Silicon Photonics Based on Photonic Wire Waveguides

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Abstract

Silicon photonic wire waveguides, featuring a very strong optical confinement and compatibility with silicon electronics, provide a compact photonic platform on which varisou passive, dynamic and active devices can be constructed.

Introduction

Recently, silicon photonics has drawn considerable interest as an emerging technology for optical tele-communications and microelectronics. Strong optical confinement, which originates from a large refractive index contrast between the core and claddings, makes photonic devices ultracompact. Moreover, silicon-based photonic systems can be easily converged with electronics. These advantages significantly appear in submicroemeter-scale silicon photonic wire waveguides. In this paper, we demonstrate various photonic devices and applications using silicon photonic wire waveguide as an ultracompact integrated photonic platform.

Propagation characteristics of the waveguide

The cross-sectional structure of the silicon photonic wire waveguide is shown in Fig. 1. The cross-sectional size of the core is designed to be about 500 by 200 nm for maintaining the single-mode condition. At the ends of the waveguides, there are spot-size converters (SSC) for external fiber coupling[1,2]. Figure 2 shows transmission charateristics of the waveguide for 1550-nm infrared light. High-NA fibers with a 4.3-μm field diameter are used for external coupling. As shown in this figure, propagation loss is typically 1~2 dB/cm, and the coupling loss to an external fiber is around 0.5 dB. The applicable bandwidth of the SSC is over 200nm [1].

Passive devices

Using silicon photonic wire waveguides, various passive devices, such as branches [3] and wavelength filters [4-6], have been developed. However, most of them, especially the wavelength filters, have serious polarization dependence originating from the large structural birefringence of the waveguide. As shown in Fig. 4(a), for example, a ring resonator filter with 10-μm radius works well for the TE-like propagation mode but does not work at all for the TM-like mode.

In order to eliminate the polarization dependence, a waveguide-based polarization diversty circuit has been developed [7]. A microscope image of the polarization diversity circuit is shown in Fig. 3. The circuit consists of waveguide-based polarization splitters, rotators, and a ring resonator. Transmission spectra of the ring resonator with polarization diversity are shown in Fig. 4(b). The filter works well for both polarizations, and the polarization dependent loss is about 1 dB.

Dynamic and active devices

Various dynamic and active devices, such as modulators, photodetectors and light sources, have recently been constructed and integrated on a silicon waveguide platform. As an example, the photograph in Fig. 5 shows a monolithic integration of a variable

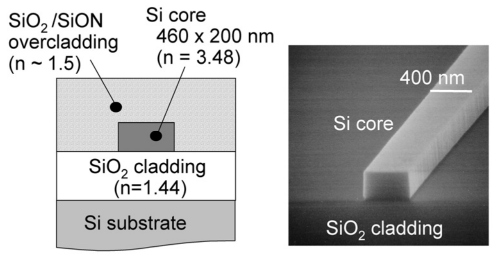

Fig. 1. Structure of a silicon photonic wire waveguide

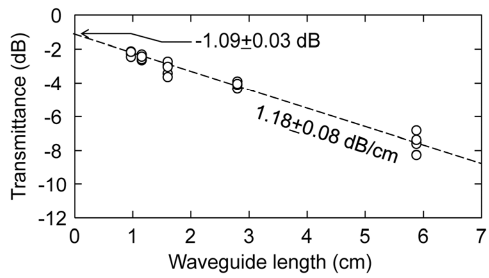

Fig. 2. Measured propagation loss of a silicon photonic wire waveguide with SSCs.

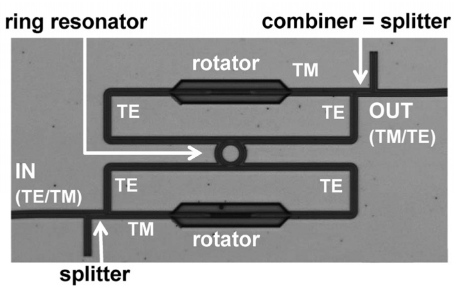

Fig. 3. Polarization diversity circuit for a ring resonator.

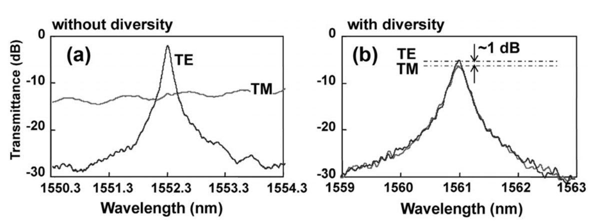

Fig. 4. Measured transmission spectra of the ring resonator without (a) and with (b) polarization diversity.

