Polarization Rotator Terahertz Photonic Crystal Slab Waveguide

Khadijeh Bayat, Sujeet K. Chaudhuri, and Safieddin Safavi-Naeini
University of Waterloo, Waterloo, ON, CA

***Abstract*— A Silicon based periodic asymmetric loaded photonic crystal polarization rotator for THz frequency band has been introduced and analyzed. The polarization rotator structure consists of a single defect line photonic crystal slab waveguide with asymmetrical top cladding layer. The top cladding layer is silicon. To maintain phase matching condition, the top cladding layer is alternated on either side of the defect line periodically. Complete polarization rotation is achieved over the propagation length of 15λ, 7.5mm. A new fabrication technique was developed to realize photonic crystal slab structure on SOI wafer. The fabrication process consists of deep reactive ion etching of the SOI layer and anisotropic wet etching of the handle Si layer.**

I. Introduction And Background

THz signal generation, guidance, manipulation and detection all can be integrated in a photonic crystal (PC) based integrated circuit [1]. One of the crucial elements in THz integrated circuits is the polarization rotator that control and manipulate the polarization of the propagating wave. Here, we introduce a novel polarization rotator based on photonic crystal (PC) structures for THz frequency band. The proposed structure is very compact and consists of a single defect line Silicon PC slab waveguide. To couple two orthogonal polarizations to each other, a geometrical asymmetry was introduced on the upper cladding layer of the defect line. The cladding layer is silicon that has been etched asymmetrically. In order to apply phase matching condition between the two polarizations, the upper cladding layer is alternated on either side of z-axis (propagation direction) with the given period. Figure 1 is the sketch of the proposed structure. From now on, the proposed structure is described as periodic asymmetric loaded PC slab waveguide. By employing silicon as the cladding layer not only shorter coupling length has been achieved but also the fabrication process has been facilitated. The length of the proposed device is 15λ.

II. Design and Simulations

To analyze the PC polarization rotator structure, the coupled mode theory based on the scalar modes of the asymmetric loaded PC slab waveguide is employed. The vector wave equation for the transverse electric field (x-y and z are the transverse and propagation directions, respectively) is [2]:

$$\frac{\partial^2 e_x}{\partial z^2}+\nabla_t^2 e_x+n^2k^2e_x=-\frac{\partial}{\partial x}(e_x\frac{1}{n^2}\frac{\partial n^2}{\partial x})-\frac{\partial}{\partial x}(e_y\frac{1}{n^2}\frac{\partial n^2}{\partial y})$$

$$\frac{\partial^2 e_y}{\partial z^2}+\nabla_t^2 e_y+n^2k^2e_y=-\frac{\partial}{\partial y}(e_x\frac{1}{n^2}\frac{\partial n^2}{\partial x})-\frac{\partial}{\partial y}(e_y\frac{1}{n^2}\frac{\partial n^2}{\partial y}) \quad (1)$$

where n is the refractive index distribution of the waveguide . The vector properties are manifested on the right hand side of the equation (1), which indicate that the two orthogonal polarizations with different propagation constants can be coupled to each other. The vector correction terms are considered as perturbations for the scalar modes. Thus, the scalar modes will couple to each other as the result of vector correction terms. The scalar modes are calculated employing the scalar wave equation; the right hand side of equation (1) is zero for scalar wave solution.

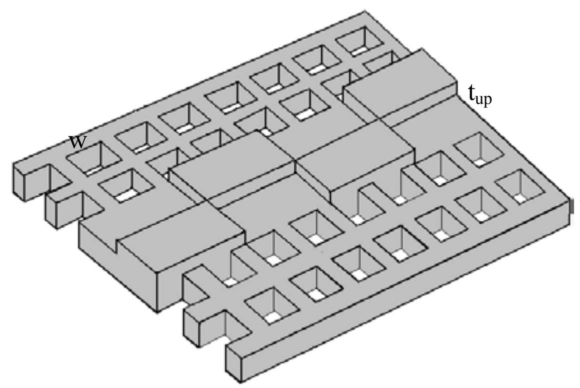

Figure 1. The sketch of the asymmetrically loaded PC slab waveguide based polarization rotator

So, to analyze the structure, first the scalar modes of the asymmetric loaded PC slab waveguide are calculated using scalar three-dimensional beam propagation method (3D-BPM). The next step is to calculate the coupling between scalar modes of the two orthogonal polarizations using coupled-mode theory. The coupled-mode equations for the amplitudes of the two polarizations is as following [3]:

$$\frac{da_x(z)}{dz}=-j\kappa_{xx}a_x(z)-j\kappa_{xy}a_y(z)$$
$$\frac{da_y(z)}{dz}=-j\kappa_{yy}a_y(z)-j\kappa_{yx}a_x(z) \quad (2)$$

Where, $a_y(z)$ and $a_x(z)$ are the z-varying amplitudes of the x-polarized and y-polarized waves. Assuming that the cross-coupling coefficients are equal $k_{xy}=k_{yx}=k$, which is a valid assumption, the coupled-mode equation (2) can be solved analytically using transfer matrix method.

