A Graphene-based Broadband Absorber at Terahertz Regime

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Abstract— In this paper, a new graphene-based broadband absorber is proposed, which is structured in three layers: a graphene square periodic array at the top layer, an F4B substrate in the middle layer, and a metal ground plane at the bottom layer. The employed graphene exhibits a Fermi level of 849.5 meV with a square resistance of approximately 100 Ω/sq. The proposed absorber possesses outstanding performance, achieving an excellent absorption rate of 99% across a wide frequency range from 92.2 GHz to 132.2 GHz, under both normal TE and TM polarized incidences. The broad bandwidth and high absorption rate prove the absorber's capability in effectively absorbing electromagnetic (EM) waves at terahertz regime, which will be an innovative solution for various EM wave absorption applications.

1. INTRODUCTION

With the continuous advancement of terahertz (THz) technology, research interest in THz absorbers has increased significantly. THz absorbers exhibit diverse configurations, including narrowband, broadband, and multi-band characteristics [1–3]. Broadband absorbers inherently possess the ability to achieve absorption across a continuous spectrum, rendering them versatile for numerous applications. Multiple design approaches have been introduced in previous studies. The structure comprises a periodic arrangement of several similar metamaterial structures, each contributed to an absorption frequency band, which makes the absorption frequency bands combined together, resulting in broadband absorption [4, 5]. Another design approach involves multiple-layer arrangement of structures responsible for absorbing different frequency bands, which also achieves broadband absorption by stacking absorption bands [6, 7]. Additionally, research on all-dielectric broadband absorbers has been explored due to their cost-effective and environmental-friendly characteristics [8].

In addition to the aforementioned design methods, novel materials represented by graphene have been widely employed in the field of broadband absorbers. Graphene, an ultrathin two-dimensional (2D) single layer of carbon atoms, demonstrates remarkable characteristics across electrical, optical, mechanical, and thermodynamic domains [9]. Its properties have led to widespread use in a variety of research disciplines and applications [10]. An extremely wideband absorption ranging from 2 to 110 GHz has been achieved through graphene square arrays and three-dimensional (3D) structures coated with graphene in [11]. In addition, an arrangement of strip-like arrays of graphene has been proposed in [12] and the changing Fermi level of graphene has brought the tunable characteristics to the absorber. Furthermore, the work in [13] employed a multi-layered substrate design along with metamaterial graphene structures, whose broadband absorption range covers 1–2 THz.

In this paper, a THz absorber is introduced, which is designed by an F4B substrate with a graphene patch array. The absorber exhibits exceptional absorption performance from 92.2 to 132.2 GHz, demonstrating good polarization insensitivity. The impact of graphene's Fermi level on the absorber has been studied as well. Furthermore, the presented broadband absorber maintains excellent performance across various incident angles.

2. DESIGN OF THE BROADBAND ABSORBER

Figure 1(a) illustrates a schematic diagram of the graphene-based broadband absorber. The absorber consists of three layers: a square graphene array as the top layer, a middle substrate layer, and a bottom metal ground plane. The utilized graphene demonstrates a Fermi level of 0.8495 eV with a square resistance of approximately 100 Ω/sq. The substrate layer material is F4B, with a relative permittivity of 2.65 and a loss tangent of 0.003, while the metal ground plane is made of copper. The dimensions of the single unit cell are shown in Fig. 1(b). As can be seen, the side length of the square graphene is $a = 0.84$ mm, while the thicknesses of substrate and metal layer are $h = 0.4$ mm and $t = 0.035$ mm, respectively. Furthermore, each pattern on the top layer is accurately aligned, maintaining a lattice constant of $p = 1.5$ mm.