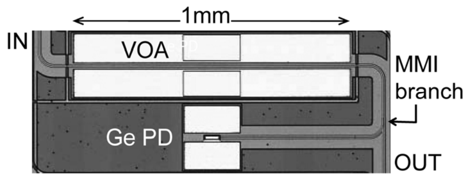

Fig. 5. Monolithic integration of VOA and germanium

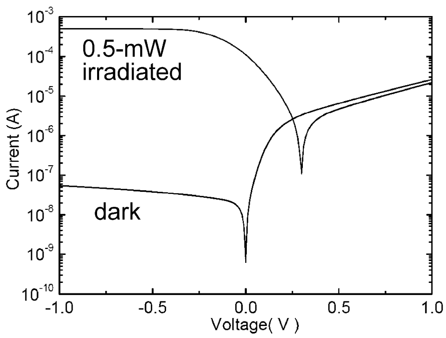

Fig. 6. I-V characteristics of the photodiode.

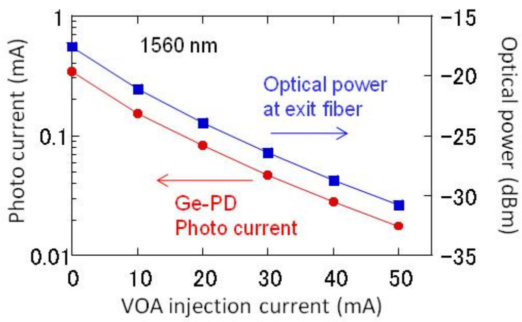

Fig. 7. Photocurrent of the photodiode and optical power measured at the exit fiber for various VOA currents.

optical attenuator (VOA) and a germanium photodiode [8]. The VOA has a lateral p-i-n carrier injection structure in which propagating light is absorbed by the injected carriers. The most important feature of the silicon-photonic-wire-based VOA is its nanosecond temporal response [9].

The output waveguide from the VOA is divided into two waveguides by a MMI branch, and one of them is connected to a germanium photodiode for power monitoring. The germanium layer is grown on the silicon waveguide by an ultra-high-vacuum CVD method [10]. Figure 6 shows typical I-V characteristics of the photodetector. For 1550-nm infrared, the responsivity of the photodiode is about 0.8 A/W and dark current is around 50 nA at 1 V reverse bias. Figure 7 shows photocurrents of the photodiode on chip and optical intensity measured at the exit fiber for various injection currents for the VOA. The change in the photocurrent agrees very well with that in the optical power at the exit[10]. This indicates that the photodiode accurately detects the optical-intensity change given by the VOA.

Nonlinear functions

In silicon photonic wire waveguides with ultrasmall cores, optical power density is remarkably increased and various nonlinear effects are enhanced [11-13]. As an example, we demonstrate here all-optical wavelength conversion based on the four wave mixing (FWM) effect, which might be an important technique in all-optical path routing. The experimental setup is shown in Fig. 8(a). Four signal lights with 0.8-nm wavelength intervals and 200-mW CW pump light are injected into a silicon waveguide. Figure 8(b) shows the power spectrum at the exit of the waveguide. Besides the peaks for pump and signals, four additional peaks for phase conjugated lights, or converted light, can be seen in a shorter wavelength region. Internal conversion efficiency is -11~-13dB, which is limited by the free-carrier absorption. Theoretical estimation shows that the elimination of free carriers would improve the efficiency to -5 dB [12].

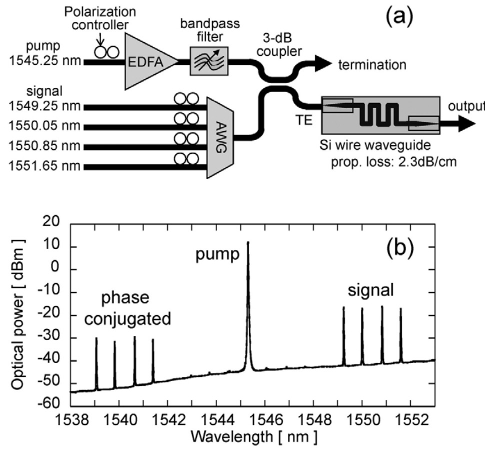

Fig.8. Setup (a) and result (b) of wavelength conversion experiment.

Very recently, effieicnt entangled-photon-pair generation has been observed through the FWM effect in silicon photonic wire waevguides [13]. The results also show the potential of silicon photonic wire waveguides as practical media for nonlinear optical functions.

Summary

As demonstrated in this paper, various photonic functions based on silicon photonic wire waveguides have been developed. In the next stage, efforts will manily shift to large-scale device integration, which is the most important advantage of silicon photonics.

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