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Optimized polarization insensitive grating antenna in the SOI platform

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Abstract— We report on an optimized polarization-insensitive grating design based on subwavelength metamaterials and L-shaped structures in a 500 nm silicon on insulator platform. The grating achieves the same scattering angle of 10° with similar efficiency for TE and TM modes based on 3D FDTD simulations.

Keywords—beam steering, polarization, silicon on insulator, subwavelength

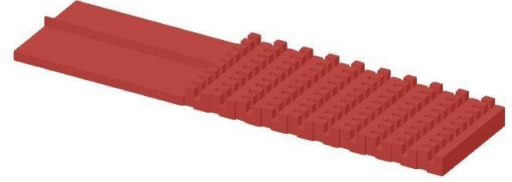
I. INTRODUCTION

Optical phased arrays (OPA) are integrated photonic devices that allow the generation and dynamic steering of laser beams in the free space. OPAs exploit an array of individual emitters, such as integrated optical antennas, each judiciously controlled in phase and amplitude. By precisely adjusting the phase of the light emitted by each antenna, OPAs can steer and shape optical beams without the need for bulky mechanical components [1,2]. OPAs, especially realized in the silicon-on-insulator (SOI) integration technology, have attracted a large interest for applications in compact systems for light detection and ranging (LiDAR) and for free-space optical communications. Optical antennas serve as the fundamental component of an OPA, defining its steering capabilities and overall efficiency [3]. Surface gratings are often used as antenna elements. However, the strong polarization dependence of their radiation angle and efficiency can represent a major drawback, especially when the OPA is used for reception.

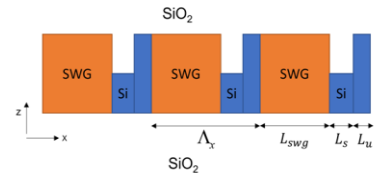
We have previously developed a design of a polarization-insensitive optical antenna in the SOI platform [4], that utilized L-shaped elements for high upward diffraction efficiency [3], and incorporated subwavelength metamaterial engineering for polarization-insensitive operation [5,6]. In this paper, we present an optimized polarization-insensitive surface grating antenna, with a thicker core thickness of 500 nm for better performance. The 3D finite-difference-time-domain (FDTD) simulations of the proposed grating demonstrate that TE and TM modes are diffracted with the same angle of 10° and a similar diffraction efficiency of 53% and 58%, respectively. We also provide a comprehensive fabrication tolerance study to ensure the feasibility of the manufacturing process.

II. GRATING DESIGN AND PERFORMANCE

As schematically shown in Fig. 1, we consider for the design an SOI platform with a 500-nm-thick silicon layer, 3 μm of buried oxide and a 2.2 μm oxide cladding. The grating unit cell is made of two distinct parts. The first one is an L-shaped structure partially etched to 250 nm for a length of L_s and with an un-etched section of length L_u . The second part is represented by a subwavelength metamaterial for a length of L_{swg} , with a transverse period of 300 nm and duty cycle ff_y .



(a)



(b)

Fig. 1. (a) 3D and (b) 2D side view of the polarization insensitive grating antenna SWG: subwavelength metamaterial.

The effective refractive index n_B of the grating Bloch mode can be approximately computed as [5]:

$$n_B = (n_{swg} \frac{L_{swg}}{\Lambda_x}) + (n_s \frac{L_s}{\Lambda_x}) + (n_u \frac{L_u}{\Lambda_x}) \quad (1)$$

where n_{swg} , n_s , and n_u are the effective indices of the fundamental slab modes supported by the different sections of the grating. The value of n_{swg} can be tuned adjusting the metamaterial duty cycle. We exploited this property to ensure that $n_B^{TE} \sim n_B^{TM}$, in order to obtain the same diffraction angle for the TE and TM modes.

For the design, we considered as parameters:

$$R_L = \frac{L_s}{L_s + L_u} \quad (2)$$

$$ff_x = \frac{L_s + L_u}{\Lambda_x}, \quad (3)$$

where ff_x is the duty cycle of the grating in the x direction and R_L is the duty cycle of the L-shaped structure. We used 3D FDTD simulations to sweep the parameters of the grating and optimize scattering efficiency and radiation angle. Based on simulations, the selected parameters used for L_{swg} , L_s and L_u are 244 nm, 180 nm and 219 nm, respectively. The grating period is hence of 643 nm. Regarding the duty cycles, the optimized choice that gives the best overall performance for both polarizations corresponds to $ff_y = 0.6$, $ff_x = 0.62$ and $R_L = 0.45$.

