GRAPHENE BASED METASURFACE POLARIZATION CONVERTER

THESIS REPORT

Submitted in partial fulfillment of the requirements for the award of the
Degree of Master of Technology in Electronics and Communication
Engineering with specialization in Communication Systems by the
A P J Abdul Kalam Technological University

by

MEKHA REGHUNADH
Reg.No TKM21ECCS07

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CERTIFICATE

Certified that this Project report titled **”GRAPHENE BASED METASURFACE POLARIZATION CONVERTER”** is a bonafide record of the work done by **MEKHA REGHUNADH** (Reg.No.TKM21ECCS07) under my supervision, in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electronics and Communication Engineering with specialization in Communication Systems by the A P J Abdul Kalam Technological University.

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ABSTRACT

Metasurface refers to a flat interface that has been artificially structured to enable precise and controlled manipulation of electromagnetic waves. It is made up of tiny elements that are arranged periodically or non-periodically to achieve the desired optical properties. The use of metasurfaces has significantly transformed the field of electromagnetic wave control and created new possibilities in photonics, optics, and communication technology.One of the primary applications of metasurfaces is in controlling electromagnetic wave polarization. Polarization is a characteristic of electromagnetic waves that describes the orientation of their electric field. By regulating the polarization of a wave, it becomes possible to manipulate its direction of propagation, intensity, and phase. Polarizers, which transmit or reflect waves of a specific polarization state, can be designed using metasurfaces.

This dissertation proposes a unique design for a reflecting type polarizer capable of linear to cross conversion in the THz domain. The polarizer unitcell comprises a substrate on which thin graphene is created, while a thin gold sheet serves as the ground plane. The converter displays a linear-cross conversion with a minimum PCR of 90% within the 1.86 to 2.92 THz frequency range.The main benefit of this design is that the metasurface's performance remains stable when electromagnetic waves strike it from oblique angles with both transverse electric (TE) and transverse magnetic (TM) incidence angles up to 45. This feature is crucial for practical applications, where the incidence angle of electromagnetic waves may vary based on the source or the environment.

The potential impact of using metasurfaces in communication technology is vast, as it has the capacity to improve transmission efficiency, reduce signal interference, and increase bandwidth by creating devices with diverse functionalities.

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Chapter 1

Introduction

Terahertz (THz) technology is concerned with electromagnetic waves with frequencies between 0.1 and 10 THz, which possess unique characteristics that make them desirable for various purposes such as spectroscopy, communication, and astronomy. However, to fully leverage their potential, efficient THz devices such as polarizers, switches, and modulators are needed to regulate and manipulate THz waves.Of particular importance are polarization-manipulating devices that play a vital role in THz imaging and spectroscopy by enabling control and modification of the polarization state of THz waves. Nevertheless, developing effective polarization-manipulating devices for THz waves has been problematic for multiple reasons. One of the significant challenges is the absence of appropriate materials that can be utilized in the THz range. Traditional techniques for modifying polarization in other frequency ranges utilize birefringent materials, which are materials with varying refractive indices for various polarizations of light. These materials can modify the polarization of light by introducing a phase difference between the two polarization components. However, in the THz range, there is a limited availability of materials that exhibit birefringence, and even the existing ones are often tough to manufacture.Another challenge is the large size of conventional polarization-manipulating devices. In THz applications, where wavelengths are much larger than those in the visible range, device size becomes a critical factor. Larger devices are harder to integrate into a THz system and result in higher losses due to scattering and absorption[1].

Polarization conversion is an important aspect of managing the flow of electromagnetic waves, especially in optical communication systems. Dichronic crystals, birefringent materials, and optical gratings are examples of materials that can be used for polarization conversion.Dichroic crystals are crystals that have different absorption coefficients for different polarizations of light. When light passes through such crystals, it gets split into two polarized beams with different intensities, which can be used for polarization conversion. Birefringent materials, also known as anisotropic materials, are materials that have different refractive indices for different polarizations of light. This property can be utilized to convert the polarization of light by passing it through a birefringent material.Optical gratings are structures with a periodic variation in refractive index, which can diffract light into different directions depending on its polarization. This property can be utilized for polarization conversion by controlling the orientation of the grating.However, these conventional methods of polarization conversion have limitations such as a smaller bandwidth and larger volume. Moreover, they are not suitable for long-distance transmission due to their sensitivity to environmental factors like temperature and pressure.

To overcome these limitations, researchers have developed polarization converters based on metamaterials. Metamaterials are artificial materials designed to exhibit specific electromagnetic properties that are not found in naturally occurring materials. They can even function in the presence of negative refractive index, which is not possible with natural materials.The geometry, size, and orientation of metamaterials can be precisely controlled to achieve the desired electromagnetic properties, including polarization conversion. This allows for the development of compact and efficient polarization converters with a broader bandwidth and higher performance. Therefore, development of metamaterial-based polarization converters has overcome the limitations of conventional methods and opened up new possibilities for the management of the flow of electromagnetic waves. The form, geometry, size, and orientation of materials play a crucial role in achieving the desired electromagnetic properties.

Metamaterials are a group of man-made materials that possess characteristics that are not present in natural substances. These materials are constructed using artificial nanostructures that are smaller than the wavelength of light, which allow them to interact with electromagnetic waves in a specific way. By manipulating the structure and composition of these nanostructures, metamaterials can control the speed and direction of light, enabling them to achieve unique optical features such as a negative refractive index. Unlike natural materials, metamaterials can manipulate the electromagnetic field at a subwavelength scale.One of the remarkable capabilities of metamaterials is the creation of super-lenses, which can achieve super-resolution imaging by overcoming the diffraction limit of conventional lenses. Metamaterials can achieve this by creating a lens with a negative refractive index using subwavelength structures. Another exciting property of metamaterials is the potential to create cloaking devices, making an object invisible to specific wavelengths of light by bending the light around it. Although still in the early stages of development, this technology has the potential to revolutionize fields such as military camouflage and medical imaging.

Overall, metamaterials have the potential to transform our ability to manipulate electromagnetic waves and enable new possibilities in communication, sensing, and imaging. While still relatively new, the field has already produced remarkable outcomes and is poised to make more significant advances in the future . The capacity to realise arbitrary manipulation of electromagnetic waves in several parameters (frequency, amplitude, phase, and polarization) with multiple degrees of freedom is the essence of metamaterials and allows for the instantaneous construction of objects with optical features. Metamaterial, which exhibits extraordinary responses in various desired frequency regimes, has promised an exotic approach to artificially manipulate the polarization state of electromagnetic (EM) waves. It enables flexible manipulation of the EM waves and can be easily scaled to work at THz frequency. Recently, it has been suggested that metamaterials offer a promising route to the realisation of effective polarization state manipulation of electromagnetic waves via ultrathin, miniaturised, and easily integrable designs. This opens up intriguing possibilities for the realisation of polarization state manipulation of electromagnetic waves in nanoscale and shows infinite potential in nanophotonics applications.

