# 0.32 THz dual circularly polarized reflectarray

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**Abstract:** A terahertz (THz) reflect-array is proposed. Dual circularly polarized (left- and right-hand-circular-polarizations) collimated beams are independently manipulated. In our model, the left-hand-circularly-polarized and right-hand-circularly-polarized beams reflect at 23-degrees along the y-direction and x-direction respectively. © 2020 The Author(s)

## 1. Introduction

Terahertz (THz) reflectarrays, which redistribute energy from the impinging free-space propagating waves to achieve the targeted near-field or far-field patterns, including beam collimation, beam focusing and Bessel beams, have had considerable recent attention [1-3]. Tailoring the THz wavefront consists of shaping the THz beam and manipulating its polarization states. Beam-shaping can be easily achieved by designing a spatial phase response across a reflect-array [4] and the Pancharatnam-Berry phase can be used to manipulating two orthogonal polarizations, namely, left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP). Nevertheless, the Pancharatnam-Berry phase can only control the LHCP and RHCP symmetrically. To independently manipulate the LHCP ($|L\rangle$=[1 $i$]) and RHCP ($|R\rangle$=[1 -$i$]), the surface of the reflect-array should provide two uncorrelated phase profile, namely, $\varphi_L(x,y)$ ($\varphi_L$ for short) for LHCP and $\varphi_R(x,y)$ ($\varphi_R$ for short) for RHCP. For the LHCP and RHCP input, we can design a birefringent surface with target output polarization state of $|R\rangle^*$ and $(|L\rangle^*$, where * denotes the complex conjugate of the input polarization state. Therefore, the original system can be expressed as:

$$J(x,y)\begin{bmatrix}1\\ i\end{bmatrix} = e^{i\varphi_L}\begin{bmatrix}1\\ -i\end{bmatrix} \qquad \text{for LHCP} \qquad (1)$$

and

$$J(x,y)\begin{bmatrix}1\\ -i\end{bmatrix} = e^{i\varphi_R}\begin{bmatrix}1\\ i\end{bmatrix} \qquad \text{for RHCP} \qquad (2)$$

Combining (1) and (2), the Jones Matrix $J(x,y)$ can be expressed as:

$$J(x,y) = \frac{1}{2}\left[\begin{matrix} e^{i\varphi_L}+e^{i\varphi_R} & ie^{i\varphi_R}-ie^{i\varphi_L} \\ ie^{i\varphi_R}-ie^{i\varphi_L} & -e^{i\varphi_L}-e^{i\varphi_R} \end{matrix}\right] \qquad (3)$$

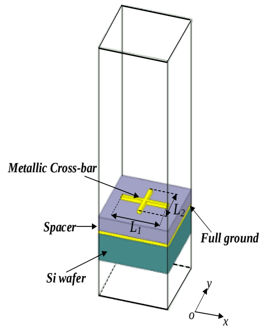
Then, the Jones matrix $J(x,y)$ can be decomposed into canonical form [5]:

$$J(x,y) = P\Lambda P^{-1} = \begin{bmatrix} \cos\frac{1}{4}[\varphi_L-\varphi_R] & \sin\frac{1}{4}[\varphi_L-\varphi_R] \\ \sin\frac{1}{4}[\varphi_L-\varphi_R] & -\cos\frac{1}{4}[\varphi_L-\varphi_R] \end{bmatrix} \begin{bmatrix} e^{i[\frac{1}{2}(\varphi_L-\varphi_R)]} & 0 \\ 0 & e^{i[\frac{1}{2}(\varphi_L-\varphi_R]-\pi} \end{bmatrix} \begin{bmatrix} \cos\frac{1}{4}[\varphi_L-\varphi_R] & \sin\frac{1}{4}[\varphi_L-\varphi_R] \\ \sin\frac{1}{4}[\varphi_L-\varphi_R] & -\cos\frac{1}{4}[\varphi_L-\varphi_R] \end{bmatrix}^{-1} \qquad (4)$$

Here, P can be regarded as a rotation matrix for the matrix $\Lambda$, the phase shifts are $\delta x(x,y) = [\varphi_L+\varphi_R]/2$ and $\delta y(x,y) = [\varphi_L+\varphi_R]/2 - \pi$ and the rotation angle is $\theta(x,y) = [\varphi_L-\varphi_R]/4$. Therefore, to achieve the full manipulation of the LHCP and RHCP, the unit cells should provide the a phase circle of $2\pi$ while keeping a $\pi$ phase difference between $\delta x(x,y)$ and $\delta y(x,y)$.

