

## Article

# Preparation of Metal–Organic-Framework-Derived Fe-CN@CoCN Nanocomposites and Their Microwave Absorption Performance

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**Abstract:** Microwave technology is commonly used in many fields such as wireless communication and medical treatment, which are closely related to social development. However, electromagnetic pollution caused by microwaves is gradually increasing and the demand for high-performance microwave absorption materials is also increasing. Porous materials obtained by the pyrolysis of metal–organic frameworks (MOFs) at high temperatures exhibit good conductivity and magnetism, and the original skeleton structure of MOFs can be maintained; thus, MOF-derived materials can be considered viable candidates of microwave absorption materials. In this paper, Fe-CN@CoCN materials were prepared by pyrolyzing a ferrocene (Fc)-doped core–shell zeolite imidazole framework (Fc-ZIF-8@ZIF-67) at 700, 800, and 900 °C for 2 h in an Ar atmosphere. The obtained Fe-CN@CoCN-0.25-700 nanocomposite exhibited excellent microwave absorption (MA) performance with a minimum reflection loss (RL<sub>min</sub>) of −42.27 dB at 5.68 GHz and an effective absorption bandwidth (EAB, RL < −10 dB) of 4.80 GHz at a thickness of 2.5 mm. The Fe-CN@CoCN-0.25-800 nanocomposite possessed optimized MA properties with an RL<sub>min</sub> of −40.78 dB at 12.56 GHz and an EAB of 4.16 GHz at relatively low thickness of 2 mm. Fe-CN@CoCN nanocomposites are expected to be efficient materials for microwave absorption coatings.

**Keywords:** microwave absorption performance; metal–organic framework; ferrocene



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## 1. Introduction

Microwave technology has been widely used in communication, electronics, information, and other industries, bringing great convenience to human life. However, electromagnetic pollution caused by microwaves is also gradually increasing, affecting people's health and the normal operation of precision instruments [1–4]. As a result, the demand for high-performance microwave absorption materials (MAMs) is gradually increasing. High-performance MAMs need to have good electrical loss and magnetic loss, and the matching effect between these two parameters directly determines the ability of electromagnetic waves entering the MAMs. The multiple reflection loss of incident microwaves between the internal pores of the materials also plays a very important role, according to the electromagnetic wave loss mechanism [5,6]. Magnetic metal (Fe, Co, and Ni)-based metal–organic framework materials (MOFs) can be pyrolyzed at high temperatures to obtain porous composites with excellent electrical and magnetic losses, such as Co/C, FeCo@C, Fe<sub>3</sub>O<sub>4</sub>@C, etc. [7–9]. During the pyrolysis process of Fe-MOF, Fe<sub>3</sub>O<sub>4</sub> and Fe can be produced, which can effectually increase the magnetic loss capacity of pyrolytic products [10–12]. Using Fe<sub>4</sub>[Fe(CN)<sub>6</sub>]<sub>3</sub> (PB) as a precursor, Qiang and co-workers provided Fe/C nanocubes which possessed an RL<sub>min</sub> of −22.6 dB at 15.0 GHz and an EAB of 5.3 GHz [13]. The conductivity and magnetism can be adjusted by changing the content of the components and the experimental environment, but the adjustment effect on porosity is

not obvious. Zn-based MOFs have attracted attention because of the relatively low melting point (420 °C) and boiling point (908 °C) of Zn metal. When the pyrolysis temperature exceeds 800 °C, carbon-reduced Zn metal begins to vaporize, forming an amorphous structure that can increase the porosity of composites [14]. Wu et al. calcined ZIF-8 at 800 °C and obtained N-doped porous carbon material with appropriate porosity, good skeleton maintenance, and a maximum reflection loss ( $RL_{\min}$ ) of  $-39.7$  dB [15]. However, the absorbing properties of zinc-based MOF-derived absorbing materials are largely limited by magnetic loss. Many recent studies have used  $Zn^{2+}$  and magnetic metal cations as mixing centers to form polymetallic MOFs as precursors of MAMs. Wei et al. obtained CoZn/C composite materials via the pyrolysis of CoZn-ZIF. Compared with ZIF-67 containing only Co, the specific surface area of pyrolytic products of CoZn-ZIF was higher due to the volatilization of Zn, and the optimized  $RL_{\min}$  was as high as  $-59.7$  dB [16]. In addition to composition, structural design also plays a crucial role in MOF-derived MAMs, especially in broadening pore size distribution. It is also a new challenge to design materials with multiple pore sizes through different methods [17].

Core-shell structures can exhibit both the chemical and physical properties of the core materials and shell materials, and the limitations of a single component can be easily overcome by various combinations of conductive and magnetic materials [18]. In addition, the different pore structures of the carbonized products obtained from the core and shell at high temperatures also contribute to the distribution of porosity-broadening and heterogeneous interfaces [19]. For example, Huang et al. used carboxy-modified  $Fe_3O_4$  microspheres to provide deposition sites for  $Zn^{2+}$  and in situ-generated ZIF-8 synthetic core-shell  $Fe_3O_4@ZIF-8$ , and a novel  $Fe_3O_4@Zn-N$ -Carbon (FZNC) nanocomposite was prepared after pyrolysis. The  $RL_{\min}$  of FZNC was  $-61.9$  dB at 13.1 GHz and the effective bandwidth was 11.5 GHz [20]. Notably, ZIF-67 can nucleate and grow on ZIF-8 due to them having the same crystal structure [21]. Liu and co-workers designed a nitrogen-doped carbon nanocage using ZIF-8@ZIF-67 as a precursor. The  $RL_{\min}$  was  $-52.5$  dB at 13.1 GHz and the EAB was 4.4 GHz [22]. However, there is still a problem of impedance mismatch caused by the reason that magnetic loss is much less than dielectric loss.

