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JOURNAL OF RARE EARTHS, Vol. 33, No. 3, Mar. 2015, P. 271
JOURNAL OF RARE EARTHS
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Effect of rare earths on microwave absorbing properties of RE-Co alloys

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Received 16 February 2014; revised 5 November 2014

Abstract: The powders of RE_2Co_{17} (RE=Y, Ce, Nd, Ho, Er) and Ho_xCo_{100-x} (x=6, 8, 10, 12) alloys were prepared by the arc melting method and high-energy ball mill process. The compositions and morphologies of the alloys were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM), and the microwave absorbing properties were studied by a vector network analyzer. The results showed that the alloy of Y_2Co_{17} had better absorbing properties at low frequencies and its lowest reflectivity value was –9.5 dB at 3.8 GHz. The lowest reflectivity value of Ho_2Co_{17} alloy was –13.7 dB at 7.02 GHz and it obtained large absorbing bandwidth. Reflectivity value less than –5 dB was from 5.1 to 10.2 GHz. When x=6 and x=8, the alloys of Ho_xCo_{100-x} consisted of Ho_2Co_{17} phase and Co phase. They had good radar absorbing properties. With increase in Ho content, the minimum reflectivity value worsened and the absorbing peak frequency shifted toward higher frequencies. But when x=12, the absorbing peak frequency shifted toward lower frequencies but the minimum reflectivity value worsened.

Keywords: RE_2Co_{17} alloy; microwave absorbing properties; high energy ball milling; Ho content; rare earths

Absorbing material[1] is a type of functional materials which can transform electromagnetic wave energy into other forms of energy to reduce the electromagnetic wave reflection. It is not only widely and importantly used in military fields, such as stealth aircrafts and missiles, but also in civilian applications in electronic devices, microwave anechoic chambers, and electromagnetic protections. New absorbing materials should meet the conditions of strong absorption, broadband and light quality performance[2–7]. Researches show that magnetic alloy powder is an excellent absorbing material due to its superior temperature stability, high permeability, high dielectric constant and high magnetic loss, etc.[8,9]. Researchers from the University of Paris[10] also found that the micron-sized powders of Co had high absorption values at 1–8 GHz. As the 4f electronic shell of rare earth elements is not filled, the atoms have a good magnetic moment, and the magnetic moment will not be affected easily by the conduction electrons and the adjacent lattice[11]. When the rare earth metal form the rare earth complexes with other elements, the coordination number may change from 3 to 12, and the crystal structure of the rare earth compounds also diverse. These unique properties just meet the basis for excellent microwave absorbing materials by regulating the complex permeability to adapt to the complex dielectric constant under microwave frequencies[12–15]. The alloys of RE_2Fe_{17} and RE_2Co_{17} have been widely studied by magnetic materials scientists because they can break the restrictions of Snoke limitation[16]. In this article we studied how different rare earths metal (RE=Y, Ce, Nd, Ho, Er) affected the absorption performance of Co-based alloys and provided the theoretical basis for researching absorption performance of the rare earth-transition metal.

1 Experimental

The alloys of RE_2Co_{17} and Ho_xCo_{100-x} (x=6 mol.%, 8 mol.%, 10 mol.%) were prepared by arc-melting high purity elements of RE-99.9% and Co-99.99%. The smelted alloys were completely sealed in vacuum silica glass tubes, followed by heat treatment at 700 ºC for 12 d, and then dropped directly from the hardening furnace into an ice water mixture. After cooling, the alloys were ground into coarse powder, then treated by means of ball milling for 50 h under the protection of petrol by using a QM-lSP planet ball mill whose speed was 350 r/min. The mass ratio of the ball to the powders was 20:1. The well-prepared powders were mixed with paraffin in 4:1 ratio (by mass). The mixture was made into a coaxial ring with a thickness of 3.5 mm, the inside and outside diameters were 3 and 7 mm, respectively. The complex per-

Foundation item: Project supported by the National Natural Science Foundation of China (50961005, 51161004, 51361007) and National Natural Science Foundation of Guangxi (2012GXNSFGA06002, 2014GXNSFAA118317)

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DOI: 10.1016/S1002-0721(14)60414-2

meability and complex permittivity in the frequency range of 2–18 GHz, which were used to calculate the reflectivity of the sample, were measured with an HP8722ES microwave vector network analyzer. The reflectivity of the powers was calculated using the formula[17]

$$R = 20\lg\left[\frac{\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi fd}{c}\sqrt{\mu_r\varepsilon_r}-1\right)}{\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi fd}{c}\sqrt{\mu_r\varepsilon_r}+1\right)}\right] \quad (1)$$

where, ε_r: the complex permeability, μ_r: the complex permeability, d: the thickness of the samples, f: the frequency of electromagnetic waves, c: the velocity of radio waves in vacuum, j: the unit of imaginary numbers. The phase structures and the microstructures of the alloys powders were analyzed by X-ray diffraction (PANalytical Empyrean) and scanning electron microscopy (JEOL-5610LV).

