Comparative Analysis of Cross Gap Coupler for high index Contrast waveguides

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Abstract: - In this article, cross gap coupler (CGC) structures are introduced. These couplers were designed using silicon waveguide suitable for highly compact integrated optical circuits. The Si photonic wire waveguide is a channel waveguide consisting of a Si core with an extremely small cross section and a surrounding SiO_2 cladding material. CGC's were designed for three different angles namely 40, 50 and 60 degrees. The different structures of CGC were simulated by two-dimensional finite-difference time-domain (2-D FDTD) method. The splitting ratio and the excess-loss for these structures were analyzed for their comparative performance analysis.

Index terms: Cross gap coupler, Finite difference time domain method, splitting ratio, comparative analysis.

1. Introduction

Planar light wave circuits were optical integrated circuits (ICs) or optical circuit boards, which usually perform their functions in the optical domain. Planar light wave circuit's uses optical waveguides to route photons in the similar way as the metal traces were used to route electrons in electronic ICs and circuit boards. The high refractive index contrast waveguides assists in designing the efficient and compact optical components, which can be very useful for making the planar light wave circuits.

In recent years, many photonics devices have been designed using the silicon and related components because it enables the use of well-developed Si processing technologies as well as Si substrates that were cheaper than the other semiconductor (GaAs or InP) substrates to fabricate a broad range of optical devices e.g. light emitters, photo-detectors, optical switches, optical passive components, and nonlinear optic devices [1-4].

The index contrast between the Si core and silica cladding (Δ) is of 40% order. Therefore, the strong optical confinement in the Si core makes it possible to bend the waveguide with a curvature of micrometer or nanometer order. In this work, we have presented the design of Cross Gap Couplers [5] using Si waveguides with coupling gap angle (θ) between the crossing waveguides, of 30˚, 40˚, 50˚ and 60˚. Their wavelength dependent properties, splitting ratio and excess loss are evaluated. Performance analyses of the cross gap couplers were done with Multi Mode Interference couplers (MMI) and Directional Couplers (DCs). All structures are evaluated using the finite difference time domain (FDTD) method [6].

2. Cross Gap Couplers

When light travels from a denser medium to rarer medium in such a way that the angle of incidence is greater than the critical angle the light completely reflects back into the transmitting medium i.e. is into the denser medium. This process is known as total internal reflection. But an important effect of total internal reflection is that an evanescent wave propagates across the boundary surface, because at the nanoscale level it was evaluated that 100 % incident light was not reflected back into the incident medium. This evanescent wave attenuates exponentially and travels in the less dense medium. This wave has negligible energy and gets attenuated out after travelling even few wavelength distances, hence not much was done for it. However, if a third medium with a higher refractive index than the low-index second medium is placed within less than several wavelengths distance from the interface, the evanescent wave will be different from the one under ordinary conditions and it will pass energy across the second into the third medium. This process is called "frustrated" total internal reflection (FTIR).

In the cross gap coupler this novel concept have been used and the nearby (cross) waveguide was separated by few wavelength distances from the interface (between the first and the second medium).Hence light travels from one waveguide to another waveguide.

2.1 Basic layout

The cross gap coupler consists of two silicon waveguides crossing each other at some specified angle. As shown in the figure 1, we have designed the cross gap coupler of 30, 40, 50 and 60 degrees. The crossed portion of the two waveguides was replaced by silica material which acts as half mirror or corner mirror at a particular wavelength. The refractive index of silicon waveguide was 3.48 and that of silica material was 1.46.

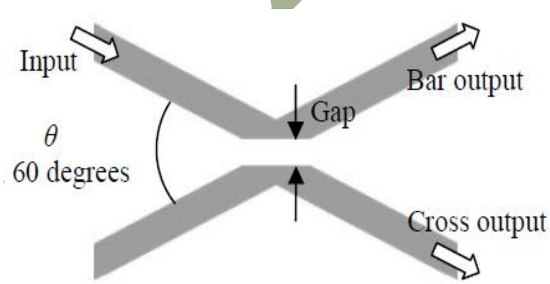

Figure1. Basic structure of a CGC

The gap dimensions were important design parameter in the cross gap coupler because it was due to the gap that at the wavelength of 1.5µm we got equal power in between the between the bar and cross waveguides. In another words, this gap functions as a half mirror or a corner mirror [7-9] for a particular wavelength.

