Chapter

Metamaterial: Smart Magnetic Material for Microwave Absorbing Material

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Abstract

Metamaterial is an artificial, advanced material that has properties such as electromagnetic waves (EM), namely isotropic materials with permittivity and permeability in a single phase at a certain frequency. Smart magnetics is one of the metamaterials that is a modified magnetic material that has a single-phase permeability and permittivity as a function of frequency depending on the type of magnetic material used. Smart magnetics in this study include perovskite, ferrite, hexagonal ferrite, and composite systems. Research that has been carried out on perovskite, ferrite, hexagonal ferrite and composite smart magnetic system materials are $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$, $Ni_xFe_{3-x}O_4$, and $Ba_{(1-x)}Sr_xFe_2O_4$, $Ba_{0.6}Sr_{0.4}Fe_{12-z}Mn_zO_{19}$ and composite silicon rubber—iron oxide. The four smart magnetic material systems have an average microwave absorption in the X-band frequency range. Very varied reflection loss characteristics depend on the smart magnetic material system formed. It was concluded that smart magnetic material is a microwave absorbent that has reflection loss values in the X-band frequency range. Smart magnetic material is certainly not able to absorb microwaves on all band frequencies because each smart magnetic material has different resonance characteristics, so the maximum effort that can be done is to find the right composition of smart magnetic material which is expected to have the maximum wave absorption capability.

Keywords: metamaterial, smart magnetic, microwave, absorbing, perovskite, ferrite, hexagonal ferrite, composite

1. Introduction

The rapid progress in communication technology in recent years has been noted by scientists and engineers working in this field. These technological advances have motivated people to utilize them with the purpose to improve their quality of life. A good level of life always strives for ease of communication, among others, by the presence of cellphone abbreviated as hand phone, a type of wireless telephone that is easy to carry everywhere and practical because of its small size so that it is easily inserted into a pocket. A cellular telephone or hand phone is a device that can make and receive phone calls transmitted via electromagnetic waves and can be used around a large geographical area. Because communication using this cellphone uses electromagnetic waves in the microwave frequency range, the microwave radiating out of the mobile emitter will theoretically affect the human body, especially the head around the ear as shown in **Figure 1**.

Radiation emitted can also affect the function of enzymes and proteins, which is a change in albumin protein that functions in supplying blood flow to the brain. For this reason, we need a microwave absorbent material that can reduce and even eliminate the effect of microwave radiation on human health [1, 2].

In the electronics field, microwave absorbers are used to reduce the presence of electromagnetic wave interference (EMI) [3, 4]. In general, electronic components that work at high frequencies often experience problems such as frequency signal leakage. EMI will not be present if the electronic device is in an open condition or is not in a closed medium. However, signals travelling in a closed medium will be reflected back to the device. This will cause the energy to increase in phase at certain frequencies due to the appearance of EMI emitted in the form of noise, which then interferes with the performance of these electronic devices. But after the closed media are protected by microwave absorbers, the effect of EMI can be avoided. An illustration of this phenomenon is shown in **Figure 2**.

In the field of defense (military) [5, 6], this microwave absorber is used for coating or painting on defense equipment and facilities such as stealth aircraft, warships (war ship), and for army clothing, especially troops in the guard front. as shown in **Figure 3**.

In a radar system, microwaves are transmitted continuously in all directions by the transmitter. If there is an object affected by this wave, the signal will be reflected by the object and received back by the recipient. This reflection signal will provide information that there is a close object that will be displayed by the radar screen. Radar (radio detection and ranging) is a microwave system that is useful for detecting and measuring distances and making maps of an object. The radar waves emitted are able to detect the presence of an object. The radar concept is measuring the distance from the sensor to the target. The measure of distance is obtained by measuring the time needed by the radar wave during its propagation from the sensor to the target and back to the sensor again. The measured distance based on the time needed by the electromagnetic waves emanating from the target is then reflected back to the radar sensor. The target is able to reflect electromagnetic

Figure 1.
Use of microwave absorbers for shielding radiation.

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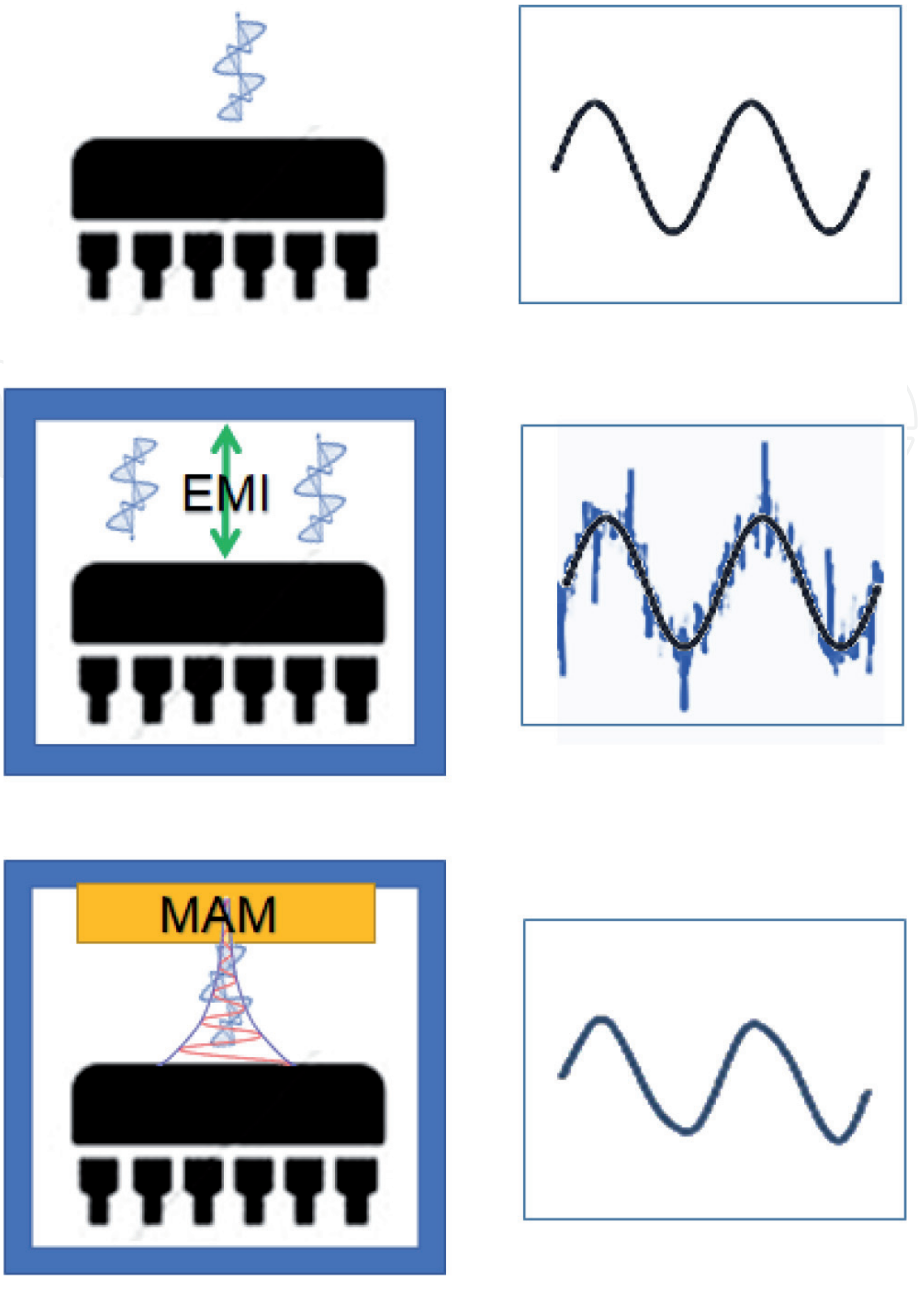

Figure 2.
Use of microwave absorbers to reduce EMI.

