Vol 16 No 6, June 2007
1009-1963/2007/16(06)/1728-03
Chinese Physics
© 2007 Chin. Phys. Soc.
and IOP Publishing Ltd

Research on factors influencing on the microwave permeability of nanocrystalline FeB alloys*

Fu Cheng-Wu(傅成武)[a)†] and Zhang Shuan-Qin(张拴勤)[b)]

[a)] *School of Chemical and Material Engineering, Southern Yangtze University Wuxi* 214122, *China*
[b)] *The First Engineers Scientific Research Institute of the General Armaments Department Wuxi* 214035, *China*

(Received 28 September 2006; revised manuscript received 7 January 2007)

Nanocrystalline FeB alloys have been prepared with optimized grain size and internal stress. Samples prepared under different annealing conditions are analysed by x-ray diffraction, and the permeability $\mu(\omega)$ is measured by HP8510B Vector Network Analyser in the frequency range 2–18GHz. The results show that annealing leads to the growth of the grain size and reduces the internal stress, and smaller grain size and larger internal stress favours the magnetic dissipation.

Keywords: nanocrystalline , grain size, internal stress, magnetic dissipation
PACC: 7000, 7500, 7520E, 7560J

1. Introduction

With the fast development of radar reconnaissance and detection technology, radar absorbing materials (RAM) play an important role in the reduction of reflection from metallic structures. Such materials are often required to provide a specified reflectivity performance over a wide frequency range. At the same time, the weight, thickness, environmental survivability, and cost of the RAM are constraining factors. Small thickness, light weight, wideband absorbing properties and good mechanical stability are the prerequisite properties of RAM in the near future.[1]

Absorbing property of RAM is mainly determined by their magnetic and dielectric properties, which can be described by the complex magnetic permeability $\mu = \mu' + \mu''$ and dielectric permittivity $\varepsilon = \varepsilon' + \varepsilon''$. For an ideal RAM which has good absorbing property in the frequency range of interest, the imaginary part of μ'' and ε'' should be relatively high. μ and ε can usually be described as functions of frequency, $\mu(\omega)$ and $\varepsilon(\omega)$. Therefore, by controlling the dielectric and magnetic properties of RAM, the absorbing properties of RAM can be tuned. Most materials only exhibit dielectric properties. RAM with only dielectric properties can be made light, but often exhibits narrow band absorbing properties. Some other materials mainly display magnetic properties. When magnetic materials are used as absorbent, the magnetic dissipation plays an important role.

Nanocrystalline magnetic material has certain excellent characteristics due to the microstructure being comprised of uniformly dispersed crystallites less than 100 nm in size, and was promising for new potential applications in a variety of fields.[2−5] In this article, we report new progress made in improving the microwave magnetic dissipation of nanocrystalline FeB alloys by optimizing the grain size and internal stress, and show that the absorbing properties can be optimized by properly controlling the grain size and internal stress.

2. Experimental

Mechanical alloying [6] was adopted to prepare FeB alloy (labelled as Sample 1). Annealing was performed at two different temperatures, and the annealed specimens were labelled as Samples 2 and 3 respectively. Nanocrystalline FeB alloys with different grain sizes were prepared.

The crystal structure and the crystal sizes of FeB alloys were measured by x-Ray diffraction (XRD), using the D/Max-RA equipment.

The magnetic properties $\mu(\omega)$ of nanocrystalline FeB alloys were measured in the 2–18 GHz frequency range. FeB powder and paraffine were mixed thoroughly according to the weight ratio 7:1. Then the paste was made into round coaxial test fixtures. After the solvent was thoroughly dried, the HP8510B Vector Network Analyser was used to measure the $\mu(\omega)$

†Corresponding author. E-mail: fuchwu-308 @163.com

of the samples.

