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Influence of Zn dispersion in SiC on electromagnetic wave absorption characteristics

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A B S T R A C T

Various materials have been developed for electromagnetic (EM) wave absorption; still, it is a challenge to develop absorbers to get better bandwidth with minimum thickness. To meet the challenge of developing EM wave absorbers with enhanced bandwidth for 8–18 GHz frequency range, in the present work, the effectiveness of metal particle dispersion in the dielectric matrix was studied in the frequency range of 2–18 GHz. For the same, Zn particles were dispersed in SiC. Zn dispersed SiC composites were prepared by dispersing various weight fractions of Zn particles in the SiC matrix using planetary ball mill. A comprehensive effort has been made to elucidate the probable mechanisms governing the characteristic changes in the EM wave absorption behavior of the composite using the concept of skin depth, interfacial polarization, impedance matching, multiple reflections and quarter wavelength destructive interference phenomena. The results indicated that the measured imaginary part of complex permittivity and dielectric loss tangent of Zn dispersed SiC composites exhibit higher value in comparison to pristine SiC. The reflection loss (RL) increases with Zn dispersion till certain loading fractions owing to the good reflecting property of Zn-metal particles and thereafter starts decreasing. Therefore, by changing the loading concentration of Zn particles in SiC, the best EM wave absorption state could be obtained in the 8–18 GHz frequency range. The maximum EM wave absorption behavior is realized for the 6 wt% (equivalent to 2.8 vol%) Zn-dispersion with minimum RL value of −49.45 dB at 15.64 GHz with a thickness of 1.7 mm and the bandwidth corresponding to −10 dB is 4.20 GHz.

1. Introduction

Today's era is manifested by the rapid development of the technological aspects such as radar systems, military aircrafts, surface warships and mammoth increase in the use of electronic gadgets around the globe [1,2]. Recently, there has been an increase in a number of applications of EM waves in the X-band and Ku-band for radar, military aircraft, and satellite communication and, consequently, much attention has been devoted to develop EM wave absorbing materials in 8–18 GHz frequency ranges. The technological explosion of the electronic gadgets in the military and the commercial sphere has paved the path for researchers to exploit new materials or smart combinations of existing materials. These EM wave absorbing materials/coatings should be designed to have the advantages of light-weight, thin thickness, wide absorption bandwidth and strong attenuation [3,4]. However, a single material cannot satisfy all the requirements and therefore, development of such materials is a challenging task. Such improved characteristics in an EM wave absorbing material can be achieved by combining dissimilar materials. Various materials such as carbonaceous materials [5,6], ferrite-based materials [7,8] and ceramic-based materials [9,10] have been used as EM wave absorbers.

Among the various ceramics, silicon carbide (SiC) has been extensively studied as an EM wave absorber. SiC is an important ceramic semiconductor with a wide band gap, good dielectric properties, high electron saturation velocity and high thermal conductivity, which makes it a very attractive dielectric candidate for EM wave absorption and high-temperature applications [10]. Much work has been carried out which depicts the use of SiC as an EM wave absorbing material. However, very few studies are reported to see the effect of metal particles loading concentration on the EM wave absorbing characteristics of the SiC-based absorber.

EM wave absorbing materials with dispersed metal particles

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have shown high EM wave absorbing capacity in comparison to their pristine EM wave absorbing counterparts. The improved EM wave absorbing capacity is attributed to dielectric relaxation and interface scattering induced by a large number of interfaces [11]. Also, the EM wave absorption behavior is influenced by the variation in particle size and dispersion concentration. According to the classical EM theory, the absorption properties of EM wave absorbers are highly dependent on the dielectric loss and magnetic loss [12]. The EM wave absorption of a material depends on its fundamental physical properties such as complex permittivity and complex permeability. For an effective EM wave absorber, by combining the characteristics of dielectric and metallic materials, the values of complex permittivity ($\mu_r = \mu' - i\mu''$) and complex permeability ($\varepsilon_r = \varepsilon' - i\varepsilon''$) could be tailored to achieve the objective.

In this article, an effort has been made to disperse fine metal particles in the dielectric medium for the development of cost-effective absorber with enhanced EM wave absorption. For the same, Zn metal particles were dispersed in SiC (with different loading concentration of Zn metal particles) which showed enhanced EM wave absorption as compared to the pristine system. An effort has also been made to elucidate the probable mechanisms governing the characteristic changes in the EM wave absorption behavior of the composite using the concept of skin depth, interfacial polarization, impedance matching, multiple reflections and quarter wavelength destructive interference phenomena.

