Conformal Patch Antenna made of graphene-based film for 2.45GHz/5.2GHz Frequencies

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***Abstract*— Antennas in wearable electronic devices face a challenge of being flexible and conformal. In this paper, flexible patch antennas made of graphene-based film (GF) are proposed for 2.45 GHz and 5.2 GHz. Due to the flexibility of the graphene-based film, the conformal antennas are achieved by attaching them on a bended surface. The simulated and measured results show that the GF antennas can achieve a return loss of -20 dB and a satisfying gain of 5 dBi, which are comparable to copper-based counterparts. Moreover, the -3 dB bandwidth of the bended antennas are at least 25 degrees wider than the planar one.**

Index Terms—conformal antenna, Internet of Things, wearable device, graphene-based film.

I. Introduction

The arrival of the 5G era would lead to a new round of industrial revolution. In this upcoming revolution, the Internet of Things (IoT) will take off with the aid of enormous wearable devices. Most of them are working at the WLAN frequency bands. In this context, the ever-increasing demand for portable, compact and wearable electronic devices[1] is emerging. What's more, it is necessary to meet these needs without sacrificing antenna weight, flexibility as well as the limited device profile. Therefore, it is necessary to focus on the antennas with conformal features to adapt the varied device shapes[2].

Usually metals like copper are used to fabricate antennas. However, it displays disadvantages, e.g., low flexibility, easy to corrupt and heavy weight, which limit its further development[1]. Besides, affected by the skin-depth effect, it is less likely to make a thin antenna[3]. These factors make it difficult for traditional metal materials to be competent in flexible and conformal RF devices.

In recent years, new materials, like polymers and nanomaterials[4] are envisioned as a solution to these problems. Among these alternatives, graphene-based film is the most promising one that can be applied in wireless communications, electromagnetic shielding, sensors, thermal conduction and stretchable transistors. Particularly, due to the high conductivity, it shows potential to replace copper as the radiator of an antenna. What's more, the antennas made of graphene-based film are flexible and can be attached on surface with arbitrary shape[5]-[6]. Compared with flexible metal film antennas, it is also worthy to notice that GF antennas have high stability upon bending fatigue and are not easy to be oxidized or corroded[7].

In this paper, conformal patch antennas operating at 2.4 GHz and 5.2 GHz are proposed made of graphene-based film with high conductivity and flexibility. Owing to the high conductivity of 1.1e6 S/m, the proposed antennas could achieve a gain of 5 dBi, and the S_{11} of -20 dB, which are no less than the metallic counterparts. What's more, because of the bending of antenna, -3 dB bandwidth has been broadened to 112.2 degrees at 2.45 GHz. With all these benefits, this work is of great significance to the development of conformal antennas.

II. Antenna Design And Simulation

To explore the application of graphene-based film in flexible antennas, rectangular patch antennas are proposed. The selected frequency bands are 2.45 GHz and 5.2 GHz, which are commonly used in WLAN communication systems. At first, we design planar antennas to validate the possibility of using graphene-based film as the radiator of an antenna. Then, curved antennas are simulated and measured for evaluating the performance of the graphene-based film in conformal structure.

A. Planar non-bending antenna design

In order to compare the performance of GF antennas with metallic counterparts, we design a pair of rectangular patch antennas based on GF and copper with coaxial pin-feed. Its structure diagram is shown as follows:

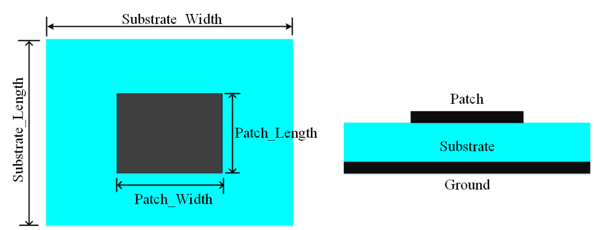

Fig. 1. Schematic diagram of rectangular patch antenna

As shown in Fig. 1, the rectangular patch antenna is a typical three-layer structure. For GF antennas, the patch on top and the ground on the bottom are made of graphene-based film with thickness of 0.03 mm and conductivity of 1.1e6 S/m. The substrate is made of polylactic acid (PLA) with relative dielectric constant of 2.58, which is obtained by coaxial transmission line method in lab with Keysight N5247A Network Analyzer. It is noted that the commercial package CST microwave studio is used for simulation. The simulation results compared with copper-based antennas are shown as follows：

