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Irina Khromova[1], **Andrei Andryieuski**[2], **and Andrei V. Lavrinenko**[3]
[1]University Colledge London, UK
aerialcrystal@gmail.com;
[2]Technical University of Denmark, Oersteds pl. 343, Kongens Lyngby, DK-2800, Denmark
andra@fotonik.dtu.dk

[3]Technical University of Denmark, Oersteds pl. 343, Kongens Lyngby, DK-2800, Denmark
alav@fotonik.dtu.dk

Mailing address: Prof. Lavrinenko A. V., DTU Fotonik, Technical University of Denmark, Oersteds pl. Bld.343, Kongens Lyngby, DK-2800, Denmark

Phone/Fax: +45 45256392/+45 4593 6581

Corresponding/Presenting Author: Andrei V. Lavrinenko

Session: SC3: Active, Tunable and Nonlinear Metamaterials

Invited

Active development of terahertz (THz)/ infrared (IR) science and technology has created a growing demand for new electronic and quasi-optical devices. In particular, the promising opportunities for broadband high-speed terahertz communication require new techniques for real-time manipulation of radiation. Various approaches have been proposed for THz/IR amplitude, phase, spatial and temporal profile modulation, including the employment of metamaterials [1] and, recently, one-atom-thick graphene [2].

Most of the proposed modulators, including graphene-based ones, are developed for free-space propagation configurations. However, high-speed THz/IR communication channels will unlikely be based on such architectures - atmospheric absorption peaks and small wavelengths (from sub-millimeter to tens of micrometers) imply strong free-space attenuation. It is therefore preferential to apply waveguide-based modulation platform similar to those used in telecom photonics. Due to specific properties constrains it is natural to consider metamaterial (structured) approach to satisfy simultaneous demands for low losses and high tunability in the waveguide configuration.

We study and classify the electromagnetic regimes of multilayer graphene-dielectric artificial metamaterials. The interplay between interband and intraband transitions in graphene allows converting the structure into a transparent and/or electromagnetically dense artificial medium. 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 and tunable bandpass filtering. The absence of scattered radiation enables dense integration of such THz waveguides and modulators without influencing their neighboring elements.

We exemplify the employment of graphene-dielectric metamaterial for waveguide-integrated modulators with three examples of tunable devices. The first one is a modulator with excellent ON-state transmission and very high modulation depth: > 38 dB with only 70 meV graphene electrochemical potential change. The second one is a modulator with extreme sensitivity towards graphene Fermi energy. The third one is a tunable waveguide-based passband filter. The narrow-band cut-off conditions around the ON-state allow the latter to shift its central frequency by 1:25% per every meV graphene Fermi energy change.

We believe that graphene-dielectric multilayer metamaterials will constitute the functional platform for THz-IR waveguide-integrated devices.

[1] M. Rahm, J. S. Li, and W. Padilla, J. Infrared Millim Terahertz Waves 34, 1–27 (2013).
[2] M. Liu, X. Yin, E. Ulin-Avila, B. Geng, T. Zentgraf, L. Ju, F. Wang, and X. Zhang, Nature 474, 64–67 (2011).