2.2 Design steps and specifications

The input power of 1mW is launched in the input waveguide and the output is obtained across the two waveguides as shown in the figure 2. The output across the throughput port was termed as bar output and the output across the coupled port was termed as cross output. Once the input power was launched in the silicon waveguide, we measure the variations in the cross and bar output with the change in the input wavelength.

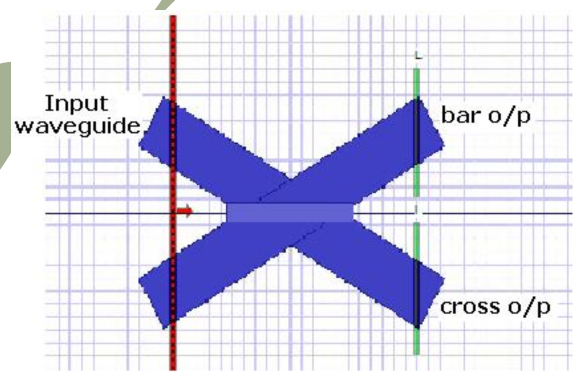

Figure 2. Fundamental layout with output states

Here the important issue was the power dependence of cross and bar output with wavelength because with the shift in the wavelength the splitting ratio fluctuates and the design no longer works as splitter. In the case of switch unwanted power enters the waveguide and this problem should be solved so that the complex planar light wave circuits (PLCs) can work effectively and efficiently [10]. Here after designing the cross gap coupler of different angles between the two waveguides we study the output power dependence on wavelength characteristics. The cross gap coupler with minimum variation in power with wavelength and small excess loss was used as a basic building block for the planar light wave circuits. So in the coming layout sections the main focus will be on finding an angle between the two waveguides such that we get minimum power variations with respect to wavelength and minimum losses. The width of the core was 0.45 µm and the length and width of gap were 1.10 µm and 0.158 µm respectively. This small gap causes the light to split into two waveguides namely cross and bar waveguides and depending on the input wavelength the splitting ratio varies.

3. Simulation and Results

We have checked the propagation losses (dB/mm) and splitting ratio occurred in above discussed CGC with different cross gap angles. All structures are simulated using FDTD methods with transparent boundary condition for TM polarized input light of centre wavelength of 1.55µm. For example, the bar output in the figure 3 signifies the dBm value of the output power taken across the bar(or through port) waveguide while the cross output signifies the dBm value of the output power taken across the cross(or coupled port) waveguide. All these output values are taken for the wavelength ranging from 1.5 to 1.6 µm.

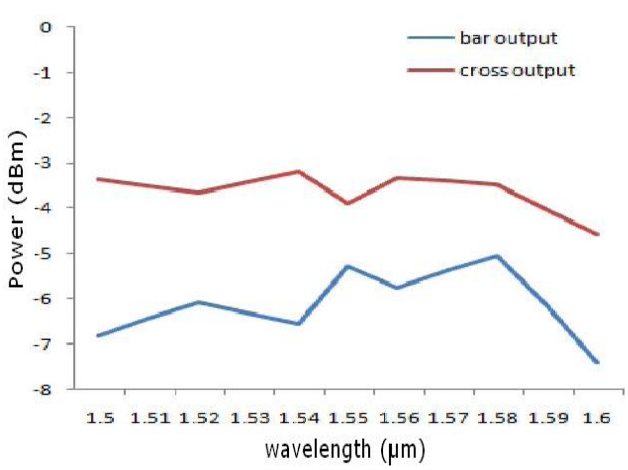

Figure 3. Output powers for bar and cross port as functions of the wavelength of 30˚ CGC

Figure 4 and 5 depicts the detailed comparative analyses for excess losses and splitting with respect to wavelength variations for the modelled CGCs, while having different cross gap angles, i.e. with 30°, 40°, 50°, and 60° angles. The cross gap coupler with the 50 degree angle has the least variation in the splitting ratio for the wavelength range of 1.5µm to 1.6µm and was best for designing the planar light wave circuits.

