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Advances in magnetic nano-wave absorbing materials

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Abstract. Magnetic materials are materials with specific magnetic properties, produced mainly by chemical methods such as co-saturation and high temperature pyrolysis, and with controllable product morphology and size. Magnetic particles have a high surface activity and a tendency to agglomerate, which can not only improve their dispersion and biocompatibility, but also achieve specific functions through surface modification in the actual research process. The research and application of wave-absorbing materials will have a major impact on the development of civilian electromagnetic radiation shields. Absorbents with good wave-absorbing properties are at the core of wave absorbing materials, and to meet the requirements of their thin, light, wide and strong properties, absorber research has also advanced towards high efficiency, composites, compatibility and intelligence. By summarising and analysing existing research, this paper provides a comprehensive overview of the research achievements and applications of magnetic wave absorbing materials in the medical and military fields to further explore the application potential, current challenges and future developments of such materials in various fields.

Keywords: Magnetic materials, wave-absorbing materials, Absorbents, surface modification.

1. Introduction

With the development of science and technology and the electronics industry, the application of various electronic devices is increasing, electromagnetic radiation has become a new social nuisance, it causes electromagnetic interference will not only affect the normal operation of various electronic devices, but also has a great harm to human physical and mental health, which promotes the widespread use of wave-absorbing materials. In addition, in modern warfare, the acquisition and counter-acquisition of information has become the focus of warfare, first enemy detection, first enemy attack is the key factor to overcome the enemy to win, in order to improve the survivability of military targets and weapons systems, the military powers will absorbing materials widely used in weapons and equipment [1]. It can be seen that wave-absorbing materials have become a current research hotspot, which has important significance for people's daily life and national defense construction. Wave-absorbing materials dissipate electromagnetic energy by converting it into thermal energy through their own loss mechanism, or by reducing the return of electromagnetic waves due to interference and dispersing the electromagnetic energy in other directions. Magnetic wave absorbing materials are currently the most studied and applied class. The paper introduces several types of magnetic wave-absorbing materials and presents the problems in the current research and the direction of further research.

2. Wave-absorbing principle of wave-absorbing materials

Generally speaking, wave absorbing materials need to have two basic characteristics: impedance matching properties and attenuation properties. The impedance matching characteristic means the use of special boundaries, so that the human wave as much as possible into the material inside and not be reflected; attenuation characteristics is to maximize the attenuation ability of absorbing materials to electromagnetic waves, so that electromagnetic waves quickly attenuate loss off for absorbing performance.

3. Classification of wave absorbing materials

Wave-absorbing materials are classified in more ways, there are three main ones: 1) according to the loss mechanism of electromagnetic waves, can be divided into resistance loss type, dielectric loss type and magnetic loss type. Conductive polymers, carbon nanotubes, graphite and other materials on the attenuation of electromagnetic wave energy is mainly caused by the material resistance, belongs to the resistive absorbing materials: silicon carbide, barium titanate and other dielectric materials on the absorption of electromagnetic waves is mainly caused by the dielectric electrodes caused by the loss of chirality, belongs to the dielectric loss absorbing materials; ferrite, carbonyl iron, polycrystalline iron fibers, ferromagnetic alloys and other materials of the absorption mechanism is mainly hysteresis The wave absorption mechanism of ferrite, carbonyl iron, polycrystalline iron fiber, ferromagnetic alloy and other materials is mainly hysteresis loss and ferromagnetic resonance loss, which belong to magnetic loss type wave absorption materials. Under the same wave absorption performance conditions. Magnetic loss absorbing materials are thinner than dielectric loss absorbing materials and are easier to match with other materials for impedance. 2) According to the forming process of absorbing materials and their ability to withstand filth, they can be divided into coated and structural types. Coating type absorbing material is the absorbent and adhesive coated on the target surface to form a wave absorbing coating, its use is relatively simple, easy to adjust, the use of a wide range. Structural absorbing materials have both wave absorption and load-bearing functions, usually by adding absorbers to high-strength polymers with load-bearing capacity, such as ceramics, cement, carbon fiber and other composite materials, and their structural forms are multi-layer plate, honeycomb, corrugated body, grid or corner cone, etc., which are usually relatively large in size.3) According to the absorption principle, they can be divided into interference and absorption. Interference type absorbing material is the use of absorption layer surface reflected wave and bottom reflected wave phase opposite and interference phase elimination, its absorption band is generally narrower. Absorption type absorbing material is through the material itself loss of electromagnetic wave energy into heat. Thus achieving the purpose of attenuation of electromagnetic waves.

