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Recent progress in two-dimensional materials for microwave absorption applications

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ABSTRACT

Two-dimensional materials refer to materials in which electrons can only move freely on the nanometer scale in two dimensions and have more diverse structures and diverse properties than solid-phase materials. In the past decade, two-dimensional materials have attracted considerable attention due to their most excellent physical properties, such as graphene, molybdenum disulfide (MoS_2) and MXenes. Meanwhile, due to their special structures, excellent electrical conductivity, rich surface and good mechanical strength, two-dimensional materials have unique electromagnetic properties and have potential applications in electromagnetic wave absorption, shielding and radar stealth. In this review, the progress in two-dimensional microwave absorption materials is reviewed objectively, including graphene, MoS_2 and MXenes, as well as their composites, focusing on the achievements of the past few years and the current challenges. In addition, the performances of two-dimensional microwave absorption materials in different frequency ranges and the application in electronic communication and radar stealth will also discussed.

1. Introduction

1.1. *Microwave absorption materials*

Microwave absorption material, also known as radar absorption material or radar stealth material, which can absorb microwave energy without scattering and reflection [1]. The essential principle of microwave absorption is to convert the microwave energy into thermal energy that dissipates into the environment through various absorption mechanisms. Microwave absorption materials should have sufficiently high microwave absorption rate and wide absorption bandwidth for applications [2,3]. In addition, they should also have other characteristics, such as small thickness, low surface density, high mechanical strength and environmental friendliness [4–10].

In general, microwave absorption materials can be divided into interference type and absorption type, depending on their working principles[11–13]. When the incident electromagnetic wave enters the interior of the material, the reflection, absorption and transmission of electromagnetic waves generally occur[14]. Under normal circumstances, when considering the evaluation of electromagnetic wave absorption performance, two points that must be considered are impedance matching and attenuation characteristics[15]. According to the type of losses, there are conductance loss, dielectric loss and magnetic loss. In order for electromagnetic waves to enter the material as much as possible, the material should match the impedance of free space. According to the transmission line theory[16], the reflection coefficient Γ of electromagnetic waves on a material, the impedance (Z_0) of the free space and the impedance (Z_{in}) of the material are given the

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following respective equations:

$$\Gamma = (Z_{in} - Z_0)/(Z_{in} + Z_0) \quad (1)$$

$$Z_{in} = \sqrt{(\mu_r/\varepsilon_r)}, Z_0 = \sqrt{(\mu_0/\varepsilon_0)} \quad (2)$$

where μ_r and ε_r represent the complex permeability and permittivity of the material, while μ_0 and ε_0 represent the permeability and permittivity of free space, respectively. The impedance of the material can be as close as possible to the that of the free space to minimize reflection of the electromagnetic waves[17]. When electromagnetic waves enter the interior of the material, they will interact with the material. In other words, the material should have large internal losses, including dielectric loss and magnetic loss[18].

1.2. Two-dimensional microwave absorption materials

Graphene is a typical two-dimensional material, which has attracted great attention since its discovery, due to its potential applications in various scientific fields, such as energy storage, energy delivery, electrochemistry, catalysis and optoelectronic, due to its excellent chemical and physical properties and ultra-thin thickness[19]. With the development of technology and science, the influence of electromagnetic radiation on environment is increasing[20]. Therefore, development of electromagnetic wave absorption materials to suppress electromagnetic pollution becomes a major subject of material science. In this regard, two-dimensional microwave absorption materials have become a research hotspot because of their light weight and excellent physical and chemical properties.

Fig. 1 shows publication data of two-dimensional materials in the field of microwave absorption, while a significant increase is observed in the last two years. Currently, two-dimensional microwave absorption materials basically include graphene[21], MoS_2[22], MXene[23,24] and their combination with other dielectric or magnetic materials. Fig. 2 shows schematic diagrams of the preparation process based on several typical composites materials. The structures of the composites are dependent on the structures of the two-dimensional materials, with layered, yolk-shell and nanowire morphologies. Such composites materials could have excellent electrical, thermodynamic and mechanical properties, together with the advantages of small density, large specific surface area and high thermal stability[21,23]. Most importantly, they have promising microwave absorption performances, with the so-called “thin, light, wide, and strong” requirements[25].

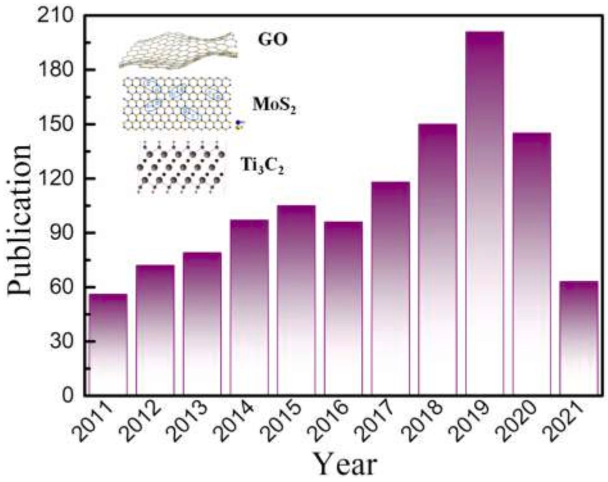

Fig. 1. Publication data of two-dimensional materials in the field of microwave absorption from Web of Science. Inset: structures of GO (Reproduced with permission from Ref. [26]), MoS_2 (Reproduced with permission from Ref. [27]) and MXene (Reproduced with permission from Ref. [28]).

This review systematically summarizes the research progress of two-dimensional materials in the field of microwave absorption. By discussing the microwave absorption properties of graphene, molybdenum disulfide, Mxene and their composites materials, the effective method to improve the microwave absorption properties of composite materials was found. Finally, we put forward some directions and prospects for future development.

2. Microwave absorption mechanisms

Microwave absorbers can be divided into three categories according to their loss mechanisms, i.e., (i) resistive absorber, (ii) dielectric loss absorber and (iii) magnetic loss absorber, which are presented and discussed in this section.

2.1. Conductive microwave absorption materials

Resistive absorbers, such as conductive carbon black[32], graphite [33], silicon carbide and high conductivity polymers[34], mainly absorb electromagnetic waves through their interaction with the electric field. With the addition of conductive fillers such as carbon black and graphite, the performances of microwave absorption materials could be largely enhanced[35]. The presence of the conductive fillers leads to the formation of a local conductive network or conductive chain inside the materials[36,37]. At the same time, the particles of the conductive fillers have very small sizes, so that they can be evenly distributed in the matrix, forming a large number of scattering sites to consume the electromagnetic waves[38–43].

Owing to its promising microwave absorption performances, silicon carbide has been extensively studied[44]. Yin’s team has made outstanding contributions in this field[45]. Silicon carbide belongs to impurity type semiconductor, whose resistivity is between metal and normal semiconductor. In order to explain the conductive microwave absorption[46], the Debye relaxation law is usually used, which is expressed as[47,48]:

$$[\varepsilon' - (\varepsilon_s + \varepsilon_\infty)/2]^2 + (\varepsilon'')^2 = [(\varepsilon_s - \varepsilon_\infty)/2]^2 \quad (3)$$

where ε_∞ and ε_s are the high and low frequency limit permittivities, respectively. Typically, the ε’-ε’’ curve is a single semicircle representing the Debye relaxation process, which with regard to the effects of interfacial polarization and conduction loss[49]. The ε’-ε’’ curve is also called Cole-Cole curve, and each semicircle represents a relaxed polarization process, indicating that the dielectric loss at this time is caused by the relaxed polarization loss. When the Cole-Cole curve is a straight line, it means that the dielectric loss is mainly caused by the conductance loss.

2.2. Dielectric microwave absorption materials

Dielectric absorbers attenuate electromagnetic waves mainly through the polarization relaxation of the media. When electromagnetic waves enter dielectric materials, energy is lost due mainly to constant polarizations, including ion displacement polarization, electron cloud displacement polarization and ferroelectric domain conversion polarization[50,51].

Ceramic microwave absorption materials have good mechanical and thermal properties, such as high temperature resistance, low coefficient of thermal expansion, high strength, chemical stability and corrosion resistance[50,52,53]. Currently, the most common ceramic microwave absorption materials are $BaTiO_3$[54], SiO_2[55,56] and silicon carbide [57]. The microwave absorption of dielectric materials like $BaTiO_3$ is closely related to the electron polarization, ion polarization and molecular polarization[58,59].

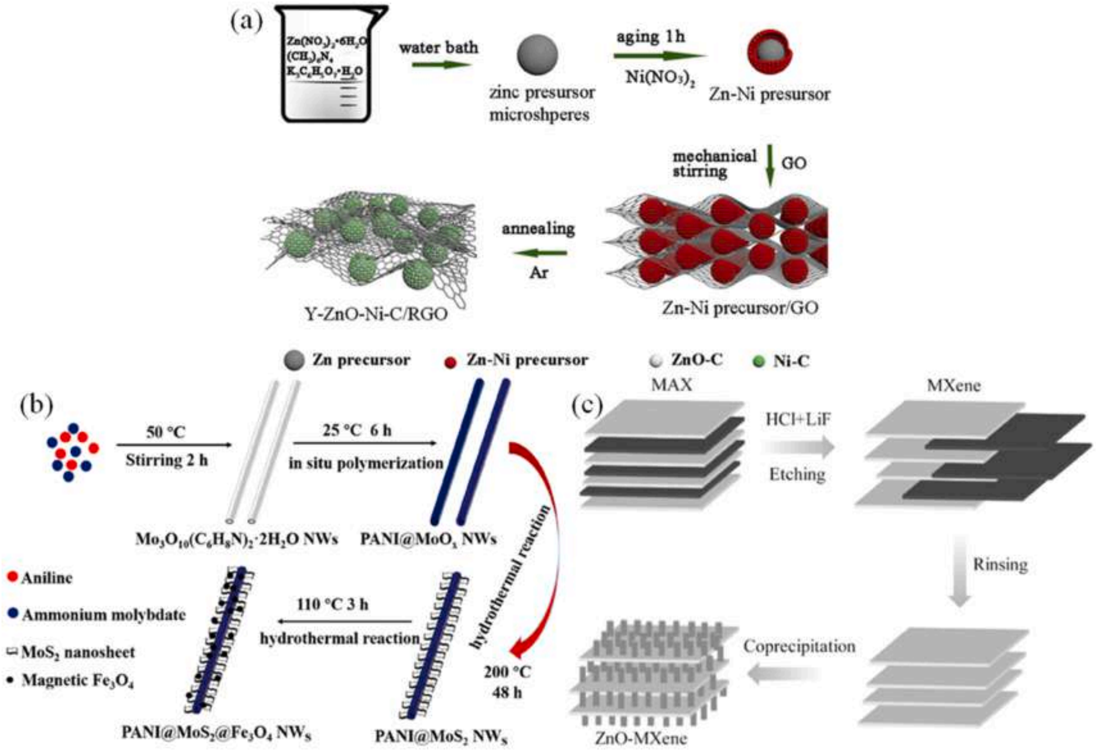

Fig. 2. (a) Schematic diagrams for the production process of yolk-shell ZnO-Ni-C/rGO composite materials (Reproduced with permission from Ref. [29]). (b) Illustration of growth mechanism of PANI@MoS_2@Fe_3O_4 nanowires (Reproduced with permission from Ref. [30]). (c) Schematic illustration of the fabrication process of ZnO-Ti_3C_2Tx nanocomposites (Reproduced with permission from Ref. [31]).

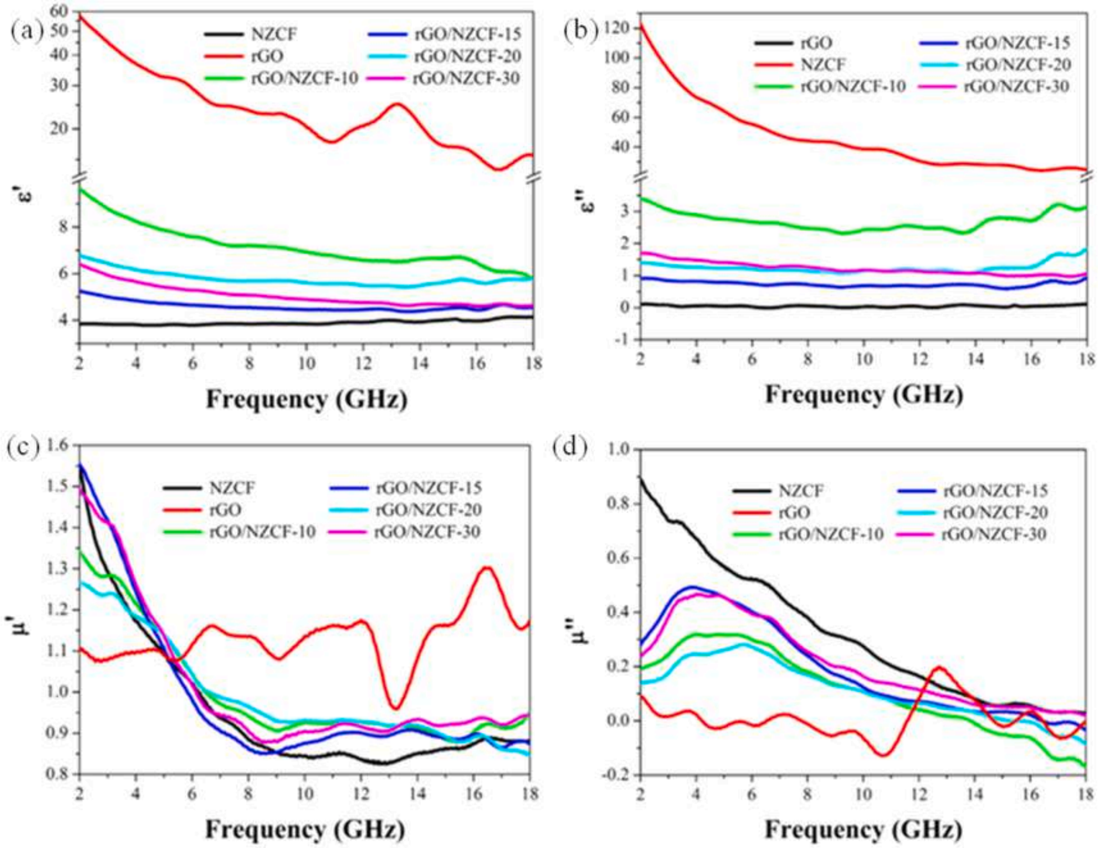

Fig. 3. Frequency dependent real (a) and imaginary (b) parts of permittivity and real (c) and imaginary (d) parts of permeability of the $Ni_{0.4}Zn_{0.4}Co_{0.2}Fe_2O_4$-rGO nanocomposites. (Reproduced with permission from Ref. [73]).

