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Full Length Research Paper

A magnetically tunable double negative material

Li Tianqian[1,2]*, Wen Guangjun[1], Huang Yongjun[1] and Xie Kang[3]

[1]School of Communication and Information Engineering, University of Electronic Science and Technology of China, Chengdu- 610054, China.
[2]School of Electrical and Information, Xihua University, Chengdu-610039, China.
[3]Key Laboratory of Broadband Optical Fiber Transmission and Communication Networks, Ministry of Education, University of Electronic Science and Technology of China, Chengdu-610054, China.

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A magnetically tunable double negative material is experimentally synthesized by incorporating PMWA (periodic metallic wire array) with negative effective permittivity into YIG (yttrium iron garnet) applied by external magnetic field with negative effective permeability. The experimental results show that electromagnetic (EM) wave can pass through the composite medium when the effective permittivity of the PMWA and the effective permeability of YIG substrate are negative simultaneously. Under an applied external magnetic field changed from 1900 to 2800Oe, the double negative transmission pass band center of the composite media is tuned from 7.5GHz to 9.8GHz accordingly.

Key words: Periodic metallic wire array, yttrium iron garnet, tunable, double negative material.

INTRODUCTION

Double negative material (DNM) is also termed as left-handed material (LHM). Negative refractive behavior of substance with simultaneously negative effective permeability and permittivity (double negative) has been predicted theoretically by Veselago (1968). The DNM based on periodically arrayed split ring resonators (SRRs) and PMWA (periodic metallic wire array) has been fabricated by D.R. Smith (Smith et al., 2000). A lot of similar structures are proposed subsequently (Smith et al., 2000; Gokkavas et al., 2006; Zhang et al., 2005; Chen et al., 2004).

However, these methods are static and application restrictive. Recently, the DNM based on YIG (yttrium iron garnet) and PMWA have been proposed and simulation verified (Cao et al., 2007). By virtue of YIG tuning capability, the tunable double negative transmission characteristics of the novel DNM has been experimental realized, and the negative refractive index has been numerical calculated (He et al., 2007). But, in all the foregoing experiments, for the DNM are put into rectangle waveguide to test, the size of rectangle waveguide limit the size of DNM.

In this letter, we realize the magnetic tunable DNM based on YIG and PMWA, design testing device, and carry out experiments to verify its magnetic tunable double negative transmission characteristics. SRRs are replaced by 1 mm–thick YIG slices. The DNM sample is wear to desired size by emery wheel and put into a parallel plate waveguide (PPW) with nonmagnetic absorber on both sides, which ease the required size of the sample.

The structure

The DNM is constituted by 1 mm-thick YIG slabs and 0.018 mm-thick copper PMWA layers cascaded alternately. The structure and photo of the tunable DNM sample is show in Figure 1. The inset shows the model of PMWA. The parameters are: a=10.16 mm, b=1 mm, c=0.2 mm, d=1.308 mm, e=18 mm, f=1 mm, g=0.254 mm, h=0.018 mm. The PMWA is etched on one sides of a 0.254 mm-thick Rogers' 5880 circuit board material substrate (dielectric constant ε_r=2.2) to minimize dispersion and losses for high frequency/ broad band

*Corresponding author. E-mail: tqplum@yahoo.com.cn.

Abbreviations: PMWA, Periodic metallic wire array; **DNM,** double negative material; **EM,** electromagnetic; **LHM,** left-handed material; **SRRs,** split ring resonators; **YIG,** yttrium iron garnet; **PPW,** parallel plate waveguide; **HFSS,** high frequency structure simulator.

