



Article Synthesis and Characterization of Composites with Y-Hexaferrites for Electromagnetic Interference Shielding Applications

Sajjad Ahmad Khan ^{1,*}, Irshad Ali ², Abid Hussain ¹, Hafiz Muhammad Asif Javed ³, Vitalii A. Turchenko ^{4,5,*}, Alex V. Trukhanov ^{6,7} and Sergei V. Trukhanov ^{6,7}

- ¹ Institute of Physics, Khawaja Fareed University of Engineering and Information Technology, Abu Dhabi Road, Rahim Yar Khan 64200, Pakistan
- ² Department of Physics, Government Graduate College Jampur, Jampur 33000, Pakistan
- ³ Nanomaterials and Solar Energy Research Laboratory, Department of Physics, University of Agriculture Faisalabad, Faisalabad 38000, Pakistan
- ⁴ Joint Institute for Nuclear Research, 6, Joliot-Curie Str., Dubna 141980, Russia
- ⁵ Donetsk Institute of Physics and Technology Named after O.O. Galkin of the NASU, 46, Nauki Ave., 03680 Kiev, Ukraine
- ⁶ Laboratory of Magnetic Films Physics, SSPA "Scientific and Practical Materials Research Centre of NAS of Belarus", 19, P. Brovki Str., 220072 Minsk, Belarus
- ⁷ Smart Sensor Systems Laboratory, Department of Electronic Materials Technology, National University of Science and Technology MISiS, Moscow 119049, Russia
- * Correspondence: sajjadhaleli@gmail.com (S.A.K.); va_turchenko@mail.ru (V.A.T.)

Abstract: The current research is focused on the chemical process and characterization of Co-based Y-type hexaferrite, electrochemically active polypyrrole doped with dodecylbenzene sulphonicacid (PPy-DBSA) and their composites. The microemulsion technique was used to produce hexaferrite with the formula $Sr_2Co_2Fe_{12}O_{22}$. The resistivity of pure ferrite specimens was 103 ohm-cm, which was lower than the 106 ohm-cm resistivity of the monomer utilized in the polymerization operation. As the temperature increases, the DC resistance decreases, revealing the specimens' semiconductor nature. The cole-cole plots have been used to assess whether significant grain boundaries were involved in the dielectric relaxation process. By increasing the frequency, the electrochemical performance of all specimens was enhanced. Using the rate equation, ionic conductivity demonstrates that polarons are responsible for conduction. Because of the characteristics of the polymer PPY-conducting DBSA, the composites PPY/DBSA + $Sr_2Co_2Fe_{12}O_{22}$ exhibit a higher dielectric loss of 35 at 1 MHz. This specimen is perfect for electrical radiation shielding (EMI).These ferrites are widely used as permanent magnets, in microwave devices, high-density perpendicular media, and rigid disk media without lubricant and protective layers.

Keywords: composites; cole-cole plots; AC conduction; dielectrics

1. Introduction

As long as ferrites have existed, they have been one of the most potent magnetic materials on the market. They may be employed in various technical applications since ferrites are extremely dependable and inexpensive [1–3]. This product may be used in any industry with substantial cost concerns that requires magnetic materials. One of the most versatile magnetic materials on the market, ferrites provide a broad spectrum of uses due to their unique properties. Many sectors, including automotive and aerospace, are using them to increase effectiveness, security, and uniformity in heavy components. Polymer-based composites are becoming more and more critical as a result. Composites are due to their composition, which includes both low and high densities. Stability and stiffness are controlled, enabling them to be utilized to their maximum potential in the technology



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Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). field. Materials may now be custom-made for various uses, thanks to recent advances in nanotechnology [4–7].

The demand for multi-purpose composites has expanded over the last several years because of their critical role in electronic gadgets. The tensile strength and other features of polymer-based nanocomposites have attracted much interest. Polymer-bonded magnetic materials have several benefits over their metallic and ferrite ceramic counterparts, largely due to their lower cost and lighter weight. Corrosion-resistant and easy to produce, they also have a high output rate. It is significant to mention that the ferrite polymer composites' magnetic properties, dielectric properties, and microwave absorption behavior are all superior to the bulk ferrites. They can be used in capacitive and transformer electronics and have excellent adsorption applications [8,9]. The frequency response for reflection loss may be altered by retaining the material layers and depth [10–12]. Checking the performance of these constructions at various operating resonance frequencies to discover the various features of these materials is therefore helpful.