In this study, ferrocene (Fc) was doped into ZIF-8@ZIF-67 and the Fe-CN@CoCN composites with wide aperture distribution and excellent electrical and magnetic losses were obtained after the pyrolysis of ZIF-8@ZIF-67. The amount of FeCo alloys and carbon nanotubes (CNTs) on the surface can be regulated by changing the doping amount of Fc and the temperature of the pyrolysis process. Their microwave absorption abilities were explored.

## 2. Experimental

### 2.1. Reagents

All chemicals were commercial obtained and used as received without further purification. Cobalt nitrate hexahydrate ( $Co(NO_3)_2 \cdot 6H_2O$ , 98.5%), zinc nitrate hexahydrate ( $Zn(NO_3)_2 \cdot 6H_2O$ , 98.5%), 2-methylimidazole (2-MeIm, 98%), and ferrocene (Fc, 98.5%) were purchased from Shanghai Macklin Biochemical Co. Ltd., Shanghai, China. Anhydrous methanol ( $CH_3OH$ ,  $\geq 99.7\%$ ) was purchased from Sinopharm Co. Ltd, Shanghai, China.

### 2.2. Synthesis of ZIF-67 and Fc-ZIF-67

ZIF-67 was synthesized according to a modified method that we used [2]. The typical process was as follows: 3.4926 g (12.0 mmol) of  $Co(NO_3)_2 \cdot 6H_2O$  and 3.9421 g (40.0 mmol) of 2-MeIm were dissolved in 135 mL of methanol and stirred at 30 °C for 10 h, during which the pink solution gradually turned purple. After centrifugation, the acquired purple precipitate was washed with 30 mL of methanol three times and then dried at 40 °C for 24 h for following use.

Fc-ZIF-67 was prepared using a facile one-pot reaction. Then, 3.4920 g (12.0 mmol) of  $Co(NO_3)_2 \cdot 6H_2O$  and 0.5587 g (3.0 mmol) of Fc were added to 105 mL of methanol and stirred for 1 h to form solution A. Then, 3.9427 g (40.0 mmol) of 2-MeIm was dissolved in

30 mL of methanol to form solution B. Afterwards, solution B was poured into solution A and stirred vigorously at 30 °C for 10 h. The formed precipitate was collected via centrifugation and washed with 30 mL of methanol three times. Finally, Fc-ZIF-67 was obtained after drying in an oven at 40 °C.

### 2.3. Synthesis of Fc-ZIF-8 and Fc-ZIF-8@ZIF-67

The preparation route of Fc-ZIF-8 was similar to Fc-ZIF-67. Firstly, 3.5712 g (12.0 mmol) of  $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  and 0.5582 g (3.0 mmol) of Fc were dissolved in 105 mL of methanol. Secondly, 3.9417 g (40.0 mmol) of 2-Melm was dissolved in 30 mL of methanol and then added to the previous solution. Finally, the Fc-ZIF-8 was obtained after centrifugation, washing, and drying.

Fc-ZIF-8@ZIF-67 was prepared using Fc-ZIF-8 as the core and was then coated with Fc-ZIF-67. The specific experimental steps were as follows: 0.5010 g of Fc-ZIF-8 was dissolved in 100 mL of methanol and uniform dispersion was obtained after ultrasound, which was denoted as solution A. Next, 0.5588 g (3.0 mmol) of Fc and 3.4924 g (12.0 mmol) of  $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  were dissolved in 100 mL of methanol and stirred for 30 min to form solution B. Then, 3.9416 g (40.0 mmol) of 2-methylimidazole was dissolved in 35 mL of methanol to form solution C. Solution A was added to solution B and stirred for 1 h, and then solution C was added to the above solution. After reacting for 10 h at 30 °C, the obtained purple solution was centrifuged for 30 min. The obtained purple precipitate was washed with 30 mL of methanol 4–5 times for clarification purposes, and then was washed twice with 30 mL of ethanol. The Fc-ZIF-8@ZIF-67 was obtained after being dried in a vacuum oven at 40 °C to a constant weight.

### 2.4. Synthesis of CoCN-800, Fe-CoCN-800, and Fe-CN@CoCN-0.25-T

The as-prepared ZIF-67 and Fc-ZIF-67 were placed in a tubular furnace and heated in a quartz tube with a ramp rate of 5 °C·min<sup>−1</sup>, and we then kept them at 800 °C under an Ar atmosphere for 2 h. The obtained samples were named CoCN-800 and Fe-CoCN-800, respectively. The Fc-ZIF-8@ZIF-67 was calcined at 600, 700, and 800 °C for 2 h in an Ar atmosphere to prepare Fe-CN@CoCN-0.25-T (T stands for calcination temperature).

