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Microwave electromagnetic properties of carbonyl iron particles and Si/C/N nano-powder filled epoxy-silicone coating

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ABSTRACT

The electromagnetic characteristics of carbonyl iron particles and Si/C/N nano-powder filled epoxy-silicone coatings were studied. The reflection loss of the coatings exceeds -10 dB at 8–18 GHz and -9 dB at 2–18 GHz when the coating thickness is 1 and 3 mm, respectively. The dielectric and magnetic absorbers filled coatings possess excellent microwave absorption, which could be attributed to the proper incorporate of the multi-polarization mechanisms as well as strong natural resonance. It is feasible to develop the thin and wideband microwave absorbing coatings using carbonyl iron particles and Si/C/N nano-powder.

1. Introduction

In recent years, electromagnetic waves in the 1–20 GHz range have been widely used in the wireless communications, high frequency circuit devices and other related fields. The study of microwave absorbing materials has been attracting much attention for electromagnetic interference (EMI) shielding and radar cross section (RCS) reduction applications with both commercial and defense purposes [1–3]. According to their lossy characteristic, the microwave absorbers can be categorized into magnetic and dielectric absorbers. Conventional magnetic absorbers, such as polycrystalline iron-fiber and ferrite particles, have been extensively studied, and some of them have been already applied in both military and civil fields [4–6], whereas some disadvantages limit their further applications. For example, the permeability spectrum of the magnetic absorbers is restricted by Snoek's limit which the permeability value below 5 in the GHz frequency range [7]. The dielectric absorbers utilize fillers like carbon black, multi-walled carbon nanotubes and Si/C/N nano-powder [8–11]. Compared to the magnetic fillers, the dielectric fillers are used to control the complex permittivity only. Furthermore, the impedance matching characteristic of dielectric dissipation materials, such as carbon fiber, is poor for the high permittivity and low permeability [12]. Many studies have been carried out to investigate the electromagnetic and microwave absorbing properties of magnetic or dielectric microwave absorber coatings by mixing rubbers or polymeric resins with spinel ferrites, hexagonal ferrites, metallic magnetic materials, carbon black and carbon nanofiber [8–15]. However, the single absorber cannot realize the low reflection with wideband microwave absorption.

According to the electromagnetic properties in previous work, the imaginary part of the complex permittivity of the carbonyl iron is almost low in the frequency range of 2–18 GHz, which resulted in the poor absorption in the high frequency [16–18]. Due to the Si/C/N nano-powder possesses good dielectric and microwave absorbing properties [19], the Si/C/N nano-powder was introduced into the carbonyl iron filled epoxy-silicone resin. The purpose of this study was to investigate the electromagnetic characteristics of carbonyl iron particles and Si/C/N nano-powder filled epoxy-silicone resin coatings, which match the natural resonance of carbonyl iron particles and the dielectric loss of Si/C/N nano-powder.

2. Experimental

Coatings with different fillers (coating A: 50 vol% carbonyl iron particles, coating B: 50 vol% carbonyl iron particles and 1 vol% Si/C/N nano-powder) were prepared to investigate the electromagnetic and microwave absorbing properties. The Si/C/N nano-powders used in this work were prepared from CH_3SiCl_3, NH_3, H_2 and N_2 by the chemical vapor deposition (CVD) method. The configuration, phase composition and dielectric properties of Si/C/N nano-powder have been described in our previous publication [19]. The carbonyl iron particles are thin flakes of 2–5 μm in diameter and blow 1 μm in thickness. The Si/C/N

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nano-powder was dispersed in the ethanol solution by an ultrasonic bath at room temperature for 1 h. After mixing the carbonyl iron particles into the ethanol-based solution, the suspensions were stirred for 10 min at 2000 rpm. Then, the mixtures were placed in an oven at 80 °C so that the ethanol could evaporate completely. After adding the resin and hardener, the mixtures were stirred at 2000 rpm for 10 min. The hybrid mixtures were precured at 90°C for 30 min and then postcured at 120 °C for 2 h.

The morphology of the coatings was observed using scanning electron microscopy (SEM) (Model JSM-6360, JEOL, Tokyo, Japan). The complex permittivity $\varepsilon(f)$ and permeability $\mu(f)$ of the coatings were measured by the T/R coaxial line method in the frequency range of 2–18 GHz using a network analyzer (Agilent technologies E8362B:10 MHz–20 GHz). The testing specimens have a cylindrical toroidal specimen of outer diameter of 7.0 mm, inner diameter of 3.03 mm and thickness of 2 mm.

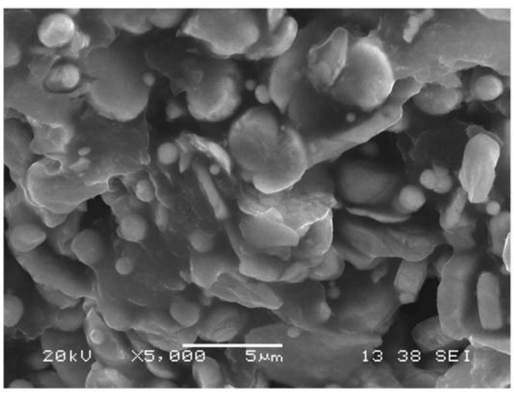

Fig. 1. SEM photograph of fracture surface of the Si/C/N nano-powder and carbonyl iron particles filled microwave absorbing coatings.

