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A Graphene Based Metasurface for Transmittive-type Linear to Circular Polarization Converter with Tunable Characteristics

Sambit Kumar Ghosh (1), Santanu Das (2) and Somak Bhattacharyya * (3)
(1, 3) Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi, India.
(2) Department of Ceramic Engineering, Indian Institute of Technology (BHU), Varanasi, India.
[1]sambitkrghosh.rs.ece17@itbhu.ac.in, [2]santanudas.cer@iitbhu.ac.in, [3]somakbhattacharyya.ece@iitbhu.ac.in

Abstract

Abstract **— An ultrathin (~λ/11.11) graphene-based metasurface polarization converter has been discussed in this report. The proposed device is a compact two-layered structure having a periodicity of ~λ/14.28. A linearly polarized (LP) electromagnetic wave gets converted to a circularly polarized (CP) wave when it passes through the proposed metasurface between 3 THz and 3.5 THz. The Stokes parameters are calculated to validate the circularly polarized nature of the transmitted wave. The characteristics is tunable in nature owing to the change of applied bias to the graphene layer.**

Keywords—Metasurfaces, Graphene, Polarizer, Transmittive-type.

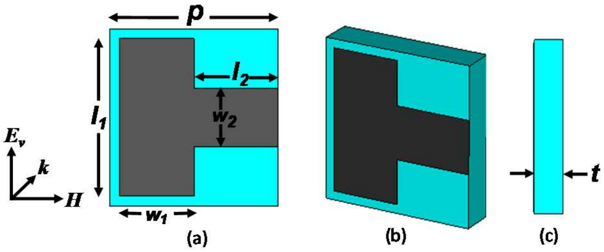
1. Introduction

Metasurfaces are distinctive over the years for its ability to manipulate the electromagnetic wave (EM) in different ways from microwave to infrared region [1-5]. Polarization manipulation is an important aspect for modern wireless terahertz communication where information carried through polarization state assures terahertz (THz) imaging, terahertz communication, and delicate detection of explosives and others [6, 7]. Most of the polarization converters reported till date are bulky in nature and also suffer from high loss [8, 9]. Several three-dimensional chiral metasurface based polarizers have been proposed; however, they are challenging to realize in practice [10-13]. A few cross-polarization converters have been reported using graphene-based metasurface design till date [14, 15]. However, the realization of linear to circular polarization conversion offers enhanced beneficial effects on wireless communication, satellite-based applications and military communications [16, 17].

In this report, a graphene-based metasurface linear (LP) to circular polarization (CP) converter has been introduced. The top layer graphene pattern has been designed in such a way that the y-polarized incident EM wave will be converted to a circularly polarized one at 3.18 THz between 3 THz and 3.5 THz. The proposed nanodevice is examined under oblique incidences of the incoming EM wave where it has been found to be angularly stable upto 40° incident angles for both TE and TM polarizations of the EM wave.

2. Design of the structure

The T-shaped 1 nm thick graphene pattern has been deposited on a 5 µm thick silicon dioxide (SiO_2) substrate having relative permittivity of 3.9 with loss tangent of 0.0006. The top, perspective and the side views of the proposed unit cell have been presented in Figure 1(a), Figure 1(b) and Figure 1(c) respectively, where the optimized structural dimensions are stated in Figure 1. The orientation of the incoming EM wave towards the top surface of the structure has also been mentioned in Figure 1.



(a) (b) (c)

Figure 1: (a) Top view, (b) perspective view and (c) side view of the unit cell of the graphene-based metasurface transmittive-type linear to circular polarization converter in lower THz region ($l_1 = 8$ µm, $l_2 = 1.5$ µm, $w_1 = 4$ µm, $w_2 = 3$ µm, $p = 12$ µm, $t = 5$ µm).

3. Simulation Results

The unit cell of the proposed graphene-based device is realized in CST Microwave Studio in the frequency domain. The shape of the top graphene pattern has been chosen in a way that the incident y-polarized EM wave is converted to the circularly polarized one as evident from the transmission response shown in Figure 2. The corresponding phase difference ($\Delta\phi$) between the two orthogonally transmitted components shown in Figure 3 is exactly 90° implying that the output wave is a circularly polarized one since the ratio of the transmitted orthogonal components is equal to unity ($T_{yy}/T_{xy} = 1$). The corresponding axial ratio (AR) and ellipticity (e) have been calculated from the data and illustrated in Figure 4 and Figure 5 respectively. The axial ratio is below 3-dB at 3.18 THz and ellipticity curve approaches -1 signifying that the transmitted wave is a right-handed circularly polarized in nature.

