3D Modelling of Plasmon Excitation By Grating

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Introduction

The design and fabrication of efficient lateral couplers are enabling features for the deployment of desired topologies of plasmonic interconnects. Potentially, grating couplers are interesting technological solutions to this issue. The aim is the efficient excitation of LR-SPP waveguide modes. It can be seen that, if the simplifying 2D numerical approximation is used to analyse and design the grating-assisted coupling, the complexity of the physical problem is under-estimated and this may lead to strongly inaccurate forecasts. Specifically, a full 3D approach is needed to account for aspects like strip modal analysis, cut-off conditions and the finite width of the beam and of the grating.
In the following, a comparison between coupling efficiency to LR-SPP mode, as estimated by an approximated 2D FEM numerical analysis and by a 3D approach, is given.

The structure

Lateral coupling into a Au-on- SiO_2 symmetric strip plasmonic waveguide is considered.

Dielectric functions are modeled as:
$\varepsilon_{Real\text{-}Au} = -215.83*\lambda_0^4+1459.46*\lambda_0^3-3712.40*\lambda_0^2+4029.07*\lambda_0-1645.36$
$\varepsilon_{Imm\text{-}Au} = 2028.83*\lambda_0^4-12207.68*\lambda_0^3+27555.30*\lambda_0^2-27625.41*\lambda_0+10383.71$
$\varepsilon_{SiO2} = (-0.0131*\lambda_0+1.4687)^2$

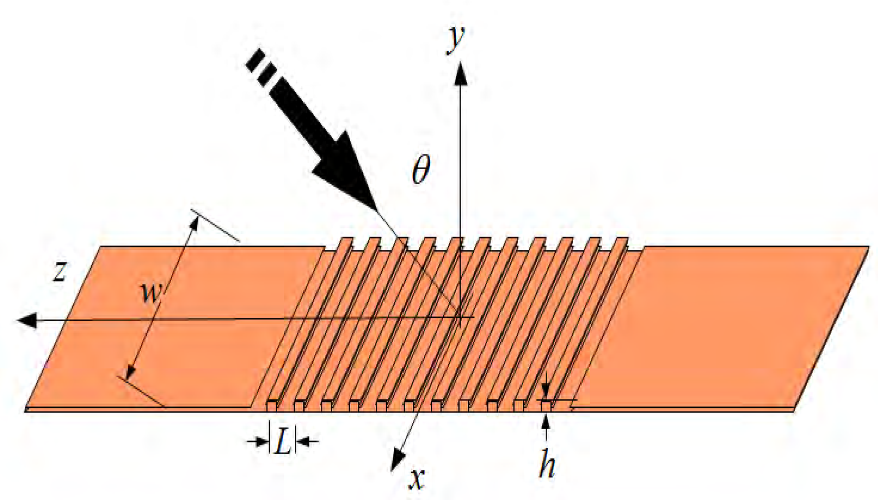


Fig 1: grating coupler on strip: geometry of excitation

Optical excitation is centered at **λ_0=1550nm** and a Gaussian incident beam is considered and it has been defined in ***Electromagnetic Wave*** section as ***Port***.

A 50% duty cycle 1-D grating is designed according to the formula: $\beta_{eff} = \frac{2\pi}{\lambda_0}\cdot\sin\theta + m\cdot\frac{2\pi}{L}$

Unidirectional LR-SPP propagation is seeked; for this 45°deg incidence is considered and the wavevector matching condition is set for a LR-SPP mode propagating on the ***m = -1*** diffraction order. The strip is **20nm** thick and **4µm** wide. A square-shaped grating of period **d= 626 nm** is chosen; peaks are**100nm-high**; the grating is **11 periods** long, to give a covered area of unitary aspect ratio.

COMSOL 3D modeling

FEM implementation by COMSOL 4.2a sw**.** ***Scattered field*** approach.
Free tetrahedral adaptive mesh; more than 600k elems; quadratic elements: about 8M degrees of freedom.
PML boundary conditions. PMC is also defined to reduce the computational complexity.
Running on Intel Xeon CPU X5660 ; 12 processors ; ck @ 2.80GHz
96 Gb RAM