Hexaferrites, one of the most effective forms of magnetic materials, have come to the top due to their magnetic and electric characteristics and the demand for high-frequency electronics. Many individuals are currently interested in Y-type ferrite nanoparticles and other forms of ferromagnetic elements found in ferromagnetic materials.

The magnetic and electrical properties of hexaferrite in the past were adjusted by doping. This was done by mixing with trivalent ions or a combination of divalent and trivalent. The doping of trivalent or divalent mainly depended on the applications. The Sr, Mn and Cr-doped Y-type hexaferrite were studied by Iqbal et al. [13]. The different properties were discussed. Bai et al. [14] reported the magnetic properties of y-hexaferrite of $Ba_2Me_2Fe_{12}O_{22}$ with (M = Zn, Co, Cu). The crystal structure and the magnetic properties of Al-substituted hexaferrite were studied by Xu et al. [15]. Similarly, Mirzaee et al. discussed the magnetic and structural properties of Co, Al and Cr doped with Y-type hexaferrite [16]. The effect of Al on different properties of Sr-based Y-type hexaferrite was reported by Nikzad et al. [17]. Farzin et al. [18] reported the effect of Mg and Ni on the structural and magnetic properties of Y-hexaferrite. However, the CO doped with rare earth (RE) and its composites with PPY-DBSA have rarely been reported in the literature. The RE element has a different effect on the structural and magnetic properties of hexaferrite due to their typical relaxation properties and change in magnetic interactions.

Ali et al. [19] studied the Tb^{3+} RE at Fe^{3+} octahedral site and Mn^{2+} ions on tetrahedral sites, i.e., the Co^2 site in the $Sr_2Co_2Fe_{12}O_{22}$ hexaferrite. It was reported that Mn^{2+} has 5e unpaired electrons replacing the Co^{2+} , which has 3e unpaired electrons. In the same way, Tb^{3+} , which has 6e unpaired electrons, replaces Fe^{3+} with 5e unpaired electrons. The study gave improved magnetic properties. Therefore, through these studies, the search for novel materials with enhanced magnetic and dielectric properties was carried out.

The composites of RE-substituted-type hexaferrite with PPY-DBSA are synthesized by a micro emulsion technique to obtain enhanced magnetic and dielectric properties. The primary target of the present work is to address the systematic correlation, the effect of occupation sites, and the transition metals with RE metals to the magnetic and dielectric properties of nano-sized Y-type hexagonal ferrite. Lastly, the study allowed an excellent understanding of using these materials in absorbing electromagnetic waves in the GHz range.

Significant advances in ferrite development are predicated on the fact that these substances come in a wide range of formats, chemical characteristics, and manufacturing processes. This enhances their use and makes them more enjoyable to deal with. These ferrites are used as permanent magnets, magneto-optical recording media, microwave devices, and high-density perpendicular media.

The Y-type hexaferrite is a potential candidate for overcoat-free and semi-contact recording media [20]. Due to their excellent chemical stability, hardness, outstanding corrosion, and wear resistance, they can be used as appropriate candidates for rigid disk

media. Since hexagonal ferrite has a low level of media noise, due to this feature, they are also used in rigid disk media without lubricant and protective layers [21–23].

The hexaferrite can be synthesized by different techniques, i.e., hydrothermal, sol-gel, citrate precursor, co-precipitation, aerosol pyrolysis, sonochemical, glass crystallization and microemulsion techniques [24,25]. However, the microemulsion technique is suitable for obtaining the controlled particle size with exact stoichiometric preparation and uniform distribution of different ions [26–28]. By altering the composition of Sr-Co Y-type hexaferrite using the microemulsion process, they may be synthesized with additional RE elements. This increases their electrical and dissipation factors, which results in improved characteristics. This is the optimal method for obtaining uniform nanostructures. The Y-type hexagonal ferrites containing Sr-Co have attracted much attention for high-frequency operating devices. Therefore, the present study adopted a microemulsion technique to prepare the Sr-Co substituted Y-hexaferrite and make composites with PPY-DBSA.

