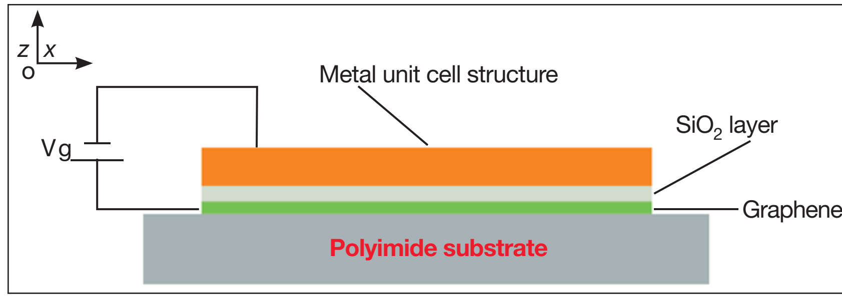
Nano Focus

Graphene meets metamaterial

The addition of graphene to a metamaterial can strongly influence the propagation of electromagnetic waves, according to an article published in the January issue of *Optics Letters* (DOI: 10.1364/OL.40.000178) by Xiaoyong He, Zhen-Yu Zhao, and Wangzhou Shi. This team from Shanghai Normal University, China, showed that a metamaterial in combination with graphene has better modulation properties than existing materials in the near-infrared region, and is tunable.



Side view of the metamaterial integrated with graphene. Reproduced with permission from *Opt. Lett.* **40** (2) (2015), DOI: 10.1364/OL.40.000178; p. 178. © 2015 Optical Society of America.

This research spans two important areas of materials science. The first, metamaterials, came into prominence because of their interesting properties such as negative refractive index and subsequently super-focusing and extraordinary transmission properties. In popular culture they are linked to invisible cloaks, which H.G. Wells wrote about in an 1897 novel. The unique electromagnetic properties of metamaterials stem from the ingenious way they are nanostructured in arrays of structures such as split-ring resonators, crosses, and H sections, rather than their chemical compositions. The second area is graphene, a single atomic layer of carbon, which has been hailed as a wonder material. Its unusual properties include strong confinement of surface plasmons, which are waves propagating across an interface, analogous to the ripples on the surface of a pond when a stone is thrown.

The materials system proposed by He and colleagues has a metamaterial that comprises 100-nm-thick silver wires that are configured into a lattice with its unit cell in the form of a cross. The substrate is a 2000-nm-thick polyimide. In between, there is a 10-nm-thick layer of silica and a graphene membrane. The graphene is only 0.34-nm-thick, but has a very significant influence. He and colleagues studied reflection, absorption, and transmission of electromagnetic waves in this structure in the frequency range of 160–220 THz. This falls within the near-infrared region, which has received much less attention than the neighboring microwave and ultraviolet regions of the electromagnetic spectrum. A device with this combination of materials can be tuned thanks to graphene, whose Fermi level can be changed by applying a voltage or magnetic field. As a consequence, the resonance of transmitted or reflected curves can be tuned in a wide range (160–193 THz). These results are helpful in designing plasmonic devices.

In the near-infrared region, graphene behaves like a dielectric. Its dielectric constant decreases with an increase in the Fermi level, resulting in an increase in transmission. The research team changed the Fermi level from 0 eV (without graphene) to 0.5 eV. When the Fermi level is greater than 0.5 eV, the real part of permittivity changes from positive to negative, and the graphene layer shows metallic properties. The use of graphene results in a modulation depth of reflection as high as 76.8%, as compared to 12% in current materials.

The research team also studied systems with complementary metamaterials where arrays of holes replace metallic parts. The spectral curve of the metamaterial–graphene is broad, which suggests possible application in switches. The sharp curve for a complementary metamaterial is more useful for filters.

According to researchers, the study will lead to practical applications in biomedical sensing and optical communications.

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