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Enhanced broadband microwave reflection loss of multiwalled carbon nanotubes (MWCNTs)/bismuth ferrite hybrid composites

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ABSTRACT

The accelerated growth of high-frequency electronic devices has increased concerns over electromagnetic interference (EMI), generating a strong need for lightweight and broadband electromagnetic (EM) absorbing materials. Bismuth ferrite ($BiFeO_3$, BFO) is a multiferroic material for EM absorption due to its coupled ferroelectric and antiferromagnetic properties. However, its performance is constrained by high leakage current, large dielectric loss, narrow absorption bandwidth, and the need for high filler loading in composite systems. To address these challenges, this study introduces a hybridization approach by combining BFO with multiwalled carbon nanotubes (MWCNTs) to improve dielectric–magnetic balance and enhance EM attenuation. MWCNTs were synthesized using BFO nanoparticles as catalysts and ethanol as the carbon source via a chemical vapor deposition (CVD) method. The resulting MWCNTs–BFO hybrid powders were incorporated into an epoxy matrix at low filler content and characterized for their microwave absorption properties in the 8–18 GHz frequency range. The hybrid system demonstrated a strong synergistic effect, leading to enhanced dielectric loss, improved impedance matching, and efficient multi-scattering attenuation. The MWCNTs-BFO/epoxy composite achieved more than 99% microwave absorption with an effective bandwidth of 4.6 GHz using only 4 *wt%* filler. These results confirm that MWCNTs–BFO hybrids offer a promising pathway for developing next-generation, lightweight, and high-performance microwave absorbing materials.

1. Introduction

The accelerated growth of high-frequency communication systems, radar technologies and wireless electronics devices has increased concerns about electromagnetic interference (EMI) and unwanted electromagnetic (EM) radiation. Continuous excessive EM exposure can degrade device performance, interrupt communication signals, and pose potential long-term risks to human health [1,2]. Consequently, the development of advanced EM wave absorbing materials with strong attenuation capability, lightweight characteristics, thin in thickness, and broadband operating frequency has become a critical research area [3–5]. However, achieving all these requirements simultaneously remains a major challenge. Extensive research has therefore focused on designing materials capable of meeting these criteria, leading to the development of various absorbers for effective EM wave attenuation [6,7].

The EM absorption performance of absorber material is strongly influenced by their dielectric and magnetic responses, which are described by the complex permittivity ($\varepsilon^* = \varepsilon' - j\varepsilon''$) and permeability ($\mu^* = \mu' - j\mu''$). The real parts indicate the material's ability to store EM energy, whereas the imaginary parts reflect energy dissipation through processes such as conductive and resonance losses [8]. Achieving efficient absorption requires a proper balance between dielectric and magnetic loss components to ensure good impedance matching. To enhance absorption capability, researchers have investigated several approaches, including combining different types of absorbers, designing multilayer architectures, and chemically modifying absorbent materials [9–11]. However, developing lightweight materials that provide broad

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