Collective resonances in plasmonic crystals

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Optical transmission through strong scattering and highly polydisperse media

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Contents

- Single plasmonic antennas: light emission
- Plasmonic crystals of antennas: emission and sensing
Localized plasmon resonances

- Metal nanoparticle (L<<λ): resonant response dominated by material

\[ \alpha = 4\pi a^3 \frac{\varepsilon - \varepsilon_m}{\varepsilon + 2\varepsilon_m} \]

- Nanoantenna (L~λ): resonant response determined by material and geometry

\[ -\varepsilon = 2\varepsilon_m(\omega_{sp}) \]
Dimers: near-field coupling

\[ \Delta \ll \lambda \]

Atto 680 in PVB

O.L. Muskens... JGR, Opt. Express (2007)
Dimer antennas: emission

Photoluminescence enhancement

$L = 80$ nm, $\Delta = 20$ nm $\lambda_{SPR} \equiv \lambda_{em} = 730$ nm

Dimer antennas: emission

- Fivefold enhancement of $\gamma_2$ with respect to $\gamma_0$
- $\gamma_1 = \gamma_0$

Fluorescence decay

![Graph showing fluorescence decay with time (ns)]
Dimer antennas: emission

Dipole radiating at 730 nm

Improvement of quantum efficiency

Giannini, ...JGR, Sanchez Gil, JOSA B (2009)
Arrays of particles: Far-field coupling

(±1,0) Rayleigh anomaly

Localized SP

Surface lattice resonance

$W = 85 \text{ nm}$, $L = 415 \text{ nm}$

$a_x = 500 \text{ nm}$, $a_y = 300 \text{ nm}$
Arrays of particles: history

- Carron et al. (JOSA B, 1986)
- Schatz et al. (J. Chem Phys, 2004)
- Kravets et al. (PRL 2008), Crozier et al. (APL 2008), Barnes et al. (PRL 2008), Vecchi et al. (PRL 2009)
Surface lattice resonances

\[
\begin{align*}
\omega / c &\ (\text{rad nm}^{-1}) \\
k_{\parallel} &\ (\text{rad nm}^{-1}) \\
0.004 &\ 0.008 \\
(-1,0) &\ (1,0) \\
(-2,0) &
\end{align*}
\]

Transmittance

Vecchi ... JGR, Phys. Rev. B (2009)
Emission

Emission vs. angle emission

Transmission vs. angle incidence

Enhanced and directional emission

Surface lattice resonance sensor

\[ \Delta n = 0.042 \]

\[ FoM = \frac{\partial \lambda}{\partial n} \frac{1}{\Delta \lambda} \]

![Graph showing transmittance (%) vs. wavelength (nm) with FoM values 1.4 and 25 highlighted.](image)
Universal scaling of FoM

Wavelength (nm)

FoM

Resonance

FoM

\[ \delta = \frac{(v_{RA} - v_{SLR})}{v_{RA}} \]

\[ \text{FoM} = \frac{0.79}{\delta} - 1.38 \]

Offermans, ..., JGR, ACS-Nano (2011)
Universal scaling of FoM

Offermans, ..., JGR, ACS-Nano (2011)
Conclusions

- Demonstrated enhanced emission of dye molecules from single nanoantennas

- The enhancement of the emission can be improved by collective resonances in periodic arrays of antennas

- These collective resonances improve the FoM of plasmonic refractive index sensors