Non-reciprocal gyrotropic semiconductor-based metasurface not requiring magnetic bias

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Abstract

A non-reciprocal metasurface with gyrotropic properties similar to those of ferrites is presented. The constitutive element of the metasurface is a pair of parallel rings loaded with a unidirectional semiconductor-based lumped element. Contrary to ferrites, the metasurface does not require any biasing magnetic field. Full-wave simulations show that the metasurface rotates the polarization of a normally incident plane wave.

1. Introduction

Ferrites are indispensable materials for many microwave devices which require non-reciprocity and gyrotropy for their operation, such as isolators, circulators and Faraday rotators [1]. Ferrites exhibit non-reciprocity and gyrotropy when biased with a static magnetic field, as a result of the electrons precession around the magnetic field. This precession of electrons creates a rotating magnetic moment which interacts differently with right-handed and left-handed circularly polarized waves and it is responsible for the two fundamental phenomena in ferrites: Faraday rotation and field displacement [2].

One major drawback of ferrite-based devices is the need of a permanent magnet for the generation of the static magnetic bias field. The presence of the magnet prevents miniaturization, integration in planar circuit technology and even, sometimes, device functionality [3].

Here, we present a novel non-reciprocal semiconductor-based gyrotropic metasurface, which does not require any magnetic bias field. Numerical simulations show that the metasurface rotates the polarization of a normally incident plane wave. An implementation of the proposed metasurface in the reflection mode has been recently published in [4].

2. Operation principle

The unit cell of the proposed metasurface is depicted in Fig. 1(a). It consists of two parallel metallic rings at the faces of a dielectric slab. The rings are loaded with an ideal isolator, which allows propagation in the right-handed direction with respect to the z-axis, while leaving the amplitude and the phase of the wave unchanged. The isolator is a semiconductor-based element, such as a transistor, and it requires a DC bias voltage for its operation.

The structure supports a travelling wave resonance when the phase difference of the wave between the isolator ports is an integer multiple of 2π. This condition corresponds to the ring circumference being

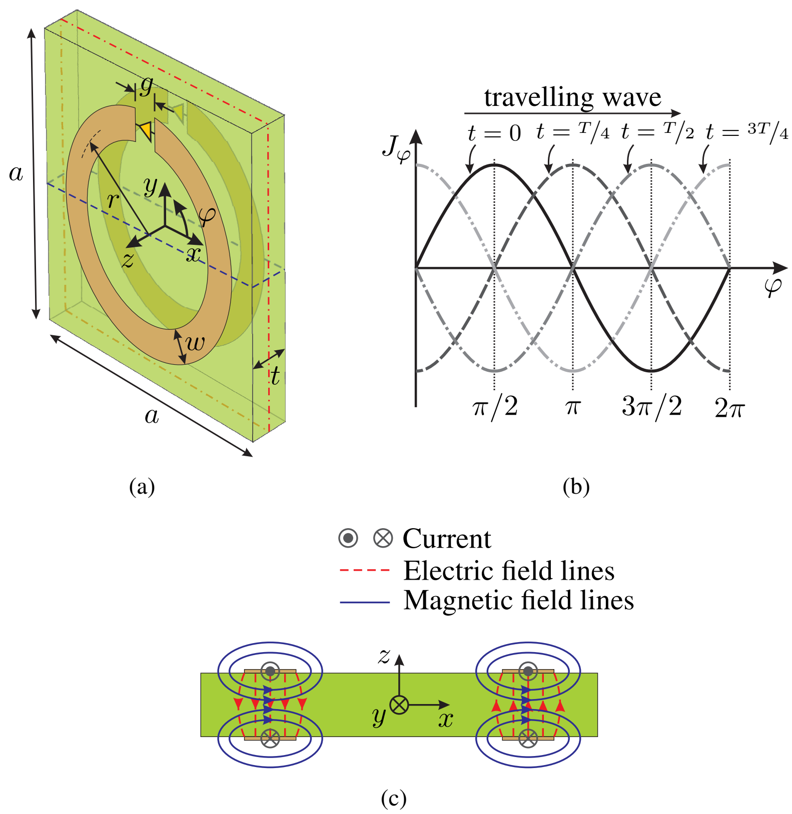

Fig. 1: Non-reciprocal gyrotropic metasurface constituted of two parallel rings placed at both sides of a dielectric slab. Each ring is loaded with an ideal isolator (yellow triangle), which produces a travelling-wave regime due to the fact that the wave is allowed to propagate only in one direction (here, the right-handed direction with respect to the z-axis). The structure resonates when the ring's length is a integer multiple of the wavelength. (a) Unit cell. (b) Time snapshots of the current in the left ring over a period, with quarter-period separation. (c) Field lines at resonance in the constant $y = 0$ xz plane denoted by the dashed line.

