Characterizing Surface-Plasmon polaritons at Lossy Interfaces

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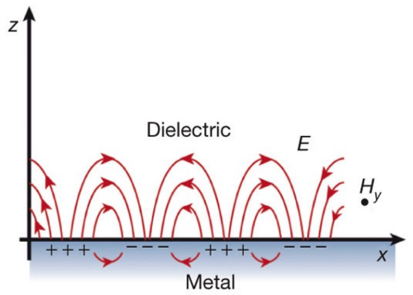
Aim:

Characterize surface-plasmon polaritons (SPPs) at lossy planar interfaces between dispersive and nondispersive linear isotropic homogeneous media, i.e., materials or metamaterials.

Previous studies of SPPs$\rightarrow$ focused on lossless interfaces, neglect the effects of losses or focus only on electric responses.

- Solve Maxwell's equations to obtain strict bounds for the permittivity and permeability of these media to decide whether a given mode is a propagating SPP or not.
- Investigate intensity concentration of modes at the interface and Poynting vector

Background: SPPs at Different Interfaces



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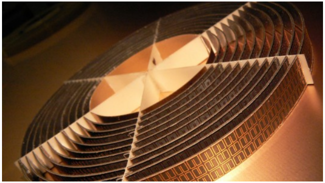

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Background: Electromagnetic (EM) Duality

EM duality presents a clear and simplified description of transverse electric (TE) and transverse magnetic (TM) modes behavior at the interface.

- EM Susceptibilities

$$\frac{\varepsilon(\omega)}{\varepsilon_0} = \varepsilon_{\mathrm{b}} + \frac{F_{\mathrm{e}}\omega_{\mathrm{e}}^2}{\omega_{0_{\mathrm{e}}}^2 - \omega^2 + \mathrm{i}\Gamma_{\mathrm{e}}\omega},$$
$$\frac{\mu(\omega)}{\mu_0} = \mu_{\mathrm{b}} + \frac{F_{\mathrm{m}}\omega_{\mathrm{m}}^2}{\omega_{0_{\mathrm{m}}}^2 - \omega^2 + \mathrm{i}\Gamma_{\mathrm{m}}\omega}$$

Methods: Characterization of SPPs at Lossy Interfaces

SPPs wavenumber and propagation coefficient at the interface

$$\gamma_j(\omega) = \sqrt{\beta^2(\omega) - k_0^2 \mu_j(\omega)\varepsilon_j(\omega)},$$

$$\beta(\omega) = k_0 \sqrt{\varepsilon_1(\omega)\varepsilon_2(\omega) \frac{\mu_1(\omega)\varepsilon_2(\omega) - \mu_2(\omega)\varepsilon_1(\omega)}{\varepsilon_2^2(\omega) - \varepsilon_1^2(\omega)}}.$$

$\beta'(\omega) > 0,\ \beta''(\omega) > 0$ for forward propagation and gain-less interfaces and from the conditions on the wavenumber $\rightarrow$

$$\boxed{(\beta^2)'' > 0,\ (\beta^2)' > k_0^2 \varepsilon_1 \mu_1}$$

Results: Characteristics Equations of SPPs at Lossy Interfaces

$$(\beta^2)'' > 0,\ (\beta^2)' > k_0^2 \varepsilon_1 \mu_1 \rightarrow$$

Our characteristic equations

$$0 < \varepsilon_2'' < \varepsilon_1',\ \varepsilon_2' < -\sqrt{\varepsilon_1'^2 - \varepsilon_2''^2},$$

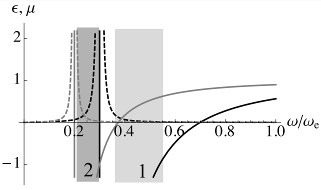
$$\mu_2'' \geq 0, \mu_2' > \frac{\varepsilon_1'\left(-\varepsilon_1'^2 + \varepsilon_2'^2 - \varepsilon_2''^2\right) + \varepsilon_2''\mu_2''\left(-\varepsilon_1'^2 - \varepsilon_2'^2 - \varepsilon_2''^2\right)}{-\varepsilon_1'^2\varepsilon_2' + \varepsilon_2'^3 + \varepsilon_2'\varepsilon_2''^2}$$

