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# Graphene Synthesis And Microwave Absorbing Applications – A Review

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**ABSTRACT**: Devices called "microwave absorbers" are useful for many applications such as electromagnetic shielding in electronic circuits, computer systems, space crafts and other communication systems to limit or completely avoid electromagnetic interference (EMI). EMI not only affects the functioning of these electronic equipment but also affects human health. Magnetic materials of different ferrites have been applied in this regard for their merits of high-saturation magnetization and high coercivity, which contribute to magnetic energy loss and hence microwave absorption. However, their absorbing requirements in the gigahertz frequency range is hardly achievable. But combining these ferrites withdielectric loss materials made the dream the reality. Since graphene manipulation has become possible, researchers are applying graphene in many composites matrices. In this paper, the possible applications of graphene-based composites in microwave absorbers has been intensively reviewed.

**Keywords:**Graphene, Nanocomposites, Synthesis, Microwave absorbers, Reflection loss

## I. INTRODUCTION

Nanotechnologies represent the new scenario for electronics and photonics, and the application of carbon nanoelectronics in the Radio Frequency (RF) and microwave frequency range is receiving increasing attention. The lack of availability of materials for absorption within the accelerator or microwave tube vacuum has limited the performance of the systems designed around them. The availability of increasingly better ferrites and artificial dielectric materials will certainly provide new ideas and solutions to accelerator builders who will benefit from the existence of improved microwave absorbers. Therefore, the development of efficient and cost-effectivemicrowave absorbing materials has gained the globalattention. Graphene is pure carbon in the form of a very thin, nearly transparent sheet, remarkably strong and conducts heat and electricity with great efficiency. Graphene hasproven to be a realsolution for a wide variety of microwave electronic devicesand circuits (Bozzi, etal, 2015). Dubey etal. (2016) reported that, Graphene is the first 2D structure (monolayer) to be made, a honeycomb in shape, an allotrope of carbon and sp2 bonded carbon atoms. They went further to clarify that, Graphene is a semiconductor that possesses many physical, electrical and chemical properties, so unique that makes it an active area of interest. Thus the use of materials for microwave absorption is a topic of interest to various scientific communities. Luo et al. (2016) added that Graphene not only possesses a unique structure (2D monolayer) but also exhibits a high specific surface area, superior electrical conductivity (high dielectric loss), low density and extraordinary mechanical properties. These excellent properties make it a very promising candidate for use as electromagnetic shields to absorb incident electromagnetic waves.

Among those interested in special materials (with graphene inclusive) are accelerator builders, microwave tube experts, fusion device builders and materials scientists from various areas of technology. A very close collaboration between those who build accelerators and materials scientists in laboratories, industries and academic environments all over the world is not only desirable but necessary (Isidoro, 1999). The potential applications of graphene range from ICT (electrodes for flat panel displays, touch screens, RF devices, photo-electronic sensors, flexible electronics, microelectromechanical systems (MEMS), complementary metal-oxide-semiconductor (CMOS) replacement to aeronautics (light carbon-based composites), electrical cars (batteries, super-capacitors, and lightweight alloys), energy (solar cells) and medical (DNA analysis and sensors) (Viera and Alan, 2014).

## II. MICROWAVE ABSORBERS

Absorbers in the RF/microwave realm are materials that attenuate the energy in an electromagnetic wave. Absorbers are used in a wide range of applications to eliminate stray or unwanted radiation that could interfere with a system's operation (Isidoro, 1999). Absorbers can be used externally to reduce the reflection from or transmission to particular objects and can also be used internally to reduce oscillations caused by cavity resonance (Rupinder & Gagan, 2014). The rapid development of electronic systems and telecommunications has resulted in a growing and intense interest in microwave electromagnetic absorber technology and microwave absorber materials (Hashem, 2018). Absorbers can take many different physical forms including flexible elastomers or foam or rigid epoxy or plastics. They can be made to withstand weather and temperature extremes. Absorbers have become a critical element in some systems to reduce interference between circuit components.RF/Microwave absorbers are found applicable in cavity resonance reduction, near field absorbers, loads absorbers, millimeter wave absorbers and for attenuation purposes (Nirajetal., 2016).