Figure 3.
Use of microwave absorbers in the defense sector.

waves, so that the radar is able to detect the existence of these objects. However, the case is different if the object cannot reflect radar waves, so that the radar is not able to detect the existence of the object. This phenomenon is then developed for certain interests related to the defense system.

Because of the vast utilization of these microwave absorbent materials, it is generally accepted, recognizing that microwave absorbent material is a material that can weaken the energy of electromagnetic waves. These microwave absorbent materials can externally reduce or even eliminate reflections or transmissions from certain objects and can be used internally to reduce oscillations caused by resonance cavities. Besides that, this microwave absorbent can be used to create a reflection free space or anechoic space.

Metamaterial is one of the solutions for the development of microwave absorbent materials. Metamaterials that are developing rapidly are smart magnetic-based materials. Smart magnetics are modified magnetic materials so these materials have a single-phase frequency-dependent permeability and permittivity depending on the type of magnetic material used. Smart magnetic is an advanced magnetic material in the future in the form of new inorganic crystalline materials with permeability and permittivity made from interpenetrating lattices with magnetic field and electric field responses.

2. Conceptual

2.1 Electromagnetic wave

Electromagnetic waves are a form of energy emitted and absorbed by charged particles, which shows wavelike behavior because it travels through space [7]. Electromagnetic waves are transverse waves that oscillate and consist of electric field and magnetic field vector components as shown in **Figure 4**.

Electromagnetic energy propagates in waves with several parameters that can be measured, namely, wavelength, frequency, amplitude (amplitude), and speed.

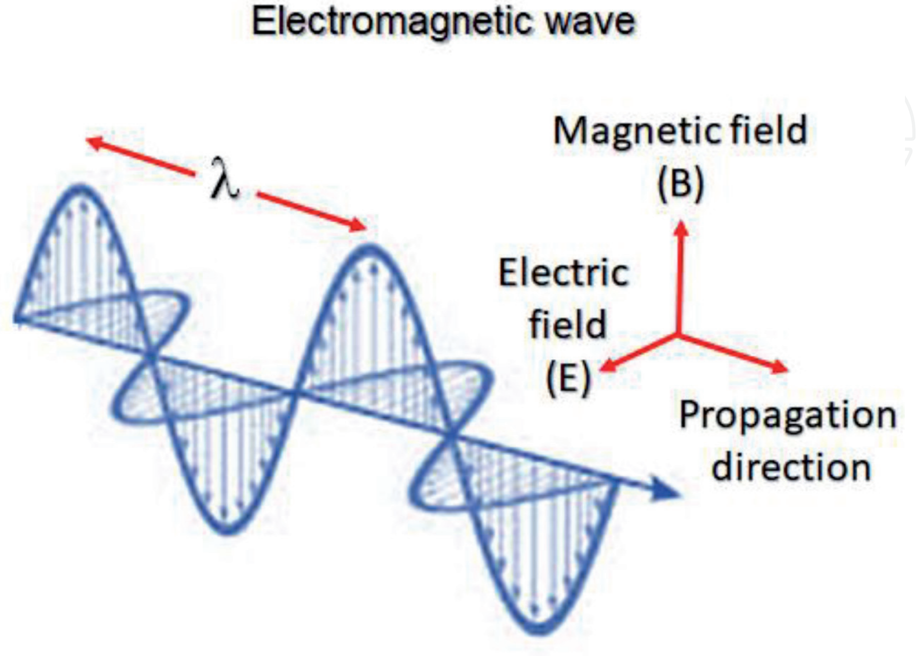

Figure 4.
Schematic propagation of electromagnetic waves.

Amplitude is the wave height, while the wavelength is the distance between two peaks. Frequency is the number of waves that pass through a point in a unit of time. The frequency depends on the speed of the wave climbed. Because the speed of electromagnetic energy is constant (the speed of light), the wavelength and frequency are inversely proportional. The longer the wave, the lower the frequency, and the shorter the wave, the higher the frequency.

The general characteristics of electromagnetic waves are that changes in the electric and magnetic fields occur at the same time, so that both fields have maximum and minimum values at the same time and at the same place. The direction of the electric field and magnetic field is perpendicular to each other, and both are perpendicular to the direction of wave propagation, electromagnetic waves are transverse waves, and electromagnetic waves experience events of reflection, refraction, interference, polarization, and diffraction. Fast propagation of electromagnetic waves depends only on the electrical and magnetic properties of the medium that it passes through.

2.2 Microwave

The arrangement of all forms of electromagnetic waves based on their wavelengths and frequencies covers a very low range of energy to very high energy called the electromagnetic wave spectrum, as shown in **Figure 5**.

Microwaves are electromagnetic waves which have a frequency range of about 0.3–300 GHz with wavelengths of around 1–1 mm. The microwave frequency range consists of several bandwidths, namely, L band to D band [8].

2.3 Absorption mechanism

Coherent and polarized microwaves obey the optical law; this wave can be reflected, transmitted, and absorbed, depending on the type of material it passes. In general, the use of microwaves is based on the phenomenon of reflection and transmission only (**Figure 6**).

But in the last few decades, the phenomenon of microwave absorption has also become very popular as the core concept in the development of rapidly advancing electronic and telecommunications technology as shown in core (**Figure 7**) [9–15]. The main requirement that is needed as microwave absorbing material is that this material has a value of permeability (magnetic loss properties) and permittivity (dielectric loss properties) material [16].

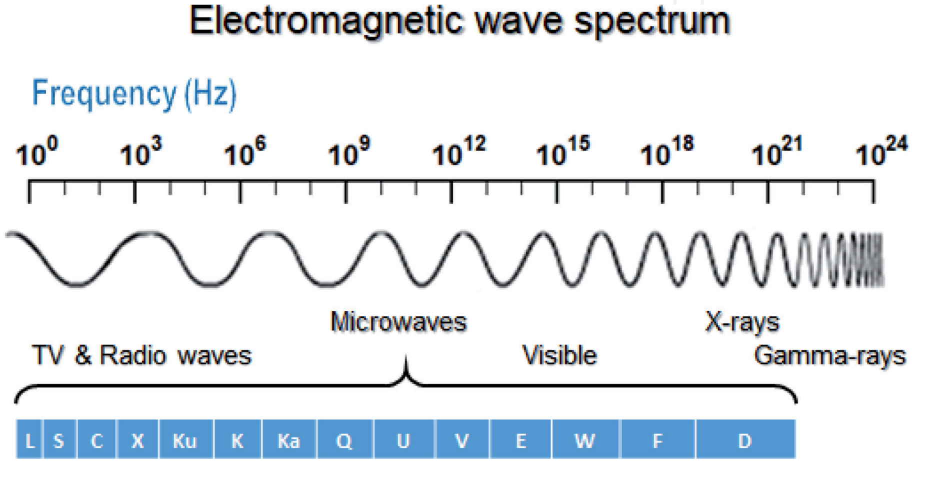

Figure 5.
Spectrum of electromagnetic waves and microwaves.