Figure 1 illustrates the preparation process of Fe-CN@CoCN composites, where Fc-ZIF-8 was firstly yielded by a simple precipitation method and then coated with a Fc-ZIF-67 layer. ZIF-67 ( $[\text{Co}(\text{Melm})_2]_n$ ) and ZIF-8 ( $[\text{Zn}(\text{Melm})_2]_n$ ) were found to have the same isoretic structure and similar cell parameters ( $a = b = c = 16.9589$  Å of ZIF-67 and  $a = b = c = 16.9910$  Å of ZIF-8), indicating that one can easily grow and overlie the other epitaxially to form a core-shell structure with regular morphology and single crystal properties. Moreover, the Fe-CN@CoCN composites were prepared after the high-temperature pyrolysis of Fc-ZIF-8@ZIF-67 in an Ar atmosphere.

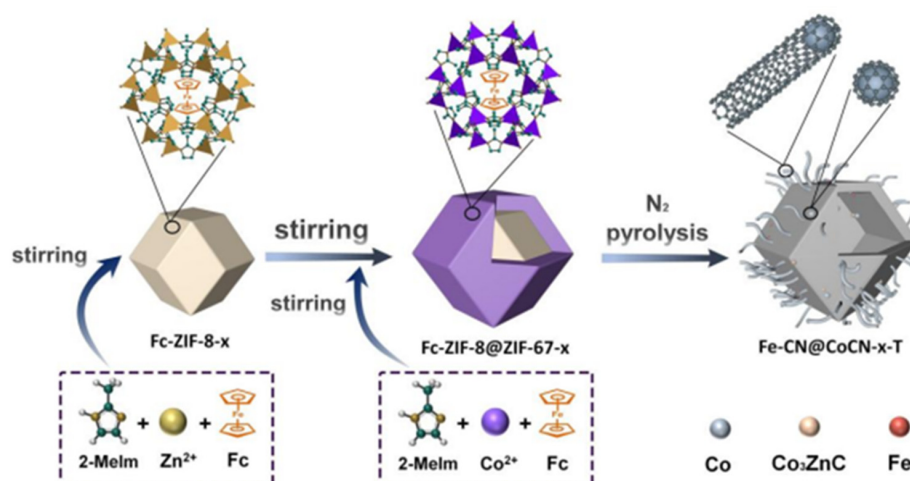


Figure 1. Schematic of the synthesis process of Fe-CN@CoCN composites.

### 2.5. Characterizations

The crystal phase was measured via powder X-ray diffraction (XRD) (PANalytical X'Pert Pro MPD, PANalytical B.V. Co. Ltd., Almelo, The Netherlands). Transmission electron microscopy (TEM) (Hitachi HT-7700, Hitachi, Ltd., Tokyo, Japan) was used to observe the morphology and microstructure of the samples. Raman spectra were characterized with a dispersive Raman microscope (HORIBA HR Evolution, HORIBA Ltd., Tenyamachi, Japan). The content of the metal elements was determined using ICP-AES (Varian 720-ES, Varian Technology Co., Ltd., Palo Alto, CA, USA). The nitrogen adsorption desorption test was performed with Micromeritics 2460. The compositions of the elements were detected through X-ray photoelectron spectroscopy (XPS) on an Axis Ultra DLD spectrometer (ESCALAB 250Xi, Thermo Fisher Scientific, Waltham, MA, USA). The hysteresis loop test was performed with a Vibrating Sample Magnetometer (Lake Shore 7404, Lake Shore Cryotronics, Inc., Westerville, OH, USA). An Vector Network Analyzer (PNA-N5244A, Agilent, Santa Clara, CA, USA) was used to test the electromagnetic shielding effectiveness of the material. The sample was mixed with solid paraffin at a mass ratio of 20 wt%, ground evenly, and pressed into a ring sample with an inner diameter of 3 mm and an outer diameter of 7 mm.

### 3. Results and Discussion

Figure 2a–c show TEM images of ZIF-67, Fc-ZIF-67, and Fc-ZIF-8@ZIF-67, respectively. They have the same structure as the regular dodecahedron prepared in the literature [23]. It can be seen that the prepared materials all had rhomboid normal dodecahedron structures, and their side lengths were distributed in the range of 400–700 nm. Figure 2d–i show the EDS mapping of Fc-ZIF-8@ZIF-67, which indicates that C, N, Co, Zn, and Fe were evenly distributed in the composite, and the core–shell structure could obviously be observed according to the mapping of Co and Zn elements. Figure 3a shows the XRD patterns of Fc, ZIF-67, Fc-ZIF-67, and Fc-ZIF-8@ZIF-67. The characteristic peaks of ZIF-67, Fc-ZIF-67, and Fc-ZIF-8@ZIF-67 were same and the characteristic peaks of Fc were not exhibited in the patterns of Fc-ZIF-67 and Fc-ZIF-8@ZIF-67. The results further indicate that Fc-ZIF-8@ZIF-67 composites with good crystallinity were successfully prepared. Figure 3b shows the XPS spectra of Fc-ZIF-8@ZIF-67. It can be seen that the Fc-ZIF-8@ZIF-67 composite contains C, N, Co, Zn, and Fe elements, and the results were found to be consistent with the EDS mapping results.

