SAPIENZA
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Modal Characterization of the Plasmonic Slot Waveguide Using COMSOL Multiphysics

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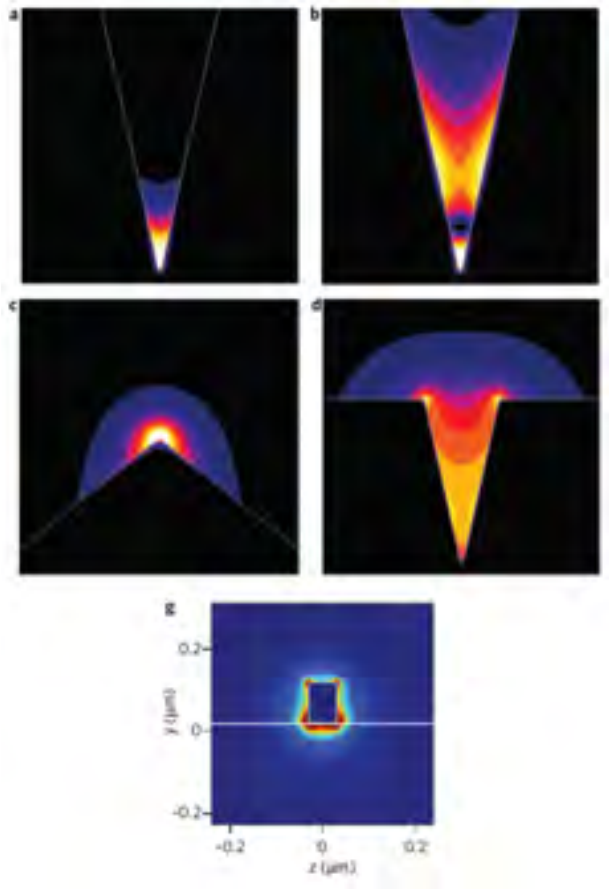
COMSOL Conference 2011 Stuttgart

Outline

Introduction

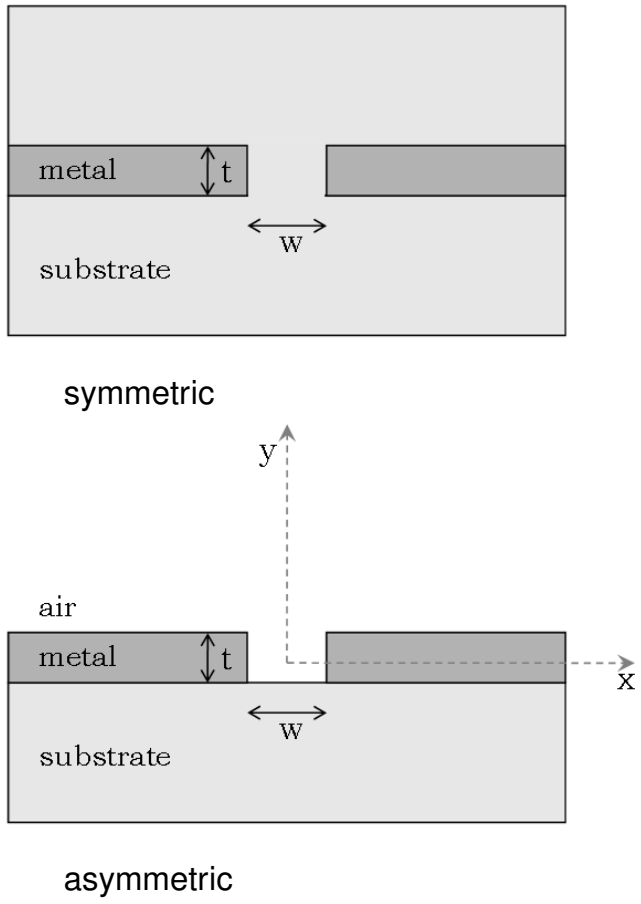
- Integrated photonic circuits require guiding structures that support highly confined modes
- Plasmonic waveguides offer a subwavelength mode confinement
- Several types of guiding structures have been proposed
- A good confinement is related to high losses



Gramotnev et al., Nat. Photon. 4, 83-91, (2010)

