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Preparation and characterization of templated barium hexaferrite ($BaFe_{12}O_{19}$) nanoparticles and investigation of its microwave absorption properties by silicone rubber matrix at x-band frequency

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Recently, barium ferrite nanoparticles have attracted substantial attention because of widespread applications in catalytic degradations, credit cards, storage hardware, sensors, microwave devices, permanent magnets, high frequency devices, photocatalyst, and etc. In this research, templated $BaFe_{12}O_{19}$ nanoparticles were prepared through the sol-gel method by use of cotton as a template in the sol step. Finally, templated nanoparticles were blended in the silicone rubber matrix and then prepared nanocomposite molded to investigate of microwave absorption properties at x-band frequency. Templated barium hexaferrite nanoparticles were characterized by Fourier transform infrared (FT-IR), diffuse reflection spectroscopy (DRS), vibrating sample magnetometer (VSM), field emission scanning electron microscopy (FE-SEM), X-ray diffraction (XRD), and microwave absorption characteristics were obtained by vector network analyzer (VNA). Microwave absorption curves showed that templated $BaFe_{12}O_{19}$/silicone rubber nanocomposite absorbed 65.80% of microwaves at 9.87 GHz.

Keyword: Barium hexaferrite $BaFe_{12}O_{19}$, Microwave absorption, Silicone rubber, Cotton

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Introduction

The issue of fighting against electromagnetic disturbance involves a significant technical aspect exposed to a decrease in the electromagnetic interruption (EMI) which happens between electronic tools. Moreover, a very significant feature of protection against EMR is concerned with the health care of individuals who are in contact with the utensils giving off EMR and subjected to its extended impacts. Microwave protecting tools should possess particular qualities; as appropriate shielding effectiveness (SE), proper mechanical features, lightness, suitable processability, and cost-effective. This can be regarded as a ground breaking effort that shows the electromagnetic protecting efficiency of nanoferrite (magnetic material), extended graphite (Carbon material), and Polyaniline (conductive polymer) compound for industrial use (Electromagnetic Interference Shielding) that is adjustable with findings that are revealed experimentally [1].

Barium ferrite is a renowned inflexible magnetic material possessing great capacity of magnetization, outstanding chemical constancy, perfect coercivity, and anti-erosion features. Presently, a large part of ferrite films are prepared through the application of pulsed and spluttering processes of laser deposition. The ferrite films which are created through sol–gel method are not satisfactory. Sol–gel method can be considered as a type of possible process for film preparation, which owns positive points of simple components modifications, chemical consistency, low temperature of calcination, and suitable cost [2].

Carbon materials like graphene, graphite, carbon nanotubes with single- or multi-walls (SWCNTs, MWCNTs), expanded graphite (EG), conducting polymers, and carbon fibers are extensively used as EMW attracting materials because of their great conductivity, lightweight, high constancy and desired dielectric features. Metal materials like cobalt, iron, nickel, and their oxides and carbonyl iron powder possess appropriate magnetism ability and reveal acceptable magnetic loss compared to carbon materials. On the other hand, metal materials possess some shortcomings including undesired corrosion resistance, their heavy weight, and poor oxidation resistance; these shortcomings cause these materials to be inappropriate for missile, aircrafts and particular fields. Carbon and metal combinations have received a great attention to ensure exceptional EMW attraction ability [3].

Ferrites can be considered as a recognized class of magnetic materials that can be applied to numerous advanced fields of technology. Ferrites can be divided into three main groups including garnets, spinel, and hexagonal Ferrites. Hexagonal or the so-called M-type ferrites can be employed in permanent-magnet uses. Such ferrites include hexagonal composites of the common formula, i.e., $MFe_{12}O_{19}$, where M=Ba, Sr, or Pb. Furthermore, $BaFe_{12}O_{19}$ is often symbolized as M-type BaM; it has the lowermost price of magnetic energy and is utilized for many purposes including long-lasting magnets, special media used for magnetic record and microwave tools because of its outstanding physical and chemical features like great curie temperature, great magnetocrystalline anisotropy, perfect chemical stability, satisfactory mechanical hardness, great resistance against corrosion, and comparatively high saturation magnetization [4].

Along the c axis of the hexagonal structure, M-type barium ferrite or the $BaFe_{12}O_{19}$, BaM possess easy axis; further, the value of uniaxial magneto-crystalline anisotropy field (HA) is 17 kOe .This feature causes this material to be very eye-catching MMD magnetic material, particularly those working at the range of millimeter frequency [5].