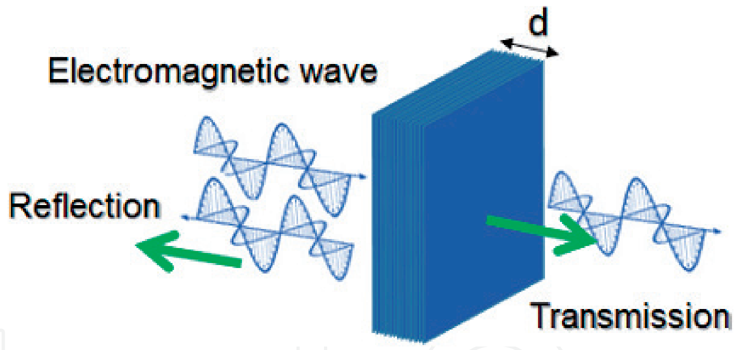

Figure 6.
Rules of optical law in microwaves.

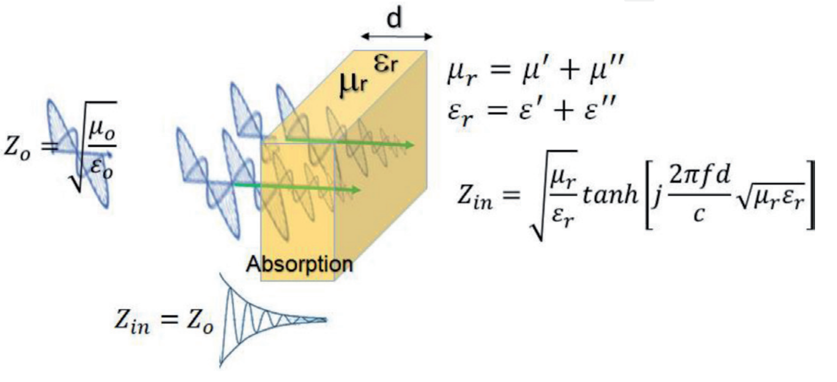

Figure 7.
Microwave absorption mechanism for materials.

In general the electrical and magnetic properties of a microwave absorbent material are characterized by complex permittivity and complex permeability, as shown by the following equations [17–19]:

$$\varepsilon_r = \varepsilon' + \varepsilon'' \tag{1}$$

$$\mu_r = \mu' + \mu'' \tag{2}$$

The real part of permittivity (ε') states the measure of the amount of energy from the external electric field stored in the material, while the imaginary part (ε'') states the measure of energy lost due to the external electric field. If the imaginary part is zero then the material is a lossless material and is called a loss factor. The same for permeability, the real part (μ') expresses a measure of the amount of energy from the external magnetic field stored in the material, while the imaginary part (μ'') shows the amount of energy dissipated due to the magnetic field.

Permittivity is present from material dielectric polarization. The quantity ε' can also be referred to as the dielectric constant of a material. The quantity ε'' is a measure of attenuation from the electric field caused by material. Loss of tangent permittivity of a material is defined as follows:

$$Tan\ \delta_\varepsilon = \frac{\varepsilon''}{\varepsilon'} \tag{3}$$

The greater the loss tangent of a material, the greater the attenuation when the wave moves through the material. The same applies to magnetic fields, namely:

$$Tan\ \delta_\mu = \frac{\mu''}{\mu'} \tag{4}$$

Both components contribute to the compression of wavelengths in the material. Because electromagnetic waves (EM) are a combination of two waves between electric and magnetic waves, loss of both magnetic and electric fields will weaken the energy in waves. In most dampers, both permittivity and permeability are functions of frequency and can vary significantly even in small frequency ranges. If permittivity and complex permeability are known in a certain frequency range, the material effect on the wave will be known.

It is well known that dielectric and magnetic parameters include electric field vectors $\vec{E}$, magnetic fields $\vec{H}$, induction fields $\vec{B}$, displacement $\vec{D}$, polarization $\vec{P}$, and magnetization $\vec{M}$. The interaction of electric fields in materials follows a pattern similar to magnetic interactions in materials. One of the requirements that must be met for practical application as an absorbent of electromagnetic waves is that this material must have the highest permeability and permittivity values with high magnetic saturation. The SI unit of permittivity and permeability respective are farad per meter and henry per meter. In terms of absorption of EM wave energy, the overall interaction can be represented by the dielectric and magnetic impedance matching of the material (Zin) equal to the air impedance (Zo) as a frequency function.

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

where Z_{in} is the impedance of material, (μ_r) and (ε_r) are the complex relative permeability and permittivity of the material, d is the absorber thickness, and c and f are the velocity of light and frequency of microwave in free space, respectively.

$$RL = -20\ log\left|\frac{Z_{in} - Z_o}{Z_{in} + Z_o}\right| \tag{6}$$

This impedance adjustment is important in the microwave frequency range. A transmission line that is given the same load as the characteristic impedance has a standing wave ratio (SWR) equal to one and transmits a certain amount of power without wave reflection. Also the absorption efficiency is optimum if there is no reflected power. Matching means giving the same impedance as the characteristic impedance of electromagnetic waves. Measured parameters are reflection loss (RL), if there is a matching impedance $Z_{in} = Z_o$, meaning that RL will be infinite or all waves have been absorbed perfectly.

3. Microwave absorbing material

This chapter focuses specifically on microwave absorbent materials from smart magnet materials which have been thoroughly studied by the authors, which include perovskite, ferrite, hexagonal ferrite, and composite systems. The results have all been reported and published in several globally indexed journals.

3.1 Perovskite system

Perovskite systems have an empirical formula ABO_3. In this research, the authors have focused on the $LaMnO_3$-based system. An $LaMnO_3$ is a magnetic material that has high permittivity but low permeability because it is paramagnetic at room temperature [20]. In a previous study [21], after $LaMnO_3$ was substituted with barium atoms forming the compound $La_{0.8}Ba_{0.2}MnO_3$, this material was ferromagnetic where the permeability of the material increased. However, the results of testing microwave absorption are still relatively low, only in the range of ~6.5 to ~3 dB at a frequency of 14.2 GHz. In this chapter book, we will also present the results of advanced material engineering based on the results obtained previously, namely, manganite-based materials with a composition of $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$ (x = 0.1–0.8) [22]. A designed $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$ composition was prepared using a conventional milling technique. Stoichiometric quantities of analytical grade $BaCO_3$, Fe_2O_3, $MnCO_3$, TiO_2, and La_2O_3 precursors with a purity of greater than 99% were mixed and milled using a planetary ball mill to powder weight ratio of 10:1 for up to 10 h. The quasicrystalline powders were then compacted into pellets and sintered in the electric chamber furnace at 1000°C for 5 h to obtain crystalline materials and confirmed using an X-ray diffractometer (XRD). The results of XRD analysis show that the highest fraction of the $LaMnO_3$ phase was found in the sample with composition x < 0.3 to 99%, while the $LaMnO_3$ phase mass fraction decreased for composition x > 0.3 as illustrated in **Figure 8**.

