Lightweight and Flexible Graphene Film for Millimeter Wave FSS Application

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***Abstract*—This paper proposes a graphene film based flexible millimeter wave bandstop FSS. The graphene film has good flexibility and low-density of 1.81 g/cm^3. The proposed graphene FSS works at 60 GHz with the -10 dB bandwidth of 58.33 GHz – 64.83 GHz, which indicates that more than 90% of electromagnetic energy is shielded. Furthermore, to expand the working bandwidth, a double layer graphene FSS with sandwich structure (FSS-Foam-FSS) is designed. The double layer graphene FSS has a wide working bandwidth of 52.78 GHz – 65.21 GHz and good angular stability.**

Keywords—graphene; millimeter wave; FSS;

I. INTRODUCTION

Millimeter wave communication has an ultra wide working bandwidth, which can achieve ultra-high data transmission rates and low latency. Frequency selective surface (FSS) is a spatial filter that can achieve effective frequency selection corresponding to electromagnetic waves, including bandstop, bandpass, etc, which has widely applied in radomes, beam control, decoupling [1]. With the increasing demand, lightweight and flexibility are indispensable features for electronics, especially in fields such as smart homes and wearables. However, the high proportion and strong rigidity exposed by metal materials contradict the new demand.

Graphene films have excellent electrical conductivity, thermal conductivity, flexibility, mechanical stability, chemical stability and lightweight, and are considered to be the most potential metal substitute materials [2, 3]. Graphene films have been used in transmission lines [4], antennas [5, 6], electromagnetic shielding [7] and other devices, and show good performance.

In this paper, we propose a graphene assembled film (GAF) based millimeter wave FSS worked at 60 GHz for frequency bandstop application. The graphene film shows good flexibility and low density of only 1.81 g/cm^3. The single layer graphene FSS has the working bandwidth of 58.33 GHz – 64.83 GHz. In addition, the double layer graphene FSS has a wide working bandwidth of 52.78 GHz – 65.21 GHz and good angular stability. Lightweight and flexible graphene FSS has great significance in the field of future mobile communication.

II. CHARACTERIZATION OF GRAPHENE FILM

Fig. 1 shows the digital photo of graphene assembled film (GAF), which indicates free-standing state and good flexibility. As shown in Fig. 2, the cross-section SEM image shows the thickness of GAF is 27 μm.

Figure 1. The digital photo of GAF

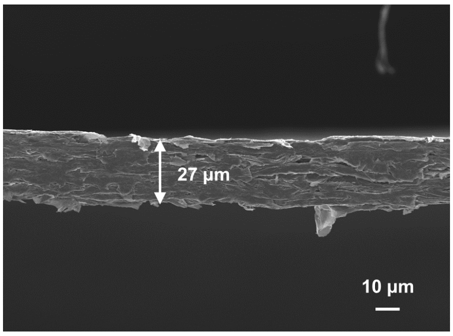

Figure 2. The cross-section SEM image of GAF

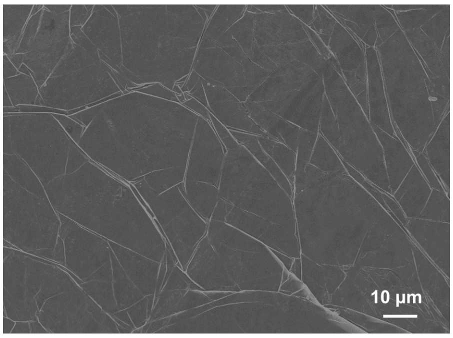

Figure 3. The surface SEM image of GAF

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In addition, as shown in the surface SEM image (Fig. 3), the GAF has many micro wrinkles on the surface. Due to the existence of micro wrinkles, GAF have great cushioning and unloading force when subjected to external force, so it has excellent flexibility. Another advanced feature of GAF is lightweight. Fig. 4 shows the weight comparison between GAF and copper foil. After calculation, the density of GAF is 1.8 g/cm^3, which is only 21% of that of copper foil (8.6 g/cm^3).

Figure 4. The surface SEM image of GAF

III. The FSS Configuration And Design

Fig. 5 shows the configuration of GAF millimeter wave FSS worked at 60 GHz. The GAF FSS is designed on the polyethylene terephthalate (PET) substrate with thickness of 0.05 mm and relatively permittivity of 3.5. To ensure polarization insensitivity, the GAF FSS element adopts a cross shaped structure ($l \times w$) and the element cycle is T.

