Air-side Optical Excitation of Surface Plasmon Polaritons on Gold

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INTRODUCTION

Prism coupling

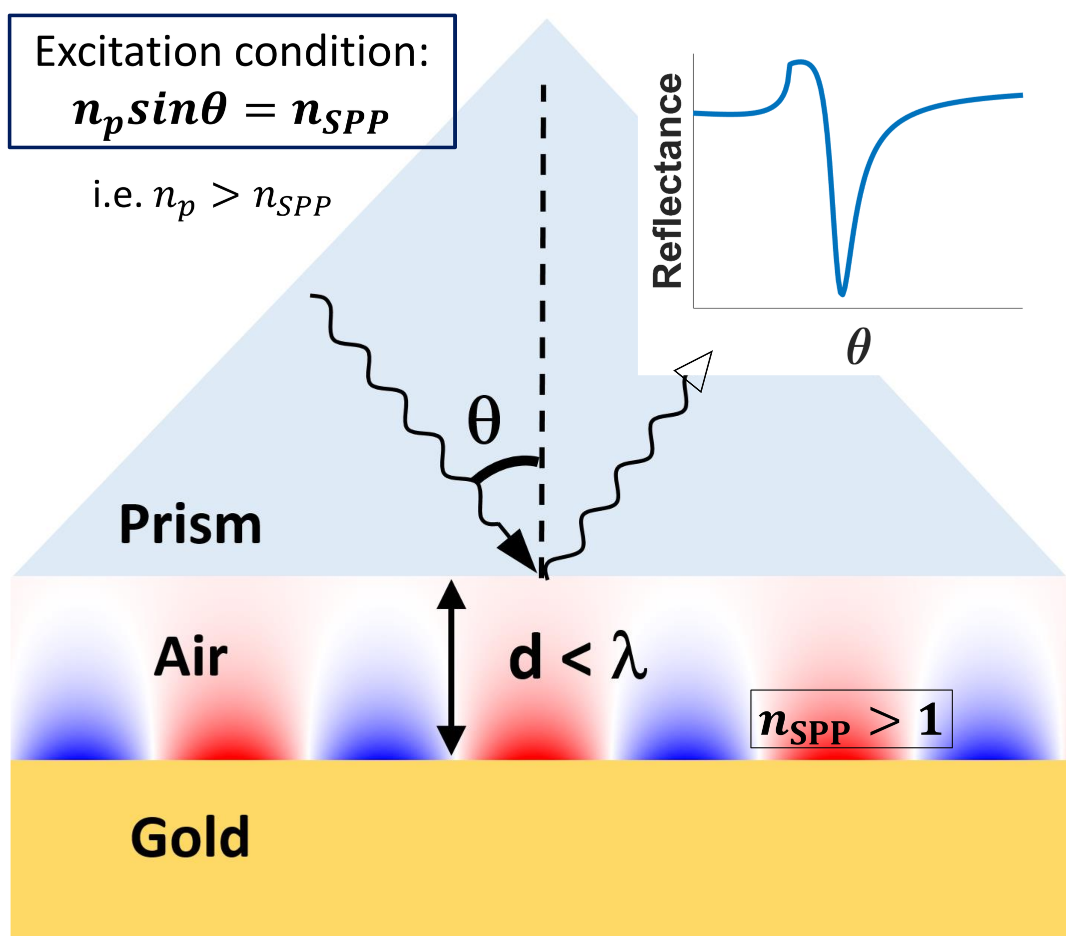
Exciting SPPs: Momentum matching

- Direct optical excitation – **forbidden**
- Momentum ∝ refractive index (n)
- Excitation at air-metal interface requires higher index medium: **prism coupling**