2.3. Magnetic microwave absorption materials

Magnetic microwave absorption materials attenuate electromagnetic waves mainly through magnetic effects[60]. Till now, Due to their high magnetic loss and dielectric loss, magnetic microwave absorption materials have strong electromagnetic wave absorption capabilities, but their high density limits their applications in some areas[61–64]. The loss mechanisms of magnetic microwave absorption materials mainly include hysteresis loss, eddy current loss, dimensional resonance, natural resonance and so on[65,66]. Generally, the level of the hysteresis loss can be evaluated by using the parameters derived from the hysteresis loop, such as saturation magnetization and the coercive force. Magnetic aftereffect refers to the delay of magnetic induction with respect to the change of external magnetic field[67]. Eddy current loss is generated when an alternating magnetic field is applied to a conductor [53,68]. Natural resonance occurs in the absence of an external stable magnetic field due to the existence of an equivalent magnetic crystal anisotropic field inside ferromagnetic materials[63,69,70].

Compared with other microwave absorption materials, ferrites have the advantages of high working frequency, wide frequency band and small coating thickness[71,72]. Almost all soft ferrites can be used as microwave absorption materials, such as NiCoZn and hexagonal ferrites [73–75]. For example, Fig. 3 shows complex permittivity and permeability of the $Ni_{0.4}Zn_{0.4}Co_{0.2}Fe_2O_4$-rGO nanocomposites, in which the NiCoZn ferrites possess promising electromagnetic performances, and it could be seen that the best group distribution ratio could obtain the best real and imaginary values of the dielectric constant. The amount of NiCoZn ferrites could effectively control the complex permittivity and complex permeability of the composites, thereby further improving the electromagnetic wave absorption performance of the composites. Magnetic metal microwave absorption materials are mainly in the forms of fine powders or fibers, including Fe, Co, Ni and their alloys[76], which absorb and attenuate electromagnetic waves mainly through eddy current loss and hysteresis loss[64,77–79].

3. Two-dimensional materials for microwave absorption

Represented by graphene, two-dimensional materials generally have high values of dielectric constant[39,80]. Graphene is the thinnest material in the carbon family and has great potential as microwave absorbers[20,21,23,81,82]. Similarly, MoS_2-based and MXenes-matrix composite materials also possess excellent microwave absorption performance, due mainly to their functionalized surfaces, abundant defects and large interlayer distances, leading to dipole polarizations [28,36,83,84].

3.1. Graphene-ferrite composites

3.1.1. Microwave absorption properties of graphene

Two-dimensional graphene has various unique properties, such as s high room-temperature carrier mobility, large theoretical specific surface area, high optical transparency, excellent mechanical properties and high thermal conductivity[69,85,86]. The structure of graphene is a two-dimensional single layer of carbon atoms stacked into a hexagonal structure. The C–C bond is sp^2 hybridization, the in-plane C–C bond is one of the strongest bonds in the material and the π bond of the out of plane contributes to the delocalized electronic network. It is not only responsible for the electronic conduction of graphene, but also provides the graphene layer with the weak interaction between the layers or between the graphene and the substrate. Shen et al.[87] prepared graphene oxide (GO) films through direct evaporation of GO suspension at a mild temperature. Fig. 4 shows schematic representation of fabrication process of the GO-films and GO-foams. The GO-foam had lower conductivity, but a shielding performance was better than that of the GO-film. This is simply because the microwaves experienced multiple reflection in the pores of the GO-foam[88].

3.1.2. Microwave absorption properties of graphene-based composites

Graphene-based microwave absorption composite materials mainly include graphene/nano metal, graphene/conductive polymer and graphene/nano metal/conductive polymer. The coaxial transmission method was used to evaluate microwave absorption properties of the composite materials. The RL is determined according to the following equations[27,89,90]:

$$\mathrm{RL(dB)} = 20\log\left|(Z_{in}-1)/(Z_{in}+1)\right| \tag{4}$$

$$Z_{in} = \sqrt{\mu_r/\varepsilon_r}\tanh\left[j(2\pi fd/c)\sqrt{\varepsilon_r\mu_r}\right] \tag{5}$$

where c is the velocity of microwaves, f is the microwave frequency and d is the absorb layer thickness. Generally speaking, when the RL value reaches below −10 dB, the absorption of the electromagnetic wave

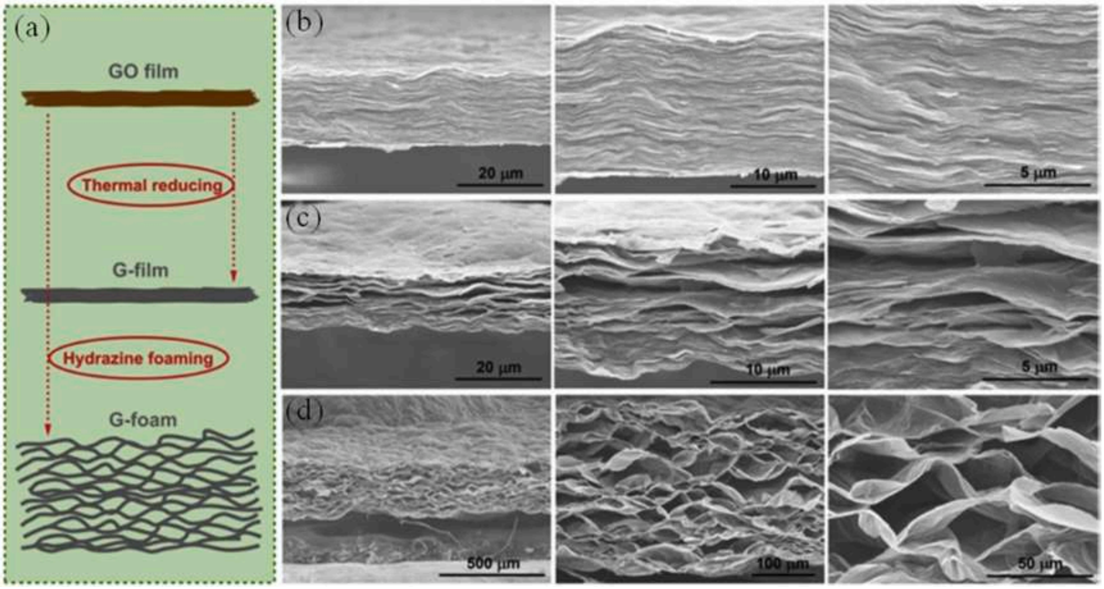

Fig. 4. (a) Schematic representation of fabrication process of the GO-films and GO-foams. (b-c) Cross-sectional SEM images of the GO-films and (d) the GO-foams. (Reproduced with permission from Ref. [87]).

materials could reach 90%, and we think that the microwave absorbing material has achieved effective absorption. Wu et al.[26] prepared reduced graphene oxides (rGO) with polypyrrole with RL of −54.4 dB. Kuang et al.[91] used natural biopolymer cellulose nanofiber to form composites with rGO, leading to maximum RL of −40.64 dB, with effective absorption bandwidth of 7.72 GHz showed in Fig. 5a-c. Besides, in order to eliminate or even convert the negative effects of heat energy into other electromagnetic energy, Cao et al.[92] first proposed a simple and versatile "material gene sequencing" method. It focused on converting and harvesting the waste electromagnetic energy in the environment, providing a better way against the electromagnetic pollution, which was different from other method.

It is expected the combination of graphene and magnetic components could result in composite materials with high microwave absorption performances. For instance, Ding et al.[94] prepared Co nanosheets@rGO composites with maximum RL of −45.15 dB while the optimal absorption bandwidth was 7.14 GHz. Composites prepared by using chemical methods usually have higher microwave absorption performances. For example, as demonstrated in Fig. 5d-e, Cao et al.[93] prepared Co_3O_4-rGO composites exhibited excellent microwave

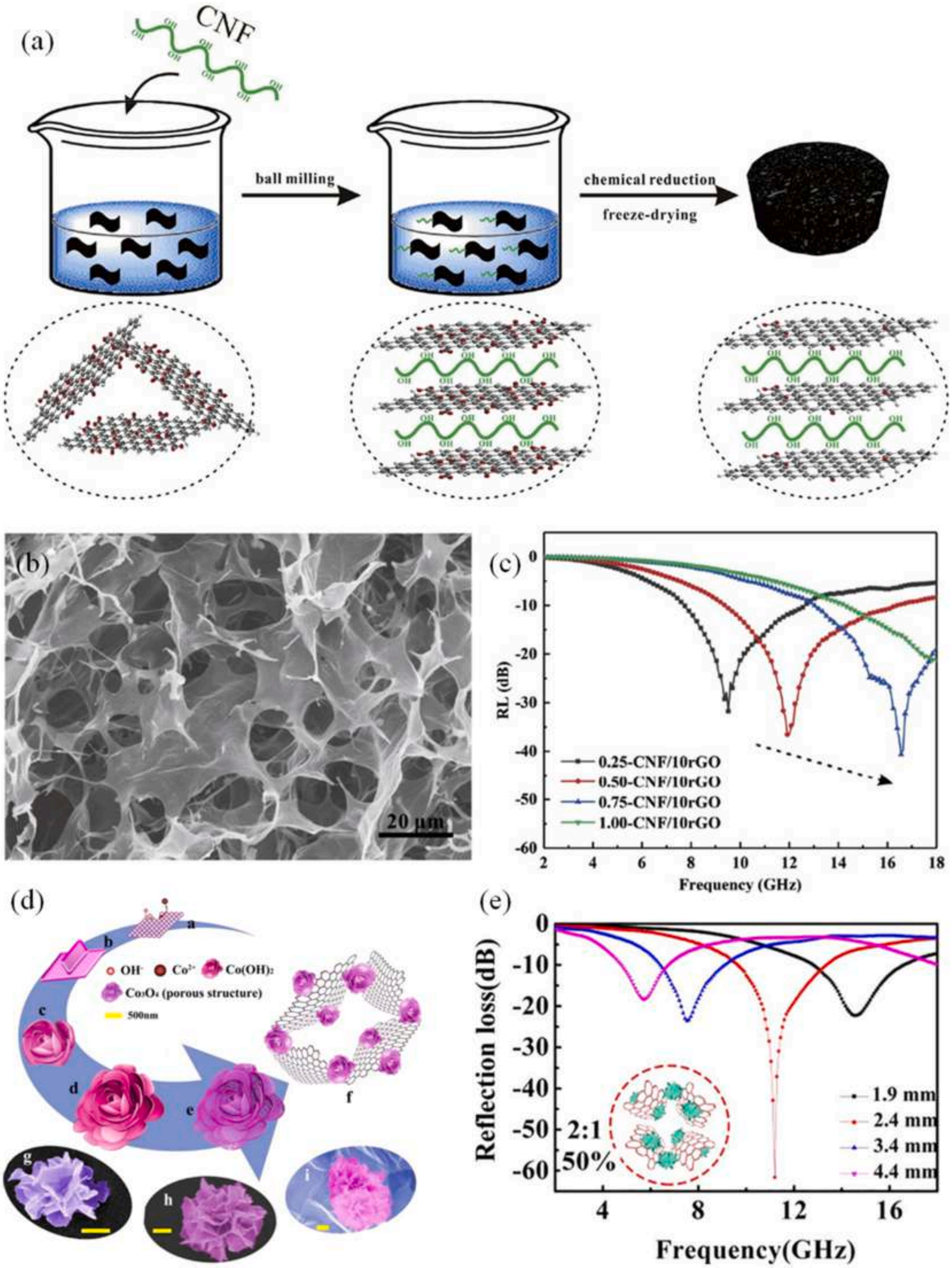

Fig. 5. (a) Schematic illustration of self-assembly process of the CNF/rGO composites. (b) SEM image of the 0.75-CNF/10rGO composite. (c) RL values of the CNF/10rGO composites with different contents of CNF. (Reproduced with permission from Ref. [91]) (d) Formation process and (e) SEM image of the Co_3O_4-rGO hybrid-architectures. (Reproduced with permission from Ref. [93]).

absorption performances, with a minimum RL of −61 dB. The authors claimed that the interfacial polarization and dipole polarization of the composites could be adjusted, so that the electromagnetic characteristics of the Co_3O_4 flowers could be tailored. Similarly, novel porous flower-like NiO@graphene composites[95] and rGO/MnOx composite aerogels[96] have been shown to have promising microwave absorption properties.

