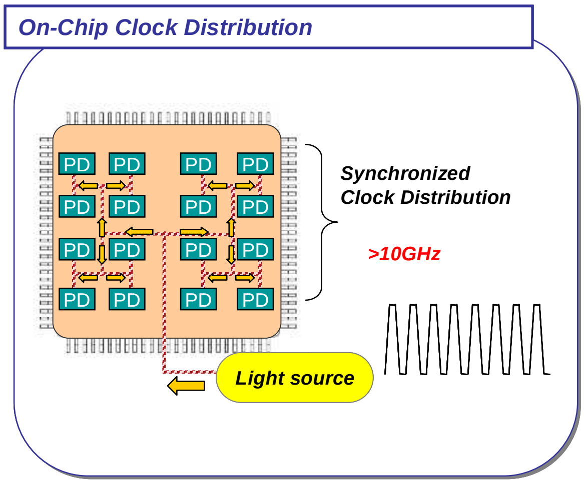

Fig 1. A schematic figure of on-chip optical clock distribution.

modulation of the external light source. On the other hand, in the optical bus system, EO modulators may be necessary to obtain optical signals from electrical data. WDM system is also desirable to multiply the data rate within a single waveguide.

Nano-photodiode

Photodiodes, where signals are changed from optical into electrical, are important devices in such on-chip optical interconnections. The devices made from group IV materials, such as Si or Ge-based system, are attractive for reducing costs and achieving reproducibility because, under Si-CMOS compatible device process, a number of devices can be fabricated on a large Si wafer. In fact, Ge-related materials are used for fabricating PDs on Si[5]. Currently, the fabrication procedure is complicated because Ge has to be deposited on Si with low misfit dislocation density.

The Si-based PD structure is the most desirable for on-chip fabrication. Due to the relatively small absorption coefficient in Si, usually Si PDs need large detection volumes, which results in slow response times. To overcome this problem, a surface plasmon antenna, that enhances evanescent light in the vicinity of periodic metallic structure, was combined with a small Si PD; this is reflected to as Si-nano-PD[6,7].

Figure 2 depicts a schematic structure of the Si nano-

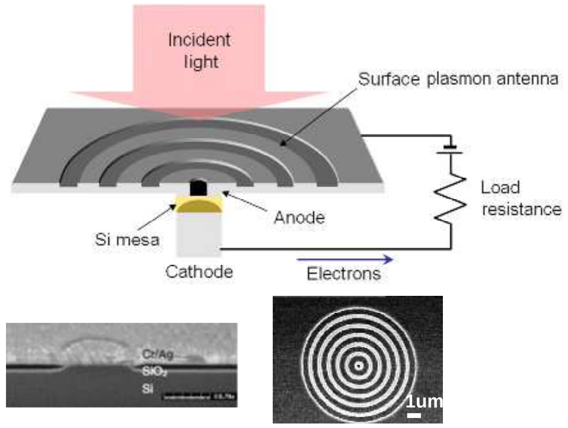

Fig 2. A Si-nanophotodiode made of surface plasmon antenna and a small volume of Si. Cross-sectional and plan views of fabricated structure are also shown.

-PD. The surface plasmon antenna is made of silver concentric grating with a small hole in the center. Incident light is collected in the center hole by coupling with surface plasmon and generates enhanced evanescent light at the other side of the antenna. There, the light generates photo-carriers within the Si in a much smaller volume (several orders of magnitude) compared to conventional PDs. Thus, both high quantum efficiency and fast response have been realized in this structure.

Waveguide

For clock distribution with a H-tree structure, the nano--PDs should be connected to optical waveguides. Because Si is used for light detection, the wavelength should be much shorter than Si bandgap. Thus, a waveguide made of SiON core/SiO_2 clad is appropriate. An arrayed waveguide grating, which acts as wavelength multiplexer /demultiplexer, can also be made by using SiON material with sub-mm size.

EO modulator

In the optical bus, small, low-voltage EO modulator is a key device. A Si-based EO modulator with a high-Q ring resonator of 12 um in diameter has been demonstrated[8]. Another candidate is to use a PZT film deposited by an aerosol-deposition (AD)[9]. The AD PZT film has a high EO coefficient of >150 pm/V. A Mach-Zehnder-type modulator with a PZT film has the potential to realize an EO modulator on a LSI chip with low operation voltage and a high-frequency response.

TIA-less clock circuits

In a conventional optical signal detection system, trans impedance-amplifiers (TIA) are necessary to match impedances between PD and electrical circuits. In on-chip interconnections, such TIAs consume power and have a large LSI footprint. Thus, a TIA-less optical clock detection circuit was proposed using two-waveguides with a series of two PDs[10]. Further improvements were proposed with one waveguide system combined with one- or two-PDs as

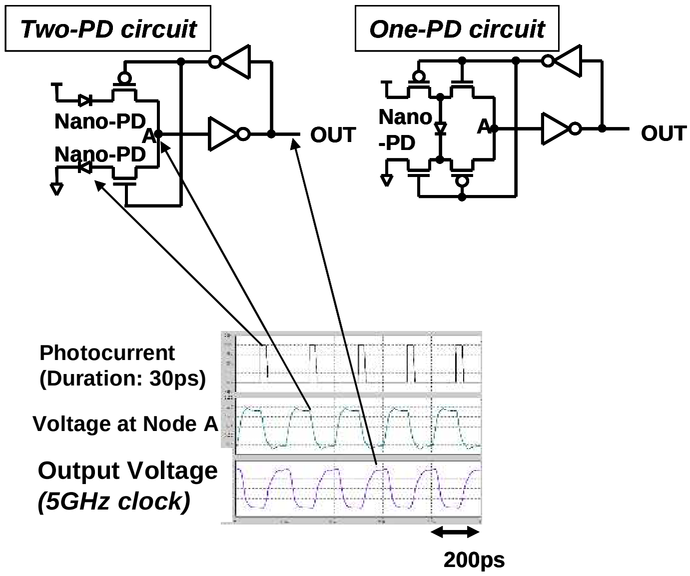

Fig 3. Two circuit designs for TIA-less optical clock distribution. A simulated result for 5GHz clock pulse response is also shown.

shown in Fig.3[4]. The response of the two-PD system was simulated and simulation results were obtained for 5-GHz clock signal system. The small consumption power and footprint of those systems would be most suitable for optical clock distribution within LSI chips.

3. Conclusions

LSI on-chip optical interconnection is discussed with examples of optical clock distribution and optical bus system. Fundamental optical devices and components are also introduced, with sizes small enough to be located on top of Si LSI and with CMOS process compatible fabrication methods. Above 10GHz clock distribution will be achieved by using TIA-less optical clock distribution circuits with a small footprint.

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