Novel Design of Two-Dimensional Grating Couplers with Backside Metal Mirror in 250 nm Silicon-on-Insulator

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***Abstract*—We present the design of two-dimensional grating couplers working as polarization splitter in a 250 nm silicon-on-insulator platform. Optimized dimensions of two grating structures with circular and square etched holes are simulated achieving coupling efficiencies of -1.8 dB and -1.9 dB, respectively. A further optimization leads to a novel two-dimensional coupler with aperiodic gratings and rectangular etched holes showing a coupling efficiency of -1.7 dB at 1.55 µm.**

I. INTRODUCTION

Over the last years, integrated silicon photonic circuits have been developed and improved for their application in communication technology. The silicon-on-insulator (SOI) technology appears as a promising solution to fabricate photonic devices due to the compatibility with the low cost CMOS fabrication process and the large refractive index difference between Si and SiO_2, which allows compact devices.

However, there are still some problems regarding this technology. The reduction of size implies a challenge on how to couple the light between optical fibers and integrated silicon waveguides. The diameter of the single mode fiber core is around 10 µm while the standard single mode SOI waveguide has a size of around 400 nm x 250 nm. This introduces losses due to a small mode overlap. Another important feature is the polarization dependence of the optical devices, which usually demands for only one well defined and controlled input polarization.

One of the solutions to bridge the gap between optical fibers and photonic integrated circuits is the use of grating couplers (GC). These Bragg structures are able to diffract the incident vertical light coming from the fiber into horizontal integrated waveguides. The highest coupling efficiencies of about -0.6 dB reported to date correspond to aperiodic one-dimensional (1D) GCs with backside metal mirror [1, 2]. Another type of 1D grating can be used to couple the light and split two orthogonal fiber polarizations into two independent transversal electric (TE) and transversal magnetic (TM) modes [3]. Going even further in the design of grating structures, two-dimensional (2D) GCs are a solution to couple the light and at the same time split two perpendicular polarizations (s and p) into two TE modes. The optimization of these structures to make them highly effective has become a challenge in the design of grating couplers in different technologies. Theoretical coupling efficiencies of -1 dB and -1.8 dB are simulated and published in [4] for Si-layer thicknesses of 160 nm and 400 nm, respectively. On double-SOI substrates a focusing 2D grating with a loss below 2 dB at 1480 nm is measured in [5]. In this work different designs are presented to achieve a high coupling efficiency of two orthogonal polarizations and a wide optical bandwidth without the need of special processing steps.

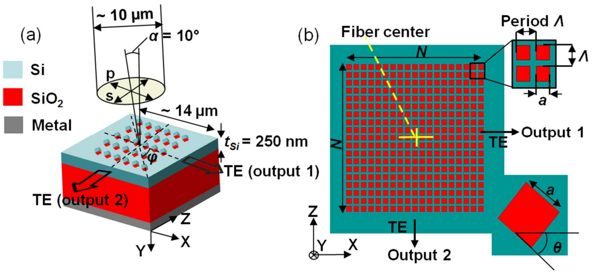

Fig. 1. (a) Scheme of the 2D grating coupler and the optical fiber. (b) Top view of the grating structure with cuboid holes (squares in the XZ-plane).

II. DESIGN AND SIMULATION

Fig. 1 shows the schematic view and the dimensions of the simulated 2D GC for an SOI-wafer. The Si thickness t_{Si} is 250 nm above a 3 µm buried oxide (BOX) layer. The etch depth of the holes is 70 nm. The backside metal mirror is located under the BOX layer to increase the coupling efficiency [6]. The structure is passivated with a 1 µm thick SiO_2 layer.

An improvement in the performance of the gratings, thanks to the use of aperiodic structures, is demonstrated in previous studies of 1D GC [1–3]. In this work a similar technique is applied in the design of the 2D GCs. The concept behind the design of aperiodic gratings is the modification of the diffracted field profile of the grating to diminish the mismatch with the field profile of the optical fiber.

Firstly, periodic 2D gratings are developed for the 250 nm SOI-platform. A first structure with cylinders as holes has been enhanced to achieve an optimized coupling efficiency. The simulations are realized using the three-dimensional (3D)

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finite difference time-domain (FDTD) method of the software RSoft. The optical fiber is tilted $\alpha = 10°$ with respect to the vertical and rotated $\varphi = 45°$ with respect to the XZ-plane (Fig. 1(a)). The optimized 2D coupler has a grating period $\Lambda = 580$ nm and the radius of the circular etched holes is $R = 200$ nm. The number of holes in a column or a row is $N = 23$, resulting in an NxN matrix of holes. For this coupler the coupling efficiency is around -1.8 dB at $\lambda = 1.55$ µm and the 1dB-bandwidth is 36 nm for both polarizations (Fig. 2).

