Surface wave supporting structures in the terahertz and optical frequency domains

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Outline

- Plasmonics Overview
- Background
- Theory and Methods
  - Sommerfeld Integral analysis
  - Dispersion relation
  - Surface Integral equation
- Results
- Conclusions

Plasmonics Overview

- Interaction of electromagnetic (EM) waves with free electrons
- Subwavelength localization of EM fields
- Plasma frequency
  - Metals - Optical frequency
  - Semiconductors - Terahertz
- Low efficiency

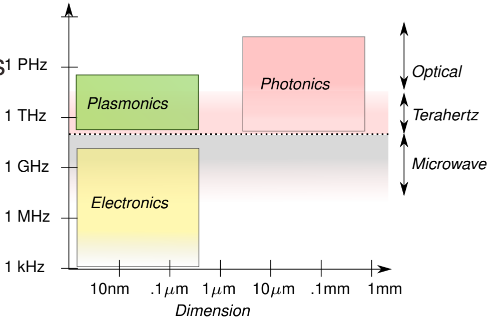


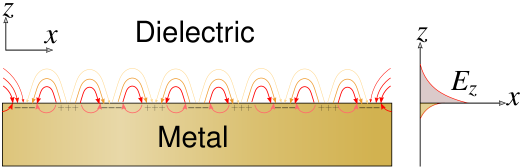
Figure: Communication Technologies at various frequencies

Plasmonics Overview

- Metal-dielectric interface
- Surface plasmon polaritons (SPPs)

$$\mathrm{Re}\left[\varepsilon_{\text{metal}}(\omega)\right] < 0$$

- Plasma frequency
  - Metals - Optical frequency
  - Semiconductors - Terahertz
- Low efficiency



Background

Surface Plasmons

- Metal-dielectric interface
- Surface plasmon polaritons (SPPs)
- Slow surface waves
  - Wavelength
  - Semiconductors - Terahertz
- Low efficiency
- Metal-dielectric interface
- Slow surface waves
- Subwavelength Control of electromagnetic waves
- Focusing beyond the

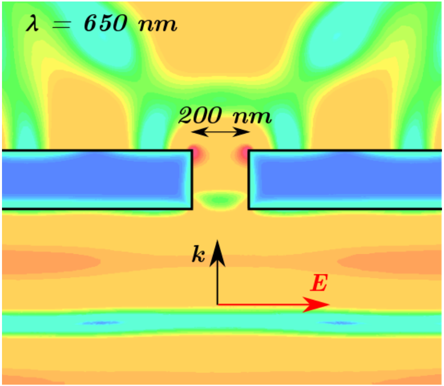


Figure: Subwavelength Transmission through a Silver slit

Background

Optical Nanoantennas

- Convert Localized near-field to efficient far-field radiation
- Low Q-factor
- Extremely small size
- High Purcell Factor

$$P = \frac{Q}{V}$$

- Directive radiation

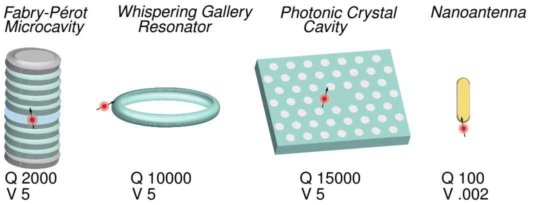
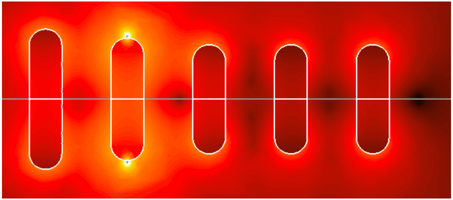


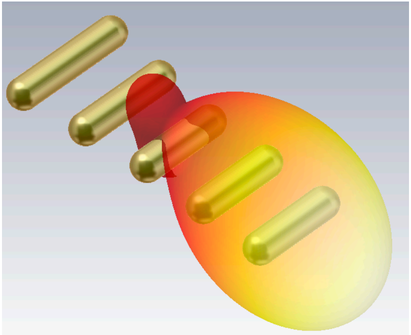
Figure: Optical resonant cavities for electric field enhancement

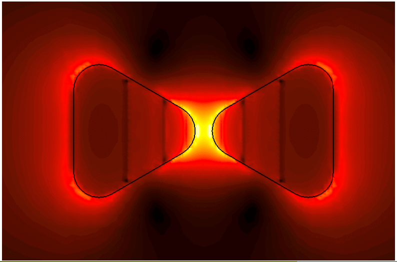
Background

Optical Nanoantennas (contd.)

