THEORETICAL DESCRIPTION OF ELECTROMAGNETIC RADIATION INTERACTION WITH GRAPHENE METASURFACES

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Graphene is a remarkable two-dimensional material able to govern light at subwavelength scale. It enriches the fields of electronics, photonics and material science paving the avenues for field effect transistors, broadband absorbers and structures of twisted bilayer graphene.

We consider a graphene metasurface composed of three types of unit cells: hemispheres, volcanos and holes. Volcanos and holes are respectively partly and completely broken hemispheres. Such a metasurface with randomly located unit cells was produced owing to the fabrication defects as discussed in [1]. Scattered electromagnetic radiation can be described by the Kirchhoff diffraction theory, which within the Fraunhofer approximation is reduced to the scattering by a unit cell averaged over three types of unit cells [2]. The graphene unit cells of different types are accounted for with their own weight coefficients borrowed from the experimental studies [1]: 60% of hemispheres, 35% of volcanos and 5% of holes. Using the Drude-like formula for graphene surface conductivity we calculate the reflectivity and transmissivity from the diffraction theory and absorptivity of the graphene metasurface as $A=1-R-T$.

We find out that the electromagnetic response of hemispheres is significantly suppressed due to the formation dark modes as a result of antiparallel dipole moments of the flat graphene and graphene hemisphere. The corresponding reduction of the metasurface reflection is the origin of its high absorptivity. Moreover, the fields scattered by randomly arranged unit cells of different types are added incoherently despite comparable unit cell size and wavelength, thus justifying the use of averaging over unit cells. The proposed theory fully confirms experimental results, both the value of the transmitted power and the angular dependence.

One of the fascinating outcomes of the research is the extremely high and broadband absorptivity [2] of the considered graphene metasurface (around 80% at 0.1 THz, 98% at 10 THz). Further increase of the frequency violates the Drude model of conductivity and, therefore, is not discussed. We reveal that the Fermi energy should be around 0.1 eV, the radius of the hemisphere about 200-300 um (unit cell size is 611 um) and the share of hemispherical unit cells is 30-60% to achieve the highest absorptivity. It is curious that one needs unit cells of the volcano type to maximize the absorptivity.

To sum up, we develop a theory for description of random graphene metasurfaces composed of several types of unit cells. Our results provide the opportunity for fabrication of thin near-perfect absorbers as well as tailoring spectral characteristics of graphene membranes.

References

1. Baah M. et. al. / Carbon. 2021. Vol. 185. P. 709.
2. Novitsky A. et. al. / Phys.Rev.Appl. 2022. Vol. 17. P. 044041.