Light propagation characteristics of hyperbolic graphene-semiconductor multilayered medium

L.A. Melnikov
Department of Instrumentation Engineering
Yuri Gagarin State Technical University of Saratov
Saratov, Russia
lam-pels@ya.ru

O.N. Kozina
Saratov Branch
Kotel’nikov Institute of Radio-Engineering and Electronics
of Russian Academy of Science
Saratov, Russia
kozinaoig@yandex.ru

I.S. Nefedov
School of Electrical Engineering
Aalto University,
Aalto, Finland
igor.nefedov@aalto.fi

The light propagating characteristic of the hyperbolic metamaterial consists of graphene and semiconductor layers tilted in relation to outer boundary are presented. Promising combination of the graphene and SiC, due to realistic technology condition was investigated. Possibility of control of the light propagating through such structure will be discussed.

Keywords—hyperbolic metamaterial; graphene

The applications of a hyperbolic metamaterial (HMM) include negative refraction, epsilon-near-zero materials, superlenses and hyperlenses, nanoscale waveguiding, super-resolution imaging, quantum optics, and many others [1]. As known, hyperbolic medium described by the diagonal extremely anisotropic permittivity tensor. The principal components of the permittivity tensor have opposite signs which results in a hyperbolic shape of the isofrequency contours. Light propagating characteristics of the graphene-based hyperbolic metamaterial were previously investigated in [2], however the structure considered includes the graphene layers in a vacuum. In present talk light propagating characteristic is presented for more realistic medium which includes periodically arranged graphene and semiconductor layers, tilted in relation to outer boundary. SiC was chosen due to good technological perspective to manufacturing of these structures [3]. We will show the possibilities to control the optical characteristic of the structure via changes of chemical potential of the graphene or permittivity of substrate layers.

The effective relative permittivity tensor of the graphene multilayer (Maxwell–Garnett homogenization) reads as

\[ \varepsilon = \{\varepsilon_{\parallel}, 0, 0 \}, \{0, \varepsilon_{\perp}, 0 \}, \{0, 0, \varepsilon_{\perp} \} \}, \]

where \( \varepsilon = \varepsilon_{\text{host}} \) is the permittivity of the host medium (SiC). For the transverse tensor component \( \varepsilon_{\perp} \) we use the homogenization model [1]

\[ \varepsilon_{\perp} = \varepsilon_{\parallel} + i \frac{\sigma(\omega)}{d \omega \varepsilon_0} \]

where \( \sigma = \sigma_{\text{intra}} + \sigma_{\text{inter}} \) and \( d \) is the period of structure [2].

Figure shows that the graphene-SiC multilayers exhibit properties of hyperbolic (indefinite) medium from the visible to the mid-infrared ranges under appropriate choice of the chemical potential \( \mu \) and period of the multilayer lattice \( d \). In particular, the transverse relative permittivity \( \varepsilon_{\perp} \) can take negative values with low losses. Transmission and reflection from the slab of material considered together with intrinsic upward and downward waves are presented in dependence on wavelength, showing the wavelength regions suitable for light control.