Flexible Graphene Based Films for Microstrip Array Antennas

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***Abstract*-Graphene based antennas have attracted wide attention due to their low cost, high stability and well flexibility. However, the manufacturing process uses graphene based films to fabricate array antennas is few reports. In this paper, a unique process for fabricating microstrip 2×2 array antennas with flexible graphene based films is reported. The microstrip array antennas with the return loss of -40.28dB and the high gain of 6.78dB at 2.46GHz, which are as high as the identical copper antennas. Moreover, the graphene antennas have similar radiation patterns to the copper antennas, indicating that the graphene array antennas can be an ideal candidate for copper array antennas.**

***Keywords*-array antennas and graphene based films.**

I. INTRODUCTION

With the development of society and the progress of technology, people's demands for the Radio-Frequency (RF) products, especially RF antennas, are not only limited to their excellent performances, but also low cost, high stability and well flexibility. The application of carbon based materials for RF antennas will be of great significance for the wireless communication technologies. Graphene, a 2D carbon material, has great potential to make highly conductive films due to its high charge mobility ($200000 cm^2 V^{-1} s^{-1}$) [1], which can be used to design good performance RF antennas [2]. Furthermore, the direction and gain of the single antenna are limited and cannot meet the product design requirements, such as telecommunication [3] and internet of things (IoT) [4]. Therefore, two or more single antennas, which operate at the same frequency, are fed and arranged in accordance with certain requirements to form an array of antennas.

However, the processing technology of graphene based films (GBF) for antenna is not mature enough, and it is seldom reported that using GBF to fabricate array antennas. A recent work [5] reports graphene-based material for a microstrip patch antenna application but the edge of patch is very rough and the return loss of antenna is much lower than the metal antenna. In this paper, we report a unique process for fabricating microstrip 2×2 array antennas with flexible GBF, which process metallic conductivity as high as 10^6 s/m. The edge of GBF antennas made by this process is very smooth and regular, and the performances ($|S_{11}|$, antenna gain, and radiation pattern) of the GBF antennas are comparable to copper antennas.

II. THE MANUFACTURING PROCESS

Three steps (hot pressing, cutting, glueing) are demanded to prepare the GBF (Fig. 1a) based array antennas. Firstly, the

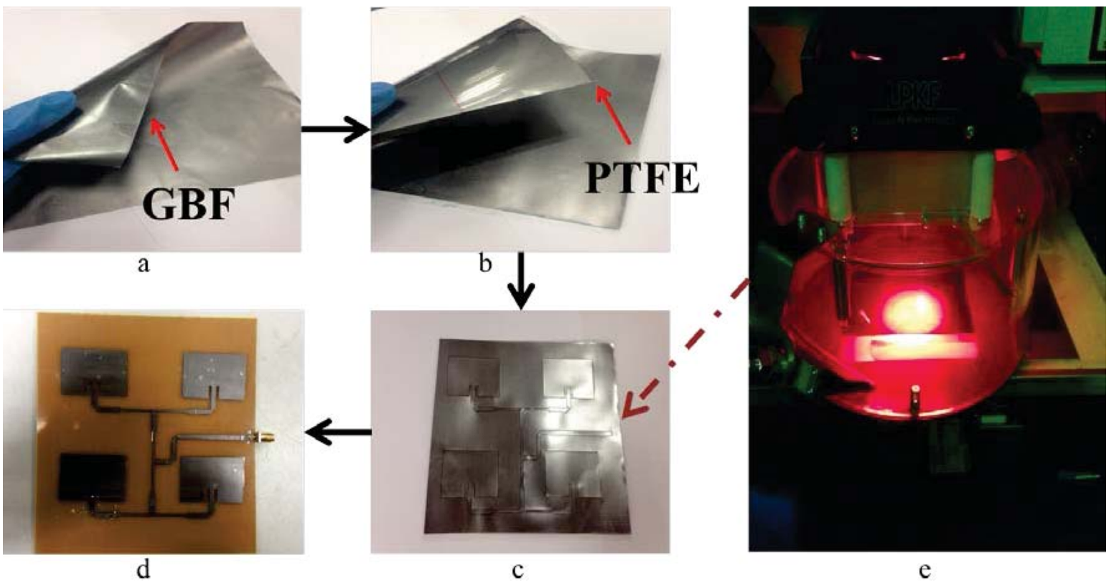

Figure 1. The manufacturing process of GBF array antennas.