- Scaled-down microwave designs
  - Directivity: Yagi-Uda antenna
  - Broadband: Bowtie antenna







Background

Optical Nanoantennas

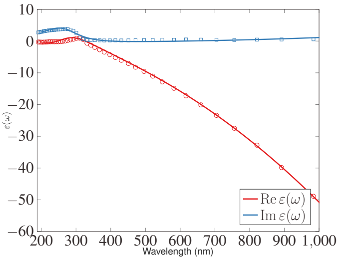
- Metal-dielectric Interface

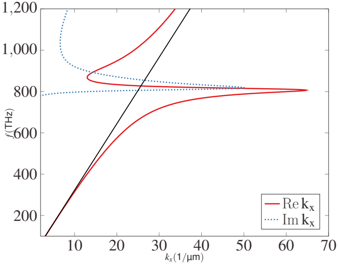
$$k_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_1 \varepsilon_2(\omega)}{\varepsilon_1 + \varepsilon_2(\omega)}}$$

- Accurate material description using Drude-critical points

$$\varepsilon_2(\omega) = \varepsilon_\infty - \frac{\omega_d^2}{\omega^2 + j\gamma\omega} + \sum_{i=1}^{N} G_i(\omega)$$

$$G_i(\omega) = C_i \left[\frac{e^{j\phi_i}}{\omega_i - \omega - j\Gamma_i} + \frac{e^{-j\phi_i}}{\omega_i + \omega + j\Gamma_i} \right]$$

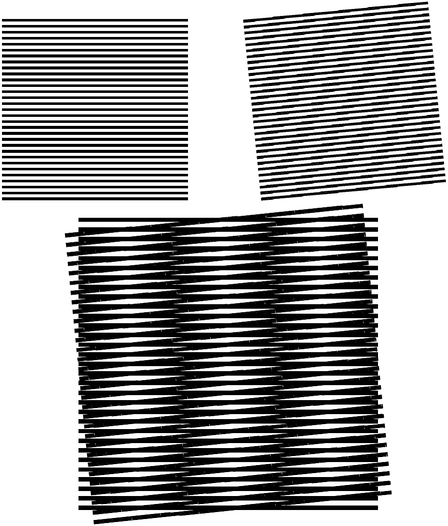




Nanoscale Imaging scheme

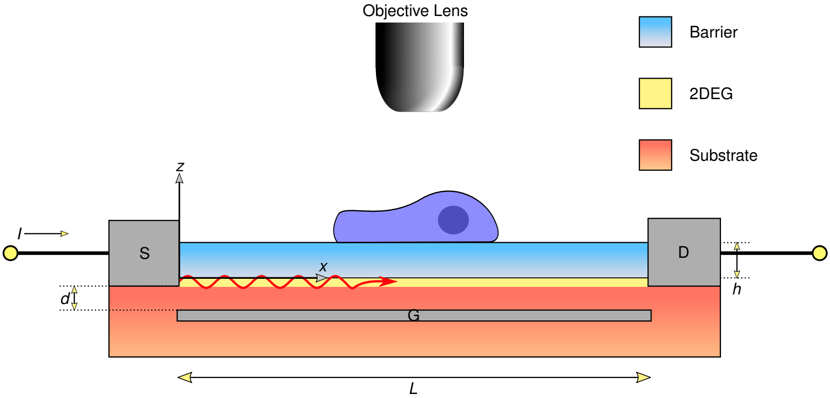
Basics

- Structured Illumination
  - Periodic sine pattern
- Moiré Fringes
  - Frequency modulation of two patterns
  - Resulting low-frequency signal
- Linear scheme
  - Low light intensity



Nanoscale Imaging scheme

Setup



Nanoscale Imaging scheme

Working Principle

- Illumination signal

$$I(\mathbf{r}) = 1 + \cos(\mathbf{k}_\rho \cdot \mathbf{r} + \phi)$$

- Observed Image (Spatial domain)