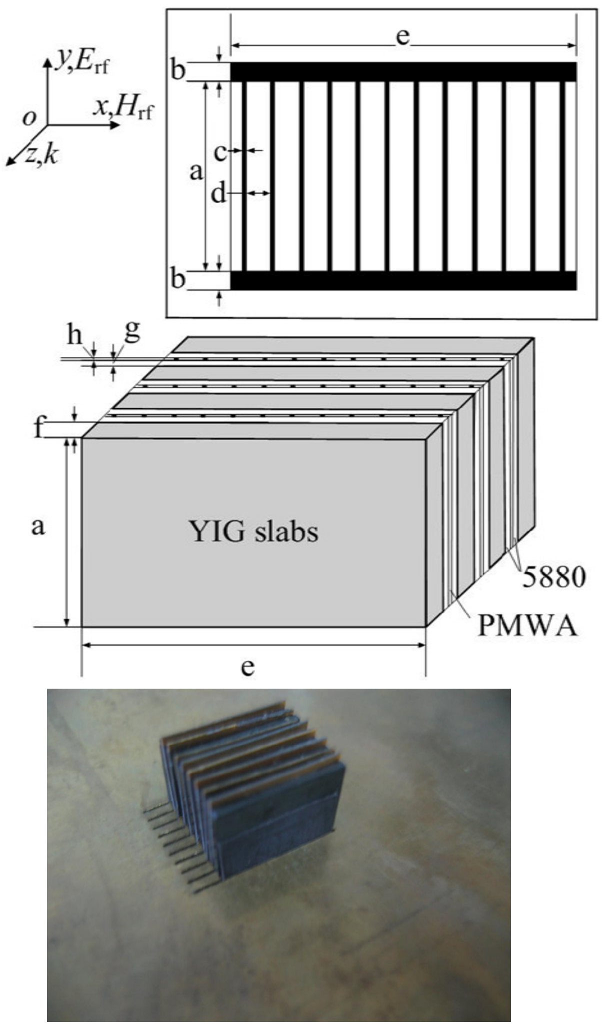

Figure 1. The tunable DNM sample.

applications. The structures are conglutinated to a block by electric glue, and the top and bottom 1mm of PMWA-5880 PCB is used to embed into the two 1mm-deep notched copper plates of PPW for fixation. The physical parameters of the YIG used in current experiment are as follows:

Saturation magnetization:

$4\pi M_s = 1830\text{Gs}$

Line width: $\Delta H = 22\text{Oe}$

Permittivity: $\varepsilon_\text{r} = 13.8$

THE EXPERIMENT DEVICE

We designed a set of experiment devices to test our DNM sample. Figure 2 shows the experimental device for the measurement of power transmission through a slab of DNM. The inset of Figure 2 is H-type magnetic core of the magnetic field generator. The magnetic field generator generates external bias magnetic .we use two E-type magnetic cores made of A3 steel to form magnetic field generator's H-type magnetic core, coiling with enameled Copper wire which diameter is 1.45 mm. The DNM sample is settle in a PPW in y direction. The TE_{10} mode RF signal ranging from 6 to 12 GHz is fed to PPW though two rectangular waveguide ports in z direction, as show in Figure 2. The electric field E_{rf} parallel to the y axis and magnetic field H_{rf} parallel to the x axis. The external magnetic field magnetic field is parallel to the PMWA along the y axis. The scattering parameters are measured by an HP8720ES network analyzer.

THE EXPERIMENTSTEPS

Five steps are done to perform the experiment. Firstly, power transmission property of two X band rectangular waveguide adaptors connected together by flanges is measured. From S parameters result gotten by scalar microwave network analyzers, the loss of rectangular waveguide adaptors on X band is limited to -0.5 dB. Secondly, power transmission property of the whole experiment devices without samples is measured. The loss of the whole experiment devices on X band is limited to -10 dB. The least attenuation on pass band is 4.667 dB. Thirdly, power transmission property of the whole experiment devices with only 10 pieces of PMWA etched on one side of 5880 substrate embedded in PPW is measured. The S21 transmission coefficient on X band is less than -20 dB. Fourthly, power transmission property of the whole experiment devices with only 10 pieces of YIG slabs placed in PPW is measured, applied by external magnetic field along y direction, to observe the magnetic tunable forbidden band induced by the negative permeability. When external magnetic field H_0 is set to 0, the YIG is equal to Dielectric Material without magnetization. When external magnetic field H0 is set to 1600Oe, there indeed exists a forbidden gap at about 7.5 GHz. when external magnetic field H_0 is tuned from 1900 to 2800Oe, the forbidden gap is changed from about 7.5 to about 9.8 GHz, correspondingly. The magnetic tunable forbidden band induced by the negative permeability. Fifthly, power transmission property of the whole experiment devices with 10 pieces of samples described in Figure 1, placed in PPW is measured, to get the result of transmission experiment of the tunable DNM sample designed.

