Multimode Interference Based Ultra-Low Loss Silicon Waveguide Crossing

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***Abstract*—We design and fabricate waveguide crossing arrays based on optimized multimode interference. Insertion loss of ~0.02dB per crossing and crosstalk <-40dB at 1550nm operating wavelength and broad transmission spectrum of 90nm are experimentally demonstrated.**

Keywords-Waveguide crossing; multimode interference; subwavelength nanostructure

I. INTRODUCTION

High-performance waveguide crossing is a key building block of silicon photonics for on-chip optical interconnects. Due to the high index contrast of the silicon-on-insulator (SOI) platform, single mode silicon waveguide crossings with normal intersections result in over 1dB loss and ~-10dB cross-talk [1, 2]. This issue has been addressed by several groups over the past decade. Multimode interference (MMI) based crossings with relatively compact sizes (13x13μm^2) have been demonstrated with insertion loss of ~0.2dB [2, 3]. In this type of structures, the self-focusing effect of the MMI is used to form a single image of the MMI input waveguide mode profile at the crossing thus minimizing the effect of the crossing waveguide on the mode profile. Recently, using 2D finite difference time domain (FDTD) simulations it was theoretically shown that a periodic structure formed by cascading multimode focusing sections can support a low-loss Bloch wave [4]. In addition to the fact that this structure can potentially lower the insertion loss to 0.04dB per crossing, a waveguide pitch ~3μm also enables compact waveguide crossing arrays.

In this paper, we design a waveguide crossing structure with a theoretical insertion loss of 0.008 dB per crossing. We fabricate waveguide crossing arrays consisting of up to 300 crossings, and experimentally demonstrate a record-low insertion loss of 0.019 dB per crossing, allowing integration of 100s of waveguide crossings with minimal insertion loss and cross-talk. The waveguide crossing arrays also feature ultra-compact size with a pitch of 3.08μm and broad transmission spectrum of 90nm.

II. DEVICE DESIGN

The platform is a SOI substrate with 3μm thick buried oxide (BOX) layer and 250nm thick top silicon layer (n_f=3.47). A schematic of the waveguide crossing array is shown in Fig. 1(a). This arrayed structure may be thought as a cascaded MMI based waveguide crossing, in which, according to the self-imaging principle of multimode waveguides, images of the input field are periodically formed along the multimode waveguide. It has been proposed that the multimode waveguide can be crossed by another one at the points where single-fold images are formed [2]. Similar to a previously reported design [4], here we assume the multimode waveguide width, W_{MMI}=1.2μm, and input/output single mode waveguide width, W=0.6μm. Linear tapers (L_t=1μm) are used for high transmissions as suggested by Chen et al [3]. We sweep L_{in}, L_s, and lateral cladding index (n_c) for the structure shown in Fig. 1(a). The simulations are done using 3D PhotoDesign FIMMPROP, an eigenmode decomposition based simulator. In these simulations, we maximize the transmission for the structure with 20 crossings, as shown in Fig. 1(b). An optimized design of L_{in}=2.27μm and L_s=1.88μm for n_c=2.5 leads to a insertion loss of 0.008dB per crossing.

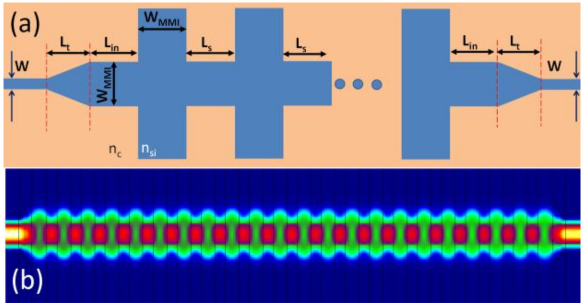

Figure 1. (a) schematic of the waveguide crossing array, (b) simulated waveguide crossing array.