3. Results and discussion

Figures 1, 2 and 3 show the XRD spectra of nanocrystalline FeB alloy Samples 1, 2 and 3 before and after annealing, respectively. There are three diffraction peaks which represent the crystalline structure of FeB alloys. Comparing Figs.1, 2 and 3, it is shown that the peak width is narrowed due to annealing, and the position of the diffraction peaks is not changed. The broadening of diffraction peaks comes from two sources: one due to the testing apparatus, the other due to the intrinsic properties of the sample. In order to measure the peak width due to the sample, the instrumental width has to be eliminated. Standard silicon (Si) sample was used for calibration.[7]

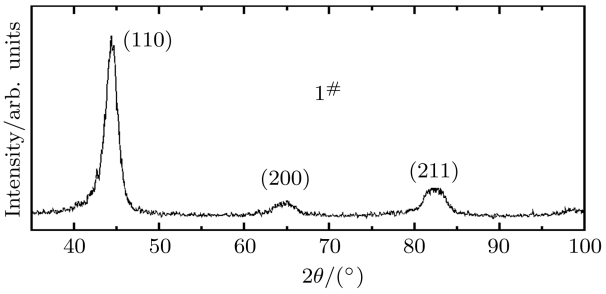


Fig.1. XRD Spectrum of unannealed Sample 1.

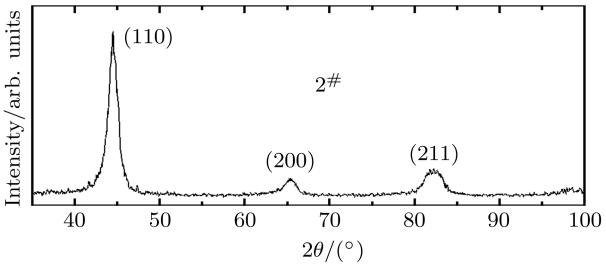


Fig.2. XRD Spectrum of Sample 2 after annealing.

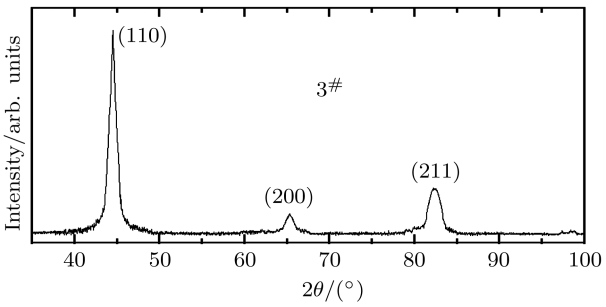


Fig.3. XRD Spectrum of Sample 3 after annealing.

According to the theory of broadening of diffraction peak,[8] the broadening of a diffraction peak can be expressed as:

$$\beta(2\theta) = \frac{K\lambda}{d\cos\theta} + 4\delta\tan\theta. \tag{1}$$

Here, d is the grain size, $K \approx 0.9$ is a constant, δ is the averaged deviation of lattice plane distance.

The first term on the right side of formula (1) represents the broadening due to the grain size, the second term represents the broadening due to internal strain. Formula (1) can be rewritten in the form

$$\frac{\beta\cos\theta}{\lambda} = \frac{K}{d} + 4\delta\frac{\sin\theta}{\lambda}. \tag{2}$$

Taking $\frac{\beta\cos\theta}{\lambda}$ and $\frac{\sin\theta}{\lambda}$ as the Y- and X-coordinates, respectively, the averaged internal strain δ and the grain size of the FeB alloy samples can be calculated by the slope and intercept of the linear curve. Table 1 shows the obtained results.

Table 1. Grain size and internal stress of FeB alloy samples.

Sample	Grain size d/nm	Internal stress/MPa
1#	11	0.49
2#	23	0.38
3#	36	0.24

It is shown that annealing is helpful for the growth of FeB grain size, and at the same time the internal stress is reduced.

Figure 4 shows the permeability $\mu(\omega)$ of Sample 1 without annealing. It shows that the magnetic dissipation reaches maximum at frequency of 5.5 GHz, and the effective complex permeability $\mu = 3.78 - \mathrm{i}3.46$. Comparing Figs.4, 5 and 6, it is seen that annealing makes the peak of μ'' flatter. Because annealing results in the increase of grain size and decrease of the internal stress, it can be inferred that decreasing the grain size and increasing the internal stress lead to the increase of magnetic dissipation μ''. As we know, magnetic dissipation is mainly caused by the damping effect when the domain wall and the magnetic moment are moving. With decreasing grain size, interface between the grains increases greatly, and the probability of the grain wall being pinned at the interface is increased. Thus much more energy is needed for the grain wall to break through the pinning of the interface. For the magnetic moment rotation, decreasing of the crystal size results in increasing of the amount of the magnetic moment, which thus results in much more dissipation energy. Whereas on further decreasing the crystalline size of FeB alloy, the magnetic

structure of the crystal grain will transform to single domain. Thus the dissipation due to the motion of the domain wall vanishes. Also, the higher coercive force due to single domain blocks the motion of the magnetic moment.[9] Thus it is believed that the magnetic dissipation is decreased for single domains.