The Plasmonic Slot Waveguide

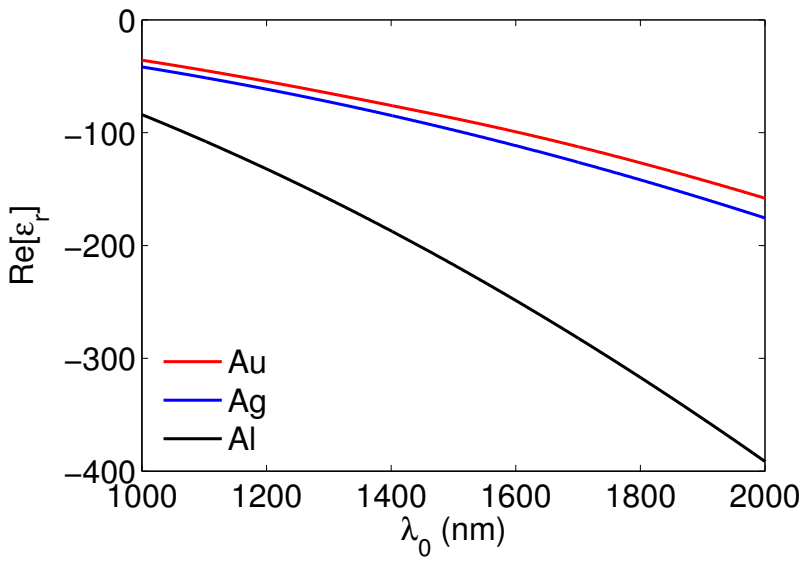
- Similar to the microwave slotline, but metals have a plasmonic response at optical frequencies
- Subwavelength confinement over a large frequency range
- Symmetric and asymmetric configurations
- The fundamental mode is quasi-TEM
  - Symmetric: always bound
  - Asymmetric: becomes leaky on certain conditions
- No higher-order bound modes (subwavelength slot)

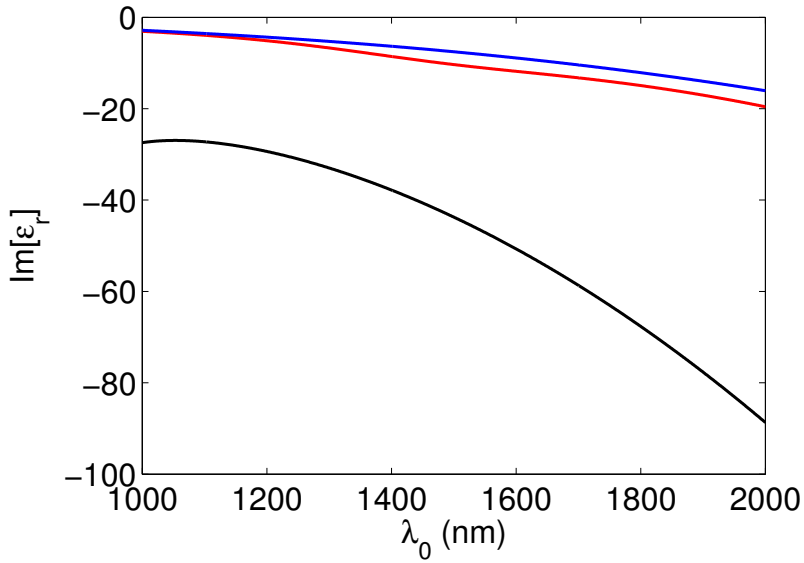


Veronis et al., Opt. Lett. 30(24), 3359-3361, 2010.

Waveguide parameters and metal dispersion

- Wavelength range of interest: from 1 μm to 2 μm
- Substrate: silica, $n = 1.44$
- Fixed metal film thickness, $t = 50$ *nm*
- Metal: gold, silver and aluminium
- Drude-Lorentz model for the metal dispersion