The results of magnetic properties analysis were measured using vibrating sample magnetometer (VSM). The results of the VSM analysis show that in all samples, $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$ (x = 0.1–0.8) contains a $BaFe_{12}O_{19}$-based hard magnetic phase. This magnetic phase increases with increasing composition of x as shown in **Figure 9**.

The characteristic of microwave absorption is measured using vector network analyzer (VNA) in the frequency range 9–15 GHz as illustrated in **Figure 10**. The results of the VNA analysis show that the highest reflection loss is found to be three absorption peaks of ~9, ~8, and ~23.5 dB which is located at 9.9, 12.0, and 14.1 GHz frequency, respectively. Based on the calculation of the reflection value obtained, microwave absorption reaches 95% with a sample thickness of 1.5 mm.

Investigation on this perovskite system has also been carried out by previous researchers. Zhang and Cao [23] succeeded in synthesizing transition metal (TM)-doped $La_{0.7}Sr_{0.3}Mn_{1-x}TM_xO_{3\pm\delta}$ (TM: Fe, Co, or Ni) for microwave absorbing materials. $La_{0.7}Sr_{0.3}Mn_{1-x}TM_xO_{3\pm\delta}$ has shown good properties for

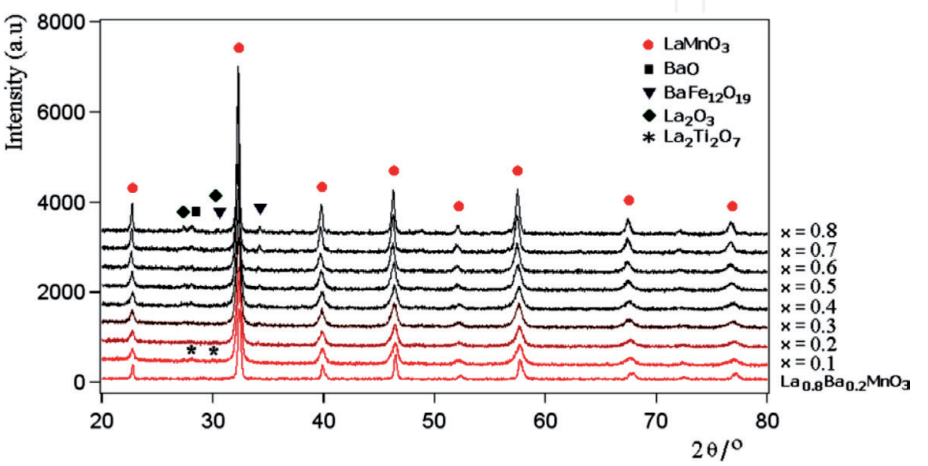

Figure 8.
X-ray diffraction pattern of $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$ (x = 0.1–0.8) [22].

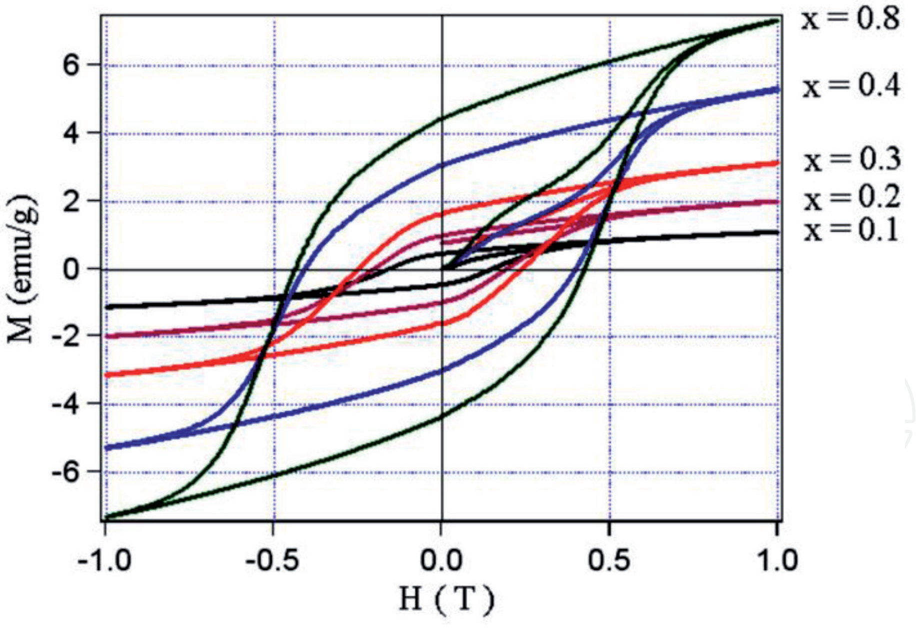

Figure 9.
The hysteresis curve of $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$ (x = 0.1–0.8) [22].

microwave absorption. The maximum reflection loss was 27.67 dB at a 10.97 GHz frequency, which was obtained from a sample thickness of 2 mm. Zhou et al. [24] reported the successful synthesis of a modified of manganite-based compound $La_{0.8}Sr_{0.2}Mn_{1-y}Fe_yO_3$ (0 < y < 0.2). They showed that the absorption bandwidth reached 8.5 GHz above 8 dB and 6.2 GHz above 10 dB; the highest absorption peak reached 34 dB.

3.2 Ferrite system

For the ferrite system, we have conducted research on nickel ferrite-based microwave absorbers [25]. A research to study the microwave absorption properties of nickel ferrite in the X-band range has been conducted by using high energy milling technique. The synthesis of nickel ferrite ($Ni_xFe_{3-x}O_4$) was performed using solid-state reaction

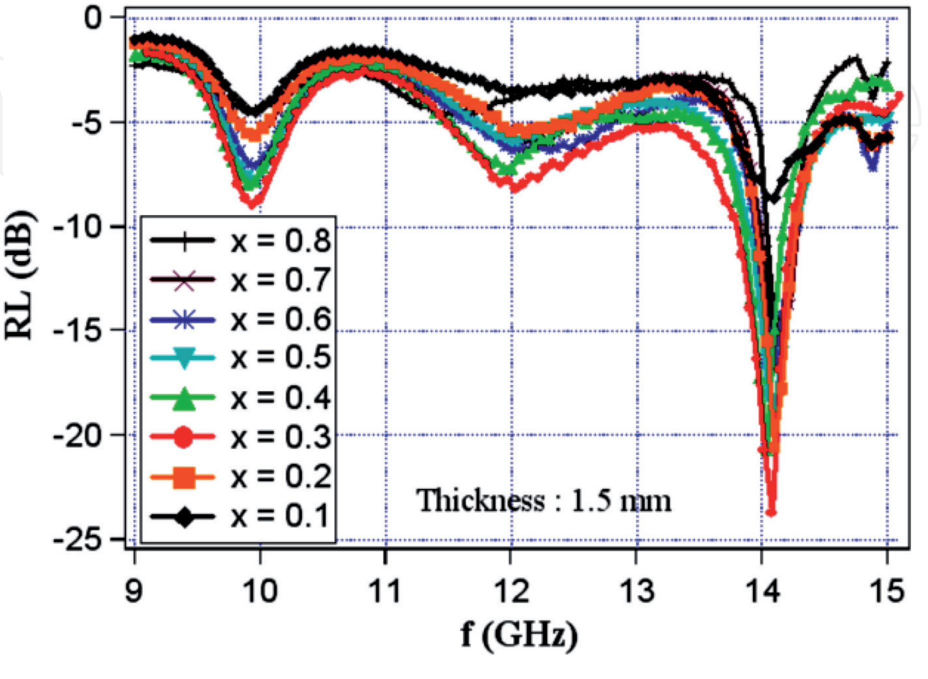

Figure 10.
Reflection loss (RL) of $La_{0.8}Ba_{0.2}Fe_xMn_{½(1-x)}Ti_{½(1-x)}O_3$ [22].

method with the material composition (2x)NiO: (3-x)Fe_2O_3 (x = 0.5, 1.0, 1.5 and 2.0) according to the molar ratio. This powder mixture was being milled for 10 hours then sintered at 1000°C temperature for 3 hours. Diffraction patterns of all varied $Ni_xFe_{3-x}O_4$ (x = 0.5, 1.0, 1.5 and 2.0) which have been synthesized by using milling technique are shown in **Figure 11**. It can be noticed that a single phase of all varied $Ni_xFe_{3-x}O_4$ (x = 0.5, 1.0, 1.5 and 2.0), which had spinel structure with lattice parameters a = b = c (space group Fd3m), has successfully formed.

