

RESEARCH ARTICLE

Chiral metasurfaces enabling tunable spin selection for multidimensional images and beam splitting

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Supporting Information

1. Polarization conversion performance of MIM

Figures 1b and c show the reflection coefficients of circularly polarized light incident when vanadium dioxide is in the dielectric state and the metallic state, respectively. The reflection spectra in Figs. 1b and c show that when vanadium dioxide is in the dielectric state, the vanadium dioxide on both sides of the ring breaks the symmetry of the original structure, showing an asymmetric structure. Therefore, under circularly polarized incidence, it has chiral properties. When vanadium dioxide is switched to the metallic state, the unit cell structure becomes a symmetric structure. The PCR spectra of copolarization (r_{RR} & r_{LL}) and cross-polarization (r_{LR} & r_{RL}) are shown in Figure S1, respectively. Among them, the polarization conversion rate (PCR) is

$$\text{PCR} = \frac{r_{ij}}{r_{ij} + r_{jj}}$$

where r_{ij} ($i, j = R$ or L) represents the reflectance of the i circularly polarized light incident on the j circularly polarized light.

Figures S1(a) and (b) show the polarization conversion rates of different circularly polarized light incident when vanadium dioxide is in the dielectric state and the metallic state, respectively. PCR1 represents the polarization conversion rate under RCP irradiation, and PCR2 represents the polarization conversion rate under LCP irradiation. It can be seen from S1(a) that the value of PCR1 when vanadium dioxide is in the dielectric state is quite different from that when vanadium dioxide is in the metallic state. Similarly, the value of PCR2 when vanadium dioxide is in the dielectric state is also different from that when vanadium dioxide is in the metallic state, as shown in Fig. S1(b). It is worth noting that when vanadium dioxide is in the metallic state, its PCR1 and PCR2 are basically the same.

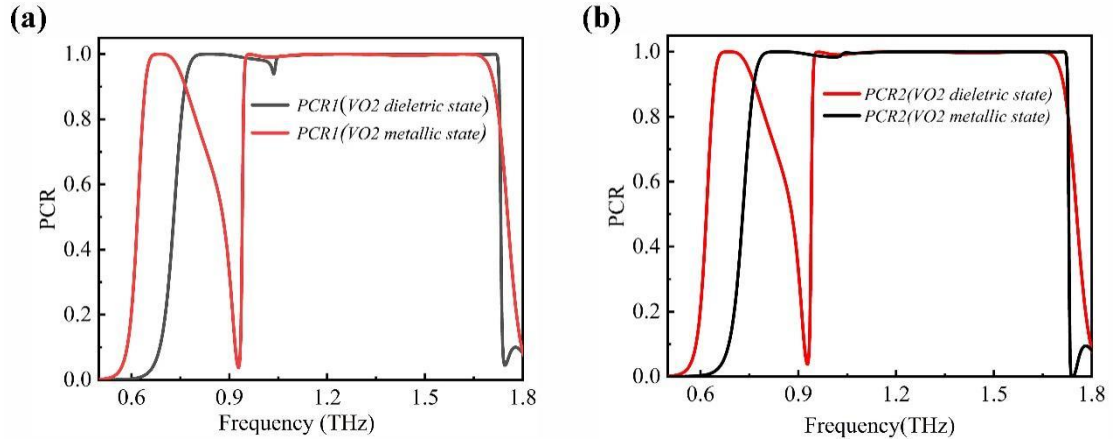


Fig. S1 (a) PCR₁ and (b) PCR₂ of vanadium dioxide in dielectric state and metal state.

In order to obtain the reasons for the differences in Fig. S1, we used the CST Microwave Studio software to obtain the electric field diagrams at 1.034 THz when vanadium dioxide is in the dielectric state and the metallic state, as shown in Fig. S2. It can be seen from the electric field diagrams in S2(a) and (b) that when vanadium dioxide is in the dielectric state, under the incidence of RCP, the electric field energy is mainly concentrated on the outer edge of the ring except for the addition of vanadium dioxide, while under the incidence of LCP, the electric field energy is mainly concentrated on the edge of the double L-shaped. It can be seen from the electric field diagrams in S2(c) and (d) that when vanadium dioxide is in the metallic state, the electric field energy shows the same characteristics under the incidence of RCP and LCP, mainly concentrated on the outer edge of the ring and the inner double L-shaped edge.

