Dipole-quadrupole plasmon coupling and Fano resonance in nanorods of T-like configuration

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Fano resonances have been found in many plasmonic structures.

The T-like structure constitutes one of the simplest plasmonic systems presenting near-field coupling and Fano resonances, arising by coupling between 1st and 3rd order multipoles plasmon modes, on spheroids and rods have been already investigated.

We propose a simple system for Fano resonance based on two rods and show how to tailor the particles in order to achieve the near-field coupling between a dipole mode and a quadrupole mode.

Fano resonances in spheroids: theoretical background

We consider T-like configuration with nanorods smaller than the wavelength to apply the quasi-static approximation [1. Grenier, Nanoplasmonics, Pan Stanford Publishing (2014)] and replace them by spheroids to describe plasmon modes analytically. To obtain the coupling conditions between the dipole and quadrupole modes of two spheroids in (a) we replace the top one by two shorter and identical spheroids (b).

The polarizabilities, dipole moment of the bottom spheroid and the absorbed powers read,

\[ \alpha_{1}(\omega) = \frac{8\pi}{3\varepsilon_{0}} \frac{\varepsilon_{1}\varepsilon_{m}}{\varepsilon_{m} - \varepsilon_{1}} \]

\[ \alpha_{2}(\omega) = \frac{8\pi}{3\varepsilon_{0}} \frac{\varepsilon_{2}\varepsilon_{m}}{\varepsilon_{m} - \varepsilon_{2}} \]

\[ \mathbf{M}_{1}(\omega) = \frac{2\pi}{\varepsilon_{0}} \mathbf{E} \times \mathbf{B} \]

\[ \mathbf{M}_{2}(\omega) = \frac{2\pi}{\varepsilon_{0}} \mathbf{E} \times \mathbf{B} \]

The plots at right showing a Fano resonance, were obtained for the following values of the spheroids: \( a = b = 30, \)

\( c = 20, \)

\( R_{1} = 1, \)

\( R_{2} = 60, \)

\( \theta = 1, \)

\( V = 4 \times 10^{-11}, \)

The plasma frequency and damping constants are \( \omega_{p1} = 9, \gamma_{1} = 0.2, \)

\( \omega_{p2} = 8, \)

\( \gamma_{2} = 0.07, \)

The dielectric functions are \( \varepsilon_{1} = \varepsilon_{m}/(1 + \varepsilon_{m}/\gamma_{1}) \)

\( \varepsilon_{2} = \varepsilon_{m}/(1 + \varepsilon_{m}/\gamma_{2}) \)

\( \xi = 1 - \frac{\omega_{p1}}{\omega} \)

\( = \frac{1}{1 + \gamma_{1}/\omega} \)

Gold rods and their multipole resonances

Multipolar resonances of gold rods were investigated solving Maxwell’s equations without approximations using COMSOL Multiphysics (optical constants from Johnson and Christy). For the two symmetrical cases (\( \theta = 0^\circ \)) and (\( \theta = 45^\circ \)), either only the longitudinal dipole mode or the transverse mode are excited. For intermediate angles, in special \( \theta = 45^\circ \), quadrupole or higher multipole resonances arise.

Conclusions

Fano resonances in T-like configuration of gold nanorods arise due to near-field coupling between a dipole and a quadrupolar mode, if the rod sizes are adequately tailored. At the Fano resonance the total extinction decreases and the near-field pattern is more concentrated at the top rod. The energy is transferred from the radiating dipole mode to a dark quadrupole mode. The T-like structure constitutes one of the simplest plasmonic systems presenting near-field coupling and Fano resonances in the visible and NIR and can be envisaged in sensing applications.

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