# Contents



# Partially-filled slot plasmonic waveguide

A plasmonic slot waveguide is composed of a thin metallic film with dielectric substrate and superstrate layers. The film is separated by a subwavelength slot in the middle. Fig. 1 shows the cross-section of this waveguide in x-y plane, where the wave propagation is assumed in the z direction. A slot plasmonic waveguide localizes and guides light through the interaction of electromagnetic waves with the surface plasmons (SP) on the interface of a metal and a dielectric. The light is confined in the slot area which is typically on the order of tens of nanometers. The specific characteristics of surface plasmon polaritons (SPPs, which are the coupled state of electromagnetic waves and oscillations of free electrons at the surface of a metal) are intended to be utilized by these waveguides, particularly for nonlinear applications and sensing due to their high light confinement.

The propagation of SPPs in a slot plasmonic waveguide is associated with the loss of the metal in the waveguide, which results in a trade-off between the confinement and the propagation length. One solution to this issue is to use a partially-filled slot with a dielectric material enabling enhancement of field confinement while maintaining a low propagation loss. In this article, the partially-filled slot plasmonic waveguide design of [1] is reproduced and confirmed using the Finite-Element Method (FEM) using OptiMode.

## Labels

Plasmonic waveguide; Surface plasmon (SP); Propagation length; Effective index.

# Design

The simulation of the partially-filled slot plasmonic waveguide (PFSPWG) is performed using OptiMode with the FEM solver. The waveguide under investigation uses silica ($SiO_2$) as a dielectric material ($\varepsilon_{SiO_2} = 2.13$) for both superstrate and substrate. The metalic film is made of silver (Ag) as a low loss plasmonic metal ($\varepsilon_{Ag} = -86.6424 - 8.7422j$ or $n_{Ag} = 0.469 - 9.32j$). The slot is partially-filled with silicon (Si) ($\varepsilon_{Si} = 12.25$). The operation wavelength is 1.55 $\mu$m. The general solver settings in the FEM solver are set as table 1. The boundary settings are selected as electric wall. The wafer dimensions in the simulation region are chosen as length = 1 $\mu$m and width = 1 $\mu$m.

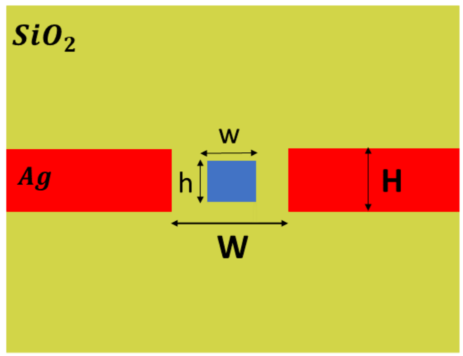


Figure 1: Schematic showing the cross-sectional view of the partially-filled slot plasmonic waveguide.

Table 1: Details of general solver settings in the FEM solver.

| General Solver Settings | Value |
|---|---|
| Minimum angle (degree) | 10 |
| Min Edge Length ($\mu$m) | 0.005 |
| Max Edge Length ($\mu$m) | 0.003 |
| Max Triangle Area ($\mu m^2$) | 0.05 |
| Element Order | 2 |
| Mode Index Estimate (real part) | 3 |

# Results

The effects of the gap width(W) and the gap height (H) on the effective modal index and the propagation length are investigated based on [1]. THe modal index is obtained directly from the mode solver output. The propagation length is defined as the distance over which the amplitude of the wave drops to $1/e$ of the peak value and is given as

$$L_p = \frac{1}{k_0 \mathbf{Im}(n)} \tag{1}$$

where Im(n) and $k_0$ represent the imaginary part of the effective index and the free space wavevector, respectively.

The effective index and the propagation length for a PFSPWG are shown in Fig. 2 when the gap width (W) varies from 60 to 200 $nm$. In this example the dimensions of the core remain fixed ($w = 50\ nm$ and $h = 50\ nm$). As can be seen from Fig. 2, the effective index is inversely proportional to the change in gap width which is an established phenomenon with gap SPP waveguides [3]. It is also seen that as the confinement is increased (decreased gap) the material losses of the metal become more relevant and propagation length decreases.

The effect of different thicknesses of the metalic part is shown in Fig. 3. The effective index increases when the gap height decreases due to the increment in the fraction of the modal power in the metal and the propagation length increases consequently. These results indicate the trade-off

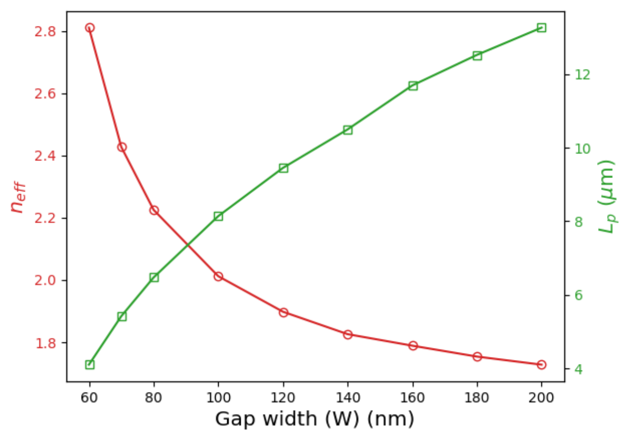


Figure 2: The effective index and the propagation length for a PFSPWG with different gap width and fixed core dimensions ($w = 50\ nm$, and $h = 50nm$).