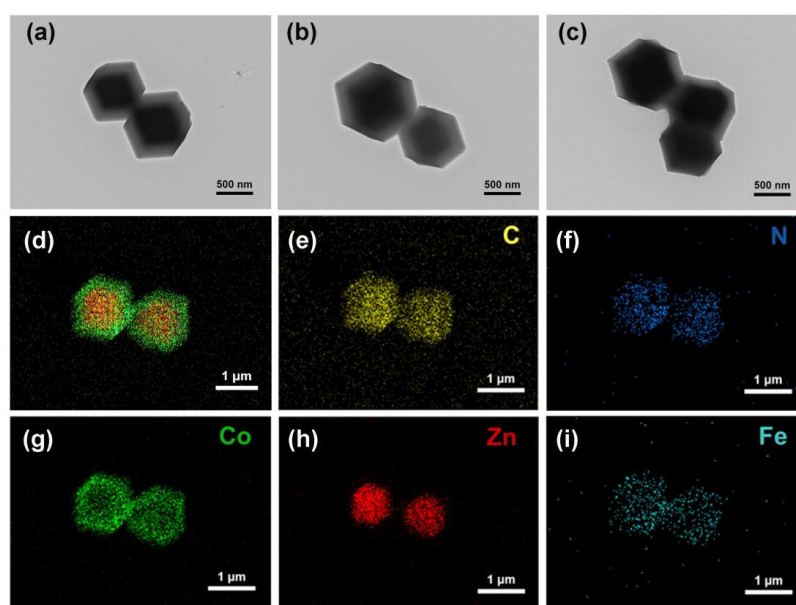


**Figure 2.** TEM images of (a) ZIF-67, (b) Fc-ZIF-67, and (c) Fc-ZIF-8@ZIF-67, and (d–i) TEM-EDS mapping images of the Fc-ZIF-8@ZIF-67 composite.

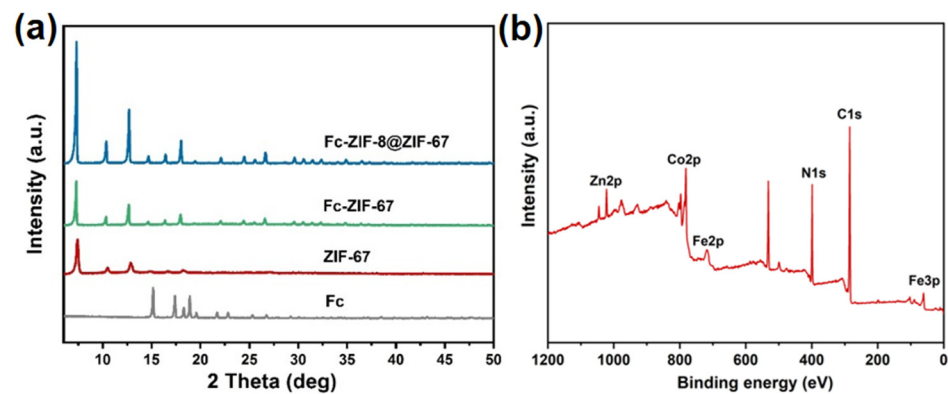


**Figure 3.** (a) XRD patterns of Fc, ZIF-67, Fc-ZIF-67, and Fc-ZIF-8@ZIF-67, and (b) XPS spectra of Fc-ZIF-8@ZIF-67.

TEM was used to study the structure, distribution, and size of the metal nanoparticles, as well as the growth of the carbon nanotubes of the three Fe-CN@CoCN-0.25-T composites. Figure 4 shows the TEM images of Fe-CN@CoCN-0.25-700, Fe-CN@CoCN-0.25-800, and Fe-CN@CoCN-0.25-900, respectively. As can be seen from Figure 4a, Fe-CN@CoCN-0.25-700 still maintained the original regular dodecahedron skeleton, but the surface of the skeleton collapsed, caused by the disappearance of organic components in MOFs during pyrolysis. Many carbon nanotubes grew on the surface of composites that was catalyzed by Fe and Co nanoparticles produced during pyrolysis. In addition, due to the volatilization of Zn in ZIF-8, the hollow nanocage structure was formed, which increased the porosity distribution. In Figure 4b, a clear hollow structure and CNT growth were also observed for the Fe-CN@CoCN-0.25-800 composite, but the void state was more pronounced because more Zn elements escaped from the skeleton. As shown in Figure 4c, part of the Fe-CN@CoCN-0.25-900 skeleton structures began to collapse, and the uncollapsed particles exhibited a more obvious hollow structure, in which most of the Zn elements were volatilized. In addition, the size of magnetic nanoparticles in Fe-CN@CoCN-900 increased significantly, which indicates that the crystallinity of metal particles increases with an increase in temperature.

