A Transmittive Type Broadband Cross Polarization Converter for Mid Wavelength Infrared Region

Rudranil Nandi [(1)], Nilotpal [(2)] and Somak Bhattacharyya [(2)]
(1) Department of Electronics and Communication Engineering, Academy of Technology, Hooghly, W.B -712121, India
(2) Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi, U.P.-221005, India

Abstract

A broadband transmittive type cross polarization converter (CPC) for the mid infrared frequency band is reported in this paper. The proposed CPC structure converts an incident linearly polarized wave to cross polarized wave over a wide frequency band extending from 24 THz to 49 THz; thus behaving as a wide band converter of bandwidth 25 THz. The structure exhibits a high polarization conversion ratio (PCR) of more than 80% for the complete operating frequency band. A PCR of more than 90% is obtained between two frequency bands extending from 39.35 THz to 47.9 THz and 24.83 THz to 26.75 THz .The structure is further studied for oblique incidence response where it maintains broadband cross polarization conversion up to 40º for both TE and TM polarizations. The structure acts as a transmittive CPC up to 30º polarization angle. The structure is compact in thickness (~λ/5) as well as periodicity (~λ/5) with respect to lower frequency of polarization conversion bandwidth.

1. Introduction

A profound control of electromagnetic waves can be possible by introducing the concept of metasurface which consists of sub wavelength size metallic elements [1]. These densely spaced metallic elements allow us to engineer the flow of electromagnetic waves with much better spatial resolution [2]. Properly controlling the transmitted and reflected waves can diversify their applications as absorbers, filters, polarizers etc. [3-5].
Polarizers are used to alter the polarization state of an electromagnetic waves incident on it. Metasurface based polarizers are of potential interest due to their compact size and high efficiency as compared to bulky conventional polarizers.
Till date several polarizer structures have been reported which are either transmittive or reflective in nature [6-9]. However many of these structures are either bulky in size [10], single band in operation or polarization sensitive [11] in nature.

In this paper we have proposed a cross polarization converter (CPC) structure for the mid-infrared frequency range. The proposed structure is a three plated structure where each plates are mutually separated with respect to one another. Each one of the plate constitute of SiO_2 as dielectric and gold as metallic patches. The plate at the top and bottom consist of horizontal and vertical metallic strips respectively. The plate in the middle layer consists of tilted tooth pick structure on one side and tilted elliptical structure on the other side. The modification is done to make the structure chiral so that it can develop necessary anisotropic condition for polarization. The structure exhibits broadband polarization conversion from 24 THz to 49 THz maintaining a polarization conversion ratio (PCR) value of more than 80% for the entire band. In the frequency range of 39.35 THz to 47.9 THz and 24.83 THz to 26.75 THz the structure exhibits PCR value of more than 90%.
The design is further analyzed under exposure to infrared radiations at different incident angles to study the polarization characteristics. The structure behaves as wideband cross polarization converter for both TE and TM polarizations so long as the angle of incidence is within 40º. The structure acts as a transmittive CPC up to 30º polarization angle.

2. Design of the Structure

The 3D perspective view of the unit cell of the CPC structure along with the electric field, magnetic field and wave vector directions are shown in Figure 1 (a). The unit cell as shown in Figure 1 (a) is a three plated structure. The top and bottom plates consist of gold metallic strips arranged in horizontal and vertical directions as shown in Figure 1 (b) and Figure 1(c) respectively. The middle plate consists of a tilted toothpick structure on the front side and tilted elliptical on the back side as shown in Figure 1 (d) and Figure 1(e) respectively. The permittivity of the gold has been modelled using the Drude expression shown in equation (1).

$$\varepsilon(\omega) = 1 - \frac{w_p^2}{w(w + i\gamma)} \qquad (1)$$

The value of plasma frequency w_p and damping frequency γ has been taken from well-known experimental results [10].

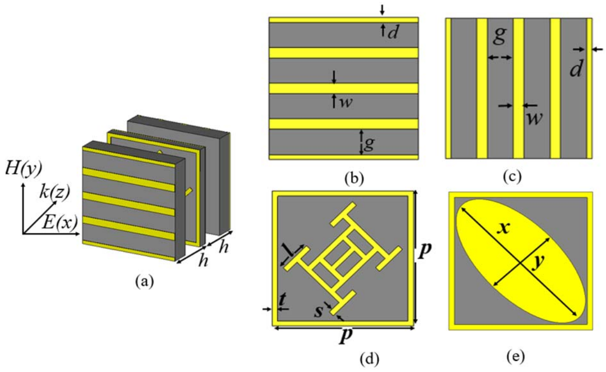


Figure 1. (a) 3-D perspective view of three layer CPC structure along with incident electromagnetic wave directions; (b) front plate with horizontal strips; (c) bottom plate with vertical strips; (d) tilted toothpick structure as front surface of middle plate and (e) tilted elliptical structure as back surface of middle plate.

