Broadband programmable metasurface for multifunctional control of THz waves

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Abstract: We report a multifunctional terahertz (THz) programmable metasurface integrated vanadium dioxide (VO_2), which can achieve dynamic beam steering from 0.735 THz to 0.965 THz and efficient polarization conversion from 0.84 THz to 1.3 THz.

1. Introduction

Over the past years, there has been a growing interest in designing metasurface combined with phase transmission materials to dynamically manipulate THz waves. The programmable metasurface has been explored to realize multiple functions, such as dynamic beam scanning [1], polarization manipulation [2], and focusing lenses [3]. However, most of these metasurfaces usually are achieved at a fixed frequency with multifunction [4] or single function at broad bandwidth [2, 5], which cannot meet the increasing demand for broadband communication system.

In this work, we propose a multifunctional programmable metasurface with broad bandwidth. By controlling the phase transformation of VO_2, the dynamic beam steering can be realized in the range of 0.735-0.965 THz. In addition, when VO_2 is in insulating state, the polarization conversion efficiency can exceed 90% in the range of 0.84-1.3 THz.

2. Simulation Results

Fig. 1(a) shows the designed metasurface which contains three layers: the symmetrical split-ring resonators (SSRRs), polyimide substrate and gold reflective layer. The yellow area indicates gold material and two symmetrical sheets of VO_2 (pink) are embedded in the pattern layer. The period P is 140 μm, the outer radius r and the width w of SSRR are 50 μm and 30 μm. The parameters α, β of the structure are opening angle, orientation angle of the ring.

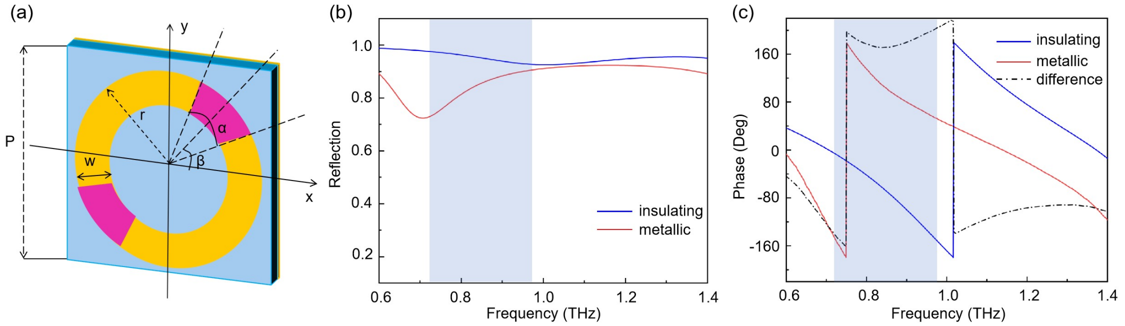

Fig. 1. (a) Schematic diagram of multifunctional programmable metasurface composed of VO_2/Au symmetrical split-ring resonators (SSRRs). Simulated reflection amplitude (b) and phase (c) of the unit cell when VO_2 before and after the phase transformation.

We generate phase gradient between the unit cells by applying electric current cause the VO_2 phase transformation to realize flexible beam steering. When the VO_2 before and after the phase transformation, the conductivity is 200 S/m (insulating state) and 200,000 S/m (metallic state), respectively [6]. When α=20° and β=0°, the reflection amplitude of the unit cell is over 0.7 and the phase difference reaches $180° \pm 20°$ at 0.735-0.965 THz, as depicted in Figs. 1(b)-(c). Therefore, we encode the unit cell before and after the phase transformation as '0' and '1'.

In order to investigate the effect of broadband beam deflection, we simulate the far-field scattering patterns of 18×18 metasurface with coding sequences "0011" from 0.735 THz to 0.965 THz, where the elements in the columns are encoded identically. Figs. 2(a)-(d) show that when the coding sequence is "0011...", two deflected beams are observed on ±43.2°, ±38°, ±36° and ±33° at 0.77 THz, 0.857 THz, 0.902 THz and 0.965 THz, respectively. Besides, the coding sequence of the metasurface can be controlled by changing the status of VO_2 , and thus change the deflection angle.

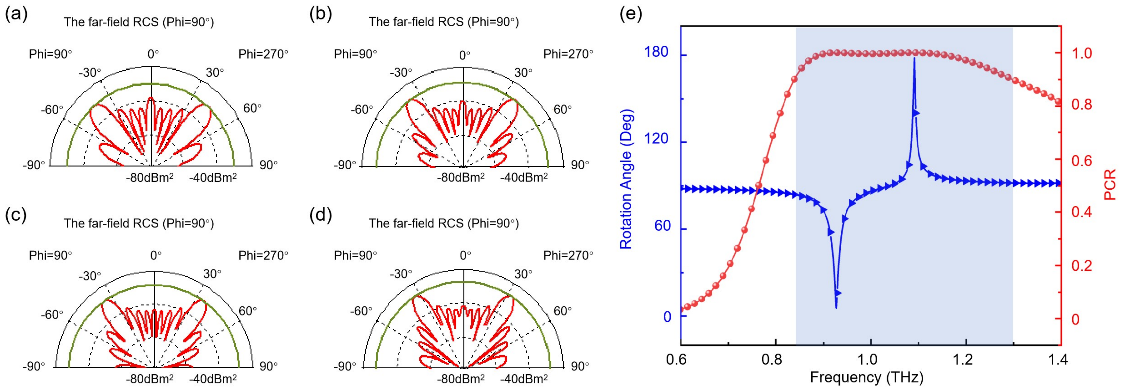

Fig. 2. Simulated far-field patterns results with "0011" coding sequences at 0.770 THz (a), 0.857 THz (b), 0.902 THz (c), 0.965 THz (d). (e) Polarization conversion rate (PCR) (red line) and polarization rotation angle (blue line, the angle between the main axis of the transmitted light and the incident polarization direction) on the THz waveband.

When VO_2 is in insulating state and the value of α, β are 50°and 45°, the polarization mode can be converted from linearly polarized light into cross-polarization in reflection mode due to the localized surface plasmon (LSP) resonances. We use the polarization rotation angle and the polarization conversion rate (PCR) to measure the conversion performance. The PCR is defined as

$$PCR = \frac{r_{yx}^2}{r_{yx}^2 + r_{xx}^2} \tag{1}$$

where r_{ij} represents i-polarized reflection from j-polarized incidence. As shown in Fig. 2(d), in the range of 0.84-1.3 THz, more than 90% of the energy of the reflected light belongs to the cross-polarization component and the polarization rotation angle is satisfied with the requirement of polarization conversion (reaches 90°).

3. Conclusion

In summary, we report a broadband programmable metasurface based on VO_2 /Au SSRR, which exhibits promising beam steering function at 0.735-0.965 THz (230 GHz). And the metasurface can change deflection angle in real-time by changing the coding sequence. In addition, this device also has the capability to realize co-polarization to cross-polarization conversion and the conversion efficiency reaches more than 90% at 0.84-1.3 THz (460 GHz). These are conducive to the construction of 6G communication system.

4. Acknowledgements

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