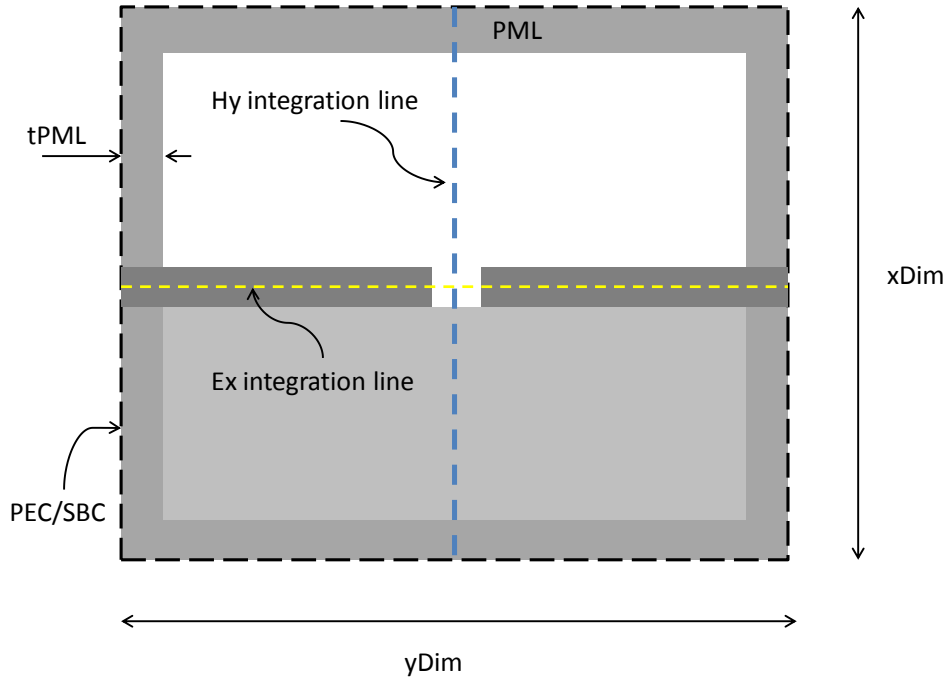




Rakic et al., Appl. Opt. 37, 5271-5283, 1998.

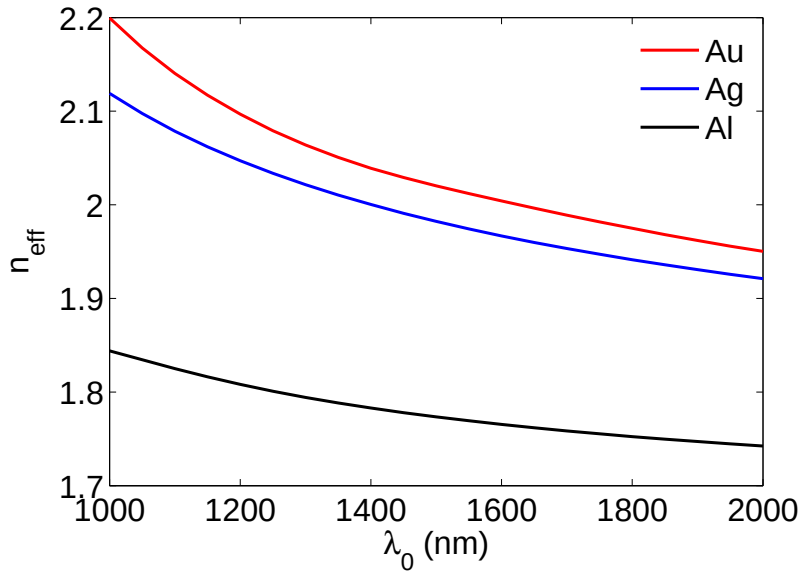
Mode Characterization and Simulation Setup