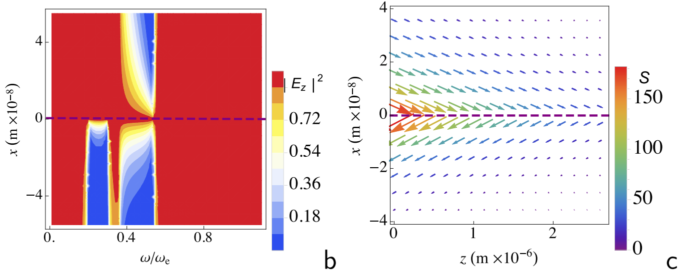
$$\varepsilon_1 = \varepsilon_1' + \mathrm{i}\varepsilon_1'',\ \mu_1 = \mu_1' + \mathrm{i}\mu_1''$$

$$\varepsilon_2 = \varepsilon_2' + \mathrm{i}\varepsilon_2'',\ \mu_2 = \mu_2' + \mathrm{i}\mu_2''$$

Results: Characterization of SPPs at Lossy Interfaces: TM SPPs

Dispersive material Interface with air→



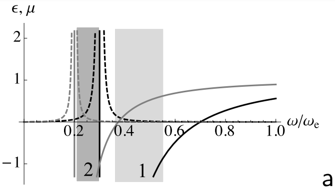


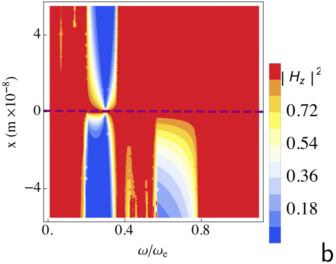
a. Dispersive material's permittivity and permeability, b. electric field intensity for TM modes and c. Poynting vector.

N. Sang-Nourpour et al, Characterization of Surface-Plasmon polaritons at Lossy Interfaces, arXiv:1611.00695v2 (2017).

Results: Characterization of SPPs at Lossy Interfaces: TE SPPs

Dispersive material Interface with air→





a. Dispersive material's permittivity and permeability, b. electric field intensity for TE modes.

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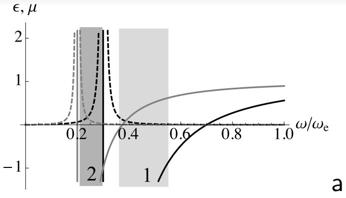
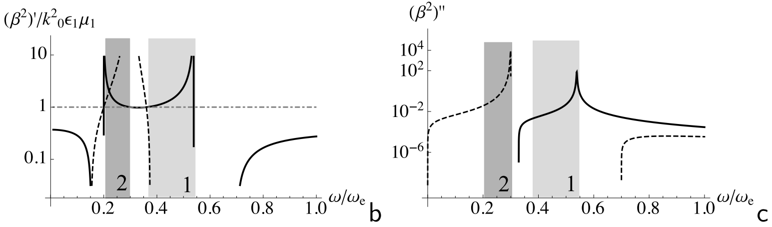
Results: Characterization of SPPs at Lossy Interfaces

Dispersive material Interface with air→





a. Dispersive material's permittivity and permeability, b. $(\beta^2)'/k_0^2\varepsilon_1\mu_1$ and c. $(\beta^2)''$.

N. Sang-Nourpour et al, Characterization of Surface-Plasmon polaritons at Lossy Interfaces, arXiv:1611.00695v2 (2017).

Summary

- Derived characteristic equations for the propagation of TM and TE SPPs at lossy flat interfaces of materials with positive and negative permittivity and permeability.
- To derive the characteristic equations we introduced strict bounds on the real and imaginary parts of the squared propagation coefficient to decide whether a given mode is a propagating SPP or not.
- These SPP propagation solutions are obtained as mathematical results, which we confirm by checking against physical intuition through analyzing field-intensity and Poynting-vector properties.

In progress→Propagation of SPPs at lossy bent interfaces ☺