Ferrites, especially spinel ferrites, have been used form composites with graphene, in order to develop high performance microwave absorption materials. Examples include $NiFe_2O_4$-rGO[72,97], $CoFe_2O_4$/rGO[98], $ZnFe_2O_4$-rGO[99], $Ni_{0.4}Zn_{0.4}Co_{0.2}Fe_2O_4$-rGO[73,100], rGO/porous $LiFe_5O_8$[100] and so on. Numerous research results indicate that relaxation loss, electrical loss, and magnetic loss are likely to be the main reasons for the excellent microwave absorption performance, which is closely related to the magnetic particles with multi-interfaces and improved impedance matching. For instance, Liu et al.[98] prepared $CoFe_2O_4$/rGO (CFO/rGO) composites that possessed an ultra-wide bandwidth of 5.8 GHz and the maximum RL of −57.7 dB as the absorbing layer thickness was 2.8 mm. Meanwhile, other ferrites have also been studied in terms of microwave absorption properties in addition to spinel ferrites[101–103].

3.1.3. Microwave absorption properties of ternary graphene composites

From the above results, the combination of the magnetic materials and graphene did increase the RL of the composite to some extent, but the absorption bandwidth did not seem to change much. In order to further improve the attenuation characteristics and impedance matching inside the material, organic materials can be added to the composite material to form a ternary composite material.

For example, Zhang et al.[104] prepared rGO/$MnFe_2O_4$/PVDF composites and the results show the most excellent wave absorption properties. Gradually, ZnO@Fe_3O_4[105], MoS_2/Fe_3O_4/rGO[106], Fe_3O_4@LAS/rGO[29,107], rGO-CNT-Fe_3O_4[108], rGO/$BaFe_{12}O_{19}$/Fe_3O_4[109] have been researched and possessed excellent absorption properties respectively. In addition, Zhu et al.[110] successfully designed the flower-like CoS_2@MoS_2@rGO with the minimum RL of −58 dB and an effective absorption bandwidth of 6.24 GHz in Fig. 6 [38,111]. In summary, graphene-based materials have been greatly progressed for microwave absorption applications, as listed in Table 1.

Table 1
Performances of recently reported graphene-based microwave absorption materials.

b	Thickness(mm)	RL(dB)	Bandwidth(GHz)	Refs.
GO foam	–	−26.30	–	[87]
MoS_2/rGO	2.30	−50.90	3.00	[27]
CoNSs@rGO	3.60	−45.15	5.61	[94]
Co_3O_4/rGO	2.40	−61.00	4.00	[93]
$CoFe_2O_4$/rGO	2.80	−57.70	5.80	[98]
NiO@graphene	1.70	−59.60	4.24	[95]
$NiFe_2O_4$-rGO	2.70	−58.00	4.08	[97]
rGO/$MnFe_2O_4$/PVDF	3.00	−29.00	4.88	[104]
rGO/Fe_3O_4/ZnO	2.00	−57.00	4.50	[105]
rGO/$BaFe_{12}O_{19}$/Fe_3O_4	1.80	−46.04	5.68	[109]
CoS_2@MoS_2/rGO	2.40	−58.00	6.24	[110]

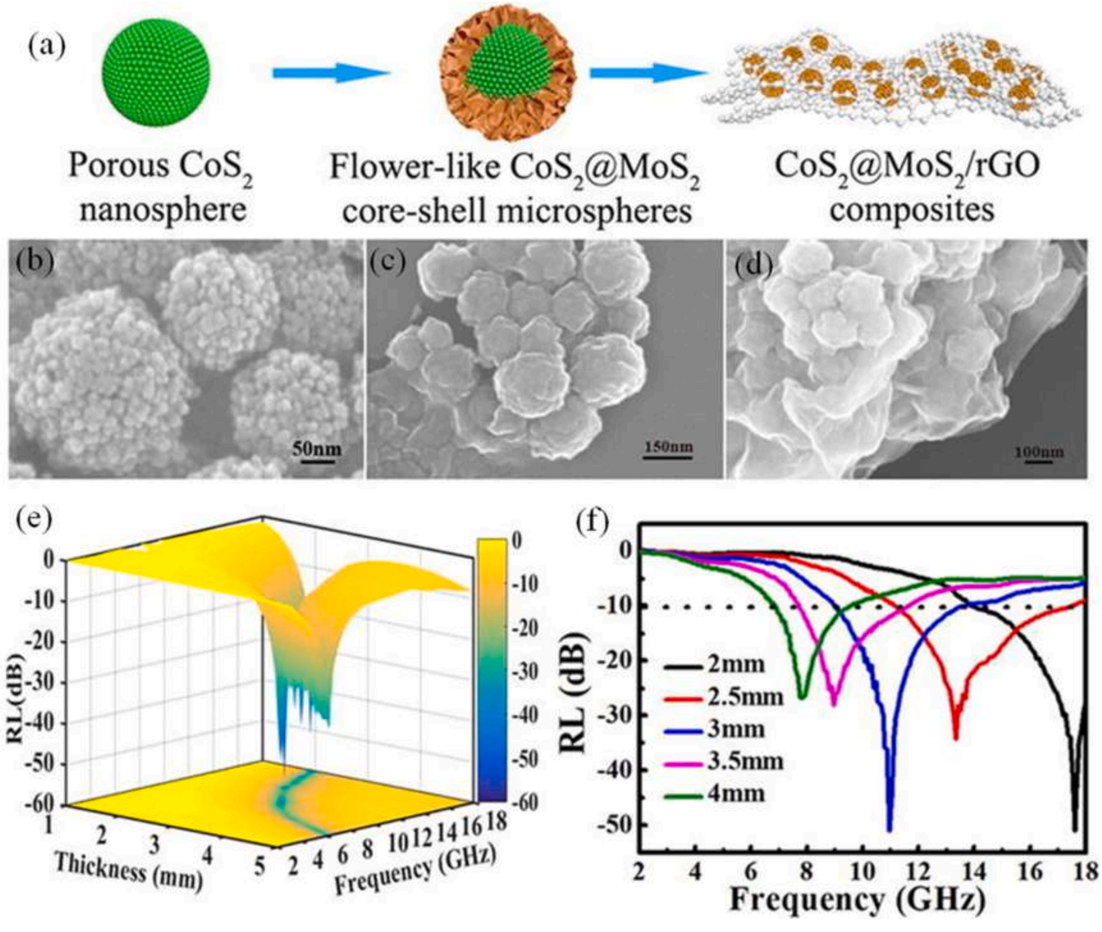

Fig. 6. (a) The schematic illustration for CoS_2@MoS_2/rGO composites. SEM images of (b) CoS_2, (c) CoS_2@MoS_2, (d) CoS_2@MoS_2/rGO. (e) the corresponding three-dimensional representation and (f) RL of CoS_2@MoS_2/rGO composite with 20% loading in the frequency range of 2–18 GHz. (Reproduced with permission from Ref. [110]).

3.2. MoS_2-based microwave absorption materials

3.2.1. Microwave absorption properties of MoS_2

MoS_2 is a new two-dimensional layered compound, similar to graphene. Recently, MoS_2 has become a research hotspot, due to its unique physical, chemical and photoelectric properties. Like graphene, MoS_2 also has a weak van der Waals force between adjacent layers. The structure of single-layer molybdenum disulfide is a sandwich layered structure formed by a layer of Mo atoms in the middle and a layer of S atoms on both sides. At the same time, one Mo atom is connected to six S atoms, and the Mo-S bond is a covalent bond. However, the distance between the layers of the multilayer molybdenum disulfide structure is 0.65 nm, and there is only weak van der Waals force between the layers, so molybdenum disulfide has excellent lubricity. MoS_2 can be prepared by using natural or chemical synthesis. Natural method refers to the removal of acid insoluble substances, such as SiO_2, Fe, Cu, Ca, Pb and other impurities in molybdenites through certain physical and chemical interactions, followed by further refinement. The MoS_2 obtained in this way can maintain the natural crystal shape of MoS_2, thus having high lubrication performance. Chemical synthesis method can result in high purity, less impurity, fine particle size sulfides, which there can be used to prepare materials with different functionalities. Therefore, this method has been widely utilized to produce nanosized sulfides. There are many ways to prepare MoS_2, but the most widely used method is hydrothermal process. In this case, molybdenum source directly reacted with sulfur to form nano-MoS_2[112].

In 2015, Cao et al.[113] obtained few-layered MoS_2 nanosheets and studied dielectric properties and microwave absorption performance of the MoS_2 nanosheets. It was found that MoS_2 nanosheets had higher imaginary permittivity than their bulk counterpart. Similarly, MoS_2 has also been incorporated with other components in order to achieve composites with high microwave absorption performance.

3.2.2. Microwave absorption properties of binary MoS_2 composites

Recently, Che et al.[114] reported hierarchical MoS_2/FeS_2 composites with a maximum RL value of −60.2 dB and an effective absorption bandwidth of 6.48 GHz at only 2 mm. Due to the hollow porous structure and high specific surface area, multi-interface polarization was present and impedance matching was improved[115], so that the composite displayed excellent microwave absorption performances, with strong broadband microwave absorption. More recently, Fe@MoS_2[116,117], MoS_2@$Bi_2Fe_4O_9$[118], and MoS_2@$CoFe_2O_4$[119] have been reported in the literature, with promising microwave absorption performances.

In addition to ferrites, conductive polymers have been combined with MoS_2 to develop microwave absorption materials[27,113]. For example, Zhao et al.[120] prepared metal–organic framework-based PB@MoS_2 core–shell microcubes with an effective bandwidth of 7 GHz[121]. In addition, Bai et al.[122] fabricated MoS_2/PANI composite with nano-flower structure, with multiple interfaces and multiple polarizations and reflections, thus leading to strong electromagnetic wave absorption capability. As shown in Fig. 7a-b, An et al.[34] prepared PPy@MoS_2 heterostructures with bandwidths of up to 6.4 GHz at 2.5 mm and a peak RL of −49.1 dB. The outstanding performances were attributed to the good impedance matching and multifarious loss pathways in the materials, such as dipole polarization, interfacial polarizations and conductive loss.

3.2.3. Microwave absorption properties of ternary MoS_2 composites

Of course, MoS_2 based ternary composites have also attracted attentions for microwave absorbing applications. With the combination of graphene and MoS_2, Prasad et al.[123] reported Ni-Cu@MoS_2@rGO composites with enhanced dielectric loss and thus microwave shielding capability. Moreover, there are various composites that possessed similar microwave absorption performances[110]. For example, polyaniline@MoS_2@Fe_3O_4 nanowires exhibited the minimum RL value of −49.7 dB[30]. Graphene nanoplatelets-based multi-component composites (GNPs@NixSy@MoS_2) could achieve a RL value of −43.3 dB with a thickness of 2.2 mm, as observed in Fig. 8a-b[124]. Besides, composite materials[125], such as polystyrene/polyaniline(PANI)/MoS_2 hybrid[51], MoS_2/TiO_2/Ti_3C_2Tx[84], MoO_3/MoS_2/PVDF hybrids [126], Fe_3O_4@C@MoS_2[127], also displayed excellent microwave absorption performances.

The relationships between effective bandwidth and thickness of the MoS_2-based microwave absorption materials reported in the open literature are summarized in Fig. 8c-d. The RL value of most MoS_2-based microwave absorption materials could exceed −40 dB, which are much

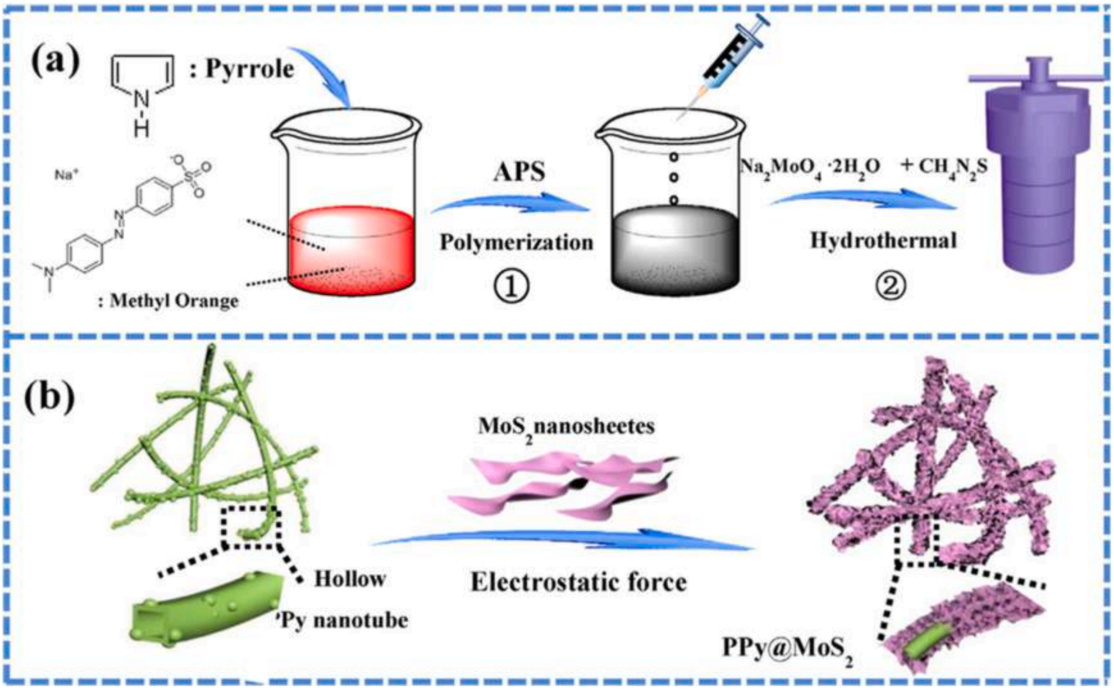

Fig. 7. Schematic diagram to illustrate preparation of the core–shell PPy@MoS_2 with nanotube-like composite. (Reproduced with permission from Ref. [34]).