3. Results and discussion

The SEM photograph of fracture surface of the microwave absorbing coatings is shown in Fig. 1. It was found that the Si/C/N nano-powder and carbonyl iron particles were well dispersed in the epoxy-silicone resin matrix.

Fig. 2 shows the complex permittivity, dissipation factor and Cole–Cole semicircles of the Si/C/N nano-powder and carbonyl iron particles filled epoxy-silicone resin coatings, which represents the dielectric property of the coatings in this study. For the coating A, the real part permittivity (ε') is almost constant and the imaginary part permittivity (ε'') is negligibly small ($\varepsilon' \approx 10.1$ and $\varepsilon'' \approx 0.2$) in the frequency range of 2–18 GHz. Both ε' and ε'' of coating B with Si/C/N nano-powder are higher than those of coating A, as shown in Fig. 2a. It is clearly that the addition of a small amount (1 vol%) of Si/C/N nano-powder is an efficient way to enhance the complex permittivity. In the microwave frequency region, the complex permittivity of the resin coatings contained dielectric filler mainly due to a phenomenon known as Maxwell–Wagner polarization (the polarization occurs at the interfaces between the resin matrix and the dielectric absorber) [20,21]. It is understandable that the addition of Si/C/N nano-powder can obviously increased the absorber/resin matrix interfaces of the coating. Therefore, it is reasonable that the complex permittivity was enhanced which result from the increased of interfacial polarization. The coating B shows the visible frequency dependence of the real and imaginary parts of permittivity, the ε' and ε'' values declined from 18 to 10 and 13 to 4 with the frequency increased from 2 to 18 GHz, respectively. The dielectric loss factor was also found to increase with the addition of Si/C/N nano-powder according to the Fig. 2b. The result shows that the dielectric loss factor of coating B varies from 0.4 to 0.8 at the 2–18 GHz.

Conventionally, the permittivity can generally be represented by the Debye dipolar relaxation expression $(\varepsilon' - \varepsilon_\infty)^2 + (\varepsilon'')^2 = (\varepsilon_s - \varepsilon_\infty)^2$

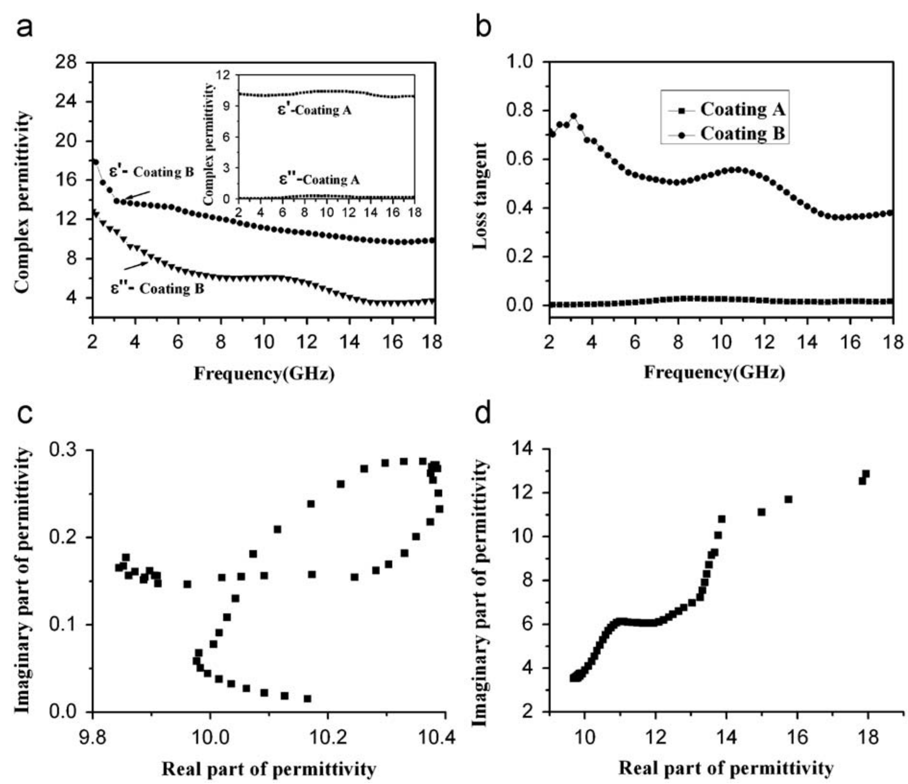

Fig. 2. The (a) complex permittivity, (b) dissipation factor and (c–d) typical Cole–Cole semicircles of the coatings A and B.