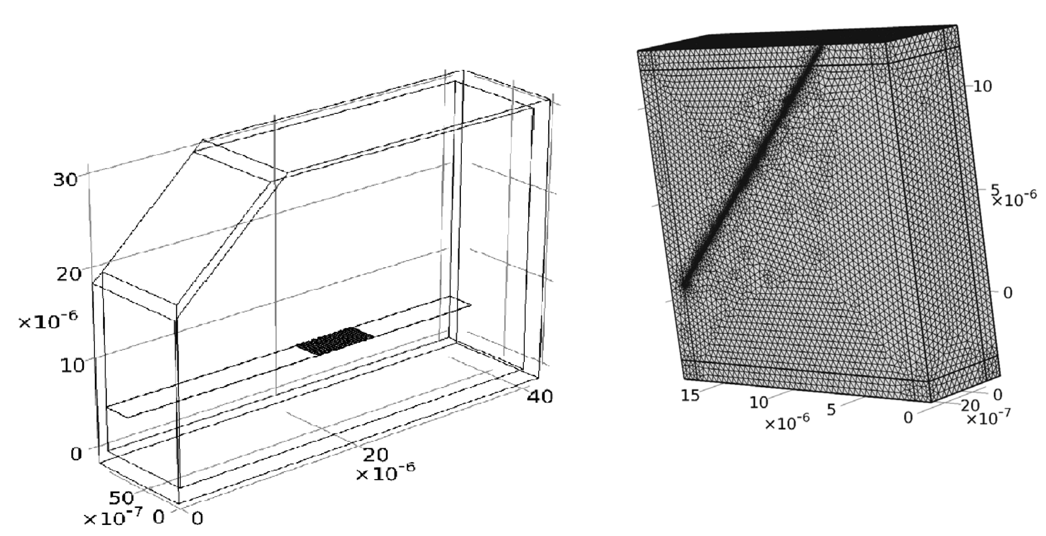


Fig. 2: the full 3D structure for FEM simulations and mesh structure

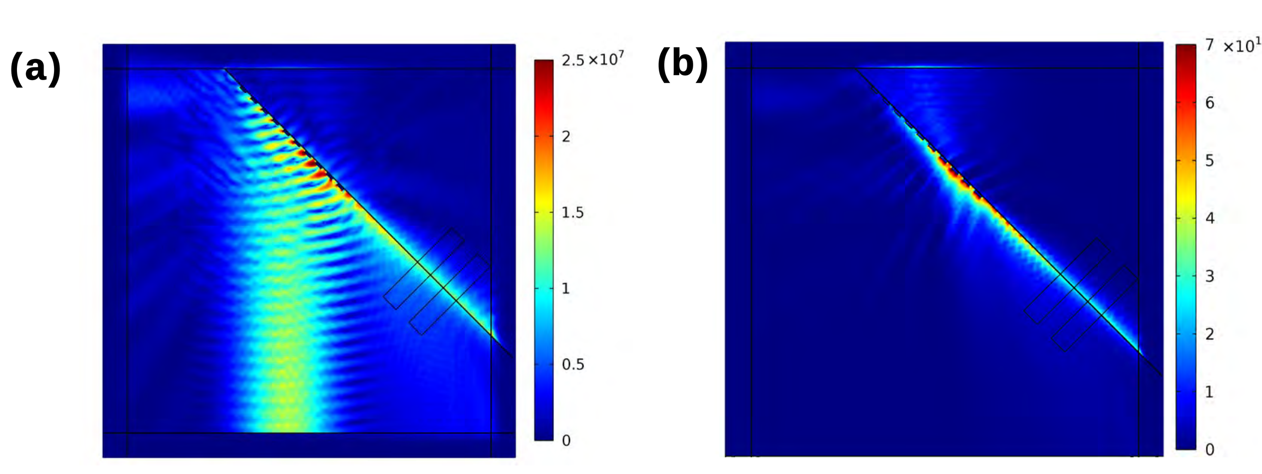
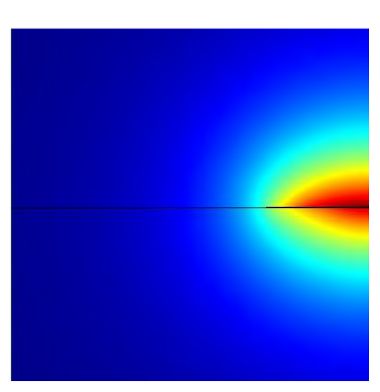
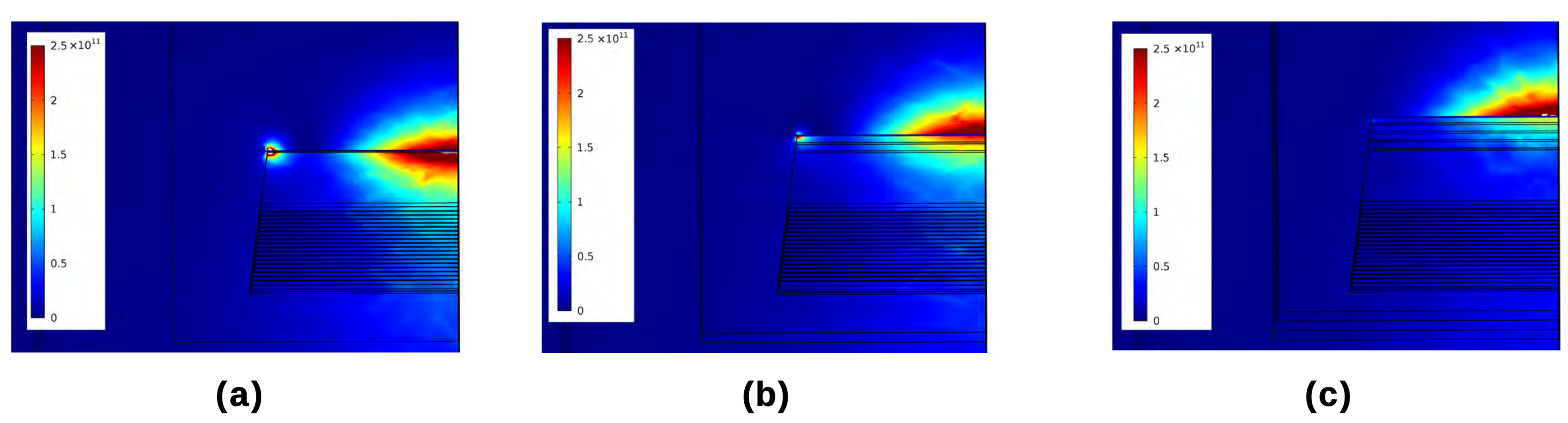


