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Electromagnetic transmission characteristics of composite frequency selective surfaces coated with conductive polymer–silver paste

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ABSTRACT

In this work, a kind of conductive polymer–silver paste was used to fabricate composite frequency selective surfaces (FSSs) with four-legged slot elements. Screen printing and 3D engraving process were carried out to coat the conductive polymer–silver paste onto the fabric preform and sculpt composite panels into composite FSSs, respectively. The substrates of the composite FSS were carbon and quartz glass fabrics, respectively. The equivalent electrical conductivity of the composite material FSS was measured and the results showed that it increased significantly after the fabrics printed by the conductive silver paste. Free space method was adopted to test the electromagnetic transmission characteristics of the composite FSS. Experimental results showed that the conductive silver paste was effective to decrease the minimum transmission loss of the composite FSS and the minimum transmission loss of the quartz glass fabric composite FSS was lower than that of the carbon ones. A finite element model was put forward to calculate the electromagnetic transmission characteristics of the composite FSS. The calculated results were in agreement with the experimental data. Effects of the equivalent electrical conductivity and the thickness of the composite substrate on the minimum transmission loss of the carbon fabric composite FSS were investigated.

1. Introduction

In order to make weapon systems less visible (ideally invisible) to opposite tracking systems, Radar Cross Section (RCS) of them should be minimized because the distance detected by the opposite radar is inversely proportional to the fourth root of RCS [1,2]. Since the radar antenna is the main cause to increase the RCS of the weapon systems, adopting low-observable radomes is the most effective method to reduce the radar detection distance [3,4]. The low-observable radome is transparent at the operating frequency band of the radar antenna and simultaneously stops nearly all of the incident power outside the operating frequency band, which decreases the RCS of the weapon systems outside the operating frequency band of the radar antenna greatly. The function of microwave filtering of the low-observable radome is usually achieved by frequency selective surfaces (FSSs) [5–8].

A FSS is a two-dimensional periodic array of conducting patches or aperture elements used in microwaves and optics, and generally patterned on, or, embedded in a dielectric slab [9,10]. Traditional FSS is made of metals, such as cooper or aluminum [11]. Chemical etching is usually adopted to fabricate thin metallic FSSs according to standard circuit board processes, which is suitable for fabricating FSSs with complex elements [12]. The metallic FSS has low transmission loss at its resonant frequency, but a bonding is needed to attach the FSS to the dielectric slabs when stealth radomes are fabricated [1,14,13]. The dielectric slabs of the low-observable radome were usually made of dielectric fiber/epoxy composite due to its low dielectric constant [11,14] and high specific strength. The low-observable radome was constructed conventionally from one or more metallic FSSs that were sandwiched between the dielectric slabs [1,3,14–16], which resulted in thermal mismatches and weak interfaces between metal and composite materials. When the FSSs adopted in the low-observable radome are thick-screen ones, the thermal mismatches are more serious and the total weight of the low-observable radome increases largely.

In order to avoid the problems mentioned above, FSSs made of polymer matrix composite materials were studied in former researches. A type of carbon film FSS with cross-shaped resistive patches was fabricated by spraying technique and studied by finite element method [10]. A lattice grid made of unidirectional glass or carbon fibers filled with spongy materials was designed and manufactured to obtain multifunctional structures with superior microwave absorbing abilities [17–19]. Sang-Eui Lee realized an inductive FSS by using carbon and dielectric fibers hybrid fabrics which corresponded to metallic parts and apertures, respectively,

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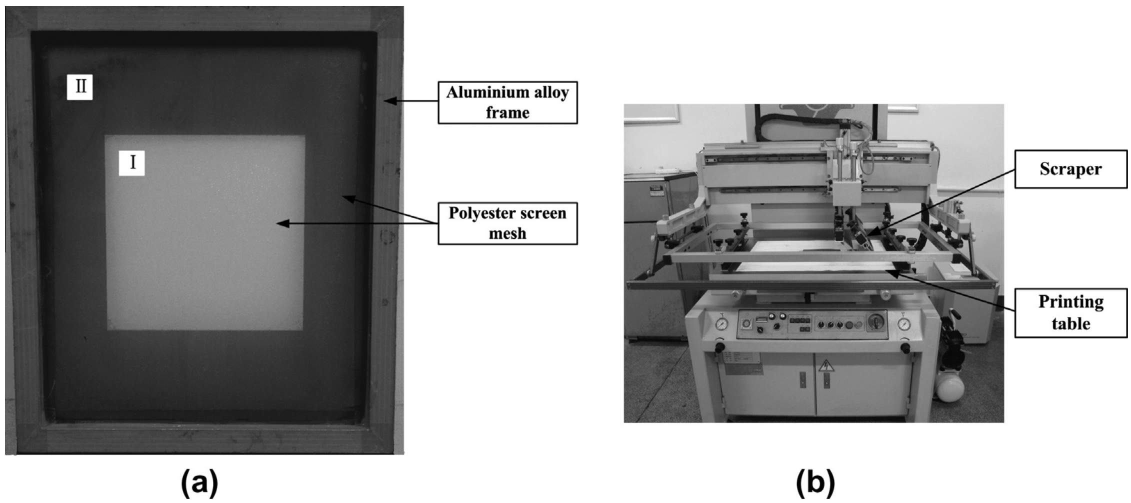