A promising tunable material for various electro-optical devices, graphene is a single layer of carbon atoms arranged in a hexagonal lattice two-dimensional material with outstanding mechanical, electrical, and optical properties including fast carrier mobility, high optical transparency, and tunability . Graphene has been widely used in tunable plasmonic devices such as polarisation converters , waveguides , modulators , photodetectors , and absorbers , taking advantage of its ability to support surface plasmon polaritons (SPPs) in the terahertz and infrared ranges . One of the biggest benefits of graphene-based converters over traditional metamaterial converters is the dynamic adjustability attained by modifying the chemical potential with external voltage. The utilisation of stacked layers, multiresonance, and fractal geometry in the design are the most popular ways to increase the bandwidth of metasurface-based devices. These methods are not applicable for real-world applications due to their complexity and high prices. As a result, there is still a critical need to create wideband polarizers based on metasurfaces that are small, easy to use, and inexpensive.

1.1 Objectives

- Design of graphene based metasurface linear-cross polarization converter
- Evaluate performance of the designed polarization converter in the THz regime.

1.2 Organization of the thesis

The notion of metasurface and the shortcomings of traditional polarization converters are introduced in the first chapter of the thesis. The second chapter provides a thorough analysis of the literature on polarization converters as a whole.The third chapter focuses on how unit cell design has changed in response to the shortcomings of previously developed structures. The fourth chapter addresses the results, interpretations, and details. The conclusion is covered in the last chapter, which is followed by references.

Chapter 2

Literature Review

T.Ako *et.al.*, Numerous research have shown polarization converters based on metamaterials. The effectiveness, bandwidth, and permissible incidence angle of a recent design of periodic two-dimensional devices or metasurfaces used for polarization control are constrained[2]. This is attributable to poor device setup and excessive dissipation in the utilised dielectric material. a reflective linear-polarization rotator that is capable of successfully reflecting electromagnetic waves with x- or y-polarization to their orthogonal counterpart. The metallic T-shaped resonator on the metallic ground plane that makes up the proposed reflecting linear polarization rotator is spaced periodically by a cyclic olefin copolymer (COC) dielectric spacer, as illustrated in Figure.2.1. (a). The ground plane and T-shaped resonators are made of 200 nm thick gold (Au). Because of its low loss tangent, COC was chosen. The low loss tangent of COC, which is three orders of magnitude lower than that of PDMS and polyimide, is the reason for its selection. The dielectric layer has a thickness of 79 m. T-shaped resonator is created as a combination of four sections in a square unit cell size of side a= 122 m.According to the measurement, spanning a broad frequency range of 0.40-1.10 THz, robust cross-polarization 80% and weak co-polarization 40% at normal incidence are maintained at oblique incidence.

The simulation's PCR is more than 80% spans a bandwidth of 101 %, between 0.34 and 1.04 THz for normal incidence, and 93% between 0.3 and 0.99 THz for 45° incidence. The experimental findings further indicate that for normal and 45° incidence, respectively, average PCR are larger than 80% spanning broad bandwidths of

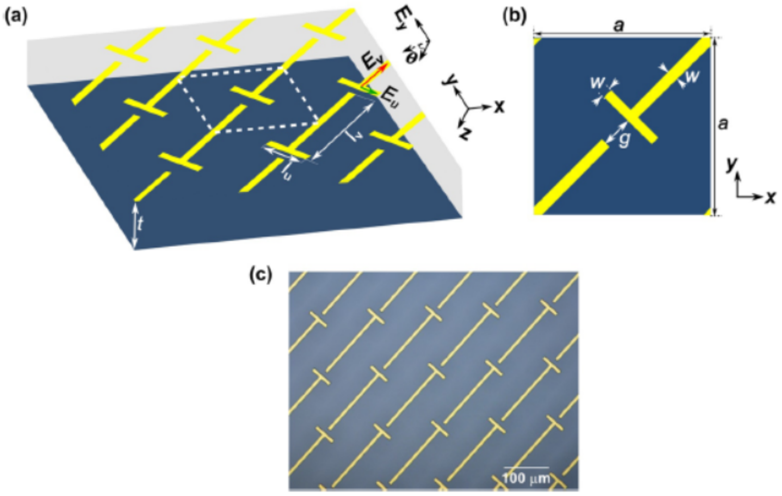

Figure 2.1: Schematic diagram of Polarization Converter(a)Side view, (b)Front view and (c) Fabricated sample

95% from 0.38 to 1.07 THz and 100% from 0.36 to 1.08 THz.

Sambit Kumar Ghosh *et.al.*, A Graphene Based Metasurface for Transmittive-type Linear to Circular Polarization Converter with Tunable Characteristics[3]. The T-shaped 1 nm thick graphene pattern was created on a 5 m thick silicon dioxide (SiO2) substrate with a relative permittivity of 3.9 and a loss tangent of 0.006 is shown in Figure 2.2. A graphene-based metasurface linear (LP) to circular polarization (CP) converter has been introduced. The top layer graphene design will change the y-polarized incident electromagnetic wave into a circularly polarized one at 3.18 THz between 3 THz and 3.5 THz. After being tested under oblique incidences of the incoming EM wave, it was found that the suggested nanodevice is angularly stable up to 40° incident angles for both TE and TM polarizations of the EM wave. The unit cell of the proposed graphene-based device is realised in CST.

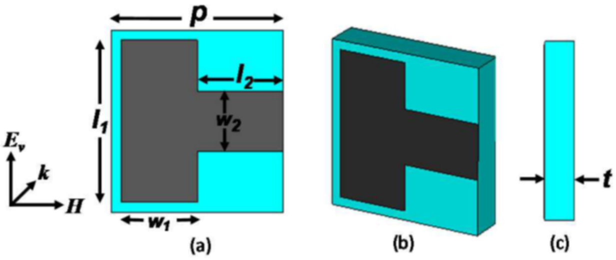

Figure 2.2: Schematic diagram of unit cell(a) Top view, (b) perspective view and (c) side view of the unit cell

Vinit Singh Yadav *et.al.*, introduces graphene based metasurface with tunable dual band mid-infrared cross polarization converter.Figure 2.3 illustrates the structure is made up of an array of split rings made from single-layer graphene sheets that have been perforated[4]. The split ring's axis is positioned at a 45° angle with respect to the direction of x. The metallic pattern is built of 0.5 m thick gold that has been developed over amorphous silicon dioxide that is 25 m thick and has a dielectric constant of 3.9 at the proposed structure's operating frequency .Periodicity px = py = p = 17.5 m, r1 = 8.5 m, r2 = 6.5 m, w = 5 m, dielectric thickness d1 = 25 m, and thickness of gold sheet d2 = 0.5 m are the optimised geometrical parameters.