Experimental procedure

Nanostructured barium hexaferrite powders were synthesized using the sol–gel combustion method. The starting materials were iron nitrate, barium nitrate, citric acid and ammonia, all of analytic purity. Appropriate amount of $Fe(NO_3)_3{\cdot}9H_2O$ and $Ba(NO_3)_2$, in a molar ratio of 12:1, were dissolved in a minimum amount of deionized water. Citric acid was then added into the prepared aqueous solution to chelate Ba^{2+} and Fe^{3+} in the solution, then sonicated for 20 min. The mixed solution was neutralized to pH 8 by adding liquor ammonia. The neutralized solution was evaporated to dryness by heating at 100 ℃ on a hot plate with continuous stirring. Templated $BaFe_{12}O_{19}$ nanoparticles were prepared through the sol-gel method by use of cotton as a template in the sol step. As water evaporated, the solution became viscous and finally formed a very viscous brown gel. Increasing the temperature up to about 300 ℃ led to the ignition of the gel. The dried gel burnt in a self-propagating combustion manner until all gels are completely burnt out to form a loose powder. Finally, the as-burnt powders were calcined in air at 1000 °C for 2 h with a heating rate of 10 °C/min to obtain barium hexaferrite nanoparticles. Templated nanoparticles were blended in the silicone rubber to ivstigation of microwave absorption properties.

Results and discussion

Phase identification

XRD pattern of templated $BaFe_{12}O_{19}$ was shown in the fig. 1. The result indicates that all the crystal planes of the templated $BaFe_{12}O_{19}$ correspond to the 00-007-0276 standard cart related to the crystal structure of barium hexaferrite. According to the XRD pattern the nanoparticles were fully calcined and no carbonic phase, relating to the citric acid and cotton template, was found in the pattern. Crystallite size of templated nanoparticles was 16.6 nm calculated by Scherrer equation [6].