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GBF are attached to a PTFE substrates through 300 °C hot pressing, as shown in Fig. 1b. After then, LPKF laser engraving machine is used to cut the attached GBF to antenna patch according to the designed dimension and shape by the CST software (Fig. 1c). Finally, the GBF array antennas are peeled from the PTFE substrate and glued to the FR-4 substrate. A SMA connector is used to connect the patch and ground, as shown in Fig. 1d. Fig. 1e is the photo of LPKF laser engraving machine with cutting precision of 30 µm.

III. MICROSTRIP ANTENNA DESIGN

Fig. 2 shows the single element microstrip antenna with the resonant frequency of 2.45 GHz, the practical size of the patch can be calculated by [6]

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{2}$$

where

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{W}{h}+0.8\right)} \tag{3}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^{-1/2} \tag{4}$$

where W and L are the width and length of the patch, f_r is the resonant frequency, ε_r is the relative dielectric constant, h is the thickness of the substrate, μ_0 is magnetic permeability of free space, and ε_0 is the dielectric constant of free space. In order to reduce the overall size, antenna is fed with an embedded structure. 50Ω transmission line is designed to connect the SMA connector and the patch. The length of the patch L is 30 mm, the width W is 37.26 mm, and the width of the transmission line W_0 is 2.98mm. The substrate is FR-4 PCB with the dielectric constant of 4.4 and thickness of 1.6 mm.

In order to demonstrate the performance of GBF antenna, 2×2 array copper antennas are fabricated in the same size, and the power divider [7] is used to achieve equal distribution of power. The $|S_{11}|$ of GBF and copper array antennas are measured with a Network Analyzer (PNA, Keysight N5225A) as shown in Fig. 3. As it can be seen, the resonant frequency of GBF array antennas occurs at 2.46 GHz with -40.28 dB of $|S_{11}|$, which has a smaller return loss than copper antenna (-33dB) at resonant frequency of 2.44 GHz. Otherwise, we can get the bandwidth (BW) of the antennas by [8].

$$BW = f_2 - f_1 \tag{5}$$

where f_1 is the lower frequency and f_2 is the upper frequency of -10 dB bandwidth. The BW of the GBF array antennas is 120 MHz, which is even better than the copper antenna (80MHz), indicating an excellent performance for GBF array antennas. It is noted that the simulated result of $|S_{11}|$ for GBF array antenna is consistent to the measured result.

In addition to the return loss and bandwidth, the gain and the radiation pattern are also very important factors for the antenna performance. The radiation patterns of GBF and copper array antennas at resonant frequency are measured in the microwave anechoic chamber, as shown in Fig. 4. The measured antennas and standard reference antenna (REF antenna) are connected with the PNA. The measured antennas are placed on the turn table as the receiver, and the REF antenna is used as the radiator. The gain and the radiation pattern are measured with the antenna measurement system (Diamond Engineering Autonated Measurement Systems). It should be explained that the DAMS platform Controller control the turn table to record the Azimuth (Az) and Elevation (El) plane per 3 degree and the gain of arbitrary direction.

Fig. 5a is the Elevation planes of GBF antennas and copper antennas, Fig. 5b is the Azimuth planes. As it can be seen the gain is the maximum (the GBF antennas is 6.78dB, the copper antennas is 7.11dB) at 0°. From the plots we can come to the conclusion that GBF antennas and copper antennas have the similar gain and radiation pattern, indicating that the GBF antennas and copper antennas have the similar performance.