RESULTS

The result of transmission experiment of the tunable DNM sample designed is shown in Figure 3. Applied by external magnetic field along y direction, a pass band appear on the position where is forbidden band in the fourth step of the experiment. When external magnetic field H0 is tuned from 1900 to 2800Oe, the pass band is changed from about 7.5 to about 9.8 GHz correspondingly. The right higher peaks appeared in the curves of Figure 3 is the double negative transmission pass band center of the composite media. The left lower peaks appeared in the curves of Figure 3 is the double positive transmission pass band center of the composite

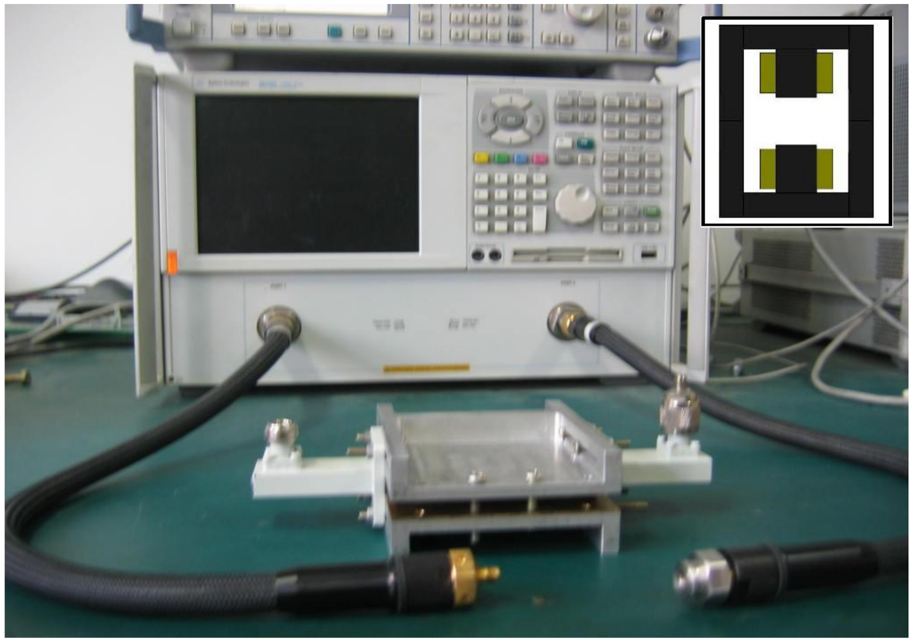

Figure 2. Method to generate plane wave and retrieve S parameter of DNM.

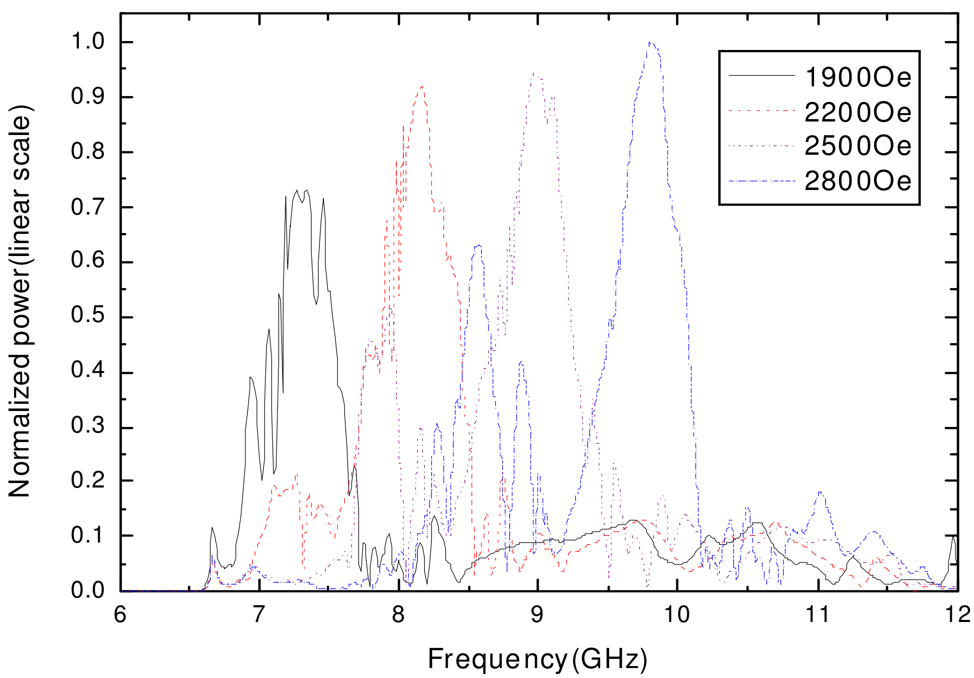

Figure 3. Results of transmission experiments.

media.

