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Influence of Salt Spray Environment on the Transmission Characteristics of the Dual Left-Handed Material

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Abstract—In order to collect information for the manufacture and application of a designed dual left-handed material (LHM) structure, the influence of salt spray test on the two conductive composite coatings consisting of silver and copper is contrastively investigated. It is found that the salt spray corrosion test can influence the microstructure of the coated copper and silver layers, leading to the decrease of electrical conductivity of the coated copper and silver layers. As results, the transmission performance of the dual-LHM structure is reduced, while the bandwidth of the dual-LHM structure is broadened. Moreover, at the same conditions, the salt spray corrosion test has less influence on the transmission characteristics of the silver-plated dual-LHM structure than those of copper-plated dual-LHM structure.

1. INTRODUCTION

Left-handed material (LHM) is a kind of artificial composite material with a negative permittivity and negative permeability. In comparison with natural right-handed material (RHM), the LHM possesses many new features such as negative refraction, backward wave propagation, reversed Doppler shift, and backward Cerenkov radiation [1–3]. Moreover, with substituting LHM structure for RHM structure in circuit, the size of device can be reduced effectively, the bandwidth of the device broadened and the performance of the device improved significantly. This distinct feature can greatly extend the applications of LHM in the industry of information technology. Moreover, with the rapid development of modern communication technology, more and more devices are needed to operate in multi-band [4–6]. An ordinary LHM structure has only one left-hand frequency band, while the dual left-handed frequency bands will meet the increasing demand of multi-band.

Usually, the main factors which influence the center resonant frequency of the dual-LHM structure are the sizes of the structure, width of the split ring and width of the defected ground structures (DGS) crack. However, the electrical conductivity of coated metal layer can be influenced by the microstructure of coated metal layer, as well as the transmission characteristics of the dual-LHM structures. Therefore, for real applications of a dual-LHM device, it is necessary to study the influence of the marine atmospheric environment on the microstructure and left-hand characteristics of the LHM device [7]. However, most of the recent attention has been focused on the fabrication and application studies of LHM structures with the relevant exploration of operation environment being ignored, which present new physical properties and important device applications.

In this paper, a LHM structure with a dual left-handed frequency bands is designed. In order to collect information for the manufacture and application of the designed dual-LHM structure, the influence of marine atmospheric environment on the two conductive composite coatings consisting of silver and copper is contrastively investigated. It is found that the salt spray corrosion test can

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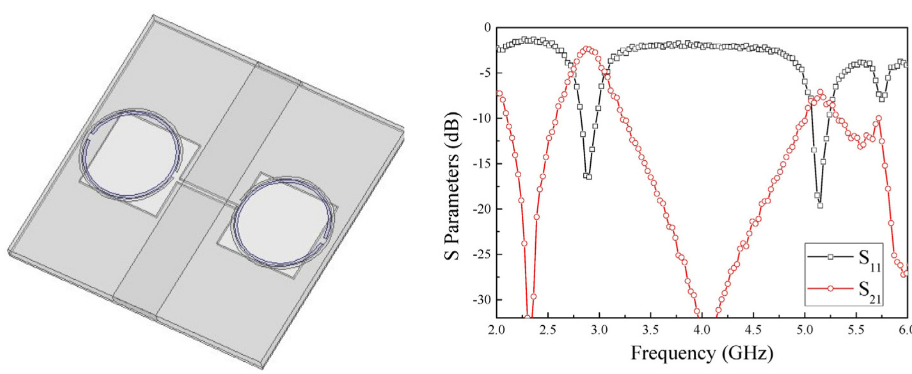
influence the microstructure of the coated copper and silver layers, leading to the decrease of electrical conductivity of the coated copper and silver layers. As results, the transmission performance of the dual-LHM structure is reduced, while the bandwidth of the dual-LHM structure is broadened. Moreover, at the same conditions, the salt spray corrosion test has less influence on the transmission characteristics of the silver-plated dual-LHM structure than those of copper-plated dual-LHM structure. The findings presented here offer an effective method to manipulate the performance of the dual-LHM device by tuning the operation environment.

