Broadband Beam Steering Based on Programmable VO_2 Metasurface at Terahertz Frequencies

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***Abstract*—We demonstrate broadband beam steering based on a programmable terahertz (THz) metasurface integrated vanadium dioxide (VO_2). The deflection angle of THz beams can be manipulated dynamically with a broad bandwidth of 14 GHz in 0.218-0.232 THz frequencies. Moreover, by changing coding sequences, the THz beams are continuously diffracted to different deflection angles, where the maximum deflection angle is 53°. Our work provides a possible method for the dynamic manipulation of the THz beams deflection in 6G wireless communication.**

***Index Terms*—Programmable VO_2 metasurface, Broadband beam steering, THz frequencies**

I. Introduction

The sixth generation of mobile communications (6G) will use the terahertz (THz) band to provide ultra-high speed information transmission and ubiquitous wireless connection [1]. Nevertheless, THz links have the disadvantages of high loss and line-of-sight transmission, which greatly limits the communication transmission [2]. As a subwavelength two-dimensional structure, metasurface provides a platform for the realization of THz technology [3]. For example, several works have achieved beam scanning at single operating frequency point [4], [5]. It is well known that bandwidth determines the maximum capacity of information transmission in wireless communication. Recent researches have been proposed to achieve broadband beam steering using metasurface, however, dynamic beam steering in a broad bandwidth is still a challenge for metasurface [6], [7].

In this work, we present a digitally programmable vanadium dioxide (VO_2) metasurface, which is enable to achieve the dynamical control of the THz beams over a broad bandwidth of 14 GHz. By changing coding sequences, the THz beams achieve different deflection angles. The proposed programmable VO_2 metasurface exhibits the potential in 6G wireless communication.

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II. Results and Discussion

The working principle of programmable VO_2 metasurface in 6G wireless communication is shown in Fig. 1(a). When the base station is unable to transmit signals directly to the users, the programmable metasurface acts as a relay that can receive signals from the base station and sending signals to the users. Firstly, the controller determines the received user by sensing and applies different digital voltage signals to the metasurface. According to the input voltage signals, the metasurface can then dynamically adjust the coding sequence and finally send information to user located in different place.

It is well known that VO_2 is a reversible phase transition material which shows the superiorities in fast response and possesses an insulator-metal phase transformation. It is triggered by thermal, optical, or electrical motivation [8]. The designed metasurface is composed of three layers: reflecting gold film, quartz substrate and pattern layer, as shown in Fig. 1(a). The yellow area indicates gold material. In order to realize the control of electromagnetic waves, VO_2 is embedded in the pattern layer, as shown in the red area in Fig. 1(a). The period P is 400 μm, the length m and width n of VO_2 are 74 μm and 40 μm. When VO_2 is in the insulating state and metallic state, the conductivity is 200 S/m and 200,000 S/m, respectively [8]. As shown in Fig. 1(b)-(c), the meta-atom achieves over 0.8 reflection amplitude and phase difference of $180° \pm 20°$ in a broadband frequency range from 0.218 to 0.232 THz. Therefore, we encode the meta-atom before and after the phase transition as '0' and '1', respectively.

The prerequisite for achieving beam steering on the metasurface is the generation phase gradient between meta-atoms. In order to investigate the effect of broadband beam scanning, we simulate the far-field scattering patterns of 12×12 metasurface with coding sequences in 0.218-0.232 THz, where the elements in the columns are encoded identically. As shown