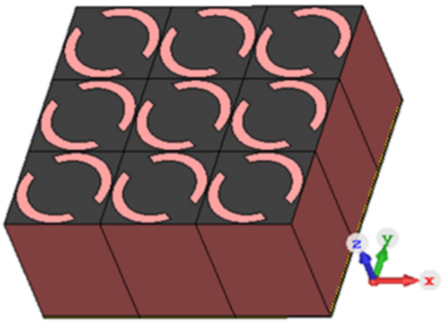

Figure 2.3: Schematic diagram of the graphene-based metasurface exhibiting broadband cross-polarisation conversion at the mid-IR region

The frequency range of 1.60 to 2.89 THz, the co-polarized component was kept below 10 dB, whereas the cross-polarized component was detected at more than 1 dB. As seen in Fig. 2.17b, the PCR is 0.9 for the frequency range of 1.62-2.75 THz, resulting in a fractional bandwidth of about 51.92% with respect to the 2.16 THz centre frequency.

Behnaz Bakhtiari , Tunable Terahertz Polarization Converter Based on Graphene Metasurfaces[5]. Figure 2.4 shows the whole design of the proposed polarization converter, which has a graphene structure on top of a metasurface structure .SiO2 substrate with a thin gold metal layer on top. A SiO2 substrate with a thickness of h2 = 6.5um and a relative dielectric constant of 2.1 at the working frequency bandwidth is placed on top of a graphene structure. The layer underneath is made of gold and has a conductivity of 4.56107 S/m. The planned unit cell structure's ideal dimensions are p = 2 um, wl = 1.48 um, g = 0.04 um, h1 = 1 um, and h2 = 6.5 um. This proposed structure was designed and simulated in CST Microwave Studio which is a time-domain based solver. The periodicity of the structure is in the XY directions, while the perfect matched layer is assumed along the z-direction.Changing the proposed metasurface's geometrical dimensions causes the polarisation conversion ratio (PCR) bandwidth to change from 0.7 THz to 1.9 THz, while altering the graphene Fermi Energy causes the PCR operational frequency range to change from [6.35-8.73] to [8.73-11.66] THz, which is actually a wide range of terahertz frequency.

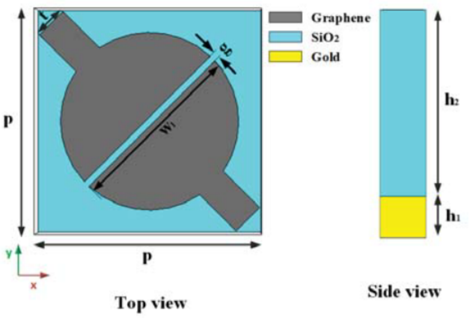

Figure 2.4: Top and side views of the proposed cross-pol converter unit cell

Shailza Gotra *et.al.*, A linearly polarised MSA and a tunable PC were used to create a broadband CP antenna[6].

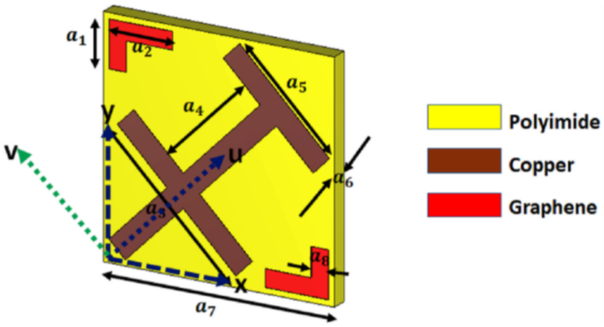

Figure 2.5: Geometry of polarization converter's unit cell

The suggested LP-CP converter is shown in Figure 2.5, which is distinctive since it is single-layered and made of coplanar graphene and metallic strips, which allows for dynamic modulation of the phase difference between two transmitted components with orthogonally polarized polarization. By combining graphene with metallic patches on the same layer over a polyimide substrate, a transmissive type single layered adjustable linear to circular polarization converter is created.By changing the chemical potential of the L-shaped graphene patches at the diagonal ends, the suggested metasurface's tunability has been made possible. The anisotropy brought on by the double T shaped copper patch results in a quadrature phase shift between the orthogonal components of the electric field. A bandwidth with an adjustable axial ratio (3 dB) between 2.57 and 3.06 THz is shown.

Xingyang Yu *et.al.*, A hybrid metamaterial-based broadband tunable polarization converter operating in the THz range is shown in Figure 2.6.[7].The suggested polarization converter performs admirably and has the ability to dynamically switch between linear-to-cross, linear-to-circular, and linear-to-elliptical polarization conversion features. This effect is caused by the carefully managed phase difference between the reflected wave's two orthogonal linearly polarized components. The metamaterial's unit cell is made up of a grounded plane on the bottom of a 59 m thick dielectric substrate, a metallic I-shaped resonator, and double layers of graphene wires on top. With a permittivity of 3.9 r, a thin film of silicon dioxide is used to divide the double layers of graphene. The dielectric constant of the dielectric substrate is estimated to be 3.5 and the gold layer is 0.4 m thick. The PCR is greater than 88 % at the frequency range of 0.4-0.95 THz.

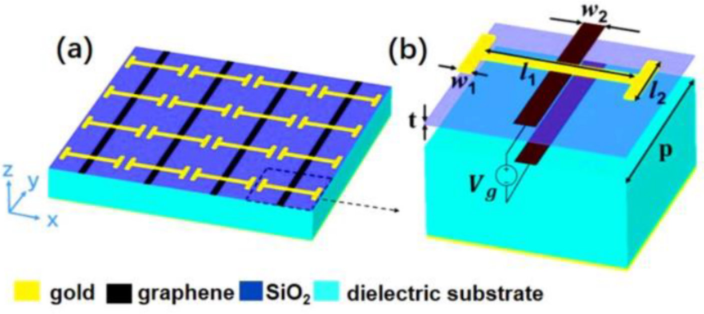

Figure 2.6: Geometry of polarization converter's unit cell

Ming Chen *et.al.* A mid-infrared hollow-carved "H" array atop a graphene metasurface-based wideband adjustable cross polarized converteris represented in Figure 2.7.[8]. The conversion device has three layers: a metal ground plane at the bottom and a periodic regular hollow carved "H" array at the top of the insulating dielectric layer. Linear light is converted into its cross polarization by the polarization converter. While the FWHM bandwidth is 3.87THz within the range of 33.8THz to 37.67THz, or around 11% of the central frequency, the polarization conversion ratio is above 90% at 2.53THz within the region of 34.39THz to 36.92THz. By changing graphene's Fermi energy, the cross polarization converter may be dynamically controlled across a large frequency range without having to redesign and fabricate nanostructures. The size of w1 or maintaining high polarization conversion ratios can also be used to adjust the operational frequency spectrum of the proposed structure. At incidence angles up to 50, the polarization conversion ratios can be kept over 90%. As a result, the suggested device has the potential to be developed and used in the control of light polarization in the mid-infrared areas.