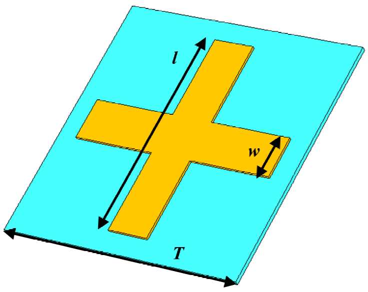
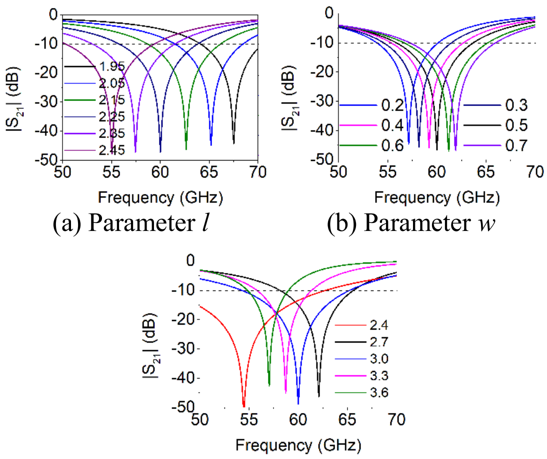


Figure 5. The schematic diagram of GAF FSS



(a) Parameter l (b) Parameter w

(c) Parameter T

Figure 6. Effect on $|S_{21}|$ due to variation of parameters

To analyze the effect of the parameters of GAF FSS element on working frequency, the performance of the GAF FSS for different values of l, w and T are described in Fig. 6. From the simulated results, both the resonant structure and the substrate structure size affect the operating frequency of the GAF FSS. The optimized parameters are l=2.25 mm, w=0.5 mm and T=3 mm, respectively. The frequency response of the optimized GAF FSS is shown in Fig. 7. The GAF FSS has the working bandwidth of 55.84 GHz – 63.68 GHz.

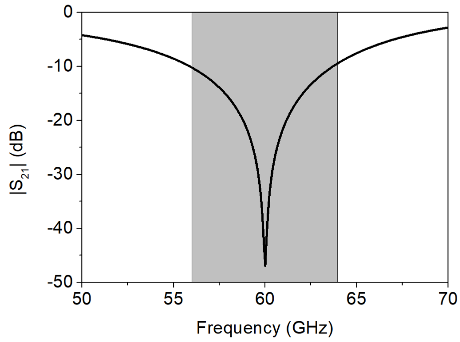


Figure 7. Optimized simulated $|S_{21}|$ of GAF FSS

IV. Measurement Results

After simulation, the GAF FSS is manufactured by laser engraving method with high precision of 25 μm. Fig. 8 shows the digital photo of single layer GAF FSS with 40 × 40 elements. The GAF FSS with the physical dimension of 125 mm × 125 mm has good flexibility and translucency. Fig. 9 illustrates the performance single layer GAF FSS. The GAF FSS works at 60 GHz with the -10 dB bandwidth of 58.33 GHz – 64.83 GHz.

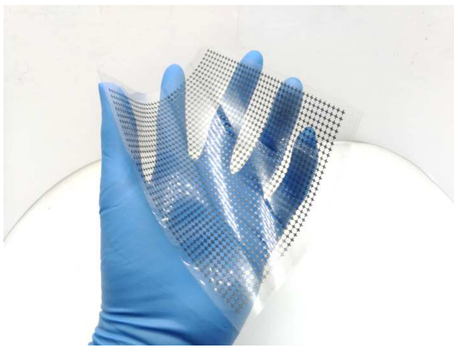


Figure 8. The digital photo of GAF FSS

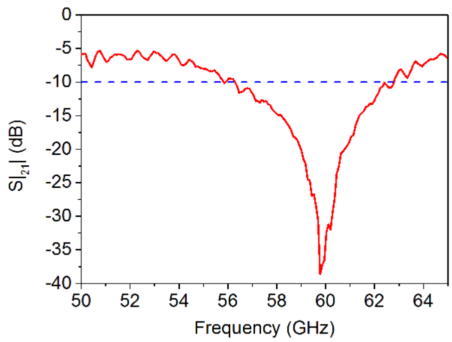


Figure 9. The measured $|S_{21}|$ of GAF FSS

Fig. 10 shows the measurement environment of GAF FSS, which in in anechoic chamber to eliminate the influence of electromagnetic waves in the environment. The GAF FSS is fixed on a rotatable bracket. In addition, two horn antennas are connected to the vector network analyzer and placed on both sides of the GAF FSS. The vector network analyzer records the reflection coefficient and transmission coefficient of the GAF FSS.