The magnetic properties were measured by using vibrating sample magnetometer (VSM) as shown in **Figure 12**. To study the effects of Ni^{2+} doping on saturation magnetization (Ms), coercivity (Hc), and remanent magnetization (Mr) of $Ni_xFe_{3-x}O_4$ of (x = 0.5–2.0), M-H hysteresis loops were recorded using VSM under the applied magnetic field in the range of −10 up to 10 kOe at room temperature. The VSM result shows that all the samples exhibited a ferromagnetic behavior and fine hysteresis loops with a decrease in magnetization (Ms and Mr) but coercivity (Hc) with increase in Ni^{2+} concentration. Its coercivity value is in the range of 164–217 Oe, and the maximum value is found at x =1.5 composition.

The microwave absorption measurement was carried out by Vector Network Analyzer (VNA). The VNA characterization shows the ability of microwave absorption with a parameter of RL (reflection loss) value. **Figure 13** shows that the highest RL peak reached −28 dB at frequency of 10.98 GHz. It means that the $Ni_{1.5}Fe_{1.5}O_4$ sample can absorb microwave about ~96% at 10.98 GHz.

Other ferrite materials, such as barium mono-ferrite-based microwave absorbers, have also been studied by Ade Mulyawan et al. [26]. Barium mono-ferrite ($BaFe_2O_4$) has a more complex structure that exhibits orthorhombic structure. In this study, barium strontium mono-ferrite has been successfully synthesized using mechanical milling technique. $BaCO_3$, $SrCO_3$, and Fe_2O_3 powders are each weighed in accordance with the mole ratio of a total weight of 10 g. The chemical composition for the $Ba_{(1-x)}Sr_xFe_2O_4$ samples was in the range of 0 < x < 0.5. X-ray diffraction patterns of all varied $Ba_{(1-x)}Sr_xFe_2O_4$ (0 < x < 0.5) show a single phase of all composition.

Figure 14 shows the RL result of $Ba_{(1-x)}Sr_xFe_2O_4$ (0 < x < 0.5). The results of VNA analysis show that the highest reflection loss of the $Ba_{(1-x)}Sr_xFe_2O_4$ (0 < x < 0.5) was

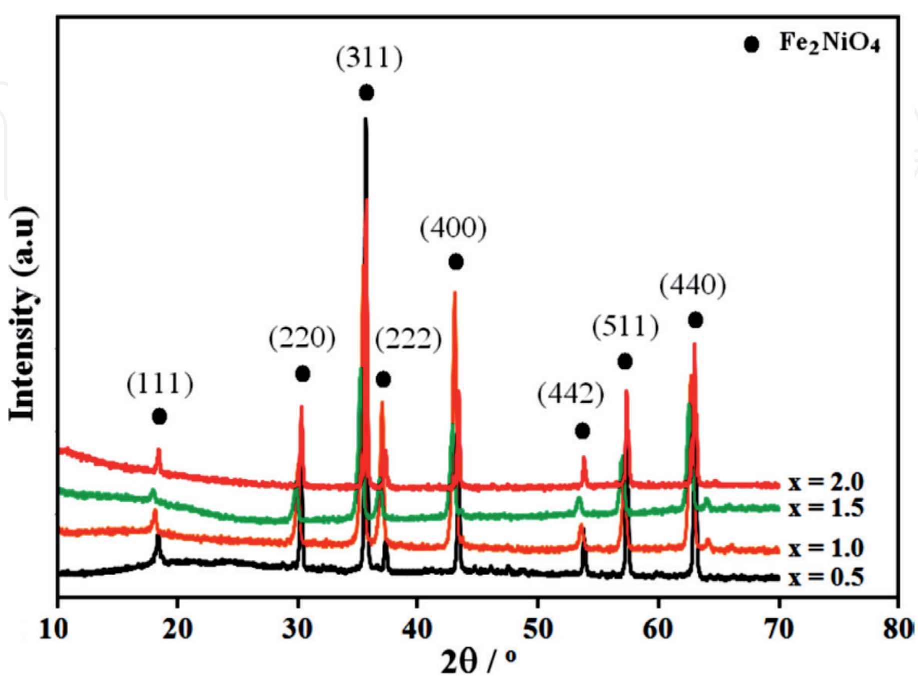

Figure 11.
X-ray diffraction patterns of $Ni_xFe_{3-x}O_4$ of (x = 0.5–2.0) [25].

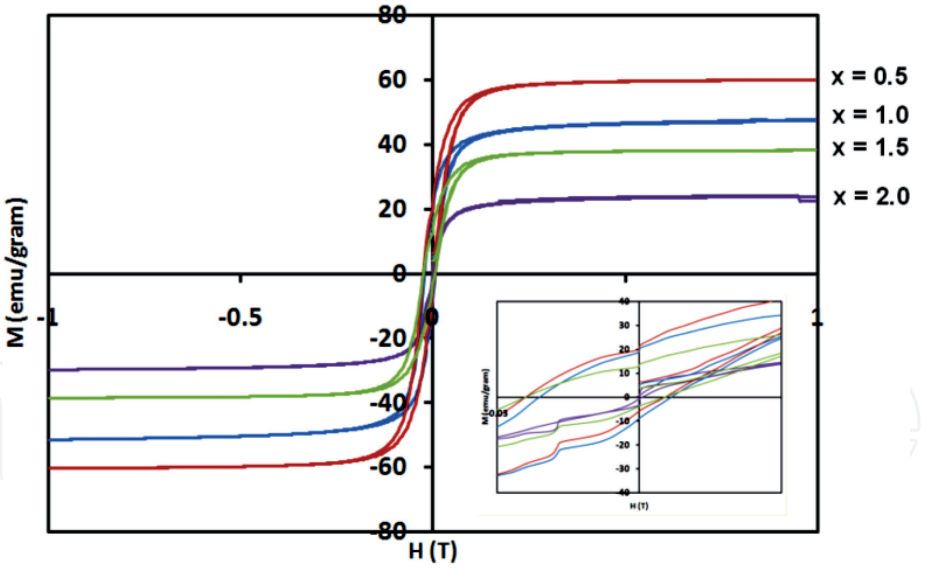

Figure 12.
Hysteresis curve of $Ni_xFe_{3-x}O_4$ (x = 0.5–2.0) [25].