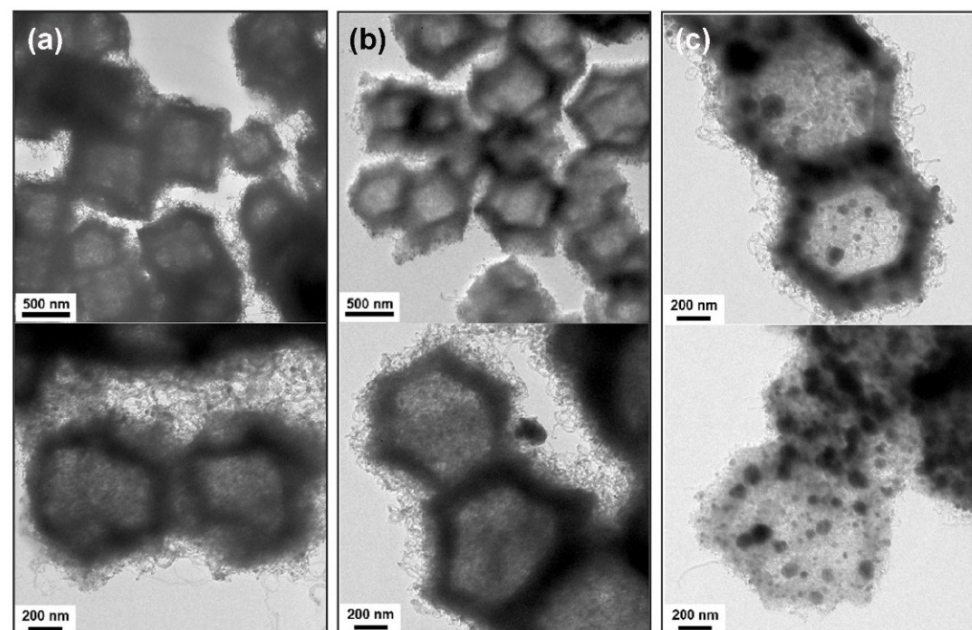


**Figure 4.** TEM images of (a) Fe-CN@CoCN-0.25-700, (b) Fe-CN@CoCN-0.25-800, and (c) Fe-CN@CoCN-0.25-900.

Figure 5a shows the ICP test results of Zn elements in Fe-CN@CoCN-0.25-T (T = 700, 800, and 900) composites. With an increase in the heat treatment temperature, the content of Zn gradually decreased. The mass fractions of Zn in the composites obtained at 700 °C, 800 °C, and 900 °C were 13.365 wt%, 4.102 wt%, and 0.736 wt%, respectively. The results further prove that Zn volatilizes during heat treatment. Figure 5b shows the Raman spectra of the three Fe-CN@CoCN-0.25-T composites, and all samples had two peaks near  $1320\text{ cm}^{-1}$  and  $1580\text{ cm}^{-1}$ , corresponding to the D and G bands. When the heat treatment temperature changed from 700 to 800, the  $I_D/I_G$  value decreased from 1.252 to 1.119, which indicates that the graphitization degree of carbon increased with an increase in temperature. However, when the heat treatment temperature was increased to 900 °C, the  $I_D/I_G$  value rose to 1.194, because high temperatures will lead to an increase in defects.

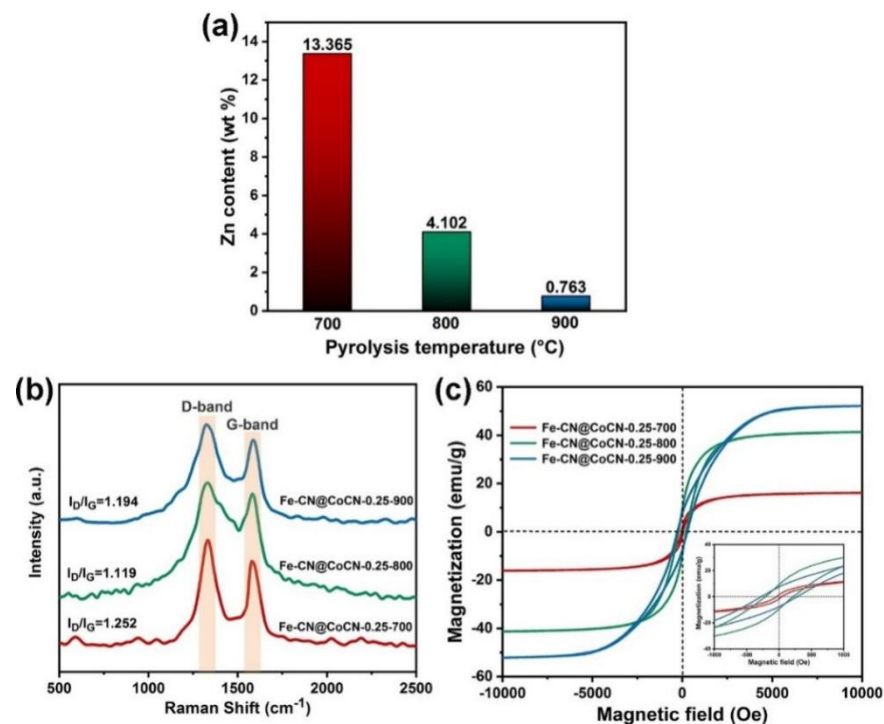


**Figure 5.** (a) Zn content, (b) Raman spectra, and (c) magnetic hysteresis loops of Fe-CN@CoCN-0.25-T.

Figure 5c shows the hysteresis loops of the three Fe-CN@CoCN-0.25-T composites. The saturation magnetization ( $M_s$ ) values of Fe-CN@CoCN-0.25-700, Fe-CN@CoCN-0.25-800, and Fe-CN@CoCN-0.25-900 were 16.16 emu/g, 41.26 emu/g, and 52.16 emu/g, respectively, because the crystallinity of Co and Fe nanoparticles was found to grow with an increase in the heat treatment temperature. The hysteresis loops of the three composites under low electric fields are shown in the lower right corner of Figure 5c. The saturation coercivity ( $H_c$ ) values of Fe-CN@CoCN-0.25-700, Fe-CN@CoCN-0.25-800, and Fe-CN@CoCN-0.25-900 were 32.83 Oe, 220.70 Oe, and 292.29 Oe, respectively. When the temperature rose from 700 °C to 800 °C, a large amount of zinc in the sample spilled out, and the content of  $\text{Co}_3\text{ZnC}$  decreased while the content of Co increased.