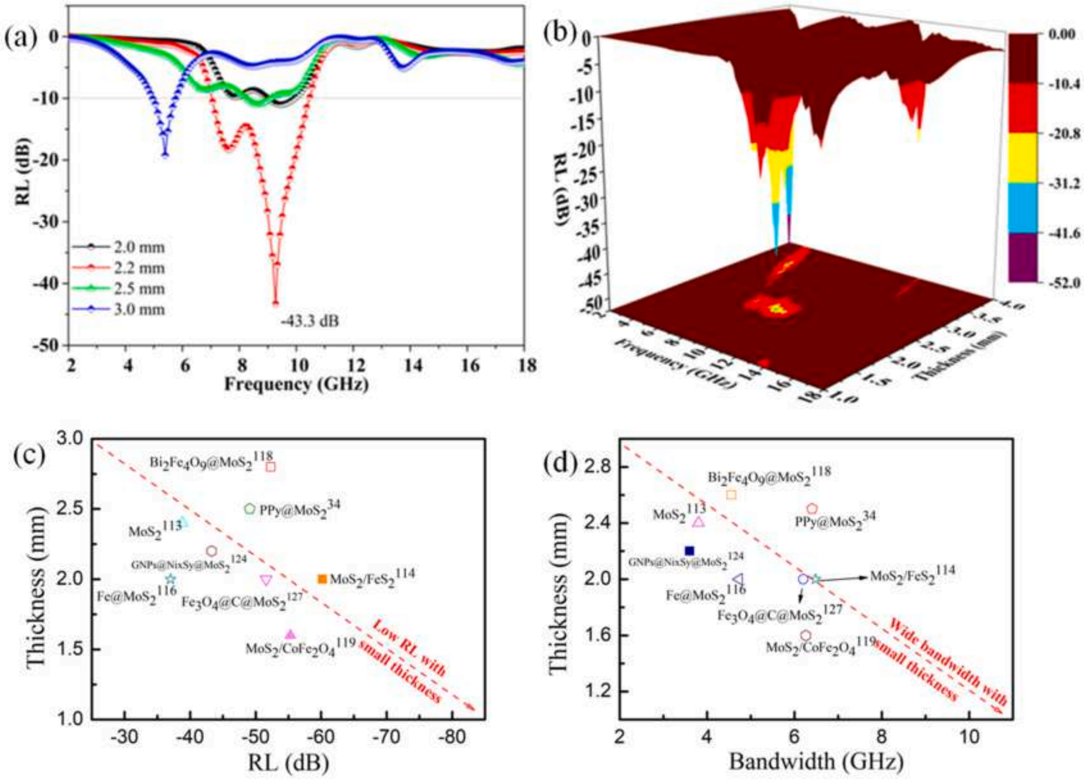

Fig. 8. (a) RL curves and (b) 3D surface plots of the GNPs@NixSy@MoS_2 composite at different thicknesses. (Reproduced with permission from Ref. [124]) Performance assessment diagram of typical MoS_2-based microwave absorption materials: (c) minimum reflection loss and (d) effective absorption bandwidth versus thickness.

higher than that of pure MoS_2. Besides, the $MoS_2/CoFe_2O_4$ composites had much better performance, with a RL level of −55.3 dB at the thickness of 1.6 mm[119]. In this case, the ferrites played an important role in improving the microwave absorption behaviors of the composites. As shown in Fig. 8d, the absorption bandwidth (<-10 dB) of almost all MoS_2-based microwave absorption materials exceeds 4 GHz and the corresponding thickness is less than 3 mm. Similarly, MoS_2/FeS_2 composite exhibited an effective absorption bandwidth of 6.48 GHz when the thickness was only 2 mm[114]. Therefore, MoS_2 and its hybrids are potential candidates as microwave absorption materials with wide bandwidth.

3.3. MXene-based microwave absorption materials

3.3.1. Microwave absorption properties of MXene materials

MXenes are metal carbides or nitrides with two-dimensional layered structures, which are similar to that of laminated potato chips, MXene synthesized by hydrofluoric acid etching has a morphological structure

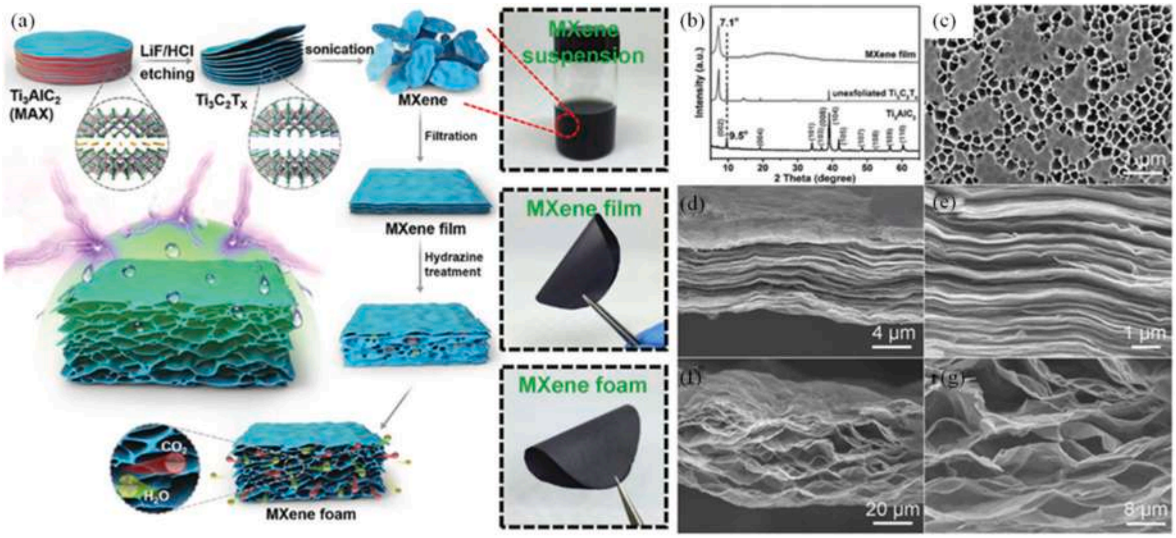

Fig. 9. (a) Schematic illustration of fabrication of the hydrophobic and flexible MXene foams. (b) XRD patterns of Ti_3AlC_2, unexfoliated $Ti_3C_2T_x$ and the MXene films. (c) SEM image of the Ti_3C_2Tx MXene sheets. Cross-sectional SEM images of the MXene films (d, e) and the MXene foam (f, g). (Reproduced with permission from Ref. [28]).

similar to an accordion, and they are multilayered[83]. MXenes have a general chemical formula of $M_{n+1}AX_n$, with n = 1–4, where M is the transition metals, such as Ti, Mn, Nb or Mo and so on, in general A is the elements of the third and fourth main groups and X represents C or N [128]. MXenes are considered a promising alternative to graphene, due to their excellent metal conductivity, MXene materials with different structural designs have also made the latest progress in wireless communication, electromagnetic interference shielding and electromagnetic wave absorption[24]. Zhang et al.[28] fabricated hydrophobic, lightweight and flexible MXene foams, which were the first hydrophobic and porous MXene based materials, as shown in Fig. 9. They achieved an outstanding electromagnetic shielding effectiveness with the lightweight MXene foams, due to the favorable porous structure. In addition, microwave absorption performances and electromagnetic shielding of MXene nanosheets are also reported by Yin[129], He [130] and others[83,128].

3.3.2. *Microwave absorption properties of binary MXene composites*

Zhang et al.[131] demonstrated that Ni-modified MXene exhibited enhanced microwave absorption capability, due to the introduction of the additional magnetic loss. Liang et al.[132] and Jiang et al.[133] reported electromagnetic shielding properties of MXene-Ni composites, but the latter team added PVDF to adjust the loss mechanism and thus the attenuation mechanism of the materials. Qian et al.[31] and Deng et al.[134] fabricated the urchin-like ZnO-MXene composites and MXene/Co_3O_4 composite to further enhance electromagnetic absorption performances. FeCo-Ti_3C_2 MXene[135] and sandwich-like CoFe@Ti_3C_2Tx[136] were designed to modify the impedance matching and enhance interfacial polarization. At the same time, spinel ferrites were combined with MXene to develop microwave absorption composites, such as $ZnFe_2O_4$/MXene[137], $Ni_{0.5}Zn_{0.5}Fe_2O_4$/MXene[74], and Fe_3O_4@Ti_3C_2Tx[138].

In addition, dielectric and resistive absorbing materials are also widely used to combine with MXene, such as SiC[139], carbon[140] and polyaniline[141]. For example, Yin et al.[142] synthesized Ti_3C_2Tx/SiCnws hybrid foams with ultralow density, with a minimum RL value of −55.7 dB. The unique interaction between $Ti_3C_2T_x$ and SiCnws, together with graded porosity, greatly reduced the degree of agglomeration of the particles, facilitating electromagnetic dissipation.

3.3.3. *Microwave absorption properties of ternary MXene composites*

Li et al.[36] fabricated graphite/TiC/Ti_3AlC_2 hybrids that showed enhanced EM absorption capability. The minimum RL reached −63 dB and the absorption bandwidth was 3.5 GHz at 2.1 mm. At the same time, Ti_3C_2/Fe_3O_4/PANI[143,144], and MXene/CNF/sliver[42] have been claimed to reveal high microwave absorption performances. In these composites, the Ti_3C_2 of multilayer structure results in a large number of interfaces, which may greatly enhance the interface polarization within the materials. At the same time, the etching reaction triggered the formation of abundant surface functional groups and localized defects, which would produce dipole polarization, resulting in high dielectric loss. Furthermore, the presence of conductive polymers can provide more conductive paths for the migration of charges, leading to conductive loss.

MXene-based materials have to be modified to have stronger microwave absorption capabilities, as demonstrated in Table 2. The microwave absorption performances of the MXene-based materials after the combination with ferrites have not been greatly enhanced, implying that there could be other influencing factors, such as materials preparation process[135]. For example, different etching methods and reaction temperature could bring out different results.

Table 2
Microwave absorption properties of MXene-based materials.

Absorber	Thickness (mm)	RL (dB)	Bandwidth (GHz)	Refs.
MXene	1.68	−40.80	3.66	[128]
MXene	1.80	−30.00	2.80	[145]
MXene/cellulose aerogels	2.00	−43.40	4.50	[146]
CoFe@Ti_3C_2Tx	2.20	−36.29	3.20	[136]
carbon/TiO_2	1.60	−36.00	4.00	[140]
FeCo-Ti_3C_2	1.60	−17.86	8.80	[135]
NiO&TiO_2@C	2.00	−25.00	9.00	[147]
Ni/MXene	2.00	−24.80	3.00	[131]
MXene/Ni hybrid	1.75	−49.90	2.10	[132]
Ti_3C_2Tx/CNZF	3.60	−58.40	2.10	[148]
Fe_3O_4@Ti_3C_2Tx	4.20	−57.20	1.40	[149]
Ti_3C_2Tx/Ni-spheres	1.50	−47.06	3.60	[150]
Ti_3C_2Tx@$NiCo_2O_4$	2.18	−50.96	1.00	[151]
MXene/PANI	1.80	−56.30	3.00	[141]
TiO_2/Ti_3C_2Tx/Fe_3O_4	1.90	−57.30	2.00	[138]
Ti_3C_2/Fe_3O_4/PANI	1.90	−40.30	5.20	[143]
PVB/$Ba_3Co_2Fe_{24}O_{41}$/Ti_3C_2	2.80	−46.30	1.60	[144]

3.4. *Other two-dimensional microwave absorption materials*

Boron nitride (BN) has graphite-like structure, with density and chemical properties similar to those of carbon fibers. BN is a good insulator with a low dielectric constant, thus having weak influence on the dielectric properties of other materials. Wei et al.[152] prepared BN/SiC composite coating to modified carbon fibers via a chemical method. After the surface of carbon fiber was modified with the BN/SiC composite coating, the oxidation resistance, dielectric property and microwave absorption property of the carbon fiber were obviously improved. In addition, some researchers have begun to study the electromagnetic wave absorption properties of WS_2[153], black phosphorus [154], and GeP_5[155]. Cheng et al.[156] have synthesized WS_2-rGO heterostructure nanosheets with the minimum RL of −41.5 dB at 2.7 mm and the bandwidth of 13.62 GHz. The synergistic mechanism of interface coupling effect and interface scattering after hybridization of WS_2 and rGO significantly enhances the microwave absorption properties of the composite.