III. Results and Discussions

In this structure, Figure 1, the unit cell, the width of the square holes, the thickness of the silicon, the thickness of the upper cover layer are represented by a, w, t and t_{up}, respectively. The refractive indices of the silicon (n_{si}), t, t_{up} and w are 3.48, 0.8a, 0.4a and 0.6a, respectively. Having

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assigned the normalized frequency of 0.285 to f=600 GHz, the unit cell size would be a=142.5 μm. The normalized electric field distribution of the scalar mode calculated using 3D-BPM , Figure 2, is asymmetric in both vertical and lateral directions as a result of the geometrical asymmetry.

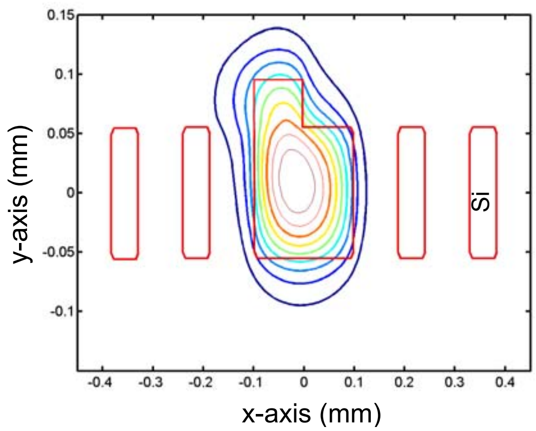

Figure 2. Transverse electric field distribution

The loading period is calculated and it is 5. Figure 3 shows the power exchange between the two polarizations along the propagation distance. It is seen that the complete coupling takes place after 15λ that is 7.5 mm. The discontinuity observed at the curves of P_x and P_y can be explained as following. After almost half of the coupling length propagation where almost half of the power was exchanged between the polarizations, P_x started going up; thus, the maximum power exchange rate would have been 50%, if the structure remained the same. However, instead of alternating the top cladding layer to the other side of the defect line, it is repeated for another period at the same side and then it was alternated as depicted. Therefore, complete power exchange was accomplished as seen in Figure 3.

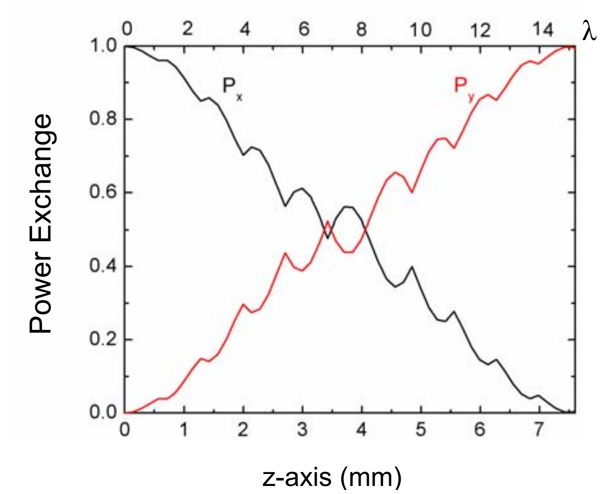

Figure 3. Power exchange between the x-polarized and y-polarized wave versus the propagation length (t=0.8a, t_{up}=0.4a, w=0.6a, a=142.5 μm, f=600 GHz)

IV. Fabrication

Here, the fabrication process implemented for the fabrication of THz PC membrane waveguide structure is explained which is used to implement the PC polarization rotator structure, as well. SOI wafer were used for implementation of PC membrane waveguide. The device layer is highly resistive silicon to maintain ultra low loss propagation. The etching of the holes was carried out using an optimized Bosch deep reactive ion etching (DRIE) process to create holes with smooth vertical side walls and desired aspect ratio. Figure. 4 shows the cross section of the PC silicon waveguide membrane.

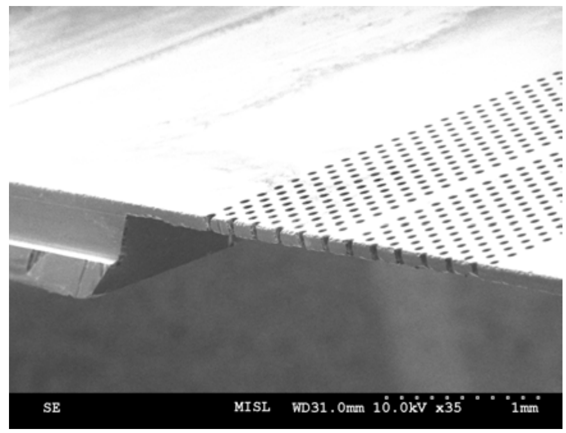

Figure 4: SEM picture of the cross section of the fabricated THz membrane PC slab waveguide

V. Conclusions

A compact silicon based periodic asymmetric loaded photonic crystal polarization rotator for THz frequency band has been introduced and analyzed. Complete polarization rotation was achieved over the propagation length of 15λ. A new fabrication process was developed for implementation of membrane PC slab structure.

VI. ACKNOWLEDGEMENT

Authors would like to acknowledge NSERC, RIM and OEC support for this work.

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