The microwave absorbing performance of the samples was tested in a vector network analyzer using the coaxial method, and the filler content of all samples in paraffin was 20 wt%. Microwave absorption performance can be expressed by a complex dielectric constant ( $\epsilon_r = \epsilon' - j\epsilon''$ ) and complex permeability ( $\mu_r = \mu' - j\mu''$ ), in which the real component ( $\epsilon'$ ,  $\mu'$ ) and imaginary part ( $\epsilon''$ ,  $\mu''$ ) of real components represent the material's ability to store electric or magnetic energy, while the imaginary part represents the material's ability to dissipate electrical or magnetic energy. The dielectric loss factor ( $\tan\delta_\epsilon = \epsilon''/\epsilon'$ ) and the magnetic loss factor ( $\tan\delta_\mu = \mu''/\mu'$ ) can be used to represent composites used for assessing the electromagnetic wave attenuation ability of dielectric and magnetic damping

capacities, respectively. Figure 6 shows the electromagnetic parameter values of the three composites in 2–18 GHz. In Figure 6a,b, the dielectric constants of Fe-CN@CoCN-0.25-700 and Fe-CN@CoCN-0.25-800 were basically similar, and their  $\epsilon'$  values ranged between 8.21 and 13.63 and between 8.50 and 13.82, respectively. The  $\epsilon''$  values ranged between 3.37 and 4.61 and between 3.56 and 5.22, respectively. However, the real and imaginary parts of the dielectric constant of Fe-CN@CoCN-0.25-900 were significantly increased, and the values of  $\epsilon'$  ranged between 11.04 and 19.04 and the values of  $\epsilon''$  ranged between 5.61 and 8.34. This is because the degree of graphitization of carbon can improve with an increase in temperature, which leads to an increase in conductivity and a higher dielectric constant. In Figure 6c,d, the variation in the permeability value of composites with pyrolysis temperature was relatively small. In the range of low frequency, the  $\mu'$  and  $\mu''$  values of Fe-CN@CoCN-0.25-700 and Fe-CN@CoCN-0.25-800 were higher than those of Fe-CN@CoCN-0.25-900. At relatively high frequencies, the  $\mu'$  and  $\mu''$  values of Fe-CN@CoCN-0.25-900 exceeded those of the other two materials. Moreover, the  $\mu'$  and  $\mu''$  values of Fe-CN@CoCN-0.25-800 and Fe-CN@CoCN-0.25-900 tended to decline as the frequency increased.

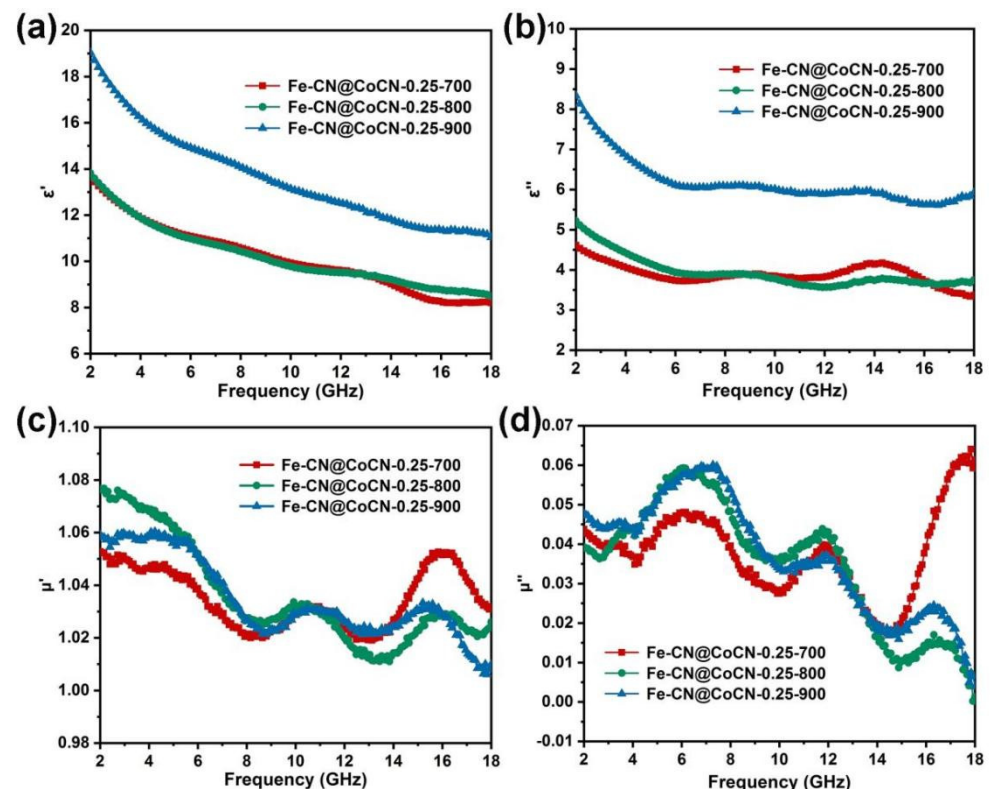


**Figure 6.** The electromagnetic parameters of the Fe-CN@CoCN-0.25-T composites in the range of 2–18 GHz: (a) the real dielectric constant, (b) the imaginary dielectric constant, (c) the real magnetic conductivity, and (d) the imaginary magnetic conductivity.

