Microelectronic Engineering 156 (2016) 55–58

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

High-performance optical waveguide devices using 300 mm Si photonics platform

Tohru Mogami *, Tsuyoshi Horikawa, Keizo Kinoshita, Hironori Sasaki, Ken Morito, Kazuhiko Kurata

Photonics Electronics Technology Research Association (PETRA), Japan

ARTICLE INFO

Article history:
Received 27 June 2015
Received in revised form 26 October 2015
Accepted 28 October 2015
Available online 7 November 2015

Keywords:
Silicon photonics
Waveguide
Propagation loss
Silicon interposer

ABSTRACT

The Si photonics platform for 300 mm SOI wafers has been built up for optical multi-applications. The performance of main optical waveguide devices has been demonstrated. State-of-the-art propagation loss values are obtained for optical waveguides of multi-thickness SOI structures in this platform. The propagation loss is less than 0.5 dB/cm at 1.55 μm wavelength for 220 nm-thick single-mode waveguides with TE-polarization. MMI coupler, AWG and WDM filter showed superior performance for their applications. The 50 × 50 mm^2 large Si interposers using photonics electronics convergence technology have been demonstrated. These results indicate that our Si photonics platform is very useful for optical multi-applications.

1. Introduction

Optical interconnect is a promising technology for wide-band and large-capacity data communications instead of electrical interconnect. For optical interconnect, silicon photonics based on Si CMOS technology is a key to product integrated photonic chips [1–5]. Silicon photonics has advantages of easy device integration on a chip and low-cost with high-speed and large-capacity performance. There are a lot of application areas in optical communication world and Silicon photonics can manufacture a variety of products. Each communication system will need its application-specific features and this can result in the individual SOI dimension design for the specific application area. We have built up 300 mm Si photonics platform for optical multi-applications. This platform enables ultra-small optical transceivers, wideband transceivers with WDM method, and Si interposers for ultra-fast optical interconnect between LSI's.

In this paper, we will present and discuss this new photonics platform and its performance.

2. Experimental

Si photonic devices was fabricated on 300 mm SOI substrates. The SOI thickness of photonic devices depends on its applied optical wavelength and applications, as shown in Table 1. Fabrication process-flow was based on Si CMOS one and ArF-immersion lithography [6,7]. This lithography technique is the most advanced process in the conventional CMOS line and is used for a device patterning to improve the photonic device performance in our experiments. Metallization structure was the planarized 2 layer interconnection. In the fabrication of large-sized optical Si interposer, we applied newly designed multi-exposure-shot operation, shown in Fig. 6(a), to the waveguide pattern formation in the Si interposer larger than the maximum exposure area by the lithography tool.

3. Results and discussions

3.1. Building blocks for photonics platform

This platform is corresponding to multi-applications of optical interconnect, as shown in Table 1. "Optical I/O core" is the multi-channel arrayed integrated chip-scale OE/EO converter and consists of waveguides (WG), grating couplers (GC), modulators (MOD), spot size converters (SSC) and laser diode (LD) on the transmitter chip and photo detectors (PD) on the receiver chip. "WDM integrated optical I/O chip" is the advanced OE/EO converter with wavelength-division-multiplexing (WDM) and consists of MOD, PD, multiplexer (MUX) and de-multiplexer (DeMUX). "GE-PON" is gigabit Ethernet passive optical network system and consists of SSC, WDM filter, PD, LD. Waveguide device dimensions can be selected for each application. 180 nm-thick and 220 nm-thick SOI are applied for high-performance servers and data centers and a 300 nm-thick SOI is applied for GE-PON networks. Furthermore, chip size of integrated optical interposer can be selected for its application. This silicon photonics platform is designed for such multi-applications and applied to 1.3–1.55 μm wavelength devices on 300 mm SOI substrates with various SOI thicknesses. The common devices, which need different performances for different applications, are waveguide, grating coupler,

* Corresponding author.
E-mail address: t-mogami@petra-jp.org (T. Mogami).

http://dx.doi.org/10.1016/j.mee.2015.10.019
0167-9317/

Table 1
Optical application vs. Si photonics platform.

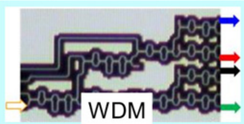
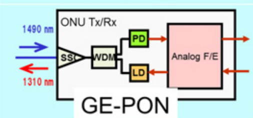
Application	Wavelength (μm)	Waveguide (nm)	Propagation loss (dB/cm)
 Opt. I/O Core	1.3	180 * 340	1.5
 WDM	1.55	220 * 440	0.5
 GE-PON	1.3 & 1.5	300 * 300	4.2

photo-detector, spot-size converter, and so on. Special devices are multi-mode interferometer (MMI) coupler, arrayed-waveguide grating (AWG), modulator, and so on. These devices should be integrated in a chip to perform the desired performance, including size, speed and power consumption.

3.2. Optical waveguide

Table 2 shows the relationship between waveguide width and propagation loss in waveguides with different dimensions. The propagation loss of waveguide was experimentally verified for the single mode conditions of TE polarization at the wavelengths of 1.31 μm and 1.55 μm.

Table 2
Relationship between propagation loss vs. waveguide structure for optical wavelength. Previous studies are refs. [10,11].