Fig 3: Amplitude evolution of in-coupled SPP ; (a):total field; (b):scattered field



reference LR-SPP mode

Fig 4: cross sectional views of the evolution of SPP strip mode along propagation , at distances from the grating respectively: 4um (a), 5.5um (b) and 7um (c) ; Ey component.



COMSOL 2D Modeling

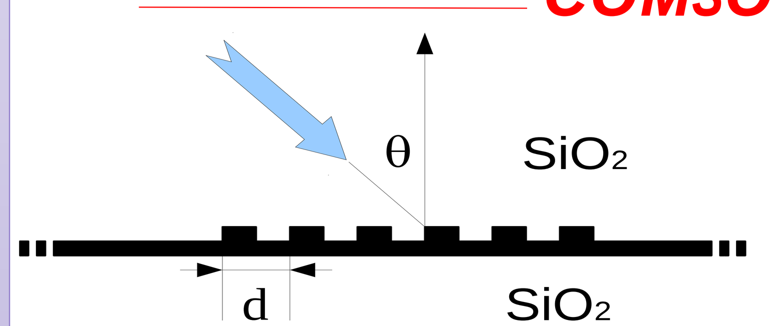


Fig 5: 2D grating launcher geometry.

Fig 6: Amplitude evolution of launched SPP along a 2D slab; total field.