2 Results and discussion

2.1 Effect of RE on the morphology and absorbing properties of the RE_2Co_{17} alloy

XRD patterns of RE_2Co_{17} (RE=Y, Ce, Nd, Ho, Er) powder samples are demonstrated in Fig. 1. All the samples have a Th_2Zn_{17} structure type. Fig. 2 shows the SEM images of RE_2Co_{17} (RE=Y, Ce, Nd, Ho, Er) alloy powders. As can be seen from the SEM images of Nd_2Co_{17} alloy and Ho_2Co_{17} alloy after 50 h milling, these two kinds of rare earth alloy powders were flattened significantly, and the average particle size was about 10 μm. The powder of Y_2Co_{17} alloy was not significantly flattened after milling, and the particle size was about 6 μm with a lot of needle-like and powder-like particles. However, the needle-like particles of the Ce_2Co_{17} and Er_2Co_{17} powders were greatly increased, and the size was about 5 μm. From the view of particle morphology, the microwave absorption properties of flaky particles of alloy powder is better than the other morphologies, so the morphology of Nd_2Co_{17} and Ho_2Co_{17} alloy powders are beneficial to the improvement of the absorbing properties.

Fig. 3 shows the electromagnetic parameters of RE_2Co_{17} (RE=Y, Ce, Nd, Ho, Er) alloy samples at 2–18 GHz after 50 h milling.

As seen from Fig. 3(a), the ε' of Y_2Co_{17} and Nd_2Co_{17} alloy powders were significantly reduced as the frequency increased in the low frequency band, and the ε' basically had no change from 6 GHz to 18 GHz. The ε' of Ce_2Co_{17} and Ho_2Co_{17} and Er_2Co_{17} alloy powders changed gently in the range of 2–18 GHz. The real part of the complex dielectric constant meets the law that $\varepsilon'(Er_2Co_{17})<\varepsilon'(Ho_2Co_{17})<\varepsilon'(Ce_2Co_{17})<\varepsilon'(Nd_2Co_{17})<\varepsilon'(Y_2Co_{17})$, and the law of the conductivity which also states that: σ (Ce=0.0115×10^6/cm·Ω)<σ (Er=0.0117×10^6/cm·Ω)<σ (Ho=0.0124×10^6/cm·Ω)<σ (Nd=0.0157×10^6/

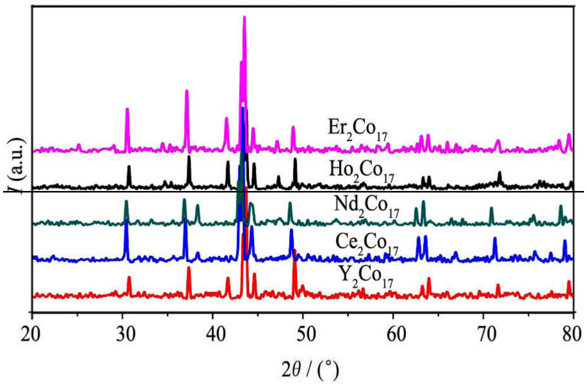

Fig. 1 XRD patterns of RE_2Co_{17} (RE=Y, Ce, Nd, Ho, Er) powder samples

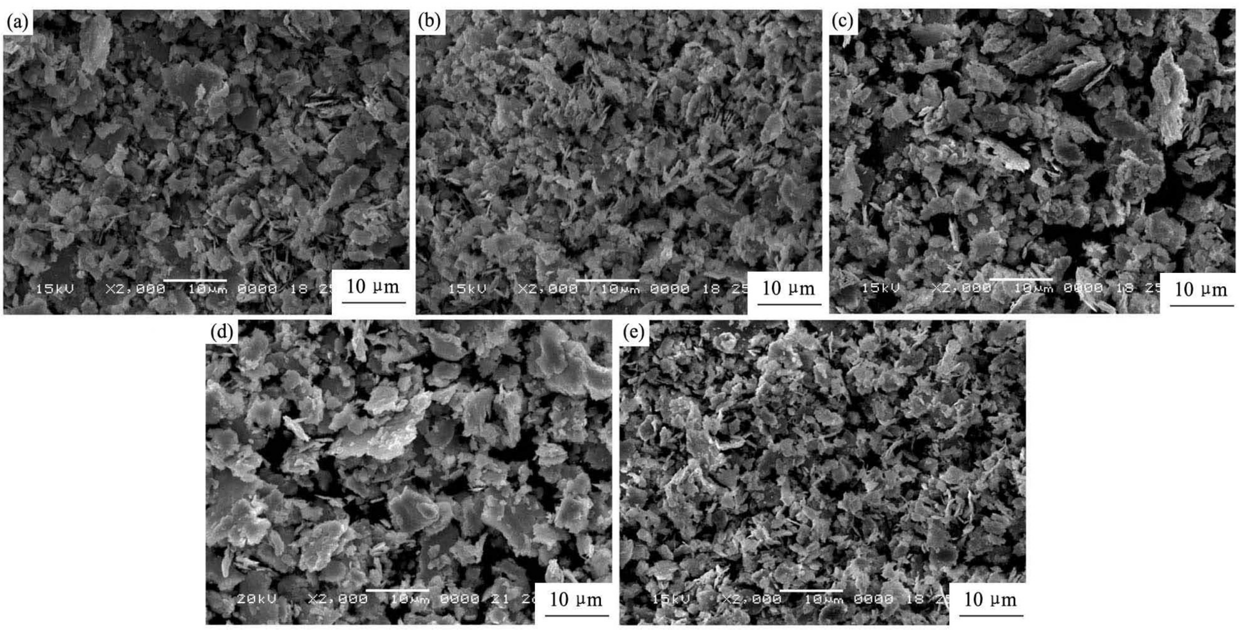

Fig. 2 SEM patterns of RE_2Co_{17} (RE=Y, Ce, Nd, Ho, Er) powder samples
(a) Y_2Co_{17}; (b) Ce_2Co_{17}; (c) Nd_2Co_{17}; (d) Ho_2Co_{17}; (e) Er_2Co_{17}