MICROWAVE ABSORPTION STUDIES ON COBALT IRON NANO-ALLOYS

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Abstract

Cobalt iron ($CoFe_2$) nano-alloy have been synthesized and studied for microwave absorption in the Ku band (12.4-18 GHz) region. Prepared material was analyzed for crystalline phase, crystallite size, particle size, magnetization and conductivity measurement relevance to microwave absorption. The microwave absorption studies of material have been done using vector network analyzer. Electromagnetic parameters like dielectric constant, magnetic permeability and reflection, transmission and absorption losses by the sample were obtained for 1.75mm thick sheet. Results reveal the absorption loss of ~65dB with reflectance loss less then 1dB and almost zero transmittance in the measured frequency range.

1. Introduction

The use of microwave absorption materials has attracted great interest due to rapid increases of electromagnetic interference (EMI) pollution by communication devices like mobile phones, local area network, radar systems etc. Electromagnetic waves cause interruption in the operation of electronically/magnetically-controlled devices. For the significant absorption of unwanted electromagnetic waves the materials is essentially required to have electric/magnetic dipoles with homogeneous distribution of particulate. For such materials, the specific shape and size distribution of particles is very important for the electromagnetic wave absorption. Particles with size less than the skin-depth (~1μm for iron in the 1–20 GHz range) are the best to increase effective incidence to EM wave absorbers by suppressing the eddy current phenomenon [1-2]. Large surface to volume ratio of these conducting and magnetic materials makes them very important. Materials like carbon coated copper, α-Fe/SmO, ferrofluid-conducting polymer composite etc. has already been studied [3-5]. Recently, use of carbon-containing nanometre size magnetic materials for electromagnetic shielding and absorption have also been investigated [6–9].

Soft metallic magnets are potential materials for microwave absorption in high frequency region. In the present investigation, our main focus is to synthesize nano-magnetic $CoFe_2$ metal alloy and to study physical properties relevance to EMI shielding in Ku band region.

2. Experimental

$CoFe_2$ nanoparticles were synthesized by chemical route followed by heat treatment in inert atmosphere. Crystalline phase has been analyzed by using Bruker D-8 Advance powder X-ray diffractometer (XRD), 40KV and 40mA with Cu K_α radiation and scan rate of 0.02^o/sec. Coherently crystallite size (d_{xrd}) was calculated from the width of diffraction peaks after correcting instrumental broadening. The material was analyzed by transmission electron microscope (TEM) model-JEM-200 CX for particle shape and size measurements. The magnetization measurements of the sample were done using DMS–880vibrating sample magnetometer (VSM). Conductivity measurements have been carried out using Keithley nano-voltmeter model 2182A and the current source 6221 by two probe method. Further the particles have been tested for microwave absorption by vector network analyzer (VNA) in Ku band region. The electromagnetic parameters were measured and their values are plotted in the frequency range 12.4 to 18 GHz.

3. Result and Discussion

X-ray diffraction pattern of sample as shown in Figure 1 reveals the formation of $CoFe_2$ alloy. In order to find out the crystallite size, a slow scan with step size 0.005^o/sec. of selected diffraction peaks such as (110) & (200) has been recorded and calculated by Scherer's formula [10]. The average crystallite size comes out to be 36nm.

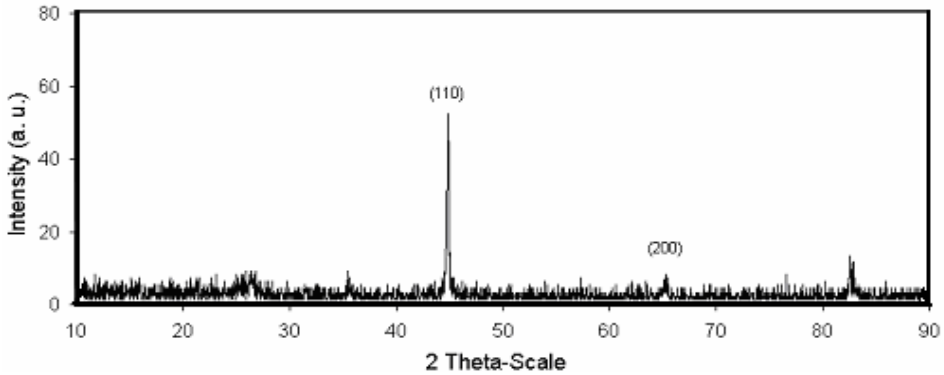

Figure 1. XRD pattern of the $CoFe_2$ nano-alloy.