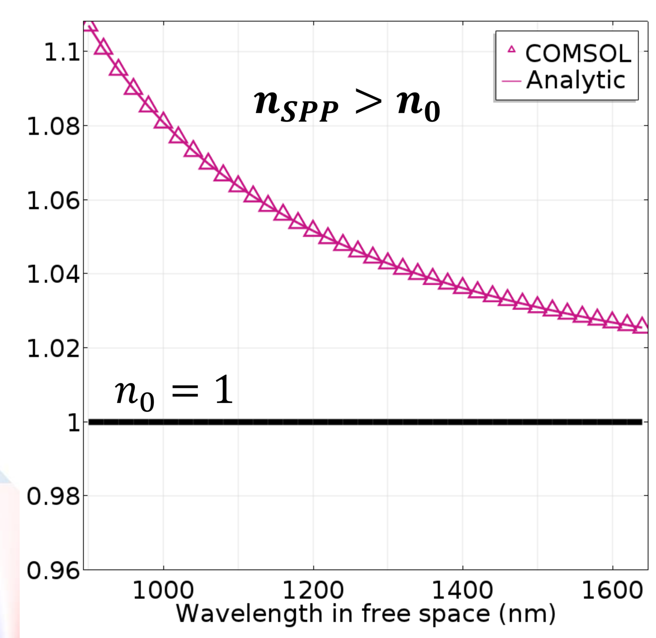
SPP momentum > photon momentum (in free space)

Can SPPs be directly excited from "free space" (n_0 = 1) i.e. air side?

Excitation condition:
$n_p sin\theta = n_{SPP}$
i.e. $n_p > n_{SPP}$



SPP Mode index, n_{SPP}
$= \beta/k_0 = \sqrt{\epsilon_d \epsilon_m / \epsilon_d + \epsilon_m}$