Figure 7a–c show the Cole–Cole curves of Fe-CN@CoCN-0.25-700, Fe-CN@CoCN-0.25-800, and Fe-CN@CoCN-0.25-900 composites. The dielectric loss mechanism of the microwave absorption materials can be judged by the Cole–Cole curves, where the semi-circles in the curve represent the polarization relaxation process and the upward tails represent the electrical conductivity. The mechanism of magnetic loss can be judged by  $C_0$  curves. Figure 7d shows the  $C_0$  curves of Fe-CN@CoCN-0.25-700, Fe-CN@CoCN-0.25-800, and Fe-CN@CoCN-0.25-900 composites. The magnetic loss mainly comes from the eddy current loss when  $C_0$  does not change with frequency. Finally, the internal loss ability of the microwave absorption material to the incident microwave can be characterized by the internal attenuation constant ( $\alpha$ ). Figure 8 shows the  $\alpha$ - $f$  curves of the Fe-CN@CoCN-0.25-T

composites. It can be seen that the higher the pyrolysis temperature, the stronger the electromagnetic wave loss capacity of the obtained materials.

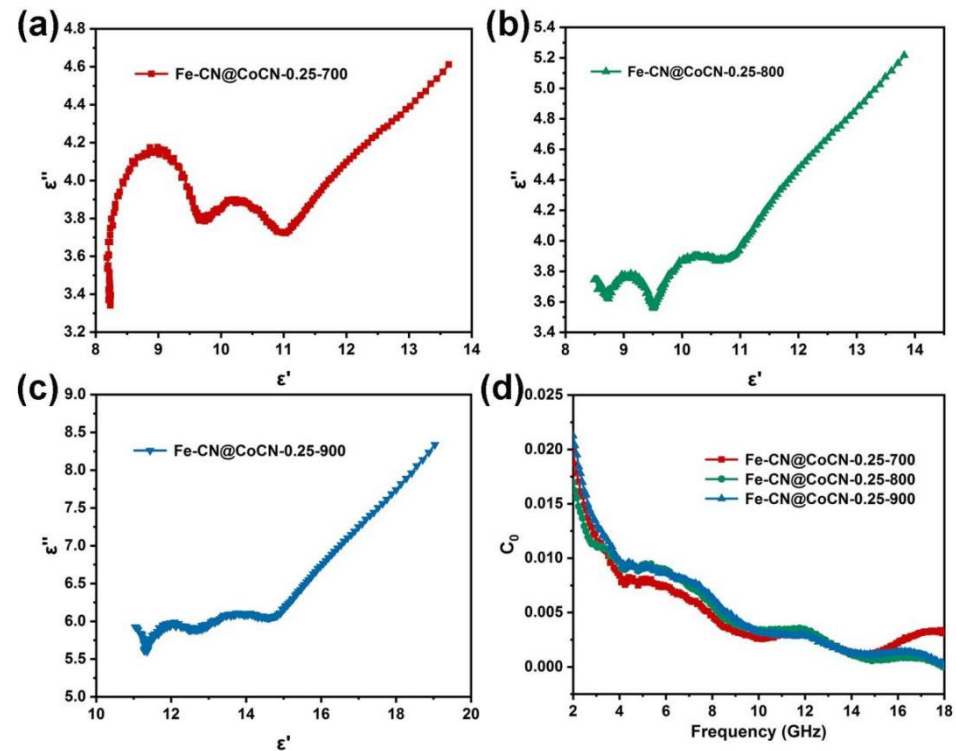


**Figure 7.** The Cole–Cole curves of (a) Fe-CN@CoCN-0.25-700, (b) Fe-CN@CoCN-0.25-800, (c) Fe-CN@CoCN-0.25-900, and (d)  $C_0$  curves of Fe-CN@CoCN-0.25-T composites.

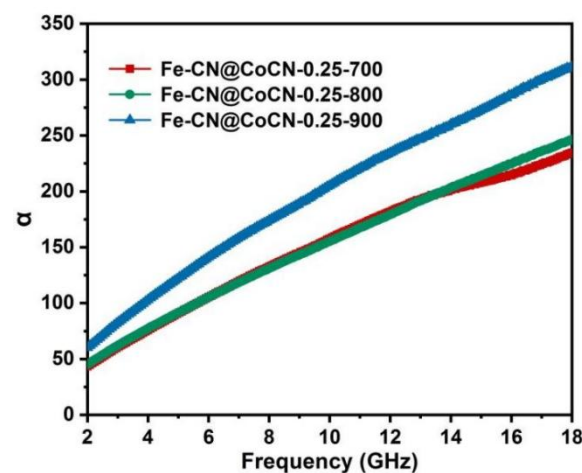


**Figure 8.** The  $\alpha$ - $f$  curves of Fe-CN@CoCN-0.25-T composites.

Figure 9 shows the RL- $f$  curves of Fe-CN@CoCN-0.25-700, Fe-CN@CoCN-0.25-800, and Fe-CN@CoCN-0.25-900 (mixed with paraffin at a mass ratio of 20 wt%). It can be observed that the Fe-CN@CoCN-700 showed the best microwave absorbing performance with an  $RL_{\min}$  of  $-43.56$  dB at 5.3 GHz at a matching thickness of 4 mm. Moreover, the microwave absorption performance of Fe-CN@CoCN-0.25-800 was also good, as it exhibited an  $RL_{\min}$  of  $-43.56$  dB at 13.1 GHz and a matching thickness of 2 mm. The reasons for this are as follows. Firstly, the impedance pairing was significantly optimized, allowing for the high absorption of microwaves. The large surface area and hollow structure repeatedly reflected and scattered the incident microwave, increasing the microwave loss. Secondly, FeCo nanoparticles were uniformly dispersed in the carbon matrix, forming