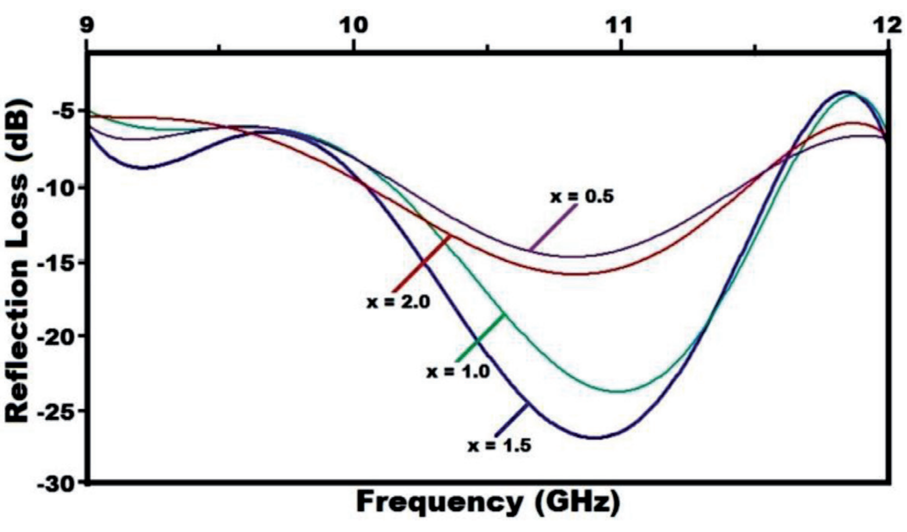

Figure 13.
Reflection loss (RL) curve of $Ni_xFe_{3-x}O_4$ (x = 0.5–2.0) [25].

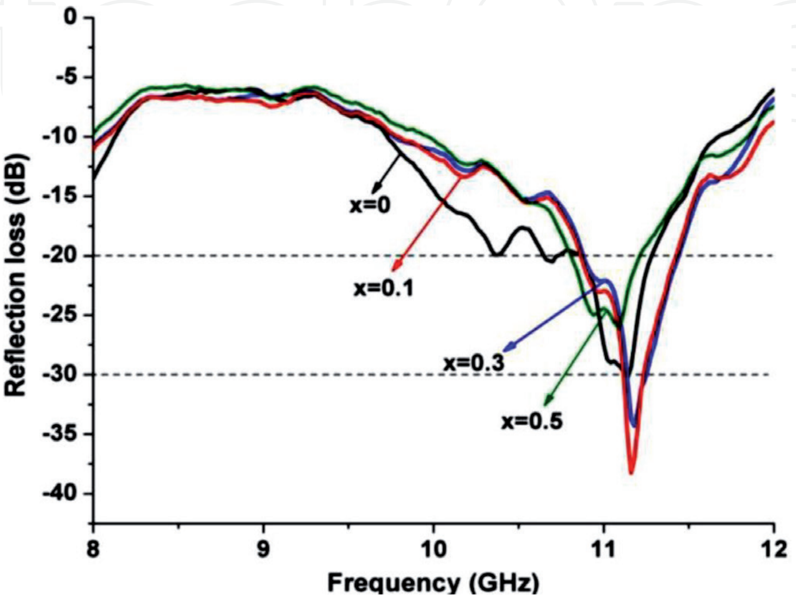

Figure 14.
Reflection loss (RL) curve of $Ba_{(1-x)}Sr_xFe_2O_4$ (0 < x < 0.5) [26].

found in the sample with composition x = 0.1, while the reflection loss of the $Ba_{(1-x)}Sr_xFe_2O_4$ (0 < x < 0.5) decreased for composition x > 0.1. A significant property of microwave absorption has also been displayed for the composition of x = 0.1, in which the value of −38.25 dB (~99.9%) for the reflection loss in the frequency range of 11.2 GHz was achieved.

3.3 Hexagonal ferrite system

The M-type hexagonal ferrite system ($BaFe_{12}O_{19}$) is generally an oxide permanent magnet. The hexagonal ferrite is one of the hard magnetic materials that is widely used in many applications. Apart from being applied to electric motors, they can be used for electronic devices because they have good phase stability at high temperatures and very high frequency responses and as switching with narrow field distribution. Material engineering for this application requires material that has magnetic and electrical specifications, and to obtain it, system modification is needed through a substitution process where trivalent iron ions Fe^{3+} will be replaced in part by M^{2+} divalent and M^{4+} tetravalent metal ions; using a material processing route can vary. We have succeeded in modifying this material into a microwave absorbent material. $Ba_{0.6}Sr_{0.4}Fe_{12-z}Mn_zO_{19}$ (z = 0, 1, 2, and 3) was successfully synthesized by solid-state reaction through a mechanical milling method [27]. The raw materials of $MnCO_3$, $BaCO_3$, Fe_2O_3, and $SrCO_3$ pro-analytic with purity > 99% were mixed according to stoichiometry composition of $Ba_{0.6}Sr_{0.4}Fe_{12-z}Mn_zO_{19}$ (z = 0, 1, 2, and 3). Based on the results of quantitative analysis using XRD, it shows that the best phase composition was found in the composition z = 1, namely, $Ba_{0.6}Sr_{0.4}Fe_{11}MnO_{19}$ as shown in **Figure 15**. Refinement of X-ray diffraction patterns reveals that $Ba_{0.6}Sr_{0.4}Fe_{11}MnO_{19}$ is a single phase and has a hexagonal structure with space group P63/mmc.

Powder $Ba_{0.6}Sr_{0.4}Fe_{11}MnO_{19}$ has an average particle size of 850 nm. Magnetic properties of $Ba_{0.6}Sr_{0.4}Fe_{11}MnO_{19}$ have a relatively low coercivity field and high remanent magnetization as shown in **Figure 16**.

The results of the microwave absorption test in the sample $Ba_{0.6}Sr_{0.4}Fe_{11}MnO_{19}$ in the frequency range 8–14 GHz show that the absorption peak values were −8 and −10 dB at 8.5 and 12.5 GHz, respectively (**Figure 17**). When compared with the results of the study by Azwar Manaf et al. [28], they have conducted research on the Ti^{2+}-Mn^{4+} ions which substituted $BaFe_{12-2x}Ti_xMn_xO_{19}$ samples with x = 0.0–0.8 through a mechanical alloying process and have studied the effect of ion substitution on

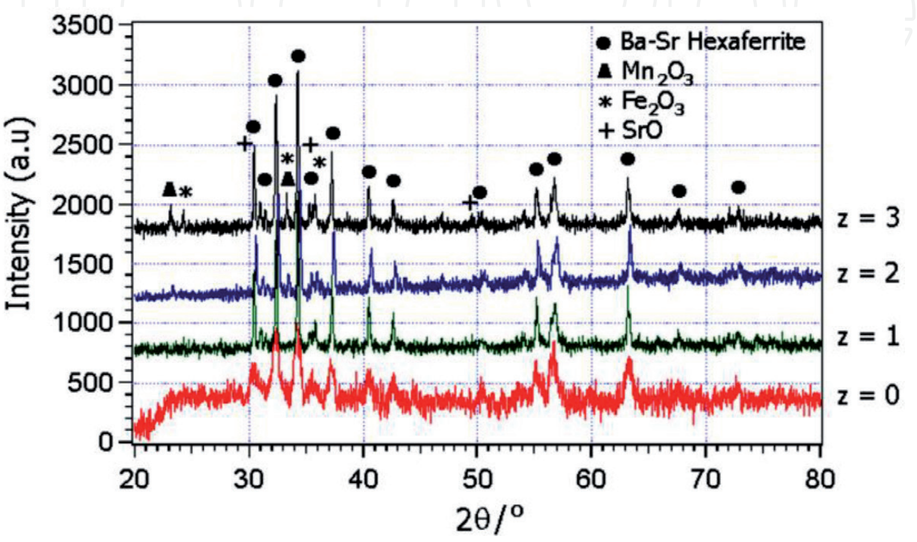

Figure 15.
X-ray diffraction patterns of $Ba_{0.6}Sr_{0.4}Fe_{12-z}Mn_zO_{19}$ (z = 0, 1, 2, and 3) [27].