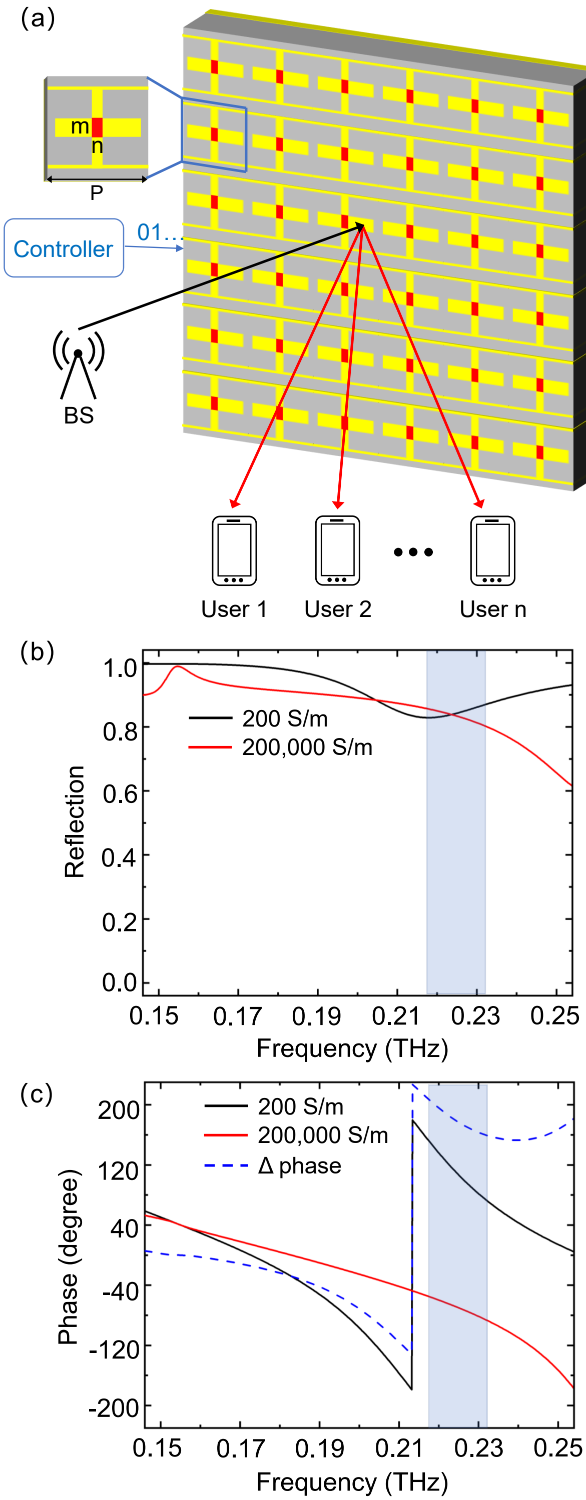

Fig. 1. (a) The working principle of programmable VO_2 metasurface in 6G wireless communication. The reflection amplitude (b) and phase (c) of the meta-atom when the conductivity of VO_2 is 200 S/m and 200,000 S/m.

in Fig. 2, when the coding sequence is "000111…", two deflected beams are observed on -27.7°/ +35.4°, -28.8°/+32.1°, -29.3°/+31.9° and -30.3°/+30.1° at 0.218 THz, 0.224 THz, 0.226 and 0.232 THz respectively. The deviation of the beam deflection is caused by the different phase differences of meta-atom at different frequencies.

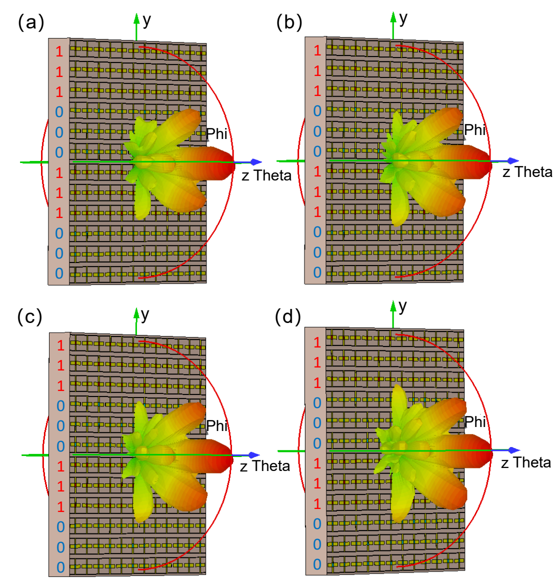

Fig. 2. The simulated far-field patterns of 12 × 12 metasurface with coding sequences of "000111…" at 0.218 THz (a), 0.224 THz (b), 0.226 THz (c), 0.232 THz (d).

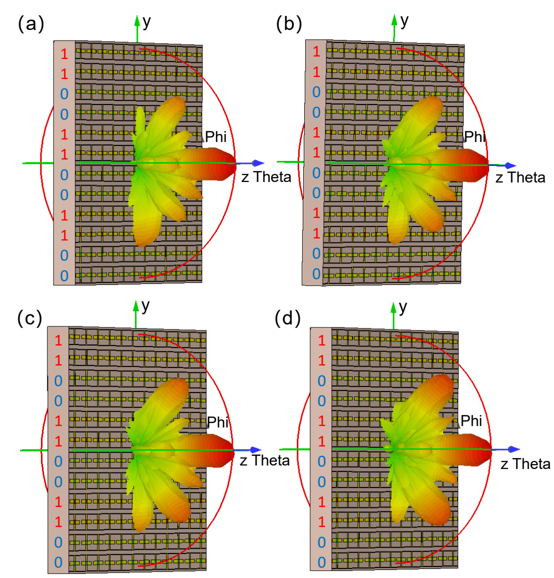

Fig. 3. The simulated far-field patterns of 12 × 12 metasurface with coding sequences of "0011…" at 0.218 THz (a), 0.224 THz (b), 0.226 THz (c), 0.232 THz (d).

Next, in order to achieve dynamic beam steering, we also design the "0011…" to observe the far-field scattering patterns, as displayed in Fig. 3. It can be seen that two deflected beams are observed on -46.3°/+53.1°, -48.5°/+50.9°,

-49.6°/+50.4° and -48.5°/+46.4° at 0.218 THz, 0.224 THz, 0.226 and 0.232 THz. Tab. 1 shows the deflection angles of the coding sequences at other frequencies of 0.218-0.232 THz, which also achieve the beam steering. Therefore, the designed programmable VO_2 metasurface shows the ability of realizing beam deflection in a broadband frequency ranging from 0.218 THz to 0.232 THz.

TABLE I
SIMULATED DEFLECTION ANGLES FOR CODING SEQUENCES AT DIFFERENT FREQUENCIES

Frequency (THz)	Codind sequence	Beam deflection
0.220	"000111"	-26.5°/+33.6°
	"0011"	-46.8°/+50.9°
0.222	"000111"	-27.6°/+32.4°
	"0011"	-46.8°/+50.3°
0.228	"000111"	-30.2°/+30.7°
	"0011"	-48.4°/+48.7°
0.230	"000111"	-30.2°/+30.2°
	"0011"	-48.4°/+48.2°

III. CONCLUSION

To summarize, the programmable VO_2 metasurface is designed for THz broadband beam steering. The meta-atom achieves over 0.8 reflection amplitude and $\sim$180° phase difference with a broadband of 14 GHz before and after the VO_2 phase transition. By changing the coding sequence, the THz beams is continuously diffracted to different deflection angles in 0.218-0.232 THz, where the maximum deflection angle can reach 53°. This work provides a possible implementation for the broadband manipulation of electromagnetic wave in 6G wireless communication.

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