2. EXPERIMENTAL

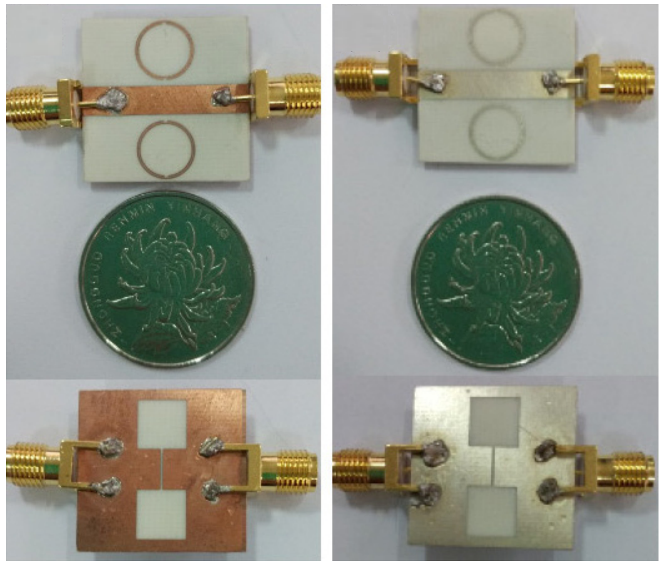
In order to obtain dual resonances effect in the microstrip transmission line device, it is of strategic importance to design a structure with the combination of the split ring resonator (SRR) [8, 9] and DGS structure [10, 11]. In this work, a microstrip transmission line device is designed with the combination of the SRR and DGS structure. A SRR structure is symmetrically placed on both sides of the microstrip transmission line device. A dumbbell-shaped DGS is placed on the ground plane below the SRR structure which consists of two squares and connected by a slot. When the magnetic field of incident wave is perpendicular to the plane of the SRR structure, the induced current is produced in SRR (equivalent as inductance). The seam capacitor is introduced by the slot between the inner and outer rings (equivalent as capacitance). The SRR resonators will produce a resonant frequency. A microstrip line with single DGS can be equivalent to an LC resonance low-pass filter. With the interaction of the two resonances, two resistance bands are generated. Therefore, the stop-band gap is achieved by adjusting the SRR and DGS structures. DGS provides low resonance, and SRR provides high resonance. The three dimensional diagram of dual-LHM structure is shown in Figure 1(a). Obviously, this structure is a microstrip line structure. There are two circular dual SRRs with two opposite openings symmetrically placed on both sides of the microstrip line. In the middle of the ground plate and corresponding SRRs position, there are two square notches DGS which are connected through the gap in the center. The thickness of the bottom metal plate is 0.3 mm. The SRR and the DGS are provided with a series resonance and a parallel resonance, respectively. Figure 1(b) shows the simulated and measured transmission characteristics of the designed dual-LHM structure. Obviously, the dual-LHM passband characteristics can be observed. The two passbands are located near 2.45 GHz and 5.8 GHz, respectively. A slight deviation between the simulated and measured results can be attributed to the losses in the manufacture and measurement process.

In order to collect information for the manufacture and application of the designed dual-LHM structure, the influence of marine atmospheric environment on the two conductive composite coatings consisting of silver and copper is contrastively investigated. In this work, RO4003C is designed as the substrate material. In the fabricated dual-LHM structure with coated copper layer, the thickness of the copper cladding is about 18 µm. For the fabricated dual-LHM structure with coated silver layer, the



(a) (b)

Figure 1. (a) The schematic diagram of the dual-LHM structure, (b) the simulated (curve S_{11}) and measured (curve S_{21}) transmission characteristics of the dual-LHM structure.



(a) (b)

Figure 2. The fabricated dual-LHM structure with copper (a) and silver (b) as the coated metal layer.

silver layer with thickness of 0.5 μm is plated over the copper cladding of the standard RO4003C. The dual-LHM structures are fabricated with copper and silver being the coated metal layer, as shown in Figures 2(a) and (b), respectively.

In the dual-LHM structure, RO4003C is designed as the substrate material. The dielectric constant of RO4003C is 3.38. The size of the plate is 23 mm × 23 mm × 0.813 mm (length × width × thickness). The thickness of the bottom metal plate is 0.3 mm. In this paper, the marine atmospheric environment is simulated by the salt spray corrosion test. The concentration of NaCl in the solution is 5%. The pH value of the solution is about 6.5 ∼ 7.2. The silver- and copper-plated dual-LHM structures are tested under the salt spray environment at 35°C for 48 hours, respectively. After that, the influence of salt spray environment on the microstructure, the dual left-handed bandwidths and center frequency of the dual-LHM structures are systematically investigated. The resonant frequency and bandwidth of the dual-LHM structure were measured using KEYSIGHT network analyzer. The scanning electron microscope (SEM) [12] was employed to characterize the microstructure of the coated meatal of the dual-LHM structure.

