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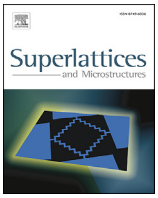

Broadband and wide angle near-unity absorption in graphene-insulator-metal thin film stacks

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Broadband unity absorption in graphene-insulator-metal (GIM) structures is demonstrated in the visible (VIS) and near-infrared (NIR) spectra. The spectral characteristics possess broadband absorption peaks, by simply choosing a stack of GIM, while no nanofabrication steps and patterning are required, and thus can be easily fabricated to cover a large area. The electromagnetic (EM) waves can be entirely trapped and the absorption can be greatly enhanced are verified with the finite-difference time-domain (FDTD) and rigorous coupled wave analysis (RCWA) methods. The position and the number of the absorption peak can be totally controlled by adjusting the thickness of the insulator layer. The proposed absorber maintains high absorption (above 90%) for both transverse electric (TE) and transverse magnetic (TM) polarizations, and for angles of incidence up to 80°. This work opens up a promising approach to realize perfect absorption (PA) with ultra-thin film, which could implicate many potential applications in optical detection and optoelectronic devices.

1. Introduction

Controlling the efficient absorption of light is one of the main goals for most of the plasmonics and metamaterials applications [1–4]. The design of perfect absorption (PA) has attracted great interest since the related potential applications in the solar energy, detection and sensing [2,5,6]. Metal-insulator-metal (MIM) configuration is one of the most commonly employed ideas to achieve PA [7,8]. An MIM perfect absorber typically has a thick metallic ground plane as the fully reflecting mirror and one or several pairs of insulator-metal structures. Recently, it was demonstrated that the use of MIM multilayer with proper control of layer thickness can provide broadband light absorption where the absorption edge can be extended to longer wavelengths [9,10]. Different types of metal and insulators have been employed to attain ultra-broadband absorption from the multilayer stacks [11–15]. However, most of the absorbers work at a single band frequency, which limits their practical applications such as multi-frequency spectroscopy and detection. Moreover, the improvements in the performance

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of PAs usually require complex and expensive fabrication methods. Thus, simple and high-performance absorbers that can operate in a wide spectral band without requiring extra pattern steps are desirable.

In this paper, we propose a resonant-cavity enhanced PA consists of flat continuous graphene and silver (Ag) films sandwiching a dielectric spacer deposited on a dielectric substrate. An alternative route for PA by using GIM stack that offer polarization independent behavior with wide angle range absorption from VIS to NIR is explored. Comprehensive full-wave EM simulations are performed, and it is demonstrated that GIM as multiband PA that can offer extremely high flexibility in engineering the properties of EM absorption over the wavelength range of 0.4–1.4 µm.

2. Model and numerical investigation

The resonant-cavity enhanced GIM absorber is designed to operate over the VIS to NIR spectra. It conceptually consists of two lossy films of different thicknesses, which are spaced by an Aluminium oxide (Al_2O_3) layer. Gold (Au) has strong absorption for wavelengths less than 500 nm. So that we have chosen Ag in this study. The thickness of the Ag film is such that the bottom film is fully reflecting while the top graphene film is semitransparent and so ensures that the resonator modes couple to freely propagating waves. Graphene multilayers are used as the top layer (3.4 nm), Ag is used as bottom (100 nm thickness) metal layer and dielectric Al_2O_3 is chosen as the insulator layer, and the refractive index of it is taken to be 1.75. The GIM stack is deposited on a glass substrate. Schematic diagram of the proposed structure is shown in Fig. 1. The relative permittivity of Ag is modeled by using the Drude model [16]:

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\omega\Gamma} \tag{1}$$

Detailed parameters are as follows, $\varepsilon_\infty = 5.0$, $\omega_p = 9.2159$ eV, and $\Gamma = 0.0212$ eV [17]. Graphene layer is modeled as infinitesimally thin surface with the surface conductivity σ_G calculated from Kubo formula [18–20]. At finite temperature it can be divided into intra- and interband contributions:

$$\sigma_G = \sigma_G^{intra} + \sigma_G^{inter}, \tag{2}$$

$$\sigma_G^{intra} = \frac{e^2}{4\hbar}\frac{i}{2\pi}\left\{\frac{16k_BT}{\hbar(\omega+i\Gamma)}\ln\left(2\cosh\left(\frac{\mu_c}{2k_BT}\right)\right)\right\}, \tag{3}$$

$$\sigma_G^{inter} = \frac{e^2}{4\hbar}\left\{\begin{array}{l} \frac{1}{2}+\frac{1}{\pi}\arctan\frac{\hbar\omega-2\mu_c}{2k_BT} \\ -\frac{i}{2\pi}\ln\frac{(\hbar\omega+2\mu_c)^2}{(\hbar\omega-2\mu_c)^2+(2k_BT)^2} \end{array}\right\}. \tag{4}$$

In Eqs. (3) and (4), e is the elementary charge, $\hbar = h/2\pi$ and k_B are the reduced Planck's constant and Boltzmann constant, respectively. ω indicates the angular frequency. T, Γ, and μ_c denote the temperature, the charge carriers scattering rate, the Fermi energy, and are chosen as 300 K, 0.1 meV, and 0.15 ev, respectively. The graphene film is composed by N monolayers, so that the film conductivity can be approximated by $\sigma_{Ng} \approx N\sigma_g$ [21]. The in-plane relative permittivity of the film reads as

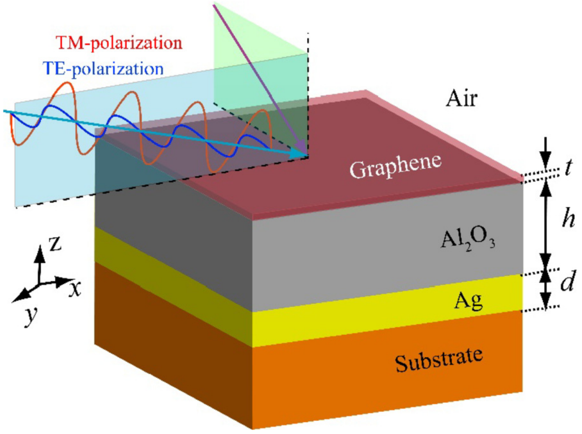

Fig. 1. Schematic of the proposed GIM absorber. The dielectric constants of all regions, geometrical parameters, and field coefficients are indicated in the figure, and their meanings are described in the main text.