Study on Barium Strontium Titanium (BST)-based Metamaterial

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Abstract— In this paper, the barium strontium titanium (BST) is employed to form the modem layer in the metamaterial. We demonstrate an active metamaterial device capable of efficient real-time control and manipulation of microwave radiation. It is demonstrated that both the resonance frequency and bandwidth of the metamaterial can be tuned by varying the external electric voltage. Additionally, BST-based metamaterial with different geometries are explored.

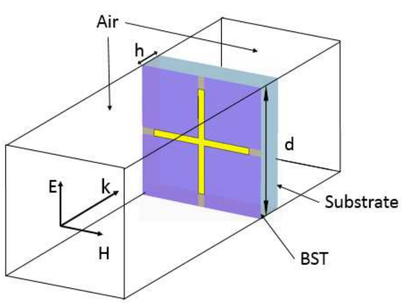
1. INTRODUCTION

Well-structured artificial electromagnetic material, known as metamaterial, has realized many unique phenomena which natural materials cannot be. In recent years, reconfigurable metamaterial has some exciting properties in scientific areas, including sensors, cloaks, and switches in optical communication [1–3]. Through the modulation of voltage, magnetic field, etc. [4–7], artificial electromagnetic materials add some new properties into materials. And makes them have more extensive applications [8].

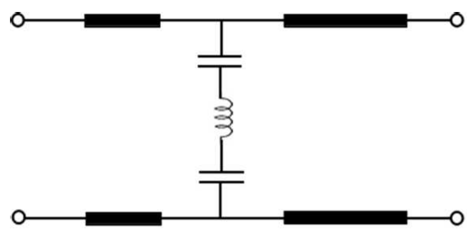
A great deal of work in metamaterial has used microwave radiation, this is because the microwave is widely used in communication as well as the ease of fabrication of sub-wavelength structures at these frequencies. Here, we demonstrate that the metamaterial with capacitor structure conclude BST film could achieve good effect of modulation in microwave frequency. Because the BST film has a high dielectric constant in the microwave and could be modulated by the external electric voltage [9]. This paper introduces a new method of modulating structure resonance frequency by voltage. The equivalent capacitance of the structure can be dramatically tuned, and the resonance frequency shifts subsequently.

2. LAALO$_3$-BASED METAMATERIAL

Figure 1(a) shows the LaAlO$_3$-based metamaterial unit, the substrate is made by LaAlO$_3$ which permittivity is 25, the top electrode is made by gold and the BST films is between them. The surface impedance can be characterized as a capacitor. The equivalent circuit model is shown in Figure 1(b).



(a)



(b)

Figure 1: (a) Schematic of the unit, the parameter: d is 3.5 mm, h is 251 µm (includes the thickness of BST film is 1 µm), and (b) equivalent circuit model.

2.1. Analytical Modeling

The reflectance R for LaAlO$_3$-BASED metamaterial with square patches is obtained by [10]

$$R = \frac{Z_s - \eta_0}{Z_s + \eta_0} \tag{1}$$

where $\eta_0 (= 377\Omega)$ is the intrinsic impedance of free-space, and Z_s is the total surface impedance. Here we set the periodic constant $d = 3.5$ mm, the length of the cross b is 3 mm. the thickness of electrode both on the top and bottom is 200 nm, with the BST film between them. And the width of the electrode is 120 μm. The thickness h of the substrate which was made by $LaAlO_3$ is about 0.25 mm. We set the length of the bottom electrode $n = 300$ μm in order to keep the overlapping part between the electrodes is 50 μm.

We get the variation range of dielectric constant is 74.6% from 0 to 1500 V/mm of the biased voltage [9]. Therefore, we will know the reflectivity under different dielectric constant due to applied voltage.