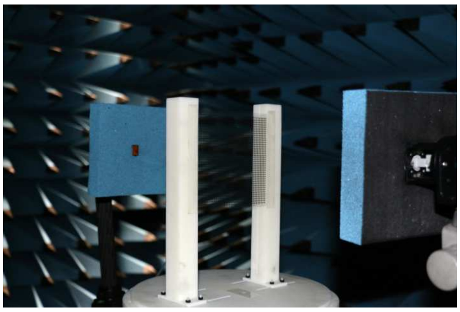


Figure 10. The measurement environment of GAF FSS

To broaden the bandwidth, a double layer GAF FSS structure is designed, as shown in Fig. 11. The layer spacing of double-layer GAF FSS is d (3mm), which is filled with foam plate with dielectric constant of 1.1.

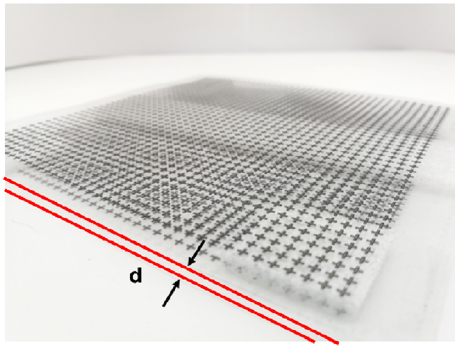


Figure 11. The digital photo of double-layer GAF FSS

The measured transmission coefficient of double layer GAF FSS is shown in the Fig. 12. Under normal incidence of electromagnetic wave, the transmission coefficient of double layer GAF FSS is less than -10 dB in 52.78 GHz – 65.21 GHz frequency band (the working bandwidth is 12.43 GHz), which is 1.9 times that of single layer GAF FSS.

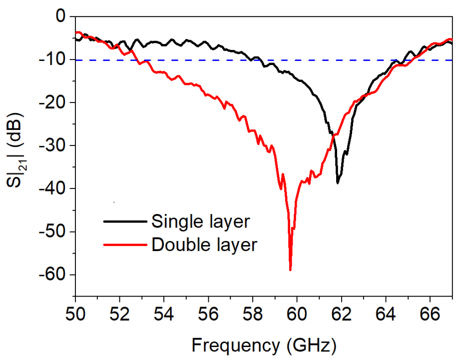


Figure 12. The measured $|S_{21}|$ of single-layer and double-layer GAF FSS

Fig. 13 depicts the frequency response of the double layer GAF FSS at different electromagnetic wave incidence angles. Within the range of ±30°, the working bandwidth of the double layer GAF FSS remains basically consistent, demonstrating its good angular stability.

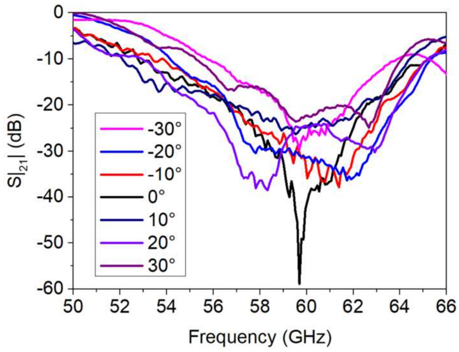


Figure 13. The angular stability results of GAF FSS

V. CONCLUSIONS

In this paper, a millimeter wave FSS based on lightweight graphene film is proposed. The proposed FSS is made of the graphene film with density of 1.8 g/cm^3. The single layer GAF FSS with good flexibility has working band of 58.33 GHz – 64.83 GHz, which is good agreement with the simulated results. Furthermore, the working bandwidth of the double layer GAF FSS is expanded by 90% and has good angular stability.

ACKNOWLEDGEMENT

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