A new periodic structure based on the design described before is designed with cuboid holes instead of cylinders (Fig. 1(b)). The new grating design has also a period of 580 nm and the etched holes have an edge length $a = 400$ nm. A sweep of different parameters of the structure without the bottom mirror is realized for $\lambda = 1.55$ µm to identify the best grating design with the maximum coupling efficiency. The cuboids are rotated an angle θ resulting in an improvement of the coupling for both polarizations. In Fig. 3 the simulation results of the coupling efficiency depending on θ of the two perpendicular polarizations are plotted for both corresponding outputs. The light coupled in the other output is neglectable (< -20 dB). The coupling efficiency is not equal for both polarizations due to a small additional fiber position offset (Fig. 1(b)). The edge length a of the squares is simulated again for three different rotation angles: 30°, 40° and 60° (Fig. 4). The results show that the best dimensions are $\theta = 30°$ for $a = 360$ nm. This structure is then simulated with the bottom mirror for a hole matrix of 23x23 showing a coupling efficiency of -1.9 dB for the s-polarization (output 1) and -2.1 dB for the p-polarization (output 2). The 1dB-bandwidth is 35 nm for both polarizations.

The structure with cuboid holes can be used as the basic structure to be tuned to achieve a better coupling efficiency of the light by adapting the diffracted mode profile to the one of the optical fiber. A Matlab script is written to automate a huge number of simulations using a genetic algorithm to modify several parameters of the grating at the same time. Only the dimensions of the first five columns and rows are tuned, since they are the ones which have most influence in the diffracted field profile of the grating. This also reduces memory and time consumption significantly. Fig. 5(a) shows with the same color the position of the holes simulated with the same dimensions to keep the symmetry of the structure. The period is kept constant ($\Lambda = 580$nm) and the length l and the width w of the rectangular etched holes are optimized for the first 5 lines. The results are plotted in Fig. 5(b). It is observed that after 300 iterations of the algorithm the coupling efficiency of the modified grating is better than the periodic structures presented before. After around 2000 iterations no more significant improvement is observed. In Fig. 5(c) the layout of the best simulated aperiodic 2D GC and its dimensions are presented. The coupling efficiency of this structure is -1.7 dB. This improvement of the performance is achieved without a rotation of the cuboids to simplify the simulations. Further optimizations can be done if more lines are tuned and other parameters like period and rotation angle θ of the rectangular etched holes are modified.

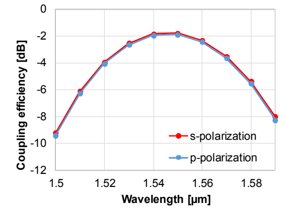


Fig. 2. Optical bandwidth of the GC with cylinder holes and backside mirror. $\Lambda = 580$ nm, $R = 200$ nm, $N = 23$.

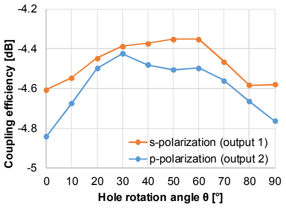


Fig. 3. Coupling efficiency versus rotation angles θ of the cuboid holes. $\Lambda = 580$ nm, $a = 400$ nm, $N = 19$ and w/o mirror.

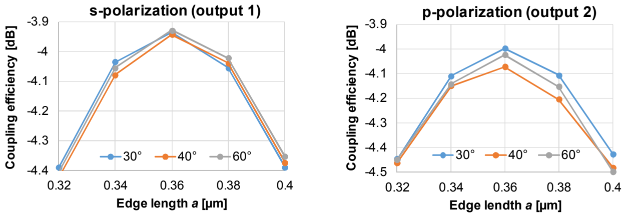
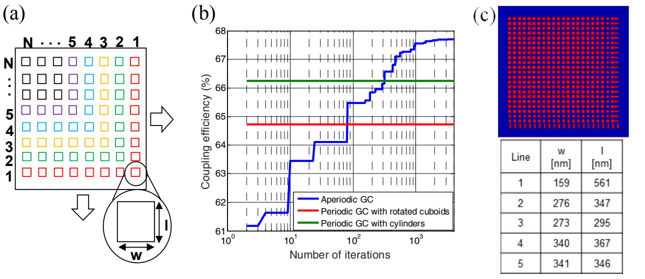


Fig. 4. Coupling efficiency versus edge length of the square etched holes for different rotation angles θ. $\Lambda = 580$ nm, $N = 19$ and w/o mirror.



Line	w [nm]	l [nm]
1	159	561
2	276	347
3	273	295
4	340	367
5	341	346

Fig. 5. (a) Schematic of the simulated aperiodic grating. (b) Best coupling efficiency achieved after the number of simulations realized with the genetic algorithm changing 10 different parameters of the grating. (c) Layout of the best simulated structure and its dimensions.

III. CONCLUSION

A novel design of the 2D grating couplers working as polarization splitter is presented. By means of aperiodic structures the coupling efficiency of the structure can be improved showing promising results for future devices.

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