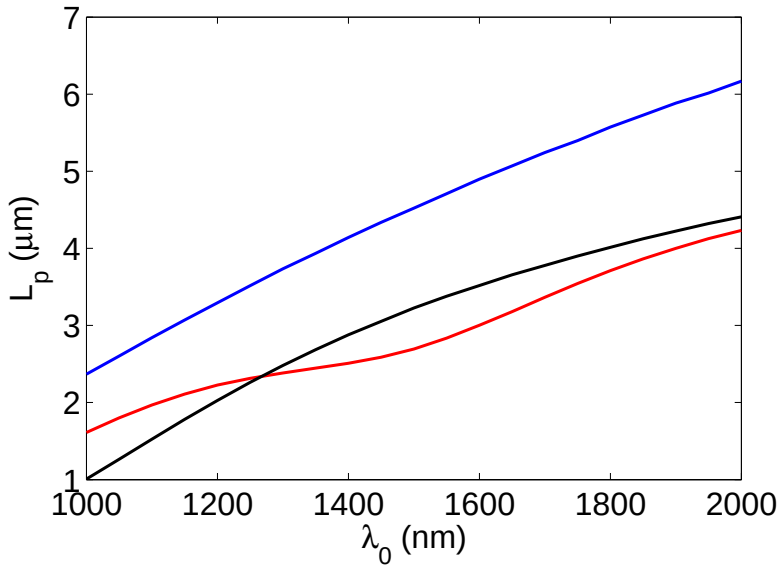
- Mode Analysis to determine the propagation modes
- Mode properties:
  - Effective refractive index
  - Propagation length
  - Mode confinement factor
  - Equivalent characteristic impedance (bound only)
- Perfectly Matched Layers used only for leaky modes

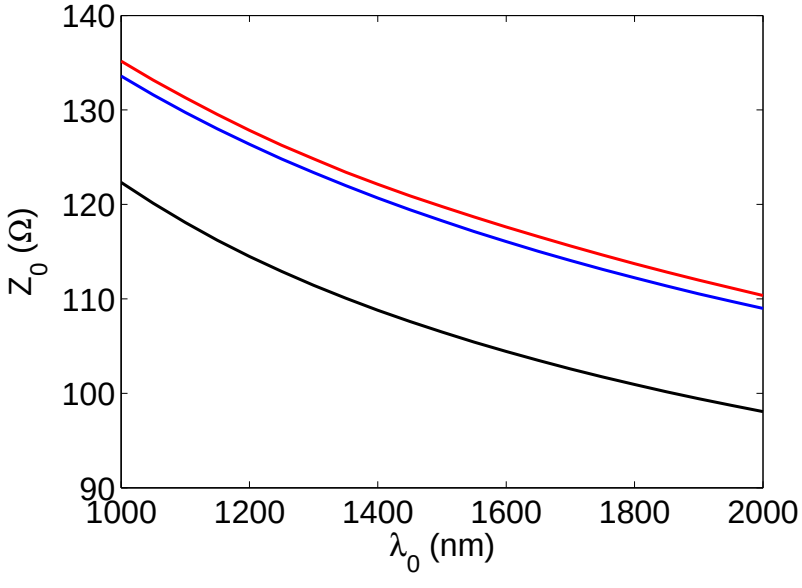


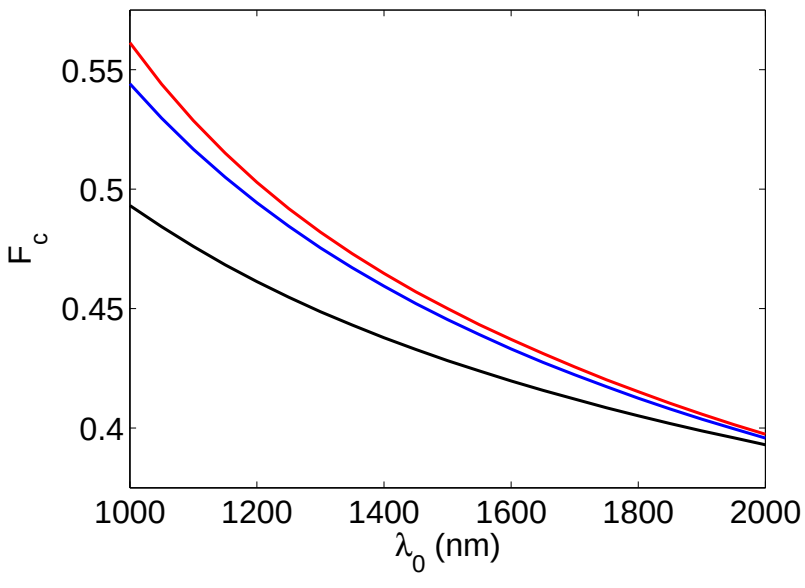
Cai et al., Adv. Mat. 22, 5120-5124, 2010.

