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ABSORPTION OF ELECTROMAGNETIC WAVES BY Fe_3O_4/PARAFFIN COMPOSITE MATERIALS

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Abstract. *Electromagnetic pollution in general and the harmful effects of microwave radiation in particular on environment is currently in the urgent stage. To eliminate the effect of electromagnetic energy the most common methods relies on the use of absorbing materials with large absorption capacities in wide frequency band. In this paper, we investigate the capability of absorption of electromagnetic waves of* Fe_3O_4 *nanoparticles in paraffin basis. The* Fe_3O_4*/paraffin composite materials were prepared with a weight ratio of 35%/65%. The dielectric constant* (ε_r) *and the magnetic permeability* (μ_r) *in the frequency* (f) *range from 8 to 18 GHz were measured for various sample thicknesses. The results indicated a large dielectric loss and strong thickness dependence of absorption capacity. The maximum absorption coefficient (RL) is of order -13.6 dB, corresponding to the achieved absorbance of 96.9% for the 2.6 mm of sample thickness. The experimental results are consisted with our simulation calculation.*

Keywords: absorbant material, electromagnetic wave absorption.

Classification numbers: 13.40.-f; 77.84.Lf.

I. INTRODUCTION

Recently novel technologies in the field of telecommunications have attracted a considerable interest of scientists. However, the development and application of devices which have the operating frequencies above 1GHz can cause sufficient electromagnetic pollution. In addition, the electromagnetic waves have various negative effects to the human health. Therefore, the problem of eliminating, or at least limiting the impact of electromagnetic pollution is studied extensively [1–5]. The soft magnetic materials, such as iron oxide, with large absorption capacity while operating in a wide frequency range are extensively researched [6–8]. For practical use, the light-weight absorbing materials with small thickness and large absorption capacity ($> 90\%$), while possessing the resistances to heat and corrosion are desirable. There are many studies on composite materials of graphites within given synthetic resins or polyaniline conducting polymers, polypyrrole [9–13].

Despite of huge efforts seen abroad, the researches of electromagnetic waves absorbing materials have not been frequently carried out in Vietnam, although there is a big demand for materials working in band range above 1GHz. Among the promising materials, the ferromagnetic Fe_3O_4 nanoparticles have attracted a lot of attention due to their high saturation magnetization and permeability at GHz frequencies. In this work, a composite of nano size Fe_3O_4 and paraffin is prepared and its structure, magnetic and electromagnetic wave absorbing properties are investigated.

II. EXPERIMENT

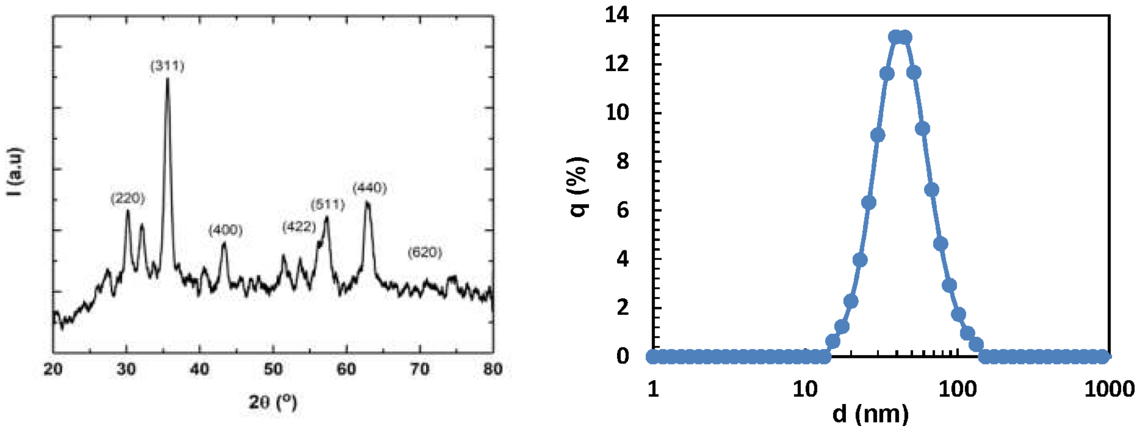
A composite of Fe_3O_4/paraffin sample with composition of 65%/35% weight ratio was synthesized by physical mixing of magnetite nanoparticles Fe_3O_4 with paraffin. The Fe_3O_4 nanoparticles were synthesized by hydrothermal method, using the inorganic salts as the precursors: Fe^{2+}, Fe^{3+}, $FeSO_4.6H_2O$ and $FeCl_3.6H_2O$ (purity 99.9% provided by Merck & Company, Inc., Germany).

