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# Fabrication and properties of meta-materials based on multilayer ceramic structure

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**Abstract** In recent years, meta-materials received wide attention for its negative refractive index in microwave system. Many papers have reported the theoretical and experience development of meta-materials. The main work of this paper includes fabrication of the samples and measuring the property. We design the parameters of the structure and then using tape-casting technique to fabricate periodic silver structure in the ceramic substrate. The measurement fixture is designed, and HP8720ES vector network analyzer is used to measure the spectra and the field distribution of samples. At about 12 GHz, samples had an obvious photonic band gap from $S_{21}$ parameter measure results. By the field distribution in the two dimension plane of samples, we obtained the abnormal refraction phenomenon which can audio–visual validate the existence of meta-materials.

**Keywords** Meta-materials · Tape casting · Negative refractive index

## 1 Introduction

In the tense research of meta-materials, the propagation of electromagnetic waves in media with negative permittivity, $\varepsilon$, and permeability, $\mu$, had been presented in several fields recently, including waveguide components, RF integrated circuits, and antenna systems [1–6]. Waves in meta-material slabs were studied, and slabs of single negative meta-materials in parallel-plate waveguides were examined [7–11]. Subsequently, 3D electromagnetic meta-materials composed of arrays of resonant cells consisting of thin wire strips and split-ring resonator (SRR) were realized to synthesize double negative materials. However, the presented meta-materials are made using 3D constructions that were complicated, bulky, and difficult to fabricate [12]. It will be much simpler and easier to use a planar structure with a circular array of resonators, such as split rings, to realize an anisotropic material with only one or two negative components of $\varepsilon$ and $\mu$ instead [13–15]. Among the fabrication methods of meta-materials, the method of tape casting technique to fabricate periodic silver structure in the ceramic substrate had successfully played a crucial role in a variety of fields.

In this paper, we prepared a ceramic template, which provided an ordered carrier array to tape casting periodic silver structure. After sintering and oven drying, we obtained the meta-materials samples with thin periodic silver wire strips. The dimension of samples was 50 mm in length, 20 mm in width, and 1 mm in height, and then, we analyzed the crystal structure, morphology, and electromagnetic properties of the meta-materials.

## 2 Experiment and discussion

### 2.1 Structural design

From existing investigation of the situation of meta-materials, only two material systems could carry out abnormal refraction phenomenon: SRR and transmission lines. We adopted the theory of transmission lines as the

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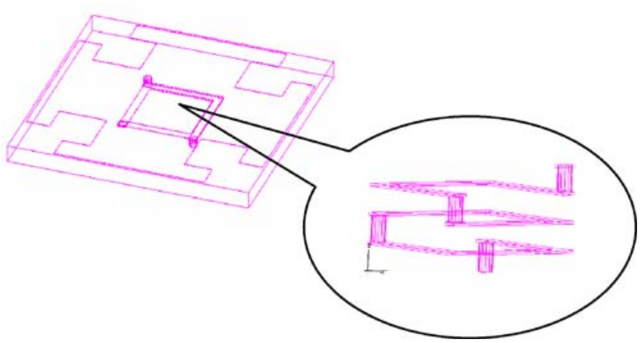

Fig. 1 Unit of pattern structure and the joint between layers

design principle. Figure 1 shows the photograph of the meta-materials' structure unit. The right part of Fig. 1 shows the connection points between the different layers. We took the cross-shaped as the basic structure of transmission lines, used the coils in the middle to simulate shunt inductance, and used the uniform width splits of structure unit to simulate tandem capacitor. The dimensions of every part are shown in Fig. 2.

## 2.2 Tape casting technology

In Fig. 3, we can see that there were 40 layers in the templates, and the thickness of every ceramic slurry layer was 20 μm, the thickness of ceramic base plate was 40 μm. In the tape casting process, there must be drying and screen-printing. Finally, we obtained primary samples.

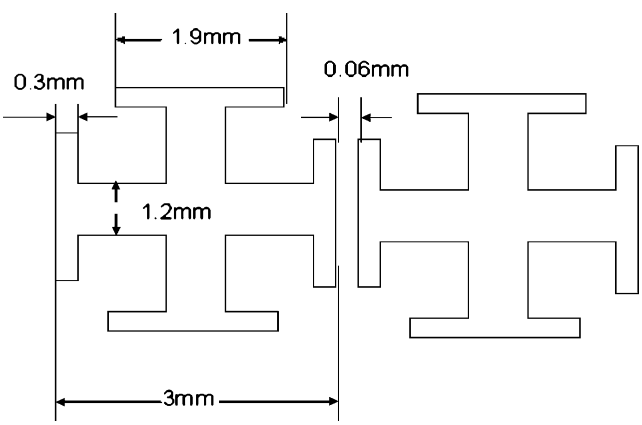


Fig. 2 Dimension of unit

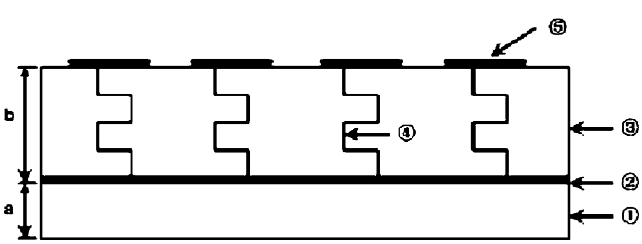


Fig. 3 Photograph of sample. (*1*) base plate, (*2*) floor, (*3*) coil layer, (*4*) inductance coil, (*5*) silver transmission lines

