3D ANALYSIS OF GRATING PLASMONIC COUPLER

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Abstract

A 3D analysis of a plasmonic coupler has been carried out with a full wave FEM software. The coupler is realized with a 1D grating that is excited by a Gaussian beam. A comparison with the usual 2D approximated analysis available in the literature is shown and some interesting features of the 3D coupler are pointed out.

1. Introduction

Owing to the great interest of plasmonics for several optics applications, such as sensors, nanoantennas, optics processing and solar cell enhancement [1-6], in recent years there has been a considerable amount of literature dealing with long range plasmon polariton mode in strip waveguides (LRSPP) [1, 2]. Aspects such as propagation properties [1], mode spectrum [7] and mode couplers [8-10] have been dealt with and a rather large set of design results and parameters is nowadays available. The subject is still under current investigation and it can be considered far from being exhaustively analyzed. In particular, input and output light coupling to plasmonic waveguides is a major issue, for the realization of plasmonic lightwave circuits. The most simple way to couple SPP modes either to free-space propagating optical beams or to modes of dielectric waveguides, is end-fire coupling [2]. Efficient end-fire couplers have been designed and experimentally characterized [3, 8] also in case of axially aligned waveguides. The search for best coupling conditions is performed by a 2D numerical model, typically based on FEM or FDTD simulations.
However, it is also of interest to launch optical power laterally into the plasmonic waveguide and along the SPP propagation. Lateral couplers, based on evanescent field coupling have been proposed since the early stages of plasmonics [11]. In order to increase coupling efficiency, and in view of more structured and 3D interconnections, diffractive gratings can be designed. At present, however, the design of optimized grating has been performed in 2D and optimization is related to coupling either with metallic layers or to slab. The plasmonic propagation is treated either by FDTD simulation [8-10, 12] or modeled by FEM [13]. In all cases, a 3D simulation, which is necessary to properly estimate the coupling efficiency in case of SPP modes of strip geometry, is still lacking.

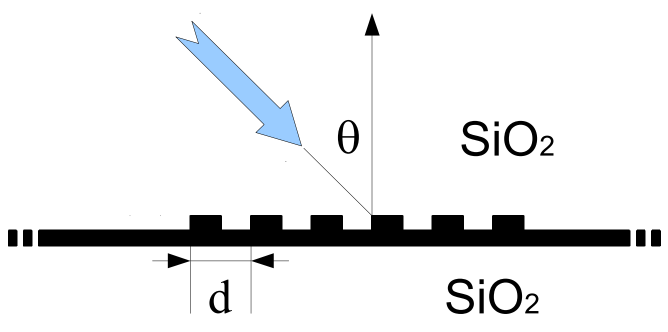

Fig. 1 Grating launcher and geometrical parameters. The metal is drawn in black.

In this work we focus on the problem of 3D analysis of LRSPP excitation in strip-like structures and in particular on grating couplers.

2. Discussion

Grating launchers are an interesting solution to the problem of LRSPP excitation, because of the simple structure, the availability of simple design formulas and the rather good simulated performances. As hinted in the Introduction, all the results available in the literature use a full-wave 2D analysis. This is commonly considered a good approximation to the "true" 3D problem, because the main aspects of light coupling to the grating are correctly represented. The design is in fact based on the following simple formula (see Fig. 1):

$$\beta_{\text{eff}} = k\sin\theta + m\frac{2\pi}{d}$$

where β_{eff} is the LRSPP propagation constant, k is the wavenumber, m is an arbitrary integer index (usually $m=\pm1$) and d is the grating period.

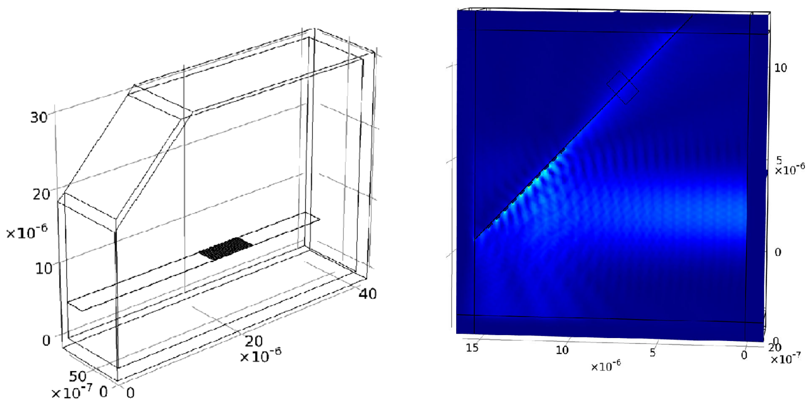

Fig. 2. Geometry of 3D plasmonic coupler.

On the other hand there are several aspect of LRSPP excitation by grating that necessarily require a 3D analysis, such as finite grating and beam size in the transverse direction and cutoff conditions for LRSPP mode. The mode can be cutoff under specific combinations of physical parameters such as metal thickness, strip width and upper and lower cladding refractive index mismatch [14]. Since none of these phenomena are described by a 2D analysis a full 3D modeling has been carried out.

3. Results

The 3D modeling of a grating Plasmon coupler is very demanding in terms of simulation time and storage. The 3D FEM model required a box of large size as shown in Fig. 2. The analysis presented in this paper refers to a launcher designed at λ=1.55 μm and this corresponds to a box size of about 40 λ along the propagation direction, 30 λ along the height and only 4 λ along the transverse direction (by using the symmetry condition). The domain is finally bound by PML as an adsorbing boundary condition. The half-strip in fig. 2 is 3 μm wide and the metal thickness is 20 nm. Finally, after trying several configurations, the scattered field formulation was used [15]. A picture of the total field, where the guided LRSPP can be easily identified, is shown in Fig. 2 (right). The strip is 45° inclined, the incident Gaussian beam horizontally propagates and the plasmonic wave is travelling upward. An example of results regarding comparison of the 2D model with the 3D one is shown in Fig. 3. In the figure the structure is the same as in Fig. 2 and the coupling efficiency is analyzed as a function of the beam waist dimension. The finite transversal dimension of the strip (6 μm) introduces significant differences in coupling performances. Also, maximum coupling is achieved at different values of the beam waist.

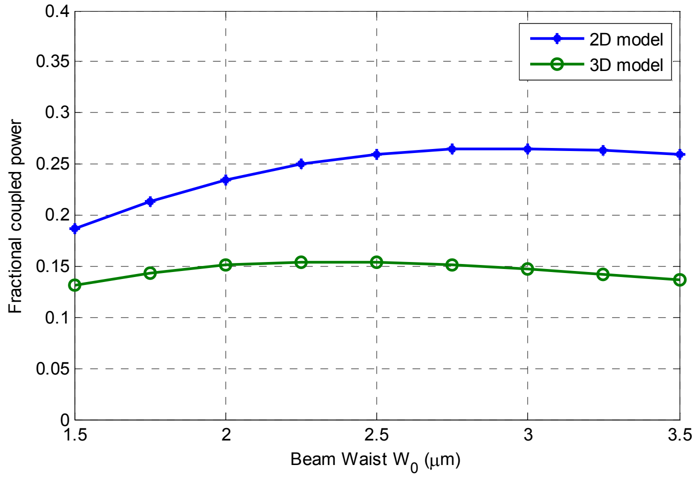

Fig. 3. Fractional coupled power vs beam waist. Comparison 2D model and 3D model.

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