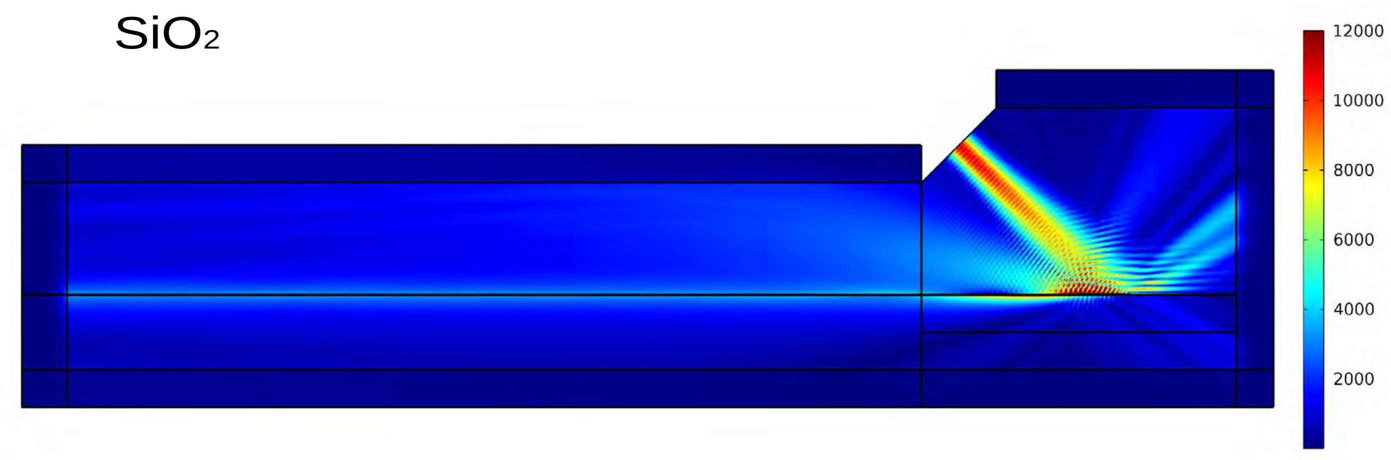
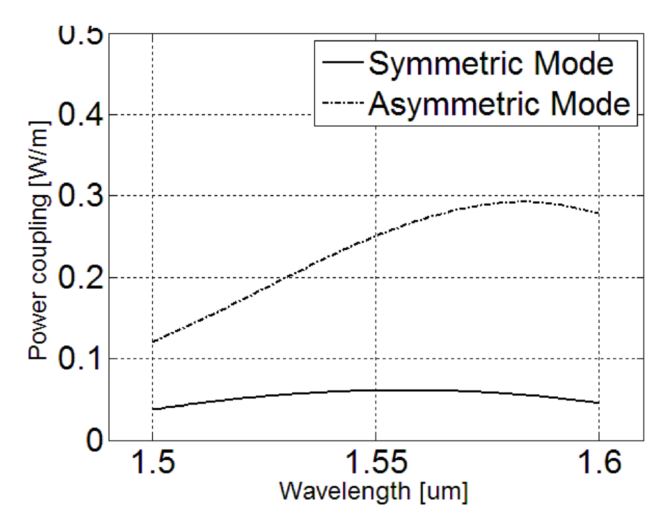


Fig 7: spectral evolution of coupling efficiency for symmetric (s_0) and asymmetric (a_0) SPP modes, as resulting from 2D approximation of strip waveguide; LR-SPP is unfavoured .



wavelength	Slab sym. mode	Slab asym. mode	Strip sym. mode	Strip asym. mode
1500nm	1.445269-j4.883620e-5	1.498210-j1.2787e-2	1.44328-j2.46747e-5	1.49079-j1.44360e-2
1525nm	1.445205-j4.553768e-5	1.499775-j1.2966e-2	1.44322-j2.44470e-5	1.48800-j1.40810e-2
1550nm	1.445144-j4.315173e-5	1.501364-j1.3349e-2	1.44930-j2.37390e-5	1.48531-j1.37390e-2
1575nm	1.445085-j4.091538e-5	1.502977-j1.3738e-2	1.44313-j2.48204e-5	1.48224-j1.34350e-2
1600nm	1.445029-j3.8818e-5	1.504615-j1.4133e-2	1.44309-j2.54412e-5	1.48026-j1.31950e-2

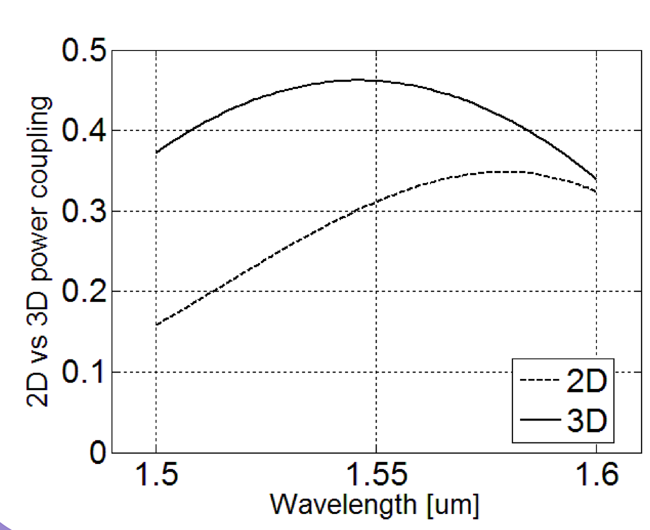


Fig 9: Spectral evolution of total SPP power coupling. Differences in ultimate efficiency values and in peak wavelength are evident.

Conclusions

Preliminary results on coupling efficiency highlight that full 3D numerical modeling is mandatory for an accurate and reliable design of launchers. Good performances on large models.