Results: symmetric, $w = 50\ nm$, λ_0 dispersion

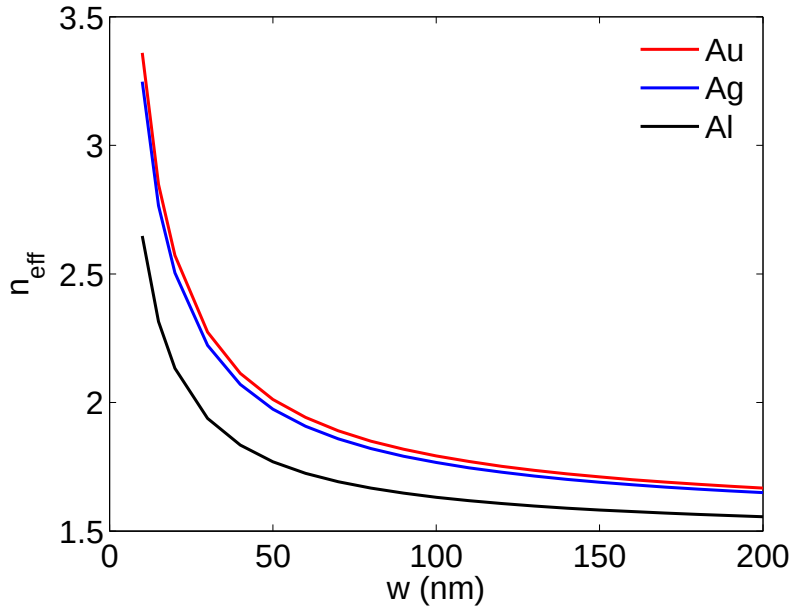


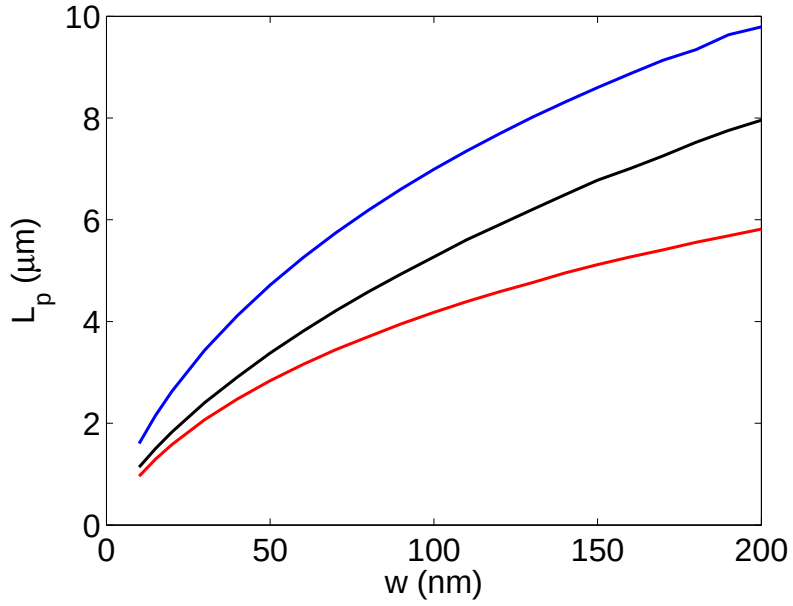


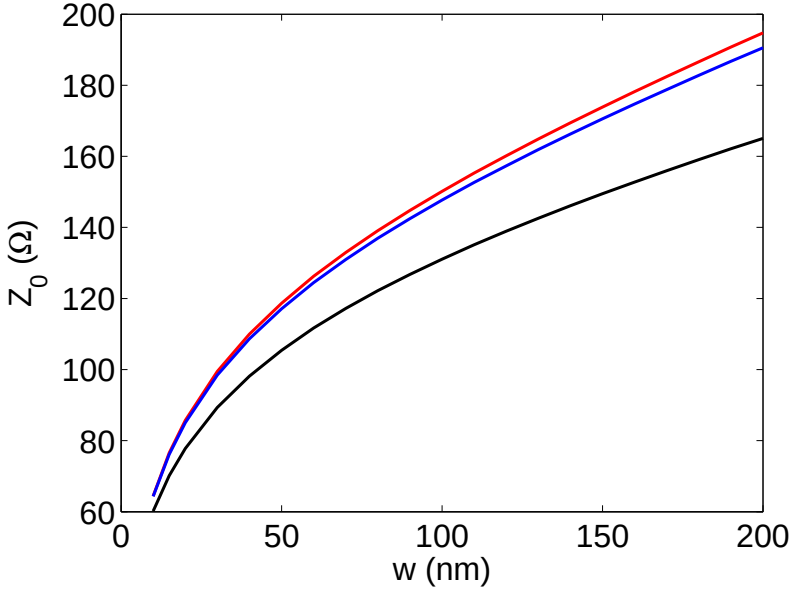