The samples were put on a magnetic stirrer with hot plate and the temperature was kept at 70°C for 30 minutes. After that, the softened mixture was pressed at room temperature into the pellets of size approximately 1.1 cm width and 2.2 cm length. To measure the electromagnetic wave absorption, the sample was inserted into the waveguide tube in a dark chamber. Then, the sample was scanned using the Vector Network Analyzer (PNA 8362B - Agilent USA) in the frequency ranged from 8 to18 GHz requiring free-space as a test site with the angle of incidence of 0°. The test was controlled by a specialized software (using Nicolson-Ross-Weir algorithm) for viewing, measuring and saving data. The set-up was based on a pair of properly designed wide-band horn antennas. Two identical antennas were located on the positioning bar and the sample was fixed in the space between the two antennas. The whole system was then placed in a dark chamber to minimize the impact from the surrounding environment. After calibration of the system, the reflective loss signal (S_{11}) and the transmitted loss (S_{21}) of the electromagnetic wave were measured. From the calculated dielectric constant (ε_r) and magnetic permeability (μ_r), the reflection loss coefficient (*RL*) has been estimated by using the MATLAB software [14].

III. RESULTS AND DISCUSSIONS

III.1. The microstructure, crystallographic structure and magnetic properties of Fe_3O_4 grains

Figure 1(a) shows the XRD diffraction patterns of Fe_3O_4 magnetic particles. All the typical diffraction peaks can be identified as belonging to the Fe_3O_4 phase, and no impurity peak was found. The peak at $2 = 36.47^\circ$ corresponding to the (311) plane had highest intensity indicating that it corresponds to the most aligned orientation. Besides, the results of the size distribution of Fe_3O_4 particles were analyzed and given in Fig. 1(b). The sizes of the particles are ranged from 20 to 200 nm. In particular, the average size of particles is from 30 to 60 nm, with a largest proportion of 40 nm.



(a) (b)

Fig. 1. a) X-ray diffraction pattern of Fe_3O_4 particles. b) Graph of size distribution of Fe_3O_4 particles.

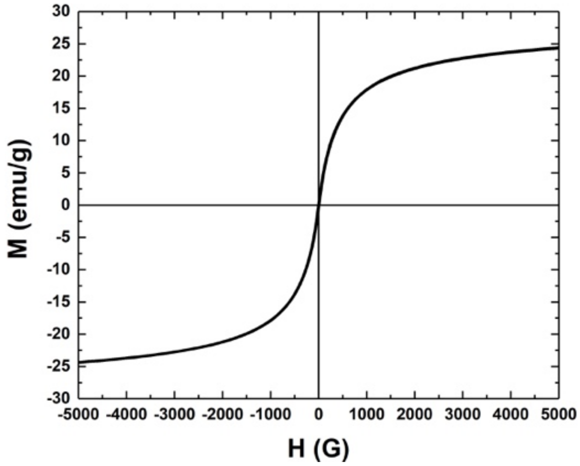


Fig. 2. Magnetic hysteresis loop of Fe_3O_4 nanoparticles.

The magnetic property of Fe_3O_4 nanoparticles has been measured by using a vibrating sampling magnetometer (VSM 7400, Lakeshore) in a magnetic field up to 5 kG as shown in Fig. 2. The result shows an in-plane magnetic anisotropy and typical soft magnetic properties of Fe_3O_4 nanoparticles. The hysteresis curve indicates the saturation magnetization $M_S = 24.2$ emu/g, the remanence magnetization $M_R = 0.97$ emu/g and the coercivity $H_C = 16.47$ G. The high saturation magnetization M_S and permeability, especially soft magnetic properties are great advantages for fabricating composite materials of high absorption ability.

III.2. The dielectric constant and permiability of electromagnetic absorbing material using simulation program