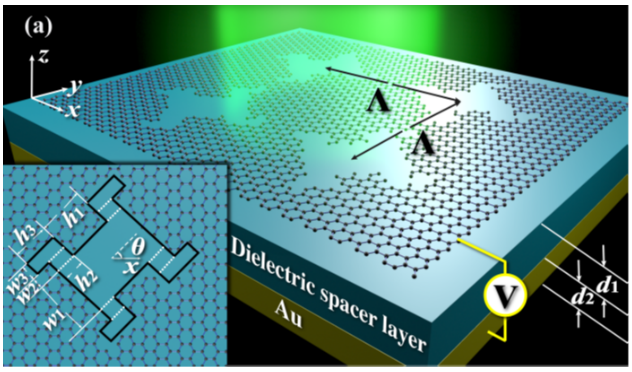

Figure 2.7: Schematic illustration of CPC and one unit cell

Li Zeng *et.al.* In the terahertz range, a tunable ultra-broadband linear-to-circular polarization converter (LCPC) with graphene is presented[9].In Figure 2.8.it consists of two "I"-shaped gold resonators, a strip-shaped graphene sheet, two dielectric layers, and a bottom gold reflector. By lowering the Fermi energy (Ef) of the graphene in the terahertz region, the proposed LCPC may transform linearly polarized waves into circularly polarized waves in an ultra-broadband frequency range that can be extended to lower frequencies.

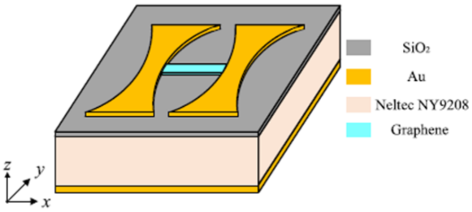

Figure 2.8: Schematic view of the unit cell for the proposed LCPC

When Ef = 0.4 eV, 0.6 eV, 0.8 eV, and 1.0 eV, respectively, the axial ratio bands of the proposed LCPC that are smaller than 3 dB are covered by frequencies of 0.9248 Hz, 0.9408 Hz, 0.9665 Hz, and 0.9746 Hz, with respective relative bandwidths of 84.86 %, 83.49 %, 80.93 %, and 80.15 %. The unit cell of such an LCPC is composed of four layers. the top layer is made up of two "I"-shaped gold resonators and a strip-shaped graphene sheet, while the bottom layer is a square reflector made of gold (Au). the second layer is a Neltec NY9208. the third layer is loss-free SiO2.

A novel approach to creating a device that can convert linearly-polarized waves to circularly-polarized waves in the terahertz frequency range has been put forth in Figure 2.9.[10]. This method involves utilizing a metasurface made from graphene that is able to be adjusted to achieve the desired effect. The metasurface consists of two separate layers that are made up of resonators composed of metal and graphene, with a dielectric spacer in between them. When a linearly-polarized wave is introduced to this metasurface with a perpendicular orientation, it is converted into a circularly-polarized wave.The tunable linear-to-circular polarization converter (LTCPC) in the terahertz range is comprised of a unit cell that consists of three layers. The top and bottom layers are resonant layers, which include two graphene stripes oriented perpendicularly to each other, as well as two "I"-shaped resonant units composed of gold When Ef (Fermi energy) is equal to 0.1 eV, the optimized result for the axial ratio (AR) band - where the difference between the major and minor axes of the polarization ellipse is less than 3 dB - is situated within the frequency range of 2.64-3.29 THz. This range has a relative bandwidth of 21.92%.

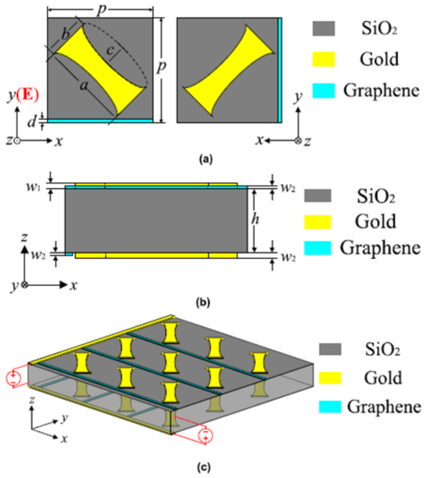

Figure 2.9: Schematic view of the unit cell for the proposed LTCPC.

2.1 Research Gap

From thorough observation of the previoused works found out that the traditional metasurface polarization conveters are bulkier in size and provides low polarization convertion in low frequency range.So there is a need to focus more on the Graphene based metasurface polarization converters in the THz range. As it offers several potentional benefits compared to traditional metasurface polarization converters.Graphene based metasurface polarization converters have been shown to operate over a much broader frequency range, which allow it to support plasmons over a wide range of frequencies.Its tunability can be adjusted by varying the chemical potential makes it possible to reconfigure the device.

Chapter 3

Proposed Model

One of the most important components of controlling electromagnetic (EM) waves is polarization, which has applications in numerous areas including sensor systems, antennas, and optical communication. Orthogonal electric and magnetic fields that flow counter-clockwise from the direction of the wave's transmission characterise electromagnetic waves, such as microwaves and visible light. In order to convert polarization, electromagnetic (EM) waves' polarization states must be managed and controlled.. The choice of polarization is important because it affects the direction and strength of the electromagnetic field that is transmitted or received.

CST Studio Suite a commercial programme with a frequency domain solver, is used to examine the performance of the suggested structures in the THz range.Applications across a wide range of industries are supported by the electromagnetic and multiphysics solvers in CST Studio Suite, including the design of 5G MIMO antenna arrays, MRI, and implant safety in the life sciences. Before you even think about spending money on actual prototypes, CST Studio Suite is essential for comprehending how electromagnetic components will behave when your goods are used in the real world.CST Studio Suite have access to the most reliable simulation solvers, which employ techniques like the Time Domain Solver and Frequency Solver. High Frequency, Low Frequency, Multiphysics, Particles, EMC (Electromagnetic Compatibility), and EDA (Electronic Design Automation) are the several fields into which CST Electromagnetic solvers are broken down. An x-polarized EM wave has been used to illuminate the device at normal incidence. Periodic boundary conditions have been applied along the xy-plane; the EM wave propagation is along the z-direction. The cross-polarization conversion can be determined in terms of the polarization conversion ratio (PCR).

The performance of the PCM's polarization conversion is assessed using the definition of polarization conversion ratio (PCR). It uses a typical incident y-polarized EM wave, abbreviated E_y^i, as an example $E_x^r$and E_y^r are reflected fields and $E_x^i$and E_y^i indicate the incident fields along the x- and y-axes, respectively.The PCR under normal incidence is determined using the formula

$$PCR = \frac{|Ryx|^2}{|Ryx|^2+|Rxx|^2} \quad (3.1)$$

where $Rxy = E_{xr}/E_{yi}$ and $Ryy = E_{yr}/E_{yi}$ represent the reflection ratios of the conversions of polarization from y to x (cross-polarization) and y to y (co-polarization), respectively. Since the geometry is symmetric, the x-polarized incident EM wave yields the same results.