2. Theoretical background

In this section, an effort has been made to identify the probable mechanisms involved in EM wave attenuation for metal particles dispersed dielectric system. The explanation is based on the concepts of skin depth (δ), interfacial polarization, multiple reflections, interface scatterings and quarter wavelength attenuation phenomena. The concept of EM wave absorbing materials arises from the fact that these materials absorb most of the incident EM energy and thus reflects weak EM signals as illustrated in Fig. 1.

The EM wave absorption behavior primarily depends on the dielectric properties of the absorber. The amount of EM wave absorption can be obtained by using the expression for reflection loss (RL) which is expressed by the following equations [13]:

$$RL = -20 \log |(Z_{in} - Z_o)/(Z_{in} + Z_o)| \quad (1)$$

$$Z_{in} = Z_o (\mu_r/\varepsilon_r)^{1/2} \tanh \{j.(2\pi f t_{cal}/c)(\mu_r.\varepsilon_r)^{1/2}\} \quad (2)$$

where, 'μ_r' and 'ε_r' are the complex permeability and complex permittivity of the absorber material respectively, 'f' is the working frequency, 't_{cal}' is the thickness of the absorber, 'c' is the velocity of light, 'Z_{in}' is the characteristic impedance of the absorber and 'Z_o' is the characteristic impedance of free space. It can be inferred from Eqs. (1) and (2) that the value of RL depends on the complex permittivity, complex permeability, thickness of absorber and working frequency. The large value of imaginary parts of the permittivity or permeability of a material at the microwave frequency aids to absorb the EM wave energy significantly. This is called EM Loss model [14].

Besides the major dielectric loss, the 'geometrical effects' or the 'quarter wavelength effect' also plays a vital role in the attenuation of the incident EM waves. Due to the quarter wavelength effect, destructive interference of EM waves occurs as a result of phase cancellation of EM waves. When the thickness of absorber satisfies the following Eq. (3), the reflected waves are totally canceled at the air-absorber interface representing the quarter wavelength effect [15–17].

$$t_{sim} = n\lambda/4 = [nc/4f_m\sqrt{(|\varepsilon_r\mu_r|)}]\ (n = 1,3,5,\ldots) \quad (3)$$

where, 'f_m' is the peak frequency of RL, 't_{sim}' is the simulated thickness of the sample, 'ε_r' and 'μ_r' are the complex permittivity and permeability at peak frequency and 'c' is the velocity of light.

According to free electron theory [18], the imaginary part of relative complex permittivity is expressed as:

$$\varepsilon'' = 1/(2\pi\varepsilon_o\rho f) \quad (4)$$

where, 'ρ' is the electrical resistivity and 'ε_o' is the permittivity of free space. It can be inferred from Eq. (4) that imaginary part of permittivity is affected by the resistivity of the composite. It is well-known fact that all metals have different resistivity and once these metals are dispersed in the dielectric matrix, the imaginary part of permittivity ε″ will change depending on the type and amount of dispersed metal, which will consequently affect RL (i.e. the EM wave absorption). The size of the dispersed metallic particle affects the skin depth and hence the EM wave absorption. The amount of EM wave absorbed depends significantly on the skin depth

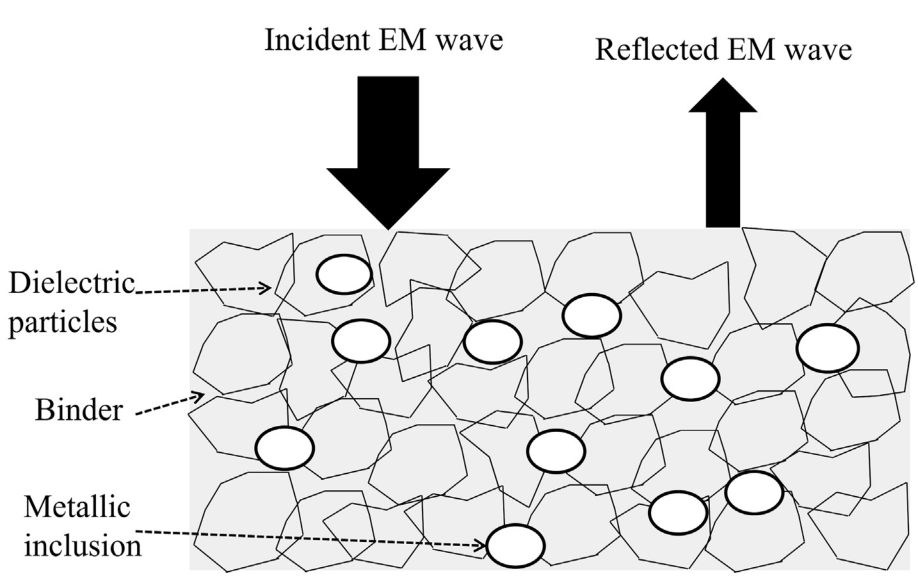

Fig. 1. Schematic representation of EM wave absorption.