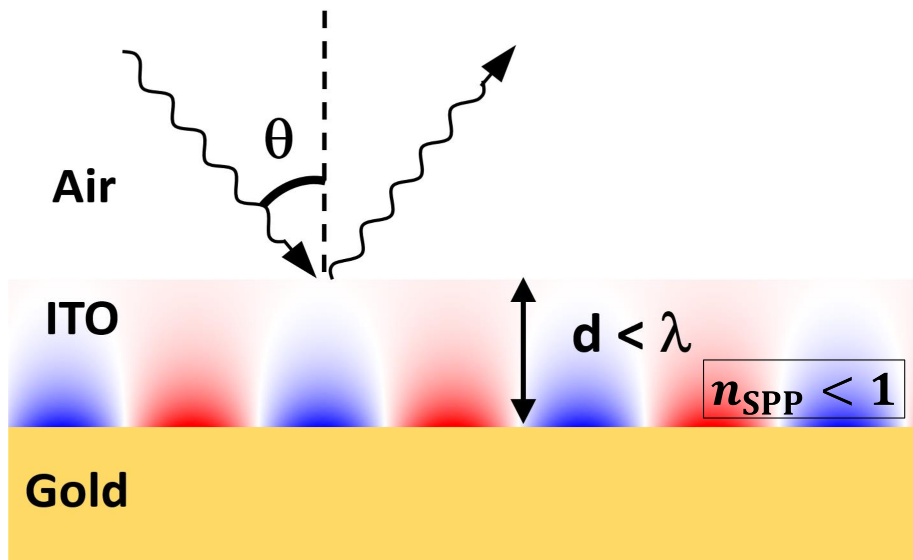


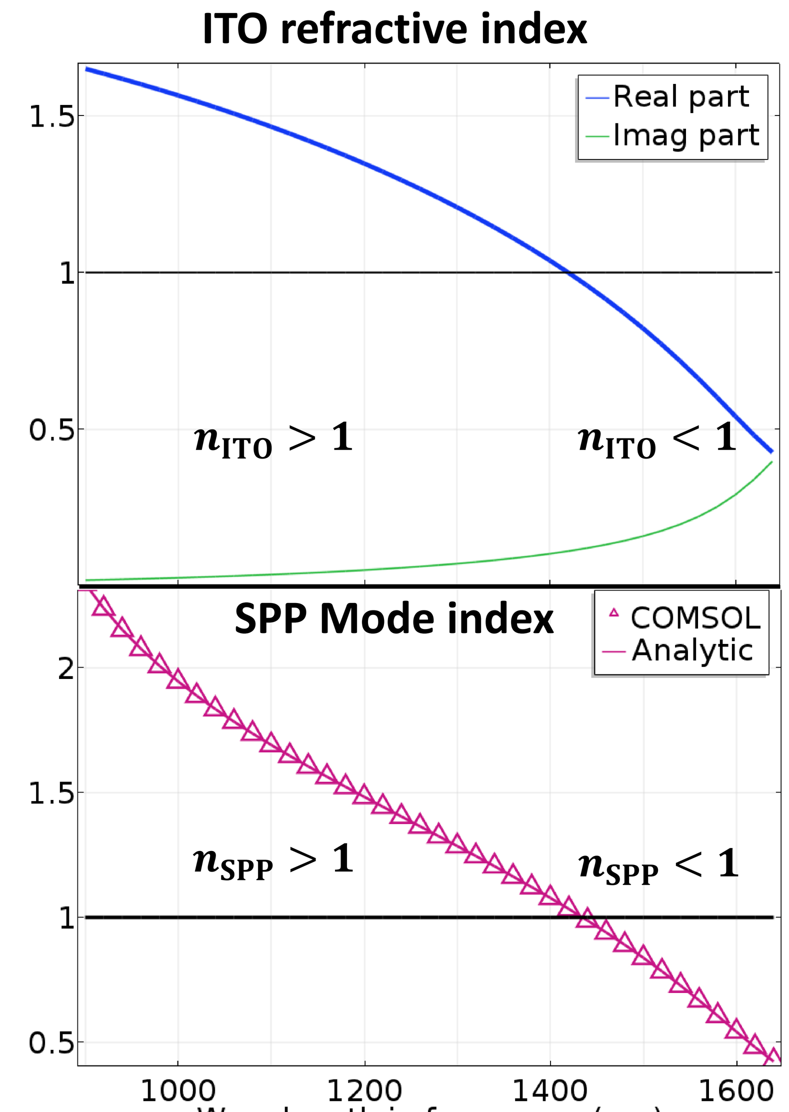
$\epsilon_{m,d}$: Permittivity of metal, dielectric
n_0: Free space refractive index
n_p: Prism refractive index
β: Mode propagation constant
$k_0 = 2\pi/\lambda$, λ: Free space wavelength

Direct coupling

SPPs can be excited from free space