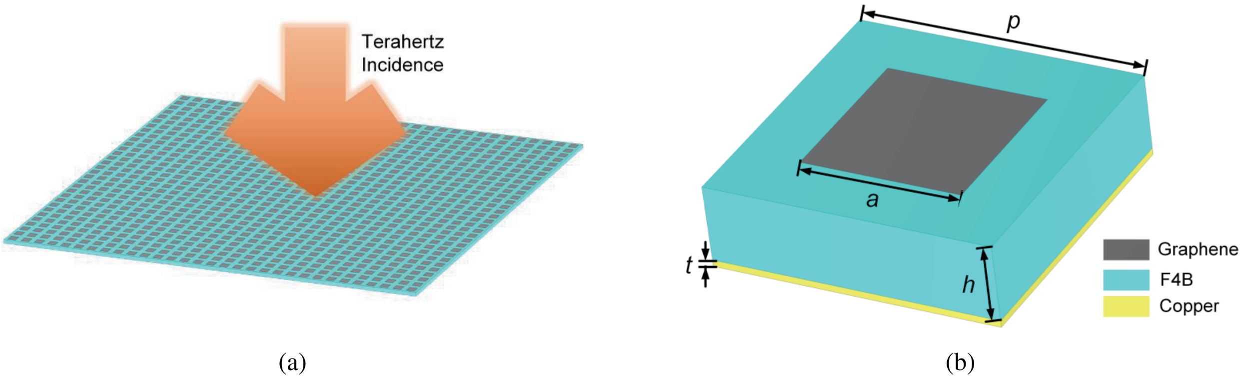

Figure 1: (a) Schematic of the proposed graphene-based broadband absorber. (b) Structure details of a unit cell.

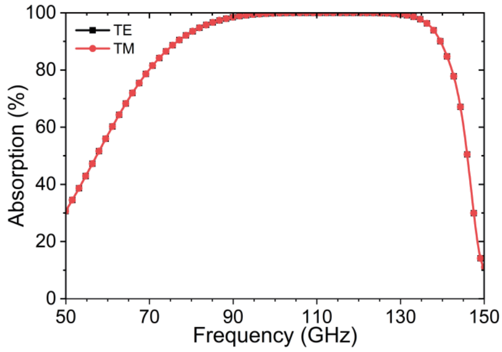

Figure 2: Absorption spectra of the proposed broadband absorber under TE and TM polarization.

In our study, the analysis of absorption characteristics involves the utilization of CST Microwave Studio simulation software. An incident plane wave is imposed downward from the top surface of the absorber, employing a unit cell boundary. The frequency-dependent absorption rate is

$$A(\omega) = 1 - R(\omega) - T(\omega), \tag{1}$$

where the $R(\omega)$ and $T(\omega)$ represent the reflection and transmission, which can be calculated by $|S_{11}|^2$ and $|S_{21}|^2$, respectively. Because of the metal ground plane functioning as a perfect reflector, the transmission can be ignored, effectively simplifying the absorption rate to

$$A(\omega) = 1 - |S_{11}|^2. \tag{2}$$

The simulated absorption spectra of the proposed absorber are depicted in Fig. 2, which shows that the absorption rate is over 99% from 92.3 GHz to 132.2 GHz under both transverse electric (TE) and transverse magnetic (TM) polarized incidence. The overlap of the two curves verifies the remarkable polarization insensitivity of the broadband absorber.

3. ANALYSIS AND DISCUSSIONS

To investigate the physical mechanism behind the broadband absorption, the distributions of the z-component electric fields under TE incidence at 100, 110, and 120 GHz are shown in Figs. 3(a), 3(b) and 3(c), respectively. The field distributions reveal the concentration of maximum field strength at the square graphene structure's left and right edges, indicating the resonance occurrence at these edges. Similarly, Figs. 3(d), 3(e), and 3(f) exhibit the electric field distributions at 100, 110, and 120 GHz under TM polarization, respectively. As observed, these distributions, rotated by 90 degree compared to the distributions under TE polarization, demonstrate excellent polarization-independent characteristics of the absorber.

The Fermi level in graphene serves as a key factor of its chemical potential. The absorption rate increases from 15% to 99.9% as the Fermi level of graphene growing from 0 to 1 eV, as illustrated in Fig. 4. This effect occurs because changes of the Fermi level will affect the graphene's surface impedance, thereby influencing the impedance match between the free space and the absorber.