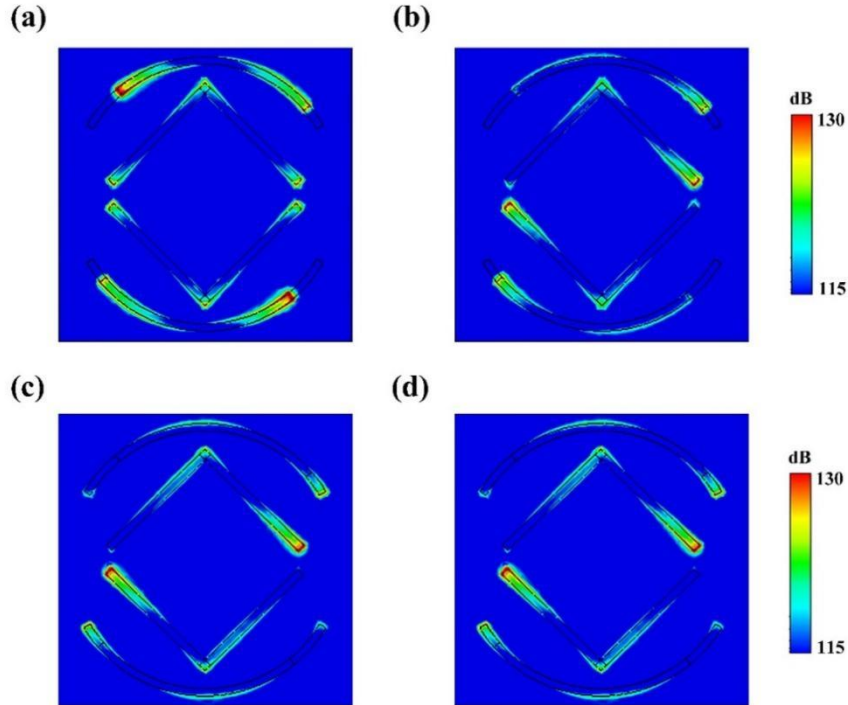


Fig. S2 The electric field patterns of vanadium dioxide in the dielectric state with (a) RCP incidence and (b) LCP incidence; and the electric field patterns of vanadium dioxide in the metallic state with (c) RCP incidence and (d) LCP incidence.

2. Switchable image control controlled by input frequency and output polarization

Four MIMs with different parameters are selected as pixels of the switchable image. Figure S2 shows the main structural parts affecting RCP and LCP when vanadium dioxide is in the dielectric state. Based on this, we can appropriately adjust the structural parameters of the unit cell structure in Fig. 1 to construct a unit cell structure sensitive to RCP and LCP. Figure 2(b) shows the co-polarization and cross-polarization reflection spectra of the four structures (A, B, C, and D). In addition, we also use the full-wave simulation software CST Microwave Studio to analyze the meta-atoms A, B, C, and D, mainly to obtain the characteristic parameters such as the absorption rate ($A_{LCP}=1-|r_{LL}|^2-|r_{RL}|^2$ or $A_{RCP}=1-|r_{RR}|^2-|r_{LR}|^2$) and circular dichroism ($CD=A_{LCP}-A_{RCP}$) of these chiral unit structures. The simulation results are shown in S3 by exciting with left and right circularly polarized electromagnetic waves incident vertically. The results in Fig. S3(a) show that the meta-atom A can efficiently absorb LCP waves at 1.034 THz, while reflecting RCP waves and maintaining chirality, the absorption rate of LCP waves reaches 99.7%, while the absorption rate of RCP waves is only 23.3%, and the circular dichroism reaches 76.4%. The results in Fig. S3(b) show that the meta-atom B can efficiently absorb RCP waves at 1.034 THz, the absorption rate of RCP waves reaches 95.9%, while the absorption rate of LCP waves is only 23.7%, and the circular dichroism reaches -72.2%. The results in Fig. S3(c) show that the meta-atom C cannot efficiently absorb LCP waves at 1.034 THz, nor can it efficiently absorb RCP waves, the absorption rates of LCP waves and RCP waves are 17.8% and 15.6%, respectively, and the circular dichroism is 2.2%. The results in Fig. S3(d) show that by removing the reflector of the meta-atom D, the absorption rates of LCP waves and RCP waves of the meta-atom at 1.034 THz are both 20.9%, and the circular dichroism is almost 0%. According to the analysis of the meta-atoms, we found that the meta-atoms A and B have opposite strong circular dichroism at 1.034 THz, so this feature can be used to achieve different chiral imaging functions.