Fig. 1. Photographs: (a) a screen stencil; and (b) a screen printing machine.

but the low electrical conductivity of carbon fiber rovings caused partial transmission in resonant frequency ranges [11]. So, the electrical conductivity of the carbon fabrics reinforced epoxy composite materials needs to be increased to fabricate the composite FSS with lower minimum transmission loss [13].

There are two major methods to increase the electrical conductivity of polymer matrix composite materials. One is to adopt mesophase pitch-based carbon fibers with high electrical conductivities, such as P55, E120 or C700. The electrical conductivities of the mesophase pitch-based carbon fibers are at least four times higher than that of the PAN-based carbon fibers such as T300, T800 and M40J [20]. However, the cost of this method is very high. The other method is to metalize surface of the carbon or glass fibers, which can increase the electrical conductivity of the carbon or glass fibers significantly [21,22]. However, the metalizing process usually damaged fibers, which resulted in low mechanical properties of composite material with the fibers. Besides, because of the low compatibility between the metal plating coat and the polymer matrix, composite materials fabricated by this method was not suitable for the low-observable radome which should be mechanically strong.

In this paper, screen printing technique was adopted to coat the conductive polymer–silver paste onto the quartz and carbon fabrics and then fabrics reinforced epoxy composite materials were fabricated. 3D engraving technique was carried out to fabricate the composite FSS with four-legged slot elements. Free space and finite element methods were used to measure and calculate the electromagnetic transmission characteristics of the composite FSS, respectively.

2. Experiment

2.1. Applied materials

The conductive silver paste OTS-5280 adopted in this paper was provided by Shenzhen D-max Technology Co., Ltd. It was a silver-filled paste with a solid content of 58% and its adhesive was a kind of thermoplastic resin. Viscosity of the paste was 12,000–15,000 MPa s and electrical conductivity was 5.3×10^5 S/m at room temperature.

Plain woven fabrics of T300 carbon fiber with 1 K and 3 K tow sizes and a twill woven fabric of quartz glass fiber with 16 threads/cm in warp and 14 threads/cm in weft were used as the substrate for the screen printing, respectively. The matrix of the composite material was Bisphenol-A epoxy resin LT5089 provided by Wells Epoxy Ltd.

Table 1
The fabricated composite panels with different thickness.

Specimen number	Matrix	Reinforcement	Thickness (mm)
A	Epoxy resin	1 K tow size carbon fabric	0.15
B		1 K tow size carbon fabric with conductive silver paste	0.15
C		3 K tow size carbon fabric with conductive silver paste	0.26
D		Quartz glass fabric with conductive silver paste	0.13
E		3 K tow size carbon fabric	0.26

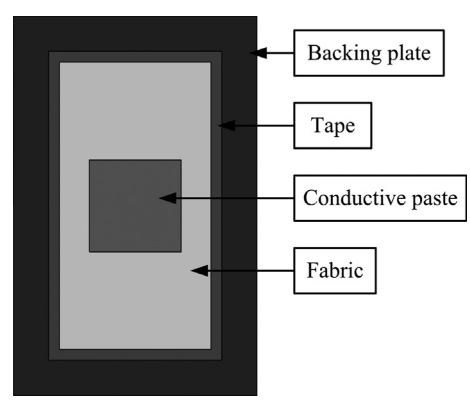

Fig. 2. Schematic illustration of fabricating fabrics with conductive silver paste.

2.2. Fabrication of the composite materials

There were three major steps for fabricating the high conductivity composite materials. The first was the screen printing process. Fig. 1 shows a screen stencil mounted in an aluminum alloy frame and a screen printing machine. The screen stencil was a kind of polyester screen mesh with a mesh count of 250. The conductive silver paste could pass through the region I and was stopped by the region II. The fabric was put on a backing plate and its four edges were fixed on the plate by adhesive tape, which could keep the fab-