Atlas of Science
another view on science
https://atlasofscience.org

Ultra-wideband absorption based on wavelength-insensitive phase matching

Due to high carrier mobility, the graphene has attracted enormous interests in developing high-speed photodetectors. In this study, for practical high-performance photodetectors, we focus on the remarkable enlargement of absorption bandwidth in the graphene perfect absorbers based on prism coupling with wavelength-insensitive phase matching.

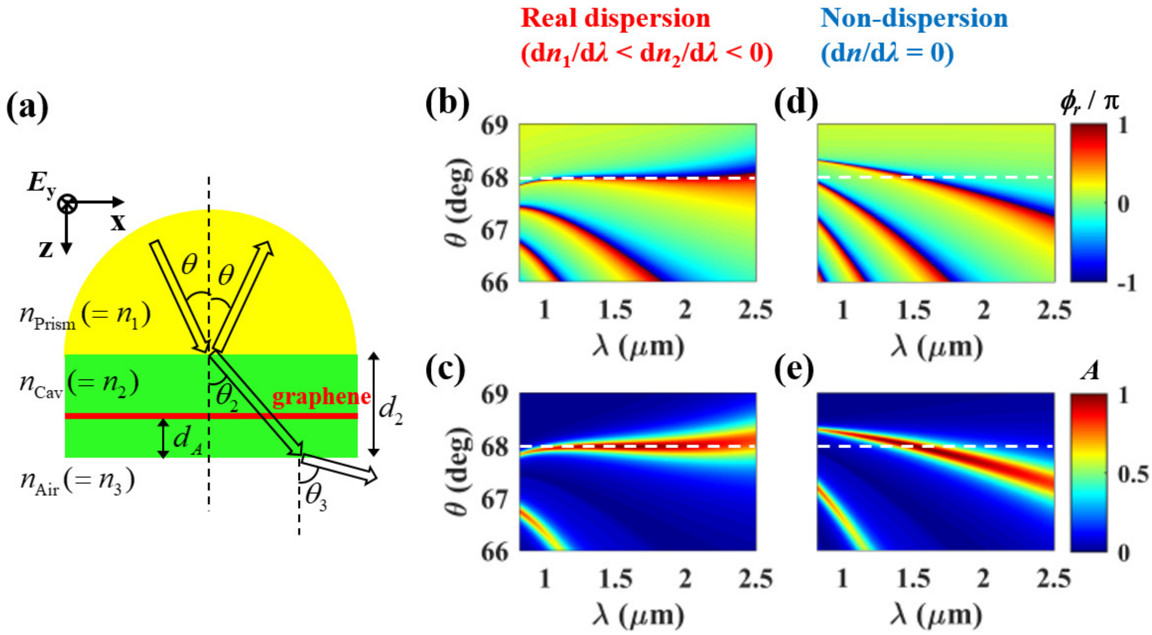

Fig. 1. (a) schematic of the proposed graphene perfect absorber, (b, d) reflection phase of the lossless structure and (d, e) graphene absorption as a function of wavelength and incidence angle for real dispersion (left panel) and non-dispersion (right panel) of the prism (BK7) and the cavity layer (PDMS).

The proposed absorber (Fig. 1(a)) consists of a prism (BK7, n_1), a cavity layer (PDMS, n_2), air (n_3), and monolayer undoped graphene embedded in the cavity layer, where $n_1 > n_2 > n_3 = 1$. At the incidence angle of interest with total internal reflection (TIR) at the bottom of the cavity layer, the proposed structure can be considered as a one-port resonant system. From the coupled mode theory (CMT), the absorption in the lossy resonator is given as $A = 4\gamma_{\rm leak}\gamma_{\rm loss} / [(\omega - \omega_{\rm o})^2 + (\gamma_{\rm leak} + \gamma_{\rm loss})^2]$, where $w_{\rm o}$, $\gamma_{\rm leak}$, and $\gamma_{\rm loss}$ are a resonant frequency, a leakage rate, and a loss rate, respectively. The resonance frequency (or wavelength) is determined by the phase matching among multiple reflected waves including the phase retardation in the cavity layer. If the resonance condition enabling the absorption peak can be manipulated so as to satisfy the phase matching over a wide range of wavelength, the almost perfect absorption can be achieved over a wide wavelength range, simultaneously increasing the FWHM. The key consideration is the proper combination of material dispersions of the prism and the cavity layer because it determines the optimal incidence angle, cavity thickness, and wavelength range for the wavelength-insensitive phase matching. Like most transparent materials, BK7 and PDMS have '*normal dispersion*', that is, their refractive indices monotonically decrease with wavelength ($dn/d\lambda < 0$). In particular, the index ratio of n_2/n_1 is proportional to wavelength, which is the basic requirement for wavelength-insensitive phase matching.

Indeed, for the real dispersion case of BK7 and PDMS, the optimal θ = 67.98 deg and d_2 = 6.4 mm were found to satisfy the wavelength-insensitive phase matching in the prism coupling structure without graphene (Fig. 1(b)). There exists a considerably wide wavelength range (~1.3 µm <λ < ~ 2.0 µm) where the reflection phase (ϕ_r) is ~ π, corresponding to the wavelength-insensitive phase matching. Herein, when the monolayer graphene is located in the middle of the cavity layer ($d_A = 0.5d_2$), the absorption peaks exist along the loci of the resonance conditions with the reflection phase of π (Fig. 1(c)). In detail, at the around optimal θ = 67.98 deg (white dashed line), there exists the almost flat absorption peak branch. Our investigation reveals that almost perfect absorption (> 99%) can be obtained over a wavelength range of ~ 300 nm (~1.37 µm < λ < ~1.67 µm) with the choice of the naturally available materials for the prism and the cavity layer, which is the best as far as we know. The full width at half maximum of our designed perfect absorber is larger than 1.5 µm. On the contrary, in the case of non-dispersion (n_1 = 1.5012 and n_2 = 1.3963) as the reference design, both the resonance condition and absorption peak branches show strong wavelength-dependent phase matching (Fig. 1(d-e)). For any incidence angle below the critical angle of $\sin^{-1}(n_2/n_1)$ = 68.4539 deg, the reflection phase increases with λ, so that the wavelength-insensitive phase matching cannot be achieved.

The proposed absorption scheme based on the wavelength-insensitive phase matching will be also useful for applications such as optical sensors, solar cells, thermal emitters, and nonlinear optics.

Sangjun Lee, Sangin Kim
Department of Electrical and Computer Engineering, Ajou University, Suwon, South Korea

Publication

Graphene perfect absorber of ultra-wide bandwidth based on wavelength-insensitive phase matching in prism coupling
Sangjun Lee, Hyungjun Heo, Sangin Kim
Sci Rep. 2019 Aug 19