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A high-temperature radar absorbing structure: Design, fabrication, and characterization

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ABSTRACT

In this investigation, a new sandwich structure called the SiC_f/SiC sandwich radar absorbing structure (SRAS) for high-temperature radar absorption was designed using SiC_f/SiC composites. Samples with the base design and optimized design were then fabricated through the PIP process, and the free space reflectivity was measured. The experimental result agrees with the calculated result, exhibiting excellent absorbing properties. The high-temperature reflectivity of the SiC_f/SiC SRAS was also measured and the variation with temperature is found to be in a small range, indicating excellent absorbing properties at elevated temperatures. The factors determining the variation of reflectivity with temperature were also investigated, and the sheet resistance of the SiC fiber fabrics (particularly, the resistance characteristics of the pyrocarbon layer of the SiC fiber has a negative temperature coefficient) used as the lossy layer in the SRAS is found to be primarily responsible for the thermal variation of reflectivity.

1. Introduction

Stealth, or low observable, technology, as one of the main electronic countermeasures to make aircrafts, ships, helicopters, missiles, and other military hardware less detectable, has attracted much attention all over the world [1]. The objective of stealth technology is to reduce the cross section of targets detected by radar to a level that they become undetectable by radar receivers, thus improving the mission success rate and also the survival rate of the military vehicles in hostile territories. Usually, stealth techniques can be divided into two categories: (1) optimizing the shape of the body so that incident electromagnetic waves can be scattered, yielding the minimum reflective wave, although the aerodynamic performance may be deteriorate; (2) using radar absorbers, including radar absorbing materials (RAMs) and/or radar absorbing structures (RASs), which aim to minimize the reflected wave by absorbing the incident EM energy and dissipating it into heat [2,3].

Generally, RAMs are fabricated in coatings composed of insulating polymer and lossy materials such as ferrites, permalloys, carbon black and carbon nanotubes [4–6], while RASs are composed of fiber-reinforced polymeric composites and lossy fillers in the matrix [7–9]. These radar absorbers (RAMs and RASs) have good absorbing performance in low-temperature environments. However, with the development of new-generation military aircrafts, especially the supersonic cruise missiles and the fighters of high Mach numbers, ideal radar absorbers should feature not only low density, favorable mechanical properties, and strong radar absorbing properties over a wide frequency range, but also good performance in high-temperature environments resulting from aerodynamic heating.

SiC_f/SiC composites possess superior properties, such as high strength and oxidation resistance at elevated temperatures, and microstructural stability under neutron irradiation. Owing to these advantages, SiC_f/SiC composites are known as one of the most promising materials for structural applications at elevated temperatures [10]. In addition, their excellent semiconductivity and relatively stable dielectric properties at elevated temperatures, are also demonstrated in high temperature microwave absorption [11,12].

In this paper, SiC_f/SiC composites were used in a sandwich structure designed for high-temperature radar absorbing application. The designed SiC_f/SiC sandwich radar absorbing structure (SRAS) can realize wideband radar absorption in relatively small thickness. More importantly, the SiC_f/SiC SRAS has excellent absorbing properties not only at the room temperature but also at elevated temperatures.

2. Design methods and experiments

2.1. Design of the SRAS

The idea of SRAS is derived from the Salisbury absorbers, which consist of the dielectric layer I, dielectric layer II, lossy layer, and reflective layer, as shown in the schematic diagram in Fig. 1. The

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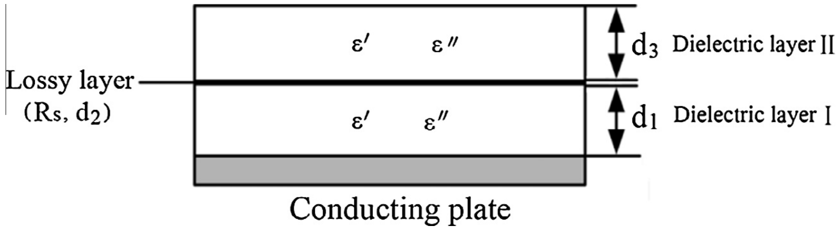

Fig. 1. Schematic diagram of SRAS.

dielectric layer I and II are made of the same materials. *In SRAS, an additional dielectric layer is introduced on top of the Salisbury absorbers. One purpose is to realize impedance matching and broaden the radar absorbing bandwidth of the absorber, and the second purpose is to avoid oxidation occurred to the lossy layer in high-temperature applications.*

