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A new triple-layered composite for high-performance broadband microwave absorption

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ABSTRACT

We report a novel, triple-layered composite composed of multi-walled nanotubes (MWNTs) dispersed in an epoxy/cotton fabric resistive layer that is sandwiched between two MWNT-dispersed E-glass fiber/epoxy dielectric absorbing layers. This structure efficiently absorbs microwave radiation over a frequency range of 2–18 GHz. This layered, composite structure is thin relative to previously developed, multi-layer systems with a resistive layer/low dielectric layer/resistive layer/low-dielectric layer structure. The paper-like resistive layer facilitates broadband microwave absorption by matching the impedance between the two absorbing layers. The E-glass fiber/epoxy laminate composites provide structural and mechanical support. The conductive MWNT filler controls dielectric losses through the formation of a network that allows high complex permittivity at low concentrations. Free-space measurements showed that the resulting triple-layered structure boasts an outstandingly broad bandwidth of reflection loss below −10 dB from 4.7 to 13.7 GHz. This new multi-layer structure offers a promising solution for attenuating electromagnetic waves over broad frequency ranges.

1. Introduction

Microwave absorbers have attracted considerable attention in recent years due to their potential applications in stealth, electromagnetic interference shielding, and telecommunications [1–3]. It is important that microwave-absorbing materials be applicable to broadband frequencies while being adaptable to the form factor of the shielded object. In addition, they should be mechanically strong and environmentally stable without significantly increasing the weight of the shielded object [4]. Although conventional magnetic materials containing magnetic fillers such as ferrite [2,5–7] and carbonyl iron [8] are excellent microwave absorbers, through the conversion of microwave energy to heat through the rotation of magnetic dipoles, they generally require a high loading of ferric material and are consequently heavy. Conversely, dielectric absorbers, which dissipate electromagnetic energy through Ohmic loss and the transfer of energy to free electrons, are relatively lightweight. Carbon black [9], conducting polymer [10–12], and carbon nanotubes (CNTs) [13,14] are commonly used as conducting, dielectric fillers and can be added to a polymer matrix to create composite materials for microwave absorption.

Recently, multi-layered composite structures have been used to create materials with broadband microwave absorbing performance. These materials are generally fabricated using two approaches: (i) periodically stacking absorbing layers to absorb a broad frequency range of incident electromagnetic (EM) waves, and (ii) the use of low dielectric spacers sandwiched between multiple resistive layers. Double layers composed of two absorbing layers, such as multi-walled carbon nanotube (MWNT)-filled glass/epoxy composites absorbers [15] and metal-doped, MWNT-filled polyvinylchloride (PVC) [16], absorb to below −10 dB over 2–5 GHz of bandwidth. Multilayers composed of graphite, fullerene, carbon nanofibers (CNFs), single-walled carbon nanotubes (SWNTs), MWNT-filled epoxy composites [17], and gradient multilayer structures of CNT/SiO_2 [18], can extend the absorbance range of these materials over the X-band (8.2–12.4 GHz). This is because the multi-layered structure provides multiple resonance peaks at each frequency. The number of resonance peaks at each frequency is equal to the number of absorbing layers.

The bandwidth of microwave absorption can also be increased by introducing low dielectric spacers between multiple resistive layers. A multi-layered structure containing a low dielectric spacer (poly(ethyleneterephthalate) (PET)) between two absorbing layers (polyaniline (PANi)) exhibited a reflection loss below −10 dB over a bandwidth of approximately 2.5 GHz [19]. Multilayers made of

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poly(ethylene oxide) (PEO) sandwiched between two resistive layers of silver and polyanilinetetrafluoroborate (PANi:HBF_4) exhibited a reflection loss below −10 dB from 7 to 16 GHz [20]. The enhanced reflection losses of these multi-layered absorbing structures are due to a gradual decrease in impedance and phase cancelation through the resistive layers and the quarter-wave-length thickness of the low dielectric spacer. Despite significant enhancements in absorption bandwidth, the thickness of these multi-layer materials often limits their use in military and industrial environments. Therefore, the development of thin, broadband microwave absorbers is highly desirable.

This report describes the construction of a triple-layered composite structure consisting of a thin resistive layer (layer 2) sandwiched between two different dielectric absorbing layers (layer 1 and layer 3). We demonstrate that the resistive layer (MWNT-filled cotton fabric/epoxy resin) plays an important role in impedance matching between the two absorbing layers (MWNT-filled E-glass fiber/epoxy resin), resulting in broadband microwave absorption. In addition, the MWNT-filled E-glass fiber/epoxy laminate acts as a structural material and boasts excellent mechanical properties. Theoretical and experimental results show that broadband microwave absorption is significantly enhanced by controlling the sheet resistance of the resistive layer and the permittivities of the two absorbing layers. Optimizing these parameters resulted in a material with an outstanding broad bandwidth of reflection loss below −10 dB from 4.7 to 13.7 GHz. Thus, the triple-layered structure described herein offers a promising means of attenuating EM waves over broad frequency ranges.

