Ge Passive Waveguide Components on Ge-on-Insulator Wafer for Mid-Infrared Integrated Photonics

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Introduction

Mid-infrared (MIR) photonics has attracted a lot of interests in sensing and optical communications [1]. At MIR wavelengths from 2 to 14 μm, Ge is very promising by showing high transparency and many attractive optical properties. Taking advantage of the useful features of Ge at MIR wavelengths, we have previously proposed a Ge waveguide platform on a Ge-on-insulator (GeOI) wafer for MIR photonic integration [2,3]. In this work, we present the design and characterization of several fundamental Ge passive waveguide components at 2-μm band on the GeOI wafer, including a single-mode waveguide, a grating coupler, a multimode interferometer (MMI) and a micro-ring based on Ge strip waveguide.

Design methodology

As a vital component for planar photonic integrated circuits, single-mode Ge strip waveguide is firstly designed based on mode analysis. Figure 1 (a) shows the effective refractive indices of TE and TM modes in a Ge slab sandwiched by SiO_2 cladding. At a wavelength of 1950 nm, single-mode operation is achieved when the slab thickness is less than 250 nm. Furthermore, at a slab thickness of 220 nm, the single-mode cutoff of a Ge strip waveguide is obtained at a waveguide width of 450 nm, as shown in Fig. 1 (b). It is interesting to note that the single-mode condition for Ge strip waveguide at 1950 nm is very similar to that for Si one at 1550 nm, which is due to the higher refractive index of approximately 4.1 in Ge at 1950 nm. Thus, Ge grating coupler is designed with a similar dimension in Si photonics. We perform the numerical simulation by 2D time-domain beam propagation method to characterize the coupling efficient. In addition, we also design a 1×2 Ge MMI coupler by 2.5D finite difference time domain simulation and a Ge micro ring resonator as well.

Experiment and results

Using the GeOI wafer prepared in advance [2], the Ge passive waveguide components are fabricated by combining E-beam lithography and conventional dry etching processes. We use 200-nm-thick SiO_2 layer for device passivation. Figure 3 shows the cross-sectional TEM image of a fabricated Ge single-mode waveguide and top-view SEM images of a grating coupler, a MMI coupler and a micro ring resonator. To characterize the transmission properties of Ge waveguide components, the MIR light from an amplified spontaneous emission source is coupled to an input grating coupler through a cleaved SMF. Then the output light is again coupled from grating coupler to SMF and the transmission spectrum is monitored by an optical spectrum analyzer. We achieve a coupling efficiency of 22% in Ge grating coupler; a 1×2 Ge MMI coupler with identical output spectra and an excess loss of -0.5 dB. From Ge micro ring resonator, we estimate the group index in 550-nm-wide Ge strip waveguide to be approximately 5.1. A good agreement is achieved between simulation and experimental results in fabricated devices.

Acknowledgement

This work was partly supported by NEDO "PECST" project and MEXT Grant-in-Aid for Scientific Research (S).

References

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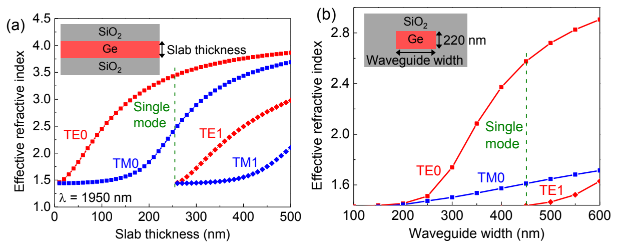

Fig. 1 (a) Effective refractive indices of Ge slab waveguide modes and (b) Effective refractive index of 220-nm-thick Ge strip waveguide modes.

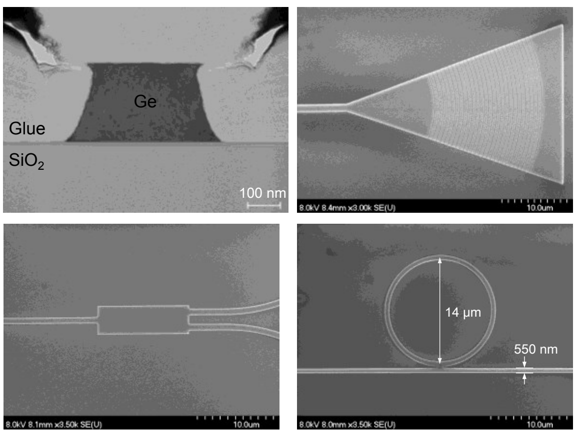

Fig. 2 cross-sectional TEM image of a Ge single-mode strip waveguide and top-view SEM images of a grating coupler, a MMI coupler and a micro ring resonator.