‘BRIGHT’ AND ‘DARK’ PLASMONS IN THE SYSTEMS OF METAL NANOWIRES

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Surface plasmons (SPs) are the collective oscillations of free electrons in metals coupled with electric field that can be optically excited over thin films of nanometers thickness and nanostructures. Various elements such as plasmonic waveguides [1], subwavelength resonators [2] and optical nanoantennas [3] have been studied recently.The plasmonic properties of nanowires and nanoparticles have recently been investigated using a variety of methods. However, there is a lack of investigations in terms of quality factor (Q) of SPs. Many authors find SPs by investigating resonance peaks in Scattering Cross Section (SCS). This study cannot be considered as a complete one, because in this way only ‘bright’ plasmons can be seen, ’dark’ plasmons that do not couple efficiently to incident wave cannot be discovered in such a description. We developed nonquasistatical expressions for the eigenvalues of SPs that includes finding of eigenfrequencies and Q-factor. Using this approach all possible SPs can be found and investigated, including ‘dark’ and multipole ones.

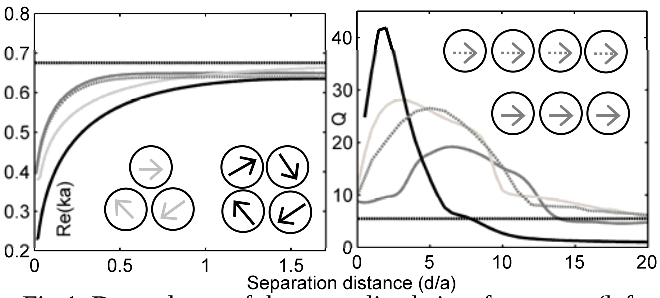

Fig.1. Dependence of the normalized eigenfrequency (left panel) and Q-factor (right panel) on the separation distance for longitudinal in-phase SPs, $\omega_p a/c = 1$, $\gamma = 10^{-3}\omega_p$.

We consider SP resonances in a finite linear chain of coupled metal nanowires and in clusters with triangular or square configurations (see Fig. 1). The radius of each nanowire is a, the separation distance between them is d. Metal is described by the permittivity ε_p that is given by the Drude model $\varepsilon_p = 1 - \omega_p^2/(\omega(\omega - i\gamma))$, here ω_p represents the plasma frequency and γ is material absorption. All eigenfrequencies are complex $\omega = \omega' + i\omega''$, where $\omega'' > 0$ represents damping and ω' is associated with the eigenoscillation frequencies. Q-factor of SPs can be evaluated through the formula $Q = \omega'/2\omega''$.

Total number of dipole plasmons in a finite linear chain of N nanowires equals to 2N (see ref. [4]). Fig. 1 presents real part of the normalized eigenfrequency and Q-factor for longitudinal in-phase SPs in a linear chain and clusters with different configuration ($\omega_p a/c = 1$, where c is the light velocity in vacuum). It is clearly seen downward frequency shift if nanowires are brought together. Enhancement of Q-factor is observable with appearance of each additional nanowire in a chain. Cluster with triangular or square configurations possess both rotation and reflection symmetries. Total number of dipole SPs is four and six for cluster of triangular and square configurations respectively. Fig. 1 shows data for SP of the particular orientation. It is seen, the placement of nanowires at the vertices of triangle or square results in additional enhancement of Q-factor.

[1] Bozhevolnyi S., Volkov V., Devaux E., Laluet J., and Ebbesen T., “Channel Plasmon Subwavelength Waveguide Components Including Interferometers and Ring Resonators”, *Nature*, vol. 440, no. 7083, pp. 508–511, 2006.

[2] Li J. and Engheta N., “Ultracompact Sub-Wavelength Plasmonic Cavity Resonator on a Nanowire”, *Phys. Rev. B*, vol. 74, 115125, 2006.

[3] Novotny L. and Hurst N., “Antennas for Light”, *Nature Photonics*, vol. 5, pp. 83–90, 2011.

[4] Stognii N. and Sakhnenko N., “PlasmonResonances and Their Quality Factors in a Finite Linear Chain of Coupled Metal Wires”, *IEEE J. Sel. Topics Quantum Electron.*, vol. 19, no. 3, 4602207, 2013.