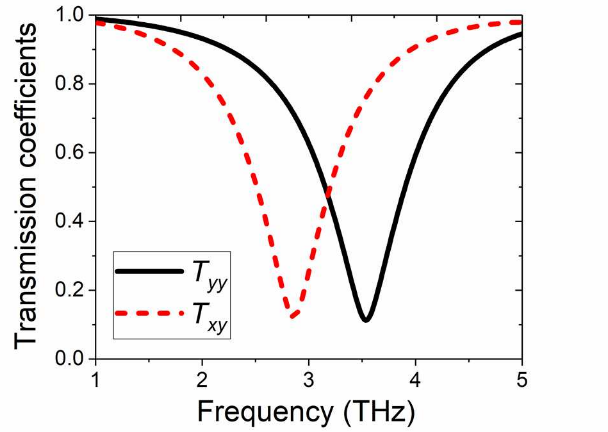


Figure 2: Frequency responses of the transmission coefficients (T_{xy} & T_{yy}) of the proposed device.

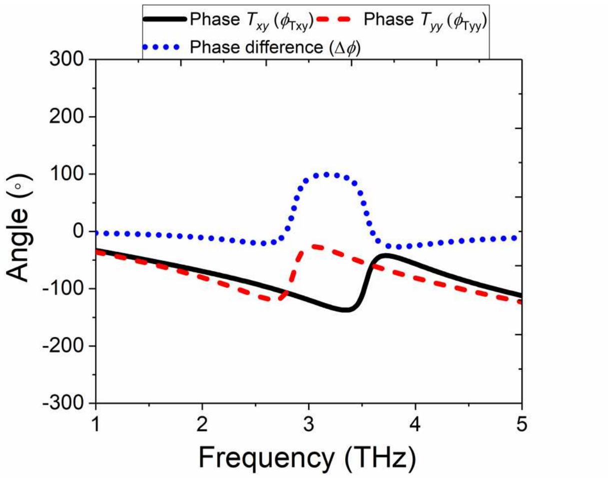


Figure 3: Frequency responses of the phase difference ($\Delta\phi$) between and (T_{xy} & T_{yy}).

The proposed graphene-based metasurface offers tunable characteristics in its spectral performance. The previously discussed transmission response can be tuned according to the need by changing the chemical potential (μ) of the graphene layer by suitably biasing the device. Tuning of ellipticity response has been observed due to variation of μ as illustrated in Figure 6. The response provided in Figure 7 clearly shows that the proposed nanodevice is angularly stable till 20° under the oblique incidences of the EM wave.

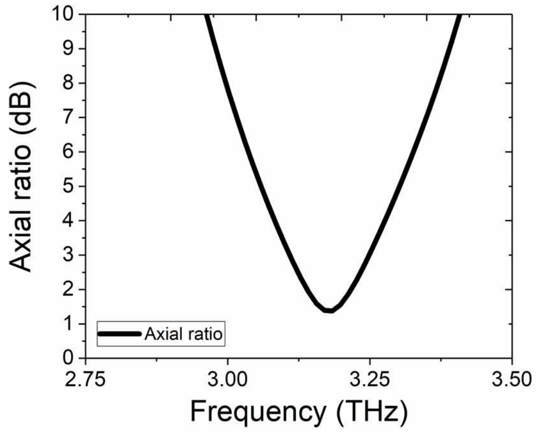


Figure 4: Response of the calculated axial ratio (AR) of the proposed device.

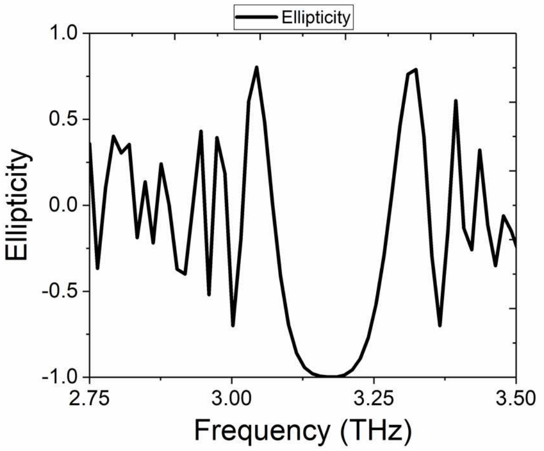


Figure 5: Response of the calculated ellipticity (e) of the proposed device within the whole frequency band.