a rich non-uniform interface, providing many active sites, causing charge accumulation, and strengthening the interface polarization. In addition, Fe-CN@CoCN defects in the composites may result in bipolar splitting in the bipolar center and the conversion of microwaves into heat dissipation. It is worth noting that the FeCo particles formed during high-temperature carbonization not only improved the conductivity, but also acted as a catalyst to graphitize the carbon in the organic ligands. The uniform distribution of carbon formed a unique conductive network, which promoted the transfer of electrons and produced a strong conduction loss. Finally, the high efficiency microwave attenuation of the absorber was closely related to the magnetic resonance, exchange resonance, natural resonance, and vortex loss of the FeCo particles.

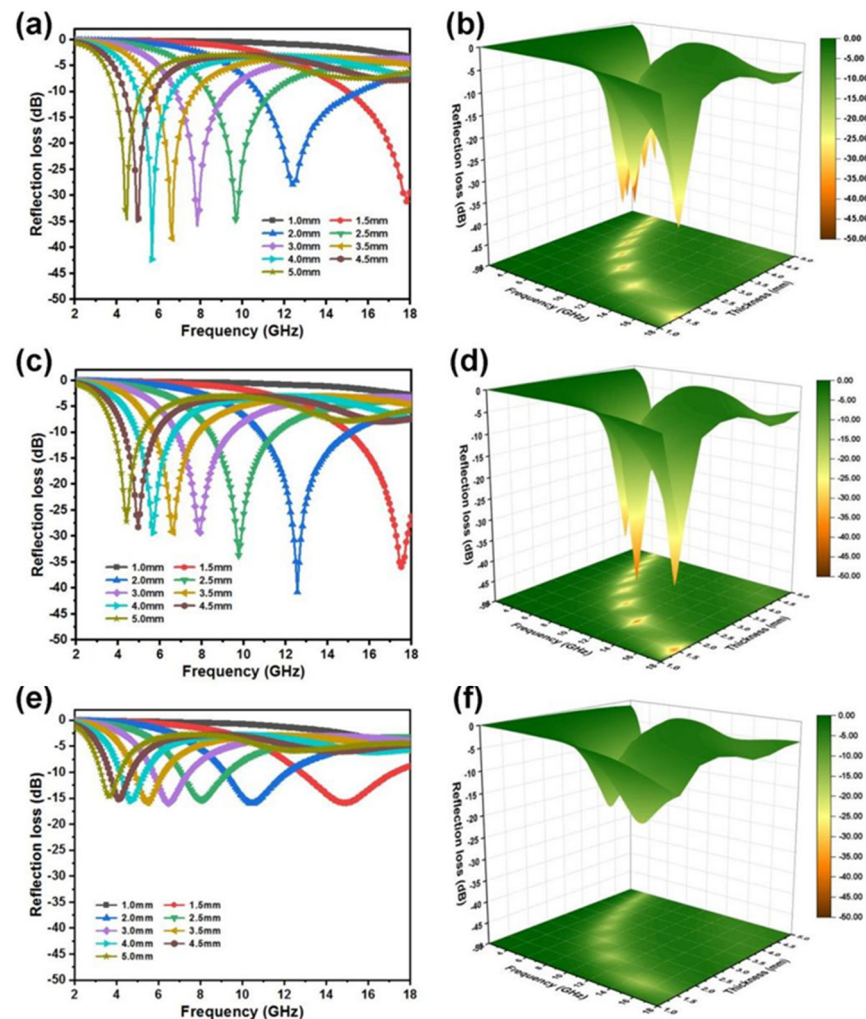


**Figure 9.** The RL- $f$  curves and 3D RL representations of Fe-CN@CoCN-0.25-T composites: (a,b) Fe-CN@CoCN-0.25-700, (c,d) Fe-CN@CoCN-0.25-800, and (e,f) Fe-CN@CoCN-0.25-900.

#### 4. Conclusions

Using Fc-ZIF-8 as the core and Fc-ZIF-67 as the shell, a series of ferrocene-doped core-shell ZIFs (Fc-ZIF-8@ZIF-67) were prepared. The hollow nanocaged Fe-CN@CoCN composites were obtained after high-temperature pyrolysis at 700, 800, and 900 °C. In addition, their microwave absorption properties were studied in detail. The experimental results show that the composites obtained after the carbonization of Fc-ZIF-8@ZIF-67 had great microwave absorption performance. The  $RL_{min}$  value of Fe-CN@CoCN-700 reached  $-42.27$  dB at 4.0 mm and 5.68 GHz, and its EAB reached 4.80 GHz with a thickness of 2.5 mm. The  $RL_{min}$  value of Fe-CN@CoCN-800 reached  $-40.78$  dB at 12.56 GHz and the EAB reached 4.16 GHz, and the matching thickness was only 2 mm. Therefore, the

Fc-ZIF-8@ZIF-67-derived Fe-CN@CoCN had good microwave absorption performance, meaning it can absorb more than 99.9% of the electromagnetic waves. MOF-derived carbon matrix composites have great application prospects in the field of electromagnetic wave absorption coatings.

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