- **Momentum matching possible if $n_{SPP} < 1$**
- Use thin film of *refractive index*, n < 1 on metal surface
- Indium tin oxide (ITO): n < 1 spectral window around 1550 nm





COMPUTATIONAL METHODS (2D)

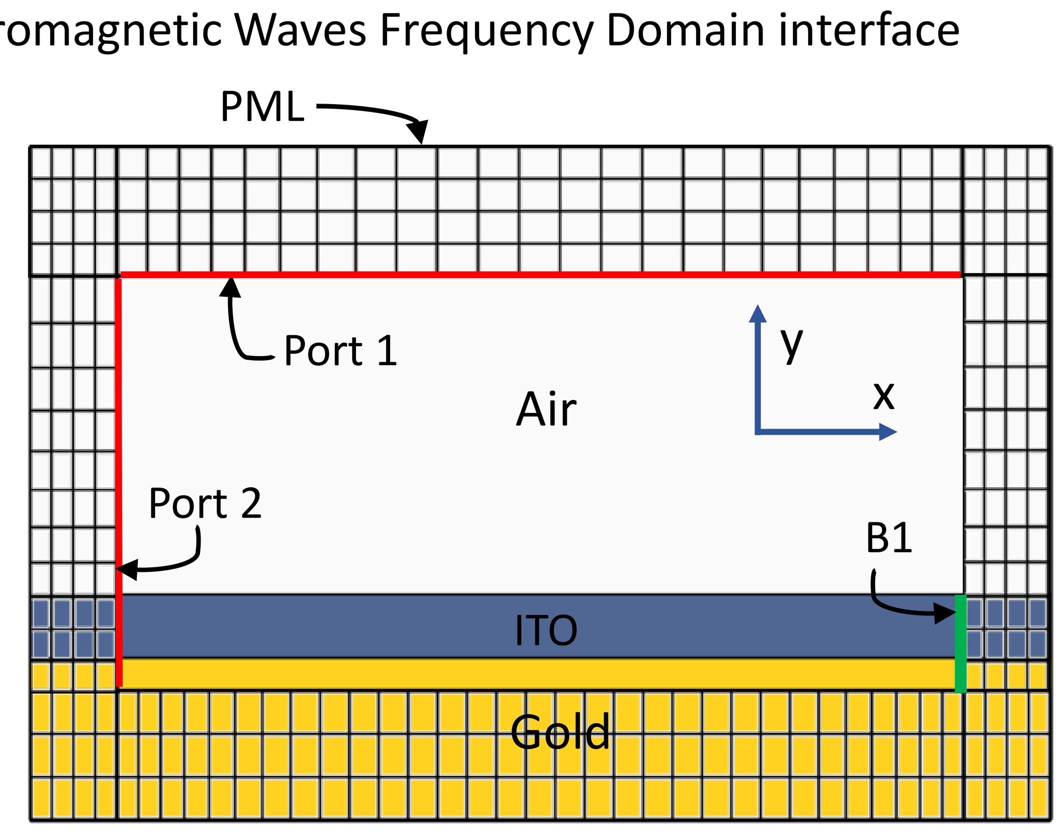
Wave Optics module -> Electromagnetic Waves Frequency Domain interface