These absorbers are mainly design to limit or completely avoid electromagnetic interference (EMI) in electronics and telecommunication systems which not only affects the functioning of these systems but also affects human health (Luo et al., 2016). Magnetic materials of different ferrites were found capable of solving this problem for their merits of high-saturation magnetization and high coercivity, which contribute to magnetic energy loss and hence microwave absorption. However, their absorbing requirements in the gigahertz frequency range is hardly achievable (Guangzhenet al., 2019). Researches show that combining these ferrites withdielectric loss materials made the absorbing ability within the range possible.

It is obvious that electromagnetic wave absorption properties of any material are controlled by its relative complex permittivity and permeability and the balance of which is known as electromagnetic wave impedance matching. This impedance matching is instrumental in improving microwave attenuation in any material. As such, microwave absorbing materials can be classified into two: dielectric materials and magnetic materials. The conjugation of these two could be an effective way to obtain excellent impedance matching and hence achieve excellent microwave absorption (Luo et al., 2016).

Luo et al. (2016) went further to clarify that though conjugating dielectric materials and magnetic materials (eg graphene and ferrites), good microwave absorbing properties are obtained with impedance matching. Records show that the impedance matching properties are restricted and this could be overcame by including conducting polymers (eg Polyaniline) into the composite due to their controllable electromagnetic parameters, and high conductivity at microwave frequencies.

Since graphene manipulation has become possible, researchers are applying graphene in many composites matrices with a view to bring solutions to the problems. As such, the amount of literature on graphene based nanocomposites in this aspect will continue to be on the rise. In this paper, the methods used in graphene synthesis and its possible applications in microwave absorbers has been reviewed.

## III. GRAPHENE SYNTHESIS

Intensive research efforts have been devoted to methods of producing a single-layer or few-layer graphene films for research and industrial purpose. Xingchen et al. (2013) synthesized Fe/G nanocomposites by the combination of the hydrothermal and reduction reactions. The detailed process is schematically illustrated in Figure 1. Graphene oxide (GO) is first prepared from high-purity graphite by modified Hummer's method. After strong oxidation, the hexagonal carbon lattice of graphite is intensively disrupted and a substantial fraction of the carbon network is bonded to functional groups such as –OH and –COOH, resulting in a negatively charged GO sheets which are suspended in the solvent.