2. Experimental

2.1. Materials and preparation

Our triple-layered, microwave-absorbing composite consists of a resistive layer (layer 2) and two absorbing layers (layer 1 and layer 3) as shown in Fig. 1(a). MWNT-filled cotton fabric/epoxy resin was used as resistive layer 2 and was sandwiched between MWNT filled E-glass fiber/epoxy resin layers 1 and 3. The multi-layered composite structure was fabricated according to the scheme shown in Fig. 1(b). Both the E-glass/epoxy laminate and cotton fabric/epoxy composites were made with various MWNT concentrations. For layers 1 and 3, MWNTs (CM-250, Hanwha Nanotech Co., Ltd., outer diameter: 10–15 nm, length: 100–200 μm, purity: 95%) were dispersed in an epoxy resin and acetone at loadings of 0.15 and 0.5 wt.%, respectively, by sonication (42 kHz, 135 W) for 1 h at room temperature. Liquid epoxy resin (232 g, (YD-115, Kukdo Chemical Co., Ltd., viscosity: 700–1100 cps at 25 °C)) was added to the pre-dispersed MWNT solution. Acetone was removed from the MWNT/epoxy resin solution by heating to 60 °C. Viscous polyamide curing agent (88 g, (G-0240, Kukdo Chemical Co., Ltd., viscosity: 1500–3000 cps at 25 °C)) was then added to the MWNT/epoxy resin and the resulting mixture was dispersed by three-roll milling. The

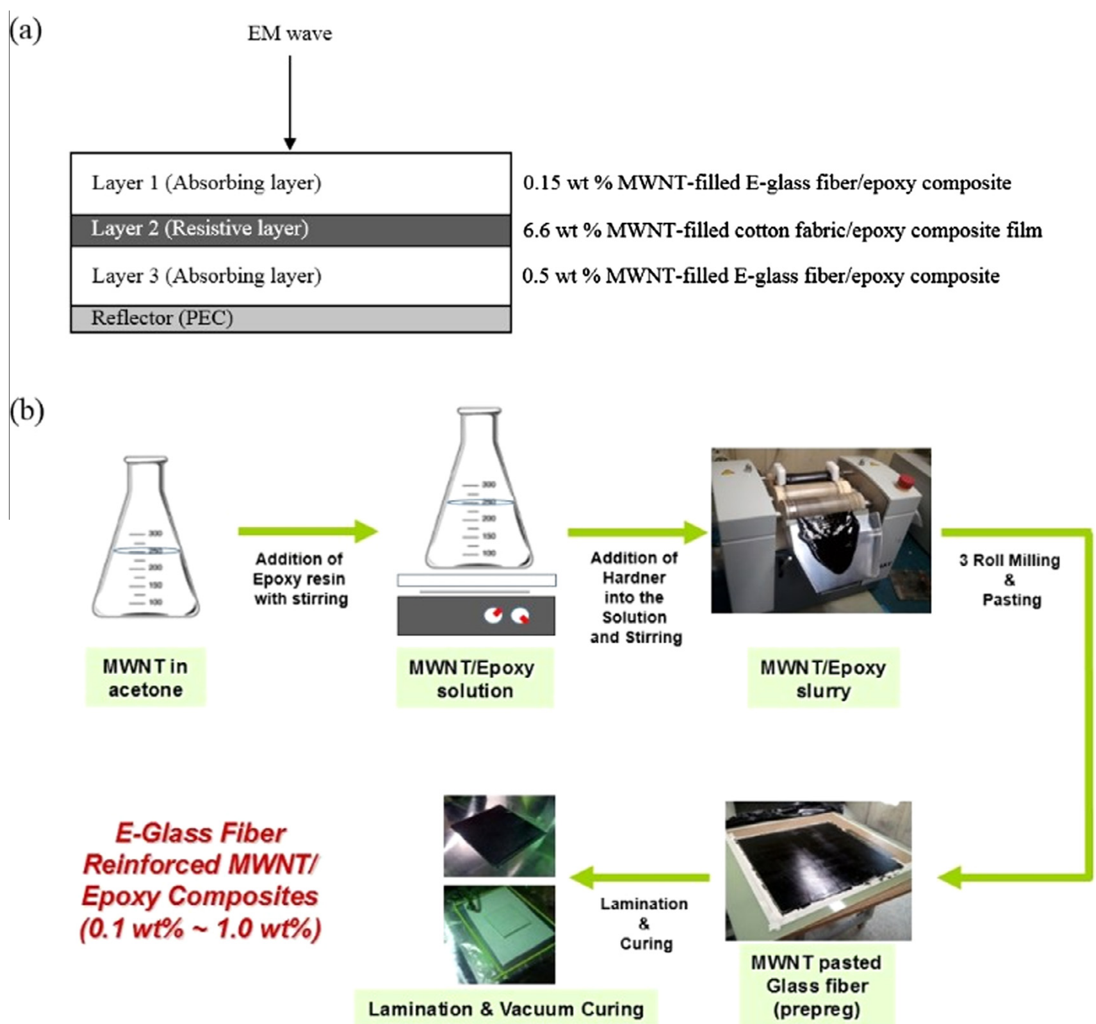

Fig. 1. (a) The architecture of the designed triple-layered, microwave-absorbing composite, (b) the fabrication scheme used to create the structure.