2. Materials and Methods

2.1. Synthesis of PPY-DBSA

The production of the polymer used a simple and inexpensive process. First, 100 mL of distilled water was used to prepare the solution. The polypyrrole and 0.15 mole of DBSA were mixed thoroughly and stirred in purified water. After 3 h, the whole mixture was placed on a magnetic stirrer. During continuous stirring, 0.15 mol of ammonium persulfate (APS) was added drop by drop as an oxidant and liquefied in 200 mL of sterile distilled water. After 24 h of stirring, 1 L of methanol was added to the reaction mixture. It was kept at room temperature for two days. This was followed by the suspension being filtered and rinsed. We created a black paste of doped polypyrrole, dehydrated under pressure at 90 °C for 24 h.

2.2. Synthesis of Ferrite

To synthesize Y-type strontium hexaferrite, the starting materials were $Fe(NO_3)_{3.9}H_2O$ (Riedel-de Haen, Seelze, Germany, 97%) Co $(NH_3)_{2.6}H_2O$ (Merck, Rahway, NJ, USA, >99%), Sr $(NO_3)_2$ (Merck, 99%), cetyltrimethylammonium bromide (CTAB) (Merck, 97%) as a surfactant, NH₃ (Fisher Scientific, Hampton, NH, USA, 35%) as a precipitating agent, and Isopropanol (Merck, 99%), the washing reagent. The Sr₂C_{O2}Fe₁₂O₂₂ hexaferrite sample, with the help of surfactants (microemulsion) by Co-precipitation, was created. In distilled water, the requisite molarities of the ferrous salt solution were made, combined in a beaker, and stirred on the magnetic hot plate at 60 °C until a clear solution was obtained. Deionized water and methanol were used to wash the precipitates. The precipitates were then dried at 150 °C in an oven before being annealed for eight hours at 1000 °C.

2.3. Ferrites Polymer Composite

The doped PPY-DBSA was mixed with $Sr_2CO_2Fe_{12}O_{22}$ in a 1:1 molar ratio for preparing the composites. An agate mortar and pestle were used for grinding. The powders of synthetic materials were then pressed into a computer-controlled Paulotto Weber hydraulic press (PWHP) under a force of 25 kN with a circumference of 89 mm. The dimension of the pellets was between 3 mm to 4 mm.

The DC electrical resistivity was measured using the two-point probe method. In contrast, the dielectric parameters such as dielectric constant, dielectric loss, dielectric loss factor and AC conductivity were measured using an RF LCR meter model 4287A. All these electrical and dielectric measurements were carried out using pellets of 12 mm diameter and 2.5 mm thickness. For the measurements of dielectric parameters, the pellets were coated with silver paste, and the connection was also made from the silver paste.

3. Results and Discussion

3.1. Electrical Properties

The majority of ferromagnetic materials exhibit semiconductor characteristics with increasing temperature. Rather than the aggregate band concept, the strength values of ferrimagnetic materials may be described using the localized electron model. The polarity change of Fe ions is essential in thoroughly clarifying the resistance trend of magnetic nanoparticles [29]. It is a fact that the decrease in resistivity is primarily due to the high movement of extra electrons created by the presence of Fe²⁺ or other positively charged ions in ferromagnetic materials through the crystalline structure of such materials.

PPY-DBSA composite work acts as an ion exchange resin and a bridge among covalently bonded and tetravalent ions on the hexagonal location of the crystal structure, which is primarily responsible for the conductivity. A significant number of dopant ions are introduced into the structure of PPy during the synthesis process to counteract the positive charge created by polymer chain degradation [30]. The DC resistance of the poly carbonyl group is exponentially related to temperature [31], which is due to the anionic dopant present in the conjugated polymers. Consequently, the dissociation of the double-bond electrons is considered [32]. Other studies have also reported the same findings [33]. It turns out that the DC characteristic impedance of ferrite is higher than that of the crystalline base substances that it is made from. It is because there are a lot of small grains that make it hard for electrons to flow through them.

Furthermore, there is a lot of inter granularity, which makes the resistivity increase [34]. Nanocomposites have a lower resistance than pure ferrite. The resistance gets even lower as the temperature increases. The addition of ferrite to PPy-DBSA caused the resistivity to go down. FeCl₃ was used to make the polymer, and as a result, a donor–acceptor complex was formed. In the future, a donor-acceptor conjugated system could be why there were so many quasi-particles (polarons or bipolarons).