4. Current status of research on magnetic wave absorbing materials

4.1. Ferrites

Ferrite series absorbers have the advantages of high absorption rate, thin coating and wide frequency band, etc. They are early developed and relatively mature absorbers. Ferrite is a double compound dielectric material, i.e. the loss of electromagnetic waves includes both dielectric and magnetic loss, where the most important loss mechanism is the natural resonance absorption of ferromagnetic in the residual loss. Ferrite according to the different crystal structure, can be divided into cubic crystal system spinel type (AFe, O, A on behalf of Mn, Zn, Ni, Mg, etc.), rare earth garnet type (LnFeOLn on behalf of Y, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Lu, etc.) and hexagonal crystal system magnetic lead stone type (AFe., OA on behalf of Ba, Sr, Ca, etc.) three , used as wave-absorbing The main materials used as wave absorbers are spinel and magnetite. Hexagonal crystalline ferrite has a high magnetic crystal anisotropy field, so the natural resonance frequency is high, and its sheet structure is the best shape for absorbers, so it has good electromagnetic wave absorption performance. At present. At home and abroad for Ba system M. w and z type hexagonal crystal system ferrite research more. Ferrite has a relatively high resistance, can avoid the skin effect of metal conductors at high frequencies, so that electromagnetic

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waves can effectively enter its internal: at the same time, ferrite also has good frequency characteristics, relatively high permeability, dielectric constant is relatively small, suitable for use as a matching layer, in the broadening of the low frequency band has good prospects for application. Ferrite as an absorber also has some defects, such as poor temperature stability, large surface density, etc., which limit its application in practice, can be improved by changing the chemical composition, controlling the particle shape and particle size, improving the preparation process and other measures to improve the wave absorption properties of ferrite. In order to improve or control the performance of ferrite powders. Ionic substitution methods have been widely studied. Deng used sol-gel method to dope La in w-type ferrite, the doped ferrite magnetic and dielectric loss is significantly enhanced, the coating thickness of 2mm. The minimum reflectivity reached one 39.6 dB, and the bandwidth below one 10 dB reached 8GHz [2]. Guo et al. prepared Lan, Nd and Sm three rare earth elements doped w-type hexagonal ferrite Ba0_9REcoFe6O by solid phase reaction, and the research results showed that all three doping can improve the saturation magnetization strength, coercivity and loss angle tangent of ferrite, and La doping has the largest loss angle tangent. In terms of controlling particle morphology and particle size, A. A. Eliseeva et al. synthesised ordered porous magnetic nano-wire strontium ferrite on the surface of mesoporous silica by co-precipitation, with saturation magnetisation strength and coercivity increasing with increasing calcination temperature to a maximum of 2.30 emu/g and 270 Oe respectively. MnFe, O powder, and the synthesized nano-ferrites have excellent magnetic properties. The research on the composite of ferrite and carbon nanotubes for wave absorbing materials has also received increasing attention [3]. Eali Ghasemil prepared multi-walled carbon nanotube/doped strontium ferrite nanocomposites by sol-gel method. Conductive polymers are a new material with both polymer and metal properties. Not only do they have high electrical conductivity, but they also have other properties such as photoconductivity and magnetism, so conductive polymers have a wide range of applications in many fields. Conductive polymers are compounded with magnetically lossy ferrite. The resulting composite has both electrical and magnetic losses, and also induces interfacial polarisationl and magnetoelectric effects due to its unique interfacial characteristics, thus adjusting the absorption frequency and improving the absorption performance. A composite powder with a core-shell structure was formed, and the wave absorption performance was significantly improved. The results of the study showed that the polarization effect at the interface between polyaniline and barium ferrite is the key factor affecting its wave absorption performance. Compared with ferrite, metal micropowders are generally more magnetic than ferrite, with saturation magnetisation strength more than four times that of ferrite, and therefore have higher permeability and magnetic loss. However, the problems of particle dispersion and oxidation and the effect of skinning. The application of metal micropowders in wave absorbing materials is limited. Ferrite has a high resistivity, which can effectively avoid the skin effect and still maintain a high permeability at high frequencies. The current research focuses on the following two aspects: Firstly, chemical plating, ball milling method and co-precipitation method are used. The metal powder is coated on the surface of the ferrite. Form a composite powder with core-shell structure, effectively broaden the absorbing bandwidth of the composite material and enhance the absorbing performance. The group has successfully prepared a new soft magnetic carbonyl iron coated hard magnetic doped strontium ferrite (srnLa(FeCo) "core-shell" magnetic composite absorbing powder by chemical vapour deposition. The reflection loss peak moves in the direction of low frequency. The minimum reflectivity of the 2 mm thick absorbing coating was 28 dB, and the bandwidth below 10 dB was 4 GHz. the minimum reflectivity decreased by 12.2 dB compared with that before the coating. Pan Xifeng used electroless nickel plating method at room temperature to coat the SrFe,0. strontium ferrite surface with metallic nickel. The composite powder has excellent microwave absorption performance with a minimum reflectivity of 41.3 dB and a bandwidth of 8 GHz below I10 dB. Secondly, the core-shell structure is formed by coating ferrite on the surface of the metal nanoparticles. Changing the composition, structure and state of the nano-metal powder surface better solves the problems of poor stability, extremely easy agglomeration and poor dispersion of metal micropowders. At the same time this core-shell structure makes the two magnetic particles produce a synergistic effect, which can overcome the shortcomings of both and make the composite material have good microwave absorption

