Simulation of Light Coupling Reciprocity for a Photonic Grating

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Abstract

1. Introduction

An effective coupling of light between a nanophotonic silicon waveguide and an optical fiber is challenging due to the high refractive index of silicon. The scattering element (grating) should be designed to couple out a signal of a particular mode profile. This demands a determination of a useful fraction of scattered power to be coupled to the fundamental mode of the optical fiber. Consequently, it requires the calculation of overlapping integral along the plane with a visually defined location and angle, which limits the accuracy.

In this work, we address this issue by utilizing optical reciprocity [1], which manifests that coupling efficiency between the two modes should not depend on the light propagation direction. This principle allows for study the operation of photonic gratings in two directions and precise determination of the coupled and lost power.

2. Use of COMSOL Multiphysics®

The simulated gratings are formed by 70-80 nm shallow etch in 220-nm-thick Si waveguide on top of a SiO2 buffer layer. Our model utilizes two different types of excitation, one through a port with a fundamental waveguide mode and another by a Gaussian beam [2] from the free space (Figure 1). We consider the gratings with symmetric and asymmetric profiles [3] (variable groove width, inlet of Figure 1).

The 2D grating model is studied in the COMSOL RF Module at a 1.55 µm wavelength. The port excitation configuration is simulated in the two steps: a boundary mode analysis to find the fundamental waveguide mode and a frequency domain analysis with the known mode field as the background illumination of a scattering problem. The free space excitation uses a Gaussian beam background field with tunable beam waist (w), angle of incidence (a), and waist position (x, y). For both scenarios, PML domains and scattering boundaries were introduced to eliminate the reflections, and the values of coupled power were obtained via the power flow integration along the boundaries (Figure 1).

3. Results

The obtained results show significant differences in the electromagnetic field distributions and the coupled power for the two excitation schemes. The symmetric grating returned essentially nonplanar wavefronts (Figure 2(a)) and a 7% difference between the power scattered upwards in port excitation configuration and the power coupled into the waveguide mode from the ideal Gaussian beam. The implementation of the asymmetric profile made the wave fronts more planar (Figure 2(b)), reduced the difference to 6% and increased the absolute coupling efficiencies by more than 2%. The lateral scattered field distributions verify the improved coupling efficiencies are due to the better overlapping of the scattered field with the Gaussian profile (Figure 3).

4. Conclusions

We presented a model to study reciprocity of operation of the fundamental photonic scattering structure. It can be used as an effective tool to separately trace the differences in the wavefronts and the scattered power for different types of excitations. The approach can be extended to perform reciprocity studies with custom scattering structures and various light collecting methods.

Reference

1. R. J. Potton, Reciprocity in optics, Reports on Progress in Physics, 67, pp. 719-749 (2004).

2. B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, Wiley, pp. 75-86 (2007).

3. D. Taillaert, P. Bienstman, and R. Baets, Compact efficient broadband grating coupler for silicon-on-insulator waveguides, Optics Letters, 29, pp. 2749-2951 (2004).

Figures used in the abstract

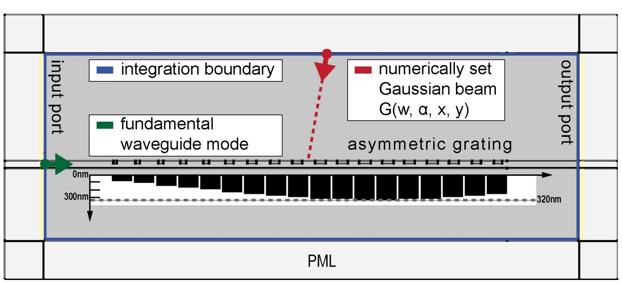

Figure 1: Schematic drawing of the simulated 2D grating with the two types of excitation.

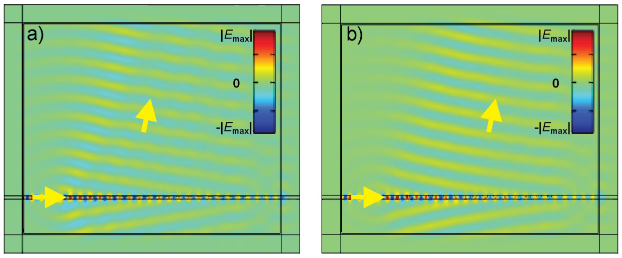

Figure 2: Distributions of the transverse electric field in the port excitation configuration for (a) the symmetric and (b) asymmetric grating structures.

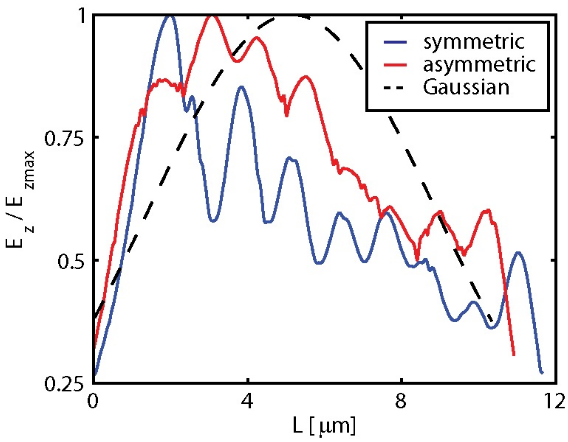

Figure 3: Transverse electric field profile of the scattered signal along the wavefront for the symmetric and asymmetric structures, referenced to the ideal Gaussian beam.