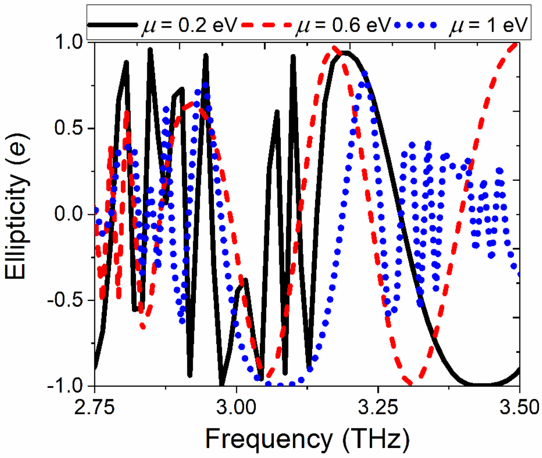


Figure 6: Performance of the ellipticity (e) under the variation of chemical potential (μ) of the graphene layer.

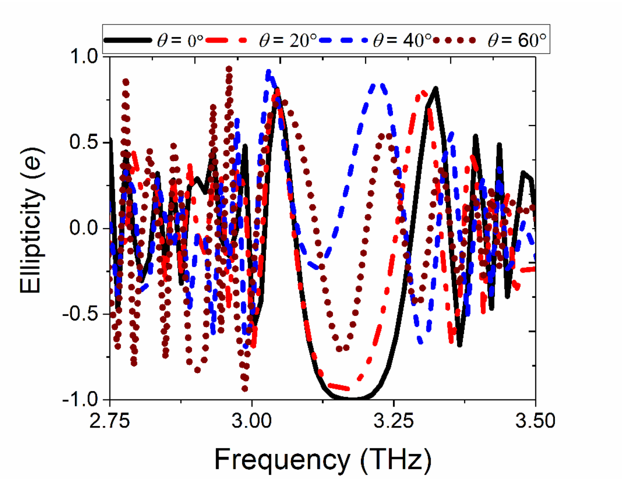


Figure 7: Performance of the ellipticity (*e*) under the variation of oblique incidence of the EM wave.

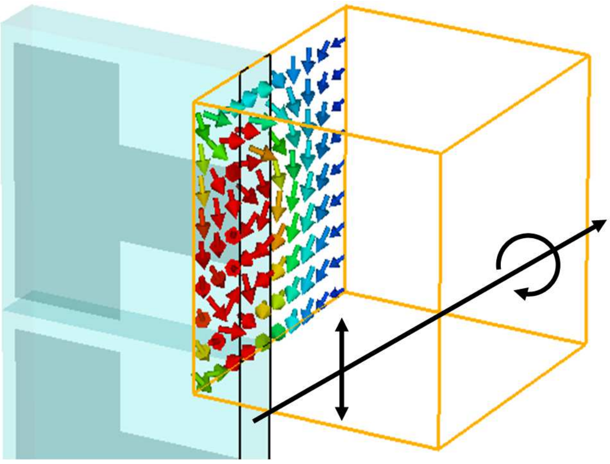


Figure 8: Orientation of the incident and transmitted *E*-field components.

The orientation of the incident and transmitted EM wave has been shown in Figure 8. It clearly indicates that a LP wave is incident on the proposed metasurface and the converted CP wave is being transmitted at a particular instance at a particular phase value. The E-field vectors are in clockwise direction at the transmitting end as the ellipticity (*e*) value is equal to -1 at 3.18 THz; proving that the converted wave is a right-handed circularly polarized (RHCP) wave.

4. Conclusion

A graphene-based transmittive-type linear to circular polarization converter for terahertz (THz) applications has been presented in this literature. The Stokes parameters have been calculated to verify the nature of the transmitted wave. The orientation of the *E*-field profile has been verified at 3.18 THz. A variation in the chemical potential of the graphene layer makes the spectral response of the proposed device tunable. The structure is also angularly stable till 40° of the incident angles of the EM wave. It has been designed in the nanotechnology domain with a thickness of $\lambda/11.11$ and a periodicity of $\lambda/14.28$. This type of transmittive-type LP to CP converter can be used in satellite communication systems.

5. Acknowledgment

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6. References

1. 1. S. K. Ghosh, V. S. Yadav, S. Bhattacharyya and S. Das, "A Graphene Based Bandwidth Enhanced Metamaterial Absorber using Circular Ring," 2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Boston, MA, 2018, pp. 1491-1492. doi:10.1109/APUSNCURSINRSM.2018.8608226.

2. S. K. Ghosh, S. Bhattacharyya and S. Das, "A Graphene Based Metasurface with Wideband Absorption in the Lower Mid Infrared Region," 2018 IEEE MTT-S International Microwave and RF Conference (IMaRC), Kolkata, India, 2018, pp. 1-4. 10.1109/IMaRC.2018.8877373.

