Technical University of Denmark

Graphene-enhanced metamaterials in THz applications

Andryieuski, Andrei; Chigrin, Dmitry N.; Khromova, Irina; Sipe, John E.; Zhukovsky, Sergei; Lavrinenko, Andrei

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Andryieuski, A., Chigrin, D. N., Khromova, I., Sipe, J. E., Zhukovsky, S., & Lavrinenko, A. (2015). Graphene-enhanced metamaterials in THz applications. Abstract from NATO Advanced Research Workshop FANEM 2015, Mink, Belarus.

Graphene-enhanced metamaterials in THz applications

Andrei Andryieuski[1], Dmitry N. Chigrin[2], Irina Khromova[3], John E. Sipe[4], Sergey V. Zhukovsky[1], Andrei V. Lavrinenko [1]

[1] Technical University of Denmark, Oersteds Pl. 343, Kongens Lyngby, DK-2800, Denmark
[2] Physikalisches Institut, RWTH Aachen, D-52056, Aachen, Germany
[3] University College London, Torrington Place, London WC1E 7JE, UK
[4] University of Toronto,60 St. George Street, Toronto, Ontario, M5S 1A7, Canada

Corresponding author: alav@fotonik.dtu.dk

Keywords: graphene, metamaterial, THz waves, multilayers.

Summary

Terahertz (THz) radiation is widely employed in a broad range of fields in biology, medicine, communication, security, chemistry, and spectroscopy. To expand the application of terahertz radiation new device designs and fabrication methods are needed. The ability of metamaterials to manipulate electromagnetic waves makes them natural candidates for THz optical components [1]. However, ranges of light manipulation can be strongly expanded by involving graphene as a structural component of metamaterials. The interplay between interband and intraband transitions in graphene allows converting a multilayer graphene/dielectric structure into a transparent and/or electromagnetically dense artificial medium in a narrow THz or infra-red frequency range. The gate voltage can be used to electrically control the concentration of carriers in the graphene sheets and, thus, efficiently change the dispersion of the whole structure.

Placed inside a hollow waveguide, a multilayer graphene/dielectric metamaterial provides high-speed modulation of radiation and offers novel concepts for terahertz modulators and tunable bandpass filters. We exemplify it showing performance of waveguide-based terahertz modulators with high ON-state transmission and competitive energetic efficiency: with a 50 meV shift of graphene's Fermi energy, it is possible to switch between transmission and attenuation regimes [2].

Structured graphene layers embedded into dielectric (graphene wire medium) can be used to create a hyperlens. We propose a realistic geometrical design for the hyperlens for the THz radiation and proved that it can resolve two line sources separated by distance $\lambda_0/5$. Simulations were done with two approaches: heavy full-3D simulations and quick 2D hyperlens modeling via homogenization in one dimension [3]. Both approaches exhibit close correspondence in results.

Furthermore, we analyze the origin of the hyperbolic dispersion behavior in graphene-dielectric metamaterials. It appears that TM-polarized plasmon-polaritons in individual graphene sheets hybridize to form volume plasmon-polaritons with hyperbolic metamaterial-like properties in the frequency range, where the imaginary part of the graphene conductivity significantly exceeds its real part. On the other hand, TE-polarized graphene plasmons-polaritons behave like long-ranged surface plasmon-polaritons in metal-dielectric multilayers, without any hints on hyperbolic-like dispersion [4].

We believe that graphene-enhanced metamaterials constitute a useful functional element for the THz-infrared integrated optics devices.

Acknowledgements. This work received partial financial support from the People Programme (Marie Curie Actions) of the European Union's 7th Framework Programme FP7-PEOPLE-2011-IIF under REA grant agreement No. 302009 (Project HyPHONE).

References

1. H.-T. Chen, J. F. O'Hara, A. K. Azad, and A. J. Taylor, Laser Photon. Rev. **5**, 513-533 (2011).
2. I. Khromova, A. Andryieuski, and A. Lavrinenko, Laser Photon. Rev., **8**, 916-923 (2014).
3. A. Andryieuski, A. V. Lavrinenko and D. N. Chigrin, Phys. Rev. B, **86**, 121108(R) (2012).
4. S. V. Zhukovsky, A. Andryieuski, J. E. Sipe, A. V. Lavrinenko, Phys. Rev. B, **90**, 155429 (2014).