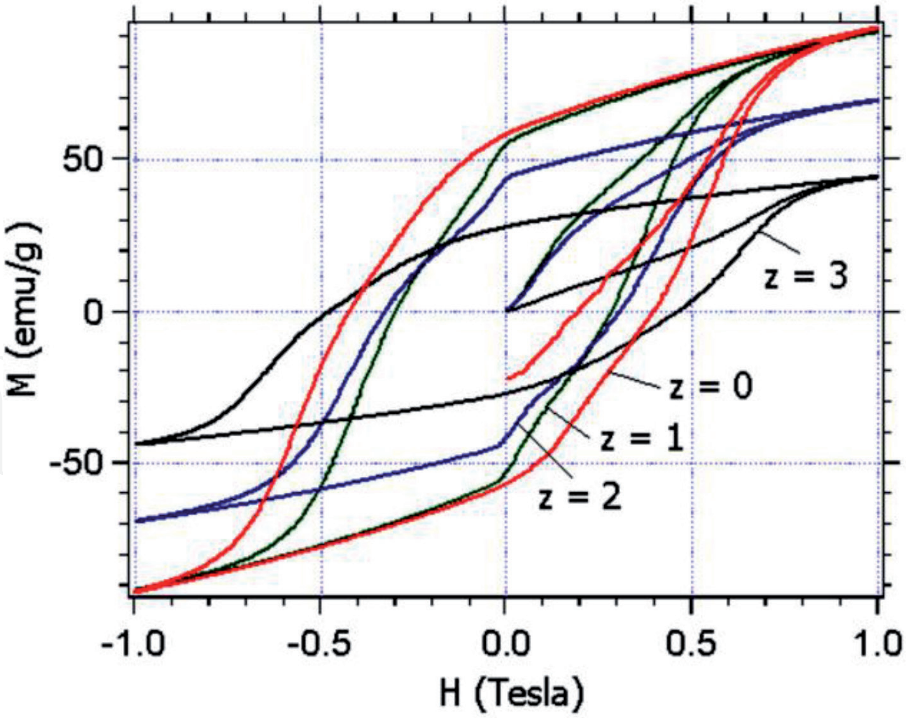

Figure 16.
Hysteresis curve of $Ba_{0.6}Sr_{0.4}Fe_{12\text{-}z}Mn_zO_{19}$ (z = 0, 1, 2, and 3) [27].

microstructure, magnetic, and microwave absorption characteristics. They obtained the results of reflection loss (RL) on series of Ti^{2+}-Mn^{4+} ions substituted $BaFe_{12-2x}Ti_xMn_xO_{19}$ samples with x = 0.0–0.8 samples which could be increased from 2.5 dB in composition x = 0 to −22 dB in composition x = 0.6 in the 8–12 GHz frequency range.

The results of this study can be concluded that the modified hexagonal ferrite system is also a good candidate for microwave absorbing material.

3.4 Composite system

At present there have been many materials developed from other types of polymer-based composite materials, because application requires that these

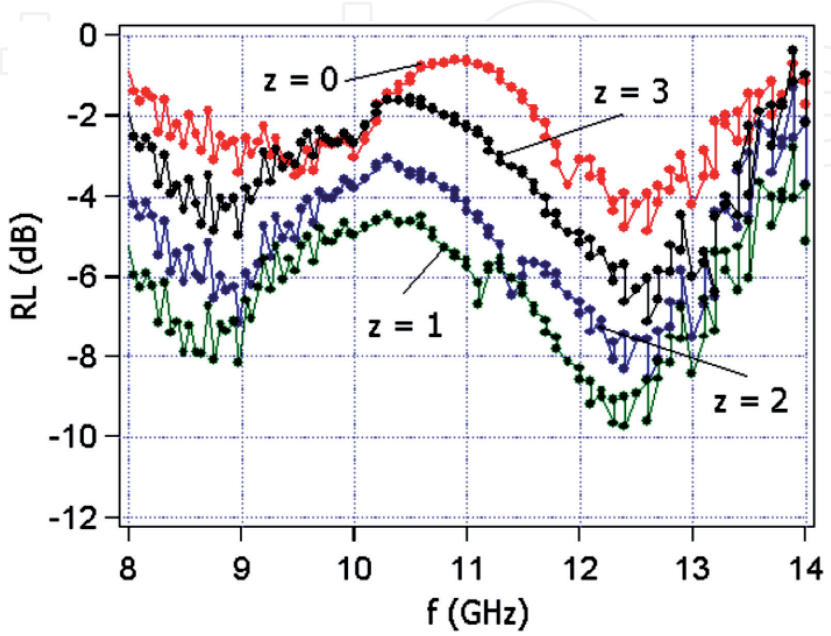

Figure 17.
Reflection loss curve (RL) of $Ba_{0.6}Sr_{0.4}Fe_{12\text{-}z}Mn_zO_{19}$ (z = 0, 1, 2, and 3) [27].

materials should be easy to form and easy to apply to other media such as electronic devices. For composite systems we have conducted research on microwave absorber sheets that are a composite of silicon rubber—iron oxide [29]. In this study, composites from the raw materials of silicone rubber, toluene, and iron oxide magnet powder have been made. The three raw materials are blended in a beaker and stirred for 60 min. The mixture is then printed on a media at 70°C and left for 15 min. The results of elemental analysis using energy-dispersive spectroscopy (EDS) show that the sample contained carbon, oxygen, sulfur, copper, and iron. While the results of the analysis of X-ray diffraction patterns show that the sample was classified as semi-crystalline with a crystallinity of 46%. So the composite consists of an amorphous matrix and a crystalline filler (namely, the phases of $CuFeS_2$, FeS, FeO_2, and Fe). Based on the results of functional group analysis using Fourier transformation infrared (FTIR), it shows that the sulfur addition modifies the polymer by forming a cross bond (bridge) between the individual polymer chain and the bond between the magnetic filler and the rubber matrix. **Figure 18** represents the FTIR spectrum between 4000 and 600 cm^{-1} from the composite sample. The peak transmittance of the FTIR spectrum in the composite sample shows the vibrations of O—H, C—H, Si—C, Si—O, and Fe—O bond. Natural rubber consists of suitable polymers of isoprene organic compounds with minor impurities from organic compounds and other water. The transmittance peaks of silicone rubber appear at wave numbers around 3000, 1250, and 1050–750 cm^{-1} which indicate the presence of successive functional groups C—H, Si—C, and Si—O bonds. Peak transmittance oxide iron was also observed at wave numbers around 3700 and 600 cm^{-1}, each of which indicated a vibration of H—O and Fe—O bonds. From the results of FTIR analysis, it is suspected that there is a bond between iron oxide as a filler and silicone rubber as a matrix.

