Frequency splitting of a multi-layered metamaterial

Sung Gug Kim [1], Kwang hoon Kim [1] , Hoesu Jung [2], HyungJoon Cho [2,3], Eunmi Choi [1,2,*]
[1] School of Electrical and Computer Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan 689-798, Republic of Korea
emchoi@unist.ac.kr
[2] School of Natural Sciences, Ulsan National Institute of Science and Technology (UNIST), Ulsan 689-798, Republic of Korea
[3] School of Nano-Bioscience and Chemical Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan 689-798, Republic of Korea

Abstract

We present new experimental results on a resonance frequency splitting of multi-stacked metamaterials. A single layer of the metamaterial consists of electric ring resonator (ERR) unit cells at X-band frequency range. The electromagnetic response of the multi-layered ERR structures has been measured by a X-band Vector Network Analyzer (VNA). Experimental results are compared to simulation results in the paper.

Keywords : Metamaterial, Frqeuency Selective Surface (FSS), X-band, Perfect Absorber

1. Introduction

Recently, interest on a metamaterial based structure has been greatly increased due to its exotic behaviour and its potential applications in which people have not been thought before. Landy et al. [1] reported in their study on a metamaterial perfect absorber at X-band frequency, which is literally absorbing almost 100 %. They have chosen a metamaterial structure based on an electric ring resonator (ERR). After the study, there have been published numerous papers in the perfect metamaterial absorber at different frequency ranges up to Far Infrared range. Aiming at a 3D metamaterial structure opens a new era for the metamaterial field [2]. People started to fabricate a nanoscale device which is not a planar structure but a bulky 3D structure in THz and IR frequency range. It enables the metamaterial to be applicable for a real life. Frequency selectiveness is the most peculiar behaviour of the metamaterial. Functioning at a right frequency is one of the critical factors in the metamaterial based device. However, a multi-layer metamaterial study on its resonance and polarization behaviours is not yet investigated. We focus on the frequency behaviour in the multi-layered metamaterial experimentally and compared to the simulation results.

2. Experimental Setup

Figure 1 shows the patterned ERR arrays which were used in the experiment and the experimental setup. The fabricated ERR planar array consists of 46x17 arrays of ERRs as shown in Figure 1. Each cell has dimensions of $a_1=a_2=3.9$, $t=0.9$, $g=0.606$, $w=4.2$, $h=12$ all in mm unit. The thickness of the FR4 substrate is 0.6 mm. The ERR is in place in the middle of two quadridge horn antennas. Agilent Vector Network Anaylzer (PHA-X N5242A, 10 MHz-26.5 GHz) was used for the S-parameter measurements. As shown in Figure 1, the two different polarizations were used in the experiment: one of which is the electric field polarized in the y direction (y pol), and the other is the electric field polarized in the x direction (x pol). The wave from one port of the VNA has a direction in the z which is normal to the plane of the ERR layer. For the multi-layer experiment, up to 4 layers of the ERR layer were stacked.