In a nano phase material particle size, shape and their distribution always plays a crucial role in modeling its physical properties [11]. Figure 2 shows the electron micrograph of the sample. Micrograph shows the average particles size in the range of 20-100nm and majority of nano- alloy particles are spherical in shape. However, few individual particles seem to be made up of more then one small particles joined from the surfaces.

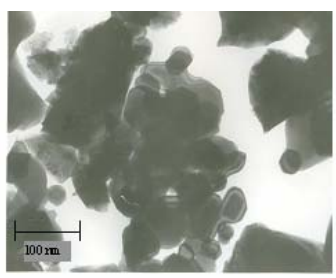

Figure 2. TEM image of the $CoFe_2$ nano-particles.

Figure 3 shows the magnetization measurements of the cobalt-iron nano alloy. From the curve it is concluded that the material is highly magnetic with saturation magnetization value of 110emu/gm, the corecivity and the retentivity parts are nearly zero which shows a very close to superparamagnetic nature of the alloy.

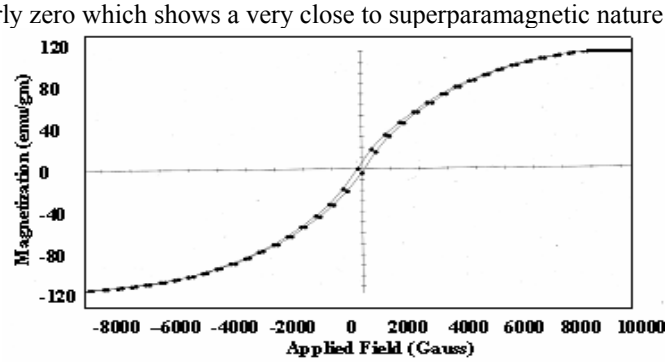

Figure 3. Magnetization measurements of the $CoFe_2$ nanoparticles.

In microwave absorption electrical conductivity as well as magnetic permeability plays crucial role in determining the skin depth for the material. Skin depth is the amount of thickness of the material, which reduces the intensity of microwaves to 1/e times when passed through it. The value of skin depth (δ) is defined as

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

where, f = frequency of microwaves, μ (magnetic permeability) = B/H is the relative increase or decrease in the resultant magnetic field inside a material compared with the magnetizing field in which the given material is located, σ = electrical conductivity of material.

Magnetically permeable and high conductivity nature of the cobalt-iron metal alloy makes it suitable for good microwave absorption. The experimental result for the VI characteristics of material is shown in Figure 4. The value of conductivity as calculated comes out to be equal to 2.5×10^2 $S^1 m^{-1}$.

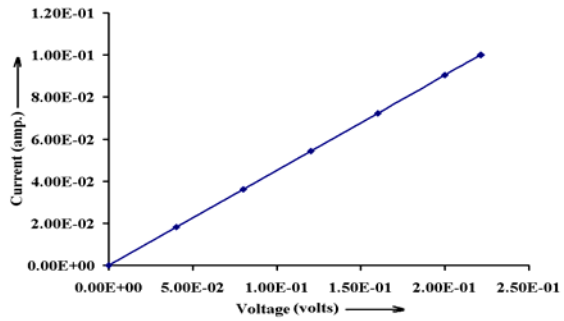

Figure 4. I-V characteristics of the material.