The proposed converter is a straightforward three-layer arrangement of periodic graphene patterns placed on a silicon dioxide (SiO2) substrate with a gold backing. For applications in the THz range, where EM behaviour differs from that of the microwave domain, the choice of materials and other structural elements is crucial .

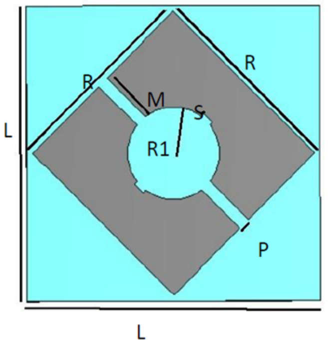

Figure 3.1: Proposed unit cell front view

Three layers of gold, SiO2, and irregularly spaced graphene patterns make up the meta-atom of the proposed cross-polarization converter (CPC). Gold entirely covers the bottom face of the SiO2 block with a relative permittivity of 3.9 (tan = 0.001). Gold is often used as a bottom ground plane material because of its excellent thermal conductivity and corrosion resistance. These properties make it ideal for use in devices that may be subjected to harsh environmental conditions or high temperatures.The choice of gold as the bottom ground plane material may also depend on other factors such as the operating frequency of the device, the size of the unit cell, and the specific application requirements

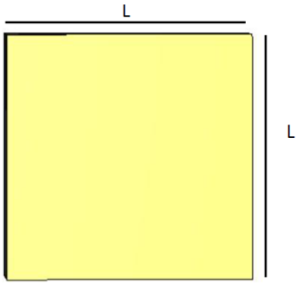

Figure 3.2: Proposed unit cell bottom view

Using SiO2 as the substrate material for unit cell antennas has numerous benefits. Firstly, the high dielectric constant of SiO2 enhances the radiation efficiency and bandwidth of the antenna. Additionally, SiO2 is a low-loss dielectric material, reducing the losses related to the substrate. As a result, the efficiency and gain of the antenna increase.Furthermore, SiO2 is an economical material that is readily accessible and can be fabricated into diverse shapes and sizes. Its mechanical properties, including scratch resistance and high hardness, make it ideal for use in severe conditions. Graphene is a material that exists in two dimensions and is composed of carbon atoms that are arranged in a pattern resembling a honeycomb lattice. Because of its unique two-dimensional structure and the way in which the carbon atoms are arranged.Graphene has exceptional properties such as being a great conductor of both heat and electricity, as well as having remarkable strength and low weight.

Rectangular slots are often utilized in the unit cell of an antenna to obtain desired radiation features. These slots essentially serve as openings or gaps within the metallic surface of the antenna structure, with their rectangular shape providing greater accuracy in governing the antenna's radiation pattern. By inserting a rectangular slot into the metallic surface of an antenna, the slot can function as a resonator or resonant cavity. This enables it to store energy within an electromagnetic field when stimulated by electromagnetic waves, which can then be emitted as an electromagnetic wave.

These advantageous characteristics of graphene suggest it could be a useful mate-

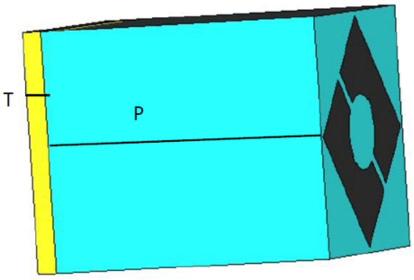

Figure 3.3: Proposed unit cell side view

rial in a wide range of applications, including electronics, energy storage, and biomedical fields. Graphene with highly dispersive surface conductivity that is regularly patterned and appropriate for THz applications covers the top face of the SiO2 substrate. The lowest layer of gold is$1\mu m$ thick. The SiO2 block has a $15\mu m$ thickness. In the simulation, the graphene surface's 1 nm ultra-thin feature has been taken into account.

Table 3.1: Proposed unit cell functional parameters in μm

L	12.50
T	1
P	15
R	8.49
R1	3.93
M	2.28
S	0.17
Gt	1(nm)

Chapter 4

Results and Discussion

Graphene possesses exceptional qualities including ultra-high carrier mobility, high thermal conductivity , high mechanical strength etc. because of its two-dimensional structure and honeycomb lattice of carbon atoms . The exceptional electrical, optical, mechanical, and thermal characteristics of graphene have sparked a lot of attention in the field of study . At sub-wavelength scales, surface plasmons in the graphene layer have unusual characteristics such as minimal losses, strong confinement, and great tunability.

4.1 S Parameter

The input-output connection between ports is described by S-parameters. S11 measures the amount of power that gets bounced back at the antenna port as a result of a transmission line mismatch. S11 is called as reflection coefficient or return loss.Specifically, the S-parameters of a unit cell antenna describe the relationship between the incident electromagnetic waves and the waves that are transmitted and reflected by the antenna. These parameters can be used to calculate the efficiency of the antenna in transmitting and receiving electromagnetic waves, as well as its impedance matching characteristics Power transferred from Port 2 to Port 1 is represented by the signal S_{12}.

4.2 Polarization Conversion Ratio (PCR)

The Polarization Conversion Ratio (PCR) measures how well a polarization converter can alter the polarization state of light from its original state to a desired state. Essentially, PCR is an indicator of the effectiveness of a device in changing the polarization of light that enters it. When the PCR value is high, it suggests that the conversion process is more efficient, and this is usually preferred in various applications such as in telecommunications, laser systems, and imaging systems.Polarization conversion ratio, which assumes a value near to unity at the frequencies where polarization conversion occurs, has been used to indicate the effectiveness of converting the incidence of a co polarized component into a cross-polarized one.

4.3 Results Of Designed Substrate

Substrate refers to a non-conductive material that serves as the foundation or base of the unit cell. The substrate provides support for the conductive elements of the antenna, and its characteristics can greatly affect the unit cell 's performance. Specifically, the thickness of the substrate plays a role in determining the radiation pattern of the antenna. If the substrate is thicker, the resulting beamwidth will be narrower, while a thinner substrate will produce a wider beamwidth .