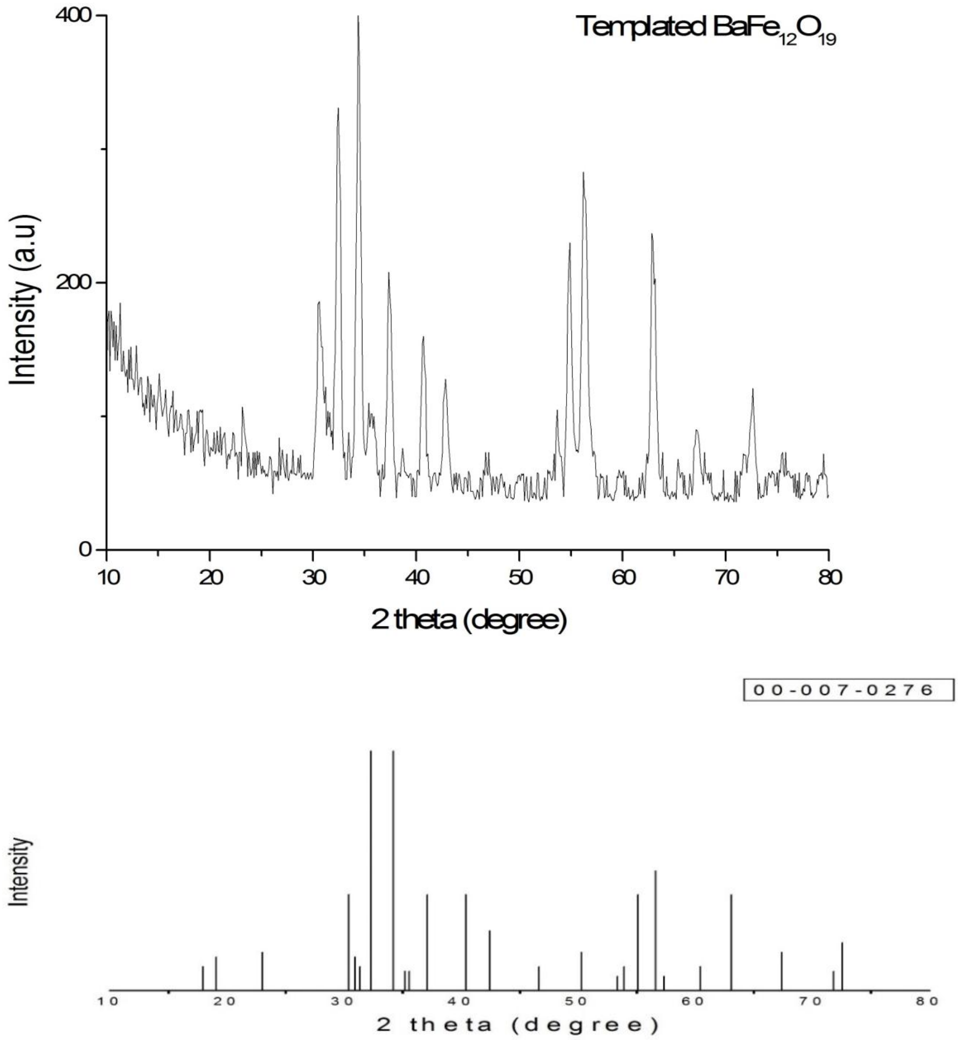

Fig. 1. XRD pattern of templated $BaFe_{12}O_{19}$ nanoparticles

FT-IR analysis

Chemical functional groups of template $BaFe_{12}O_{19}$ were characterized by FT-IR spectroscopy. According to the fig. 2, absorbing bands at 440.05, 600.25, and 1076.39 cm^{-1} are assigned to the octahedral, tetrahedral, and hexagonal positions of metal-oxide stretching vibrations. The peaks at 3600, 1532.51, and 1690.48 cm^{-1} are related to the O-H vibrations related to the adsorbed water. The peak at 2351.30 cm^{-1} is attributed to the adsorbed CO_2 on the surface of nanoparticles. FT-IR result of the templated nanoparticles showed that all the carbonic functional groups related to the precursors were eliminated.

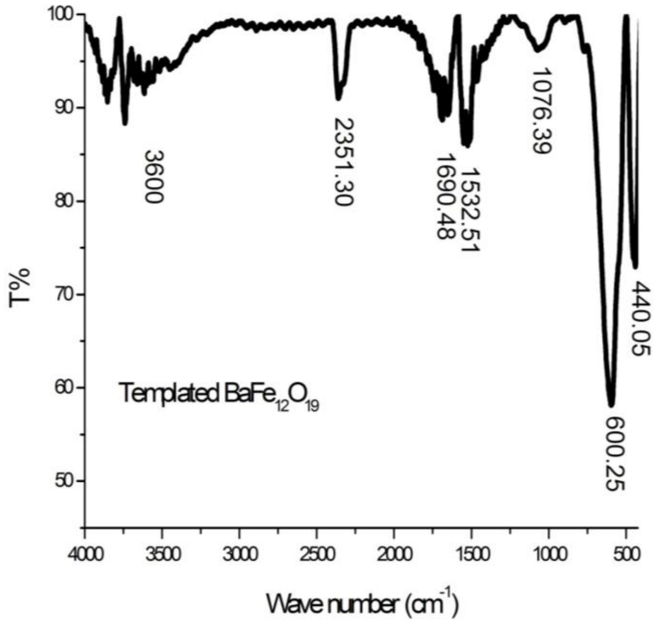

Fig. 2. FT-IR spectrum of templated $BaFe_{12}O_{19}$ nanoparticles

SEM images

SEM images of templated $BaFe_{12}O_{19}$ nanoparticles were shown in the fig. 3. The uniform structure of the nanoparticles and the elimination of the cotton matrix are confirmed by SEM images. According to the result, the majority of the textured nanoparticles have a rod shape with an average nanoparticle size of 55 nm.

