Optics Communications 312 (2014) 148–152

Contents lists available at ScienceDirect

Optics Communications

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

Demonstration of a highly efficient multimode interference based silicon waveguide crossing

Xianyao Li, Hao Xu, Xi Xiao, Zhiyong Li, Jinzhong Yu, Yude Yu *

State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, P.O. Box 912, Beijing 100083, PR China

ARTICLE INFO

Article history:
Received 15 March 2013
Received in revised form
7 August 2013
Accepted 8 August 2013
Available online 29 August 2013

Keywords:
Waveguide crossing
Multimode interference
Silicon-on-insulator
Integrated optics devices

ABSTRACT

We present the design, fabrication and characterization of a highly efficient silicon waveguide crossing based on multimode interference (MMI). The crossing is formed by only one step etching with the grating couplers on a silicon-on-insulator (SOI) platform. High transmission efficiency of 98.5% (loss of −0.07 dB) and low crosstalk (< −43 dB) are predicted by the 3D FDTD simulation. Our experiment results showed good agreement with the simulation and, loss of −0.1 dB per crossing, and crosstalk better than −40 dB was obtained over a broad optical spectrum from 1520 nm to 1580 nm. Such a low loss, low crosstalk waveguide crossing is suitable for future on-chip optical interconnect.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Silicon-on-insulator (SOI) has become an attractive platform for on-chip photonic integrated circuits (PICs) due to its high index contrast and compatibility with standard complementary-metal-oxide-semiconductor (CMOS) technologies. In the past few years, significant progress has been made for the basic building blocks of PICs, such as high speed silicon modulators [1–3], photo-detectors [4,5], optical filters [6,7] and high efficient lasers [8,9]. In order to exploit flexible, high-density, and advanced photonic devices, such as optical routers and switches [10–12], waveguides crossings are critical components as they offer to facilitate connectivity and device size reduction.

However, it has been well known that conventional waveguide crossings inherently suffer from reflection and crosstalk due to the lack of light confinement at the crossing point [13]. These issues become particularly true for the high index contrast SOI platform waveguides. Typically, 1.1–1.4 dB transmission loss and crosstalk around −10 dB silicon wire waveguide crossings have been experimentally demonstrated [13,14] and they severely limit the development of high performance photonic integration. To improve the crossing quality, various schemes have been proposed and investigated [13–20]. Among them, the multimode interference (MMI) based waveguide crossing is quite famous as it enables both wavelength insensitivity and ease of design and fabrication [21,22]. The cross operation is achieved by forming the self-image of the input optical field at the crossing center and output plane, such that the diffraction at the crossing center can be reduced without introducing much loss. Although enhanced performances have been reported based on MMI waveguides in the previous literatures [22,25], crossings with high transmission efficiency as well as low crosstalk loss are not experimentally achieved yet.

In this paper, we present the complete design, simulation and experimental demonstration of a highly efficient MMI based silicon waveguide crossing. 2D finite-difference time-domain (FDTD) simulation was performed to optimize the device dimension and the resulting structure was verified by the 3D-FDTD method. High transmission efficiency of 98.5% (loss of −0.07 dB) and low crosstalk (< −43 dB) were predicted. The MMI waveguide crossing was fabricated with a grating coupler using electron beam patterning and one step inductively coupled plasma (ICP) reactive ion etching (RIE). The experiment results showed transmission loss of −0.1 dB per crossing and crosstalk better than −40 dB was obtained over a broad optical spectrum from 1520 nm to 1580 nm.

2. Device design and simulation

The operation of MMI waveguide crossing is based upon self-imaging [23], that is, reproduction of the input field at the crossing center and output plane. The self-imaging at crossing center counteracts the wave front expansion, thus mitigates the scattering loss and crosstalk of the cross junction. The device layout is shown in Fig. 1. Two MMI waveguides of width W_M, length L_M intersect with each other perpendicularly. Between the MMI

* Corresponding author.
E-mail addresses: xianyaoli@semi.ac.cn (X. Li), yudeyu@semi.ac.cn (Y. Yu).

0030-4018/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.optcom.2013.08.021

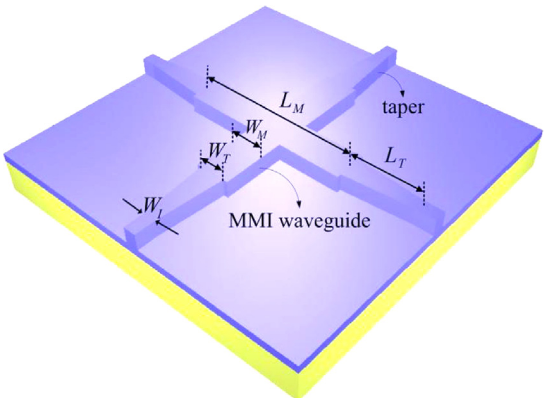

Fig. 1. 3D model of the MMI based waveguide crossing formed by one step etching.

region and single-mode input/output waveguides, four identically tapered waveguides of length L_T, maximum width W_T are introduced to reduce the transition loss.

To simulate and optimize the MMI based waveguide crossings, we implement the 2D-FDTD method with perfectly matched boundary conditions as a good approximation of the 3D devices, and this improves the working efficiency. Since the crossing performance is a function of multi variables (as shown in Fig. 1), such that it can be time consuming and inefficient for computing the structure as a whole. To circumvent this problem, we implement the method proposed in [25] by decomposing the MMI based crossing into the MMI intersection region and tapered waveguides, as shown in Fig. 2. Thereby, our efforts will be concentrated on optimizing the MMI region and finding the proper tapers respectively.