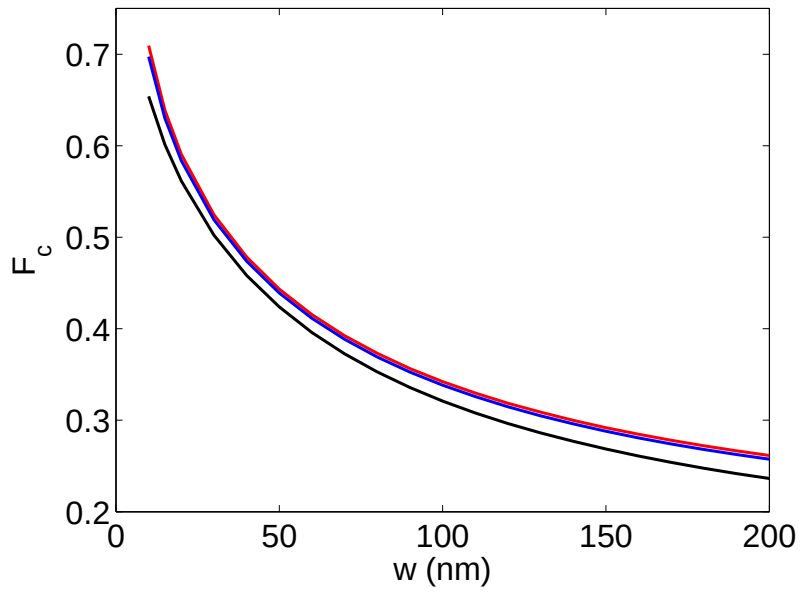


Results: symmetric, $\lambda_0 = 1.55\mu m$, w dispersion

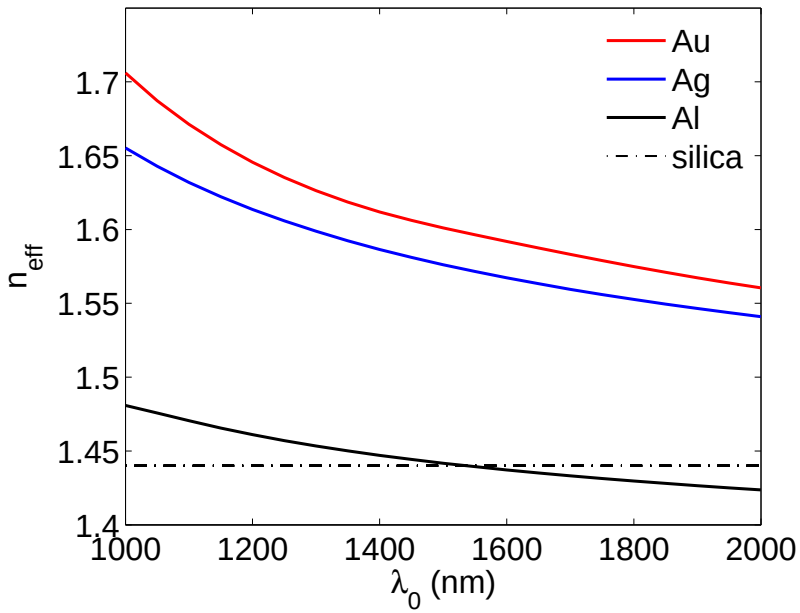


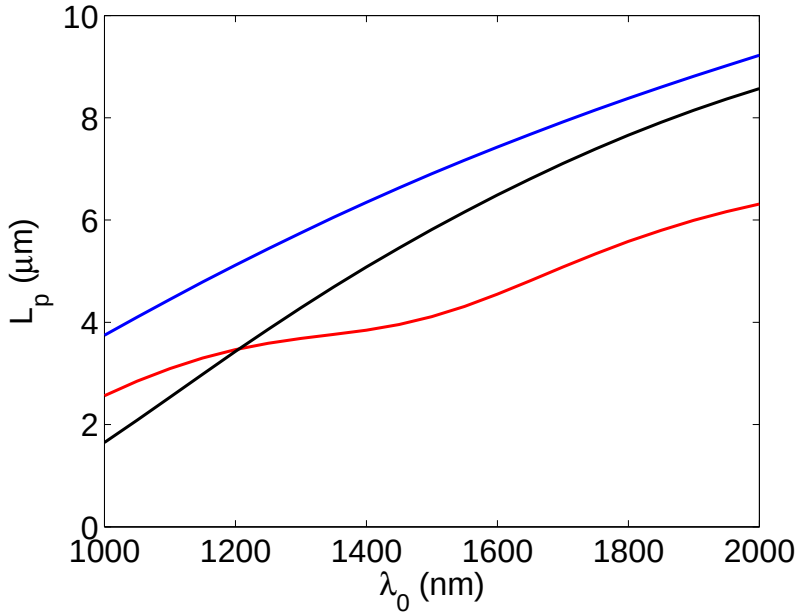




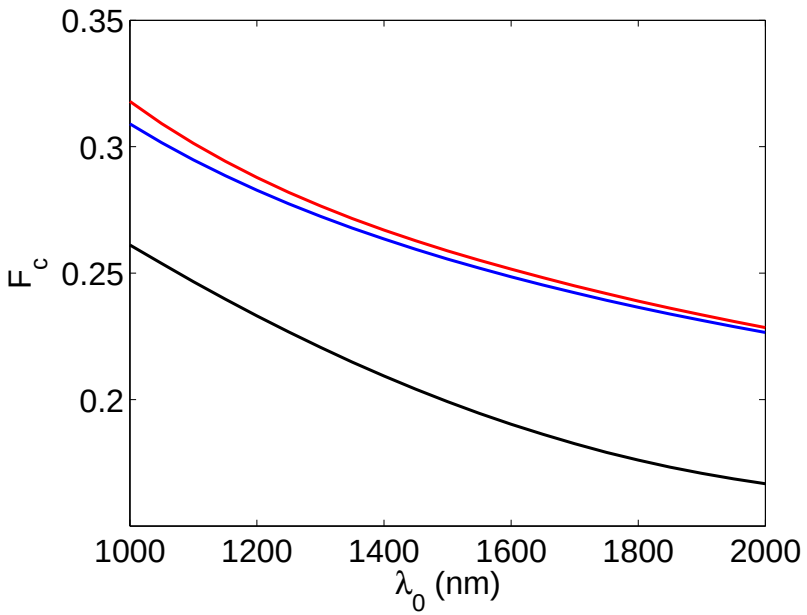


Results: asymmetric, $w = 50\ nm$, λ_0 dispersion





- The mode is bound for silver and gold
- For aluminium, becomes leaky into the substrate at $\lambda_0 \approx 1.5\ \mu m$