4. Applications of two-dimensional microwave absorption materials

On one hand, electromagnetic waves can be used as information carriers for the applications in communications, TV, remote sensing, navigation and so on. On the other hand, they could also serve as energy carriers for applications microwave heating, electromagnetic confrontation, medical therapy so on. In both cases, there could be electromagnetic radiation that is not only harmful to human's health but also interferences with various electronic instruments and equipment. In addition, electromagnetic waves have strong links with defense applications, such as microwave absorption for stealth[13]. Fig. 10 shows working principle of radars. With the development of a variety of radar detection technologies, the requirement of stealth performance will be gradually increased. For example, the lighter the microwave absorbing materials, the less the impact on the flight performance of aircraft and missiles will be. Additionally, in order to adapt to the harsh environment, microwave absorption materials also need to have high temperature resistance, ocean resistance, strong environmental adaptability, radiation resistance, impact resistance and so on.

In addition to applications for radar wave absorption, two-dimensional materials also play a vital role in the field of electromagnetic shielding[157–159]. Information appliances products would make noise owing to high frequency electromagnetic shielding, which affects public communication quality. Furthermore, if people are exposed to strong electromagnetic pollution in the environment for a long time, it is possible to develop cancer. The spraying technology is used to coat the material on the surface of electronic communication equipment, which can effectively improve the electromagnetic wave shielding effect of the

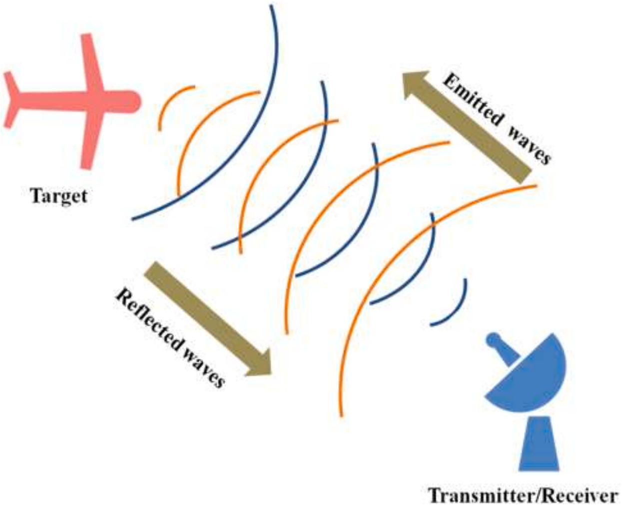

Fig. 10. Schematic diagram of the working principle of radar.

equipment.

Basically, microwave absorption materials at the L, S and C bands were studied in early years[160–164]. Comparatively, materials for X and Ku bands have been extensively studied. The high frequency Ka band is usually used for satellite communications. At Ka-band, the antenna size of the user terminal is mainly restricted not only by the antenna gain, but also by the ability to suppress the interference of other systems. Therefore, the development of microwave absorption materials at this frequency band is important[165,166].

5. Overview

In summary, we have systematically reviewed the recent advances in two dimensional microwave absorption materials and their application, including rGO, MoS$_2$, Mxenes and their composites and others two dimensional materials. In order to meet the needs of the complex electromagnetic environment in the future, the absorbing performance of two-dimensional materials needs to be further improved. We believe that there is important research space in the following areas:

(1) . Optimize the composition and structure of the composite absorbing material, enhance the polarization relaxation of the interface between the components, give full play to the synergy between the components, and pursue absorption Under the premise of strong absorption frequency bandwidth, the density and thickness of the composite wave absorber are minimized. For example, a suitable chemical method such as hydrothermal method could be used to combine the two-dimensional materials and the magnetic materials to obtain the composites with a special microstructure and morphology.

(2) . It can adapt to the various frequency bands corresponding to the working frequencies of most civilian wireless electronic equipment and important military detection instruments, such as meter waves, centimeter waves, millimeter waves and infrared waves.

(3) . Meanwhile, environmental friendliness, convenience in use and simple preparation process are additional requirements of microwave absorbing materials without sacrificing their performances. Besides, the capability of two-dimensional microwave absorption materials to adapt complex environments, such as high temperature and corrosion resistance, should be further studied, so as to extend their applications in the harsh battlefield environments.

(4) . It is necessary to further explore the relationship between the microstructure and morphology of two-dimensional materials and their composites at different scales. In addition, two-dimensional microwave absorption materials could find applications in flexible devices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] J. Luo, P. Shen, W. Yao, C. Jiang, J. Xu, Synthesis, Characterization, and Microwave Absorption Properties of Reduced Graphene Oxide/Strontium Ferrite/Polyaniline Nanocomposites, Nanoscale Res. Lett. 11 (2016) 141.
[2] M.S. Cao, X.X. Wang, M. Zhang, J.C. Shu, W.Q. Cao, H.J. Yang, X.Y. Fang, J. Yuan, Electromagnetic Response and Energy Conversion for Functions and Devices in Low-Dimensional Materials, Adv. Funct. Mater. 29 (2019) 1807398.
[3] B. Wen, M. Cao, M. Lu, W. Cao, H. Shi, J. Liu, X. Wang, H. Jin, X. Fang, W. Wang, J. Yuan, Reduced graphene oxides: light-weight and high-efficiency electromagnetic interference shielding at elevated temperatures, Adv. Mater. 26 (2014) 3484–3489.
[4] X. Li, L. Wang, W. You, L. Xing, L. Yang, X. Yu, J. Zhang, Y. Li, R. Che, Enhanced polarization from flexible hierarchical MnO$_2$ arrays on cotton cloth with excellent microwave absorption, Nanoscale 11 (2019) 13269–13281.
[5] Y. Hou, L. Cheng, Y. Zhang, Y. Yang, C. Deng, Z. Yang, Q. Chen, X. Du, C. Zhao, L. Zheng, Enhanced Flexibility and Microwave Absorption Properties of HfC/SiC Nanofiber Mats, ACS Appl. Mater. Interfaces 10 (2018) 29876–29883.
[6] F. Ye, Q. Song, Z. Zhang, W. Li, S. Zhang, X. Yin, Y. Zhou, H. Tao, Y. Liu, L. Cheng, L. Zhang, H. Li, Direct Growth of Edge-Rich Graphene with Tunable Dielectric Properties in Porous Si$_3$N$_4$ Ceramic for Broadband High Performance Microwave Absorption, Adv. Funct. Mater. 28 (2018) 1707205.
[7] H. Mei, X. Zhao, J. Xia, F. Wei, D. Han, S. Xiao, L. Cheng, Compacting CNT sponge to achieve larger electromagnetic interference shielding performance, Mater. Des. 144 (2018) 323–330.
[8] Z. Wu, K. Pei, L. Xing, X. Yu, W. You, R. Che, Enhanced Microwave Absorption Performance from Magnetic Coupling of Magnetic Nanoparticles Suspended within Hierarchically Tubular Composite, Adv. Funct. Mater. 29 (2019) 1901448.
[9] C.G. Jayalakshmi, A. Inamdar, A. Anand, B. Kandasubramanian, Polymer matrix composites as broadband radar absorbing structures for stealth aircrafts, J. Appl. Polym. Sci. 136 (2018) 47241.
[10] M. Zhang, M.-S. Cao, J.-C. Shu, W.-Q. Cao, L. Li, J. Yuan, Electromagnetic absorber converting radiation for multifunction, Mater. Sci. Eng.: R: Rep. 145 (2021), 100627.
[11] W.Y. Lv Xingjun, L.i. Hang, Li Wei, Research Progress of Microwave Absorbing Materials Based on Graphene, Mater. Sci. 08 (2018) 222–234.
[12] X. Li, L. Yu, W. Zhao, Y. Shi, L. Yu, Y. Dong, Y. Zhu, Y. Fu, X. Liu, F. Fu, Prism-shaped hollow carbon decorated with polyaniline for microwave absorption, Chem. Eng. J. 379 (2020), 122393.
[13] H. Ahmad, A. Tariq, A. Shehzad, M.S. Faheem, M. Shafiq, I.A. Rashid, A. Afzal, A. Munir, M.T. Riaz, H.T. Haider, A. Afzal, M.B. Qadir, Z. Khaliq, Stealth technology: Methods and composite materials-A review, Polym. Compos. 40 (2019) 4457–4472.
[14] J.C. Shu, W.Q. Cao, M.S. Cao, Diverse Metal-Organic Framework Architectures for Electromagnetic Absorbers and Shielding, Adv. Funct. Mater. 31 (2021) 2100470.
[15] L. Wu, F. Wu, Q. Sun, J. Shi, A. Xie, X. Zhu, W. Dong, A TTF–TCNQ complex: an organic charge-transfer system with extraordinary electromagnetic response behavior, J. Mater. Chem. C 9 (2021) 3316–3323.
[16] F.B.C. Qin, A review and analysis of microwave absorption in polymer composites filled with carbonaceous particles, J. Appl. Phys. 111 (2012), 061301.
[17] H. Xu, X. Yin, M. Li, F. Ye, M. Han, Z. Hou, X. Li, L. Zhang, L. Cheng, Mesoporous carbon hollow microspheres with red blood cell like morphology for efficient microwave absorption at elevated temperature, Carbon 132 (2018) 343–351.
[18] X.X. Wang, W.Q. Cao, M.S. Cao, J. Yuan, Assembling Nano-Microarchitecture for Electromagnetic Absorbers and Smart Devices, Adv. Mater. 32 (2020), e2002112.
[19] B. Liu, K. Zhou, Recent progress on graphene-analogous 2D nanomaterials: Properties, modeling and applications, Prog. Mater Sci. 100 (2019) 99–169.
[20] M. Cao, X. Wang, W. Cao, J. Yuan, Ultrathin graphene: electrical properties and highly efficient electromagnetic interference shielding, J. Mater. Chem. C 3 (2015) 6589–6599.

[21] F. Meng, H. Wang, F. Huang, Y. Guo, Z. Wang, D. Hui, Z. Zhou, Graphene-based microwave absorbing composites: A review and prospective, Compos. Pt. B-Eng. 137 (2018) 260–277.

[22] M. Ning, M. Lu, J. Li, Z. Chen, Y. Dou, C. Wang, F. Rehman, M. Cao, H. Jin, Two-dimensional nanosheets of MoS_2: a promising material with high dielectric properties and microwave absorption performance, Nanoscale 7 (2015) 15734–15740.

[23] M. Cao, Y. Cai, P. He, J. Shu, W. Cao, J. Yuan, 2D MXenes: Electromagnetic property for microwave absorption and electromagnetic interference shielding, Chem. Eng. J. 359 (2019) 1265–1302.

[24] P. He, M.S. Cao, W.Q. Cao, J. Yuan, Developing MXenes from Wireless Communication to Electromagnetic Attenuation, Nano-micro Letters 13 (2021) 115.

[25] L. Huang, C. Chen, Z. Li, Y. Zhang, H. Zhang, J. Lu, S. Ruan, Y. Zeng, Challenges and future perspectives on microwave absorption based on two-dimensional materials and structures, Nanotechnology (2019).

[26] F. Wu, A. Xie, M. Sun, Y. Wang, M. Wang, Reduced graphene oxide (RGO) modified spongelike polypyrrole (PPy) aerogel for excellent electromagnetic absorption, J. Mater. Chem. A 3 (2015) 14358–14369.

[27] Y. Wang, D. Chen, X. Yin, P. Xu, F. Wu, M. He, Hybrid of MoS_2 and Reduced Graphene Oxide: A Lightweight and Broadband Electromagnetic Wave Absorber, ACS Appl. Mater. Interfaces 7 (2015) 26226–26234.

[28] J. Liu, H. Zhang, R. Sun, Y. Liu, Z. Liu, A. Zhou, Z. Yu, Hydrophobic, Flexible, and Lightweight MXene Foams for High-Performance Electromagnetic-Interference Shielding, Adv. Mater. 29 (2017) 1702367.

[29] X. Liu, L. Wang, Y. Ma, Y. Qiu, Q. Xie, Y. Chen, D.-L. Peng, Facile synthesis and microwave absorption properties of yolk-shell ZnO-Ni-C/RGO composite materials, Chem. Eng. J. 333 (2018) 92–100.

[30] W. Zhang, X. Zhang, Y. Zheng, C. Guo, M. Yang, Z. Li, H. Wu, H. Qiu, H. Yan, S. Qi, Preparation of Polyaniline@MoS_2@Fe_3O_4 Nanowires with a Wide Band and Small Thickness toward Enhancement in Microwave Absorption, ACS Appl. Nano Mater. 1 (2018) 5865–5875.

[31] Y. Qian, H. Wei, J. Dong, Y. Du, X. Fang, W. Zheng, Y. Sun, Z. Jiang, Fabrication of urchin-like ZnO-MXene nanocomposites for high-performance electromagnetic absorption, Ceram. Int. 43 (2017) 10757–10762.