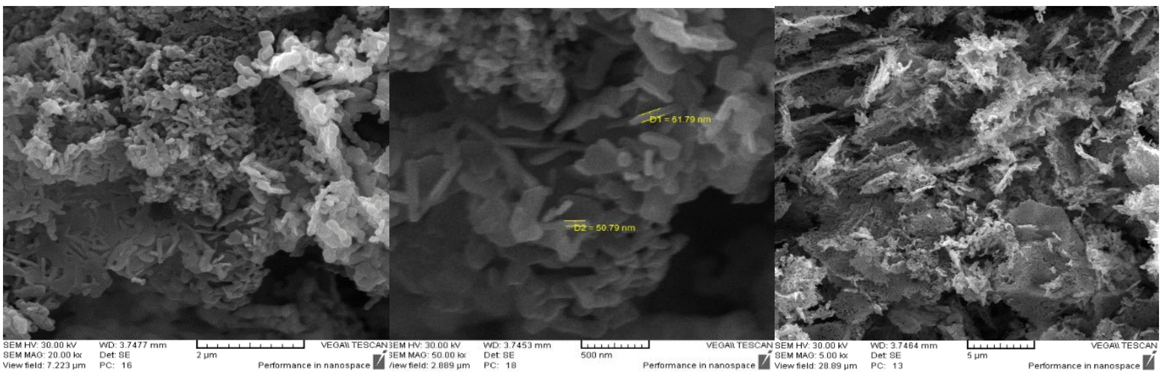

Fig. 3. SEM images of templated $BaFe_{12}O_{19}$ nanoparticles

Microwave absorption properties

Base on the transmission line theory complex permeability, complex permittivity, diameter of absorber, and frequency are the most effective factors in microwave properties of materials [7]. Barium hexaferrite as a hard magnetic material has magnetic properties desirable for complex permeability and silicone rubber as a dielectric polymer matrix is desirable for complex permittivity. In this research, templated nanoparticles were prepared by the sol-gel method allowing a reduction of the size of the nanoparticles and increasing the surface of the nanoparticles having an interaction with the polymer matrix, favoring the enhancement and the accumulation of the charges, and consequently the Maxwell-Wagner effect. [8]. Microwave absorption curve of templated $BaFe_{12}O_{19}$/silicone rubber nanocomposite was shown in the fig. 4. Microwave absorption curves exposed that templated $BaFe_{12}O_{19}$/silicone rubber nanocomposite has absorbed 65.80% of microwaves at 9.87 GHz.

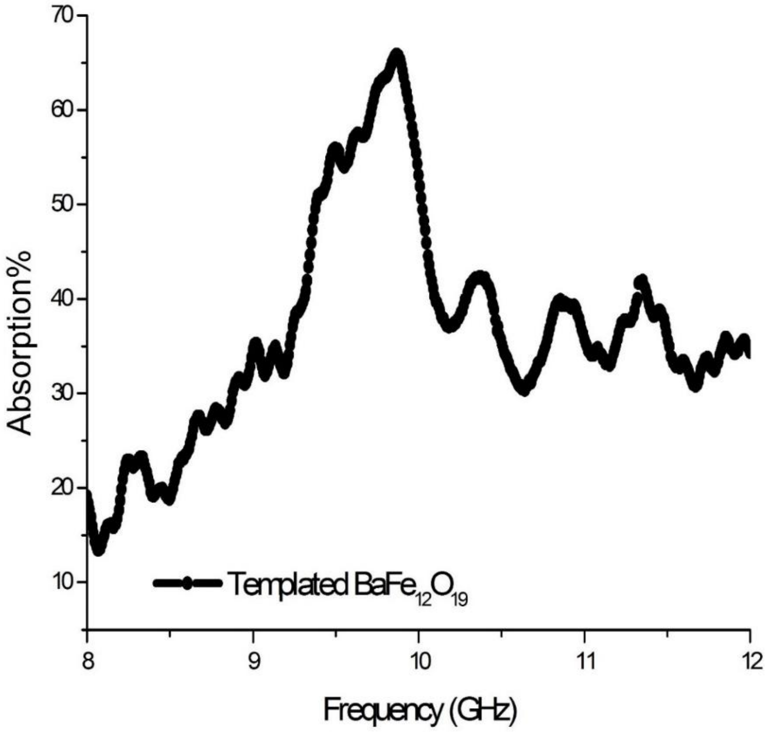

Fig. 4. Microwave absorption curve of templated $BaFe_{12}O_{19}$/silicone rubber nanocomposite

Conclusion

The obtained results confirmed that the nanometric particles of barium hexaferrite were successfully synthesized at a relatively low temperature through the sol–gel combustion method using of novel template. SEM images confirmed the uniform structure of the as prepared nanoparticles. According to the FT-IR spectrum all the carbon precursors and other impurities were fully calcined. Base on the XRD pattern, single-phase crystalline structure of barium hexaferrite was synthesized. Finally, VNA result showed that the templated $BaFe_{12}O_{19}$/silicone rubber nanocomposite has a microwave absorption equal to 65.80% at 9.87 GHz. Improving the interfacial polarization by decreasing size of nanoparticles through the use of natural organic template on one side, and the use of silicone rubber with dielectric properties as a polymeric matrix on the other hand could be the cause of microwave absorption properties of $BaFe_{12}O_{19}$/silicone rubber nanocomposite.

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