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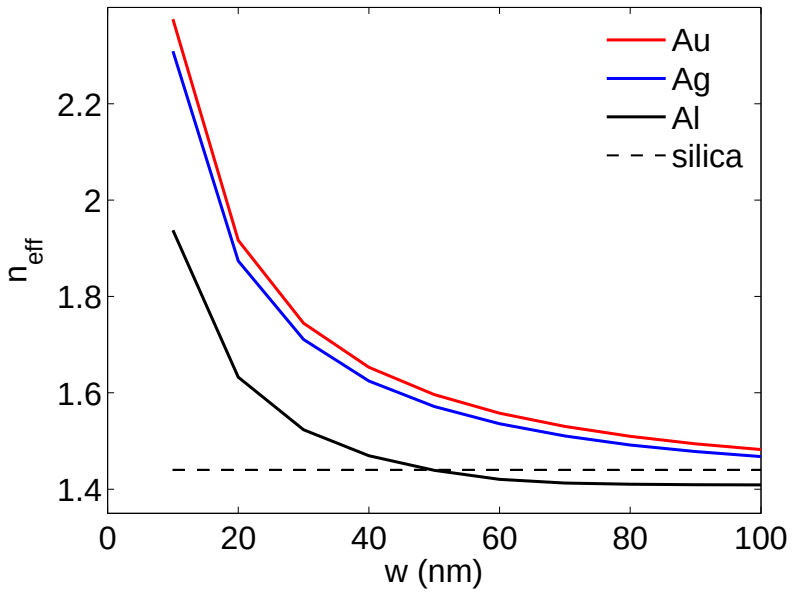
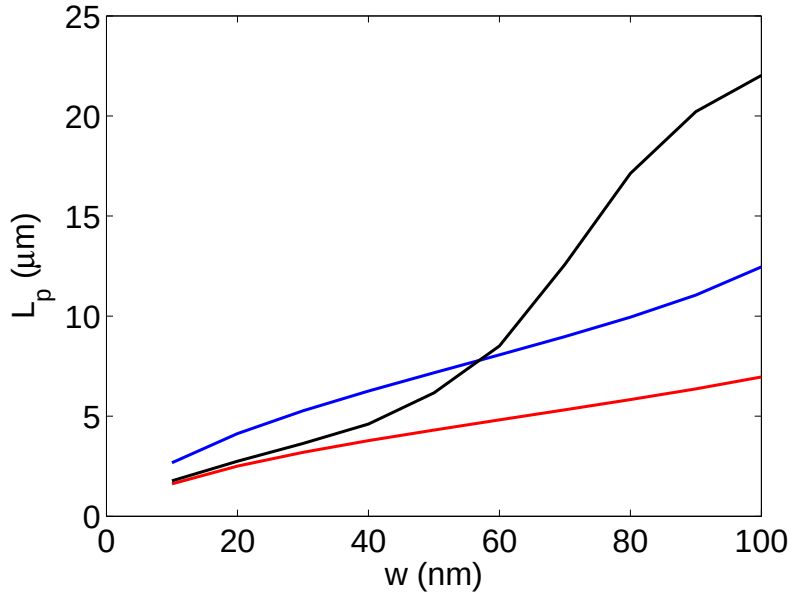
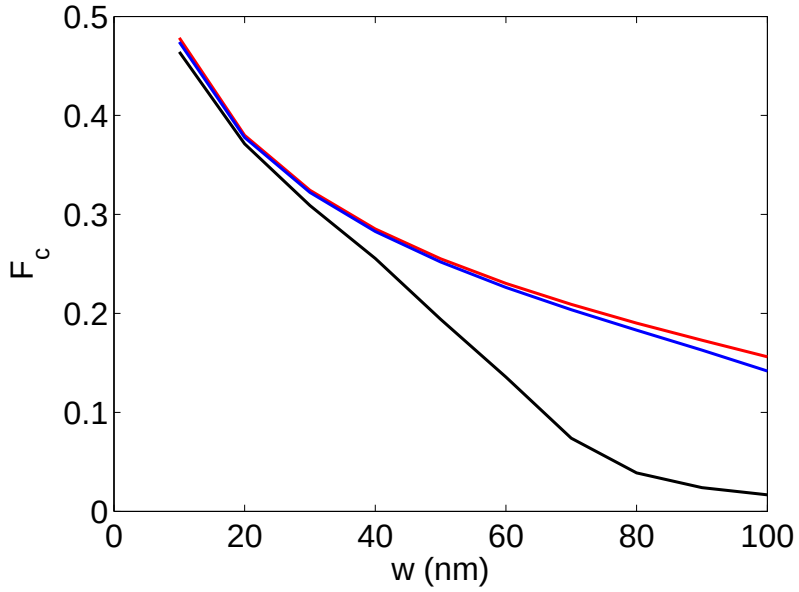




- In each case exists a cutoff
- Analysis limited to $w \leq 100$ *nm*
- For high leakage the model must be improved (PML reflections)



Summary

- The study of the fundamental mode properties shows that, by properly choosing the metal and waveguide geometry, specific mode properties can be obtained
- COMSOL Multiphysics offers a fast and accurate means to determine the mode properties of bound guided modes
- A better model for the study of leaky modes must be developed