DYNAMIC MANIPULATION OF TERAHERTZ WAVE USING GRAPHENE METASURFACE

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Graphene-combined devices enable a convenient and robust way for terahertz(THz) wave manipulation due to its plasmonic behavior and tunability via electrical biasing [1, 2]. Here we propose a type of graphene metasurfaces consisting of rectangular graphene patches for efficient THz wave manipulation. The metasurfaces can convert both linear and circular incident wave to its cross-polarized component with perfect polarization conversion. Moreover, the phase of the cross-polarized wave can be tuned in a wide range over 180° via electrical biasing, so we can develop several functional devices such as a switchable anomalous deflection device and a tunable dual-polarity focusing mirror.

The basic structure is composed of a graphene patch with size $L_1 = 23$ μm and $L_2 = 18$ μm on a metal ground, with a 20 μm-thick silica spacer inserted in between, demonstrated in Fig. 1(a). The size of each unit cell is $P_x = P_y = 40$ μm and the chemical potential μ_c is 0.5 eV. The plasmonic resonance modes along both sides L_1 and L_2 are coupled with the dielectric cavity, leading to a halfwave-plate behavior, shown in Fig. 1(b). When illuminated by an *x*-polarized incident wave, both resonance modes can be excited, leading to a polarization conversion ratio ($\mathrm{PCR} = R_{xy} / (R_{xx} + R_{xy})$) higher than 99% in a range from 217 μm to 237 μm. The same principle applies to circular incidence, thereby leading to a straightforward design of high-efficiency metasurfaces based on Pancharatnam–Berry phase, see in Fig. 2(a). The efficiency is higher than previous work using graphene cut-wires [3] or nano-crosses [4].

The cross-polarization response of a unit cell versus μ_c is shown in Fig. 2(b), with incidence wavelength $\lambda = 230$ μm. Varying μ_c from 0.21eV to 0.68eV can result in a phase change of 180° while keeping the normalized amplitude larger than 0.6. Taking mirror image of the structure, an additional 180° phase shift is added, leading to a full 360° phase modulation. Utilizing these mirror-imaged unit cells, we can design a switchable beam deflection device whose reflection angle can be tuned from −46° to 0° and 46° simply by changing μ_c of each patch, as shown in Fig. 3. Another functional metasurface demonstration is a tunable focusing mirror whose focal spot can be tuned in both longitudinal and transversal direction. Besides, it can also be switched from a concave mirror to a convex one, shown in Fig. 4. It is worth emphasizing that these devices work under both linear and circular incidences.

In conclusion, we have proposed a type of graphene metasurfaces which can convert incident wave to its orthogonal counterpart with nearly 100% PCR. Moreover, the response of each unit cell can be tuned individually, leading to a dynamic manipulation of the wavefront. The proposed metasurfaces may have great potential in various THz applications.

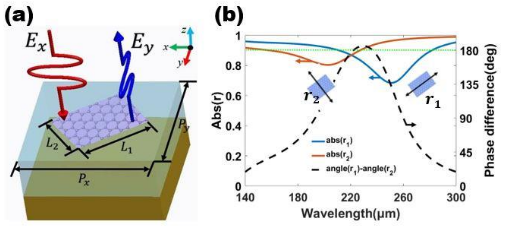


Fig. 1. (a)Schematic of the unit cell. (b) Amplitudes of the reflection coefficients of the two resonance modes (solid line) and phase difference between them (dashed line). The green dotted line indicates a phase difference of 180 °.

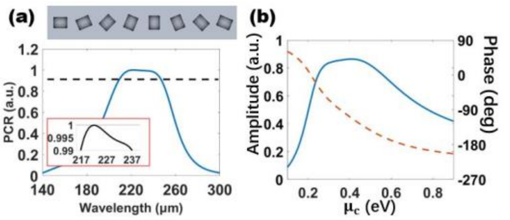
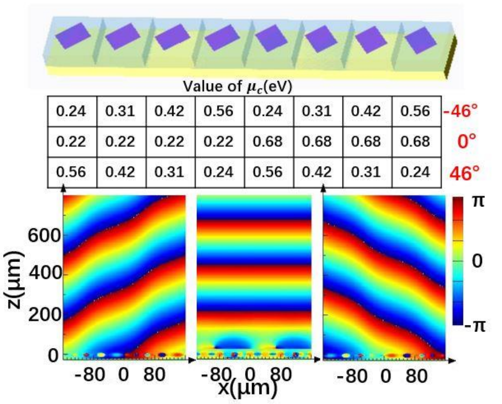


Fig. 2. (a) Schematic of a Pancharatnam-Berry-phase metasurface with phase gradient 45 °and calculated PCR of the structure. the dashed line indicates the level of PCR = 0.9 and the inset shows the range of the curve where PCR>99%. (b) Dependence of the amplitude and phase of the cross-polarized reflected field on μ_c.


Value of μ_c(eV)

0.24	0.31	0.42	0.56	0.24	0.31	0.42	0.56	-46°
0.22	0.22	0.22	0.22	0.68	0.68	0.68	0.68	0°
0.56	0.42	0.31	0.24	0.56	0.42	0.31	0.24	46°

Fig. 3. The anomalous reflection metasurface: the schematic, three sets of μ_c value to realize -46 °, 0 °, 46 ° reflection and simulated phase distribution.

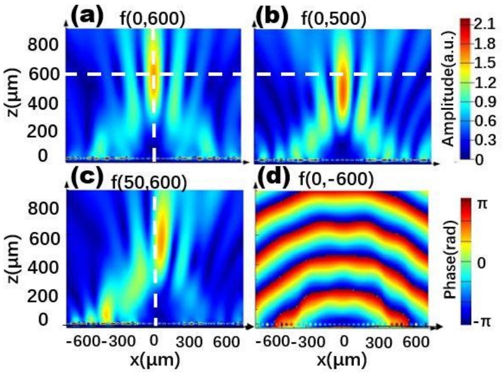


Fig. 4. Planar reflective mirror whose focal spot can be tuned in longitudinal (a) (b) and transversal (a) (c) directions. The polarity of the mirror can also be tuned (f).

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