In our demonstration, the performances of crossing are characterized by using the grating couplers formed by one step etching. Single mode operation in the input and output waveguides is ensured with width W_I=450 nm, etching depth of 210 nm for a 340 nm thick top layer SOI wafer with a 2 μm BOX layer, and our design is based on these parameters, but it should be noted that the following procedures are generally applicable.

As a starting point, the MMI width W_M=1.8 μm was selected by utilizing the 3-D BPM method to support four TE modes, but only the two lowest order even guided modes were excited (the TE_{00} and TE_{02} modes) due to the structure symmetry [24,25]. To simulate the cross performance of the intersected MMI waveguides, continuous wave (CW) fundamental mode and the second order mode at the wavelength of 1.55 μm are used as the input fields, with a power ratio of η ($\eta=P_{02}/P_{00}$, P_{02} and P_{00} are the power of the second order mode and fundamental mode, respectively). Insertion loss is calculated as the power dissipated when passing through the cross junction, whereas crosstalk loss is characterized as the power coupled to the intersecting waveguides.

Fig. 2(b) shows the calculated results of the MMI intersection region with an increasing power ratio from 0 to 0.1. The ideal crosstalk loss value is achieved at a power ratio of 0.03. For $\eta<0.03$, the crosstalk loss is mainly attributed to the wave front diffraction of the fundamental mode, while at $\eta>0.03$, the second order mode possessing a wide angular spectrum suffers strong scattering through the crossing and results in the increased crosstalk loss. Due to the compromise of scattering loss and mode mismatch loss, the minimum insertion loss is presented at a power ratio around 0.05. As the minimum insertion loss and crosstalk cannot be reached at the same time, we chose a power ratio of 0.04 for our following discussion.

To reduce the transition loss between the single mode input/output waveguides (width of W_I=0.45 μm) and MMI waveguides (width of W_M=1.8 μm), tapers with a length of L_T=4.5 μm are introduced as shown in Fig. 2(c). Taper width W_T is of great importance during our simulation since it directly decides the self-image profile. To find the desired taper, we change its width W_T from 1.2 μm to 1.8 μm in steps of 0.1 μm and extract the power ratio by trial experiments: firstly, we note the mode field of the self-image as M_1 and record the mode field M_2, which is synthesized by the fundamental mode and the second order mode at a power ratio of η; after that evaluation of the similarities between M_1 and M_2 is carried out by computing the mode overlap integral with Matlab script, and we hold that M_1 and M_2 share the same η if the integral value is >98%. The extracted values are plotted in Fig. 2(d). When W_T increases, the self imaging profile is broaden, which indicates that more power of the input feild is converted to the fundamental mode of the MMI waveguides; thus a reduced power ratio η is expected. To achieve a power ratio of 0.04, we see that a taper width W_T=1.45 μm will meet our requirement.

As indicated in [25], the phase difference between TE_{00} and TE_{02} modes can also have an effect on the effective beat length of MMI waveguides, such that after we integrated the MMI intersection region with tapered waveguides, an MMI length (L_M) optimization was carried out to achieve maximized performance, with the self-image formed at the crossing center. The simulated field distribution of 2D TE mode is shown in Fig. 3(a). To confirm and further refine the design, we implement the 3D FDTD method of the Lumerical Solution and the calculated results predict high transmission efficiency of 98.5% (loss of 0.07 dB) and low crosstalk (< −43 dB) at the wavelength of 1550 nm, as shown in Fig. 3 (b) and (c), respectively. As a reference, a direct waveguide crossing and an elliptical waveguide crossing (with the radius of 6 μm and 1 μm for the major axis and minor axis, respectively) were also simulated and their transmission profiles are shown in Fig. 3 (d) and (e). The simulation results suggest that the direct waveguide crossing has a high insertion loss of 0.8 dB and crosstalk of −21 dB, while the elliptical waveguide crossing has a relatively high loss of 0.5 dB and crosstalk of −38 dB at a wavelength of 1550 nm. It is evident to see that the MMI based waveguide crossing shows better performances when compared with the other two type of crossings.

3. Fabrication and experiment results

The MMI based waveguide crossings and grating couplers were fabricated on an SOI wafer with a 340 nm silicon top layer and a 2 μm BOX layer. The designed grating couplers have a width of 12 μm, a grating period of 600 nm and a filling factor of 50%. The devices were patterned in hydrogen silsesquioxane (HSQ) by electron beam lithography and then transferred into the top silicon layer by RIE, with an etching depth of 210 nm. After that the samples were coated with a 1 μm thick SiO_2 layer by plasma-enhanced chemical vapor deposition (PECVD) to prevent measurement errors induced by dusts and airflow disturbances. To determine the loss per crossing, we implemented the testing structures with 1, 10, 20, 30 and 40 crossings, while the crosstalk was characterized from the cross state of the first crossing structure, as shown in Fig. 4(a–d) presents scanning electron microscope (SEM) images of the fabricated grating coupler and MMI based waveguide crossings. The actual dimensions were measured by a Raith 150 and results showed a fabrication bias of 20 nm from our design.

We characterized crossing performances by vertical coupling a tunable light source (AQ2200-136, yokogawa) into silicon waveguides using conventional single mode fibers, and a polarization controller was used to ensure TE mode input. The output signal is monitored by a wideband optical spectrum analyzer (AQ6370C, yokogawa). We measured the testing structures with 1, 10, 20, 30

Download English Version:

https://daneshyari.com/en/article/7931884

Download Persian Version:

https://daneshyari.com/article/7931884

Daneshyari.com