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Double layer microwave absorber based on Cu dispersed SiC composites

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ABSTRACT

The present work has been focused on designing an efficient and cost-effective double layer microwave absorber in 8.2–12.4 GHz frequency range. For the same, Cu particles were dispersed in SiC to achieve enhanced microwave absorption by combining the excellent dielectric characteristics of SiC with highly conductive Cu. Cu dispersed SiC composites were prepared by dispersing various weight fractions of Cu particles in the SiC matrix using planetary ball mill. The Cu dispersion in SiC yielded excellent relative complex permittivity values translating into a decrease in the reflection loss (RL) values of dispersed composites as compared to the pristine counterpart. The minimum RL of -17.18 dB has been observed for 2 wt% Cu dispersed SiC composite at 11.81 GHz with a thickness of 1.3 mm and bandwidth corresponding to -10 dB is 1.77 GHz. Genetic algorithm approach has been implemented to design double layer microwave absorber to further enhance the microwave absorption of the prepared composites for realizing a cost-effective solution. The optimum double layer results show the RL of -32.16 dB at 11.05 GHz with 1.67 mm total thickness and bandwidth corresponding to -10 dB is 2.35 GHz.

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1. Introduction

In recent years, there has been an astronomical development in the use of microwave operated electronic devices in the commercial, communication and defense sectors. These devices use electromagnetic radiation and therefore, electromagnetic radiation pollution is becoming a serious problem. These increasing problems create the need for the development of effective ways to protect information security and human health. The growing need for microwave absorbing materials requires effective and cost-effective solutions for both defense and civilian fields. Microwave absorbing materials impart stealth features which increase the possibility of survivability of the military equipment in the advent of any war. Apart from instilling stealth features to the military equipment, microwave absorbing materials also plays a significant role in suppressing the problem of electromagnetic interference (EMI) problem in this technology-driven era. EMI not only disrupts the proper functioning of electronic gadgets by interfering with the electronic circuitry but also acts as a source for hazardous health implications to human and other biological systems from chronic exposures to microwave radiations [1,2]. In response to the need,

much attention has been focused on tailoring the structural parameters of the microwave absorbers to achieve enhanced microwave absorbing properties. The importance of microwave absorbing materials has significantly drawn the keen attention of the researchers to develop new materials and techniques for achieving enhanced microwave absorption [3–6]. Many studies have been carried out to study the effect of metal particles in the ceramic matrix for achieving enhanced microwave absorption performance. Y. Liu et al. [7] fabricated $\text{Ti}_3\text{SiC}_2/\text{nano Cu}/\text{epoxy resin}$ coatings with various percentage of nano Cu. The coating containing 20 wt% nano Cu achieved a minimum RL of -37 dB with 2.8 GHz bandwidth corresponding to -10 dB at 1.8 mm thickness. X.L. Su et al. [8] synthesized Cu doped SiC nanopowders via combustion synthesis. The 5 wt% Cu doped SiC composite achieved a minimum RL of -30 dB with 2.14 GHz bandwidth corresponding to -10 dB at 2 mm thickness. X. Su et al. [9] showed that the microwave absorption properties of SiC and Fe solid solution powder is influenced by the reaction time. The minimum RL value was observed for 30 min reaction time. The minimum RL value obtained was around -27 dB with 2 GHz -10 dB bandwidth at 2.1 mm thickness. J. Yuan et al. [10] developed Ni decorated SiC for achieving enhanced microwave absorption at high temperatures. J. Kuang et al. [11] studied the effect of Fe doping on the microwave absorption characteristics of SiC whiskers. The Fe doping improved the microwave absorption

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of SiC whiskers. The minimum RL value obtained was -21.2 dB with 2.6 GHz -10 dB bandwidth at 2 mm thickness. H. Wang et al. [12] investigated the microwave absorption property of SiC/Co hybrid composites in 2 – 18 GHz frequency range. The minimum RL value obtained was -25 dB with 6.6 GHz -10 dB bandwidth at 2.1 – 2.5 mm thickness. However, single layer absorbers are mostly faced with limitations such as narrow absorption bandwidth and large absorber thickness which limits their use in stealth applications [13]. Moreover, due to impedance mismatch, single layer microwave absorbers are limited to definite microwave absorption and hence, cannot satisfy the requisites for enhanced microwave absorption. These limitations have led to the advent of multi-layering approach, which is an important tool to produce microwave absorbers with enhanced microwave absorption. The increase in the number of boundaries and interfaces due to multi-layering cause multiple scatterings and reflections [14,15]. This also increases the electrical path traversed and the probability of phase cancellation leading to enhancement in microwave absorption. Besides this, Maxwell-Wagner polarization occurs at the interfaces of the heterogeneous media due to the entrapment of the charge carriers leading to enhanced microwave absorption [16]. Various phenomenon such as multiple scatterings, multiple reflections, phase cancellations, interfacial polarization induced capacitive behavior direct the microwave absorption performance of a multi-layered microwave absorber as depicted in Fig. 1.