Fig. 4 Appearance of sample

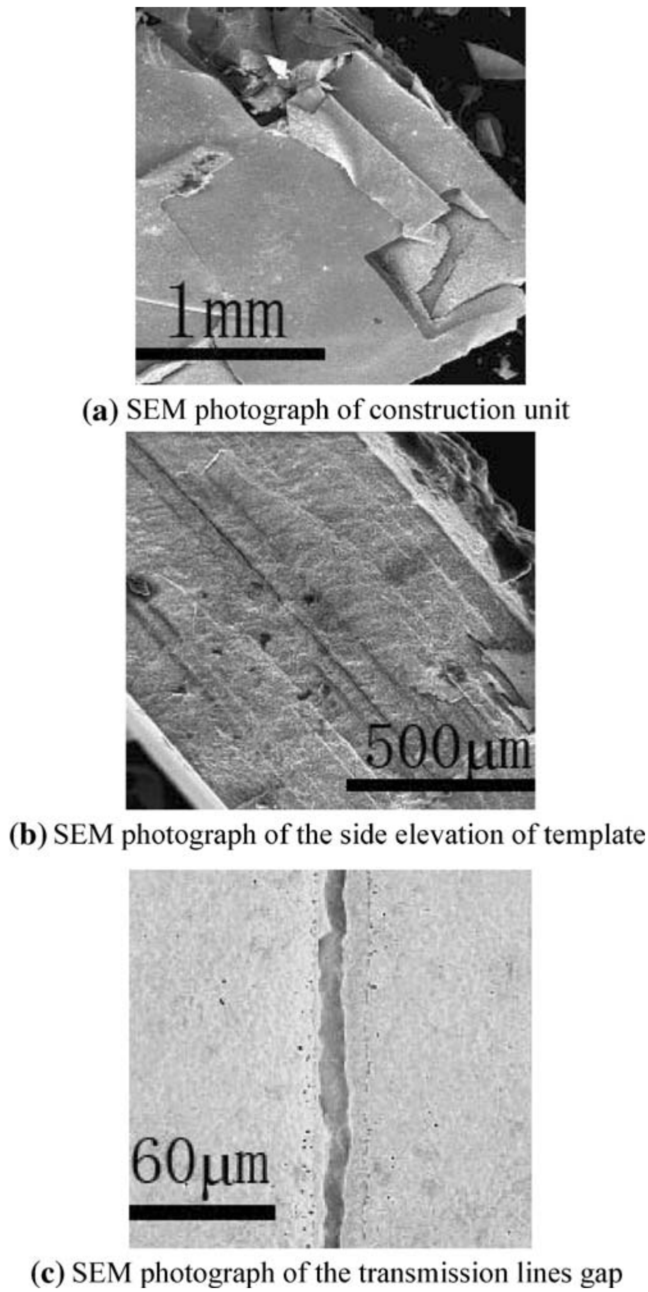


Fig. 5 (**a**) SEM photograph of construction unit. (**b**) SEM photograph of the side elevation of template. (**c**) SEM photograph of the transmission lines gap