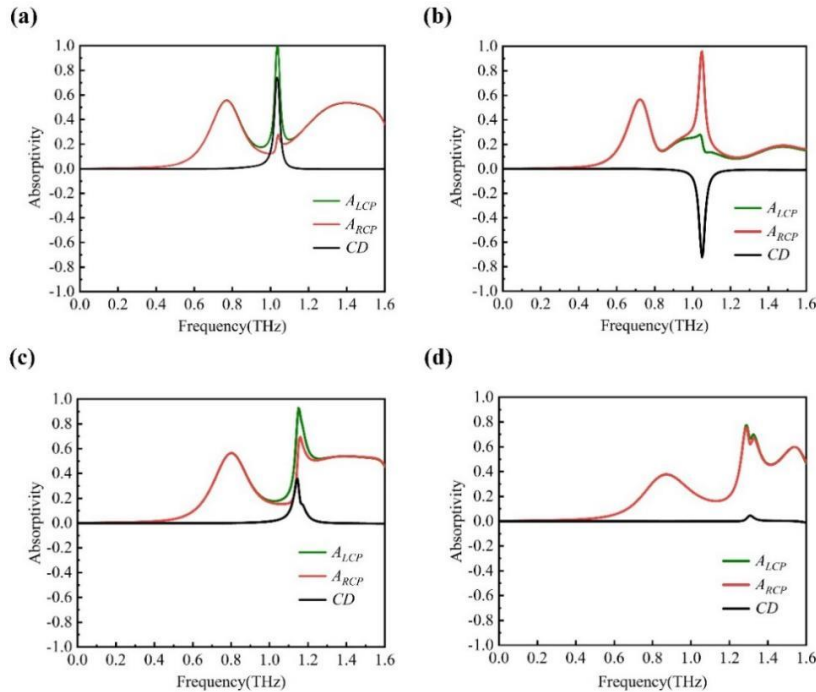


Fig. S3 The simulation results of absorption rate and circular dichroism of (a) meta-atom A; (b) meta-atom B; (c) meta-atom C; and (d) meta-atom D at 1.034 THz.

In addition, we also analyzed the absorption rate and circular dichroism of meta-atoms A, B, C, and D at 4.28 THz. Under the excitation of left and right circularly polarized electromagnetic waves incident vertically, the simulation results are shown in S4. The results in Fig. S4(a) show that when the reflector of meta-atom A is removed, the absorption rates of LCP and RCP waves of the meta-atom at 4.28 THz are both about 78%, and the circular dichroism is almost 0%. The results in Fig. S4(b) show that the absorption rates of LCP and RCP waves of meta-atom B at 4.28 THz are both about 49%, and the circular dichroism is almost 0%. The results in Fig. S4(c) show that meta-atom C can simultaneously reflect RCP and LCP waves, the absorption rate of LCP waves reaches 81.9%, while the absorption rate of RCP waves is 99.9%, and the circular dichroism reaches -52.6%. The results in Fig. S4(d) show that meta-atom D can efficiently absorb LCP waves at 4.28 THz, the absorption rate of LCP waves reaches 99.9%, while the absorption rate of RCP waves is 48%, and the circular dichroism reaches -52%. According to the analysis of the meta-atoms, we found that meta-atoms C and D have opposite strong circular dichroism at 4.28 THz, so the opposite circular dichroism of meta-atoms A, B, C, and D at two frequencies can be used to achieve imaging functions of different polarization states at different frequencies.

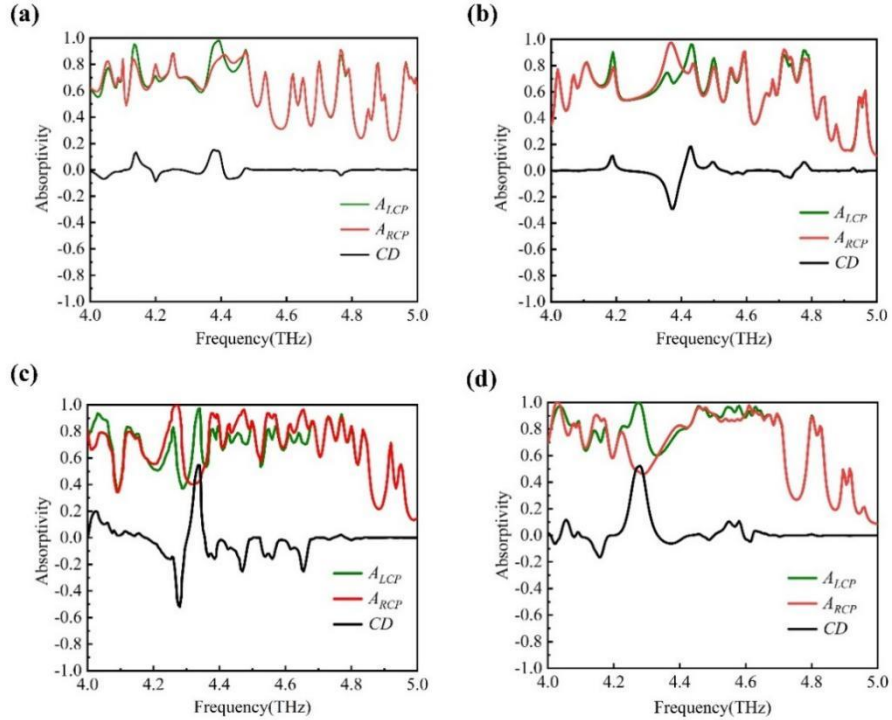


Fig. S4 Simulation results of absorption rate and circular dichroism of (a) meta-atom A; (b) meta-atom B; (c) meta-atom C; and (d) meta-atom D at 4.28 THz.