In the present work, Cu metal particles were dispersed in SiC for combining the excellent dielectric behavior of SiC with conductive Cu particles for generating enhanced interfacial polarization which culminates into the enhancement of complex permittivity values. Cu particles in various loading fractions were dispersed in SiC using ball mill which is cost effective and easy-bulk production method. Microwave absorption performance of developed Cu dispersed SiC composites has been studied in 8.2 – 12.4 GHz frequency range. For further enhancement in microwave absorption performance, Genetic Algorithm assisted multi-layering approach has been employed to develop double layer Cu dispersed SiC microwave absorber.

2. Experimental

2.1. Materials

The precursors used for the development of Cu dispersed SiC composites were copper metal particles (Alpha Aesar, mesh size:

325 , 99% purity), silicon carbide (Sigma Aldrich, mesh size: 200 – 325) and toluene (Merck, India). All the materials were used as received without further purification.

2.2. Synthesis of Cu dispersed SiC composites

Cu dispersed SiC composites were developed using a planetary ball mill (Retsch PM 100, Germany) using steel jar and steel balls at 300 rpm for 10 h. The milling operations were carried out at room temperature with the ball to powder ratio (BPR) of $10:1$ in the toluene medium to protect composites from the environment. The Cu particles were dispersed in different weight fractions viz. 2 , 4 , 6 , 8 and 10% in the SiC matrix and the developed composites are represented as SC 2, SC 4, SC 6, SC 8 and SC 10 respectively. Sample code SC 0 represents as-received SiC.

2.3. Characterization

X-ray diffraction (XRD) phase analysis of the powder samples was carried out using Rigaku Smartlab diffractometer with Cu-K α radiation ($\lambda = 1.5406$ Å). The intensities of all the diffracted beams were recorded against diffraction angle (2θ) for all the samples. Scanning electron microscopy (SEM) was used to study the particle morphology using Zeiss EVO18. The magnetic properties of the dispersed samples were determined using vibrating sample magnetometer (VSM, Versha Lab). Vector Network Analyzer (Agilent N5222 PNA series) was used to determine the relative complex permittivity and permeability values of prepared samples at room temperature. The dispersed composites (80 wt%) were uniformly mixed with epoxy resin (20 wt%) and cast into rectangular pellets with 10.16 mm $\times$ 22.86 mm for dielectric measurements.

3. Results and discussion

3.1. Phase analysis

The indexed XRD patterns of Cu dispersed SiC powder samples SC 0, SC 2, SC 4, SC 6, SC 8 and SC 10 are shown in Fig. 2. The XRD peaks of sample SC 0 correspond to SiC (ICSD collection code: 27051). The XRD patterns reveal that with the increase in Cu dispersion, the intensity of the peak corresponding to Cu increases (ICSD collection code for Cu: 53756). XRD pattern of ball-milled samples also features peak of iron ($2\theta = 44.57^\circ$) as an impurity, which corresponds to α -Fe (ICSD collection code: 631729). The

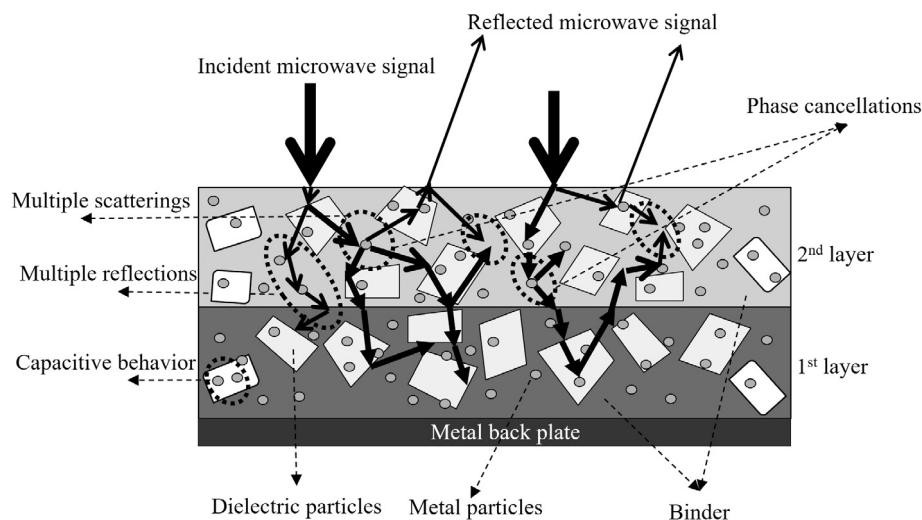


Fig. 1. Schematic representation of microwave interactions in metal dispersed dielectric composites based double layer absorbers.

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