Two-Layer Dual-Mode Reflective-Transmissive Polarization Converter by Stereometamaterials

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The ability to control light polarization is vital for applications in imaging, communications, metrology, among others. and. This work reports a systematic approach using supercells of periodic metamaterials to achieve enhanced polarization control. The use of supercells, with identical resonators, provides enhanced parameter flexibility, enabling facile control over the phase and polarization of scattered beams through rotation, flipping, and shifting of the resonators. In particular, we show that by changing the symmetry of the structure from reflection to inversion in a subwavelength two-layer supercell, a transmissive polarization conversion device can be transformed into a reflective counterpart, both with near-unity polarization conversion ratios. This systematic use of supercells highlights their potential for advanced polarization manipulation in electromagnetic and optical devices.

In recent years, the development of multifunctional and reconfigurable polarization devices has gained growing importance, especially for adaptive optics and dynamic optical systems [1-4]. Various polarization converters have been demonstrated that switch between reflection and transmission modes by utilizing interactions between resonators across multiple layers—typically more than two [5-7]. However, achieving such reconfigurability using less than three layers, while still maintaining high polarization conversion performance in both modes, remains a significant challenge.

In this study, we address this challenge by employing supercells as a fundamental building block in our design. Instead of increasing the number of layers, we leverage the interaction between resonators within the supercell in each layer. Our periodic setting in each layer consists of multiple identical resonators within a large unit cell, each oriented differently in space. The distinct spatial arrangement of these resonators results in unique electromagnetic interactions, offering a systematic and flexible design room for an efficient control of polarization states in both transmission and reflection modes. We numerically demonstrate that by flipping, shifting, or rotating the resonators within a subwavelength two-layer supercell, it is possible to manage polarization states in both transmission and reflection modes with high polarization conversion performance. Notably, by changing the symmetry of the system from reflection to inversion in a subwavelength two-layer supercell, a transmissive polarization conversion device can be transformed into a reflective counterpart, both with near-unity polarization conversion ratios.

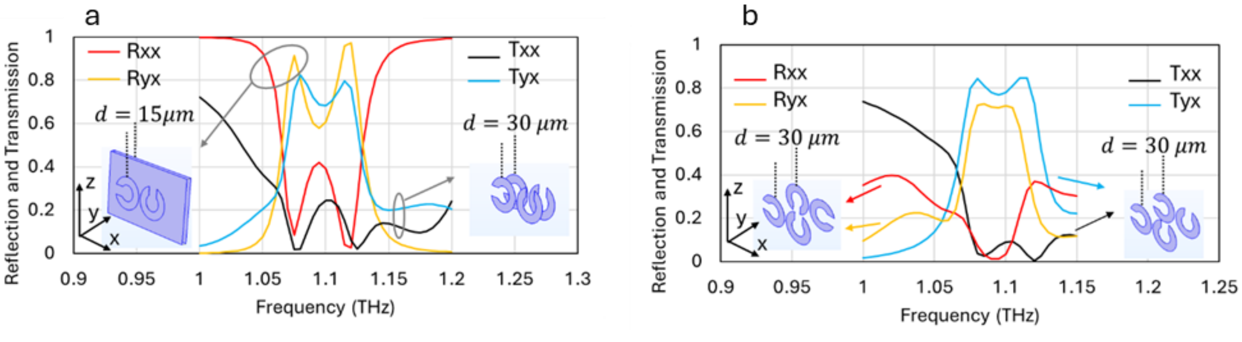

Fig. 1. Reflection spectra of the reflective polarization converter device (left inset) are compared with transmission spectra of a transmissive structure (right inset). The reflective device is created by placing a conductive plane 15 μm away from the resonators, while the transmissive configuration is made by removing the conductive plane and mirroring the resonators relative to this surface. **b.** When the 2nd layer of SRRs is made by inversion symmetry from the first layer relative to the center of unit cell at backplane, the structure now acts very similar to the reflective polarization converter with the conductive plane.