SOI thickness (nm)	WG width (nm)	Wavelength (μm)	Propagation loss (dB/cm)	Propagation loss (dB/cm) @ previous study
220	440	1.55	0.41	0.7
300	285	1.55	3.3	–
180	340	1.31	1.3	4.2
300	285	1.31	4.2	8.2

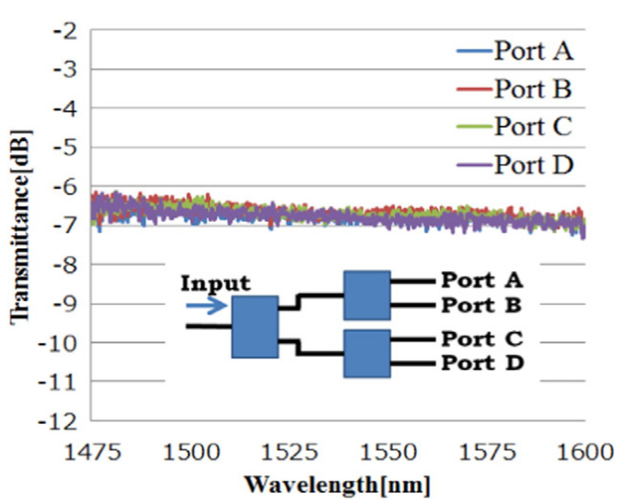


Fig. 1. MMI couplers spectra of 1 × 2 + 1 × 2 cascade. 4 outputs show the same values between the measured wavelengths [6].

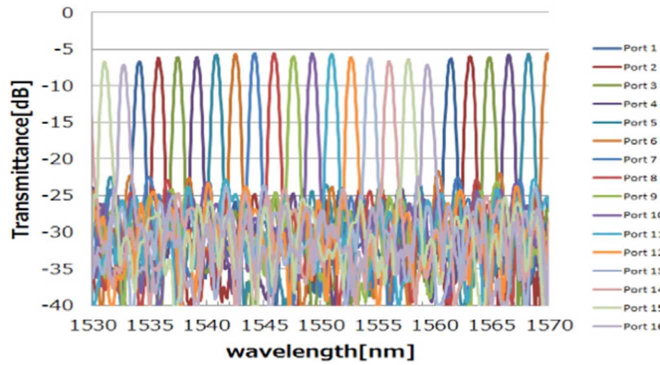


Fig. 2. AWG spectra of 16 arrays. −20 dB low crosstalk was measured for all output.

The input polarization was controlled by the polarizers. For 1.55 μm wavelength, 220 nm-thick waveguide has only 0.41 dB/cm propagation loss by using a cutback method. From an integration point of view, waveguide devices are essential for integrated optical circuits and such low propagation loss is critical since these are used in almost all of them. State-of-the-art propagation loss values are obtained for optical waveguides of multi-thickness SOI structures in this platform. This is because CMOS process with ArF-immersion lithography has been applied and the line edge roughness of waveguide has been reduced [8]. The loss values were less than 0.5 dB/cm for 1.55 μm wavelength in 220 nm-thick waveguides and less than 1.5 dB/cm for 1.31 μm wavelength in 180 nm-thick ones, respectively. These values are the world-record lowest as the propagation loss in Si wire waveguide.

3.3. Other optical devices

Fig. 1 shows the transmittance spectra of 1 × 2 + 1 × 2 MMI coupler. A 1 × 2 MMI coupler designed in this experiment has a length of 2.2 μm and a width of 1.6 μm with tapered input/outputs. For this MMI, the <0.5 dB excess loss was obtained. Divided signals have the same strength and the bandwidth over 100 nm was shown for 1.55 μm wavelength in this device as we have designed. Fig. 2 shows the measured spectra of AWG. Crosstalk was clearly measured to be about −20 dB between all output channels. For polarization-independent WDM filter, an upstream and downstream isolation better than the standard GE-PON specification was demonstrated in Fig. 3. Crosstalk reduction is realized by multi-stage Mach–Zehnder interferometer (MZI) type filters, demonstrating isolation better than GE-PON standard, −23 dB at 1310 ± 50 nm. The 5th-order coupled resonator optical waveguides

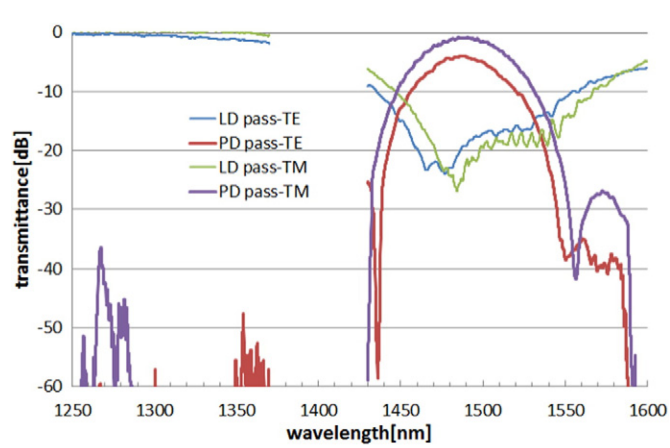


Fig. 3. WDM filter spectra for multi-stage MZI-type. Superluminescent LED was used as a wide band light source in this measurement. The tapered fibers were used at the fiber and waveguide interface. The input polarization was controlled by the polarizers. The output was measured by spectrum analyzer.