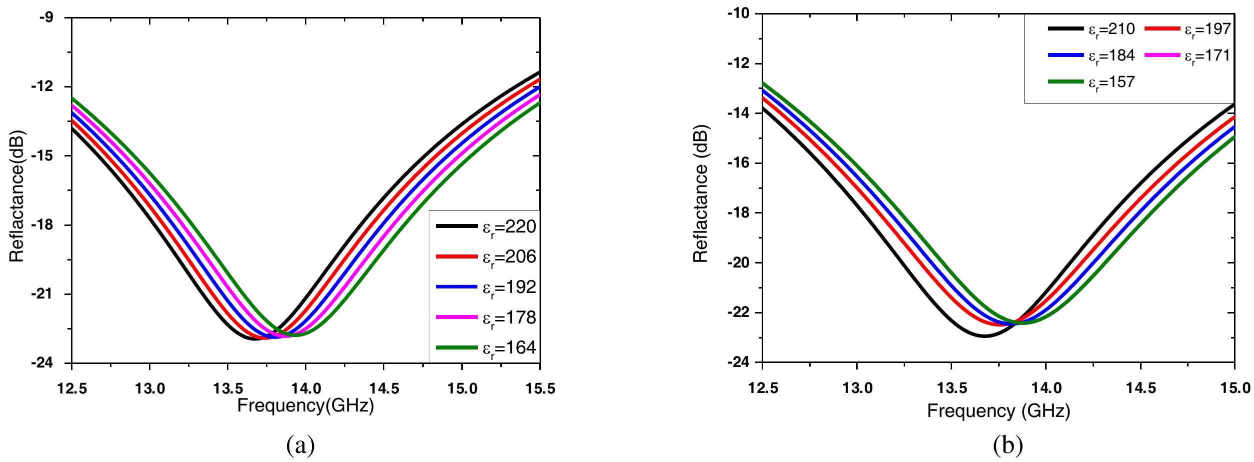


Figure 2: (a) Reflectance of the structure made by Au, relative dielectric constant are 220, 206, 192, 178, 164 and (b) Reflectance of the structure made by Pt. relative dielectric constant are 210, 197, 184, 171, 157 [11].