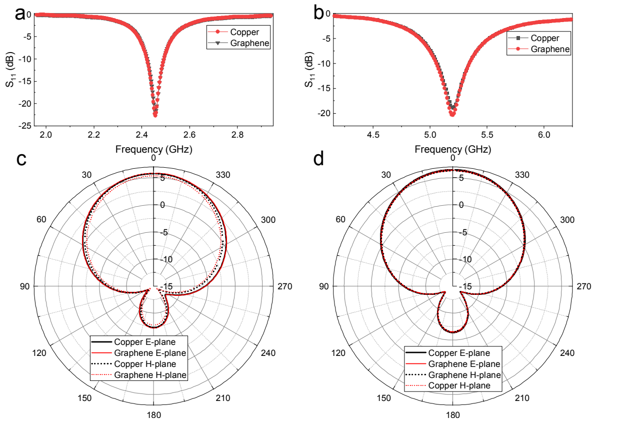

Fig. 2. The simulation results of GF and copper-based antennas. (a) simulated S_{11} curve at 2.45 GHz. (b) simulated S_{11} curve at 5.2 GHz. (c) simulated gain at 2.45 GHz. (d) simulated gain at 5.2 GHz.

As can be seen in Fig. 2, the resonant frequencies of both antennas occur at 2.45 GHz and 5.2 GHz, and the reflection coefficients are less than -19 dB, which means good impedance matching is achieved. One can also observe that GF antennas and copper antennas have similar radiation patterns. In addition to the radiation patterns, the maximum gain of GF antennas is 6.29 dBi, which is comparable to that of copper antennas with 6.47 dBi at 5.2 GHz. Therefore, graphene-based film has completely similar properties to copper in terms of being radiator in antenna design.

B. Conformal antenna design

To demonstrate the flexibility of graphene-based film, a structure is 3D-printed with GF patch conformed on it. The schematic diagram is shown as follows:

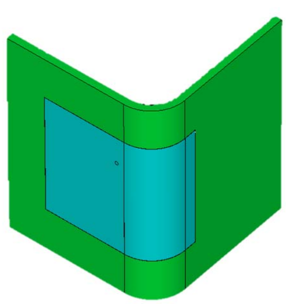

Fig. 3. Schematic diagram of conformal GF antenna

As the planar antenna designed above is conformal directly to the curved surface, the effective electronic length of the antenna varies, and the resonant frequency f_0 of the antenna shifts to lower frequencies. The S_{11} are also significantly affected. For a certain substrate thickness, the antenna dimensions should be carefully adjusted to achieve a better impedance matching, which leads to relatively low S_{11} values. The optimized antenna performance are as follows:

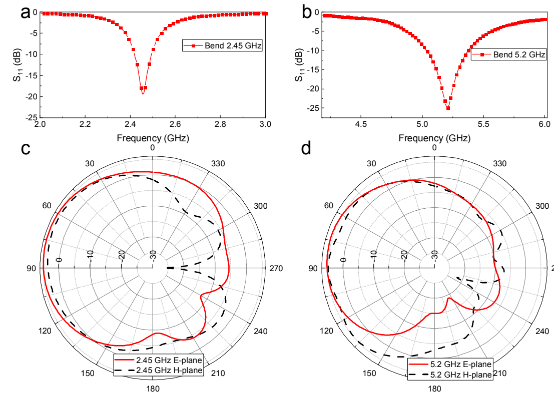

Fig. 4. The simulation results of conformal patch antennas. (a) simulated S_{11} curve at 2.45 GHz. (b) simulated S_{11} curve at 5.2 GHz. (c) simulated gain at 2.45 GHz. (d) simulated gain at 5.2 GHz.

It is noticeable in Fig. 4 that the performance of the optimized conformal antennas is as good as that of the planar antennas, which indicates that graphene-based film has great potential in flexible antenna applications.

C. Coupling between conformal antennas

To investigate the coupling effect between the curved antennas, we designed the structure as shown in Fig. 5 below.

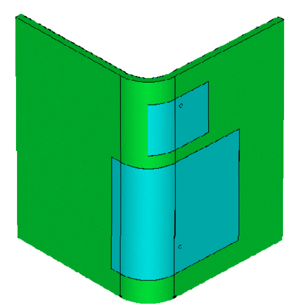

Fig. 5. Schematic diagram of the coupling structure

By changing the distance between the antennas, the variations of S_{12} and S_{21} values are plotted. The simulation results are shown in Fig. 6 below.

