Surface plasmon frequency spectrum in a system of two spherical metallic nanoparticles

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Composite materials based on dielectrics containing metallic nanoparticles demonstrate unique optical properties. Depending on dielectric permittivity of the matrix and shape of the nanoparticles both the red and blue shifts of surface plasmon (SP) frequency from Mie frequency are observed. The system of two almost touching spherical nanoparticles in a dielectric medium is of special interest, since in such structures substantial change of SP frequency in a controllable way can be realised. However the calculation of the SP frequency of this system using only analytical methods is not possible.

If the size of the system is much smaller than the wavelength corresponding to SP frequency, it is possible to neglect the retardation effects, and then the problem is reduced to the standard boundary problem of electrostatics with the bound in the form of two spheres, for solving of which various approximate methods are applied. Thus, in [1] starting from Laplace equations in bispherical coordinates a complicated recurrent equation is obtained, which is solved numerically. In the papers [2, 3] the boundary problem of electrostatics is converted into an integral equation, which is solved using finite element method. In [4] in the multipole expansion of the solution of Laplace equation the first ten or more terms are kept, and the truncated system of linear algebraic equations are solved numerically as well.

In this work a semi-analytical method of calculation of SP frequency of a system of two almost touching coupled metallic nanospheres with equal radii is developed based on physical reasoning. The method allows to transform the problem to numerical solution of two simple algebraic equations for arbitrary values of parameters – particle radius, distance between sphere centers, dielectric permittivity of the matrix and metals. It is especially easy to get the obvious graphical solution.

The main point of the method is that the point inside the sphere, with respect to which the multipole expansion of the charge distribution is performed, may be chosen in a way that the quadrupole moment becomes zero. Naturally, this point is shifted from the centre of the sphere along the axis of symmetry of the system. It is proved, that the magnitude of this shift is determined by the ratio of quadrupole and dipole moments calculated with respect to the centers. The contribution of the higher order multipole moments is analyzed.

The longitudinal and transversal in-phase and counter-phase oscillations of the system are calculated and comparison with the numerical results of [1] is performed. In case of in-phase oscillations, which is of interest for nanooptics due to nonzero dipole moment, for intercenter distances down to 1.1d (d – diameter of spheres) the deviation does not exceed 1.5%.

References

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