Steerable Free Space Optical Interconnect with Corrugated Waveguide Gratings Optically Isolated by 2D Photonic Crystal

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***Abstract*-An optical phased array of corrugated waveguide gratings is fabricated to realize free space optical interconnects with wavelength routing. A 2D photonic crystal is experimentally shown to prevent optical crosstalk between closely spaced array elements.**

Keywords—SOI, photonic crystal, optical phased array

I. INTRODUCTION

Free space optical interconnects are of interest for applications in which beam steering elements are used to route optical signals between two ends of a link. These types of interconnects include long distance applications such as between satellites or from aircraft to ground based targets. Free space optical interconnects can also be used over shorter distances such as in high performance computing systems for chip to chip or board to board optical communications. Optical phased arrays (OPAs) integrated on chip can provide agile and precise beam steering in free space without any moving parts.

Recent optical phased arrays achieve free space optical beam steering through shallow etched gratings [1-3]. Although shallow etching achieves a narrow beamwidth in the far field by reducing a silicon grating's inherently large index contrast, precise etching control is required; otherwise, the beam profile is compromised. Furthermore, shallow etching requires multiple lithography steps in order to pattern the shallow etch grating and the rest of the photonic circuit, which is typically etched completely through the silicon, thereby increasing the complexity and cost of such a device.

In optical phased arrays, closely spaced elements allow for greater steering/routing spread, but as with all optical interconnects, element density is limited by crosstalk. Inter-element isolation is necessary to maximize element density.

In this work, an optical phased array of corrugated waveguides that function as grating couplers is fabricated in a single etch step. Introducing this structure as a grating coupler is advantageous for precise control of the grating strength, as the index contrast is lithographically controlled.

In addition, a 2D photonic crystal slab is used to prevent optical cross talk between adjacent array elements in the waveguide array by providing optical isolation of each element. To our knowledge, this is the first demonstration of such isolation.

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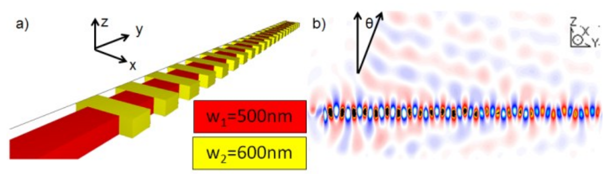

Fig. 1. (a) Schematic of a corrugated waveguide. (b) Simulation of corrugated waveguide cross section showing grating emission.

II. DESIGN AND SIMULATION

A schematic of such a corrugated waveguide is shown in Figure 1 (a). The corrugations are comprised of alternating waveguide widths w_1 and w_2, which have different effective indices and can be used to determine angle of emission, governed by the phase matching condition $\sin\theta = \frac{n_{eff,avg}\cdot\Lambda - \lambda}{\Lambda\cdot n_c}$, where θ is the steering angle in the YZ plane, $n_{eff,avg}$ is the average effective refractive index of the grating, Λ is the grating period, n_c is the refractive index of the cladding, and λ is the operating wavelength. 3D Finite Difference Time Domain (FDTD) is used to simulate a single corrugated waveguide with w_1=500nm, w_2=600nm, and Λ=700nm for Transverse Electric (TE) polarized light. The E_y field is shown in the cross sectional view of Figure 1(b).

For large angle optical beam steering, it is necessary that the element spacing be reduced to about half the operating wavelength [4]. For optical waveguides with λ/2 spacing, the strong coupling between adjacent waveguides results in optical crosstalk and jeopardizes the far field pattern. This limits the minimum spacing, as shown in [1]. Moreover, corrugated waveguides themselves also function as a grating in the lateral direction, thereby enhancing the coupling to adjacent elements

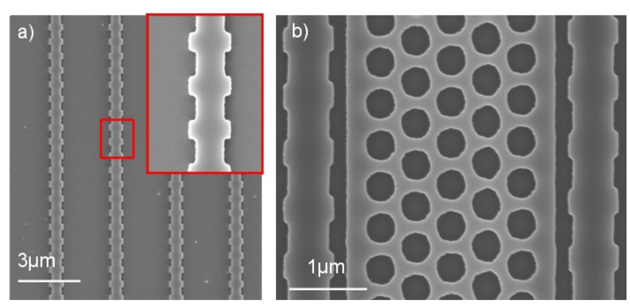

Fig. 2. (a) Top down SEM of 4 elements of the OPA with no photonic crystal slab. (b) Top down SEM of 2 elements in the OPA separated by photonic crystal slab.

in the phased array, similar to the phenomenon exhibited in grating assisted directional couplers. This optical crosstalk necessitates that the element spacing be increased, which is undesirable due to the reduction in steering angle.