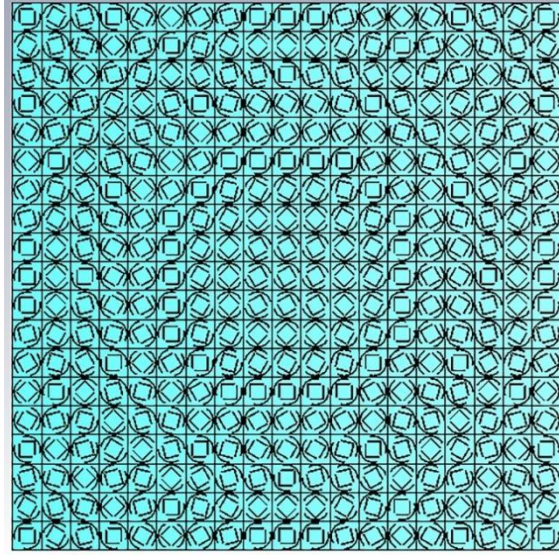
Finally, we also analyzed the reflection coefficients of the transformed meta-atoms A, B, C, and D vanadium dioxide in the dielectric and metallic states under LCP and RCP irradiation, as shown in Table 1. It can be seen from Table 1 that when vanadium dioxide changes from the dielectric state to the metallic state, its reflection coefficients remain almost unchanged under the irradiation of LCP and RCP waves, and there is no chiral characteristic. Therefore, the state transition of vanadium dioxide can be used to realize imaging functions in different dimensions.

Table 1 Reflection coefficients of meta-atoms A, B, C, and D under LCP and RCP incidence.

Vanadium dioxide state	Geometric structure	Reflection coefficient			
		1.034 THz		4.28 THz	
		RCP	LCP	RCP	LCP
VO2 dielectric state	A	0.86	0.04	0.22	0.23
	B	0.19	0.87	0.63	0.62
	C	0.92	0.91	0.22	0.78
	D	0.03	0.04	0.76	0.08
VO2 metallic state	A	0.68	0.68	0.232	0.232
	B	0.89	0.89	0.795	0.796
	C	0.93	0.93	0.93	0.93
	D	0.15	0.15	0.61	0.61

3. Dynamically tunable polarization-multiplexed terahertz beam splitter

The terahertz beam splitter demonstrated is designed by arranging the unit structure in Fig. 1 into a gradient with a rotation angle $\alpha(x, y) = \pi r / P_r$. According to the principle of phase compensation, it is found that the phase change of this metasurface exhibits an inverse change under the incidence of LCP and RCP waves regardless of whether vanadium dioxide is in the dielectric or metallic state, thus enabling the construction of a terahertz beam splitter. This beam splitter is composed of 19×19 meta-atoms, as shown in Fig. S5.

**Fig. S5** Arrangement diagram of eight-unit beam splitter of meta-atoms.

4. Dynamically tunable polarization-multiplexed anomalous reflection devices

Similarly, the designed anomalous reflection device is also designed by arranging the unit structure in Fig. 1 into a gradient with a rotation angle $\alpha(x, y) = \pi r / P_r$. The difference is that anomalous reflection only requires sequentially arranging the periodic meta-atoms satisfying the 2-phase and keeping the y -axis meta-atoms unchanged. The anomalous reflection metasurface consists of 16×16 meta-atoms, as shown in Fig. S6.

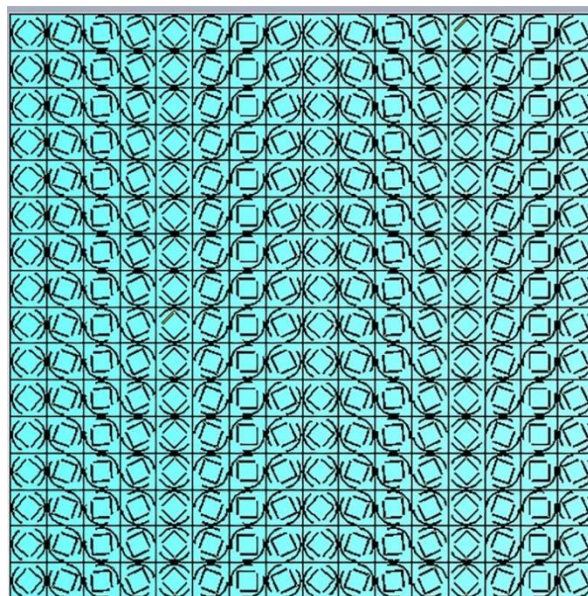


Fig. S6 Arrangement diagram of eight-unit anomalous reflection of meta-atoms.