Optical magnetism and doubly negative metamaterials based on metallic sphere loops

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In this paper we analyze the design of three dimensional collection of periodic metallic spheres that could exhibit resonant electric and magnetic collective response in the optic frequency region, and the potential application to realize optical metamaterials when combining these two effects. Such behaviors result from the coupled surface plasmon interaction between spheres, and they can be conceptualized from the optical LC circuit resonance viewpoint. The structure, first proposed by Alù (A. Alù, A. Salandrino and N. Engheta, Opt. Express, 14, 1557-1567, 2006), constitutes an array of circularly arranged plasmonic spheres to excite resonant magnetic momentum due to the displacement current loop when the magnetic filed is oriented perpendicular to the plane of sphere loops. The phenomenon is similar to the diamagnetic response formed by the anti-symmetric surface plasmon resonance between a pair of nanorods, as pointed out in theory by Podolskiy et al. (V. A. Podolskiy, A. K. Sarychev, and V. M. Shalaev, Opt. Express, 11, 735-745, 2003), and experimentally shown by Shalaev et al. (V. M. Shalaev, et al. Opt. Lett. 30, 3356-3358, 2005). Following the circuit analogy established by Engheta et al. (N. Engheta, A. Salandrino and A. Alù, Phys. Rev. Lett, 95, 095504, 2005), on the other hand, we could think of the metal spheres as inductors, and the dielectric gaps between adjacent spheres as capacitors; the resulting resonant LC circuit could give rise to optical magnetic response for the incident magnetic field vector being normal to the loop plane.

As opposed to the numerical analysis based on commercial simulator (for instance, CST Microwave Studio) performed by most previous papers, the present paper utilizes a photonic version of the layer Korringa-Kohn-Rostoker (LKKR) method, which is based on rigorous multiple-scattering theory (N. Stefanou, V. Yannopapas and A. Modinos, Comput. Phys. Commun. 132, 189-196, 2000). With this approach, we calculate the transmission, reflection and absorption spectra of the structure, and investigate the contribution to the result from different order of sphere multipoles (dipole, quadrupole, etc.) The numerical analysis shows that, like the case of the pairs of metal strips, two resonances, corresponding to symmetric and anti-symmetric coupled modes, respectively, are observed. While the spectral position of the resonance due to the symmetric mode remains essentially unchanged regardless of the size of the sphere loop, the spectral intensity and position of the resonance associated with anti-symmetric modes depend strongly on the radius of the loop. These results could open interesting doorways to achieving three dimensional bulk negative refractive index metamaterials in the visible regimes.