[32] S. Gupta, N. Tai, Carbon materials and their composites for electromagnetic interference shielding effectiveness in X-band, Carbon 152 (2019) 159–187.

[33] Song Weina, W. He Chunying, Y. Zhang, Y. Gao, Y. Yang, Z. Wu, X. Chen, Y. Dong Li, Synthesis and nonlinear optical properties of reduced graphene oxide hybrid material covalently functionalized with zinc phthalocyanine, Carbon 77 (2014) 1020–1030.

[34] L. Gai, Y. Zhao, G. Song, Q. An, Z. Xiao, S. Zhai, Z. Li, Construction of core-shell PPy@MoS_2 with nanotube-like heterostructures for electromagnetic wave absorption: Assembly and enhanced mechanism, Compos. Pt. A-Appl. Sci. Manuf. 136 (2020), 105965.

[35] D.A. Dikin, S. Stankovich, E.J. Zimney, R.D. Piner, G.H. Dommett, G. Evmenenko, S.T. Nguyen, R.S. Ruoff, Preparation and characterization of graphene oxide paper, Nature 448 (2007) 457–460.

[36] M. Li, M. Han, J. Zhou, Q. Deng, X. Zhou, J. Xue, S. Du, X. Yin, Q. Huang, Novel Scale-Like Structures of Graphite/TiC/Ti_3C_2 Hybrids for Electromagnetic Absorption, Adv. Electron. Mater. 4 (2018) 1700617.

[37] X. Zhang, J. Xu, X. Liu, S. Zhang, H. Yuan, C. Zhu, X. Zhang, Y. Chen, Metal organic framework-derived three-dimensional graphene-supported nitrogen-doped carbon nanotube spheres for electromagnetic wave absorption with ultralow filler mass loading, Carbon 155 (2019) 233–242.

[38] X. Zhang, J. Xu, H. Yuan, S. Zhang, Q. Ouyang, C. Zhu, X. Zhang, Y. Chen, Large-Scale Synthesis of Three-Dimensional Reduced Graphene Oxide/Nitrogen-Doped Carbon Nanotube Heteronanostructures as Highly Efficient Electromagnetic Wave Absorbing Materials, ACS Appl. Mater. Interfaces 11 (2019) 39100–39108.

[39] X. Zhang, X. Wang, F. Meng, J. Chen, S. Du, Broadband and strong electromagnetic wave absorption of epoxy composites filled with ultralow content of non-covalently modified reduced graphene oxides, Carbon 154 (2019) 115–124.

[40] Y. Huang, X. Yuan, M. Chen, W.-L. Song, J. Chen, Q. Fan, L. Tang, D. Fang, Ultrathin multifunctional carbon/glass fiber reinforced lossy lattice metastructure for integrated design of broadband microwave absorption and effective load bearing, Carbon 144 (2019) 449–456.

[41] R. Mo, X. Yin, F. Ye, X. Liu, X. Ma, Q. Li, L. Zhang, L. Cheng, Electromagnetic wave absorption and mechanical properties of silicon carbide fibers reinforced silicon nitride matrix composites, J. Eur. Ceram. Soc. 39 (2019) 743–754.

[42] W. Xin, G. Xi, W. Cao, C. Ma, T. Liu, M. Ma, J. Bian, Lightweight and flexible MXene/CNF/silver composite membranes with a brick-like structure and high-performance electromagnetic-interference shielding, RSC Adv. 9 (2019) 29636–29644.

[43] P. Sambyal, A. Iqbal, J. Hong, H. Kim, M.K. Kim, S.M. Hong, M. Han, Y. Gogotsi, C.M. Koo, Ultralight and Mechanically Robust Ti_3C_2Tx Hybrid Aerogel Reinforced by Carbon Nanotubes for Electromagnetic Interference Shielding, ACS Appl. Mater. Interfaces 11 (2019) 38046–38054.

[44] A. Chaudhary, S. Teotia, R. Kumar, V. Gupta, S.R. Dhakate, S. Kumari, Multi-component framework derived SiC composite paper to support efficient thermal transport and high EMI shielding performance, Compos. Pt. B-Eng. 176 (2019), 107123.

[45] J. Xue, X. Yin, L. Cheng, Induced crystallization behavior and EMW absorption properties of CVI SiCN ceramics modified with carbon nanowires, Chem. Eng. J. 378 (2019), 122213.

[46] H. Lv, H. Zhang, G. Ji, Z.J. Xu, Interface Strategy To Achieve Tunable High Frequency Attenuation, ACS Appl. Mater. Interf. 8 (2016) 6529–6538.

[47] J.B. Cheng, H.B. Zhao, M. Cao, M.E. Li, A.N. Zhang, S.L. Li, Y.Z. Wang, Banana Leaflike C-Doped MoS_2 Aerogels toward Excellent Microwave Absorption Performance, ACS Appl. Mater. Interfaces 12 (2020) 26301–26312.

[48] B. Zhao, G. Shao, B. Fan, W. Zhao, Y. Xie, R. Zhang, Synthesis of flower-like CuS hollow microspheres based on nanoflakes self-assembly and their microwave absorption properties, J. Mater. Chem. A 3 (2015) 10345–10352.

[49] D. Jiang, V. Murugadoss, Y. Wang, J. Lin, T. Ding, Z. Wang, Q. Shao, C. Wang, H. Liu, N. Lu, R. Wei, A. Subramania, Z. Guo, Electromagnetic Interference Shielding Polymers and Nanocomposites-A Review, Polym. Rev. 59 (2019) 280–337.

[50] M. Li, X. Yin, G. Zheng, M. Chen, M. Tao, L. Cheng, L. Zhang, High-temperature dielectric and microwave absorption properties of Si_3N_4–SiC/SiO_2 composite ceramics, J. Mater. Sci. 50 (2014) 1478–1487.

[51] A. Saboor, S.M. Khalid, R. Jan, A.N. Khan, M.U. Farooq, S. Afridi, M. Sadiq, M. Arif, PS/PANI/MoS_2 Hybrid Polymer Composites with High Dielectric Behavior and Electrical Conductivity for EMI Shielding Effectiveness, Materials 12 (2019) 2690.

[52] F. Li, W. Zhan, Y. Su, S.H. Siyal, G. Bai, W. Xiao, A. Zhou, G. Sui, X. Yang, Achieving excellent electromagnetic wave absorption of $ZnFe_2O_4$@CNT/polyvinylidene fluoride flexible composite membranes by adjusting processing conditions, Compos. Pt. A-Appl. Sci. Manuf. 133 (2020), 105866.

[53] H. Jia, H. Xing, X. Ji, S. Gao, Self-template and in-situ polymerization strategy to lightweight hollow MnO_2@polyaniline core-shell heterojunction with excellent microwave absorption properties, Appl. Surf. Sci. 537 (2021), 147857.

[54] K. Baek, S. Lee, S. Doh, M. Kim, J.K. Hyun, Axial oxygen vacancy-regulated microwave absorption in micron-sized tetragonal $BaTiO_3$ particles, J. Mater. Chem. C 6 (2018) 9749–9755.

[55] Q. Liu, Q. Cao, H. Bi, C. Liang, K. Yuan, W. She, Y. Yang, R. Che, CoNi@SiO_2@TiO_2 and CoNi@Air@TiO_2 Microspheres with Strong Wideband Microwave Absorption, Adv. Mater. 28 (2016) 486–490.

[56] B. Zhao, X. Guo, W. Zhao, J. Deng, B. Fan, G. Shao, Z. Bai, R. Zhang, Facile synthesis of yolk–shell Ni@void@SnO_2(Ni_3Sn_2) ternary composites via galvanic replacement/Kirkendall effect and their enhanced microwave absorption properties, Nano Res. 10 (2016) 331–343.

[57] C. Liang, Z. Wang, Eggplant-derived SiC aerogels with high-performance electromagnetic wave absorption and thermal insulation properties, Chem. Eng. J. 373 (2019) 598–605.

[58] H. Jia, W. Zhou, H. Nan, J. Dong, Y. Qing, F. Luo, D. Zhu, Enhanced high temperature dielectric polarization of barium titanate/magnesium aluminum spinel composites and their potential in microwave absorption, J. Eur. Ceram. Soc. 40 (2020) 728–734.

[59] Y. Huang, J. Ji, Y. Chen, X. Li, J. He, X. Cheng, S. He, Y. Liu, J. Liu, Broadband microwave absorption of Fe_3O_4-$BaTiO_3$ composites enhanced by interfacial polarization and impedance matching, Compos. Pt. B-Eng. 163 (2019) 598–605.

[60] J. Liu, H. Liang, H. Wu, Hierarchical flower-like Fe_3O_4/MoS_2 composites for selective broadband electromagnetic wave absorption performance, Compos. Pt. A-Appl. Sci. Manuf. 130 (2020), 105760.

[61] Y. Liu, B. Quan, X. Liang, B. Huang, S. Huang, X. Li, G. Ji, Z. Jin, G. Yang, Energetic metal-organic frameworks deflagration enabled ultrafast low-temperature synthesis of ultra-light magnetic nanoparticles decorated high-lossy materials, Carbon 165 (2020) 286–295.

[62] Shams Alam, Reza Moradi, Mahmood Nikmanesh, Hossein Ventura, Joao Rostami, Mohammad, Magnetic and microwave absorption properties of $BaMg_{x/2}Mn_{x/2}Co_xTi_{2x}Fe_{12-4x}O_{19}$ hexaferrite nanoparticles, J. Magn. Magn. Mater. 402 (2016) 20–27.

[63] H. Yang, J. Dai, L. Wang, Y. Lin, F. Wang, P. Kang, A novel approach to prepare Bi2Fe4O9 flower-like spheres with enhanced photocatalytic performance, Sci. Rep. 7 (2017) 768.

[64] D. Lan, M. Qin, R. Yang, S. Chen, H. Wu, Y. Fan, Q. Fu, F. Zhang, Facile synthesis of hierarchical chrysanthemum-like copper cobaltate-copper oxide composites for enhanced microwave absorption performance, J. Colloid Interface Sci. 533 (2019) 481–491.

[65] M. Ma, W. Li, Z. Tong, W. Huang, R. Wang, P. Lyu, Y. Ma, G. Wu, Q. Yan, P. Li, X. Yao, Facile synthesis of the one-dimensional flower-like yolk-shell Fe_3O_4@SiO_2@NiO nanochains composites for high-performance microwave absorption, J. Alloy. Compd. 843 (2020), 155199.

[66] R. Wang, X. Qi, R. Xie, X. Gong, C. Deng, W. Zhong, Constructing heterostructural Fe@Fe_3C@carbon nanotubes/reduced graphene oxide nanocomposites as lightweight and high-efficiency microwave absorbers, J. Mater. Chem. C 8 (2020) 14515–14522.

[67] Z. Wang, R. Gao, G. Chen, X. Deng, W. Cai, C. Fu, Dielectric, ferroelectric and magnetoelectric properties of in-situ synthesized $CoFe_2O_4$/$BaTiO_3$ composite ceramics, Ceram. Int. 46 (2020) 9154–9160.

[68] L. Wang, X. Yu, M. Huang, W. You, Q. Zeng, J. Zhang, X. Liu, M. Wang, R. Che, Orientation growth modulated magnetic-carbon microspheres toward broadband electromagnetic wave absorption, Carbon 172 (2021) 516–528.

[69] H. Luo, R. Gong, X. Wang, K. Song, C. Zhu, L. Wang, Synthesis and excellent microwave absorption properties of reduced graphene oxide/$FeNi_3$/Fe_3O_4 composite, New J. Chem. 40 (2016) 6238–6243.

[70] S.R. Saeedi Afshar, M. Hasheminiasari, S.M. Masoudpanah, Structural, magnetic and microwave absorption properties of $SrFe_{12}O_{19}$/$Ni_{0.6}Zn_{0.4}Fe_2O_4$ composites prepared by one-pot solution combustion method, J. Magn. Magn. Mater. 466 (2018) 1–6.

[71] Y. Lin, X. Liu, H. Yang, F. Wang, C. Liu, Low temperature sintering of laminated $Ni_{0.5}Ti_{0.5}NbO_4$-$Ni_{0.8}Zn_{0.2}Fe_2O_4$ composites for high frequency applications, Ceram. Int. 42 (2016) 11265–11269.

[72] F. Yan, D. Guo, S. Zhang, C. Li, C. Zhu, X. Zhang, Y. Chen, An ultra-small $NiFe_2O_4$ hollow particle/graphene hybrid: fabrication and electromagnetic wave absorption property, Nanoscale 10 (2018) 2697–2703.

[73] P. Liu, Z. Yao, J. Zhou, Fabrication and microwave absorption of reduced graphene oxide/$Ni_{0.4}Zn_{0.4}Co_{0.2}Fe_2O_4$ nanocomposites, Ceram. Int. 42 (2016) 9241–9249.

[74] Y. Li, X. Zhou, J. Wang, Q. Deng, M. Li, S. Du, Y. Han, J. Lee, Q. Huang, Facile preparation of in situ coated $Ti_3C_2T_x$/$Ni_{0.5}Zn_{0.5}Fe_2O_4$ composites and their electromagnetic performance, RSC Adv. 7 (2017) 24698–24708.