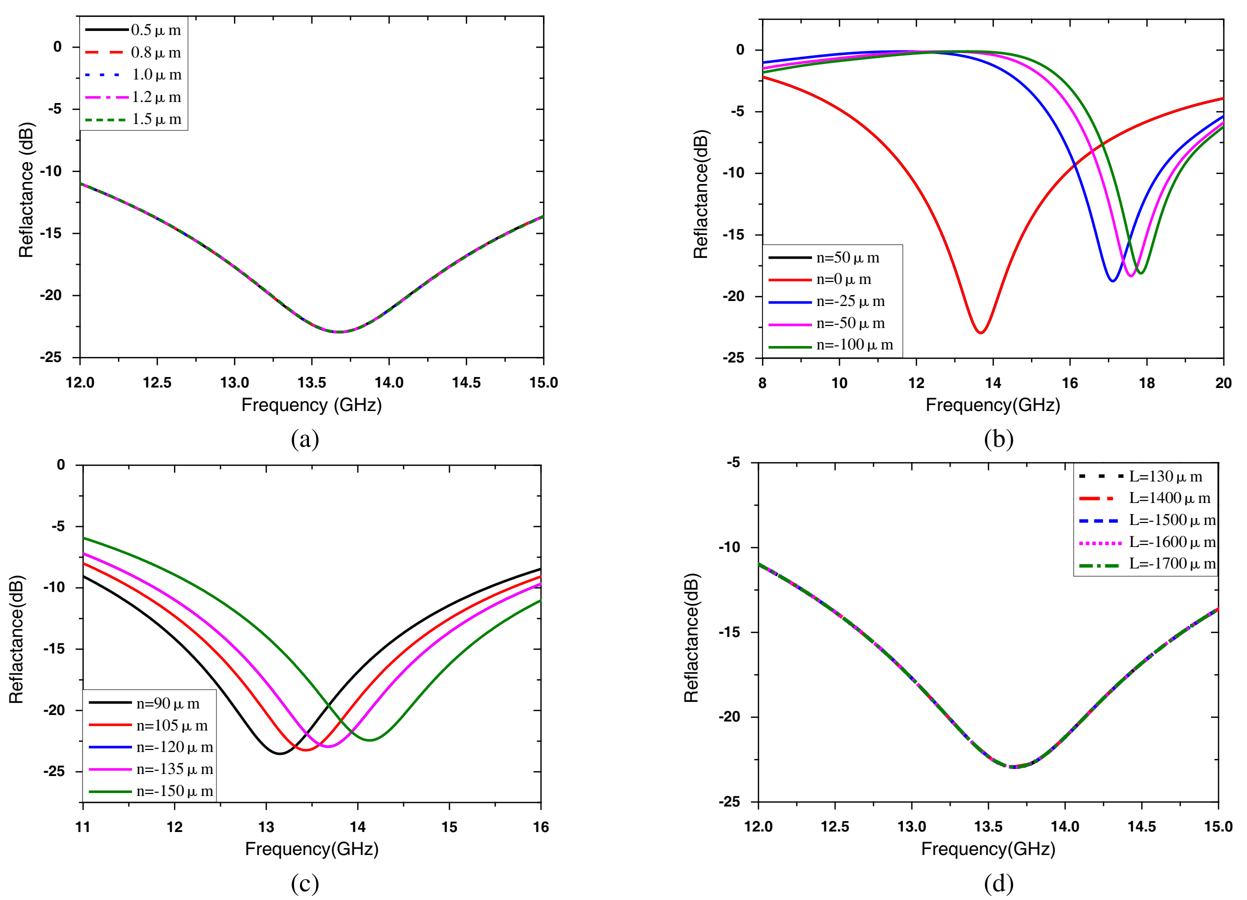


Figure 3: Parametric study of BST-based metamaterial with (a) thickness of BST film; (b) coincidence length between top and bottom electrode; (c) width of electrode; (d) length of the cross.

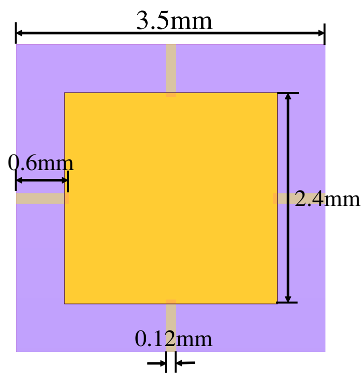
2.2. Study of Geometries

The thickness of BST film, the width of the electrode, the length of the bottom electrode and the cross may has an impact on the resonance frequency of the structure.

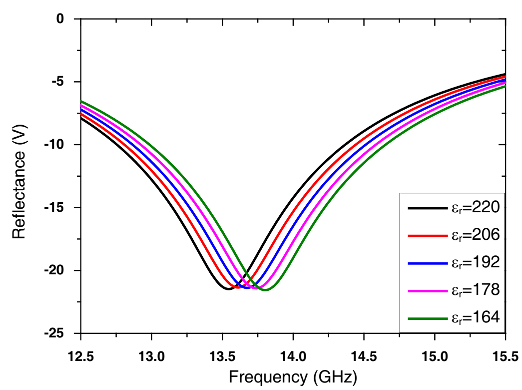
Figure 2(a) shows that the thickness of BST film has no effect on the resonance frequency with the permittivity of the BST film is 220. But this situation is based on that the stability of the permittivity of the BST film. And the thickness of the BST film will affect the permittivity if the voltage stay the same. So, if we want to keep the resonance frequency do not shift during the growing of the BST film, we must increase the voltage the same magnification of with the thickness. Figure 2(b) shows the influence of the top and bottom electrode's coincidence length on the resonance frequency. The black line means the coincidence length is 50 μm, and the green line means the horizontal distance between the top and bottom electrode is 100 μm, where we signed −100 μm. We could easily get the coincidence length has an impact on the resonance frequency when it is negative. But has no effect when it becomes positive (black line and red line coincide in Figure 2(b)). From Figure 2(c), we could clearly see that the width of the electrode has huge impact on the resonance frequency. And Figure 2(d) show the length of the cross has no impact on it.

2.3. Different Geometric Shape

Other interesting geometric shape is studied here (see Figure 4(a)), and its reflection is plotted in Figure 4(b). The modulation bandwidth is 0.3 GHz, it is similar to the original structure. This indicate the modulation ability are more dependent on the special properties of BST materials under applied voltage.



(a)



(b)

Figure 4: Parametric study of BST-based metamaterial with (a) thickness of BST film; (b) coincidence length between top and bottom electrode; (c) width of electrode; (d) length of the cross.

3. CONCLUSION

In this work, the structure which could be adjusted by applied voltage has been proposed and demonstrated. The parameter of the structure has been fully studied and compared. At last, the comparison of the tuning results of different structures confirm the tuning properties was mainly from the material itself.

ACKNOWLEDGMENT

This work is partially supported by the National High Technology Research and Development Program (863) of China (No. 2012AA030402)

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