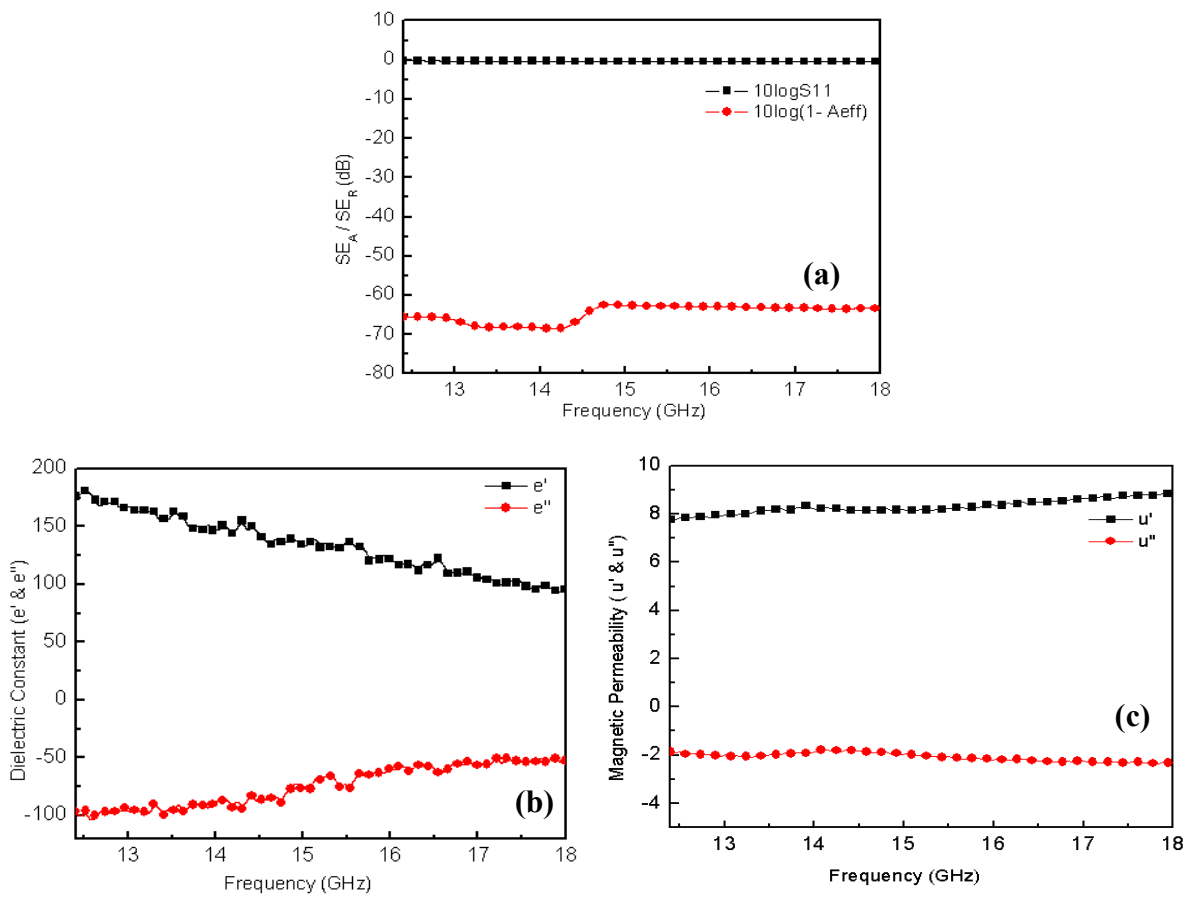

Figure 5. (a) Reflection and absorption loss by the material; Real and imaginary parts of (b) dielectric constant and (c) Magnetic permeability in frequency range 12.4-18 GHz.

The reflection loss R of less than −1 dB was obtained in the frequency range 12.4-18 GHz. Strong microwave absorption properties by $CoFe_2$ nanoparticles were observed as calculated. Figure 5 shows the reflection

and absorption loss of incident microwave and the values of dielectric constant and magnetic permeability of the material. An absorption loss of 65 dB was reached in the entire frequency range with an absorber thickness of 1.75 mm. The high-frequency permeability of metallic magnetic materials decrease due to the eddy current phenomenon induced by EM wave interference [4]. These materials exhibit improved microwave absorption properties because of their proper EM matching between the dielectric loss and the magnetic loss.

4. Conclusion

Developed cobalt-iron nano-alloy having excellent electrical and magnetic properties are in good agreement for EMI shielding material. Further, physical properties like crystalline size, particle shape/size, and magnetization of $CoFe_2$ nano metal alloy are explored relevance to microwave absorption (12.4-18 GHz) measurements. The reflection loss and transmission loss measurements indicate strong absorption properties by the material. Therefore, the developed material may find good applications in EMI shielding demand of new generation devices such as computers, cell phones, radar and other electronics gadgets working in high frequencies.

5. References

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