[75] X. Shen, M. Liu, Q. Ye, J. Xiang, J. Li, Microwave Absorption Properties of Double-layer Absorbing Coatings Based on $Ni_{0.4}Co_{0.2}Zn_{0.4}Fe_2O_4$ and $BaTiO_3$ Nanofibers, J. Inorg. Mater. 30 (2015) 479–486.

[76] B. Zhao, Y. Li, Q. Zeng, L. Wang, J. Ding, R. Zhang, R. Che, Galvanic Replacement Reaction Involving Core-Shell Magnetic Chains and Orientation-Tunable Microwave Absorption Properties, Small 16 (2020), e2003502.

[77] F. Yan, S. Zhang, X. Zhang, C. Li, C. Zhu, X. Zhang, Y. Chen, Growth of $CoFe_2O_4$ hollow nanoparticles on graphene sheets for high-performance electromagnetic wave absorbers, J. Mater. Chem. C 6 (2018) 12781–12787.

[78] P. Liu, Z. Yao, J. Zhou, Preparation of reduced graphene oxide/$Ni_{0.4}Zn_{0.4}Co_{0.2}Fe_2O_4$ nanocomposites and their excellent microwave absorption properties, Ceram. Int. 41 (2015) 13409–13416.

[79] Z.Yu. Zheng Jing, G. Ji, X. Lin, H. Lv, Y. Du, Reduction synthesis of FexOy@SiO_2 core–shell nanostructure with enhanced microwave-absorption properties, J. Alloy. Compd. 602 (2014) 8–15.

[80] A. Gupta, T. Sakthivel, S. Seal, Recent development in 2D materials beyond graphene, Prog. Mater Sci. 73 (2015) 44–126.

[81] M. Cao, C. Han, X. Wang, M. Zhang, Y. Zhang, J. Shu, H. Yang, X. Fang, J. Yuan, Graphene nanohybrids: excellent electromagnetic properties for the absorbing and shielding of electromagnetic waves, J. Mater. Chem. C 6 (2018) 4586–4602.

[82] J. Yang, W. Yang, F. Li, Y. Yang, Research and development of high-performance new microwave absorbers based on rare earth transition metal compounds: A review, J. Magn. Magn. Mater. 497 (2020), 165961.

[83] M. Naguib, M. Kurtoglu, V. Presser, J. Lu, J. Niu, M. Heon, L. Hultman, Y. Gogotsi, M.W. Barsoum, Two-dimensional nanocrystals produced by exfoliation of Ti_3AlC_2, Adv. Mater. 23 (2011) 4248–4253.

[84] H. Wang, H. Ma, The electromagnetic and microwave absorbing properties of MoS_2 modified $Ti_3C_2T_x$ nanocomposites, J. Mater. Sci.-Mater. Electron. 30 (2019) 15250–15256.

[85] S. Sajjad, S.A. Khan Leghari, A. Iqbal, Study of Graphene Oxide Structural Features for Catalytic, Antibacterial, Gas Sensing, and Metals Decontamination Environmental Applications, ACS Appl. Mater. Interfaces 9 (2017) 43393–43414.

[86] Wang Tieshi, M.Lu. Liu Zhaohong, B. Wen, Graphene–Fe_3O_4 nanohybrids: Synthesis and excellent electromagnetic absorption properties, J. Appl. Phys. 113 (2013) 666.

[87] B. Shen, Y. Li, D. Yi, W. Zhai, X. Wei, W. Zheng, Microcellular graphene foam for improved broadband electromagnetic interference shielding, Carbon 102 (2016) 154–160.

[88] O. Balci, E.O. Polat, N. Kakenov, C. Kocabas, Graphene-enabled electrically switchable radar-absorbing surfaces, Nat. Commun. 6 (2015) 6628.

[89] Renchao Che, Lianmao Peng, Xiaofeng Duan, Qing Chen, X. Liang, Microwave Absorption Enhancement and Complex Permittivity and Permeability of Fe Encapsulated within Carbon Nanotubes, Adv. Mater., 16 (2004).

[90] M. Li, X. Fan, H. Xu, F. Ye, J. Xue, X. Li, L. Cheng, Controllable synthesis of mesoporous carbon hollow microsphere twined by CNT for enhanced microwave absorption performance, J. Mater. Sci. Technol. 59 (2020) 164–172.

[91] B. Kuang, M. Ning, L. Wang, J. Li, C. Wang, Z. Hou, Y. Zhao, H. Jin, Biopolymer nanofiber/reduced graphene oxide aerogels for tunable and broadband high-performance microwave absorption, Compos. Pt. B-Eng. 161 (2019) 1–9.

[92] M. Cao, X. Wang, W. Cao, X. Fang, B. Wen, J. Yuan, Thermally Driven Transport and Relaxation Switching Self-Powered Electromagnetic Energy Conversion, Small (2018), e1800987.

[93] J. Ma, X. Wang, W. Cao, C. Han, H. Yang, J. Yuan, M. Cao, A facile fabrication and highly tunable microwave absorption of 3D flower-like Co_3O_4-rGO hybrid-architectures, Chem. Eng. J. 339 (2018) 487–498.

[94] Y. Ding, Z. Zhang, B. Luo, Q. Liao, S. Liu, Y. Liu, Y. Zhang, Investigation on the broadband electromagnetic wave absorption properties and mechanism of Co_3O_4-nanosheets/reduced-graphene-oxide composite, Nano Res. 10 (2016) 980–990.

[95] L. Wang, H. Xing, S. Gao, X. Ji, Z. Shen, Porous flower-like NiO@graphene composites with superior microwave absorption properties, J. Mater. Chem. C 5 (2017) 2005–2014.

[96] H. Chen, S. Bai, S. Li, F. Huang, Y. Lu, L. Wang, H. Zhang, Facile synthesis RGO/MnOx composite aerogel as high-efficient electromagnetic wave absorbents, J. Alloy. Compd. 773 (2019) 980–987.

[97] Y. Zhang, X. Wang, M. Cao, Confinedly implanted $NiFe_2$O4-rGO: Cluster tailoring and highly tunable electromagnetic properties for selective-frequency microwave absorption, Nano Res. 11 (2018) 1426–1436.

[98] Y. Liu, Z. Chen, Y. Zhang, R. Feng, X. Chen, C. Xiong, L. Dong, Broadband and Lightweight Microwave Absorber Constructed by in Situ Growth of Hierarchical $CoFe_2O_4$/Reduced Graphene Oxide Porous Nanocomposites, ACS Appl. Mater. Interfaces 10 (2018) 13860–13868.

[99] Z. Yang, Y. Wan, G. Xiong, D. Li, Q. Li, C. Ma, R. Guo, H. Luo, Facile synthesis of $ZnFe_2O_4$/reduced graphene oxide nanohybrids for enhanced microwave absorption properties, Mater. Res. Bull. 61 (2015) 292–297.

[100] Y. Lin, J. Dong, H. Zong, B. Wen, H. Yang, Synthesis, Characterization, and Electromagnetic Wave Absorption Properties of Composites of Reduced Graphene Oxide with Porous $LiFe_5O_8$ Microspheres, ACS Sustain. Chem. Eng. 6 (2018) 10011–10020.

[101] Y. Lin, J. Dai, H. Yang, L. Wang, F. Wang, Graphene multilayered sheets assembled by porous $Bi_2Fe_4O_9$ microspheres and the excellent electromagnetic wave absorption properties, Chem. Eng. J. 334 (2018) 1740–1748.

[102] S. Gao, Q. Wang, Y. Lin, H. Yang, L. Wang, Flower-like $Bi_{0.9}La_{0.1}FeO_3$ microspheres modified by reduced graphene oxide as a thin and strong electromagnetic wave absorber, J. Alloy. Compd. 781 (2019) 723–733.

[103] H. Zhao, J. Cheng, J. Zhu, Y. Wang, Ultralight CoNi/rGO aerogels toward excellent microwave absorption at ultrathin thickness, J. Mater. Chem. C 7 (2019) 441–448.

[104] X. Zhang, G. Wang, W. Cao, Y. Wei, J. Liang, L. Guo, M. Cao, Enhanced microwave absorption property of reduced graphene oxide (RGO)-$MnFe_2O_4$ nanocomposites and polyvinylidene fluoride, ACS Appl. Mater. Interfaces 6 (2014) 7471–7478.

[105] N. Zhang, Y. Huang, M. Wang, 3D ferromagnetic graphene nanocomposites with ZnO nanorods and Fe_3O_4 nanoparticles co-decorated for efficient electromagnetic wave absorption, Compos. Pt. B-Eng. 136 (2018) 135–142.

[106] Y. Wang, Y. Chen, X. Wu, W. Zhang, C. Luo, J. Li, Fabrication of MoS_2-graphene modified with Fe_3O_4 particles and its enhanced microwave absorption performance, Adv. Powder Technol. 29 (2018) 744–750.

[107] Y. Yang, L. Xia, T. Zhang, B. Shi, L. Huang, B. Zhong, X. Zhang, H. Wang, J. Zhang, G. Wen, Fe_3O_4@LAS/RGO composites with a multiple transmission-absorption mechanism and enhanced electromagnetic wave absorption performance, Chem. Eng. J. 352 (2018) 510–518.

[108] J. Li, Y. Xie, W. Lu, T. Chou, Flexible electromagnetic wave absorbing composite based on 3D rGO-CNT-Fe_3O_4 ternary films, Carbon 129 (2018) 76–84.

[109] S. Jiao, M. Wu, X. Yu, H. Hu, Z. Bai, P. Dai, T. Jiang, H. Bi, G. Li, RGO/$BaFe_{12}O_{19}$/Fe_3O_4 nanocomposite as microwave absorbent with lamellar structures and improved polarization interfaces, Mater. Res. Bull. 108 (2018) 89–95.

[110] T. Zhu, W. Shen, X. Wang, Y. Song, W. Wang, Paramagnetic CoS_2@MoS_2 core-shell composites coated by reduced graphene oxide as broadband and tunable high-performance microwave absorbers, Chem. Eng. J. 378 (2019), 122159.

[111] J. Ma, J. Shu, W. Cao, M. Zhang, X. Wang, J. Yuan, M. Cao, A green fabrication and variable temperature electromagnetic properties for thermal stable microwave absorption towards flower-like Co_3O_4@rGO/SiO_2 composites, Compos. Pt. B-Eng. 166 (2019) 187–195.

[112] K. Chang, W. Chen, L-Cysteine-Assisted Synthesis of Layered MoS_2 Graphene Composites with Excellent Electrochemical Performances for Lithium Ion Batteries, ACS Nano 5 (2011) 4720–4728.

[113] M. Ning, B. Kuang, Z. Hou, L. Wang, J. Li, Y. Zhao, H. Jin, Layer by layer 2D MoS_2/rGO hybrids: An optimized microwave absorber for high-efficient microwave absorption, Appl. Surf. Sci. 470 (2019) 899–907.

[114] L. Xing, X. Li, Z. Wu, X. Yu, J. Liu, L. Wang, C. Cai, W. You, G. Chen, J. Ding, R. Che, 3D hierarchical local heterojunction of MoS_2/FeS_2 for enhanced microwave absorption, Chem. Eng. J. 379 (2020), 122241.

[115] J. Luo, K. Zhang, M. Cheng, M. Gu, X. Sun, MoS_2 spheres decorated on hollow porous ZnO microspheres with strong wideband microwave absorption, Chem. Eng. J. 380 (2020), 122625.

[116] J. Pan, X. Sun, T. Wang, Z. Zhu, Y. He, W. Xia, J. He, Porous coin-like Fe@MoS_2 composite with optimized impedance matching for efficient microwave absorption, Appl. Surf. Sci. 457 (2018) 271–279.

[117] A.V. Menon, G. Madras, S. Bose, Mussel-Inspired Self-Healing Polyurethane with "Flower-like" Magnetic MoS_2 as Efficient Microwave Absorbers, ACS Appl. Polym. Mater. 1 (2019) 2417–2429.

[118] J. Dai, H. Yang, B. Wen, H. Zhou, L. Wang, Y. Lin, Flower-like MoS_2@$Bi_2Fe_4O_9$ microspheres with hierarchical structure as electromagnetic wave absorber, Appl. Surf. Sci. 479 (2019) 1226–1235.

[119] X. Cui, W. Liu, W. Gu, X. Liang, G. Ji, Two-dimensional MoS_2 modified using $CoFe_2O_4$ nanoparticles with enhanced microwave response in the X and Ku band, Inorg. Chem. Front. 6 (2019) 590–597.

[120] Z. Zhao, S. Xu, Z. Du, C. Jiang, X. Huang, Metal-Organic Framework-Based PB@MoS_2 Core-Shell Microcubes with High Efficiency and Broad Bandwidth for Microwave Absorption Performance, ACS Sustain. Chem. Eng. 7 (2019) 7183–7192.

[121] L. Liu, S. Zhang, F. Yan, C. Li, C. Zhu, X. Zhang, Y. Chen, Three-Dimensional Hierarchical MoS_2 Nanosheets/Ultralong N-Doped Carbon Nanotubes as High-Performance Electromagnetic Wave Absorbing Material, ACS Appl. Mater. Interfaces 10 (2018) 14108–14115.

