# Fine Manipulation of Terahertz Wave via All-Silicon Metasurfaces with Independent Amplitude and Phase

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**Part1. Details about the design principles of the proposed metasurfaces.**

For the first design, the phase difference $\Delta\varphi$ is set to $\Delta\varphi$=90°, the co- and cross-polarized components have the same energy partition. By adjusting the values of the summation of propagation phase $\sum\varphi/2$ and the rotation angle $\alpha$, specific phase distributions can be set in the co- and cross- polarized components.

In the design process, the phase distribution of $\varphi_{LL}$ and $\varphi_{LR}$ as

$$\begin{aligned} \varphi_{LL} &= \frac{2\pi}{\lambda}\left(\sqrt{f^2+r^2}-f\right)-2\theta \\ \varphi_{LR} &= \frac{2\pi}{\lambda}\left(\sqrt{f^2+r^2}-f\right)-\theta \end{aligned}$$ * MERGEFORMAT (S1)

Here, the phase distribution of $\varphi_{LL}$ is controlled by changing the lengths of two rectangles $L_1$ and $L_2$, while the phase of $\varphi_{LR}$ is controlled by rotating the meta-atoms. The rotation angle $\alpha$ is described as

$$\alpha=\left(\theta+\pi/2\right)/2$$ * MERGEFORMAT (S2)

When the handedness of incident wave is changed to RCP, the phase distribution of the co-polarized component would change to

$$\varphi_{RR} = \frac{2\pi}{\lambda}\left(\sqrt{f^2 + r^2} - f\right) - 2\theta \quad \text{* MERGEFORMAT (S3)}$$

As for the cross-polarized component, the phase distribution would change to

$$\varphi_{RL} = \frac{2\pi}{\lambda}\left(\sqrt{f^2 + r^2} - f\right) - 3\theta \quad \text{* MERGEFORMAT (S4)}$$

For the second design, the intensity ratio of the co- and cross- polarizations can be tuned by adjusting the phase difference Δφ. Before the start of these designs, the transmission amplitudes and phase shifts of the meta-atoms have been simulated by parameter sweeping using CST Microwave Studio. Here, five metasurfaces are designed by adopting five groups of meta-atoms with different phase difference Δφ (Δφ = 0°, 45°, 90°, 135°, and 180°). The specific parameters of these five groups of meta-atoms are listed in the following table, and this table has been added in the Supplementary Information.

Table 1 The specific parameters of the adopted meta-atoms

| | 0 | | π/4 | | π/2 | | 3π/4 | | π | | 5π/4 | | 3π/2 | | 7π/4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $L_1$ | $L_2$ | $L_1$ | $L_2$ | $L_1$ | $L_2$ | $L_1$ | $L_2$ | $L_1$ | $L_2$ | $L_1$ | $L_2$ | $L_1$ | $L_2$ | $L_1$ | $L_2$ |
| Δφ=0° | 85 | 85 | 69 | 69 | 59 | 59 | 53 | 53 | 49 | 49 | 45 | 45 | 41 | 41 | 34 | 34 |
| Δφ=45° | 96 | 81 | 83 | 66 | 69 | 56 | 59 | 52 | 53 | 48 | 50 | 44 | 46 | 39 | 43 | 30 |
| Δφ=90° | 100 | 83 | 96 | 65 | 88 | 55 | 71 | 51 | 60 | 47 | 55 | 43 | 52 | 38 | 50 | 30 |
| Δφ=135° | 40 | 96 | 35 | 85 | 97 | 60 | 93 | 51 | 79 | 47 | 64 | 44 | 58 | 39 | 56 | 32 |
| Δφ=180° | 46 | 96 | 43 | 83 | 39 | 69 | 31 | 63 | 96 | 46 | 84 | 42 | 68 | 39 | 62 | 32 |

The process of designing the phase distributions of the co- and cross-polarized components is the same as that of the first design. The difference is that the adopted meta-atoms need to be selected from these five groups, which correspond to different intensity ratios of the co- and cross- polarizations.