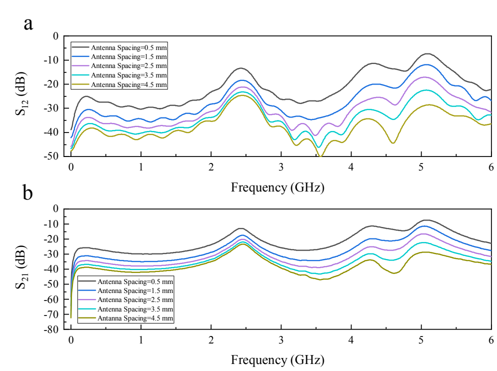

Fig. 6. The simulation results of S_{12} and S_{21} values at different distances between curved antennas.

As can be seen in Fig. 6, the isolation coefficient, i.e. S_{21}, is inversely proportional to the antenna spacing. As the distance increases to 4.5 mm, the coupling decreases to the minimum value, -20 dB. Therefore, the trade-off between size and coupling should be carefully considered in designing curved antennas.

III. Antenna Fabrication And Measurement

In this section, we fabricate the proposed flexible patch antennas made of graphene-based film, as shown in Fig. 7. The substrate is obtained by a 3D printer to simulate the structure with bended shape. Then the Keysight N5225A Network Analyzer is used to measure its return loss. The measurement results are displayed in Fig. 8 below.

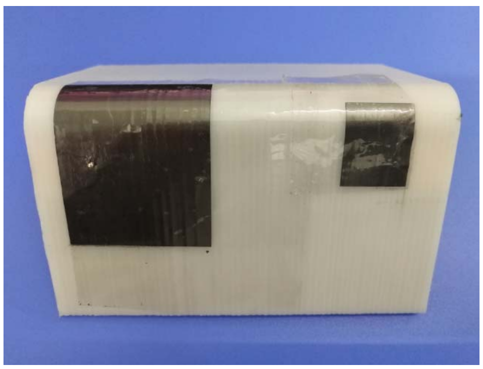

Fig. 7. Photograph of the proposed conformal patch antennas

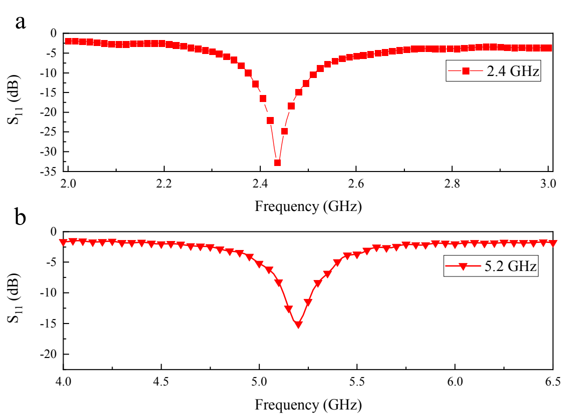

Fig. 8. Measurement results of flexible GF antennas

One can find in Fig. 8 that our proposed conformal patch antennas can achieve a well-matched state with S_{11} value less than -15 dB. And the bandwidth is more than 100 MHz, which is better than simulation results.

In order to have a clear understanding of the performance of our proposed antennas, the following summary Table I is made according to the simulation results.

TABLE I
FURTHER DETAILS ABOUT THE IMPACT OF BENDING

Parameter / Antenna	Gain	-3 dB Band-width	Efficiency
Before-bending 2.45 GHz	5.32 dBi	87.0°	65%
After-bending 2.45 GHz	4.05 dBi	112.2°	70%
Before-bending 5.2 GHz	6.29 dBi	81.1°	82%
After-bending 5.2 GHz	4.89 dBi	126.3°	86.3%

IV. Conclusion

In this paper, conformal GF antennas operating at 2.45 GHz and 5.2 GHz are proposed for WLAN applications. It has been proved that GF antennas have a satisfying gain of 5 dBi and a well-matched state with S_{11} of -20 dB. Furthermore, it has also been proved GF antennas can be bent to meet the requirements of complex conditions without sacrificing the performance of the antenna. It has been confirmed that conformal GF antennas perform as well as simulation. Therefore, graphene-based film is significant to the development of conformal antennas.

Acknowledgment

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