3. RESULTS AND DISCUSSION

In order to investigate the influence of the salt spray environment on the copper-plated dual-LHM structure, SEM was employed to characterize the microstructure of the coated copper. Figure 3 shows the microstructure of coated copper layer of the dual-LHM structure before and after the salt spray corrosion test for 48 hours. Obviously, before the salt spray corrosion test, the surface of the coated copper layer is relatively smooth and flat with few cracks. However, after the salt spray corrosion test in the ambient air for 48 hours, the surface of coated copper layer becomes rough, and a large number of cracks and holes appear. Because additional interfacial cracks are formed, and some atoms of copper favor the formation of copper chloride oxide, the electrical conductivity of coated copper layer decreases significantly. This can lead to the increase of the surface resistance of the copper-plated dual-LHM structure, and consequently, it will have much influence on the transmission characteristics of the designed dual-LHM structure.

Figure 4 shows the variation of two resonant frequencies points from the measured transmission curves of the copper-plated dual-LHM structure before and after the salt spray corrosion test. Obviously, the salt spray environment has little influence on the positions of two center frequencies of the copper-plated dual-LHM structure. The first resonant frequency remains at around 2.66 GHz after the salt

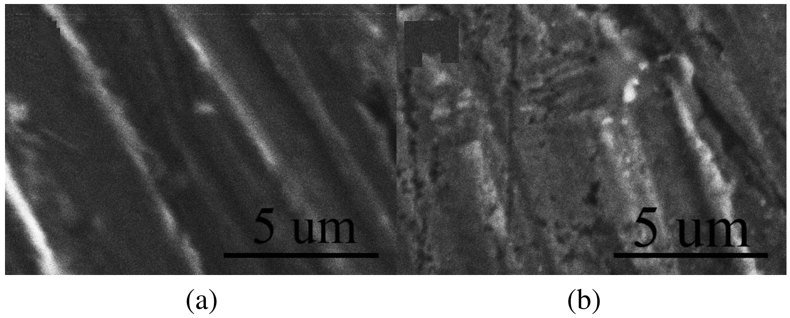


Figure 3. SEM images of the copper-plated dual-LHM structure (a) before salt spray corrosion test; (b) after salt spray corrosion test.

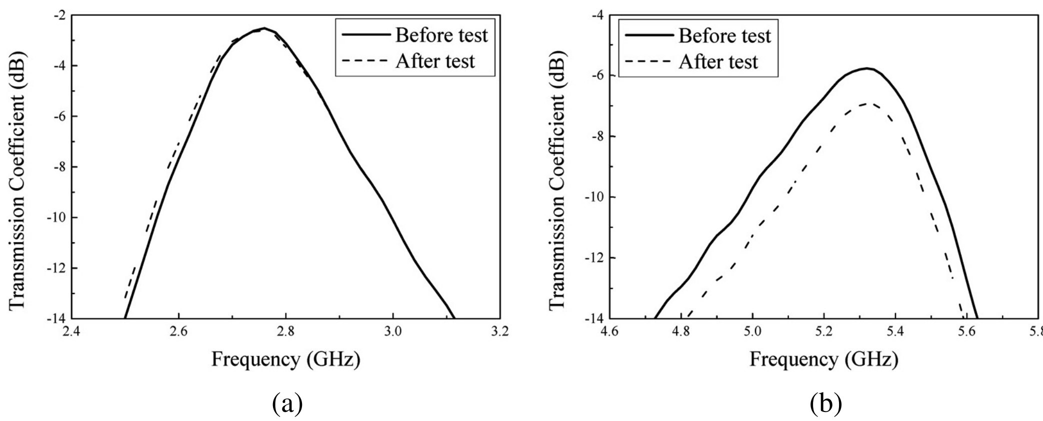


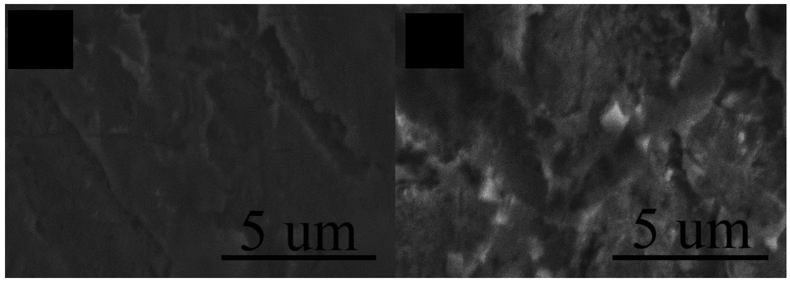
Figure 4. Influence of salt spray corrosion test on the resonant points of the copper-plated dual-LHM structure (a) the first resonant point; (b) the second resonant point.

spray corrosion test for 48 hours. The transmission loss of the first resonant frequency point decreases about 0.1 dB. On the contrary, the center of the second resonant frequency point remains in the same frequency after the salt spray corrosion test. However, the transmission loss of the resonant frequency point increases about 1.2 dB. Moreover, the transmission bandwidths of the two resonant frequencies also increase slightly.