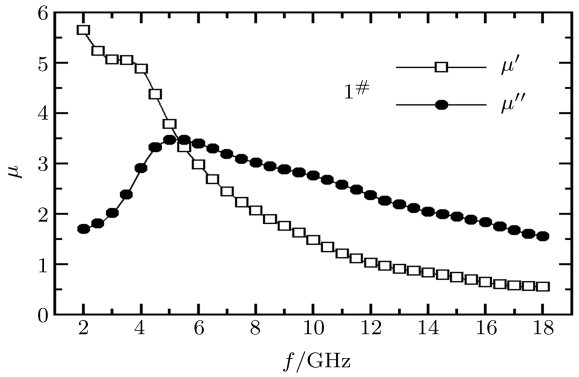


Fig.4. Curves of permeability vs. frequency for the unannealed Sample 1.

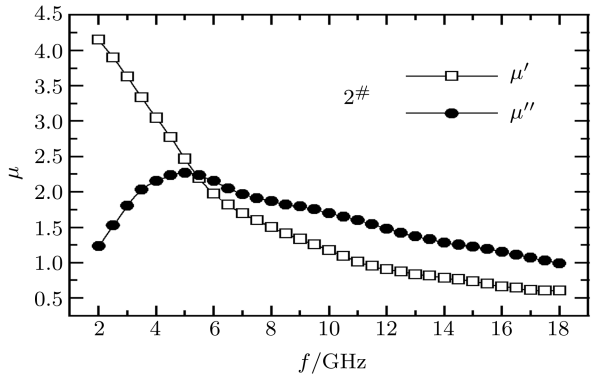


Fig.5. Curves of permeability vs. frequency for annealed Sample 2.

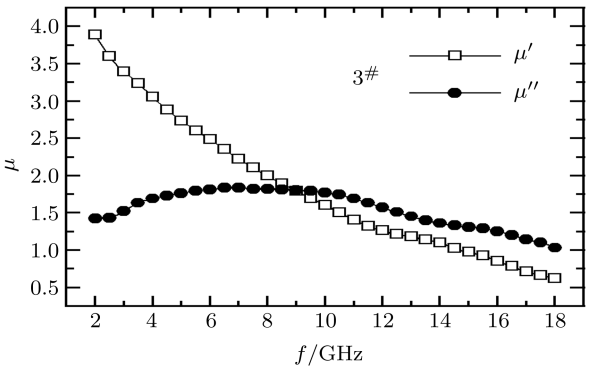


Fig.6. Curves of permeability vs. frequency for annealed Sample 3.

4. Conclusions

Nanocrystalline FeB alloys are prepared under different conditions. Annealing leads to the growth of the grain size and decreasing of the stress. The permeability and permittivity measurements show that small grain size and large inner stress favours the magnetic dissipation. It is concluded that the pinning of the domain wall and magnetic moment at interface of the grains is the major cause of magnetic dissipation, thus drastic increasing in magnetic dissipation can be achieved by properly controlling the grain size and internal stress. Crystalline FeB alloy can make a good absorbent of RAM.

References

[1] George T R, Donald E B, William D S and Clarence K K 1970 *Radar Cross Section Handbook* (New York: Plenum) p35

[2] Yang G, Zhuang H and Biswas P 1996 *Nanostructured Mater.* **7** 676

[3] Hagfeldt A, Valachopoulos N and Gratzel M 1994 *J. Electrochem. Soc.* **47** 182

[4] Lu J, Wang J and Rai R 1991 *Thin Solid Films.* **204** 113

[5] Mann S and Ozin G 1996 *Nature* **382** 313

[6] Jiang Z S and Lian C C 1999 *NanoStructured Materiasl* **6** 13

[7] Wu X S 1996 *Physica* C **273** 99

[8] Huang S T 1985 *X-Ray Diffraction of Solids* (Beijing: Senior Education Publishing House) p89 (in Chinese)

[9] Chien C L 1991 *In Science and Technology of Nanostructured Magnetic Materials: Granular Solids* (New York: Plenum) p477