The results of magnetic property analysis on absorber sheets were carried out using a vibrating sample magnetometer (VSM) which produced magnetic particle hysteresis curves as shown in **Figure 19**.

The reflection loss value which is a microwave absorbent indicator from the absorber sheet is shown in **Figure 20** where each profile for sheet-1, sheet-2, and sheet-3 has been compared. **Figure 20** shows the relationship between reflection loss (RL) of the absorber sheet and the X-band microwave frequency in the range 10–15 GHz which was measured at a sample thickness of 1.5 mm. There were two observed absorption peaks and high RL in the high frequency range for all samples.

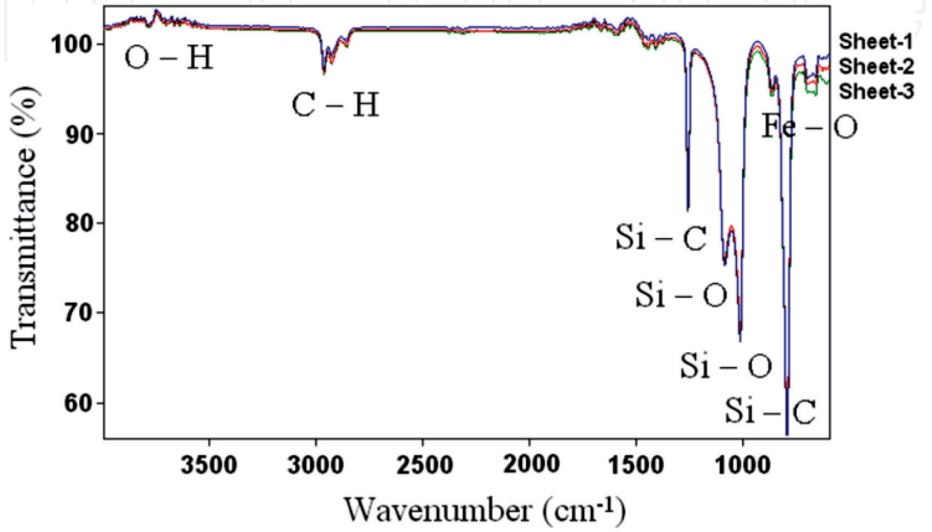

Figure 18.
The transmittance spectrum (FTIR) of the composite sample of silicon rubber—iron oxide [29].

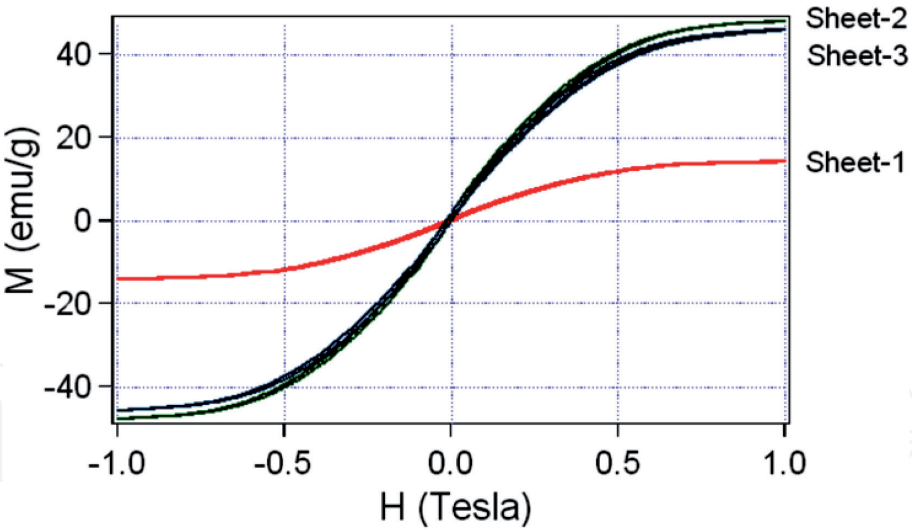

Figure 19.
Hysteresis curve of composite silicon rubber—iron oxide samples [29].

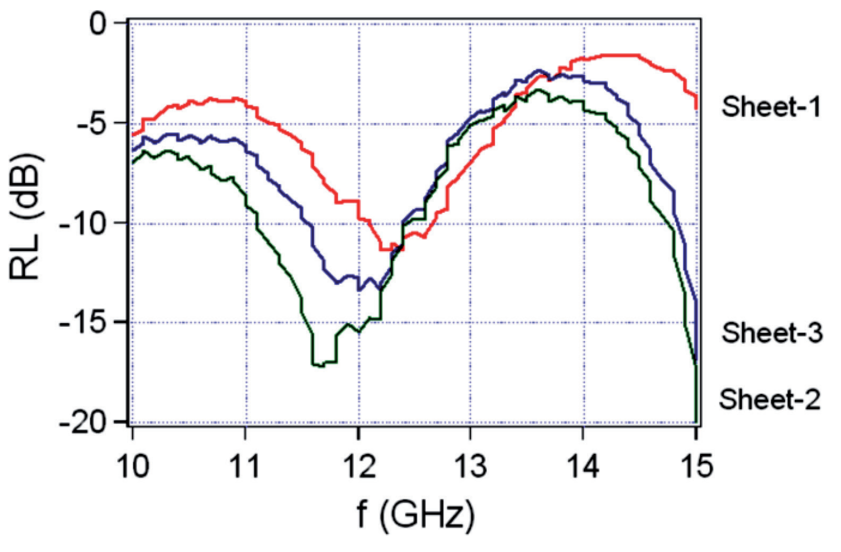

Figure 20.
Reflection loss curve (RL) of composition of silicone rubber—iron oxide [29].

The RL value increases with the addition of filler composition in the matrix. It seems that the RL value increases with the same sample thickness and the absorption frequency slightly shifts. This can be explained by the effects of electromagnetic properties on attenuation characteristics in each sample. Thus according to the results of this study, it was found that the best composite sample was sheet-3 with an absorption peak value of −15 dB at a frequency of 12 GHz.

Based on the results of this study, we conclude that all microwave absorbent materials can be made in the form of silicon rubber-based composite sheets as a composite matrix.

4. Conclusions

Based on the above explanation, wave absorbing materials are composed of materials that have magnetic and electrical properties which are shown by intrinsic parameters in the form of complex permittivity (ε_r) and complex permeability (μ_r) and extrinsic parameters in the form of geometry factors (thickness) of a material [14–16]. If a travelling electromagnetic wave is incident upon and absorbed by a microwave absorbent, spin resonance will occur due to the presence of these material parameters. In smart magnetic materials, the resonance that occurs between electromagnetic waves and material is divided into two mechanisms, namely, the wall resonance domain and spin electron resonance (ferromagnetic resonance). The wall resonance domain is resonance that occurs in magnetic domains caused by induction of electromagnetic waves, while spin electron resonance is resonance that occurs in electrons that are precise in the direction of the internal magnetic field due to the induction of electromagnetic waves. However, it should be noted that smart magnetic material is certainly unable to absorb microwaves on all band frequencies because each smart magnetic material has different resonant characteristics, so the maximum effort that can be done is to find the right composition of smart magnetic material which is expected to have the maximum wave absorption ability.

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