Metamaterial Mirrors with a Twist

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***Abstract* – We demonstrate a novel type of mirror, which reflects one circular polarization without reversing its handedness, while being a perfect absorber for the other circular polarization. This ultimate 2D-chiral effect enables circularly polarized cavities and lasers as well as novel spectroscopic techniques.**

I. INTRODUCTION

Conventional metallic and dielectric mirrors convert right-handed circularly polarized waves (RCP) into left-handed circularly polarized waves (LCP) and vice versa, see Fig. 1(a-c). Here we demonstrate a novel type of chiral mirror that will reflect one circular polarization without polarization change, while absorbing waves of the opposite handedness, see Fig. 1(d-f). This functionality, which fundamentally relies on planar chirality, is enabling for circularly polarized cavities and lasers, detection of circularly polarized electromagnetic waves and optical activity measurements with resonantly enhanced sensitivity.

II. 2D- CHIRAL MIRRORS

Key for the realization of such polarization selective RCP or LCP mirrors is a chiral structure to enable different responses to waves of opposite handedness. In principle, conventional 3D-chiral media can exhibit different absorption for waves of opposite handedness, however, for a reflecting device, handedness reversal upon reflection would undo any discrimination between RCP and LCP during the second pass through the 3D-chiral medium. In fact, what is needed is a medium that reverses its chiral response with the handedness reversal of the wave upon reflection in order to amplify the polarization selectivity, rather than eliminating it. This peculiar property is associated with 2D (planar) chirality. In contrast to a 3D-chiral helix, which has the same sense of twist when observed from opposite ends, a flat 2D-chiral spiral reverses its sense of twist for observation from opposite sides. The same is true for any pattern that cannot be superimposed with its mirror image without being lifted out of its plane and such patterns are said to be 2D-chiral. Lossy, anisotropic, 2D-chiral metasurfaces have been shown to exhibit a corresponding optical effect, where opposite sides of the metasurface predominantly absorb waves of opposite circular polarization [1, 2]. We note that also the Faraday effect enables differential absorption of circularly polarized waves, which would aggregate during both passes through the Faraday medium, however, such a “Faraday absorber mirror” would still reverse the handedness of the reflected wave [3]. In contrast, 2D chirality leads to circular polarization conversion enabling it to undo the handedness reversal of the wave upon reflection.

We realize polarization preserving mirrors for one circular polarization by placing a 2D-chiral metamaterial in front of a conventional mirror. Fig. 1(f) shows proof-of-principle experiments in the microwave part of the spectrum, where an array of 2D-chiral split rings has been placed in front of a metal mirror. The metadevice reflects RCP without polarization change, and it absorbs LCP around 5.7 GHz. The opposite response is observed for the enantiomeric metadevice, which is based on split rings of the opposite handedness.

For a 2D-chiral metasurface without backing mirror, the reflectivity for RCP and LCP cannot differ by more than 25% of the normally incident power. The 2D-chiral metadevice demonstrated here avoids the fundamental limitations of 2D-chiral optical effects in metasurfaces and can offer up to 100% reflectivity contrast.