These "quasi-particles" carry the charge. They become more mobile as the temperature rises, which means that the resistance of these electric charges decreases. So, as the temperature rises, the polarons or partial discharge move at a faster rate, which lowers the resistivity [35]. The activation energy of different samples is shown to be similar to that of the room temperature's characteristic impedance. Figure 1 depicts the temperature coefficient of DC resistance for all the samples, measured between 292 K and 342 K. The DC electric resistance decreases with increasing fundamental measures because of the photogenerated electrons' mobility electric charge [36].



Figure 1. Temperature-dependent resistivity for y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA) and polymer (PPy-DBSA).

3.2. Dielectric Properties

As far as we know, PPy-DBSA is an amorphous material. It is also considered that amorphous materials feature faults that may be readily seen, such as point defects and small interstitial spaces. Impurities are believed to be present in the point defect, whereas in crystals, microscopic interstitial spaces help to build up the difficulty inside the band gap [37].

The electronic Coulomb opposing energy is caused by an imperfection in the lattice. Dipole-dipole forces in materials similar to PPy-DBSA also play a significant part in the processes of localization. Moreover, it is a well-known fact that these regional hubs are being considered to improve electricity-hopping transit. The changes in the samples' dielectric constant with frequency are seen in Figure 2.



Figure 2. The dielectric constant of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22} + PPy-DBSA$) and polymer PPy-DBSA.

As seen from the figure, values of dielectric constant increase with lower frequencies and decrease with higher frequencies greater than 3 GHz. This is the same behavior that ceramics such as ferrites exhibit when their specifications of dielectric permittivity are increased. Other researchers have reported a similar trend [38–40].

The drop in dielectric permittivity with greater frequency proves that dielectric materials exhibit generated electric moments when subjected to the external electric field. The further point is that as the applied electric field grows, the generated moments' polarization cannot [41]. By increasing the applied field frequency, the electron exchange between Fe²⁺ and Fe³⁺ ions decreases, which results in a lower absorption coefficient and dielectric loss in ferrite samples.

The dielectric constant of PPy, DBSA spectrum and capacitance loss exhibit considerable fluctuation throughout the frequency spectrum. Changes in a fundamental component of absorption coefficient and dielectric loss reveal that the molecular mass of surface plasmons or bipolarons is decreasing with relative frequency. When it comes to ferrite–polymer composites, on the other hand, magnetization and relaxing were seen due to the nonuniform system generated by the semi-conductive ferrite particles distributed by insulating matrix components and dielectric. Compared to pure ferrite, the composite sample has a high dielectric constant as a result of a decrease in the electrical resistivity.

By increasing the frequency, the imaginary permeability components may be seen in Figure 3. The relaxation of a variety of polarization in the hexagon ferrite structure mainly results from charge separation caused by electron hopping, as shown by several relaxing frequencies. There are hopeful signs that high dielectric loss is being used in more and more technology. A possible application in radiation interference is suggested by the composite-enhanced dielectric loss.



Figure 3. The dielectric loss of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22} + PPy-DBSA$) and polymer PPy-DBSA.

Figure 4 shows the connection between the tangent loss of the nonconductor and the resonant peaks of the spectra. Polymer and applied external frequencies were in resonance with the interfacial loss spectra of electrons [42]. The A to B or B to A bouncing probabilities, for example, cannot be separated when an ion has two unique optimal conductivity states, A and B, with equal performance abilities. This comparison may help in understanding the presence of resonance peaks in the data. An equilibrium mixture frequency of switching between states A and B is referred to as the "frequency of hop" between regions A and B.



Figure 4. Dielectric loss factor of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22} + PPy-DBSA$) and polymer PPy-DBSA.

Furthermore, the resonance identifies the existence of both n-type and p-type electric components in the present hexaferrite, according to Rezlescu's theory [44]. Secondly, the resonance may also occur as the hopping of electrons between the ferric and ferrous ions could not follow the applied external field, and this may also occur due to the presence of ferromagnetic ions such as cobalt. In the case of polypyrrole, the resonance peaks were also observed and can explain the phenomenon based on the conduction mechanism. It is believed that transport processes in polymers such as polypyrrole are due to the hopping of pi (π) electrons, and the conductivity is also due to the hopping of these electrons. The resonance peaks appeared in the polymer when the most possible relaxation time of the hopping electrons coincided with the applied frequency.

3.3. AC Conductivity

Figure 5 demonstrates the variance in conductivity for the current task. The graph clearly shows that increasing the frequency of all versions of traditional experiment enhances AC conductivity. It can be shown that increasing the frequency decreases the permittivity of all the samples.