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performance [4]. Liu Jiao et al. used a combination of non-uniform nucleation and chemical precipitation method to prepare MgFe0 ferrite in situ coated carbonyl iron ultrafine composite powder, absorbing coating thickness of 1.5 mm, the absorption peak of a 17.8241 dB < a 10 dB bandwidth of 5.52 GHz, effectively improving the absorption performance of a single absorbent. Ferrite in the microwave band mainly relies on natural resonance absorption of electromagnetic waves. Different types of ferrite resonance frequency band varies, different types of ferrite composite can effectively broaden the absorption bandwidth of the material [5]. At present, different ferrite composites are mainly concentrated in spinel/hexagonal crystalline system and spinel/spinel. The composite of spinel ferrite and hexagonal crystalline ferrite can effectively improve the electromagnetic properties of both, and achieve better absorption effect in a wider frequency band.

4.2. Magnetic metal micropowder and polycrystalline iron fibres

Usually referred to as metal powder is the particle size of 0.5 ~ 20 m single metal or metal alloy particles, they have high microwave permeability, good temperature stability and other characteristics, mainly through the hysteresis loss, eddy current loss to absorb electromagnetic waves. Metal micropowder as wave-absorbing materials have been widely used in stealth technology. Such as the United States "Hornet" on the use of a large number of carbonyl iron powder. There are two main types of metal micropowder: one is carbonyl iron, carbonyl nickel, carbonyl cobalt and other carbonyl metal micropowder; the other is the magnetic metal micropowder made by physical vapour deposition, chemical reduction or thermal decomposition of carbonyl compounds. The electromagnetic parameters of metal micropowders are closely related to the components, particle size and morphology. The electromagnetic parameters can be adjusted by adjusting the components and particle size of micropowders to match and broaden the frequency band. Carbonyl iron powder is one of the most commonly used metal powders. The carbonyl iron powder is blended with FeSiA1 particles. Change the content of FeSiA1 particles, can obtain a better low-frequency absorption performance (a 4.5-1.1 dB) and a wide band (<4 dB band 3.8 ~ 18 GHz) of wave-absorbing materials [6]. Wu et al. studied the effect of particle size of iron-based soft magnetic particle composites on their microwave properties, the results show that the magnetic spheres in the composite The results show that the particle size of the magnetic spheres in the composite has a great influence on its effective magnetic permeability. Wen et al. investigated the wave absorption performance of iron carbonyl in an epoxy resin matrix with a volume fraction of 40% by dispersing iron carbonyl in different shapes. When the carbonyl iron powder changed from a spherical structure to a flaky structure, the eddy currents, magnetic motion orientation and spatial polarization were reduced, which would have a better wave absorption effect. Although metal micropowders have been widely used in stealth technology, magnetic metal micropowders still have disadvantages such as high density, poor resistance to oxidation and acid and alkali, low resistivity, easy to produce skin effect in the coating, high dielectric constant, poor spectral characteristics, and poor absorption performance in the low frequency band. Magnetic metal micropowder nano and composite will be an important research direction in the future people's research on polycrystalline iron fiber began in the mid-1980s. Polycrystalline iron fibres absorbing materials include iron, drill, nickel and their alloy fibres, compared with metal micropowder, polycrystalline iron fibres can effectively reduce the density of the absorbing coating (40%-60% mass reduction in the same volume), and can effectively improve the absorption capacity of electromagnetic waves and broaden the width of the absorption band, in addition to having the advantages of absorption independent of the angle of incidence. It has been found that the main wave absorption mechanisms of polycrystalline iron fibres are eddy current loss, hysteresis loss and dielectric loss. The axial permeability and the radial dielectric constant are the main reasons affecting its electromagnetic parameters, so increasing the length-to-diameter ratio is the key to improve the wave absorption performance. Tong Guoxiu et al. used high purity argon as the carrier gas. By controlling the thermal decomposition temperature to control the grain size and components of the resulting polycrystalline iron fibres, the grain size of the polycrystalline iron fibres prepared at 700 was 61.1 nm, the aspect ratio was 10-40, and the C content was 3.88%, with the best soft magnetic properties. At the same time, the dielectric and magnetic losses were also the greatest. The resistivity of the polycrystalline iron fibre surface is very low, and it is easy to form a conductive network inside the absorbing coating when used, thus reducing its absorbing efficiency. In practical applications, the surface resistivity can be increased by means of surface modification [7]. In terms of radar wave absorption, polycrystalline iron fibres have broad application prospects.

