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Shift Resonant Frequency by Changing Space Between Layers in Left-handed Materials*

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Abstract: In order to study the relation between the space between layers and the resonant frequency in periodic structures left-handed materials, the prism-shaped samples are produced as the spacing of 3.08 mm, 2.93 mm, 2.73 mm and 2.33 mm. The diagrams of the intensity and frequency are obtained by measuring the refraction of electromagnetic waves through the samples with HP8720ES scalar network analyzer. And the curves of the electromagnetic wave frequency and intensity are simulated of the spacing for 3.23 mm, 3.13 mm, 3.03 mm, 2.93 mm and 2.73 mm of prism-shaped samples. Experimental and simulation results are consistent, that is, the resonant frequency shifts from high frequency to low frequency with the decreasing space between layers.

Key words: Resonant frequency; Space between layers; Left-handed materials
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0 Introduction

In 1968, Veselago theoretically investigated an unusual material and predicted some extraordinary properties such as negative refraction, inverse Doppler and inverse Vavilov-Cherenkov effects. This material does not exist naturally, and his idea did not almost attract much attention in the past 30 years. Since Smith have experimentally demonstrated the phenomenon of negative refraction with artificial metallic composites[1], which consists of small metallic wires and split ring resonators (SRRs), many papers have reported about these materials[2-9]. Among these artificial materials, rectangular SRRs composite is the first and the most frequently used to study the properties of left-handed materials.

The negative refraction phenomena occurs only in the microwave band, and the application of the left-handed materials is greatly limited. Our goal is to shift the resonant frequency from low frequency to the visible light band by changing the space between layers.

1 Experiment

We take the rectangle periodic structures as example to confirm the theoretical results through fabricating corresponding samples. The thickness of copper film is 0.03 mm.

We design the rectangle SRRs, and the unit of the rectangle periodic structures is shown in Fig. 1. The experimental samples are fabricated to confirm the relationship predicted theoretically. The experimental device and experimental samples are shown in Fig. 2 and Fig. 3.

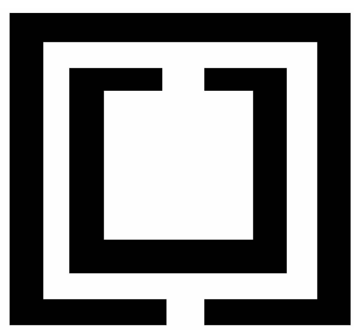

Fig. 1　The unit of the rectangle periodic structures

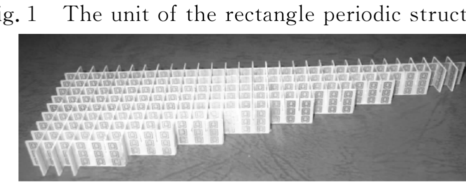

Fig. 2　The prism-shaped samples

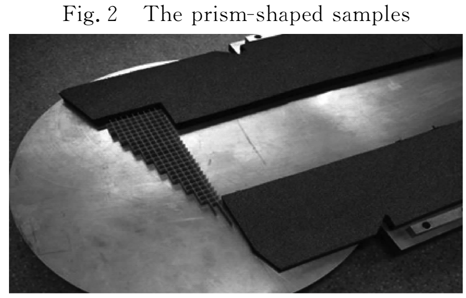

Fig. 3　The experimental device and experimental samples

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The microwave source and the detector are the HP8720ES scalar network analyzer[10]. The microwave is transformed by the coaxial waveguide. The microwave beam impinges on the longer side of sample with an incident angle of about 18.4°. After microwave propagating through the sample, the microwave beam encounters the second surface of the prism, the refraction interface, and is refracted into a direction determined by Snell′s law. To measure the refractive angle, we rotated the waveguide/power meter assembly in 1.5° steps and recorded the transmitted power spectrum over the 7～15 GHz microwave band range at each step[11-15].

To obtain the relationship between resonant frequency and space between layers, we use four prism-shaped samples, whose space between layers have different sizes. The spaces are 3.08 mm, 2.93 mm, 2.73 mm and 2.33 mm respectively. When the microwave goes through the samples, the result is given in Fig. 4.

According to Fig. 4, the space between layers is 3.08 mm, 2.93 mm, 2.73 mm and 2.33 mm. The negative refraction occurs at different frequency band with different geometry parameter of the space between layers. For the 3.08 mm space between layers in Fig. 4 (a), the frequency band is 9～14 GHz, the power of wave centralizes on 9～14 GHz; when space between layers is 2.93 mm, the resonant frequency band is 8.9～13.8 GHz; when space between layers is 2.73mm, the resonant frequency band is 8.8～13.1GHz; when thickness is 2.33mm, the resonant frequency band is 7～12.5 GHz. At the same time, the distribution of the power is different, the power concentrates at 9.2～10.0 GHz and 13.0～14.0 GHz for 3.08 mm in Fig. 4 (a); 9.0～9.5 GHz for 2.93 mm in Fig. 4 (b); 11.8～13.0 GHz for 2.73mm in Fig. 4 (c); 9.5～12.4 GHz for 2.33mm in Fig. 4 (d).