Wavelength domain

- Excitation and reflectance through Port 1
- Reflectance vs λ, θ - Periodic boundaries
- Scattered field formulation (PML)
- Poynting vector normal to boundary B1 (green)

Boundary Mode analysis

- Mode analysis at port 2



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[2] E. Ozbay, Science 311, 189 (2006).
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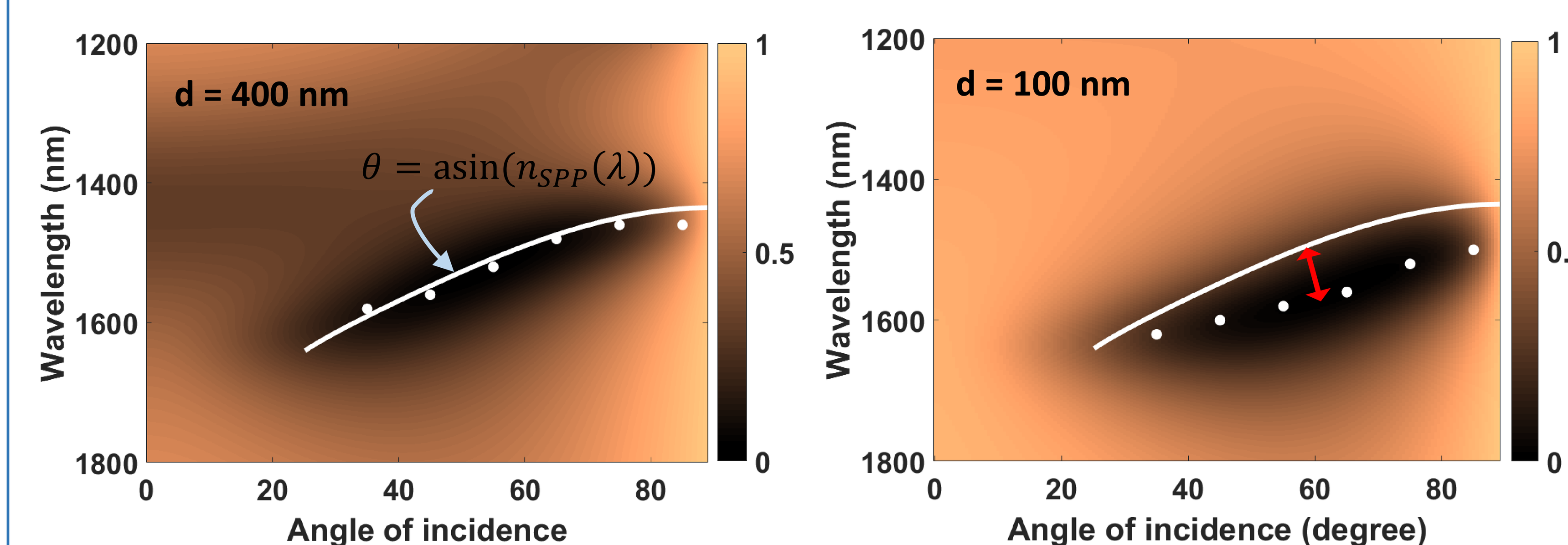
[4] G. V. Naik, V. M. Shalaev, and A. Boltasseva, Adv Mater 25, 3264 (2013).