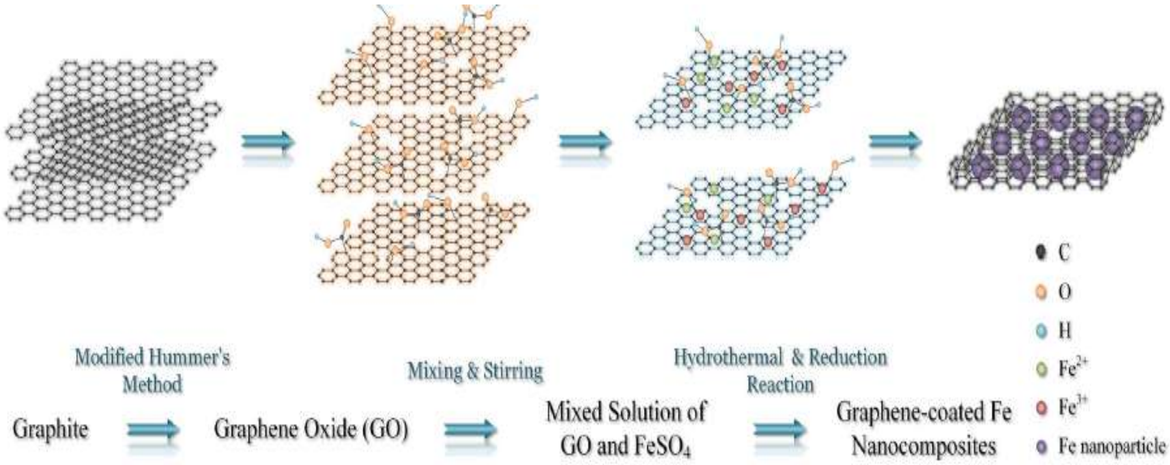


**Figure 1. Schematic Diagram for the Synthetic Process of Fe/G Nanocomposites (Xingchen et al., 2013)**

Sundaram (2014) stated that chemically derived graphene from the liquid phase exfoliation of graphite oxide provides an easy, cost-effective and large-scale production technique for graphene. Huang etal. (2014) grown EG on single-crystal SiC wafers, polycrystalline SiC and SiC thin films via thermal decomposition under UHV or ambient-pressure conditions and concluded that high-quality graphene films with controllable layer numbers and relatively large domain sizes exceeding 1 μm can be obtained on single-crystal SiC substrates. Frank and Kalbac(2014) opined that CVD-based technique among others represent the most promising method not only for production of graphene, but also for the ever growing family of other 2-D materials such as hexagonal boron nitride and many others.

Dubey etal. (2016) declared that graphene is mostly produced by Chemical Vapour Deposition (CVD) in large quantity particularly for industrial consumption. In this situation, Ni and Cu are used as catalysts. The produced quantity is transferred on insulating substrates for making transistors, logic gates, and other industrial purpose devices. Similarly Zicheng et al. (2018) successfully fabricated macroscopic three-dimensional (3D) free-standing porous all-graphene aerogel with ultra-light density and high compressibility through a mild in-situ self-assembly and thermal annealing processes. Zhou et al. (2014) added that, Graphene nanoparticles can be produced by plasma exfoliation.

Dipankar (2015) reported that Chemical Vapour Deposition has become the preferred choice of growing graphene and transferring it to different substrates to study its physics for various applications. He however, noted that the method results in multilayer graphene patches due to surface contamination and point defects in metal foils. Therefore a novel method was developed in his work to grow monolayer graphene by "Pulsed-CVD" method. In the method, the carbon precursor gas ($CH_4$) was injected into the growth chamber intermittently. The duration of injection ($t_1$) and stop time ($t_2$) was adjusted in such a way that multilayer patches were removed leaving only a monolayer graphene. Shown in figure 2 is an illustration of Graphene production using CVD technique as reported by him.

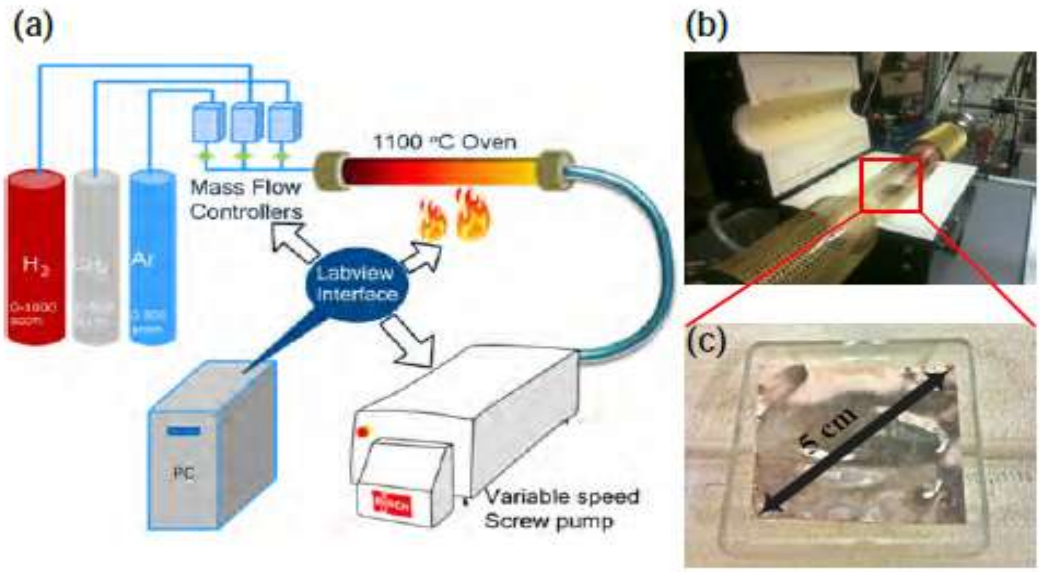


**Figure 2. Graphene Production Using CVD Technique. (A) Schematic of CVD Graphene Growth Setup. (B) Photo of CVD Machine. (C) Zoomed Image of First Generation Quartz Plate with Copper Foil (Dipankar, 2015)**