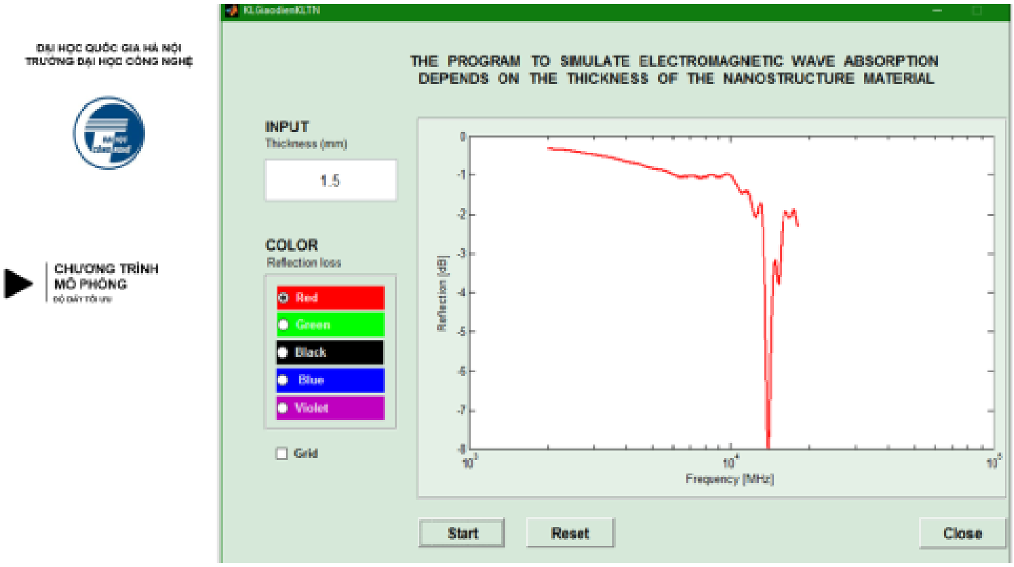
To determine the electromagnetic wave absorption, the reflection loss was calculated by using the following formula [14]:

$$RL = 20\log\left|\frac{Z-\eta_0}{Z+\eta_0}\right| (dB) \tag{1}$$

$$Z = \eta_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi f d}{c}\sqrt{\mu_r\varepsilon_r}\right);\ \eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{2}$$

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'';\mu_r = \mu_r' - j\mu_r'';\quad j = \sqrt{(-1)} \tag{3}$$

Where: Z is the intrinsic input impedance of the material, η_0 is the intrinsic impedance of the free space, ε_0 is the dielectric constant of free space, μ_0 is the permeability of free space, f is the frequency of the incident wave, and c is the velocity of light in free space. Also, ε_r', ε_r'', μ_r', μ_r'', d, respectively, are the real part, the virtual part of the dielectric constant, magnetic permeability and thickness of absorber. The value of ε_r' ε_r'' used for calculation was independent of frequency and the same as measured value.



THE PROGRAM TO SIMULATE ELECTROMAGNETIC WAVE ABSORPTION DEPENDS ON THE THICKNESS OF THE NANOSTRUCTURE MATERIAL

INPUT
Thickness (mm): 1.5

Fig. 3. The interface design of the simulation program.

Base on measured of the P8 E8362B vector analyzer, we can calculate the real and virtual part from permeability (μ', μ'') and dielectric constant (ε', ε'') of the material. Fig. 3 shows the interface design of electromagnetic wave absorption simulation program. The simulation code is based on the calculation expressions and equations related to the electromagnetic wave absorption characteristic of the nanocomposite system written under the Matlab programming language. In order to run the simulation program, we have to provide a set of five important input parameters:

frequency (f), the real part (ε', μ'), the virtual part (ε'', μ'') of the dielectric constant and the magnetic permeability of the material.

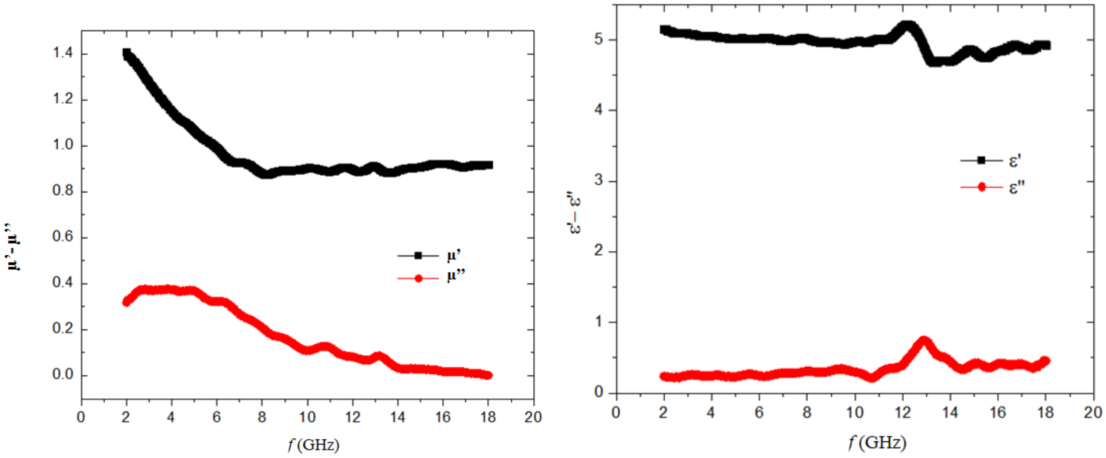


Fig. 4. The real part (μ', ε') and virtual part (μ'', ε'') of permiability and dielectric constant.