The absorbing mechanism of the proposed SRAS is explained with its impedance characteristics. Fig. 2 shows the frequency dependence of the normalized complex impedance of Dielectric layer I (Fig. 2a), Dielectric layer I and Lossy layer (Fig. 2(b)), and the SRAS (Fig. 2c), derived from the reflection and transmission responses (the transmission is zero because of the backed metal). These functions are also shown in the Smith chart (Fig. 2d), where curve 1 corresponds to DI, curve 2 to DI + L, and curve 3 to SRAS (DI + L + DII). Fig. 2a and b shows that at the matching frequency f_m, the imaginary part of Z_I and Z_{I+L} vanish, but their real parts are close to the maximum, thus the reflection coefficient is low at this frequency. Deviation to either side from f_m leads to small variation in the real part of the impedance; however, the absolute value of the imaginary part $|\mathrm{Im}\, Z|$ rapidly increases, thus leading to the increase of the reflection coefficient [13]. An additional dielectric layer in the sandwich structure can keep the imaginary part of the impedance to be approximately zero in a wide frequency range (Fig. 2c), as the imaginary parts of Z_{II} and Z_{I+L} have opposite signs and compensate each other in addition [14]. As a result, the bandwidth of absorption of the SRAS increases, and the reflection coefficient- frequency curve has a double-hump shape [13].

2.2. Numerical optimization of radar absorbing properties of SRAS

Normally, it is rather difficult to study the absorbing properties of multilayer radar absorbers with a single experimental method because of their complex structures and large number of alterable parameters. Therefore, numerical optimization, model actualization, and experimental validation are combined to optimize the design. Numerical optimization of radar absorbing properties of the RASs was extensively investigated in [15–17]. The numerical optimization is basically a minimization procedure which seeks the best tradeoff between the thickness of absorber (to be minimized) and the absorbed EM power (to be maximized). The absorbed

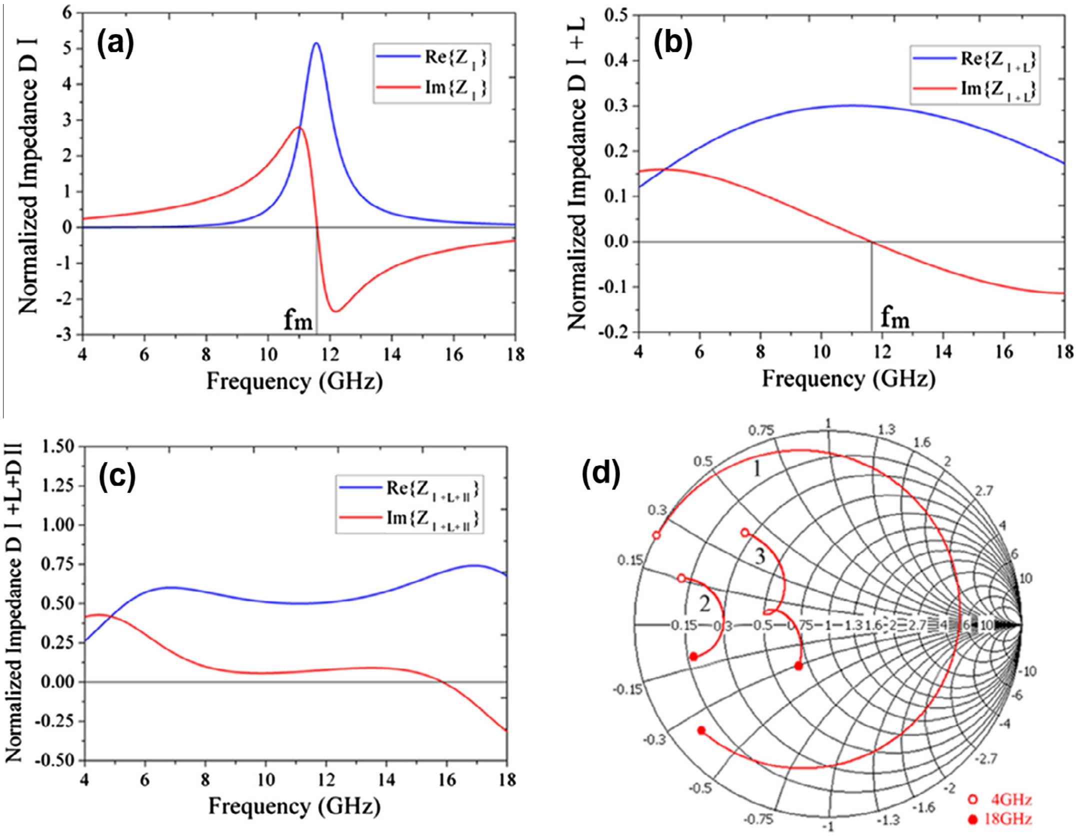

Fig. 2. Normalized complex impedance as a function of frequency: (a) Normalized complex impedance of Dielectric I, (b) normalized complex impedance of Dielectric I and Lossy layer, (c) normalized complex impedance of the sandwich structure, and (d) the Smith chart for D I (1), D I + L (2), and sandwich structure (3).