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Two step synthesis, electromagnetic and microwave absorbing properties of FeCo@C core–shell nanostructure

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ABSTRACT

In this research synthesis of FeCo@C core–shell nanoparticles was done using a novel two step process including the microemulsion technique and alcohol catalytic chemical vapor deposition. X-ray diffraction, transmission electron microscopy, electron beam diffraction and energy dispersive spectroscopy confirm the formation of FeCo@graphite core–shell nanostructure. Compared with FeCo nanoparticles with an oxide shell, the graphite shell restricts the growth of the FeCo nanoparticles, leading to lower saturation magnetization and higher natural-resonance frequency. The electromagnetic characteristics including permittivity, permeability and loss tangents of FeCo nanoparticles/nanoencapsulates were determined in the frequency range of 2–18 GHz. Results show that the graphite coating dramatically improves electromagnetic wave absorption of FeCo nanoparticles due to several dielectric/magnetic loss mechanisms. The main mechanism enhancing the dielectric loss tangent is Deby's dual relaxation phenomenon and for magnetic loss is the ferromagnetic resonance. The maximum reflection loss of −40 dB at 2.5 mm thickness and the maximum effective absorption bandwidth (RL < −20 dB) of 5.6 GHz at 3 mm thickness were obtained for FeCo nanoencapsulates.

1. Introduction

Core–shell nanoparticles have been the subject of intensive research due to their potential applications from electromagnetic wave absorption to biomedicine [1–7]. Due to rapid development of wireless technology it is necessary to develop advanced electromagnetic wave absorbers with light weight, strong absorption and wide range of working frequency. Soft ferromagnetic nanoparticles like (e.g. FeCo) are good candidates for this purpose because of their high saturation magnetization, higher snoek's limit and high permeability at frequencies in the gigahertz range [8–10]. There are various efforts using carbon as a non-magnetic highly dielectric material in various morphologies including nanoshells [5,9,11,12], nanofalkes [13], nanotubes [14,15] and nanofibers [16,17] along with soft ferromagnetic metallic nanomaterials to enhance the electromagnetic wave absorption capability. The main advantages of using hybrid dielectric-magnetic nanoscale materials are increasing the relative complex permeability and permittivity. Some mechanisms which promote complex permeability include suppression of eddy currents which results in reducing the backward reflections and increasing the magnetocrystalline anisotropy which influences the resonance frequency. Also various mechanisms like polarizations between magnetic and dielectric phases and natural electronic relaxation of the dielectric phase promote the complex permittivity [5,8–17].

There are several methods to synthesize carbon coated magnetic nanoparticles including arc discharge [12], hydrothermal [18], magnetron and ion-beam co-sputtering [19], laser pyrolysis of organometallic compounds [20] and spraying methods [21]. Many of these methods suffer from major drawbacks such as incomplete coating of carbon, poor efficiency of the graphite formation and incapability of controlling the size of nanoparticles.

In this research we have used a two step process including the synthesis of magnetic nanoparticle cores with microemulsion technique and then creating the carbon shell with the chemical vapor deposition (CVD) method as an efficient way to control the core size and shell thickness which enables the capability of tuning the electromagnetic properties of the material. In the first step the precipitation of nanoparticles takes place inside nanocages which called micelles. The micelle is in the form of sphere or cylinder of oil in water (normal micelle) or water in oil (reverse micelle) which is surrounded by a layer of surfactant molecules. The microemulsion method has the capability of controlling the shape, size and size distribution of nanoparticles [22]. For the second step alcohol catalytic chemical vapor deposition (ACCVD) was used as an economical method employing alcohol as the