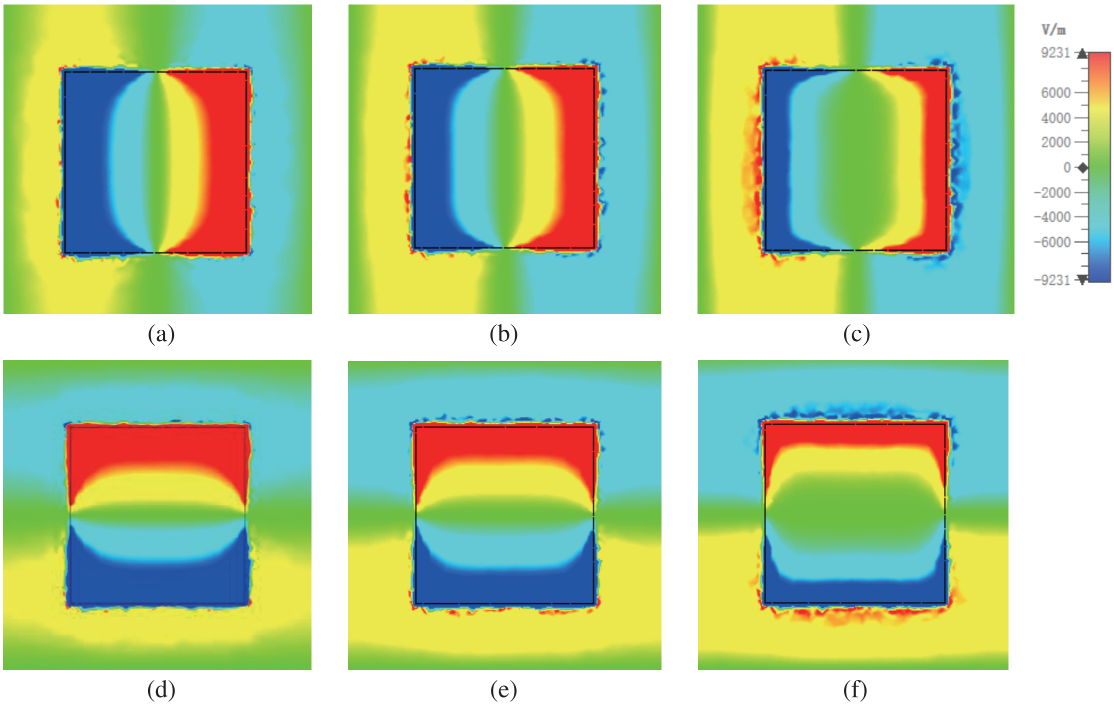

Figure 3: Distributions of the z-component electric fields at (a) 100 GHz, (b) 110 GHz, and (c) 120 GHz under TE polarization as well as (d) 100 GHz, (e) 110 GHz, and (f) 120 GHz under TM polarization.

As the Fermi level is closed to 1 eV, the absorber's overall impedance tends to approach 377 Ω, optimizing its absorption performance. In order to facilitate fabrication, we select the graphene with a Fermi level of 0.8495 eV, which has a square resistance of about 100 Ω/sq Additionally, the relationship between the absorption property and incident angle of EM wave is also analyzed. The absorption spectra of the proposed absorber against the varied incident angles, are depicted in Fig. 5. Notably, the absorption rates maintain stability within an incident angle ranging from 0° to 40°.

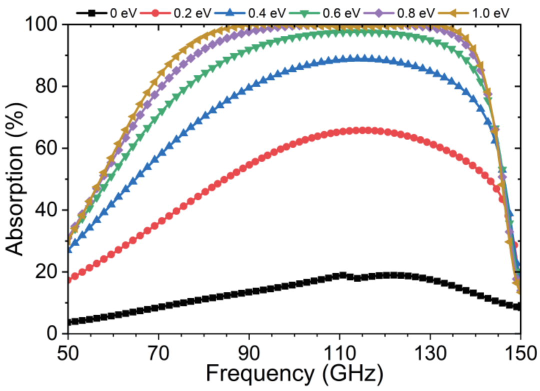

Figure 4: Absorption spectra of the absorber with the Fermi level of the graphene changing from 0 to 1 eV.

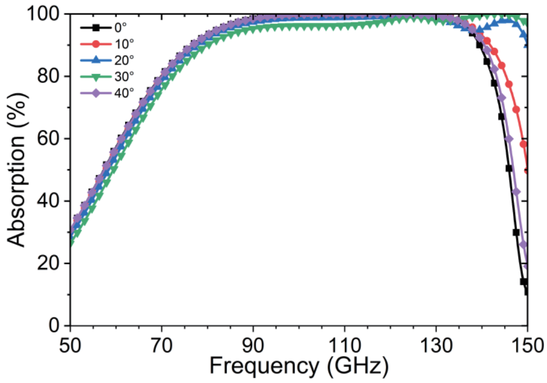

Figure 5: Absorption spectra of the absorber with the incident angle varied from 0° to 40°.

4. CONCLUSION

In this paper, a new broadband absorber based on graphene is introduced, which is working at millimeter-wave frequencies up to THz band. Under both TE and TM polarized incidence, the proposed absorber shows an impressive absorption rate of 99% over broad frequency spectrum ranging from 92.2 GHz to 132.2 GHz. The variation of graphene Fermi level affects the surface impedance, which can adjust the absorption properties of the proposed absorber. Additionally, the absorber maintains excellent absorption rate at various incident angles from 0° to 40°. With its broadband and stable absorption characteristics, the proposed graphene-based absorber will be a good candidate for THz band EM wave absorption applications.

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