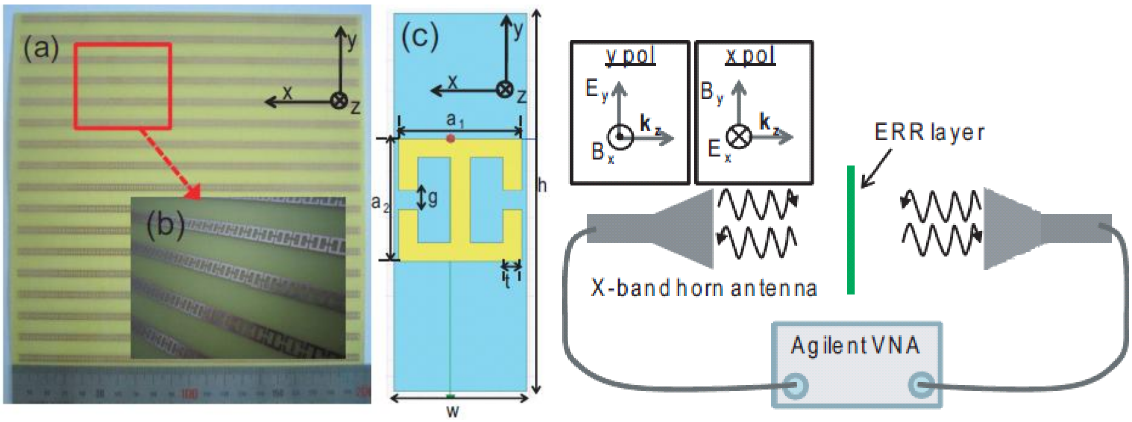

Figure 1. The planar array of ERR unit cells and experimental setup

3. Experimental Results and Analysis

Figure 2 shows the experimental results of the transmission as a function of frequency and comparison to the simulation. The simulation of the multi-layer ERR structure were done by a commercial software High Frequency Structure Simulator (HFSS, v12). A Floquet port option in the software was used for the repeating ERR unit cell simulations. Experimental results up to 4 layers (single, double, triple, and quad layer) are plotted a s seen in Figure 2, and the simulation result are compared at the y pol and the x pol cases.

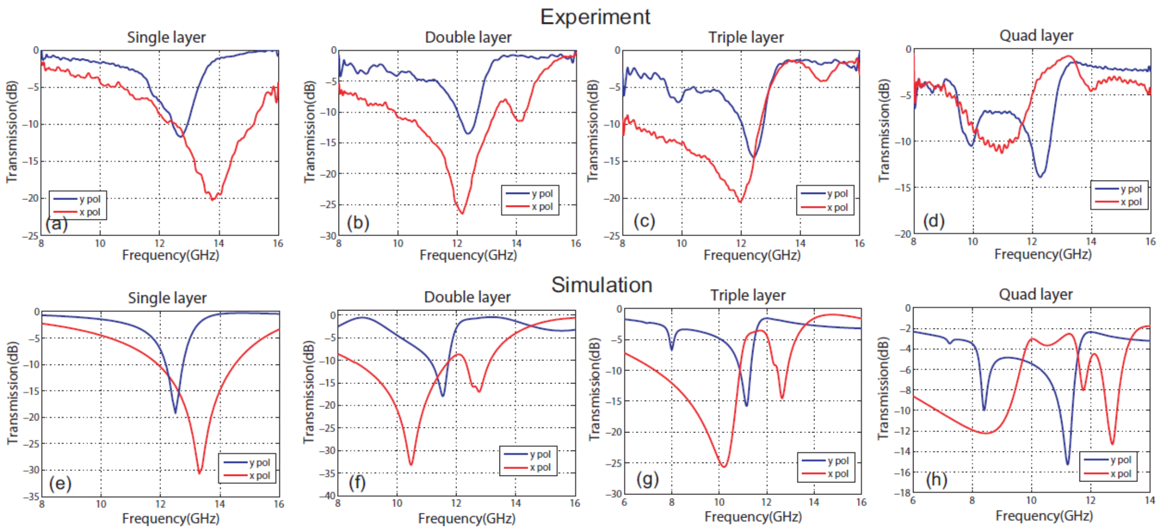

Figure 2. Experimental and simulation transmission spectral results of the multi-layer ERR test

Noticeably, the experimental results are in good agreement with the simulation results. For the single layer, only one resonance peak appeared in both experiment and simulation under the y pol and the x pol. However, for the double layer, two resonance peaks are observed in the x pol in both experiment and simulation. For the triple layer, the y pol also has two resonance peaks one of which appears at the lower frequency with a weak peak, which is also seen in the simulation. As for the quad layer, the two resonance peaks in the y pol and the multiple resonance peaks in the x pol are observed in both experiment and simulation. Starting from the single layer, as the layer is added, the resonance frequency starts to splitted. For the analysis, we have carefully examined the surface current of each layer. The polarizations due to the multi-layering effect introduce anti-symmetric or asymmetric surface current at the splitted resonance frequency, which happens at lower resonance frequency.

Table 1. Summarized surface current distribution symmetry

		1^{st} peak		2^{nd} peak	
		y pol	x pol	y pol	x pol
Single layer		symmetry	symmetry		
Double layer	1^{st} layer	symmetry	symmetry		antisymmetry
	2^{nd} layer	symmetry	symmetry		asymmetry
Triple layer	1^{st} layer	symmetry	symmetry	antisymmetry	symmetry
	2^{nd} layer	symmetry	symmetry	antisymmetry	symmetry
	3^{rd} layer	symmetry	symmetry	antisymmetry	asymmetry

Table 1 summarized the symmetric behaviour of the surface current for multi-layered ERR under different polarizations.