Figure 5. The plot of AC conductivity vs. frequency of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA) and polymer PPy-DBSA.

It is because, as frequency increases, electric polarization diminishes because dipole antennas cannot follow the externally applied AC field. As a result, the generated dipole moment weakens as the externally applied frequency increases. The resonance frequency of the conductivity connection is provided by the equation below [45]:

$$\sigma_{\text{tot}}(\omega) = \sigma_{\text{DC}} + A\omega^n \tag{1}$$

In this mathematical statement, n denotes the frequency component, and A is a premathematical notation component. The Maxwell–Wagner theory and Koop's phenomenology theory can be used to explain the shown trend in AC conductivity. According to this idea, the experimental data of ionic conductivity at shorter wavelengths indicate intergranular behavior, whereas scattering data at higher frequency may be considered grain conductivity [46].

Figure 6 depicts the log characteristics of the frequency response of electrical properties of the samples. AC conductivity follows the empirical law. The n is a fractions exponential $(0 \le n \le 1)$, which is connected to the dynamics of different jumping ions [47]. The n = 0 indicates direct current conductivity. The presence of greater values of "n" in the analyzed sampling indicates that the conduction phenomena follow a hopping process [48].



Figure 6. Modification in log σ with log ω of Y-type hexaferrite Sr₂Co₂Fe₁₂O₂₂, composite (Sr₂Co₂Fe₁₂O₂₂ + PPy-DBSA) and polymer PPy-DBSA.

Bright ions traveling through their sub-lattices and jumping to the adjacent near site ended the energy obstruction. The following equation will be followed by alternating electrical current (AEC) conductivity:

$$\tau_0(T) = \tau_\infty \exp(E_{\rm AC}/kT) \tag{2}$$

In general, the activation energy for the absorption coefficient will be less than the chemical potential for DC conduction. The connection here between AC chemical potential and the DC reaction temperature is given as:

$$E_{dc} = E_{AC} / (1 - n) \tag{3}$$

3.4. Impedance Analysis

The impedance (*Z*) can be defined as the opposition in the movement of charges through a circuit applying the external electric field, which is a complex function having phase angle and magnitude, and the magnitude is the proposition of current and voltage. This is given as:

$$Z = \frac{R_{p}}{1 + \omega^{2} R_{p}^{2} C_{p}^{2}} + j \frac{\left(\omega R_{p}^{2} C_{p}\right)}{1 + \omega^{2} R_{p}^{2} C_{p}^{2}}$$
(4)

Figure 7 and its inset show the change in resistance (Z) with wavelength and follow relationship:

I

$$Z \downarrow = Z' + jZ'' \tag{5}$$



Figure 7. The plot of impedance vs. frequency of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA) and polymer PPy-DBSA.

As Z is the regarding particular of the impedance and Z'' is a complex conjugate of the impedance. With a reduction in impedance (Z) and a rise in frequency, AC conductivity increases. It also determines the sample semiconducting behavior.

3.5. Nyquist Plot (Cole-Cole Plot)

Interface spectrometry is frequently used to define the electrical characteristics of dielectric materials and their building interfaces. The impedance analysis includes both tangible and intangible components of the material. Admittance, permittivity, impedance, and electric modulus may be expressed using the four following complexities on a complex plane plot: Y*, Z*, M*, and tan δ (Nyquist plot). The link between such factors is shown in the following Table 1 according to:

$$\tan \delta = \varepsilon'' / \varepsilon' = Y'' / Y' = Z'' / Z' = M'' / M'$$
(6)

Parameters Composite Ferrite Polymer Dielectric constant(ε') 15.910 71.020 120.990 Dielectric loss(ε'') 2.310 34.630 41.910 0.340 Tangent loss($\varepsilon'' / \varepsilon'$) 0.160 0.480 $1.29 imes 10^{-4}$ 1.92×10^{-3} $2.33 imes 10^{-3}$ AC conductivity(σ_{AC}) 38,218 42,933 Impedance |Z| (Ω) 41,247 0.011 0.006 Real part of electric modulus (M')0.061 Imaginary part of electric modulus (M") 0.008 0.005 0.002 Exponential Factor n (± 0.011) 0.810 0.820 0.900 Estimated activation energy (EAC) 0.067 0.043 0.012

Table 1. The dielectric values of ferrite, composite and polymer.