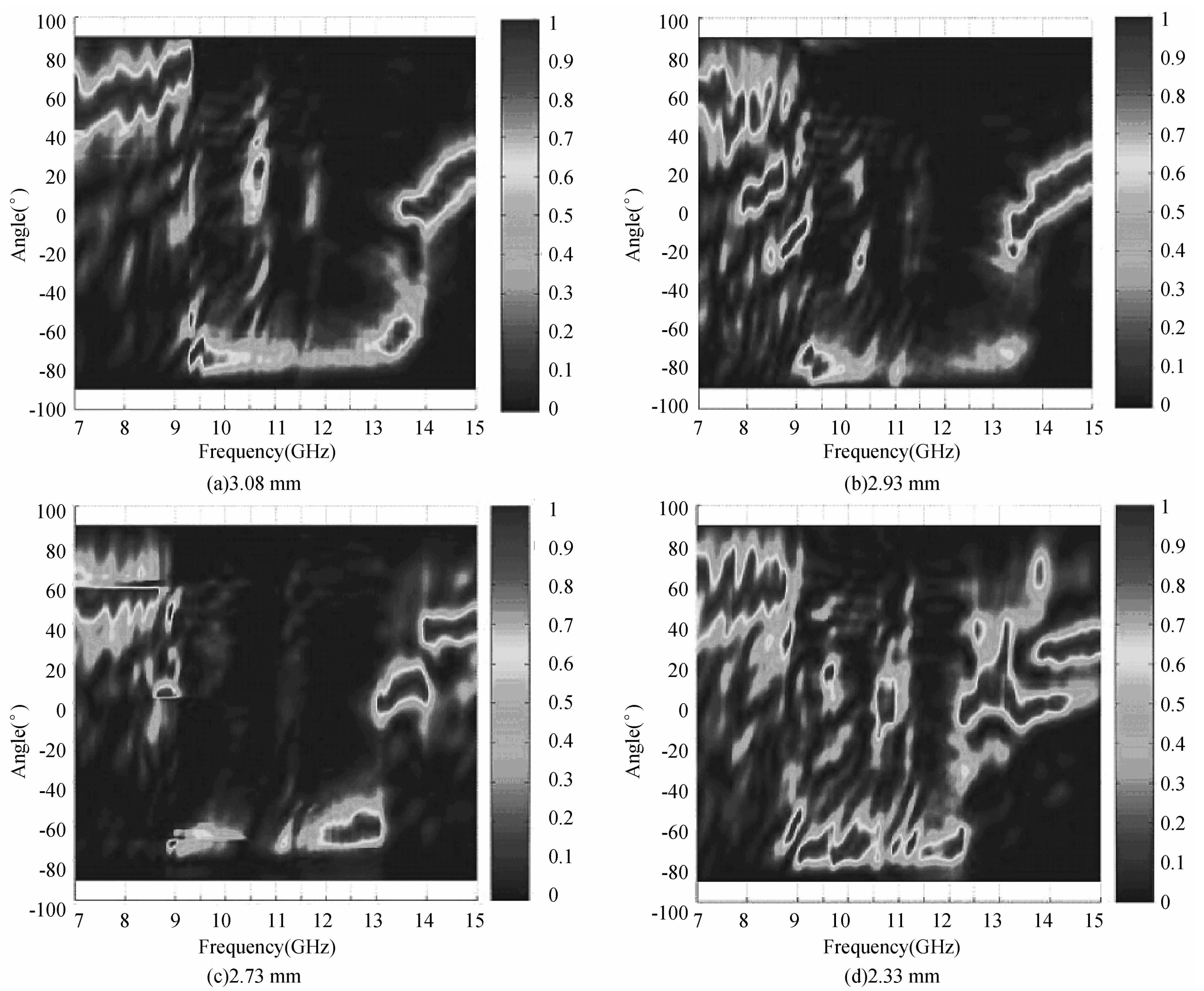

Fig. 4 Experimental results

The results are: when space between layers is becoming smaller, the resonant frequency band is shifting from high frequency to low frequency. At the same time the width of the response frequency is becoming small, the distribution of the power is different too. We realized the resonant frequency′s shifting by changing space between layers.

2 Simulation

We gave the five sizes of space between layers, such as 3.23 mm, 3.13 mm, 3.03 mm, 2.93 mm and 2.73 mm. The results of simultion are in the Fig. 5 (a)～(e).