an integer multiple of the guided wavelength λ_g between the rings. The diameter of the rings is then λ_g/π. Considering that λ_g is less than the free space wavelength and that the periodicity a of the lattice is close to the diameter of the ring, a is well below the Bragg diffraction limit, which ensures absence of any scattering phenomena. Note also that any real isolator, such as a field effect transistor, introduces a non-zero phase shift, which brings a to even smaller values. Fig. 1(b) depicts different time snapshots of the current in the left ring and Fig. 1(c) illustrates the fields in the $y = 0$ plane at $t = T/4$. The current, the direction of which is obtained from Fig. 1(b), determines the form of the magnetic field lines. The form of the magnetic field reveals that an x-directed equivalent magnetic moment may be assigned to the structure. This moment performs a full rotation around the z-axis during a period, as it is illustrated in Fig. 2. Therefore, the proposed metasurface possesses a rotating magnetic moment exactly as ferrites do, without, however, the need of a magnetic bias field. On the other hand, the metasurface needs a DC voltage source for the biasing of the isolator.

3. Numerical results

Full-wave simulations for normal incidence of a plane wave on the proposed ring metasurface have been performed via the CST simulation package. Fig. 3 presents the electric field of the incident and transmitted wave for propagation along the $+z$ direction at the first resonance. The transmitted wave in the ab-

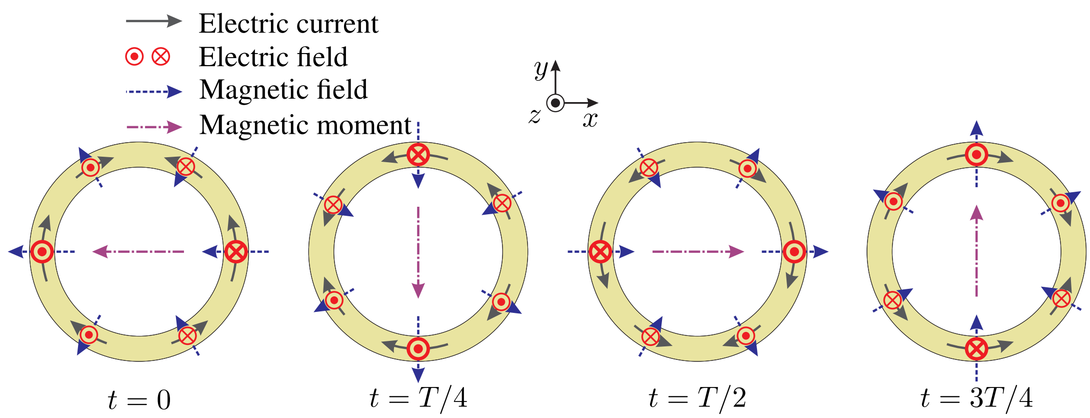

Fig. 2: Time snapshots over a period, with quarter-period separation, of the significant quantities in Fig. 1, which are the electric current in the left ring, the electric and the magnetic field in the $z = 0$ plane (plane denoted by the dash-dotted line) and the magnetic moment at the coordinate system origin.

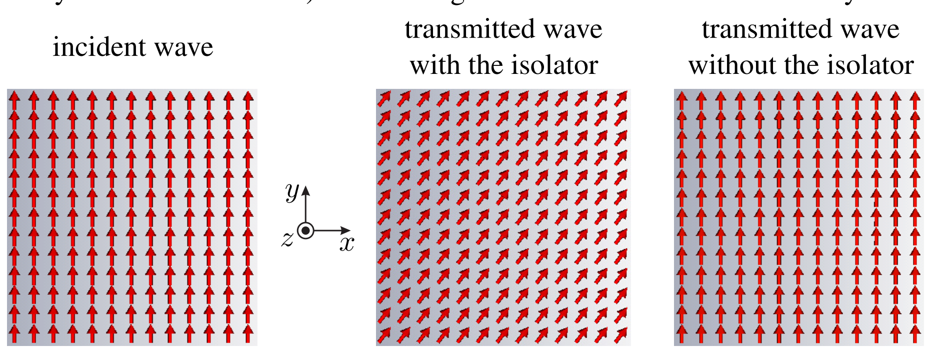

Fig. 3: Normal incidence of a plane wave on a metasurface with $r = 5.75$ mm, $g = 2$ mm, $w = 2$ mm, $t = 1.6$ mm and slab relative permittivity 2.6, at 5.34 GHz (first resonance). Incident and transmitted electric field. The transmitted field in the absence of the isolator is also included to eliminate the possibility of any cross-polarization effects due to the geometry asymmetry.

sence of the isolator has also been included in order to eliminate the possibility of any cross-polarization effects due to the geometry asymmetry. It is clear that the metasurface rotates the polarization of the incident wave, exhibiting a similar effect to Faraday rotation in ferrites.

4. Conclusions

A metasurface consisting of non-reciprocal rings has been presented and it has been shown to posses gyrotropic properties similar to those of ferrites. However, contrary to ferrites, the proposed metasurface does not require any biasing magnet, which makes it totally transparent and suitable for antenna applications.

References

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