Bogolyubov Kyiv Conference ”Problems of Theoretical and Mathematical Physics”

Contribution ID: **67** Type: **Poster**

Influence of the unit cell size of periodic electromagnetic metamaterials on their optical properties

Tuesday, 24 September 2024 17:55 (5 minutes)

To date, the most of metamaterials used in diverse applications (from nanooptics and plasmonics to mobile communication and biophysics) are periodic structures consisting of spatially arranged inclusions. In the theory of metamaterials, they are treated as homogeneous media, if their unit cell size d (the lattice constant) is much smaller than the wavelength λ of the incident electromagnetic wave the metamaterials operate with, $d \ll \lambda$. A number of homogenization theories have been proposed to calculate metamaterial's effective parameters, such as the effective permittivity ε_{eff}, permeability μ_{eff}, and index of refraction n_{eff}, based on the geometry and material parameters of the metamaterial's inclusions. In practice, however, condition $d \ll \lambda$, or, equivalently, $d/\lambda \ll 1$, is not always met.

In the present work, the properties of metamaterials are analyzed in a wider range of their relative unit cell size d/λ values for several types of the metamaterials' inclusions of practical interest. The optical reflectance R and transmittance T of the metamaterials are numerically calculated based on the Lorentz volumetric averaging of the local electric and magnetic fields inside the unit cells, rather than using recent metamaterials homogenization theories proposed in the last two decades.

It is shown that behavior of the optical properties of metamaterials declines more and more from what is expected based on the homogenization concept, as the relative unit cell size increases from small values $d/\lambda \ll 1$ (the quasistatic regime) to the unity (the intermediate operating regime). In the latter regime, a crucial role in the optical properties formation play the diffraction and interference effects in the metamaterials, and the properties exhibit an oscillating behavior which cannot be predicted within the homogenization concept.

Publications:

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Session Classification: Poster Session

Track Classification: CONDENSED MATTER PHYSICS