The length and width of the antenna were optimized by varying the number of grating periods N_x in the x direction and the number of the subwavelength metamaterial periods N_y in

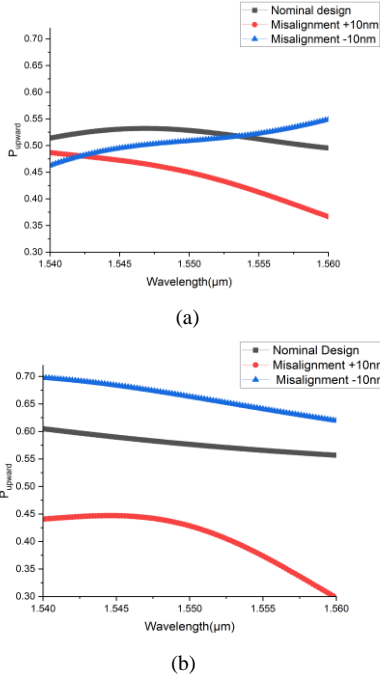


Fig. 2. (a) TE and (b) TM scattering efficiency of the designed grating for the nominal design (black solid lines) and when a positive (red lines) or negative (blue lines) misalignment of the shallow etched section is considered in the x direction.

the y direction in order to maximize the antenna far-field beamwidth and upward diffraction efficiency. We designed the grating to have $N_x=10$ periods (which ensures full light scattering), resulting in an overall length of $6.43 \mu\text{m}$. In the y direction, $N_y = 9$ was chosen, for a grating width of $2.7 \mu\text{m}$. For light injection in the grating, we designed a 250-nm -thick rib waveguide. Its width was tapered from 500 nm to 50 nm at the input of the grating, with a taper length of $11.8 \mu\text{m}$. This input was chosen to reduce back-reflection and ensure that only fundamental TE and TM modes were excited at the input of the grating.

The scattering efficiency of the proposed grating antenna as a function of wavelength for both TE and TM input modes as obtained by 3D FDTD simulations are shown in Fig. 2 with black solid lines. At the desired operative wavelength of $\lambda = 1550 \text{ nm}$, the antenna achieves a similar scattering efficiency P_{upward} of 53% and 58% for TE and TM inputs, respectively. Since the grating design was the result of a compromise between TE and TM performance, the antenna achieves even better scattering efficiency above 60% for a TM input at shorter wavelengths. As can be seen in the far field projection of the scattered field shown in Fig. 3, the grating scattering occurs at an angle of 10° at $\lambda = 1550 \text{ nm}$ for both polarizations, confirming the polarization insensitive operation. The beamwidth is also the same, being equal to 9° in the elevation direction θ and 104° in the azimuth direction ϕ . These results are summarized in Table 1.

A fabrication analysis tolerance was conducted to assess the grating coupler antenna sensitivity to fabrication errors. We considered in particular the case of a misalignment between the shallow and fully etched sections. Results are reported in Fig. 2 with red solid lines for a positive misalignment of 10 nm

in the x direction and with blue solid lines for a negative misalignment of 10 nm . While for a TE input the diffraction efficiency remains higher than 45% at 1550 nm , the efficiency exhibits a rather strong variability for TM input. However, the diffraction angle only shows minimal variations as a consequence of misalignment errors, with values of 9° and 12° in the two considered cases for a TE input and 8° and 7° for a TM input.

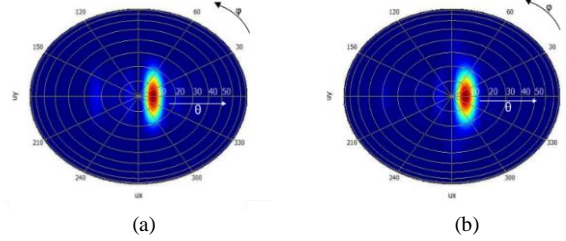


Fig. 3. (a) TE and (b) TM farfield radiation patterns of the optimized grating at a wavelength of 1550 nm .

Table 1. Radiation angle, diffraction efficiency and beamwidth of the designed grating

	TE	TM
Diffraction angle	10°	10.5°
Upward diffraction efficiency	53%	58%
Beamwidth ($\theta \times \phi$)	$9^\circ \times 104^\circ$	$9.5^\circ \times 104^\circ$

CONCLUSION

In this work, we have proposed and demonstrated a polarization insensitive grating antenna in the 500 nm SOI integration platform. The grating exhibits the same scattering angle of 10° for both TE and TM inputs and a similar radiation efficiency of 53% and 58%, respectively.

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