Yakubu et al. (2019) emphasized that, in the recent, chemical vapour deposition is the most popular method of producing CNT and graphene. They noted that, in the process, thermal decomposition of a hydrocarbon vapour can be achieved in the presence of a metal catalyst. Mayora-Curzio et al. (2014) mentioned mechanical exfoliation, chemical exfoliation, chemical vapour deposition and epitaxial growth of silicon carbide as potential methods of producing graphene. After comparison, they were of the opinion that, the manufacturing process that would be more interesting for industrial scale production is the chemical vapour deposition on a copper substrate. They equally justified the analysis by saying mechanical exfoliation gives the best quality graphene, but would be economically convenient only to small production scales and hence a good method for manufacturing graphene for research purpose. Mayora-Curzio et al. (2014) went further to clarify that, the epitaxial growth on silicon carbide has not only discarded by its little current scalability, but also provides a product of poorer quality than CVD.

## IV. APPLICATIONS OF GRAPHENE IN MICROWAVE ABSORBERS

The application of graphene and GNP in electromagnetic interference (EMI) shielding devices has a potential impact in electronics, automotive and aerospace sectors. Graphene is an interesting material also from the point of view of electromagnetic shielding. In particular, beside its high electrical conductivity, a graphene plane yields a good shielding efficiency against microwave radiation (Bozzi, etal, 2015). Omar etal. (2012) investigated the effect of graphene nanoparticles on the dielectric and microwave properties of natural rubber based composites filled at 2.0 up to 10.0 phr in the 1 - 12 GHz range. They realized that the attenuation coefficient values increase drastically with the increasing filler amount and frequency in the 9 - 12 GHz range. This proves a very good microwave property attributed to graphene and hence a promising agent in manufacturing microwave absorbers. Figure 3plots the frequency dependence of the electromagnetic shielding effectiveness (S.E.) at different filler (graphene) contents as reported by Omar etal. (2012). At lower frequencies S.E. values are higher but begin to decrease with the increasing frequency. There is a significant attenuation increase with the increasing frequency and filler amount.

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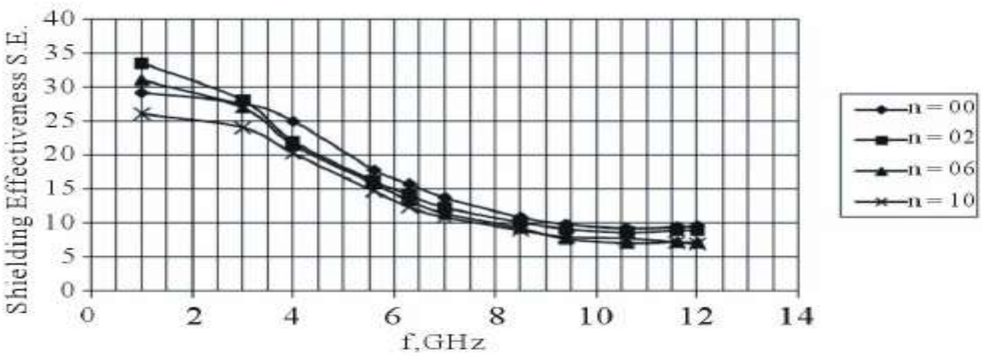


**Figure 3. Frequency Dependence of Shielding Effectiveness at Various Filler Content (n-phr of Graphene) (Omar etal., 2012).**