All the metallic structures consist of 0.035 µm thick gold layer. Each of the plate constitutes of SiO_2 as dielectric having thickness 0.50 µm and dielectric constant of 4.0. The geometrical dimensions of the unit cell as shown in Figure 1 are optimized as p = 2.6 µm, s = 0.1 µm, t = 0.25, l = 0.60 µm, x = 1.5 µm, y = 0.7 µm, h = 0.709 µm, w = 0.189 µm, g = 0.460 µm, d = 0.094 µm.

The evolution of the final geometrical shape of the front surface of middle plate along with its effect on the polarization bandwidth is discussed in Table 1. For the structures as shown in Case 1, 2 and 3, the PCR obtained in the desired frequency range is less than 80%. For case 4 we can observe a band of 10 THz where the PCR is more than 80%. Maximum polarization bandwidth of 25 THz has been achieved between 24 THz to 49 THz for case 5 which is the final optimized design.

3. Simulated Results

The proposed structure whose unit cell is shown in Figure 1 (a) is simulated using CST Microwave Studio under periodic boundary conditions. The transmission coefficients of X and Y polarized waves are shown in Figure 2.

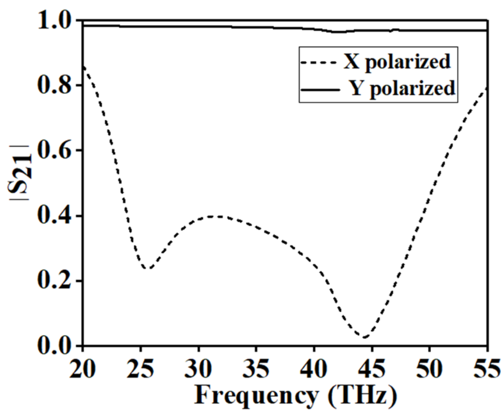
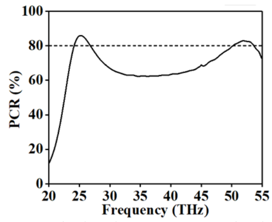
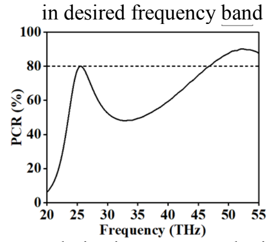
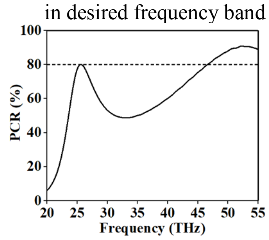
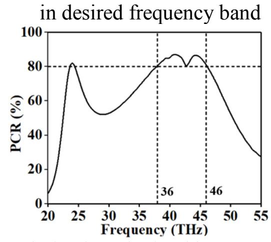
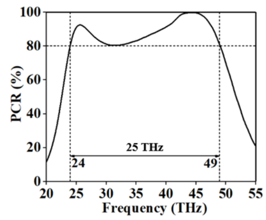


Figure 2. X and Y polarized transmission coefficients of proposed structure whose unit cell is shown in Figure 1.

It is well depicted from Figure 2 that the structure is allowing only the Y polarized waves to pass This is because the strips on the top plate are arranged in the x direction which reflects all the X polarized waves leaving Y polarized waves to pass.

Table 1: Evolution of Geometry of the front surface of the middle plate

Evolution of Geometry	**PCR Response**
 Case 1	 No polarization property obtained in desired frequency band
 Case 2	 No polarization property obtained in desired frequency band
 Case 3	 No polarization property obtained in desired frequency band
 Case 4	 polarization obtained between 36 THz and 46 THz
 Case 5	 Maximum Polarization bandwidth obtained between 24 THz and 49 THz

The transmitted Y polarized waves through the top plate reaches the middle plate. The wave is further converted into X and Y polarized waves as it passes from the middle plate. When the waves reaches the bottom plate the y oriented vertical strips will restrict the Y polarized waves leaving only X polarized waves to pass. This is nothing but the cross polarization conversion of incident linearly polarized waves. The above physics is well depicted from Figure 3 where it can be seen clearly that the cross-polarized conversion has been achieved.

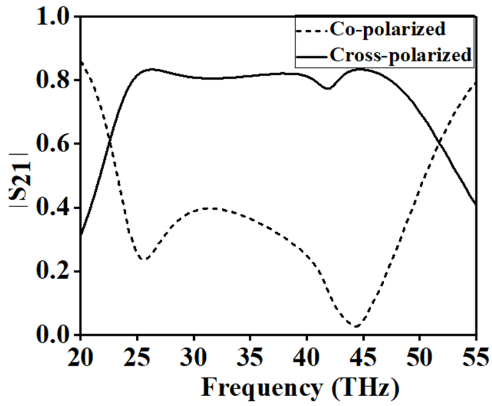


Figure 3. Co-polarized and cross-polarized transmission coefficient responses of proposed CPC structure whose unit cell is shown in Figure 1.