## 2. Design and Result

Based on the theory above, a THz reflect-array operating at 0.32 THz is proposed. The configuration of the phasing element is shown in Fig. 1 (a). Both the upper cross-bar and the full ground are made of gold with a spacer (dielectric constant of 2.33 and loss tangent of 0.0007) with a thickness of 100 um between them. Si located at the bottom is used as a wafer. This design can be realized by making use of a cyclo olefin copolymer (COC) microfabrication technique [6]. The reflection phases of x-pol and y-pol with different lengths of $L_1$ are shown in Figs. 2 (b) and (c), respectively. The reflection phases of x-pol and y-pol can be independently controlled by



| 3-bit unit | 000 | 001 | 010 | 011 | 100 | 101 | 110 | 111 |
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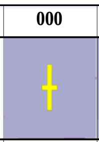
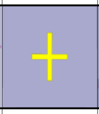
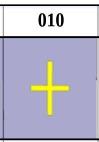
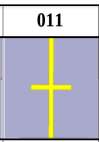
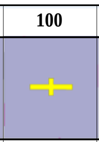
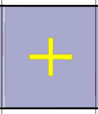
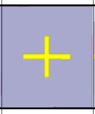
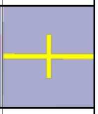
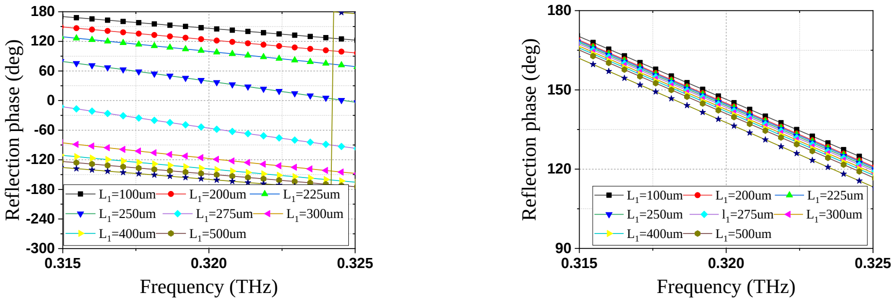
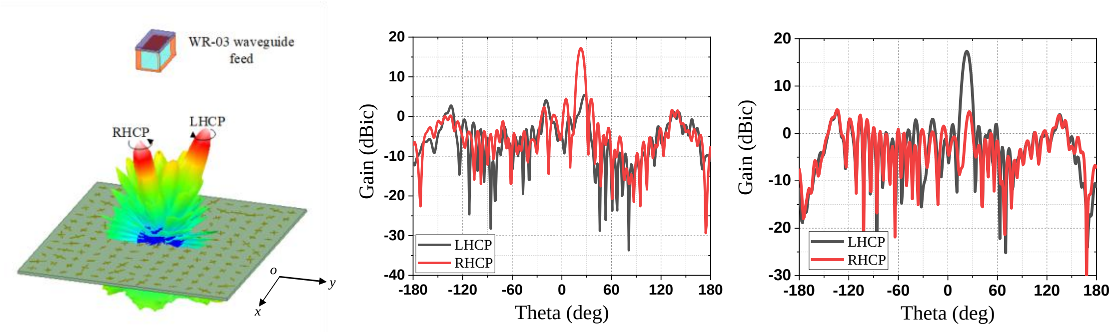
| Geometry |  |  |  |  |  |  |  |  |
| *($L_1$ , $L_2$)* ( μm ) | (100, 270) | (225, 280) | (245, 310) | (260, 600) | (270, 100) | (280, 225) | (310, 245) | (600, 260) |

Fig. 1 (a) Configurations of the phasing element. (b) 3-bit phasing elements.



(a) (b)

Fig. 2 (a) Reflection phase of ox-polarization with different lengths of the $L_1$. (b) Reflection phase of oy-polarization with different lengths of the $L_1$.



(a) (b) (c)

Fig. 3. (a) Simulated 3-D radiation pattern. (b) Simulated 2-D radiation patterns at xoz-plane. (c) Simulated 2-D radiation patterns at yoz-plane. In (b) and (c), LHCP is the black line, RHCP is the red line.

adjusting the length of $L_1$ and $L_2$. Therefore, we can easily select 3-bit units (each unit provides π reflection phase difference between x- and y-polarized incident waves and the total 3-bit units provide the phase circle of 2π), as shown in Fig. 1 (b), to build the reflect-array with WR-03 rectangular waveguide as a feeding source (linearly polarized). The RHCP and LHCP collimated beams are designed to reflect along with different directions, as shown in Fig. 3. Specifically, the RHCP beam is tilted 23-degree along ox-direction and the LHCP beam is tilted 23-degree along oy-direction. The main-beam gain will drop and sidelobe gain will increase if larger deflection angles are adopted. The maximum deflection angles are 53-degree for both LHCP and RHCP beam (above this angle, the sidelobe gain will exceed the main-beam gain).

## 3. References

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