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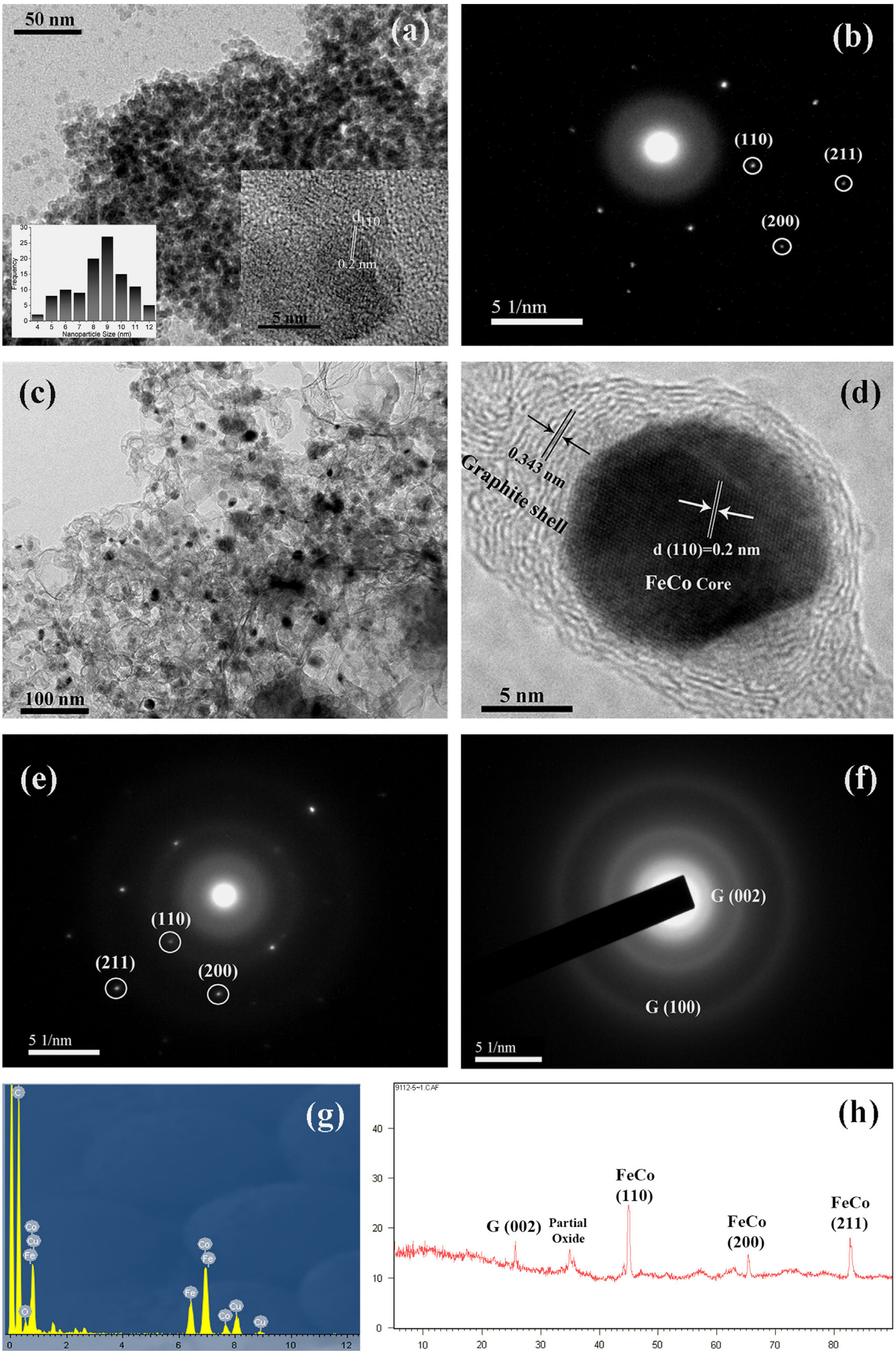

Fig. 1. (a) TEM and HRTEM (inset) of as-synthesized FeCo nanoparticles, (b) NBD of FeCo nanoparticles, (c) TEM image of FeCo@C core–shell nanostructure, (d) HRTEM of FeCo@C core–shell nanoparticle, (e) NBD of the core nanoparticle, (f) NBD of the graphite shell, (g) EDS spectrum of as-synthesized nanoencapsulates and (h) XRD pattern of FeCo@C powders.

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