The PCR of the structure has been calculated from equation 2 where r_{xy} and r_{xx} are cross-polarized and co-polarized reflection coefficients respectively with incident Y polarized wave.

$$PCR = \frac{r_{xy}^2}{r_{xy}^2 + r_{xx}^2} \qquad (2)$$

The curve of PCR response of the structure is shown in Figure 4. It is observed from Figure 4 that the structure maintains a high PCR value of more than 80% in the complete desired frequency between 24 THz to 49 THz giving a PCR bandwidth of 25 THz. Furthermore, PCR of more than 90% has been achieved in the frequency range between 39.35 THz to 47.9 THz and 24.83 THz to 26.75 THz as evident from Figure 4.

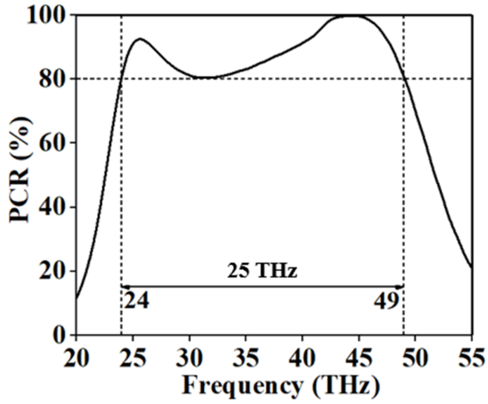
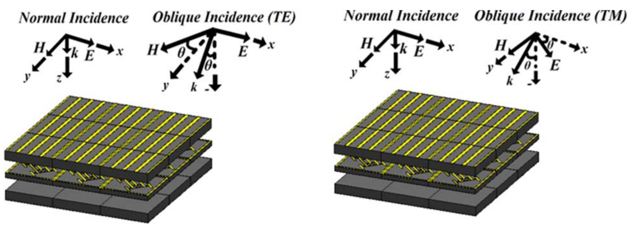


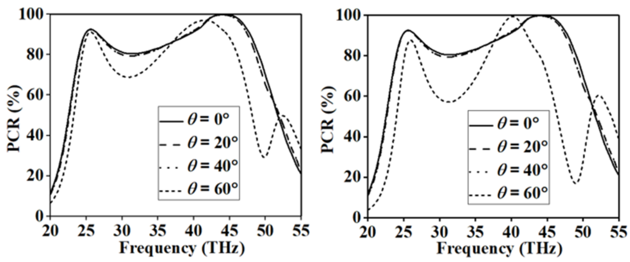
Figure 4. PCR response of proposed CPC structure whose unit cell is shown in Figure 1.

4. Oblique Incidence Response



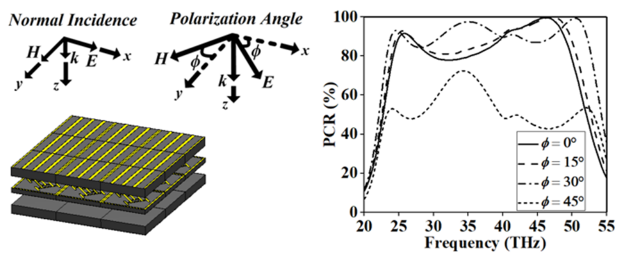
(a) (b)

Figure 5. Set-up of the oblique incidence responses under (a) TE polarization and (b) TM polarization.



(a) (b)

Figure 6. Simulated PCR responses for oblique incidence response under (a) TE polarization and (b) TM polarization.



(a) (b)

Figure 7. (a) Set up and (b) simulated PCR response for different polarization angles under normal incidence of the proposed structure.

The proposed structure whose unit cell shown in Figure 1 is studied for different angles of incidence under TE and TM polarizations. Under TE polarization the electric field remains constant but the magnetic field varies thus making the wave incident on the structure angularly as shown in Figure 5 (a). Similarly for TM polarization, magnetic field remains a constant but the electric field varies so that the wave incident on the structure angularly as shown in Figure 5(b) [11]. The PCR variations under TE and TM polarization with respect to the frequency are shown in Figure 6 (a) and Figure 6 (b) respectively; where it is found that up to 40° incident angle, it is behaving as wide band cross polarization converter.
The structure is further studied under polarization angle variation for normal incidence as shown in Figure 7 (a). It can be depicted from Figure 7 (b) that the structure is found to be insensitive to polarization of incident wave so long as the angle of polarization is within 30º.
A comparison table showing the comparison between the proposed structure and existing state of the art co-

polarization converter is shown in Table 2. It is well observed that the design proposed in this manuscript exhibits a total cross polarization conversion bandwidth of 25 THz while maintaining compactness in periodicity as provided in Table 2.