Transverse electrical absolute value is a critical strategy for understanding and searching for various electrical properties in dielectric materials, such as relaxation time, conductance, and ion bouncing. Additionally, the particular use of complicated electric elasticity charts must be discussed for dielectric materials with low capacitance. Transverse electric elasticity plots are more favorable, according to the study, since they provide a substitute method for resolving numerous problems encountered during polarized analysis. The electric modulus is an excellent tool to clarify the conduction phenomenon in the insulator and dielectric materials, which can be defined as the inverse of the complex permittivity, which can be calculated using the following equation:

$$M^* = i/\varepsilon^* = M'(\omega) + i M''(\omega)$$
(7)

$$\mathbf{M}' = \varepsilon' / \{ (\varepsilon')^2 + (\varepsilon'')^2 \}$$
(8)

$$M'' = \varepsilon'' / \{ (\varepsilon')^2 + (\varepsilon'')^2 \}$$
(9)

where ε' and ε'' are the real and the complex part of the permittivity.

The real portion of the elasticity (M') and the exponent of the electrical modulus (M'') may be observed in Figures 8 and 9. As observed in the figures, the amount of (M) is smaller in the low-frequency zone and somewhat rises as the applied field increases.



Figure 8. Variation in the real part of electric absolute value with the frequency of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA) and polymer PPy-DBSA.



Figure 9. Variation in imaginary parts of electric modulus with the frequency of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA) and polymer PPy-DBSA.

The presence of resonant peaks in the M versus frequency plots for the current samples demonstrates the relaxing effect. The Maxwell–Wagner model more firmly establishes the presence of complicated resistivity conduction in non-uniform systems, including components [49]. If, as in the first case, the grain boundary is constrained inside a small region, the impedance spectrum (Z versus Z") provides additional information on the plane semi-circles. In the second circumstance, there may be a strong link between intergranular behavior and the presence of maxima in the Z plot as a function of frequency. If the grain boundaries are distributed across a vast area, the graph of the electric modulus ($M^* = i/\epsilon^*$) M vs. M offers additional information regarding semi-circles. It suggests a link between intergranular conductivity and the presence of maxima in the M plot as a specific wavelength [50]. The latter is more similar to the empirical evidence presented here.

Figure 10 illustrates the complicated electric resistance (Cole-Cole) graphs of the samples under study. The left end of the crescent shape was used to identify the grain resistance of the material [51]. The medium frequency represented the grain boundaries rule [52,53] and the right end or particular intensity was used to determine the entire resistance of grains boundaries.



Figure 10. Cole-Cole plots of electric modulus with the frequency of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA) and polymer PPy-DBSA.

3.6. Quality Factor

The variation in the Q values as a purpose of the relative frequency of the current instance is seen in Figure 11. Above the 2 GHz frequency, tremendous values of Q occur, and somewhat higher values were discovered. Due to the high Q values and resonance frequencies above 2 GHz, these samples are suitable for use in an elevated number of layers of chip inductors [54].



Figure 11. Variation of quality factor (Q) values with the frequency of Y-type hexaferrite $Sr_2Co_2Fe_{12}O_{22}$, composite ($Sr_2Co_2Fe_{12}O_{22}$ + PPy-DBSA), and polymer PPy-DBSA.

3.7. EMI Shielding Study

Electromagnetic (EM) waves that enter a sample are reflected, absorbed, and transmitted in different ways. Low reflection rates and high transmission of incident electromagnetic waves through the material result in low-incident wave attenuation by the sample, as is characteristic of traditional EMI shielding. The effectiveness of shielding is routinely used to calculate transmission-line energy loss. The sum of reflection-shielding efficiency (SER), absorption-shielding efficiency (SEA), and multiple reflection-shielding efficiency (EMISET) is EMISET (MRSE). The effectiveness of Y-type hexaferrite Sr₂Co₂Fe₁₂O₂₂, composite (Sr₂Co₂Fe₁₂O₂₂ +PPy-DBSA), and polymer PPy-DBSA in preventing electromagnetic interference (EMI) between 7 and 11 GHz is shown in Figure 12. At 11 GHz, the SE values for Y-type hexaferrite Sr₂Co₂Fe₁₂O₂₂ polymer PPy-DBSA and composite (Sr₂Co₂Fe₁₂O₂₂ + PPy-DBSA) are 15, 44, and 55 dB, respectively. As a result, modern $Sr_2Co_2Fe_{12}O_{22} + PPy$ -DBSA nanocomposite has enhanced EMI-shielding efficiency and performs a comparable function in separating laptop and desktop computers. According to popular perception, electrical conductivity experiments show that SE depends on AC. Shielding effectiveness can be increased by incorporating electric/magnetic dipoles easily triggered by the input signal. The dielectric constant is high, due to the ease with which the carriers can be polarized. As a result, both dielectric loss and electrical conductivity increase.