Zhiwei et al. (2012) investigated and reported that graphene shows saturable absorption at microwave band. They went further to clarify that, this unique microwave property renders graphene as a promising broadband saturable absorber with potential applications at both optical and microwave band. They concluded that the nonlinear microwave property of graphene may lead to new graphene microwave devices (microwave saturable absorber, modulator, polarizer etc) and this could also pave a way for its applications in microwave communications: such as microwave signal processing, broad-band wireless access networks, sensor networks, radar, satellite communications and so on. Pallab et al. (2012) reported that graphene and multi-walled carbon nanotube (MWCNT) can both be used as a RADAR absorbing material but Graphene is much superior to MWCNT. It is proved from their permeability plot that Graphene/MWCNT both has the magnetic property also. Hence Graphene/MWCNT can be used for the synthesis of different composite materials for this particular application. Xingchen et al. (2013) reported that, due to the charge transfer at Fe-graphene interface in Fe/G nanocomposites, the nanocomposites show distinct dielectric properties which result in excellent microwave absorption performance in a wide frequency range. Their work provides a novel approach for exploring high-performance microwave absorption material as well as expands the application field of graphene-based materials.

Zhou et al. (2014) fabricated Graphene nanoplatelet (GNP)–epoxy composites for the investigation of their effective dielectric permittivity, electric conductivity and microwave reflection loss over the frequency range of 8 to 20 GHz. They reported that the interaction of microwave radiation with GNP filler in the composites attenuates the electromagnetic energy and contributes to the microwave absorption.

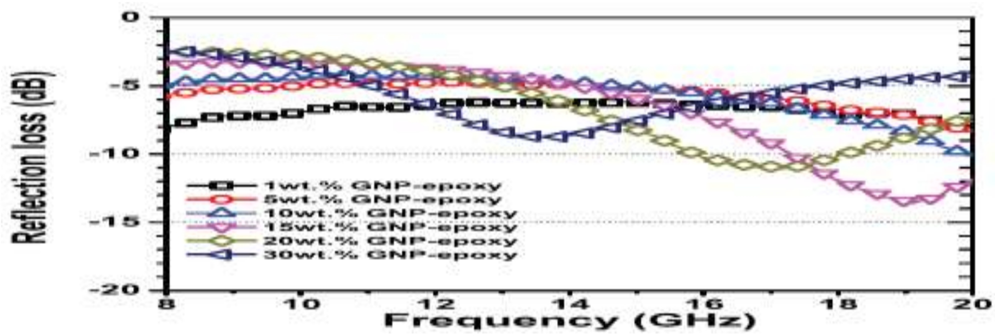


**Figure 4. Reflection Loss of GNP-Epoxy Composites with Different GNP Loadings in the Measured Frequency Range from 8 to 20 GHz (Zhou et al., 2014).**

As seen in Figure 4, the minimum reflection loss of the GNP–epoxy composites is −14.5 dB at 18.9 GHz for the composite with 15 wt. % GNP loading, which is attributed to

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dielectric loss due to the improvement of electric conductivity and the charge multi-poles at the polarized interfaces. This GNP–epoxy composites showing high and tunable reflection loss have the potential for the development and improvement of high performance electromagnetic wave absorbing materials.

Luo et al. (2016) prepared Strontium ferrite nanoparticles by a co-precipitation method, and reduced graphene oxide/strontium ferrite/polyaniline (R-GO/SF/PANI) ternary nanocomposite by in situ polymerization method. The nanocomposite exhibited the best absorption property with the optimum matching thickness of 1.5 mm in the frequency of 2–18 GHz with maximum RL of −45.00 dB at 16.08 GHz which made it a prospective candidate for microwave absorption applications. Graphene, as a two-dimensional carbon material acts as a potential microwave absorber for its special physical properties of low density, high specific surface area and moderate dielectric loss. However, the design of the graphene with 3D structures improves its microwave absorption capacity (Zheng et al., 2017).

