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PHOTONICS AND NANOSTRUCTURES
Fundamentals and Applications

Photonics and Nanostructures – Fundamentals and Applications 12 (2014) 429–436

www.elsevier.com/locate/photonics

Magnetic monopole-like response in metamaterials

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Received 24 September 2013; received in revised form 3 May 2014; accepted 3 May 2014
Available online 29 May 2014

Abstract

In this paper, we explored magnetic monopole-like responses in metamaterials. We designed a sub-wavelength metamolecule that is composed of two dielectric-spaced split-ring resonators. In response to incident waves, the induced magnetic field in the metamolecule resembles that of a two-dimensional magnetic monopole. The magnetic monopole-like response is resulted from electric resonance of the metamolecule, so an electric dipole is always attached. By combining two mirror-symmetric metamolecules with inward and outward radial magnetic fields, magnetic dipole-like responses can be produced just as an electric dipole is formed by separating two opposite-signed electric charges.

Keywords: Magnetic monopole; Metamaterials; Electric resonance

1. Introduction

One of the most basic properties of magnetism is that a magnet always has north and south poles that cannot be separated into two isolated poles. This is in contrast to electricity where there are isolated negative/positive electric charges and an electric dipole can be generated simply by separating two opposite-signed electric monopoles. Usually, a magnetic dipole is thought to be produced by a closed circulation of electric current (Fig. 1(a)), rather than the separation of two magnetic monopoles. In spite of the lack of favorable experimental evidence of magnetic monopoles, there are sound theoretical reasons for believing that magnetic monopole must exist [1–3]. Researchers have never ceased to find monopoles in nature in the last several decades and there are some promising results. Magnetic monopoles are found to exist in frustrated magnetic materials, known as spin ice [4–8]. The spin ice state manifests itself in the fractionalization of the microscopic dipole degrees of freedom, leading to the de-confined magnetic monopoles. Inspired by this, researchers have also found similar magnetic monopoles in two-dimensional artificially structured thin films [9–12].

Metamaterials, as one typical kind of emerging artificial materials, exhibit unique physical properties

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http://dx.doi.org/10.1016/j.photonics.2014.05.002
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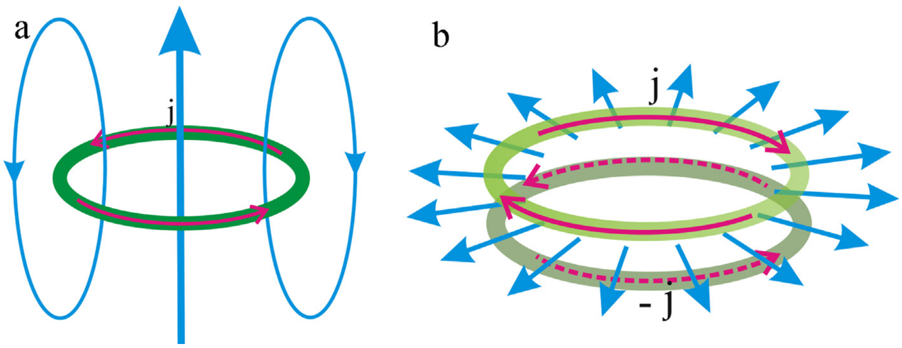

Fig. 1. Realization of magnetic dipole- and monopole-like responses. (a) A current loop **j** produces magnetic dipole-like response; (b) two anti-parallel current loops **j** and −**j** with a small spacing produce magnetic monopole-like response.

such as exotic artificial magnetism [13–15]. One motivation of driving metamaterials is the idea of building perfect lens [16,17]. With the rapid development of metamaterials, researchers have found that metamaterials can be used to realize many other novel functional devices such as electromagnetic cloaks [18], wormholes [19] and wave-shape transformers [20]. Especially, due to the design freedom of metamaterials, many elusive electromagnetic response modes can be realized quite conveniently. For example, based on the electromagnetic responses of magnetic metamaterials with asymmetric unit cells, magnetic toroidal dipole-like responses can be achieved [21,22].

In this paper, we are devoted to exploring magnetic monopole-like response in metamaterials. First of all, we must consider how to get a magnetic monopole imaginarily. As is well known, a magnetic dipole can be produced by a closed current loop **j**. The orientation of magnetic flux through the current loop is determined by the current direction on the loop. If we put two sub-wavelength loops with anti-parallel currents **j** and −**j** close enough (far less than the wavelength), the magnetic lines threading through the two loops would vanish, leaving only radial magnetic lines, as shown in Fig. 1(b). In this way, a two-dimensional magnetic monopole-like response can be produced. Hence, the key to obtaining the magnetic monopole-like response is to construct sub-wavelength metamolecules on which anti-parallel induced currents can be excited.

2. Metamaterial design

To get the magnetic monopole-like response, a double-side metamaterial slab is designed as shown in Fig. 2(a). The sub-wavelength metamolecule is composed of two split-ring resonators (SRRs) with opposite

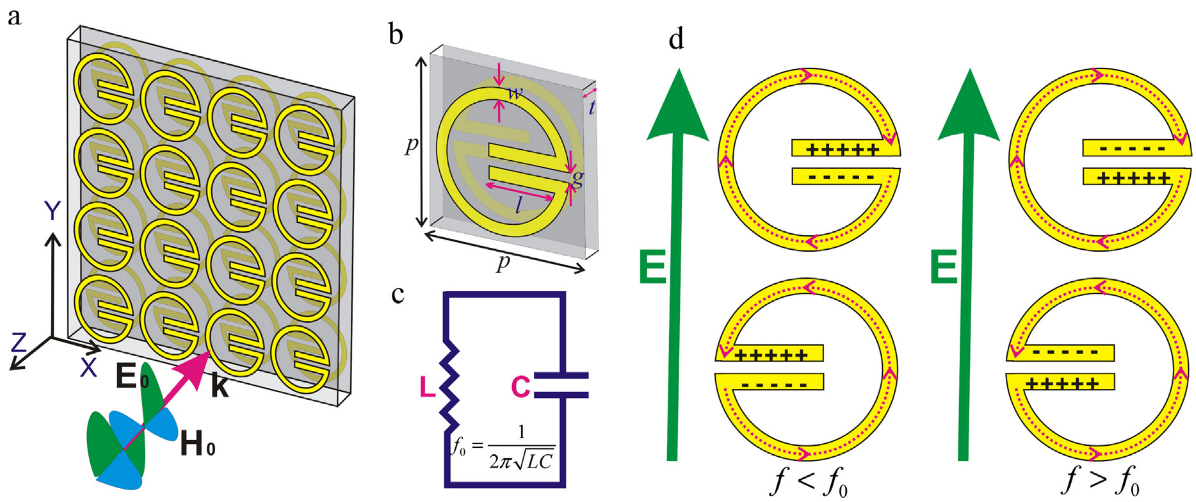

Fig. 2. Metamaterial slab supporting magnetic monopole-like response. (a) A thin layer of metamaterial slab; (b) the metamaterial unit cell: a SRR is patterned on the front side of the dielectric spacing while a mirror copy of the front SRR is patterned on the back side; (c) the equivalent LC resonant circuit model of the unit cell; (d) Formation of anti-parallel currents on the SRR pair.