

Preparation, surface modification and microwave characterization of magnetic iron fibers

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Abstract

In this paper, magnetic iron fibers of 3–10 μm diameter and an adjustable aspect ratio were synthesized successfully by a method involving pyrolysis of carbonyl under a magnetic field. A surface modification technology was also investigated. The electromagnetic parameters of the iron-fiber-wax composites were measured using the transmission/reflection coaxial line method in the microwave frequency range of 2–18 GHz. The results show that the prepared iron-fiber-wax composites exhibit high magnetic loss that can be further improved after phosphating. On the other hand, the complex permittivity was significantly decreased after phosphating. As a result, this kind of iron fiber may be useful for thin and lightweight radar-absorbing materials.

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1. Introduction

The application of radar-absorbing materials can reduce the radar cross-section of the target effectively, thus contributing to the stealthy defense system [1–3]. As a result, many research groups all over the world have been studying the preparation and the electromagnetic properties of absorbers. Up to now, the most commonly used absorbers are magnetic materials (such as ferrite particles) and dielectric materials (such as carbon black particles) [4–6]. However, the expansion of applications was limited due to their thickness and weight. Recently, some research has been devoted to the study of the electromagnetic properties of nonspherical magnetic materials [1,7–10]. Some kinds of metal fibers have been produced by bundle drawing, shatter machining, and melt extracting [11–15]. All these works show that they exhibit higher permeability and hence better absorption in the radar band. But all these

methods are not suitable for producing fibers with a diameter down to several micrometers, which can be detrimental to the further increase in the permeability according to the analysis in Ref. [9]. In this paper, a novel technology based on pyrolysis of carbonyl and the application of a magnetic field has been put forward to produce magnetic iron fibers. The magnetic iron fibers with diameter of 3–10 μm and an adjustable aspect ratio were prepared. Such a method proved to have the ability of large amount production. Furthermore, a surface modification technology was also adopted to improve the electromagnetic property and had been proved to be effective.

2. Experiments

2.1. Preparation technique

The assembled laboratory preparation set-up is shown in Fig. 1.

Liquid $\text{Fe}(\text{CO})_5$ is used as the source of the iron element. First, it is heated to 140 °C by an oil-bath and, hence is converted into $\text{Fe}(\text{CO})_5$ vapor. Then, the produced vapor is

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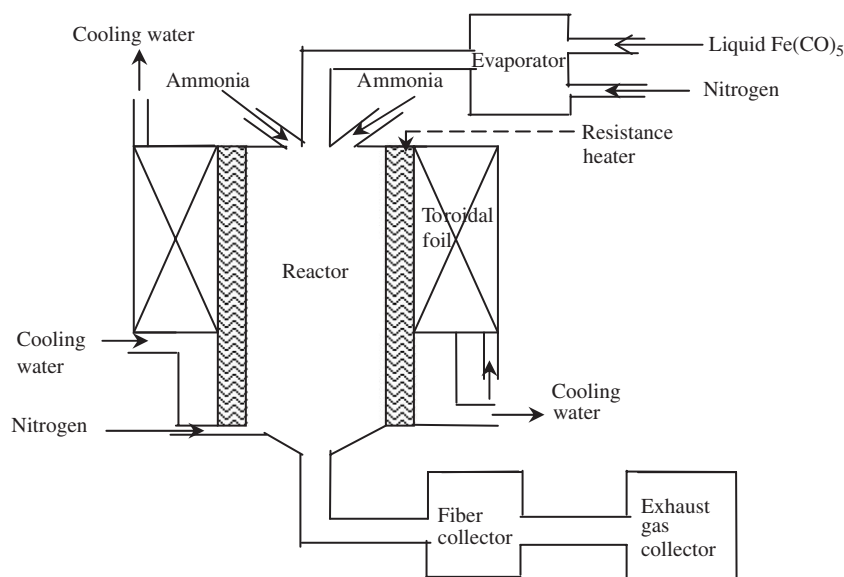
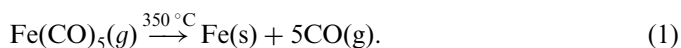


Fig. 1. The schematic diagram of iron fiber preparation set-up.

Table 1
Process parameters

Parameter	Value
Fe(CO) ₅ vapor flow	500 ml/h
Nitrogen flow	150 ml/h
Ammonia flow	150 ml/h
Magnetic field	11000 A/m
Actor temperature	350 °C

introduced into the reactor from the top using nitrogen as the carrier gas. Meanwhile, ammonia is also added into the reactor simultaneously through two different inlets lying in the top part, diluting the vapor and controlling the composition of the prepared fibers. The chamber temperature is raised to 350 °C by using the resistance heater arranged around the side wall. In this hot environment, the vapor decomposition takes place as shown in Eq. (1). After the agglomeration and nucleation stages, the formed iron elements adhere to one another under a constant magnetic field along the vertical axis of the reactor, which is provided by the toroidal coil. Finally, the chain-shaped magnetic iron fibers are produced. Some specific parameters used in the process are described in Table 1.



2.2. Surface modification technique

The complex permittivity of the fiber–wax composite sample presents a high value (both the values of ϵ' and ϵ'' higher than 100 at 2 GHz as discussed below), compared with those of other magnetic inclusions (ferrite, iron,

cobalt, permalloy, iron-coated multiwall carbon nanotubes, etc.), which are lower than 100 over the whole investigation band [16–18]. Too high values of ϵ' and ϵ'' may bring about the mismatch of normalized input impedance and reduce the absorption property in radar band [19]. Thus, a phosphating process technique is put forward to solve this problem. The treatment flow is shown schematically in Fig. 2. The solution used is mainly made up of sodium dihydrogen phosphate (NaH_2PO_4) and phosphorous acid (H_3PO_4) with concentrations 49.5 g/l and 2 ml/l, respectively, and the pH value of the solution controlled between 4 and 5. At the beginning of the process, the solution is heated to 28 °C, and then the fibers are added accompanied by solution agitation. After 1 min treatment, the fibers are extracted out of the solution by using magnetic separating technology and then dried in a vacuum.

2.3. Characterization techniques

The morphology of magnetic iron fibers was observed by Philips XL-30TMP scanning electron microscope (SEM). The transmission/reflection method was adopted to determine the relative complex permeability μ and permittivity ϵ of the magnetic material–wax composites using an HP8722ES vector network analyzer system [20]. The magnetic fillers were randomly dispersed in the wax with a different volume fraction. The cylindrical toroidal samples were fabricated. The samples were 3 mm in inner diameter, 7 mm in outer diameter, and 3–3.5 mm in thickness.

3. Results and discussion

Fig. 3 shows the SEM of the typical fibers prepared by the proposed technique. It can be seen from graphs (a) and

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