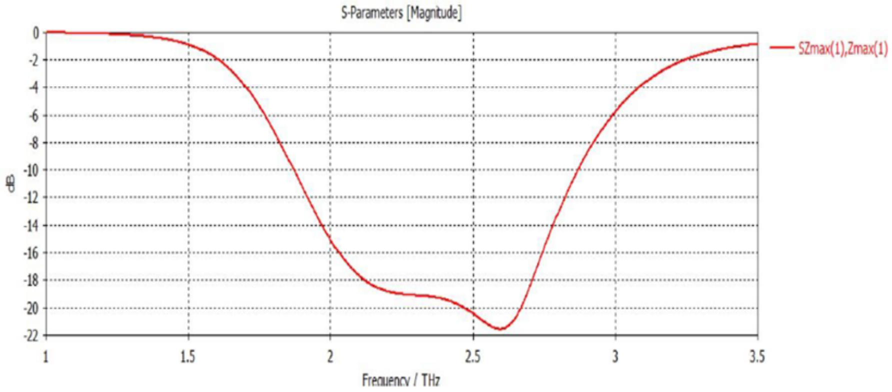

Figure 4.1: S parameter in designed substrate

Following a thorough parametric research, the suggested CPC design has undergone structural optimization. Over silicon-based substrates, graphene THz antennas offer greater directivity, increased bandwidth, and less back lobe emission. In our

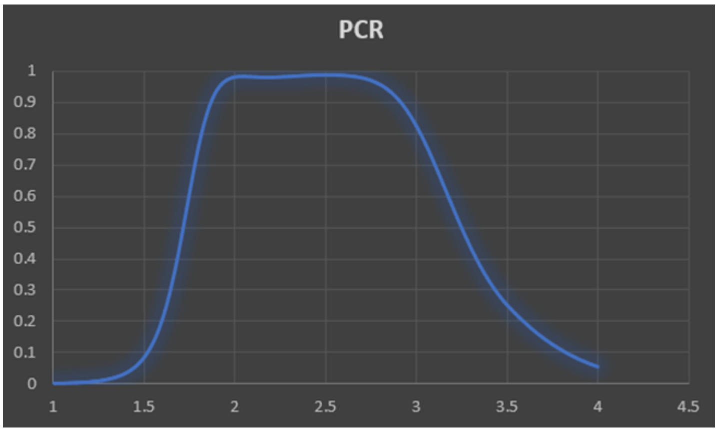

Figure 4.2: PCR in designed substrate

proposed model SiO2 is taken as substrate .The thicknesss of the substrate is taken into 15μm.The S parameter shows -21 dB dip in 2.5 THz.It shows a PCR nearly unity in 1.84 -2.77 THz.

4.4 Results of Designed Circular Slots

Circular slots are commonly employed in the unit cell of antennas to boost their effectiveness. These slots are essentially gaps or apertures on a metallic surface that permit the passage of electromagnetic waves. Skillful placement and design of these slots can enhance the radiation properties of unit cell, such as its bandwidth, gain, and polarization. The optimal size, shape, and placement of the slot will depend on the intended use and the desired performance. The slot can improve the unit cell's impedance matching and bandwidth, as well as its radiation efficiency.

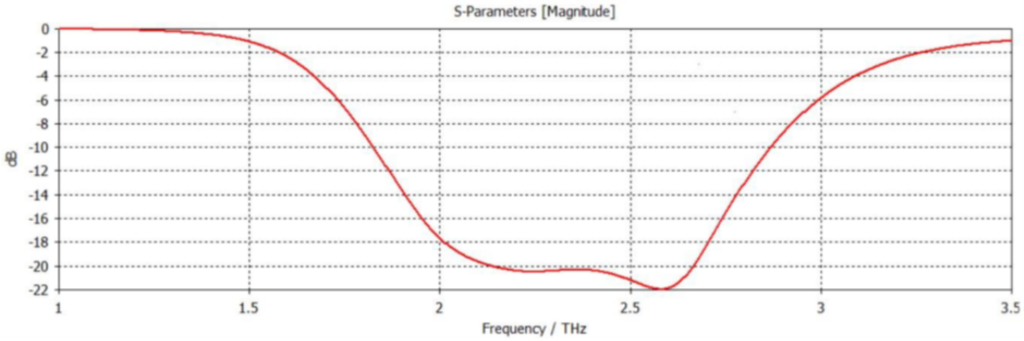

Figure 4.3: S parameter in designed circlular slots

Wideband PCR performance is achieved by optimising the circular slot's radius (R1) on the graphene layer of the meta-atom. This strengthens the wave-matter

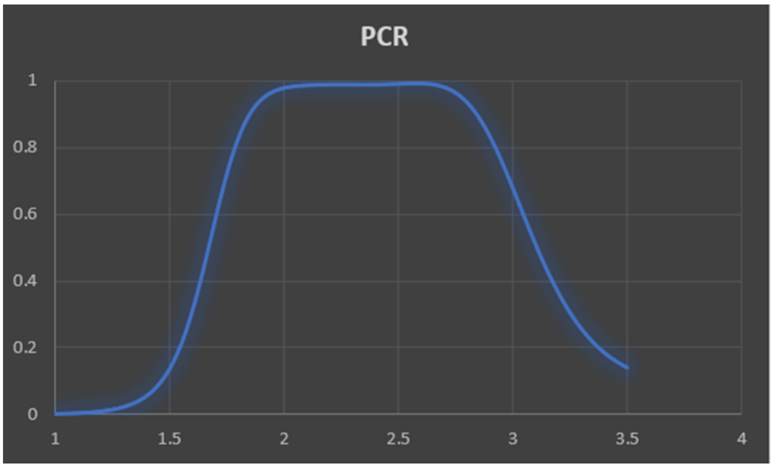

Figure 4.4: PCR in designed circular slots

interactions between the graphene and SiO2.The circular patch has taken radius of 3.93μm.The S parameter shows -22 dB dip in 2.62 THz.It shows a PCR nearly unity in 2 to 2.65 THz.

4.5 Results Of Designed Slots

The antenna's radiation pattern can be regulated by manipulating the rectangular slot's size, shape, and location concerning other elements of the antenna structure. Additionally, the resonant frequency and radiation traits of the antenna can be controlled by adjusting the rectangular slot's size and location.

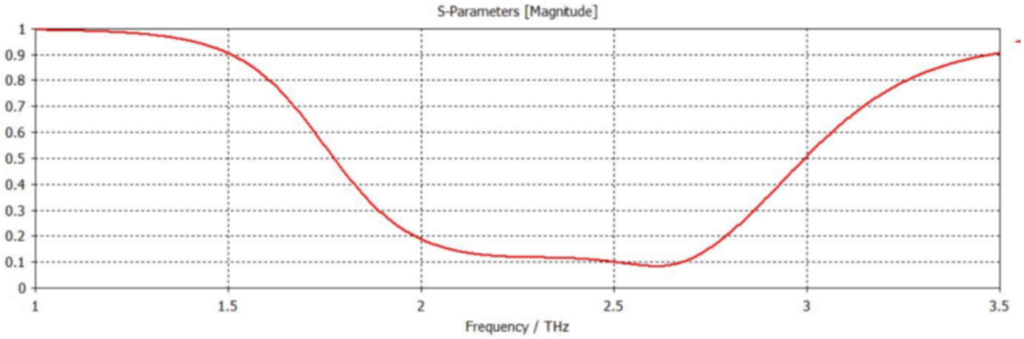

Figure 4.5: S parameter in designed slots

To reduce the impact of capacitive effects on the performance of the PCR, the width of the rectangular slots (p and S) between the identical graphene patches within a meta-atom has been altered.The size of the slots are given 0.17μm and 2.28μm.The S parameter shows -21 dB dip in 2.68 THz.It shows a PCR nearly unity in 2 to