4.3. Magnetic nano-absorbing materials

When the material particle size in the nanometer quantum level (1 ~ 100nm). The quantum effect causes the electron energy level to split, and the split energy level spacing is in the energy range corresponding to microwaves (10~~10 eV), which will produce a new wave absorption effect; the small size of nanoparticles, large specific surface area, high ratio of surface atoms, increased unsaturated bonds and hanging bonds, interface polarization and multiple scattering become important wave absorption mechanisms: in addition, magnetic nanoparticles have a high coercivity, which can cause large hysteresis loss. Therefore, in addition to the loss characteristics of traditional absorbing materials, nano-absorbing materials also have the advantages of wide absorption band, low density, thin thickness and good compatibility, etc. They are a new class of absorbing materials with good development prospects and application values. The main forms of nanomagnetic absorbing materials include nanoparticles or ultramicro particles, multilayer films, nanoparticle films (compared to multilayer films, the ferromagnetic particles in nanoparticle films are irregularly statistically distributed) and nano-assembled systems [8]. Magnetic nanomagnetic wave-absorbing materials exhibit better microwave absorption performance due to the characteristics of nanocrystals asking for multiple exchange coupling, small size effect, surface effect and the presence of a large number of lattice distortions, and therefore higher hysteresis loss. At present, the research on magnetic nano-absorbing materials mainly focuses on nano-magnetic film absorbing materials, nano-metal and alloy absorbing materials, nano-ceramic absorbing materials, nano-oxide absorbing materials, nano-composite absorbing materials and so on. The alloy powder made by composite method can avoid the disadvantages of narrow frequency band and poor absorption effect of single nano metal powder or oxide, which is also a hot topic of current research. The minimum reflectivity at 5.4GHz was 35dB. A. X. Huang et al. prepared carbon microtubule (CMT)/triiron tetroxide nanocomposites, and the results showed that when the coating thickness was 2.0mm, the minimum reflectivity at 10.64GHz was used the sol-gel method to synthesize ordered mesoporous Si. LiGuoxian et al.] used sol-gel method to synthesize ordered mesoporous SiC/FeNi nanocomposites with a coating thickness of 3.0 mm and a minimum reflectivity of 1.45.6 dB at 11.1 GHz [9].

5. Conclusion

The ideal wave-absorbing material should meet the requirements of "thin thickness, low density, wide frequency band, strong absorption". In order to overcome these shortcomings, the following will be the key research direction in the future: 1) the composite of a variety of materials, the preparation of composite wave-absorbing materials, mainly the electric loss of materials and magnetic loss of materials compound, so that they tend to impedance matching, thereby improving the absorption effect. 2) the structure of magnetic wave-absorbing materials to design, made of fiber, honeycomb, cluster or sheet, can reduce the absorbing material 3) Develop new types of absorbers and conduct in-depth research on their absorbing mechanism, so as to guide people to develop absorbers with more excellent performance [10].

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