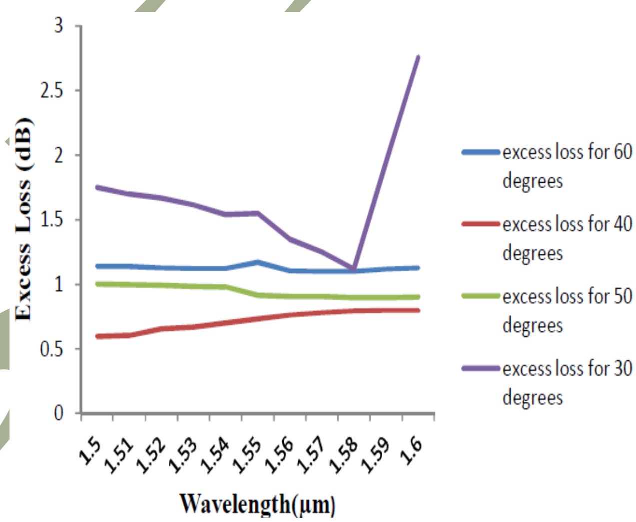

Figure 4. Excess loss comparison of CGCs with 30°, 40°, 50°, and 60° angle

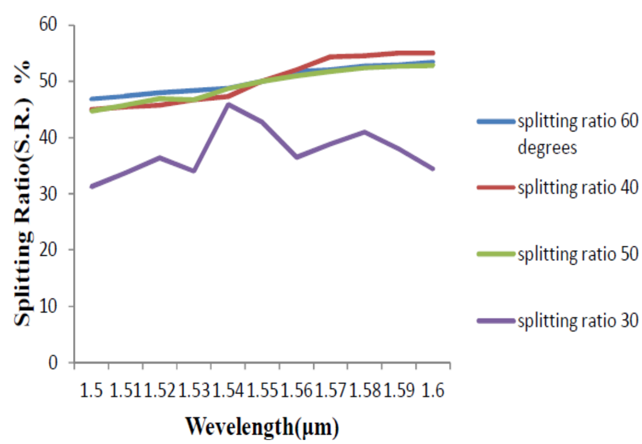

Figure 5. Splitting ratio comparison of CGCs with 30°, 40°, 50°, and 60° angle

4. Conclusions

With the aim of exploring new layout of CGCs and to optimize their excess loss and wavelength dependence of the splitting ratio for application in planar light wave circuits are explained. Following observation can be concluded with this work.

- Cross gap coupler of 40 degree has least excess loss among all other cross gap coupler.
- Cross gap coupler of 60 degree has least variation in splitting ratio and best wavelength dependence characteristics.
- The cross gap coupler of 30 degree has large excess loss and has poor wavelength dependence characteristics while for 50degree excess loss and splitting ratio variations were moderate.

Hence, cross gap coupler with 50 degree with moderate excess loss and moderate variation in splitting ratio was found to be best for designing the planar light wave circuits with silicon on insulator substrates.

References

[1] L. Pavesi, "Will silicon be the photonic material of the third millennium?," J. Phys., condens. matter, vol. 15, pp. r1169–r1196, 2003.

[2] B. Jalali, S. Yegna narayanan, T. Yoon, T. Yoshimoto, I. Rendina, and F. Coppinger, "Advances in silicon-on-insulator optoelectronics," IEEE journal of selected topics in quantum electronics, vol. 4, no. 6, pp. 938–947, Nov.–Dec. 1998.

[3] L. C. Kimerling, "Silicon micro photonics," Appl. Surf. Sci., vol. 159–160, pp. 8–13,2000.

[4] G. T. Reed, "The optical age of silicon," Nature, vol. 427, pp. 595–596, 2004.

[5] D. Tanaka, Y. Ikuma, H. Tsuda, K. Kintaka "Comparative Simulation of Three Types of 3-dB Coupler Using a Si Wire Waveguide," 978-1-4244-7057-2010 IEEE.

[6] OptiFDTD, "Technical Background and Tutorials Finite Difference Time Domain" Photonics Simulation Software. 2008.

[7] L. Li. G. P. Nordin, J. M. English, and J. Jiang, "Small-area bends and beam splitters for low-index-contrast waveguides," Opt. Exp., vol. 11, no. 3, pp. 282-290, Feb., 2003.

[8] E. J. Norberg, J. S. Parker, U. Krishnamachari, R. S. Guzzon, and L. Coldren, "InGaAsP/InP based Flattened Ring Resonators with Etched Beam Splitters,"OSA/IPNRA/NLO/SL 2009, iwa1, July 12-17, Honolulu, Hawaii, 2009.

[9] R. U. Ahmad, F. Pizzuto, G. S. Camarda, R. L. Espinola, H. Rao, and R. M. Osgood, "Ultracompact Corner-Mirrors and T-Branches in Silicon- on-Insulator," IEEE Photon. Technol. Lett., vol. 14, no. 1, pp. 65-67, Jan., 2002.

[10] R. A. Forber and E. Marom, "Symmetric directional coupler switches," IEEE J. Quantum Electron., vol. qe-22, no. 6, pp. 911–919, Jun. 1986.