Figure 12. Variations of shielding efficiency of pure y-type hexaferrites, ppy-DBSA and ferrite-ppy-DBSA composite.

The ability of any material to attenuate strength of electromagnetic waves is known as the electromagnetic shielding. It is a logarithmic ratio between incoming power (pi) to transmitted power (pt)of electromagnetic waves in decibels (dB).

Shielding Effectiveness (SE) =
$$10\log(pi/pt)$$
 (10)

The electromagnetic waves interact in three processes with shielding materials. They are partly reflected or partly absorbed and multi-reflected inside the shielding materials. The reflection of electromagnetic waves from the surface is due to the interaction with electrons. The absorbed waves produce the heat or leaked currents due to the interaction with electric or magnetic dipoles of shielding materials. The third process is due to interface or presence of defects. The later process gives the same results as that of the second process, so electromagnetic interference shielding is described by two processes, i.e., reflection (R)and absorption (A). The electromagnetic interference shielding efficiency can thus be written as total shielding efficiency (SET):

$$SET = SER + SEA \tag{11}$$

In the above equation the reflection coefficient (R), transmission coefficient (T) and the absorption (A) can be calculated by S parameters (S11 or S22 and S21 or S12)in a two port network. The following equation is used for calculation [55]:

$$T = [ET/EI]^2 = [S21]^2 = [S12]^2$$
(12)

$$R = [ER/EI]^2 = [S11]^2 = [S22]^2$$
(13)

$$A = I - R - T \tag{14}$$

The effective absorbance can be defined as

$$A_{\rm eff} = (1 - R - T/R - T)$$
 (15)

The SEA, SER and SET can thus be described as

$$SER = -10Log(1 - R) = -10Log(1 - [S11]^{2})$$
(16)

and similarly

$$SEA = -10Log(1 - A_{eff})$$
(17)

$$SET = SER + SEA = -10Log([S21]2)$$
(18)

It is worth noting that SE also depends upon the complex function of the permittivity and permeability, the mathematical details are given elsewhere [56]. In general the SE of EMI strongly depends upon the frequency, the thickness of the sample, and conductivity of the materials. In the present study SE is calculated in the X band frequency region of Y-type hexaferrite, PPy-DBSA) and their composite [57,58]. Figure 11 shows the variation of SE of pure Y-type hexaferrite, conducting ppy-DBSA and their composite in the higher frequency range. It is observed that the pure Y-type hexaferrites and pure ppy-DBSA are neither the good absorber nor good reflector of the EM waves [59–61]. It is clear from Figure 11 that the composite of y-type hexaferrite/ppy-DBSA has higher shielding efficiency. The higher efficiency is due to the magnetic $Sr_2Co_2Fe_{12}O_{22}$ ferrite and conducting ppy-DBSA. The combined effect of the magnetic dipoles of ferrites and electric dipoles enhances the SE of the materials [62,63]. The total efficiency of the composite thus increases compared to the pure materials. The composite is thus a potential candidate for EMI shielding material due to its light weight with enhanced SE with wide bandwidth.

4. Conclusions

 $Co_2Sr_2Fe_{12}O_{22}$ is mixed with disposal polymer PPy-DBSA (1:1), and the findings are determined by the initial data. For ferrite and polymers, resistivity and dielectric measurements are used to characterize each sample. Due to the conductivity of the polymer PPY-DBSA, the composite sample (PPY/DBSA + $Sr_2Co_2Fe_{12}O_{22}$) has a higher dielectric loss than the ferrite filler. As dielectric loss and the dielectric constant rise, it is conceivable that these characteristics might have a wide range of uses in technology. They are used as magneto-optical recording media in microwave devices for overcoat-free and semicontact recording media. Due to their excellent chemical stability, hardness, outstanding corrosion, and wear resistance, they can be used as appropriate candidates for rigid disk media. Specifically, the composite's improved dielectric loss values strongly indicate its applicability in electromagnetic shielding above 3 GHz.

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