Plasmonic Properties of Negative Index Metamaterials at Optical Frequencies

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The split-ring resonator (SRR) was originally proposed for microwave frequencies as a unit cell for a metamaterial that influences the effective permeability. Along the path to achieve electronic resonances in the optical domain, various geometrical modifications of the original design have been implemented. Moreover, in the microwave region, the material properties of the utilized metals for the SRRs are dominated by the imaginary part of the permittivity. In contrast, in the optical region, real and imaginary parts are comparable. Despite these differences the explanation of SRR resonances at optical frequencies has remained largely unaltered.

In this contribution, we develop a coherent explanation for the working principle of SRRs at optical frequencies which is based on the excitation of plasmonic eigenmodes by the electric field component of the light. We show that the excited currents in the SRRs, which are the origin of the magnetic response, are associated with particular plasmonic eigenmodes of the entire SRR. Our conclusion is confirmed by measurements of the optical nearfield of the eigenmodes using an apertureless SNOM. By analyzing different excitation geometries, we show that selected higher-order modes can also support pronounced magnetic resonances.

Furthermore, we evaluate the potential to obtain a negative refractive index at optical frequencies by incorporating metallic wires into the unit cell design. Our work is an essential contribution to understand the pathway for the design of metamaterials that show negative permeabilities and indices at optical frequencies.

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