3. S. K. Ghosh, V. S. Yadav, S. Das, and S. Bhattacharyya, "Tunable Graphene Based Metasurface for Polarization-Independent Broadband Absorption in Lower Mid Infrared (MIR) Range," Early Access, IEEE Transactions on Electromagnetic Compatibility, doi:10.1109/TEMC.2019.2900757.

4. W. F. Bahret, "The beginning of stealth technology," IEEE Transactions on Aerospace Electronic Systems, **29**, 4, October 1993, pp. 1377-1385, doi: 10.1109/7.259548.

5. X. Liu, T. Tyler, T. Ttarr, A.F. Starr, N. M. Jokerst and W. J. Padilla, "Taming the blackbody with infrared metamaterials as selective thermal emitters," Physical Review Letters, **107**, 4, July 2011, pp. 045901,doi: 10.1103/PhysRevLett.107.045901.

6. Y. Choi, J. W. Choi and J. M. Cioffi, "A geometric-statistic channel model for THz indoor communications," J. Infrared Millim. Te., **34**, April 2013, pp. 456-467, doi: 10.1007/s10762-013-9975-5.

7. N. K. Grady, J. E. Heyes, D. R. Chowdhury, Y. Zeng, M. T. Reiten, A. K. Azad, A. J. Taylor, D. A. R. Dalvit and H. T. Chen, "Terahertz metamaterials for linear polarization conversion and anomalous refraction," Science, **340**, 6138, June 2013, pp. 1304-1307, doi: 10.1126/science.1235399.

8. K. Wiesauer and C, Jordens, "Recent advances in birefringence studies at terahertz frequencies," J. Infrared

Millim. Te., **34**, May 2013, pp. 663-681, doi: 10.1007/s10762-013-9976-4.

9. M. Khosronajad, G. G. Gentili and G. Macchiarella, “Multilayer Full Polarization Conversion Transpolarizing Structures,” Hindawi, **2019**, 3956206, 2019, pp. 1-5, doi: 10.1155/2019/3956206.

10. A. V. Rogacheva, V. A. Fedotov, A. S. Schwanecke and N. I. Zheludev, “Giant gyrotropy due to electromagnetic field coupling in a bilayered chiral structure,” Phys. Rev. Lett., **97**, 17, October 2006, pp. 177401, doi: 10.1103/PhysRevLett.97.177401.

11. Aba, Y. Qu, A. Abudukelimu, H. Ullah, and Z. Zhang, "Chiral response of a metasurface composed of nanoholes and tilted nanorods," Appl. Opt. **58**, 2019, pp. 5936-5941, doi: 10.1364/AO.58.005936.

12. N. Chiotellis and A. Grbic, "Analytical modeling of tensor metasurfaces," J. Opt. Soc. Am. B**, 33**, 2016, pp. A51-A60, doi: 10.1364/JOSAB.33.000A5.

13. J. Sperrhake, M. Decker, M. Falkner, S. Fasold, T. Kaiser, I. Staude, and T. Pertsch, "Analyzing the polarization response of a chiral metasurface stack by semi-analytic modeling," Opt. Express, **27**, 2019, pp. 1236-1248, doi: 10.1364/OE.27.001236.

14. V. S. Yadav, S. K. Ghosh, S. Das and S. Bhattacharyya, “Wideband tunable mid-infrared cross polarization converter using monolayered graphene-based metasurface over a wide angle of incidence,” IET MAP, **13**, 1, January 2019, pp. 82-87, doi: 10.1049/iet-map.2018.5373.

15. V. S. Yadav, S. K. Ghosh, S. Das and S. Bhattacharyya, “Graphene based metasurface for a tunable broadband terahertz cross polarization converter over a wide angle of incidence,” Applied Optics, **57**, 29, 2018, pp. 8720-8726, doi: 10.1364/AO.57.008720.

16. H. F. Ma, G. Z. Wang, G. S. Kong and T. J. Cui, “Broadband circular and linear polarization conversions realized by thin birefringent metasurfaces,” Optical Materials Express, **4**, 8, 2014, pp. 1717-1724, doi: 10.1364/OME.4.001717.

17. Y. Huang, L. Yang, J. Li, Y. Wang and G. Wen, “Polarization conversion of metasurface for the application of wide band low-profile circular polarization slot antenna,” Applied Physics Letters, **109**, 054101, July 2016, pp. 1-5, doi: 10.1063/1.4960198.