The preliminary numerical results have been demonstrated in Fig. 1. The inset of Fig. 1a on left side, shows a configuration where two identical split ring resonators (SRRs) has been placed in close proximity of each other, one of which is rotated by 90 degrees. The combined resonator is backed by a conductive plane that is placed 15 μm away from the SRRs. As shown in this figure, an x-polarized incident wave is reflected as a dual band y-polarized beam (yellow line) with more than 80% reflection at two bands and with near 100% polarization conversion ratio. Now, we replace the conductive backplane with a second layer of SRRs, arranged as a mirror image of the original resonators with respect to the backplane. Interestingly, the new setting transforms the reflective device into a transmissive arrangement with a very similar co- and cross-polarization spectra. The structure of transmissive polarization converter is illustrated in the inset of Fig. 1a (right), and its co- and cross-polarization spectra (black and blue lines) are compared to the corresponding reflection spectra of the reflective device (red and yellow lines). Now, if the second layer of SRRs in transmissive setting is rotated by π radians about the y axis passing through the center of the unit cell, the transmissive polarization converter will be transformed into a reflective counterpart. This is demonstrated in Fig. 1b, with the inset on the left showing the reflective configuration. Remarkably, this modified device closely mimics the behavior of the setup with a backplane, reflecting cross-polarized light while nearly suppressing co-polarized wave.

We next expanded the supercell to include six resonators, providing greater flexibility in the parameter space and enabling a broadband response using only two layers of SRRs. While there are eighteen possible permutations to analyze, we focus on three key configurations. Figure 2a illustrates the spectral response of a 5-element setting, which transmits cross-polarized light and suppresses co-polarized wave in the frequency range from ~1.1 to ~1.15 THz. If the rightmost resonator in this configuration is flipped, the spectral response changes significantly. Specifically, the transmission drops to nearly zero between ~1.10 and ~1.13 THz, and the reflected wave contains both x- and y-polarized components. To improve the polarization conversion ratio and further extend the spectral response of the transmissive polarization converter, additional resonators can be added. This is illustrated in Fig. 2c, where the inclusion of an extra SRR on the rightmost side of the first layer broadens the cross-polarization bandwidth from ~1.1 to ~1.14 THz, while completely suppressing co-polarized light. This demonstrates a broadband complete linear polarization conversion in the transmissive mode.

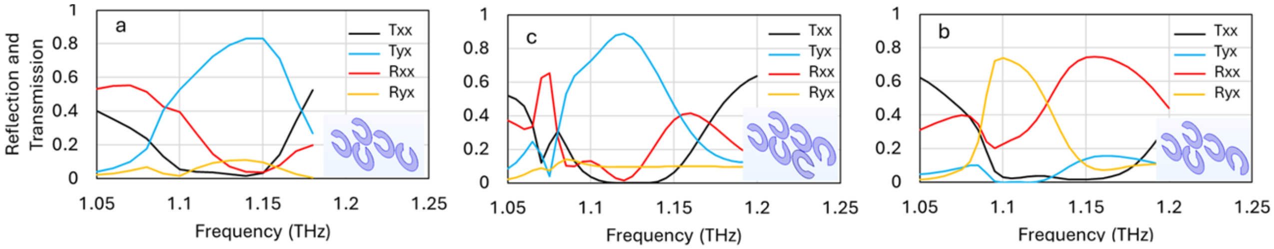

Fig. 2. a. The spectral response of a 5-element metamaterial demonstrating cross-polarization conversion in transmissive mode between ~1.1 and ~1.15 THz. **b.** The corresponding response from a structure where the rightmost SRR has been flipped. In this configuration, transmission is suppressed, and the reflected wave includes both co- and cross-polarizations between ~1.1 and ~1.15 THz frequency range. **c.** By incorporating an additional SRR on the rightmost side of the first layer, the spectral response is improved, with both efficiency and polarization conversion ratio enhanced, thereby extending the bandwidth from ~1.1 to ~1.15 THz.

Acknowledgment

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