In order to prevent this optical crosstalk without increasing the element spacing, it is necessary to block lateral coupling from the corrugated waveguide to the adjacent element. Thus, a 2D photonic crystal slab with a bandgap in the wavelength range of interest, which is from 1480-1580nm for our application, is inserted between each pair of corrugated waveguides to provide optical isolation of each array element.

For our OPA, input light is coupled on chip via a broadband subwavelength grating coupler that has a 3dB bandwidth of 125nm. The light is split into 16 uniform outputs by 4 levels of cascaded 1x2 multimode interference (MMI) optical beam splitters, which are fed into the 16 element array composed of corrugated waveguides with 4μm spacing.

III. FABRICATION AND EXPERIMENTAL RESULTS

We use silicon-on-insulator (SOI) with a top silicon layer of 250nm and 3μm Buried Oxide (BOX). The photonic circuit is patterned by a single electron beam lithography and Reactive Ion Etch (RIE) step. Top down SEMs of the corrugated waveguide without and with photonic crystal are shown in Figure 2 (a) and (b), respectively.

To test our device, TE polarized light from a polarization maintaining fiber (PMF) is coupled into the input grating coupler. The far field pattern is directly observed on an IR CCD that is suspended 5cm above the device.

We first observe the far field pattern of a single corrugated waveguide, which forms the envelope for the array. By tuning the wavelength from 1480nm to 1580nm, we observe the expected steering with excellent agreement, as shown in Figure 3(a). For this wavelength range, we achieve over 15° of steering. Some representative far fields of the corrugated waveguide are shown at different wavelengths in Figure 3(b).

We also test the two OPAs with and without the photonic crystal in between adjacent elements. Figure 4(a) shows the far field pattern of the 16 element OPA with 4 micron spacing without any photonic crystal in between. As can be seen,

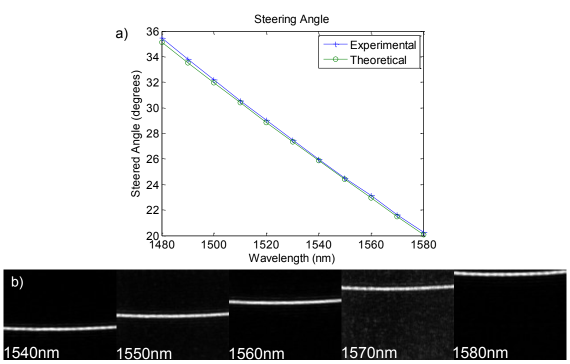

Fig. 4. (a) Experimental and theoretical steering angle as a function of wavelength. (b) Far field patterns of a single corrugated waveguide showing steering for different wavelengths.

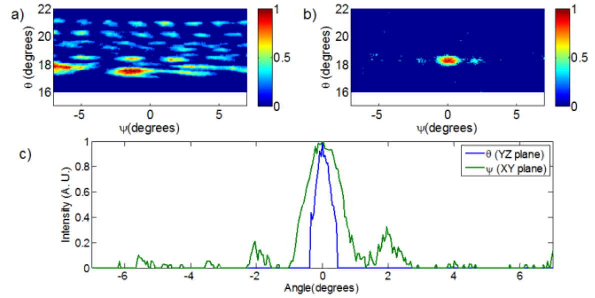

Fig. 3. Far field pattern of the OPA without (a) and with(b) photonic crystal slabs between adjacent elements. (c) Intensity profile of the far field beam spot for horizontal and vertical directions.

multiple bands in the far field indicate light with different effective indices being emitted. This is due to optical crosstalk and the associated supermodes which have slightly different propagation constants from each other. These small differences in effective refractive index will cause the light to be emitted at slightly different angles, again according to the phase matching condition, and ultimately scrambling the far field pattern.

Figure 4(b) shows the far field of the same OPA but with the 2D photonic crystal slab inserted between each array element. It can clearly be seen that only a single spot is present, which shows the photonic crystal is successful in blocking the laterally coupled light from the corrugated waveguides, thereby preventing optical crosstalk. The intensity profiles for the θ and ψ (XY plane) directions are shown in Figure 4(c), and we determine that the FWHM beam widths are ~1° and ~0.5°, respectively. The presence of the small sidelobes in the ψ direction is due to random phase errors from fabrication imperfections, and can be reduced with thermo-optic phase tuning as demonstrated by [1-2].

IV. CONCLUSION

We demonstrate the corrugated waveguide as a free-space grating coupler suitable for optical beam steering/routing by implementing it in a 16 element OPA. 2D photonic crystals are used to provide optical isolation of each array element, thus eliminating optical crosstalk, which is confirmed by the far field pattern.

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