Surface Plasmon Polaritons on Metal-Dielectric Nanocomposite Films

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Outline

- Background and motivation
- Experimental results
- Numerical modeling and analysis
- Summary
Surface Plasmon Polaritons (SPPs) are important for sensing, localized excitations of transition, miniaturized photonic interconnection, nonlinear optics, etc.

To design or control the properties of SPPs, e.g., its propagation (mode index), dispersion (group index), spatial profile, etc., for better performances.

- Stern and Ferrell, Phys. Rev. 120, 130 (1960).
- Danckwerts and Novotny, PRL. 98, 026104 (2007).
Background of Surface Plamson Polaritons (SPPs)

- Photonic interconnect
- Sensing
- Nonlinear Nano-Optics
- Nano laser source
- Subdiffraction Imaging

- Localized excitation of transition

- Stern and Ferrell, Phys. Rev. 120, 130 (1960).
- ...
Motivation

- Free conduction current can support SPPs on a metal-dielectric surface.

- Q: Can displacement current support SPPs?

- Further Q: To what extent can we tailoring the properties of SPPs via changing the volume fraction of metal in a random metal-dielectric nanocomposite?
Experiment: samples

- **Samples:** a collection of 30-nm-thick gold-air nano-composite film with gold fill fraction ranging from 1 to 0.35.

  - **SEM image**
    - $f = 1$
    - $f = 0.95$
    - $f = 0.85$
  - **TEM image**
    - $f = 0.65$

  - *Continuous* → *Semi-continuous* → *Isolated*
Experiment: setup

➢ Reflectance in Kretschmann configuration
  - Wavelength: 1550 nm
    (far away from localized SP resonance wavelength)
Gold fill fraction decreases from sample #1 to #5.

- Sample #1: Pure gold
- Sample #2: Intermediate
- Sample #3: Intermediate
- Sample #4: Intermediate
- Sample #5: 'Dielectric'

Critical angle
Modeling the optical property of nanocomposite films

» Anisotropic effective medium approximation (EMA)
  - Nano-structural variation in x-y plane only

Comparison between experimental and numerical results

EMA can describe qualitatively the optical properties of the nanocomposite.
Evolution of reflectance curve

- Continuously change the gold fill fraction

![Graph showing the evolution of reflectance curve with changing gold fill fraction.](attachment:image.png)
Evolution of reflectance curve

- Continuously change the gold fill fraction

For $1 > f > 0.6$, the conventional SPP dip transits smoothly

What happens for $0.4 < f < 0.6$?
Spatial profiles of the four supported modes

Color indicates $|H_x|$ amplitude

air
film
glass
Longitudinal and transverse mode properties

\[
\begin{align*}
\Re \{ n_{\text{film}} \} & \quad \Im \{ n_{\text{film}} \} \\
\Re \{ n_{\text{glass}} \} & \quad \Im \{ n_{\text{glass}} \} \\
\Re \{ k_{\text{film}} \} & \quad \Im \{ k_{\text{film}} \} \\
\Re \{ k_{\text{glass}} \} & \quad \Im \{ k_{\text{glass}} \} \\
\Re \{ k_{\text{air}} \} & \quad \Im \{ k_{\text{air}} \}
\end{align*}
\]
Coupling strength of each mode with incident plane wave

\[ |F(\theta)|^2 = \frac{\cos^2 \theta}{(\Re\{n_{sp}\} - n_g \sin \theta)^2 + (\Im\{n_{sp}\})^2} \]

We have experimentally excited SPPs on a collection of gold-air nanocomposite films with various values of gold fill fraction.

The reflectance as func. of $\theta_{inc}$ shows very different characteristics, which falls into one of three distinct regimes.

The air-nanocomposite-glass geometry supports four mathematical modes, and different modes may be responsible for the reflectance shapes for films with different values of the gold fill fraction.
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  Website: www.optics.rochester.edu/~boyd

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Thank you for your attention!
Dispersion relations

\[ \text{frequency ( } \times 10^{14} \text{Hz) } \]

(a) \( f = 1 \)

(b) \( f = 0.8 \)

(c) \( f = 0.6 \)

(d) \( f = 0.5 \)

\[ \Re \{ \kappa_{spp} \} \left( \times 10^7 \text{ m}^{-1} \right) \]