4. Experiment and Analysis of an Oblique Incident Angle

Figure 3 is the result of the resonance frequency behaviour at oblique incident angle of a single ERR layer.

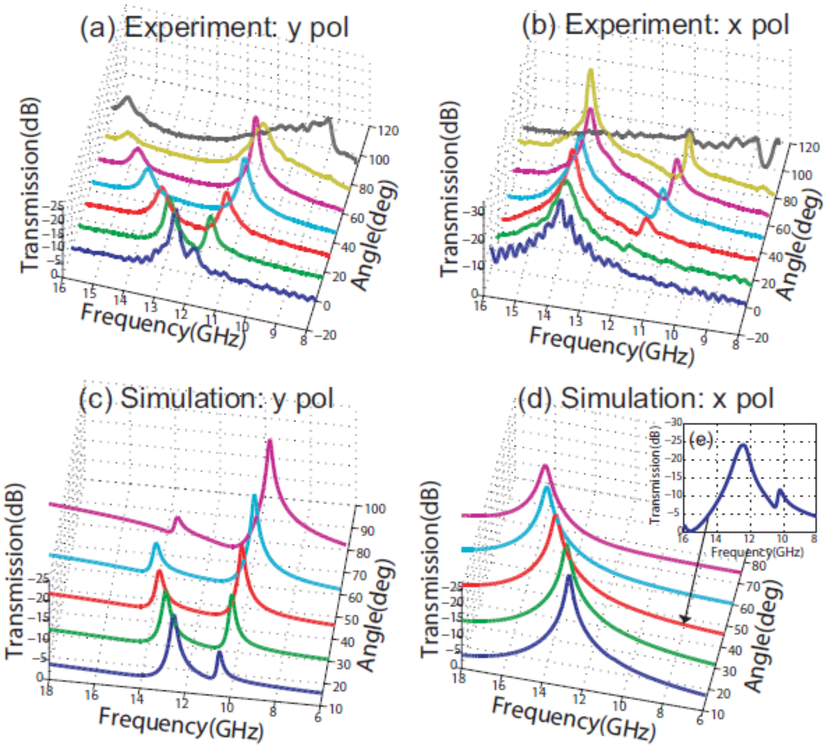

Figure 3. Experimental and simulation transmission results of transmission under oblique incident angle

The frequency is splitting as the incident angle becomes greater for the y pol in both experiment and simulation. For the x pol, the experimental result shows the frequency splitting while the simulation result does not have a frequency splitting. The reason for the difference in the x pol measurement, we have noticed that if a small angle of the ERR plane with respect to the y axis, which is due to misalignment of the layer is introduced, magnetic dipole coupling could be excited. And it was confirmed by simulation shown in the inset graph of Figure 3. Unlike the x pol, when a small angle is introduced, there is not much of change in the y pol (result not shown in the paper).

5. Conclusions

We have demonstrated that the multi-layered metamaterial structure could have different behaviours in frequency compared to the single metamaterial layer. The resonance peak splitting is more dominant when the electric field is polarized in short arms of ERR (x pol in the paper) while the wave is propagating perpendicularly to the ERR layer plane. Obliquely incident wave also shifts and splits the resonance peak of a single layer.

References

[1] N. I. Landy, S. Sajuyibe, J. J. Mock, D. R. Smith, and W. J. Padilla, "Perfect Metamaterial Absorber," Physical Review Letters 100, 207402, 2008.
[2] H. T. Chen, F. O'Hara, F. Chen, A. Azad, and A. J. Taylor, R. D. Averitt, D. B. Shrekenhamer, and W. J. Padilla, "Experimental demonstration of frequency-agile terahertz metamaterials," Nature Photonics, Vol. 2, pp.295-298, 2008.

Acknowledgments

The authors wish to thank J. H. So and W. S. Lee at the Agency for Defence Development (ADD) for the use of quadridge horn antennas for the study. This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (Contract No. 2011-0006023)