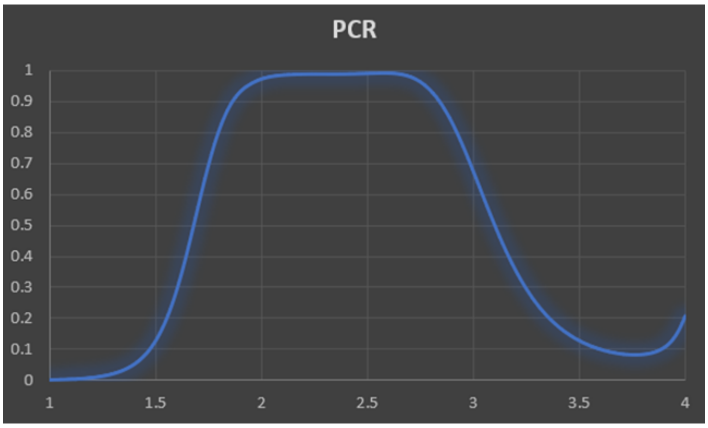

Figure 4.6: PCR in designed slots

2.71THz.

4.6 Simulation Results Of Proposed Unit Cell

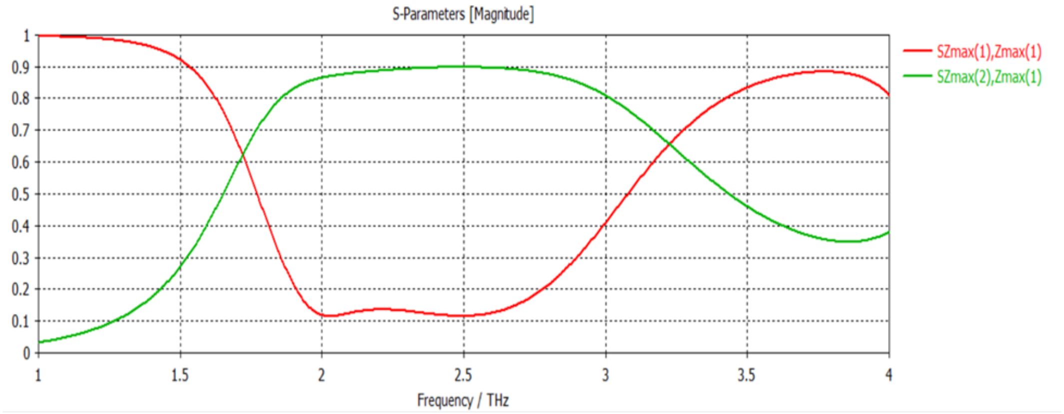

Figure 4.7: S parameter of proposed unit cell

The S parameter shows dip in the 2THz to 2.6 THz . It exhibits stability for both the TE and TM polarizations of the EM wave with near-unity PCR (up to 40°). To obtain a broad PCR performance throughout the bottom half of the THz gap, the chemical potential (μ) and the relaxation duration (τ) have been held constant at 0.75 eV and 1.2 ps, respectively. The values of and have been selected in a way that accounts for both ohmic and plasmonic losses.

The converter has a cross polarization conversion ratio (PCR) that is almost unity and has a 90% PCR bandwidth of 1.06THz within the intended band (1.86 THz–2.92 THz).

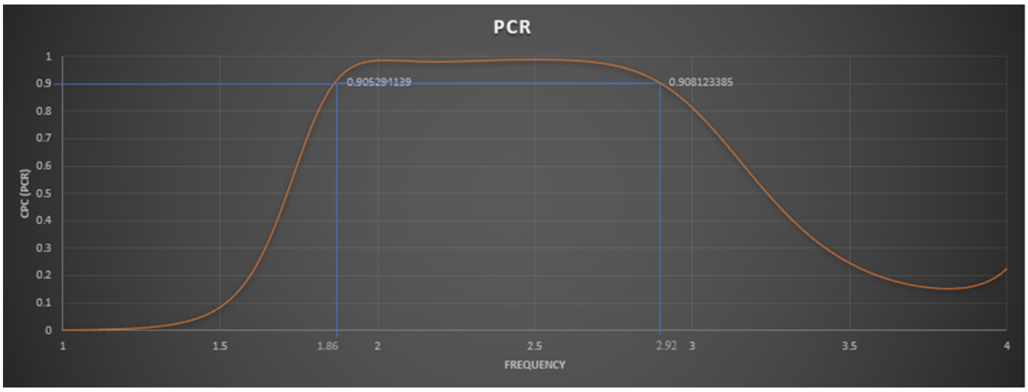

Figure 4.8: PCR of proposed unit cell

Two axes, u and v, are specified at a 45° offset from the xy axes in order to fully comprehend the working of polarisation conversion . The incidence electric field (El) of the wave flowing in the +z direction may be expressed as the orthogonal sum of the field components along the u- and v-components, respectively, due to the unitcell asymmetry along the x/y axes.

$$\vec{E_l} = (E_i^u u + E_i^v v)e^{jkz} \tag{4.1}$$

The Transfer Matrix Method (TMM) may be used to determine the reflected electric field component.

$$\begin{bmatrix} E_r^u \\ E_r^v \end{bmatrix} = \begin{bmatrix} r_{uu} & r_{uv} \\ r_{vu} & r_{vv} \end{bmatrix} \begin{bmatrix} E_i^u \\ E_i^v \end{bmatrix} \tag{4.2}$$

The cross-pol components ruv and rvu are essentially insignificant due to the structural symmetry along u- and v-axes, and the reflected electric field component would be best described as

$$\vec{E_r} = (r_{uu} E_i^u u + r_{vv} E_i^v v)e^{jkz} \tag{4.3}$$

The complex co-pol reflection coefficients of u- and v-incidences are represented here by r$_{uu}andr_{vv}$.

4.7 Surface Current Distribution

The way in which electric current flows over the surface of an antenna's conductive material within one unit cell of the antenna structure is known as the surface current distribution. Various analytical and numerical techniques, including the method of moments (MoM), finite element method (FEM), and finite difference time domain (FDTD) method, can be used to determine the surface current distribution within a unit cell of an antenna. These methods involve solving the Maxwell's equations for the electric and magnetic fields within the antenna structure, considering the appropriate boundary conditions to obtain the current distribution.To understand the physics underlying polarization conversion, surface current patterns are examined. Due to symmetric and asymmetric coupling of the electric and magnetic fields, surface current is generated in the metallic section of the unit cell. It then triggers plasmonic resonance, which causes the polarization to change.