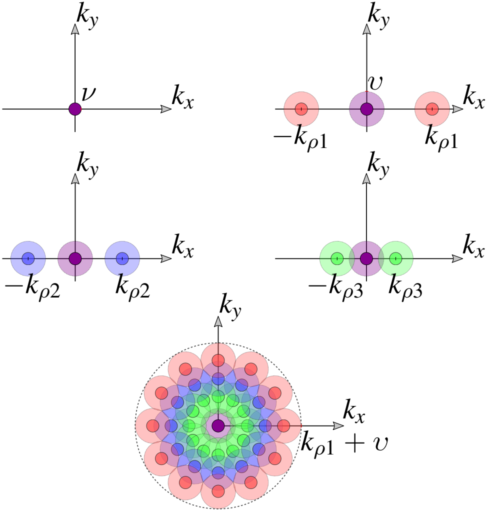
$$M(\mathbf{r}) = [F(\mathbf{r}) \cdot I(\mathbf{r})] \otimes H(\mathbf{r})$$

- Fourier transformed Image

$$\begin{aligned}\tilde{M}(\mathbf{k}) &= \left[\tilde{F}(\mathbf{k}) \otimes \tilde{I}(\mathbf{k})\right] \cdot \tilde{H}(\mathbf{k}) \\ &= \frac{1}{2}\left[2\tilde{F}(\mathbf{k}) + \tilde{F}(\mathbf{k} - \mathbf{k}_\rho)\mathrm{e}^{-\mathrm{j}\phi} + \tilde{F}(\mathbf{k} + \mathbf{k}_\rho)\mathrm{e}^{\mathrm{j}\phi}\right] \cdot \tilde{H}(\mathbf{k})\end{aligned}$$

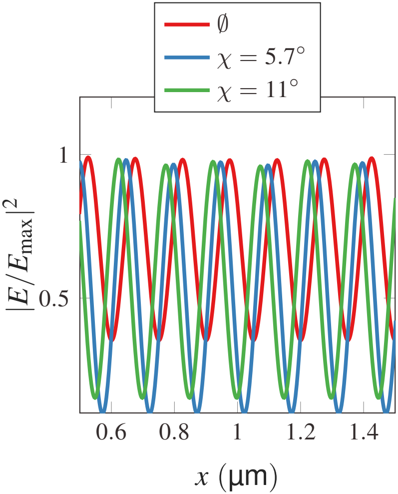
Nanoscale Imaging scheme

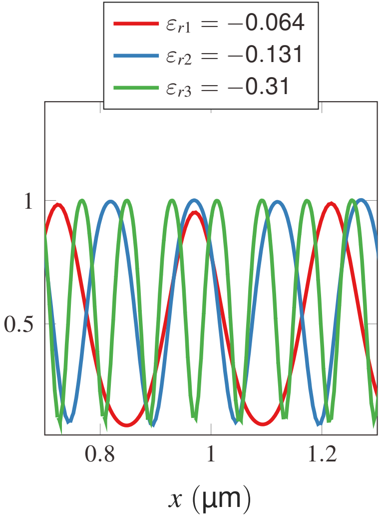
Image Reconstruction



Nanoscale Imaging scheme

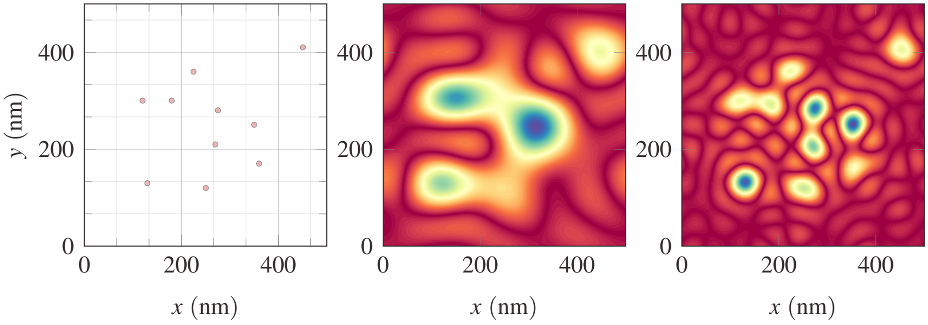
Image Reconstruction





Nanoscale Imaging scheme

Results



(a) (b) (c)

Figure: (a) Sample distribution. Simulation of the reconstructed sample image at: (b) $\mathrm{Re}\, k_\rho = 39.5$ (c) $\mathrm{Re}\, k_\rho = 80$

Summary

Two-dimensional plasmonic devices

- Subwavelength wave phenomena at optical and terahertz frequencies
- Realization of terahertz sources and sensors
- 2D nature of waves permits subwavelength confinement
- Plasmonic activity
- Nanoscale imaging using terahertz plasma waves

Acknowledgements

Sponsorship

- The Fulbright Program

Thank you!

Questions?