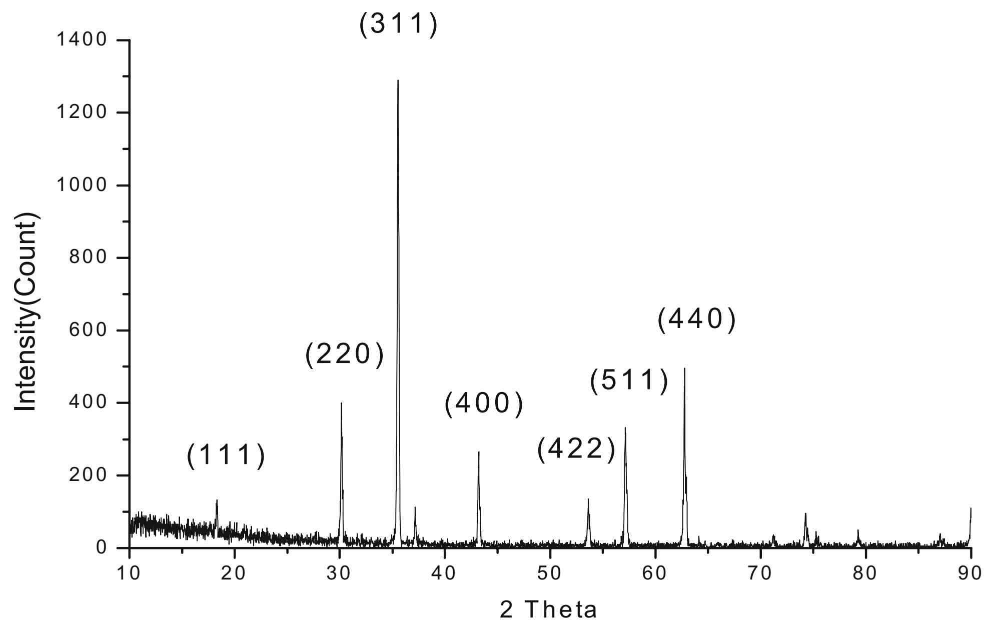


**Fig. 6** XRD pattern of ceramic template

2.3 Sintering

After tape casting progress, we put the sample into the batching-out unit to batch at 400°C; the size of samples was 5 cm×3 cm. In the progress, the heating-up time and insulation time were both 6 h every 100°C, respectively. The samples must be fastened with two ceramic wafers so that the samples will not be deformed. At the sintering temperature of 800°C, we obtained the final samples with the rate of contraction at about 87%. Figure 4 is the photograph of the sample's appearance.

We can see that the silver wire strips in the ceramic template were symmetrical in Fig. 5(a). Figure 5(b) shows the side photograph of ceramic template; 20 uniform layers distributing in the template can be seen. In Fig. 5(c), the size of transmission line gaps that simulate capacity effect was about 30–40 μm and is smaller than the design structure. It may bring on the change of microwave transmission characteristic.

2.4 XRD analysis

By the comparison of XRD pattern and standard Powder Diffraction File (PDF), we got the (311) and (220) character peaks of ceramic template, and ferrite were fabricated in the template was considered reasonable here (Fig. 6).

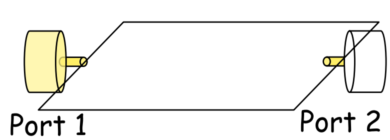


**Fig. 7** Sketch map of spectra measure equipment (HP8720ES)

2.5 Spectra and field distribution analysis

Because all the transmission lines structures were inside the ceramic template, we adopted the method of coaxial line and microstrip line to measure the spectra (Fig. 7). HP8720ES vector network analyzer was used to measure the spectra ($S_{21}$) and the field distribution of samples. Band gap structure was obtained from the spectrum line.

Figure 8 shows the $S_{21}$ parameter distribution of different samples at different frequencies; the long sample has an obvious band gap at about 12.6 GHz, and the short sample has one at 12.8 GHz. Because two samples had different sizes, different periodicities, the peak position of band gap had a certain extent shift. Because of the ferrite impurity in the samples, there are some little peaks in the spectra. In the experiment, we measured the electromagnetic distribution at a little range around 12 GHz. We carved up the samples into many grids, measured the field and phase strength of every grid, then put them together in a diagram. Figures 9 and 10 show the field strength and phase distribution of samples at 12 GHz. From the photograph, it can be seen that the diffraction direction of the wave vector is at the normal line's same side with the incidence direction; this phenomena can audio–visual validate the existence of meta-materials.

## 3 Conclusion

Ceramic templates with two dimension surfaced silver transmission lines were successfully fabricated by tape casting process. The x-ray diffraction and the SEM photo-