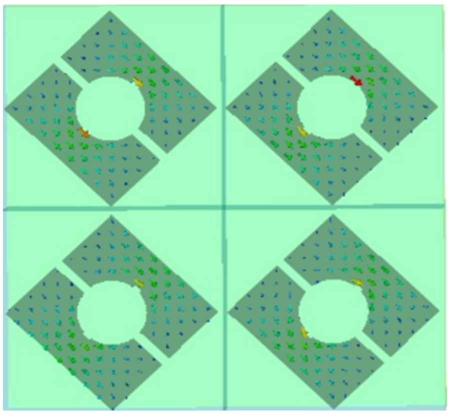

Figure 4.9: A perspective view of the 2.34 THz surface currents with top graphene metasurface

To comprehend the physics underlying polarization conversion, it is crucial to examine surface current patterns. In the metallic section of the unit cell, symmetric and asymmetric coupling of the electric and magnetic fields generates surface current, which triggers plasmonic resonance and causes the polarization to change.

The circular current loop is utilized in the unit cell of the antenna to create magnetic excitation at a specific frequency. By incorporating the circular current loop with antiparallel surface currents on the top and bottom sides, the antenna can exhibit a higher level of efficiency and gain. This is achieved by inducing an inductive effect through the circular orientation of current vectors along circular slots

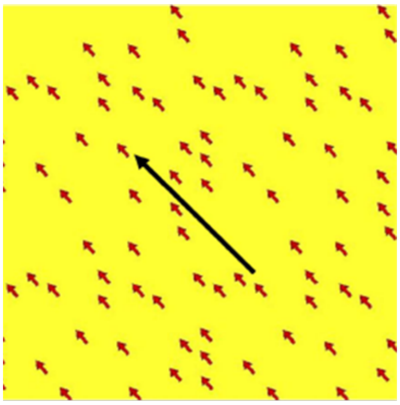

Figure 4.10: A perspective view of the 2.34 THz surface currents with bottom gold plate

and a capacitive effect via parallel current vectors running through rectangular slots simultaneously. The circular current loop, therefore, plays a crucial role in enhancing the performance of the antenna. A circular current loop showing magnetic excitation at 2.34 THz has formed as a result of the antiparallel surface currents on the top and bottom sides. The inductive effect of the graphene metasurface is produced by the circular orientation of the current vectors along the circular slots. The capacitive effect of the graphene metasurface is produced by the parallel current vectors running through the rectangular slots simultaneously.The electromagnetic resonance is created by these inductive and capacitive effects working together.

Chapter 5

Conclusion and Future Scope

Numerous polarization converters operate in the GHz range. Future advancements must put more of an emphasis on the THz frequencies because the GHz bands are already congested.So moved on to THz frequencies. The results from the aforementioned discussions support the suggested graphene-based metasurface conversion in the THz range. A PCR above 90 percentage transforms the x-polarized wave into its cross component. The proposed structures display reasonable angular stability during polarization conversion.It also exhibits compact size.Thus being highly promising in several EM applications.

Biosensor using graphene based metasurface polarization converter can be achieved using the new design.Biosensors are instruments that are capable of detecting and examining biological molecules or chemicals. In the context of biosensors, graphene-based metasurface polarization converters can be employed to identify and analyze the polarization characteristics of light that is either emitted or absorbed by biological molecules. This could offer valuable insights into the structural and functional properties of these molecules.

References

[1] F. Heismann and R. Aferness, "Wavelength-tunable electrooptic polarization conversion in birefringent waveguides," F. Heismann and R. Aferness, IEEE J. Quantum Electron., vol. 24, no. 1, pp. 83-93, Jan. 1988 .

[2] T.Ako “Broadband and wide-angle reflective linear polarization converter for terahertz waves,” APL Photon., vol. 4, no. 9, 2019 Art. no. 096104.

[3] Sambit Kumar Ghosh, Santanu Das, Somak Bhattacharyya “A Graphene Based Metasurface for Transmittive-type Linear to Circular Polarization Converter with Tunable Characteristics”IEEE 2021 XXXIVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS).

[4] Vinit Singh Yadav,Sambit Kumar Ghosh,Somak Bhattacharya,Santanu Das, “Graphene Based Metasurface with Tunable Dual Band Mid-Infrared Cross Polarization Converter” Journal of IET Microw.Antennas Propag.,2019, Vol. 13 Iss. 1.

[5] Behnaz Bakhtiari,“TunableTerahertz PolarizationConverter Based onGraphene-Shaped Metasurfaces” 2020 14th European Conference on Antennas and Propagation (EuCAP).

[6] Shailza Gotra , V.S. Pandey , R.S. Yaduvanshi “A wideband graphene coated dielectric resonator antenna with circular polarization generation technique for THz applications” Superlattices and Microstructures Volume 150, February 2021, 106754

[7] Xingyang Yu, Xi Gao, Wei Qiao, Lili Wen, and Wanli Yang “Broadband Tunable Polarization Converter Realized by Graphene-Based Metamaterial” IEEE Photonics Technology Letters.

[8] Ming Chen, Linzi Chang, Xi Gao, Hui Chen, Chongyun Wang, Xiaofei Xiao, and Deping Zhao “Wideband Tunable Cross Polarization Converter Based on a Graphene Metasurface with a Hollow-Carved “H” Array” IEEE Photonics Journal (Volume: 9, Issue: 5, October 2017)

[9] Li Zeng , Tong Huang , Guo-Biao Liu, Hai-Feng Zhang “A tunable ultra-broadband linear-to-circular polarization converter containing the graphene” Optics Communications Volume 436, 1 April 2019, Pages 7-13.

[10] Li Zeng , Tong Huang , Guo-Biao Liu, Hai-Feng Zhang “Tunable Linear-to-Circular Polarization Converter Using the Graphene Transmissive Metasurface” IEEE Access (Volume: 7)

[11] X. Huang, D. Z. H.Yang, and Y. Luo, “Ultrathin dual-band metasurface polarization converter,” IEEE Trans. Antennas Propag., vol. 67, no. 7,pp. 4636–4641, Jul. 2019.

[12] M. Ismail Khan and Farooq A. Tahir, “An angularly stable dual-broadband anisotropic cross polarization conversion metasurface”, J Optic (2017).

[13] Sakib Quader, Jin Zhang, Muhammad Rizwan Akram, and Weiren Zhu,et.al.”Graphene-Based High Efficiency Broadband Tunable Linear to Circular Polarization Converter for Terahertz Waves”.IEEE Journal Of Selected Topics In Quantam Electronics, VOL. 26, NO. 5,2020

[14] Xue Yang,Bo Zhang,Jingling Shen.”An tunable terahertz polarization converter based on composite metamaterial”.Optical and Quantum Electronics, Springer,2019

[15] Song K, Liu Y, Luo C, Zhao X. High-efficiency broadband and multiband crosspolarization conversion using chiral metamaterial. J Phys D Appl Phys 2014;47:505104.