Sensing

Development of dynamic metasurfaces for highly-efficient terahertz chiral sensing

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Abstract

The terahertz frequency range has attracted much interest from the perspective of sensing technology because there are giant- and bio-molecule vibrations in this frequency range. Measuring the response for the left- and right-circular polarizations is needed to detect the chirality of some molecules whose mirrored structure differs from the original structure. Therefore, a technique to switch the rotational direction of circular polarization is strongly demanded. In this study, we realize a device that can efficiently convert an incident linear polarization into a circular polarization and dynamically reverse its rotation direction. The device realizes desired functionality by deforming a metallic pattern (Fig. 1). The pattern deformation is achieved by introducing vanadium dioxide (Fig. 2a), of which resistivity changes with temperature. In the end, we demonstrated its highly-efficient operation of terahertz circular-polarization switching.

Background & Results

In the terahertz frequency range, demands for high-sensitivity sensing and high-speed communication require the development of dynamic devices. However, due to various limitations, conventional dynamic devices such as semiconductor and liquid-crystal devices cannot be directly used in the terahertz region. In addition, terahertz waves have much longer wavelengths compared to light, so the devices tend to become thick. To solve these problems, artificially-structured surfaces called metasurfaces are attracting attention. Metasurfaces often leverage metallic structures, which produce strong responses despite their subwavelength thickness. Additionally, metasurfaces can incorporate dynamic materials that can change their response depending on external stimuli. In this study, we realized a dynamic metasurface with vanadium dioxide for highly-efficient switching of terahertz circular polarization.

Figure 1 shows the schematic of the operation principle of the device. In the left of Fig. 1, metallic crosses with different lengths are arranged on the top surface of a dielectric substrate with a metallic bottom ground. The anisotropy of the cross induces the conversion from an incident linearly polarized wave into a reflected circularly-polarized one. When an external stimulus is applied to the structure, the metal pattern is deformed to be shorted. This deformation reverses the direction of rotation of the reflected circular polarization. The pattern deformation is implemented by introducing vanadium dioxide between the metal crosses (Fig. 2a). When the temperature is increased, vanadium dioxide changes from insulator (OFF) to metallic (ON) states, resulting in metallic pattern deformation. Figure 2b represents the power conversion efficiency from linear polarization into circular polarizations for the OFF and ON states of the device. The efficiency is beyond the principal limit of single-layer transmissive metasurfaces. In other words, we can invert the rotational direction of terahertz circular polarization while maintaining high efficiency.

Significance of the research and Future perspective

Because the developed device converts the incident wave based on reflection, it achieves highly-efficient conversion, which has been impossible for conventional transmissive devices in principle. As shown in Fig. 2b, a power conversion efficiency of over 80% was successfully achieved when vanadium dioxide is in both insulator (OFF) and metallic (ON) states, exceeding the theoretical limit for single-layer transmissive devices. This device is applicable to highly-efficient terahertz chiral sensing and also communications utilizing polarization degrees of freedom.

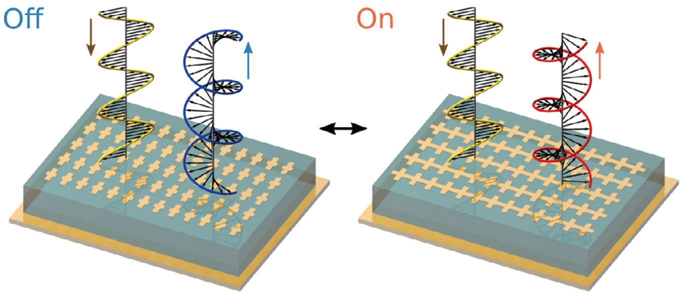

Figure 1: Operation principle. A linearly-polarized terahertz wave enters the metasurface. The rotation direction of the reflected terahertz circular polarization is switched by deforming the metallic pattern.

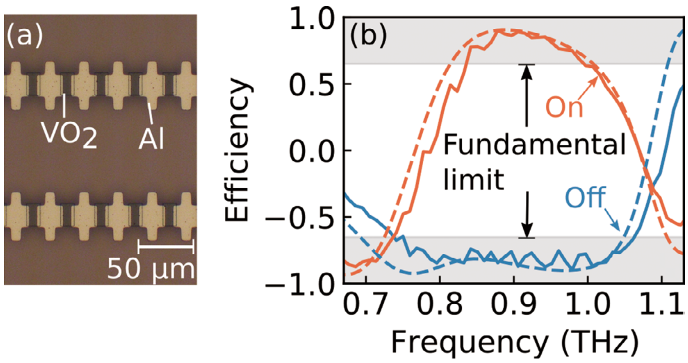

Figure 2: Physical device and its characterization: (a) Photomicrograph of the metasurface. (b) Power conversion efficiency from linear polarization to circular polarization. The efficiency sign (±) represents the difference between right- and left-circular polarizations. The shaded region is beyond the theoretical limit for single-layer transmissive devices.

Patent

Treatise Kobachi, Mitsuki; Miyamaru, Fumiaki; Nakanishi, Toshihiro et al. Dynamic quarter-wave metasurface for efficient helicity inversion of polarization beyond the single-layer conversion limit. Advanced Optical Materials. 2022, 10(2), p. 2101615, doi: 10.1002/adom.202101615

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