GRAPHENE-BASED MICROWAVE COMPONENTS

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Abstract

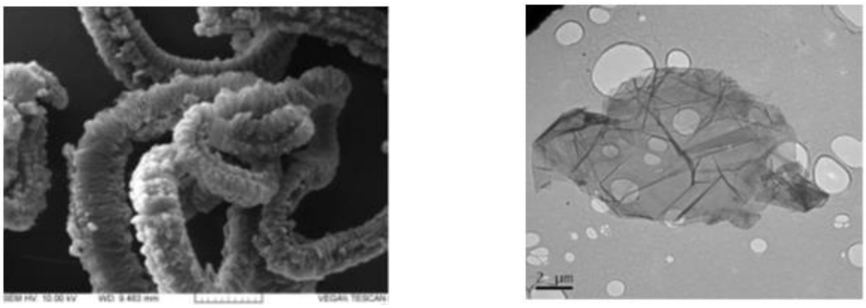
It was with the innovative technique of deploying the use of few layer graphene (FLG) flakes that the bottleneck in the design of microwave passive components with graphene, owing to the large dimensions of components at microwave frequencies, was overcome. With the increase in the number of graphene layers and their dimensions, the higher carrier mobility is lost, since a regime beyond ballistic comes into play. The interesting property of tunability, however remains intact. An added benefit of FLG is that they are easily produced and do not require any sophisticated and expensive equipment. In this brief review, we recap a few recently proposed devices and prototypes, exploiting the electrostatically tunable conductivity of FLG thin films in the microwave frequency range, i.e. broadband graphene attenuators, patch antennas and phase shifters.

Index Terms – Microwave components, Graphene, voltage controlled tunable components.

I. INTRODUCTION

Graphene has very interesting electronic properties, owing to the 2D nature and the arrangement of carbon atoms. In customary electronic devices semiconductors are in use, which are bulky and have no linear relationship between energy and momentum (E-k). In contrast, in graphene, the E-k relationship is linear and the charge carriers behave like massless Dirac fermions. In addition to these remarkable electronic properties, broadband optical absorption is also very interesting. Combining optoelectronic and electronic properties makes graphene a suitable material for a wide range of terahertz applications including modulators, emitters and detectors. At the frequency of microwaves and millimeter waves, unlike the terahertz frequencies, the sample size increases, thus increasing the mean free path of the carriers. Hence, the ballistic condition is no longer valid, which greatly reduces carrier mobility in the microwave range. Nevertheless, the possibility to adjust the conductivity graphene (tunability) is still present, hence allowing for several microwave applications [1].

Graphene can be easily implemented in passive microwave applications, such as attenuators, phase shifters and modulators [2],[3]. For these applications, because large amounts of graphene deposits are required, graphene nanoflakes have been used. Here, like in other microwave applications, the adjustable conductivity has been exploited because it is also applicable in the frequency range of the micro / mm wave.



(a) (b)

FIG. 1 – Graphene Flakes fabrication: (a) Wormlike structures (b)Individual Flakes.

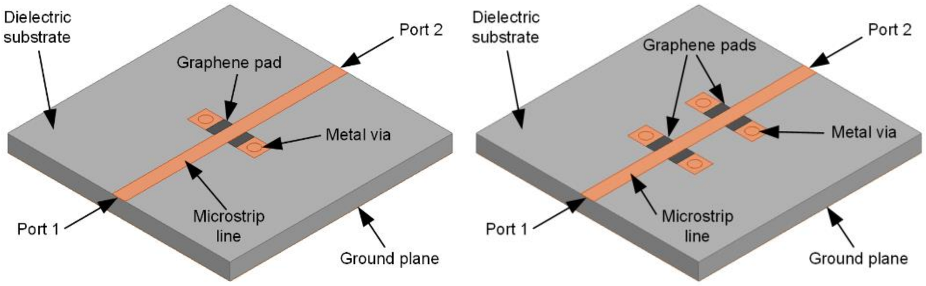
II. FEW LAYER GRAPHENE FLAKES FABRICATION

The method as first described in [4] involves the microwave irradiation of expandable graphite. The graphite obtained is commercially available and supplied by Asbury. It is a common practice to use expandable graphite for obtaining nanoplatelets of graphene. Expandable graphite contains sulfates and nitrates among the individual layers of graphene. Upon the introduction of a sudden thermal shock the intercalated substances tend to vaporize impacting the layers of graphene. The pressure exerted on the sides tends to expand the gap between the layers. A significant separation of the layers is caused resulting in exfoliated graphite material. In the procedure adopted here, the thermal shock is introduced by a microwave oven. The result is an increase in the temperature of up to 1000°C. The vaporization of the intercalated substances tends to change the dielectric properties of air resulting in visible sparks. The sparks result in a self-feeding process inducing the required thermal process.