As observed in Figure 3, the salt spray corrosion test can influence the microstructure of the coated copper layers, leading to decrease of the electrical conductivity of the coated copper layers. Consequently, it leads to the decrease of the transmission coefficient and increase of frequency bandwidth of the copper-plated dual-LHM structure.

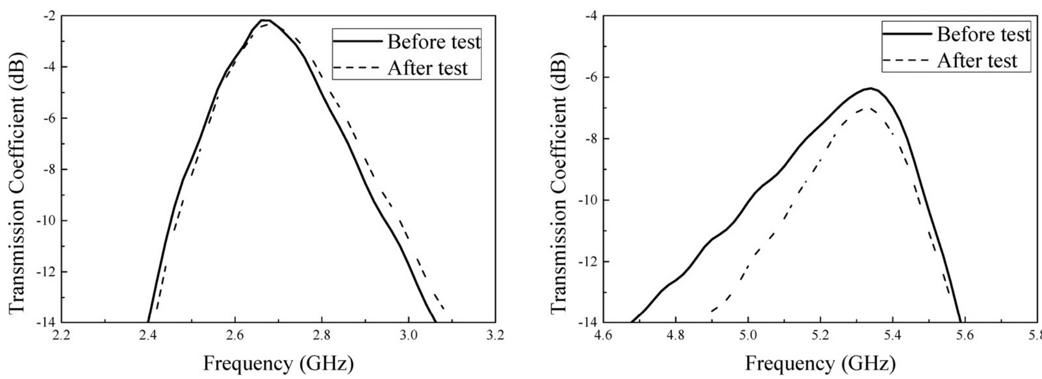
Figure 5 shows the microstructure of coated silver layer of the dual-LHM structure before and after the salt spray corrosion test for 48 hours. Obviously, before the salt spray corrosion test, the surface of the coated silver layer is relatively smooth, and there are few minor cracks. However, after the salt spray corrosion test for 48 hours, the surface of coated silver layer becomes rougher, and some cracks appear. The surface resistance of the silver-plated dual-LHM structure increases because of the reduction of electrical conductivity of coated silver layer. However, the salt spray corrosion tests do not cause significant microstructure damage to the coated silver layer as observed in coated copper layer. Therefore, the salt spray corrosion test will have less influence on the transmission characteristics of the silver-plated dual-LHM structure than those of copper-plated dual-LHM structure.

Figure 6 shows the variation of two resonant frequencies points from the measured transmission curves of the silver-plated dual-LHM structure before and after the salt spray corrosion test. Obviously, after the salt spray corrosion test, the transmission loss of the first resonant point increases about 0.13 dB. Similarly, the transmission loss of the second resonant point increases about 0.6 dB. However,



(a) (b)

Figure 5. SEM images of the silver-plated dual-LHM structure (a) before salt spray corrosion test; (b) after salt spray corrosion test.



(a) (b)

Figure 6. Influence of salt spray corrosion test on the resonant points of the silver-plated dual-LHM structure (a) the first resonant point; (b) the second resonant point.

the salt spray corrosion test has almost no influence on the frequency bandwidth of the silver-plated dual-LHM structure. Obviously, at the same conditions, the salt spray corrosion test has less influence on the transmission characteristics of the silver-plated dual-LHM structure than those of copper-plated dual-LHM structure.

4. CONCLUSIONS

In summary, an LHM device with a dual left-handed frequency bands is designed. The influence of marine atmospheric environment on the two conductive composite coatings consisting of silver and copper in the the designed dual-LHM structures is contrastively investigated. It is found that the salt spray corrosion test can influence the microstructure of the coated copper and silver layers, which leads to the decrease of electrical conductivity of the coated copper and silver layers. As results, the transmission performance of the dual-LHM structure is reduced, while the bandwidth of the dual-LHM structure is broadened. Moreover, under the same conditions, the salt spray corrosion test has less influence on the transmission characteristics of the silver-plated dual-LHM structure than those of copper-plated dual-LHM structure.

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