Three-dimensional Split-Ring Resonators for Isotropic Magnetic Metamaterials

Che Chin Chen[1,2], Atsushi Ishikawa[2], Takuo Tanaka[2,3], Yu-Hsiang Tang[1], Ming-Hua Shiao[1], and Din Pin Tasi[4]
[1] *Instrument Technology Research Center, National Applied Research Laboratories, Taiwan*
[2] *Metamaterials Laboratory, RIKEN, Japan*
[3] *Research Institute for Electric Science, Hokkaido University, Japan*
[4] *Research Center for Applied Sciences, Academia Sinica, Taiwan*
E-mail: t-tanaka@riken.jp; http://metamaterials.riken.jp/

1. Introduction

The unique effective material parameters, such as negative indices, corresponding to its geometry design of Metamaterials (MMs) have attracted enormous interests in last decade. Among them, the split ring resonators (SRRs) were demonstrated as the promising candidate to perform the magnetic response which revealing a negative permeability. To obtain magnetic response of SRRs, the magnetic field component of incident light must oscillate through the SRR plane. Thus, fabricating the standing-up type SRRs, in which the normal incident light easily has largest magnetic field component perpendicular to the SRR plane, are the most direct solution [1]. In the application point of view, the criterion to construct a substantial device is to possess isotropic optical responses between electromagnetic waves and MMs. In the present work, we fabricated a four-fold symmetric MMs by metal-stress-driven assembled three-dimensional (3D) SRRs and demonstrated isotropic characteristics of the fundamental mode with illuminated light within a finite incident angle.

2. Methods

The fabrication procedures of our SRRs are as follows. First, by means of electron beam lithography, the four-fold symmetric unit cells with a total area of 4mm by 4mm were defined and thermally deposited with Ni (10nm)/Au (60nm) on the substrate (Si). The unit cell consists of two arms and a center connecting pad. Notice that, the connecting pad was purposely designed in a wider width comparing to the arms so that after dry etching process the connecting pad was still remain on the substrate. During deposition process the stress was intrinsically formed inside the metal. The dry etching process was then utilized to release arms from the substrate. While the arms released from the substrate, the metal stress pulls up the arms forming a 3D SRR. A Fourier transform infrared spectroscopy (FTIR) is employed for the characterization of transmittance spectra. The calculated transmittance spectra and the corresponding field patterns were accomplished through COMSOL multiphysics (not shown here).

3. Results and Discussion

The fabricated four-fold symmetric MMs consisting of two checkered array with 45^0 stagger design of 5.9 and 8 um pitch, respectively, was shown in Fig 1 (a). The normal illumination transmittance spectra with varying polarization were shown in Fig. 1 (b). The unambiguous resonant deeps (ϕ=0) were observed at wavelength around 11.5 (fundamental mode), 5.7, and 3.8 μm, respectively. While the simulated spectrum showing similar trend with FTIR experiment revealed deeps around 10, 5, and 3μm, respectively. The corresponding field patterns and analyses by simulation will be discussed later. Note that, with varying the polarization of incident light, the result show almost same spectrum meaning that at normal incidence our MMs present the isotropic properties. Moreover, in Fig. 1 (c), we demonstrate the oblique incident experiment with incident angle (ψ) from 0 to 40 degree. We observe a striking phenomenon that for the fundamental modes the variations of the spectral position and excitation strength are less than 8 %. More details about experiments and simulations will be discussed in the presentation.

References

[1] Che Chin Chen et al., Opt. Express. **20** (2012) 9415.

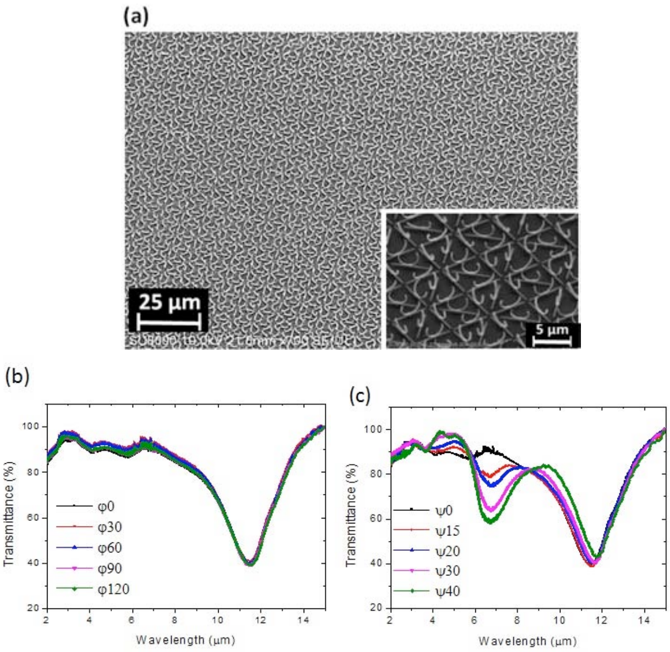

Fig. 1 (a) SEM micrographs of the present symmetric SRRs. Insets represent the scale bars, respectively. (b) Transmittance spectrum of normal illumination experiment. With varying polarization, the results show isotropic responses. (c) Transmittance spectrum of oblique illumination experiment. For the fundamental mode, the spectral position and excitation strength variation is about few percent.