The use of microwave for heating and thus obtaining the exfoliated graphite is very advantageous in that it is a very fast and effective process besides being green. Green in a sense that no solvents or other hard chemicals are required. Only 10 seconds of microwave irradiation is required to initiate thermal expansion. After the microwave irradiation and the resulting thermal expansion, the intercalated graphite turns into worm like structures, which is a result of the contact of one side of the planes to the structure. The next step is to ultrasound treat these worm-like structures in order to free the FLG from these worm-like structures. The first step in the ultrasound treatment is to mix the worm like structures in isopropyl alcohol followed by passing the solution through an ultrasound. The resulting mixture contains the quasi 2D flakes with planar dimensions of the order of tens of micrometers while the thickness is of several graphene layers typically less than 5nm. The last step in the process is to separate the flakes from the isopropyl alcohol in order to deposit them on a desired substrate. The solution containing both the isopropyl alcohol is drop casted on substrate. Isopropyl alcohol being volatile can be either left to evaporate at room temperature or the substrate on which the deposition is desired can be heated up to 100°C in order to speed up the process.

III. ELECTRONIC APPLICATIONS OF FEW LAYER GRAPHENE-RESULTS OBTAINED

In realizing electronic devices based on FLG, the flakes must be typically deposited in some designated slots. The FLG thin film is acquired by the process described in detail in [5]. The FLG was proposed in electronics as a thin film to realize a tunable attenuator



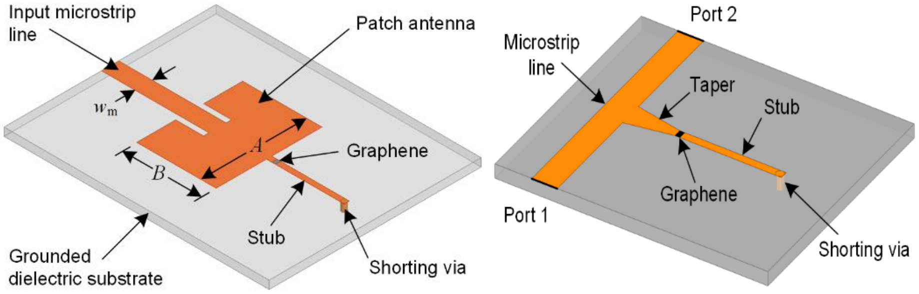
(a) (b)

FIG. 2 – Graphene shunt Attenuators: (a) two-post (b)four-post.

device, as early as 2014 [6-9]; examples of tunable attenuator devices made of a patch deposited in two configurations were obtained firstly in the gap of a microstrip line [2,10] and secondly, as a novel enhanced design, in two graphene patches located between the main microstrip line and two metal vias [11]. The results show for the first configuration a wide band functionality from DC to 20 GHz, with a tuneability of 7 dB and minimum insertion loss of 5 dB, and for the second an operation in a frequency band of DC to 5 GHz, with 14 dB tunability and minimum insertion loss of 0.3 dB. The Enhanced Graphene Attenuator of [11-13], the prototype of which is as shown in the Fig. 2., shows a reduction in the graphene resistance on an increase in the bias voltage, along with lower transmission for lower resistance and vice versa, as well as a higher dissipative attenuation, in comparison with the reflective contribution.

The FLG-based thin film was used for a tunable patch antenna [3,14], obtaining a change in the radiating frequency of the antenna, as well as almost 500 MHz of shift in its resonant frequency at 5GHz. The protype of the antenna is as shown in the Fig. 3(a). The operating principle of the antenna is the variation of the reactance at the radiating edge of the patch in order to mimic a varactor for tuning its radiating frequency. The reactance variation is acquired by putting graphene as a variable resistor between microstrip lines.

The introduction of a delay in a transmission line causes a shift in the phase of the transmission signal. For this purpose, the FLG based phase shifter is composed of a 50 Ω two-post transmission line connected to a stub through a tapered line and FLG depositions [15] as shown in the Fig. 3 (b). A change in the resistance of the FLG by the introduction of a Bias voltage causes a net change of reactance at the end of the taper. This introduces a delay in the transmitting signal causing a phase shift.



(a) (b)

FIG. 3 –Reactance variation components based on Graphene: (a) Tunable antenna (b)Phase Shifter.

The tapered line was designed so as to reduce the return loss introduced in the middle of the 50 Ω microstrip line in order to minimize the variation of the insertion loss between the ports. The variation of insertion loss is from 2dB to 3dB.The maximum differential phase shift yielded by the device put forward in [15] is around 40 deg.

IV. CONCLUSION

In this paper we examined progress made in the past five years on the use of graphene for microwave tunable passive components. This opens a new paradigm in the use of innovative and cost-effective methods for producing tunable microwave components based on graphene. Specifically, it paves the way for future key components of microwave and wireless communication systems such as attenuators, phase shifters and antennas.

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