For the third design, we select six groups of meta-atoms (48 meta-atoms), which correspond to the amplitude values 0, 0.2, 0.4, 0.6, 0.8, and 1, respectively. These meta-atoms can constitute a structure database which can achieve a free combination of transmitted amplitude from 0 to 1 and phase shifts of 0 to 7π/4. For this design, the required complex amplitude distribution of the co-polarized component is described as

$$E = \alpha_1 e^{i\left(\frac{2\pi}{\lambda}\left(\sqrt{f^2+(x+\xi)^2+y^2}-f\right)-\theta\right)} + \alpha_2 e^{i\left(\frac{2\pi}{\lambda}\left(\sqrt{f^2+(x-\xi)^2+y^2}-f\right)-\theta\right)} \quad \text{*}$$

MERGEFORMAT (S5)

Hence, the amplitude distribution can be described as abs|E|, and the required phase is angle(E). We need consider the amplitude and phase distributions in this design simultaneously. For example, E(m, n), it is the meta-atom in the mth row and nth column. Its amplitude is abs|E(m, n)| and its phase is angle(E(m, n)). According to these amplitude and phase values, we can select the meta-atom from the structure database. As for the cross-polarized component, it is arranged as linear gradient phase profile along x-axis, which can be realized by rotating the meta-atoms.

**Part2: The overall layouts of the metasurfaces corresponding to the second design.**

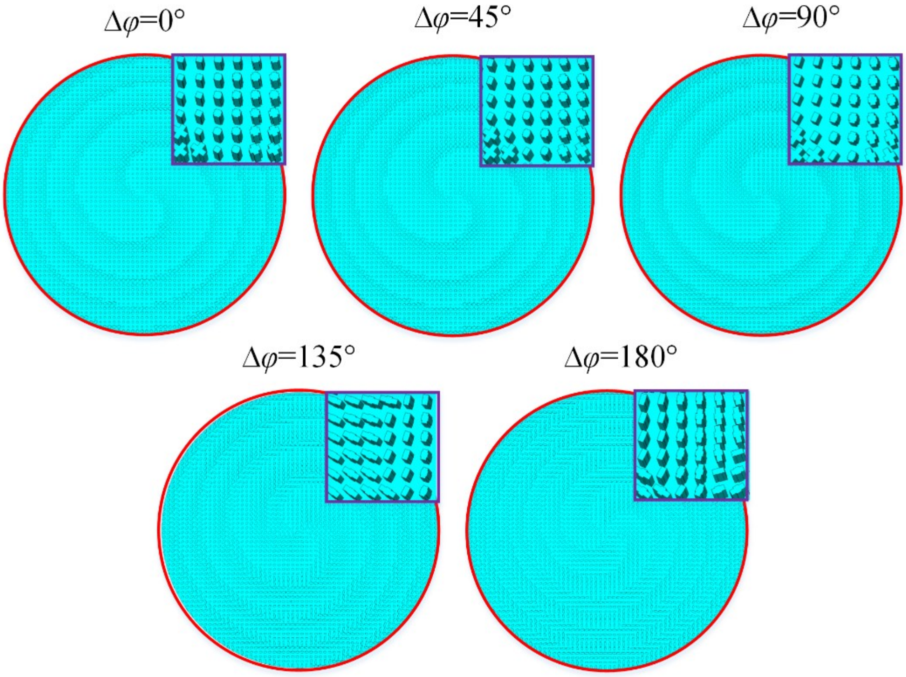


**Fig. S1** The overall layouts of the metasurfaces corresponding to the second design.

**Part3. The overall layout of the metasurface corresponding to the third design.**

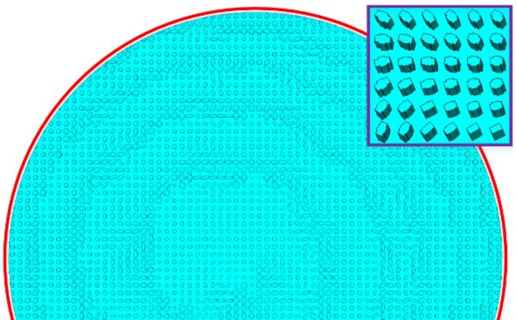

**Fig. S2** The overall layout of the metasurfaces corresponding to the third design.