Yau et al. (2017) investigated the electromagnetic properties and microwave absorbing characteristics of $Fe_3O_4$-Graphene (FG) in a frequency range of 1-18 GHz. The absorption or minimum reflection loss (RL) is -40.44 dB at 6.84 GHz with a thickness of 7 mm for the sample containing 73 wt·% of $Fe_3O_4$.

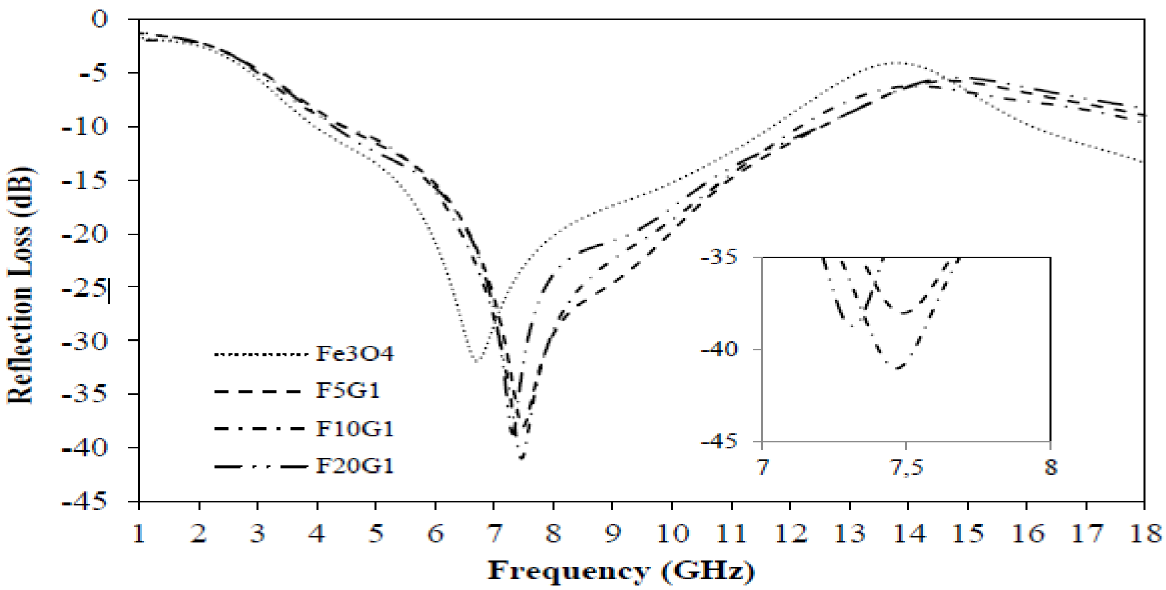


**Figure 5. Frequency Dependence of Reflection Loss for $Fe_3O_4$ and FG Nanohybrids (Yau et al., 2017)**

The bandwidth corresponding to the RL below -10 dB is 7.05 GHz as indicated in Figure 5. The authors therefore concluded that, the as-prepared $Fe_3O_4$-graphene nanohybrids showed good microwave absorption ability in the low frequency band (C-band) which can be attributed to the improved impedance matching characteristics, enhanced interfacial polarizations as well as the magnetic loss contributions.

Fanget al. (2018) proposed a broadband microwave absorbing composite with a multi-scale layered structure in which a reduced graphene oxide (RGO) film sandwiched between two layers of epoxy glass fiber laminates and serves as the frequency selective surface (FSS). The composite exhibits excellent microwave absorption performance with a total thickness of 3.2 mm and a reflection coefficient (RC) of less than -10 dB in the entire X and Ku band.

Yan et al. (2018) investigated the microwave absorption properties of polyaniline coated porous carbonyl iron powder and graphene sheets/epoxy composites. The -10 db absorption bandwidth and the minimum RL of the composite material showed improvement in comparison to the pure graphene sheets composite. The minimum reflection loss reached -45 db at a thickness of 3.5 mm while the bandwidth with less than -10 dB RL

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reached up to 4.6 GHz with a matching thickness of 2 mm. The improved microwave absorption performance of the hybrid composite is due to the interfacial polarization, enhanced conductivity and loss of the electromagnetic radiation through increased transmission routes due to multiple reflection. Shown in figure 6 is the Reflection loss curves.