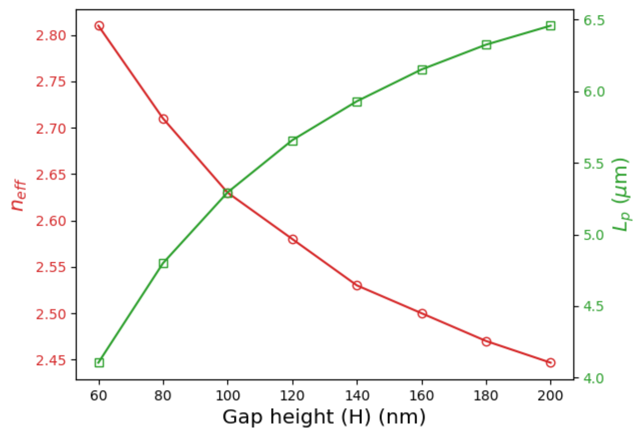


Figure 3: The effective index and the propagation length for a PFSPWG with different gap height and fixed core dimensions ($w = 50\ nm$, and $h = 50\ nm$).

between the field localization and propagation length appropriately and how the geometrical parameters (W and H) affect the performance of the waveguide.

As an example, the distribution of the amplitude of the Poynting vector in the z-direction for representative dimensions ($W = 100\ nm$, $H = 100\ nm$, $w = 50\ nm$, and $h = 50\ nm$) is shown in Fig. 4. The corresponding dominant E-field component (i.e. $E_x$) along the x-axis and the middle of the waveguide is plotted in Fig. 5 using horizontal cut in OptiMode Analyzer.

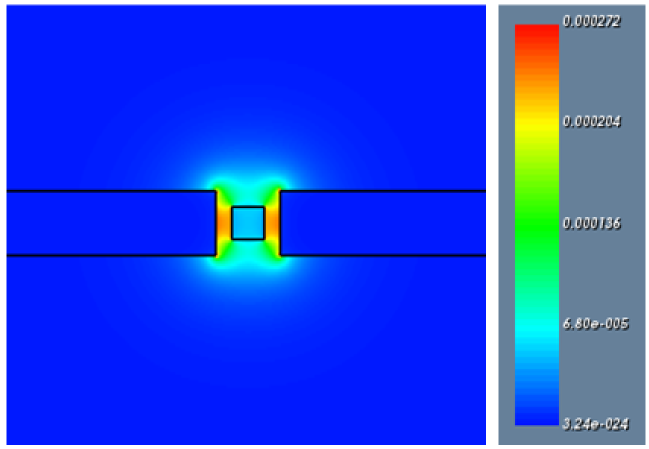


Figure 4: The Poynting vector distribution in the z-direction for a waveguide with geometrical dimensions $W = 100\ nm$, $H = 100\ nm$, $w = 50\ nm$, and $h = 50\ nm$.

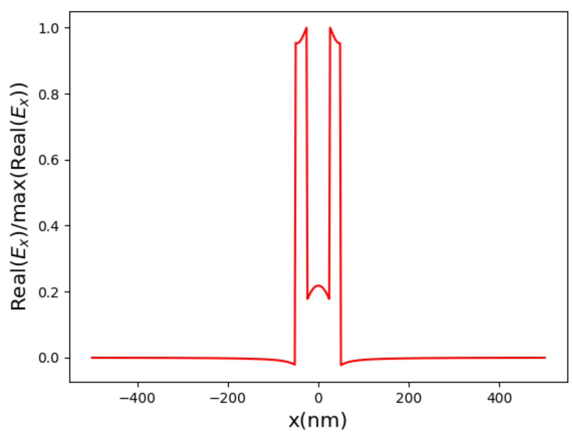


Figure 5: The distribution of the normalized $E_x$ component along the x-axis and the middle of the waveguide.

# References

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2. G. Veronis, and S. Fan, “Modes of subwavelength plasmonic slot waveguides,” J. Light. Technol., vol. 25, no. 9, pp.2511-2521, Sep. 2007.

3. Z. Han, and S. Bozhevolnyi, “Waveguiding with Surface Plasmon Polaritons,” Reports on progress in physics, Physical Society (Great Britain), vol. 76, no. 1, pp. 016402, Dec. 2012.