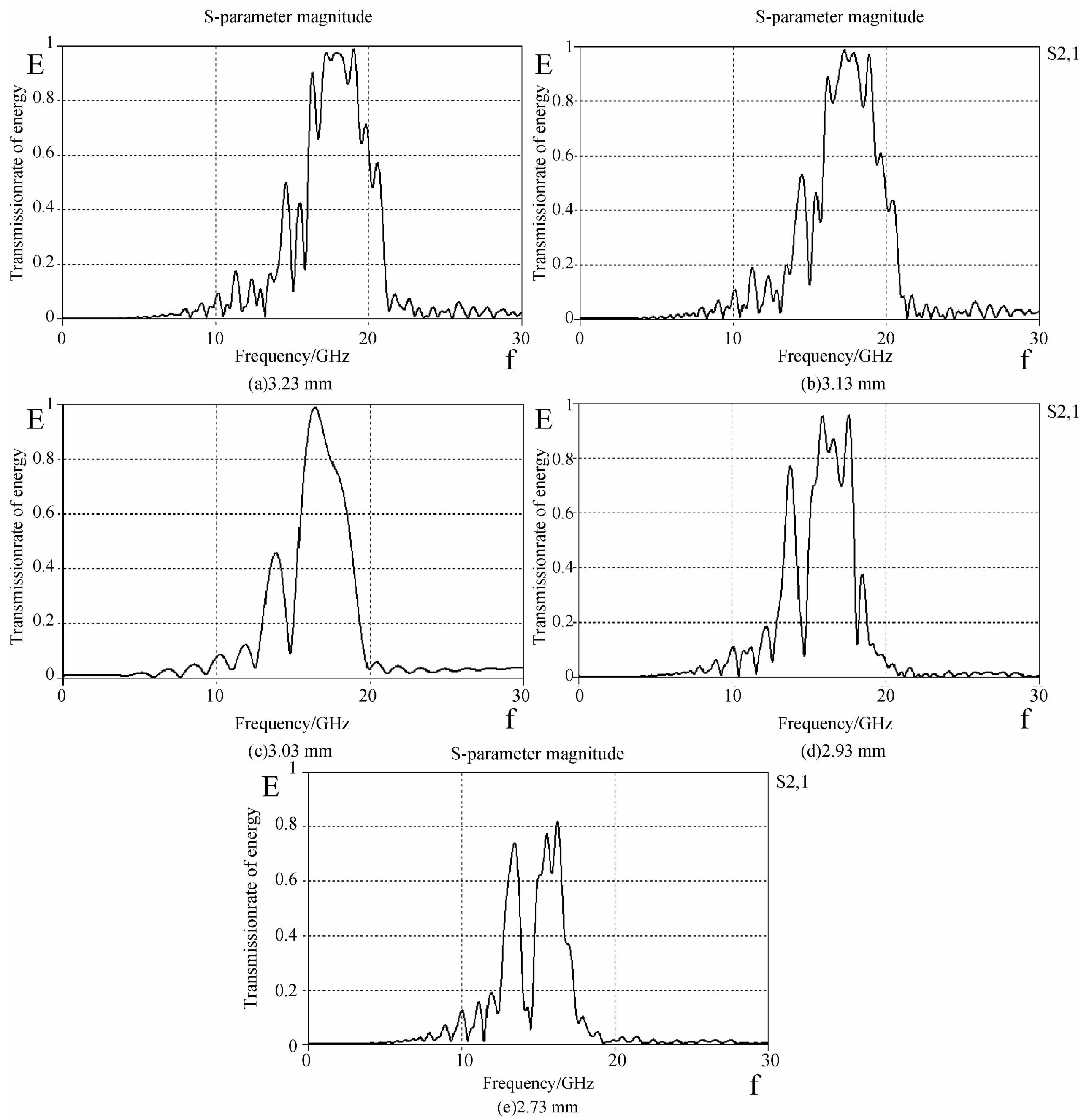

Fig. 5　The results of simultion

From the Fig. 5, we find the top of the power is near the 20GHz in (a), but in (e), the top of the power is in the midle of the 10GHz and 20GHz. The conclusion is that the top of the power shifts from high frequency band to low frequency band with the space between layers becoming smaller. The result is consistent with the experiment.

3 Conclusion

By experiment and simulation, we realized shifting the resonant frequency by changing space between layers. That is the resonant frequency shifts from high frequency to low frequency with the decreasing space between layers. If we want to realize the negative refraction in visible light frequency band, we can increase the space between layers. The paper may offer new method for shifting the resonant frequency to realize the negative refraction in visible light frequency band. This can greatly enhance the application of left-handed materials.

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左手材料中通过改变层间距实现谐振频率的移动

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摘　要：为了研究周期性结构的左手材料中层间距和频率的关系，分别制作了层间距分别为 3.08 mm，2.93 mm，2.73 mm 和 2.33 mm 的棱镜形样品。用网络分析仪 HP8720ES 测量了电磁波通过样品折射后的强度和频率的关系图。同时还模拟了层间距为 3.23 mm，3.13 mm，3.03 mm，2.93 mm 和 2.73 mm 的样品，得到了相应的频率和电磁波强度的关系曲线。实验和模拟结果一致，即：随着层间距的减小，谐振频率从高频向低频移动。

关键词：谐振频率；层间距；左手材料

WU Jun-fang was born in 1969, and graduated from Northwest University in 2004 with the M. S. degree. She is currently an associate professor at Xi'an Polytechnic University.