RESULTS

Mode excitation

- Investigated for ITO films of thickness d = 400, 100 nm
- Reflectance minima (light incident from air side) follow dispersion relation (solid line) – shows efficient mode excitation
- Red-shifted dispersion of 100 nm ITO-on-gold SPP (red double headed arrow) – effect of finite film thickness



Analytical reflectance (colour map), n_{SPP} (solid line) and reflectance minima - COMSOL (scatter)

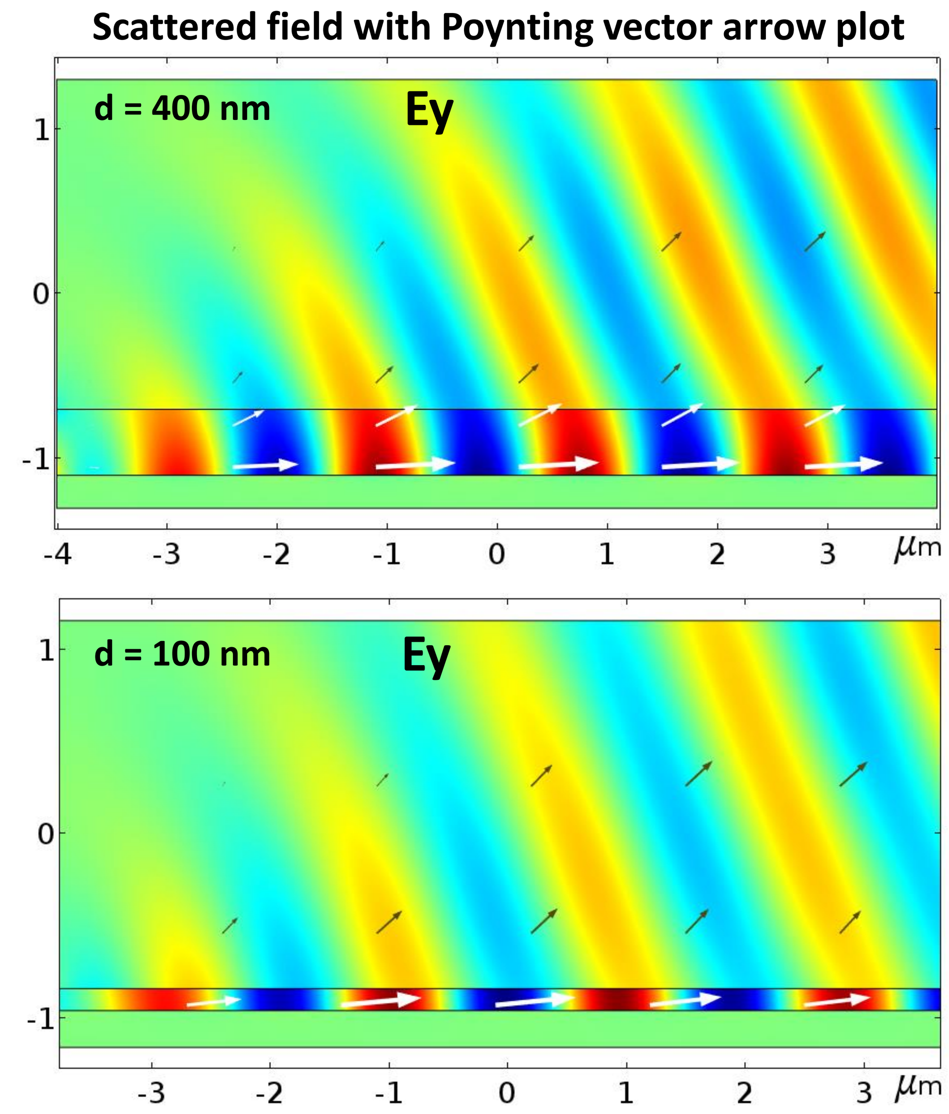
Field characteristics & propagation

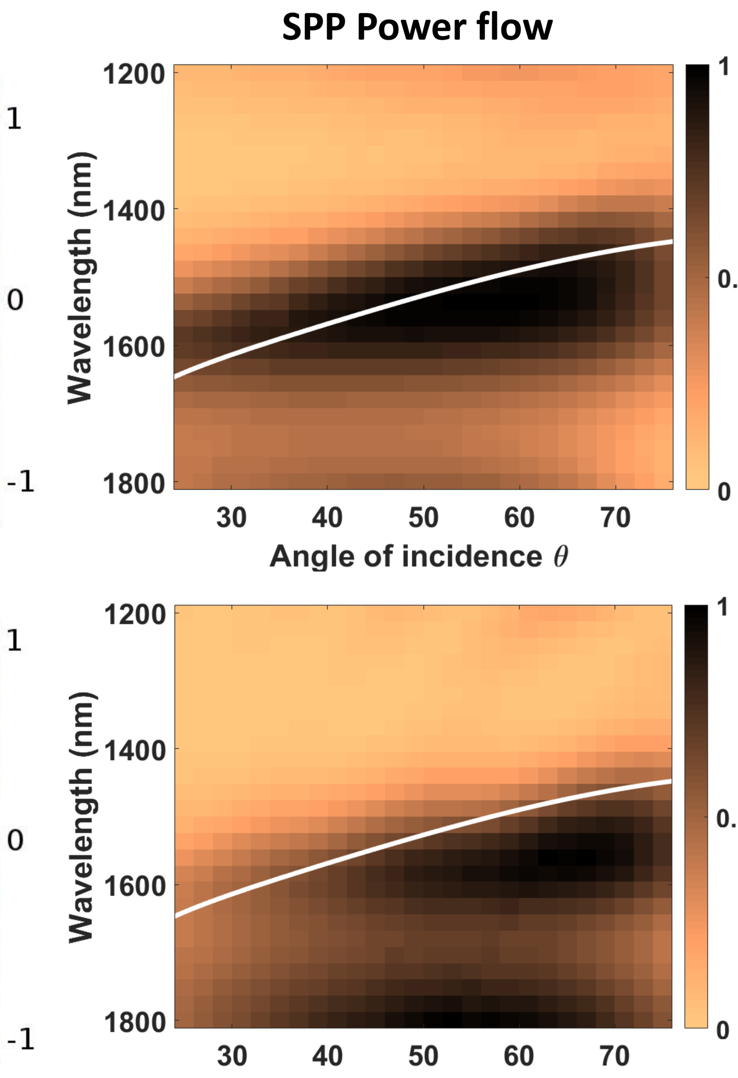
Scattered field formulation: visualize mode fields independent of source

- SPP fields confined within film
- Decay away from ITO – gold interface
- Energy flow parallel to the interface (white arrows) within ITO
- Radiation loss into air (black arrows)

SPP power flow: Integrated Poynting vector

- Poynting vector integrated along boundary B1 – power flow parallel to the interface
- Follows SPP dispersion relation (solid line)





CONCLUSIONS

- Direct, air side excitation of SPPs on gold at near-IR wavelengths is demonstrated
- SPP at ITO – gold interface has mode index below 1. This mode does not require prism/grating/scatterers to couple with EM radiation
- Mode dispersion, air side excitation, energy flow and field profiles are modelled in COMSOL Multiphysics®
- Future work should aim to uncover similar materials with mode index below 1 including visible and IR ranges

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