[122] D. An, L. Bai, S. Cheng, Z. Zhang, X. Duan, Z. Sun, Y. Liu, Synthesis and electromagnetic wave absorption properties of three-dimensional nano-flower structure of MoS_2/polyaniline nanocomposites, J. Mater. Sci.-Mater. Electron. 30 (2019) 13948–13956.

[123] J. Prasad, A.K. Singh, M. Tomar, V. Gupta, K. Singh, Strong electromagnetic wave absorption and microwave shielding in the Ni–Cu@MoS_2/rGO composite, J. Mater. Sci.-Mater. Electron. 30 (2019) 18666–18677.

[124] W. Zhu, L. Zhang, W. Zhang, F. Zhang, Z. Li, Q. Zhu, S. Qi, Facile Synthesis of GNPs@NixSy@MoS_2 Composites with Hierarchical Structures for Microwave Absorption, Nanomaterials 9 (2019) 1403.

[125] P. Wang, J. Zhang, G. Wang, B. Duan, D. He, T. Wang, F. Li, Synthesis and characterization of MoS_2/Fe@Fe_3O_4 nanocomposites exhibiting enhanced microwave absorption performance at normal and oblique incidences, J. Mater. Sci. Technol. 35 (2019) 1931–1939.

[126] C. Li, X. Shen, R. Ding, G. Wang, Controllable Synthesis of One-Dimensional MoO_3/MoS_2 Hybrid Composites with their Enhanced Efficient Electromagnetic Wave Absorption Properties, ChemPlusChem 84 (2019) 226–232.

[127] Y. Zhang, S. Gao, H. Xing, Hierarchical core–shell Fe_3O_4@C@MoS_2 composites synergistically enhance microwave absorption, Mater. Lett. 246 (2019) 80–83.

[128] G. Cui, X. Zheng, X. Lv, Q. Jia, W. Xie, G. Gu, Synthesis and microwave absorption of Ti_3C_2Tx MXene with diverse reactant concentration, reaction time, and reaction temperature, Ceram. Int. 45 (2019) 23600–23610.

[129] X. Li, X. Yin, S. Liang, M. Li, L. Cheng, L. Zhang, 2D carbide MXene Ti_2CT_X as a novel high-performance electromagnetic interference shielding material, Carbon 146 (2019) 210–217.

[130] P. He, X. Wang, Y. Cai, J. Shu, Q. Zhao, J. Yuan, M. Cao, Tailoring Ti_3C_2Tx nanosheets to tune local conductive network as an environmentally friendly material for highly efficient electromagnetic interference shielding, Nanoscale 11 (2019) 6080–6088.

[131] W. Feng, H. Luo, S. Zeng, C. Chen, L. Deng, Y. Tan, X. Zhou, S. Peng, H. Zhang, Ni-modified Ti_3C_2 MXene with enhanced microwave absorbing ability, Mater. Chem. Front. 2 (2018) 2320–2326.

[132] L. Liang, G. Han, Y. Li, B. Zhao, B. Zhou, Y. Feng, J. Ma, Y. Wang, R. Zhang, C. Liu, Promising Ti_3C_2Tx MXene/Ni Chain Hybrid with Excellent Electromagnetic Wave Absorption and Shielding Capacity, ACS Appl. Mater. Interfaces 11 (2019) 25399–25409.

[133] S. Wang, D. Li, L. Jiang, Synergistic Effects between MXenes and Ni Chains in Flexible and Ultrathin Electromagnetic Interference Shielding Films, Adv. Mater. Interfaces 6 (2019) 1900961.

[134] R. Deng, B. Chen, H. Li, K. Zhang, T. Zhang, Y. Yu, L. Song, MXene/Co_3O_4 composite material: Stable synthesis and its enhanced broadband microwave absorption, Appl. Surf. Sci. 488 (2019) 921–930.

[135] J. He, D. Shan, S. Yan, H. Luo, C. Cao, Y. Peng, Magnetic FeCo nanoparticles-decorated Ti_3C_2 MXene with enhanced microwave absorption performance, J. Magn. Magn. Mater. 492 (2019), 165639.

[136] C. Zhou, X. Wang, H. Luo, L. Deng, S. Wang, S. Wei, Y. Zheng, Q. Jia, J. Liu, Interfacial design of sandwich-like CoFe@Ti_3C_2Tx composites as high efficient microwave absorption materials, Appl. Surf. Sci. 494 (2019) 540–550.

[137] F. Yu, X. Wang, R. Du, F. Jiang, Y. Zhou, $ZnFe_2O_4$ nanoparticles decorated Ti_3C_2Tx nanosheet as anode materials for enhanced lithium storage, Mater. Lett. 253 (2019) 162–165.

[138] P. Liu, V.M.H. Ng, Z. Yao, J. Zhou, L.B. Kong, Ultrasmall Fe_3O_4 nanoparticles on MXenes with high microwave absorption performance, Mater. Lett. 229 (2018) 286–289.

[139] Y. Cai, N. Wang, L. Cheng, X. Yin, H. Yin, Y. Wang, X. Ren, X. Li, X. Fan, Electrical conductivity and electromagnetic shielding properties of Ti_3SiC_2/SiC functionally graded materials prepared by positioning impregnation, J. Eur. Ceram. Soc. 39 (2019) 3643–3650.

[140] M. Han, X. Yin, X. Li, B. Anasori, L. Zhang, L. Cheng, Y. Gogotsi, Laminated and Two-Dimensional Carbon-Supported Microwave Absorbers Derived from MXenes, ACS Appl. Mater. Interfaces 9 (2017) 20038–20045.

[141] H. Wei, J. Dong, X. Fang, W. Zheng, Y. Sun, Y. Qian, Z. Jiang, Y. Huang, Ti_3C_2Tx MXene/polyaniline (PANI) sandwich intercalation structure composites constructed for microwave absorption, Compos. Sci. Technol. 169 (2019) 52–59.

[142] X. Li, X. Yin, H. Xu, M. Han, M. Li, S. Liang, L. Cheng, L. Zhang, Ultralight MXene-Coated, Interconnected SiCnws Three-Dimensional Lamellar Foams for Efficient Microwave Absorption in the X-Band, ACS Appl. Mater. Interfaces 10 (2018) 34524–34533.

[143] Y. Wang, X. Gao, L. Zhang, X. Wu, Q. Wang, C. Luo, G. Wu, Synthesis of Ti_3C_2/Fe_3O_4/PANI hierarchical architecture composite as an efficient wide-band electromagnetic absorber, Appl. Surf. Sci. 480 (2019) 830–838.

[144] H. Yang, J. Dai, X. Liu, Y. Lin, J. Wang, L. Wang, F. Wang, Layered PVB/$Ba_3Co_2Fe_{24}O_{41}$/Ti_3C_2 Mxene composite: Enhanced electromagnetic wave absorption properties with high impedance match in a wide frequency range, Mater. Chem. Phys. 200 (2017) 179–186.

[145] M. Han, X. Yin, H. Wu, Z. Hou, C. Song, X. Li, L. Zhang, L. Cheng, Ti_3C_2 MXenes with Modified Surface for High-Performance Electromagnetic Absorption and Shielding in the X-Band, ACS Appl. Mater. Interfaces 8 (2016) 21011–21019.

[146] Y. Jiang, X. Xie, Y. Chen, Y. Liu, R. Yang, G. Sui, Hierarchically structured cellulose aerogels with interconnected MXene networks and their enhanced microwave absorption properties, J. Mater. Chem. C 6 (2018) 8679–8687.

[147] W. Feng, H. Luo, Y. Wang, S. Zeng, Y. Tan, L. Deng, X. Zhou, H. Zhang, S. Peng, Mxenes Derived Laminated and Magnetic Composites with Excellent Microwave Absorbing Performance, Sci. Rep. 9 (2019) 3957.

[148] P. Liu, Z. Yao, V.M.H. Ng, J. Zhou, L.B. Kong, Novel multilayer-like structure of $Ti_3C_2T_X$/CNZF composites for low-frequency electromagnetic absorption, Mater. Lett. 248 (2019) 214–217.

[149] X. Zhang, H. Wang, R. Hu, C. Huang, W. Zhong, L. Pan, Y. Feng, T. Qiu, C. Zhang, J. Yang, Novel solvothermal preparation and enhanced microwave absorption properties of Ti_3C_2Tx MXene modified by in situ coated Fe3O4 nanoparticles, Appl. Surf. Sci. 484 (2019) 383–391.

[150] N. Li, X. Xie, H. Lu, B. Fan, X. Wang, B. Zhao, R. Zhang, R. Yang, Novel two-dimensional $Ti_3C_2T_X$/Ni-spheres hybrids with enhanced microwave absorption properties, Ceram. Int. 45 (2019) 22880–22888.

[151] T. Hou, B. Wang, M. Ma, A. Feng, Z. Huang, Y. Zhang, Z. Jia, G. Tan, H. Cao, G. Wu, Preparation of two-dimensional titanium carbide (Ti_3C_2Tx) and $NiCo_2O_4$ composites to achieve excellent microwave absorption properties, Compos. Pt. B-Eng. 180 (2020), 107577.

[152] H. Wen, L.U.O. Heng, L.I. Yang, X. Peng, Z. Wei, Microwave Absorbing Properties of Carbon Fibers Modified with BN/SiC Composite Coatings, J. Inorg. Mater. 29 (2014) 1093.

[153] N. Huo, J. Kang, Z. Wei, S. Li, J. Li, S. Wei, Novel and Enhanced Optoelectronic Performances of Multilayer MoS2-WS2 Heterostructure Transistors, Adv. Funct. Mater. 24 (2014) 7025–7031.

[154] P. Chen, N. Li, X. Chen, W. Ong, X. Zhao, The rising star of 2D black phosphorus beyond graphene: synthesis, properties and electronic applications, 2D Mater., 5 (2017) 014002.

[155] Chang Yukai, Mu Congpu, Yang Bingchao, Nie Anmin, Wang Bochong, Xiang Jianyong, Yang Yong, Wen Fusheng, L. Zhongyuan, Microwave absorbing properties of two dimensional materials GeP5 enhanced after annealing treatment, Appl. Phys. Lett., 114 (2019).

[156] Deqing Zhang, T. Liu, Junye Cheng, Qi Cao, G. Zheng, Shuang Liang, Hao Wang, M. Cao, Lightweight and High-Performance Microwave Absorber Based on 2D WS2-RGO Heterostructures, Nano-micro letters, 11 (2019).

[157] D. Jiang, V. Murugadoss, Y. Wang, J. Lin, T. Ding, Z. Wang, Q. Shao, C. Wang, H. Liu, N. Lu, R. Wei, A. Subramania, Z. Guo, Electromagnetic Interference Shielding Polymers and Nanocomposites - A Review, Polym. Rev. 59 (2019) 280–337.

[158] L.B. Kong, Z.W. Li, L. Liu, R. Huang, M. Abshinova, Z.H. Yang, C.B. Tang, P. K. Tan, C.R. Deng, S. Matitsine, Recent progress in some composite materials and structures for specific electromagnetic applications, Int. Mater. Rev. 58 (2013) 203–259.

[159] Q. Song, F. Ye, L. Kong, Q. Shen, L. Han, L. Feng, G. Yu, Y. Pan, H. Li, Graphene and MXene Nanomaterials: Toward High-Performance Electromagnetic Wave Absorption in Gigahertz Band Range, Adv. Funct. Mater. 30 (2020) 2000475.

[160] H. Wang, H. Guo, Y. Dai, D. Geng, Z. Han, D. Li, T. Yang, W. Liu, Z. Zhang, Optimal electromagnetic-wave absorption by enhanced dipole polarization in Ni/C nanocapsules, Appl. Phys. Lett. 101 (2012), 083116.

[161] W. Huang, P. Zhang, W. Yan, L. Zhou, H. Xu, Microwave absorption capability of microcapsules by coating FeSiAlCr with SiO_2, J. Phys. D-Appl. Phys. 45 (2012), 405001.

[162] W. Zhang, S. Bie, H. Chen, Y. Lu, J. Jiang, Electromagnetic and microwave absorption properties of carbonyl iron/MnO_2 composite, J. Magn. Magn. Mater. 358 (2014) 1–4.

[163] Z. Liu, H. Xing, L. Wang, D. Tan, Y. Gan, X. Ji, G. Xu, Facial Synthesis of Zn-Doped Fe_3O_4 with Enhanced Electromagnetic Wave Absorption Performance in S and C Bands, NANO 11 (2016) 1650091.

[164] Z. Zhang, L. Zhang, X. Chen, Z. Wu, Y. He, Y. Lv, Y. Zou, Broadband metamaterial absorber for low-frequency microwave absorption in the S-band and C-band, J. Magn. Magn. Mater. 497 (2020), 166075.

[165] S.B. Narang, K. Pubby, Electromagnetic Characterization of Co-Ti-Doped Ba-M Ferrite-Based Frequency-Tunable Microwave Absorber in 12.4–40 GHz, J. Supercond. Nov. Magn 30 (2016) 511–520.

[166] S.B. Narang, K. Pubby, C. Singh, Thickness and Composition Tailoring of K- and Ka-Band Microwave Absorption of $BaCo_xTi_xFe_{(12-2x)}O_{19}$ Ferrites, J. Electron. Mater. 46 (2016) 718–728.