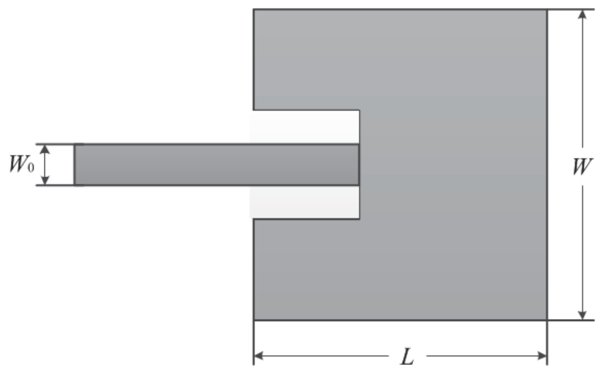


Figure 2. Single element microstrip antenna

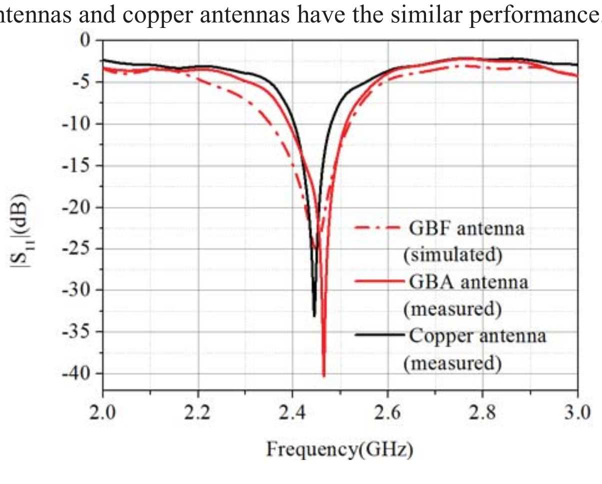
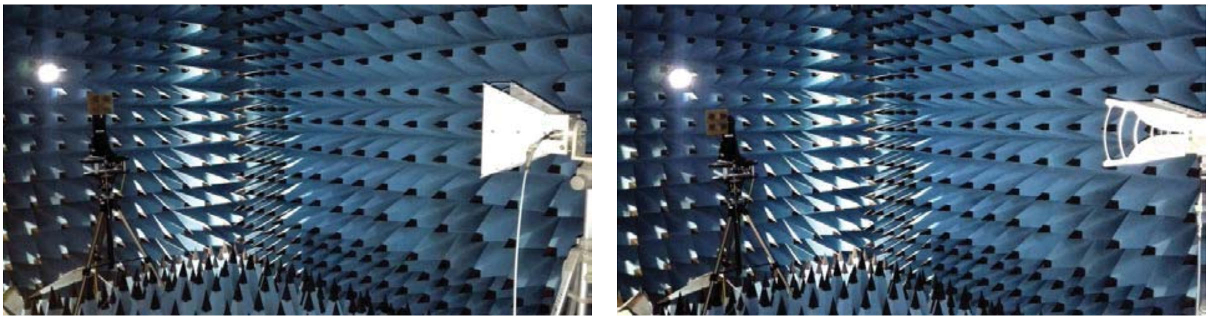


Figure 3. Simulated and measured $|S_{11}|$ of GBF and copper antennas



a b

Figure 4. Radiation pattern and gain measurement in anechoic chamber. (a) Photo of Elevation plane measurement, (b) Photo of Azimuth plane measurement.

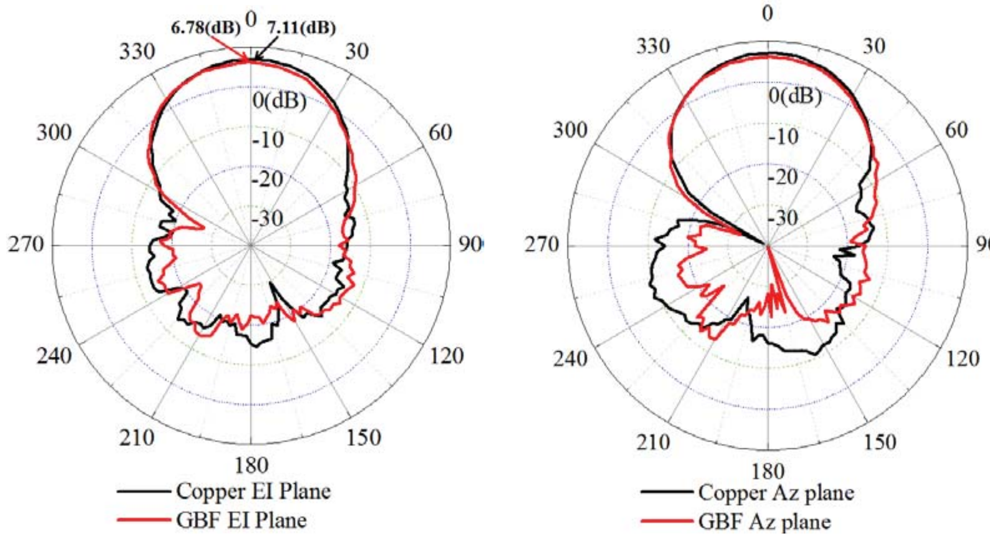


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Figure 5. Radiation pattern of antennas. (a) Elevation plane of antennas; (b) Azimuth plane of antennas.

IV. CONCLUSION

A unique process for fabricating microstrip array antennas with flexible graphene based films has been mentioned in this paper. The antenna edge made by this process is very regular. From the results of measurement, such as $|S_{11}|$, bandwidth, gain, radiation pattern, the GBF array antennas show comparable performance to that of traditional copper array antennas.

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