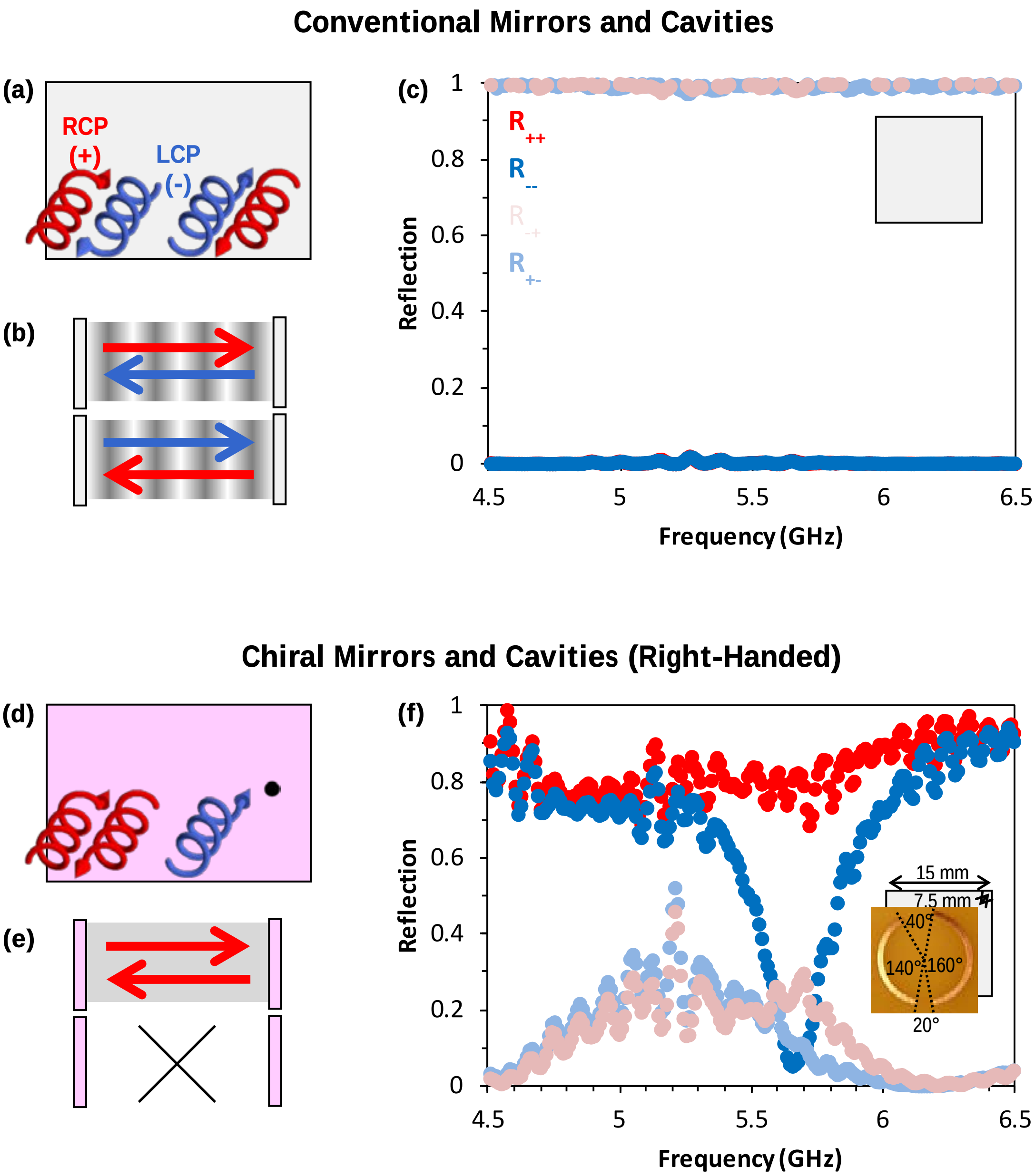

Fig.1 Conventional mirrors vs. chiral mirrors. (a) Reflection characteristics of a conventional mirror in terms of right-handed (RCP,+) and left-handed (LCP,-) circularly polarized waves, (b) the corresponding cavity modes and (c) reflectivity measurements for circularly polarized waves. (d) Reflection characteristics of a right-handed chiral mirror, (e) the corresponding cavity mode and (f) experimental demonstration of a chiral mirror reflecting only right-handed circularly polarized waves without polarization change (R++, red, around 5.7 GHz). The inset shows the unit cell consisting of a 2D-chiral wire split ring on a lossy dielectric substrate in front of a metal mirror.

VI. Conclusion

In summary, we experimentally demonstrate a novel chiral metadevice that acts as handedness-preserving mirror, reflective circular polarizer and polarization selective perfect absorber. In principle, it offers unlimited polarization contrast and therefore it exhibits the ultimate 2D-chiral optical effect.

Acknowledgement

This work is supported by the Leverhulme Trust, the MOE Singapore (grant MOE2011-T3-1-005) and the UK's Engineering and Physical Sciences Research Council (grant EP/G060363/1).

References

[1] V. A. Fedotov, P. L. Mladyonov, S. L. Prosvirnin, A. V. Rogacheva, Y. Chen, and N. I. Zheludev, “Asymmetric propagation of electromagnetic waves through a planar chiral structure,” Phys. Rev. Lett. 97, 167401 (2006)
[2] E. Plum, V. A. Fedotov, and N. I. Zheludev, “Planar metamaterial with transmission and reflection that depend on the direction of incidence,” Appl. Phys. Lett. 94, 131901 (2009).
[3] M. Martinelli, “A universal compensator for polarization changes induced by birefringence on a retracing beam,” Opt. Commun. 72, 341 (1989).