Table 2. Compariosn of the performance of the proposed structure with existing cross polarization converter for Terahertz Region.

Terahertz polarizer	**PCR Bandwidth (in THz)**	**PCR**	**Period**
Cheng *et. al.* [6]	0.65-1.45 THz	>80%	~λ/2.5
Cong *et. al.* [7]	37.5-60 THz	>80%	~λ/1.3
Grady *et. al.* [8]	0.52-1.82 THz	>80%	~λ/7.4
Proposed Design	24.00-49.00 THz	>80%	~λ/5

5. Conclusions

A broadband transmittive type CPC structure for mid infrared frequency application is explored in this paper. The structure maintains a high PCR of more than 80% in between 24 THz to 49 THz; thus providing a wide bandwidth of 25 THz. Further the structure is studied for oblique incidence response where it is behaving as CPC converter as long as the angle of incident is under 40°. The structure is compact in thickness (~λ/5) as well as periodicity (~λ/5) with respect to lower frequency of polarization conversion bandwidth.

7. References

1. H. T. Chen, A.J. Taylor, and N. Yu, “A review of metasurfaces: Physics and applications,” *Reports on Progress in Physics*, **79**, June 2016, pp. 076401, doi: 10.1088/0034-4885/79/7/076401.

2. S. B. Glybovski, S. A. Tretyakov, P. A. Belov, Y. S. Kivsharm and C. R. Simovski, “Meta surfaces: From microwaves to visible,” *Physics Report*, **634**, 11, April 2016, pp. 1-72, doi:/10.1016/j.physrep .2016.04.004.

3. S. Bhattacharyya, S. Ghosh, and K.V. Srivastava, “Triple band polarization independent metamaterial absorber with bandwidth enhancement at X-band,” *Journal of Applied Physics*, **114**, 2013, pp. 094514, doi: /10.1063/1.4820569.

4. A. Soni, S. Purohit and R. S. Hegde, “Multilayered Aluminum plasmonic Metasurfaces for ultraviolet Bandpass Filtering,” *IEEE Photonics Technology Letters*, **29**, November 2016, pp. 110-113, doi: 10.1109/LPT.2016. 2629504.

5. S. Bhattacharyya, S. Ghosh and K. V. Shrivastava, “A wideband cross polarization conversion using metasurface,” *Radio Science*, **52**, November 2017, pp. 1395-1404, doi: /10.1002/2017RS006396.

6. Y. Zhi Cheng, W. Withayachumnankul, A. Upadhyay, D. Headland, Y. Nie, R. Zhou Gong, M. Bhaskaran, S. Sriram, and D. Abbott, “Ultra broadband reflective polarization convertor for terahertz waves,” *Applied Physics Letters*, **105**, 2014, pp. 181111, doi: /10.1063/1.4901272.

7. L. Cong, W. Cao, X. Zhang, Z. Tian, J. Gu, R. Singh, J. Han, and W. Zhang, “A perfect Metamaterial polarization rotator, ” *Appl. Physics Letters*, **103**, 2013, pp. 171107, doi: /10.1063/1.4826536.

8. N. K. Grady, J. E. Heyes, D.R Chowdhury, Y. Zeng, M. T. Reiten, A. K. Azad, A. J. Taylor and Diego, A. R. Dalvit, Terahertz Metamaterial for Linear Polarization Conversion and Anomalous Refraction, *science report*, **340**, 14, June 2013, pp.1304-1306, doi: 10.1126/science.1235399.

9. L. Nama, S. Bhattacharya, P. K. Jain, “Ultra-thin Wideband Reflective Polarization Converter using Elliptical Split Ring Structure,” *Antenna Test & Measurement Society*, 6, Feb 2018, pp.1-4.

10. M. A. Ordal, L. L. Long, R. J. Bell, S. E. Bell, R. R. Bell, R. W. Alexander, Jr, and C. A. Ward, “Optical properties of the metals Al, Co, Cu, Au, Fe, Pb, Ni, Pd, Pt, Ag, Ti, and W in the infrared and far-infrared,” *Appl. Opt*, **22**, 1983, pp. 1099-1119, doi: 10.1364/AO.22.001099.

11. S. Bhattacharyya, and K. V. Srivastava, “Triple Band Polarization-Independent Ultra-thin Metamaterial Absorber using ELC Resonator,” *Journal of Applied Physics*, **115**, 2014, pp. 064508, doi: 10.1063/1.4865273.