We perform numerical simulations of an ideal model using High Frequency Structure Simulator (HFSS). The program simulated a single unit as shown in Figure 1 with perfect electric boundary condition (y direction) and perfect magnetic boundary condition(x direction). External magnetic field along y direction is applied. Waveguide ports on the other boundaries simulated a TEM plane wave propagating through the medium. Take into account t the precision of experimental device and

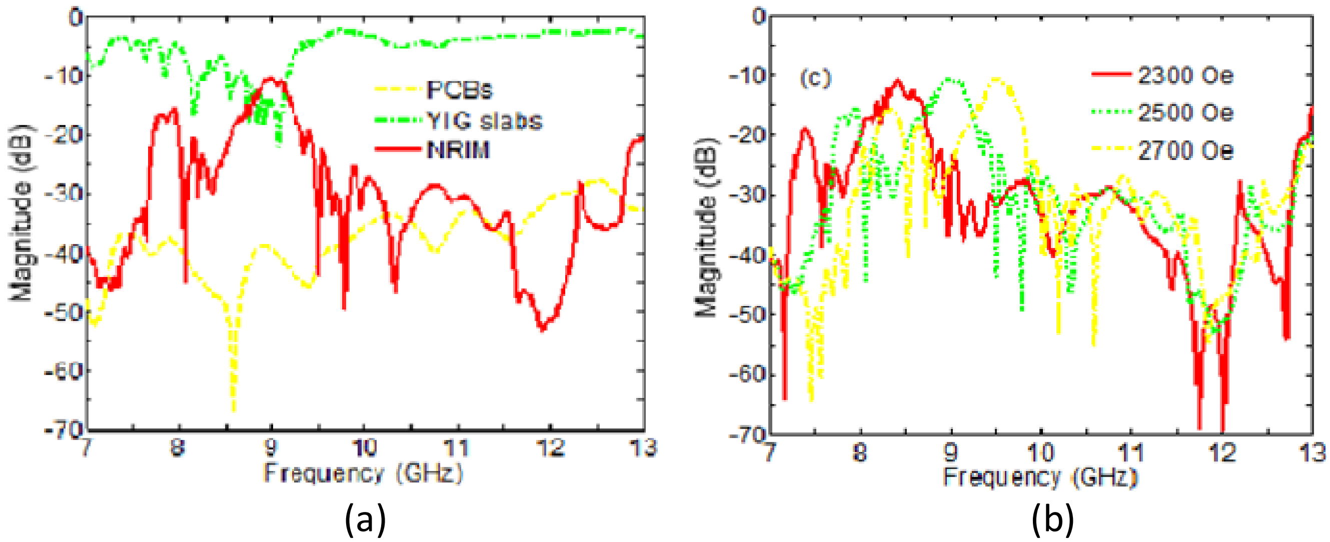

Figure 4. Results of simulation: (a) Electromagnetic wave transmitting characteristic simulation of the DNM model; (b) The magnetic tunable characteristic simulation of the DNM model.

DNM tailoring, the result of simulation and experiment accord approximately. From the simulation result shown in Figure 4(a), the double negative transmission pass band can be observed in microwave X frequency band. From the simulation result shown in Figure 4(b), The double negative transmission pass band's central frequency is increased from 8.42 to 9.50 GHz, while external magnetic field increase from 2300 to 2700 Oe.

Conclusion

A simple novel method to fabricate magnetic tunable DNM is validated in this letter by experiments. We replace SSRs with YIG slice to realize negative permeability. The PMWA show plasma-like behavior. With the addition of YIG slab we demonstrate magnetic tunable DNM employing YIG and PMWA. Such a DNM provide a novel means to fabricate a low-loss, magnetic tunable double negative material.

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