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III. DEVICE FABRICATION

The designed structures are fabricated on a SOI wafer using electron beam lithography (EBL) and reactive ion etching (RIE). A schematic of the cross-sectional structure is shown in Fig. 2(a). In order to implement n_c>1, subwavelength nanostructure (SWN) is used to engineer the lateral cladding refractive index [5]. The SWN is periodic along the light propagation direction, and its refractive index (n_{SWN}) can be engineered by tuning the filling factor (ff) of air trench inside the SWN, which is defined as the ratio between the air trench width (W) and the SWN period (Λ). We use Λ=200nm for the SWN to fabricate devices with W=30, 40, 50, 60, 70 and 80nm. The width of the SWN is 200nm to accommodate the field penetration into the lateral cladding. A scanning electron microscope (SEM) image of the waveguide crossing structure with SWN is shown in Fig. 2(b).

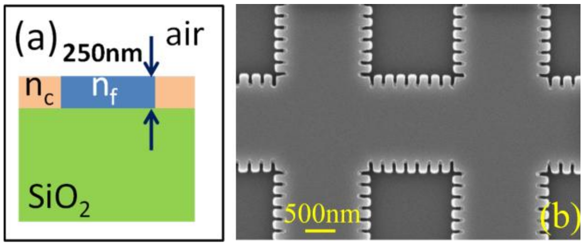

Figure 2. (a) schematic of the cross-sectional structure, (b) SEM image of the waveguide crossing structure with SWN.

IV. DEVICE CHARACTERIZATION

Transverse electric (TE) polarized light from a broadband amplified spontaneous emission (ASE) light source is coupled in and out of the cross-grid using SWN based grating couplers [6]. The transmissions obtained from the waveguide crossings arrays are normalized to the transmission of a reference waveguide with the same propagation length. We experimentally find that the index-engineered MMI crossing with W=50nm had the best performance. Fig. 3 shows the normalized transmissions of waveguide crossings arrays with 100, 200, and 300 cascaded waveguide crossings, respectively. The cross-talk measured from a crossed waveguide in the middle of the array is also shown in Fig. 3.

The results show that the index-engineered MMI crossing has an insertion loss of 0.019dB at 1550nm operating wavelength. The cross-talk signal is below the noise floor of our testing system, so the exact cross-talk cannot be extracted from the transmission. However, the estimated cross-talk is at -40dB level over 1520-1610nm wavelength range. Besides the ultra-low insertion loss and low cross-talk, cascading index-engineered MMI crossings enable a crossing pitch of 3.08μm in a waveguide crossing array, which is the most compact footprint for a non-resonant crossing to our knowledge.

V. CONCLUSION

In summary, while the high-index-contrast of the SOI platform allows small footprints for photonic devices, it also makes excess loss reduction and cross-talk suppression challenging. An ultra-low loss waveguide crossing structure with a waveguide pitch of only 3.08μm has been demonstrated on SOI platform. The crossing structure, utilizing cascaded index-engineered MMIs, has insertion loss of 0.019dB and crosstalk lower than -40dB at 1550 operating wavelength, and broad transmission spectrum over more than 90nm bandwidth.

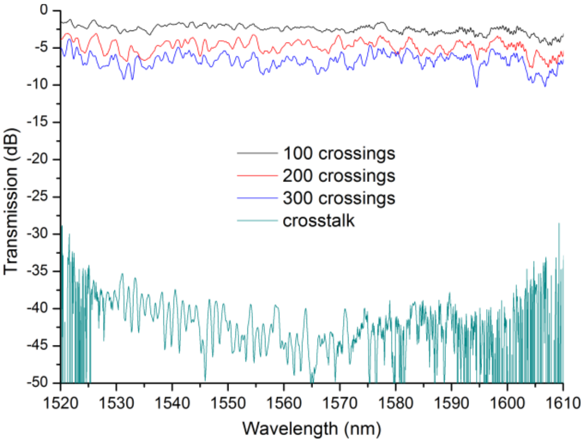

Figure 3. Measured transmission and crosstalk of the waveguide crossing arrays.

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