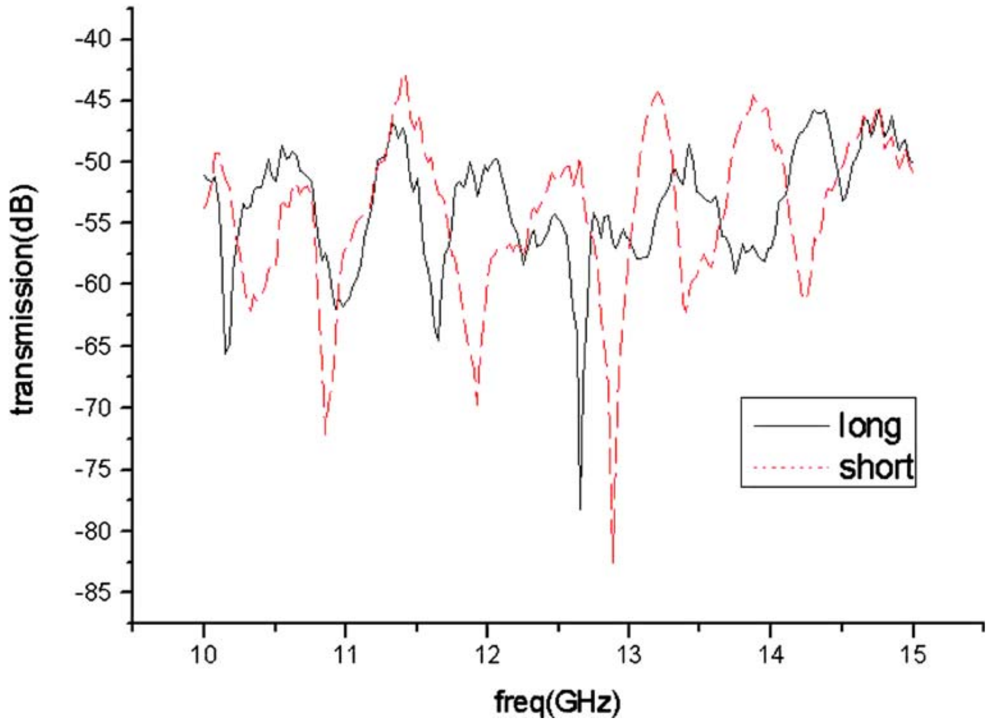


**Fig. 8** Intensity of different samples' $S_{21}$ parameters

graphs demonstrate that silver transmission lines had been filled in the ceramic template certainly. At about 12 GHz, sample had an obvious photonic band gap from $S_{21}$ parameter measure results. By the field distribution in the plane of sample, we obtained the abnormal refraction phenomenon. This work finds a new method to prepare meta-materials and other similar microwave devices; on the other hand, it exploits many new application areas of traditional ceramic tape casting technique.

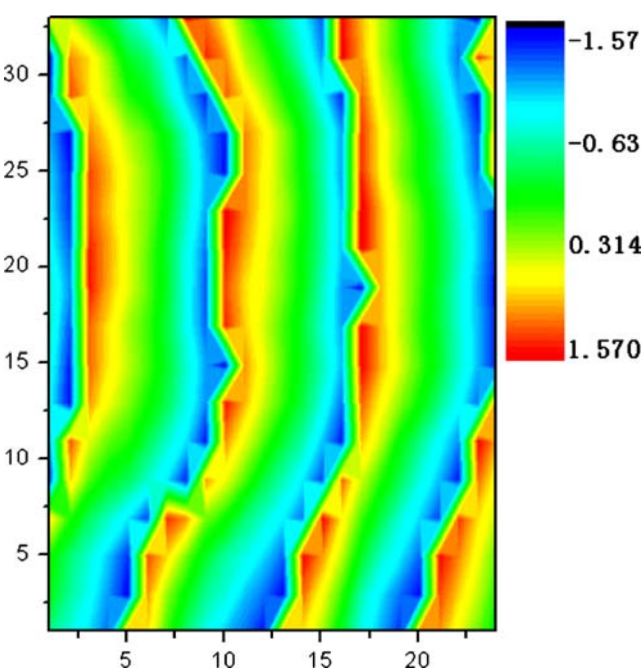


**Fig. 9** Field strength distribution at 12 GHz

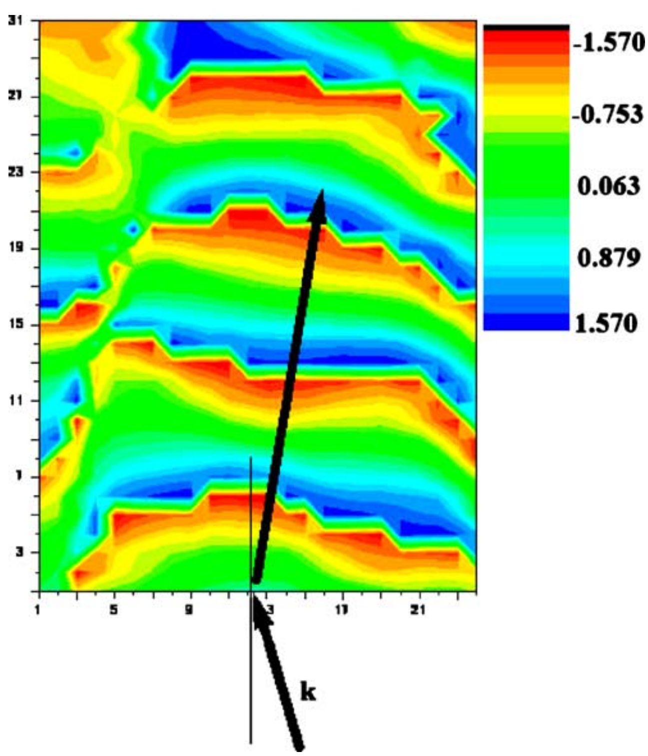


**Fig. 10** Phase distribution at 12 GHz

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