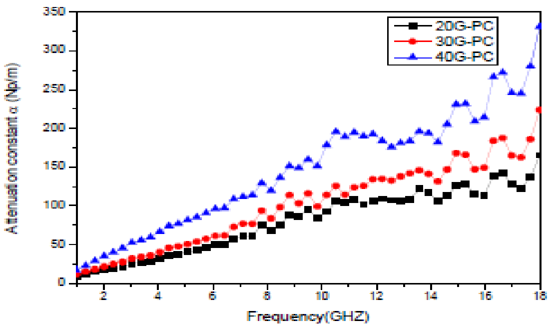


**Figure 6. Attenuation Constant α of the Composites (Yan et al., 2018)**

Xuchen and Sergei (2018) confirmed that in the terahertz frequency range, perfect absorption as well as excellent tunability can be realized with graphene. They also emphasized that the absorption can be dynamically tuned either in the absorption frequency or absorption levels with nearly 100% modulation efficiencies when low quality graphene is used. Zicheng et al. (2018) declared that the microwave absorption performance of the graphene aerogel was effectively self-adjusted via a simple mechanical compression. The optimal absorbing value was up to 61.09 dB with a broad qualified bandwidth of 6.30 GHz at the thickness of 4.81 mm when the compression strain ratio of the sample was controlled to be 30%. Furthermore Guangzhenet al. (2019) successfully synthesized hollow $Fe_3O_4$@RGO composites by the one-step solvothermal reaction route, which exhibited excellent microwave absorption properties in terms of the maximum RL value and the absorption bandwidth in the range of 2–18 GHz through tuning the hollow [$Fe_3O_4$]/[RGO] ratio. The maximum RL was observed to reach -41.89 dB at 6.7 GHz and the absorption bandwidth below -10 dB was as wide as 4.2 GHz at a thickness of 2.5 mm. This excellent performance of the novel composites could be attributed to the strong magnetic loss and favourable impedance matching.

Shang et al. (2021) fabricated a novel three-dimensional graphene-like networks material (3D-GLN) exhibiting the hierarchical porous structure with a large-scale preparation method by employing an ion exchange resin as a carbon precursor. They studied 3D-GLN first as the effective microwave absorbing material and reported that a minimum reflection loss (RL) reached -34.75 dB at 11.7 GHz. To enhance the absorption performance of the nonmagnetic 3D-GLN, they loaded the magnetic $Fe_3O_4$ nanoparticles on the surface of the 3D-GLN by using the hydrothermal method to develop the 3DGLN/$Fe_3O_4$ hybrid. The hybrid exhibited the prominent absorbing properties with a minimum RL of -46.8 dB at 11.8 GHz under the matching thickness of 3.0 mm. This proved that, 3D graphene has higher microwave absorption than the 2D and also forming a hybrid of the 3D and the magnetic nanoparticles ($Fe_3O_4$) also improves the microwave absorption of the 3D graphene.

## V. CONCLUSION

An in-depth review on the synthesis and microwave absorption properties of Graphene is presented, reviewing meaningful results obtained by different researchers around the world. From the review, Chemical Vapour Deposition, hydrothermal and reduction reactions, furnace heating, plasma exfoliation, mechanical exfoliation, chemical exfoliation, epitaxial growth on silicon carbide among others are the methods used for Graphene synthesis. The review also showed that mechanical exfoliation gives the best quality Graphene but in a small scale product while CVD is the must use method of producing Graphene as it yields a large amount. Results obtained by various researchers on microwave absorption show that Graphene-based nanocomposites are highly effective. It can be concluded that, forming a ternary of Reduced Graphene Oxide, a conducting polymer particularly polyaniline (PANI) and magnetic particles nanocomposites (eg. $Fe_3O_4$) might result to a perfect microwave absorber. However, research on how to improve microwave absorption properties of Graphene is seriously needful.

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