Figure 4 shows the dielectric constant and magnetic permeability of the composite material. In the frequency range of 8 - 18 GHz of typical sample with thickness $d = 2.6$ mm. Clearly, it can be seen that the real and virtual parts of the dielectric constant and the magnetic permeability depend on the frequency. The values change slightly, corresponding to different thickness of samples (not shown here). This is explained that it is difficult to control the uniformity of the magnetic particles in the composite during fabricating process.

III.3. The effect of thickness on the absorbance of the electromagnetic wave material of the material

The change in absorption loss (SE_A) and the reflective loss (SE_R) with different thicknesses (d) were obtained as the function of frequency (f) and angular frequency (w). In fact, the materials absorb electromagnetic waves when waves travel through them. The absorption ability of electromagnetic energy depends not only on absorption mechanisms but also on the characteristics of each material. For Fe_3O_4/paraffin composites, there exists three absorption mechanisms: dielectric heating (dielectric loss); magnetic heating (magnetic losses) due to electric dipole and spin polarized at high frequencies; and the energy transfer of the Foucault currents into heat (vortex energy). For these samples, the absorption occurs strongly in the frequency range of 12-15 GHz. Moreover, the sample thickness has direct effect on internal resistance and reflection loss as can be seen from Formula (2). Each sample has a maximum reflection loss at unique resonant frequency (listed in Tab.1). At resonant frequency, the total absorption loss is greatest (SE_T). As seen from Fig. 5, the sample with thickness d= 2.6 mm reached the maximum reflective loss of -13.6 dB at 13.9 GHz, correspondingly with almost 96.9% absorption efficiency. From the calculations above we can reveal that the thickness of the material is one of important factors affecting the electromagnetic wave absorption of the materials.

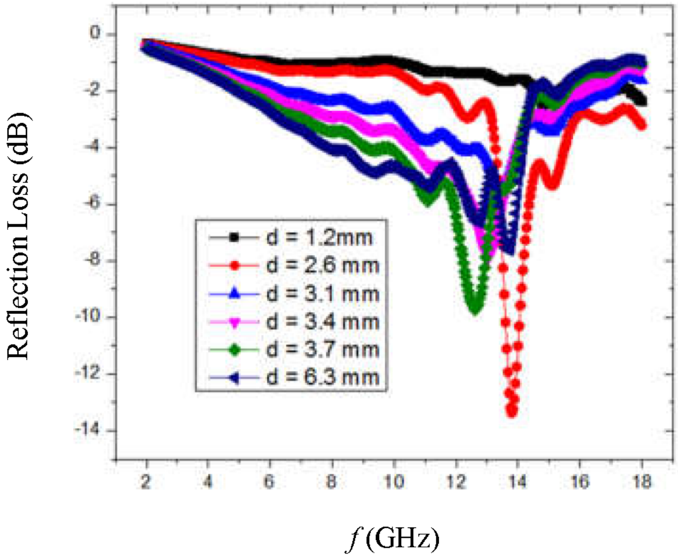


Fig. 5. Reflection loss of paraffin/Fe_3O_4 composite with different thicknesses.

Table 1. Maximum value of reflection loss measured at different thicknesses.

Thickness d (mm)	**Reflection Loss RL (dB)**	**Frequency f (GHz)**
1.2	- 21	15.0
2.6	- 13.6	139
3.1	- 52	134
3.4	- 78	13.0
3.7	- 98	12.3
6.3	- 7.2	13.5

IV. CONCLUSIONS

The composite electromagnetic wave absorbing materials containing Fe_3O_4 nanoparticles in a paraffin basis, with a weight mixture ratio of 35%/65% was successfully prepared. The microstructure, crystallographic structure and magnetic properties of the materials have been studied. The effect of thickness on absorption ability was investigated. The results show that with different thicknesses, the samples featured different absorption capacities. Accordingly, the proposed wide-band absorbent provided a reflection coefficient lower than -15 dB in a range from 12 to 15 GHz. The maximum reflection loss coefficient R_L = -13.6 dB was reached for a sample with a thickness

$d = 2.6$ mm. This result is promising for development of wireless information devices working in a high frequency region. Based on these results, a further work is proposed for another composite material, such as dielectric oxides/magnetic oxides, dielectric oxides/magnetic alloys.

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