

DESCRIPTION

SOFT MAGNETIC POWDER AND COMPOSITE MAGNETIC MATERIAL USING THE SAME

TECHNICAL FIELD:

The present invention relates to a magnetic material having excellent magnetic loss characteristics at high frequency regions. More particularly, the present invention relates to a soft magnetic material having excellent characteristics in complex magnetic permeability effective for suppressing extraneous radiation that is a problem in high frequency electronic components and electronic appliances and to composite magnetic material using the soft magnetic material.

BACKGROUND ART:

Use of highly integrated semiconductor elements that can operate at high speed is widely spreading. Examples of such elements include a random-access memory (RAM), read-only memory (ROM), microprocessor (MPU), and central processing unit (CPU).

Calculation speed and signal processing speed are continuously progressing in these active elements. Since electric signals transmitted through high speed electronic circuitry accompanies large voltage and current variations, they are liable to generate inductive noises and serve as extraneous radiation sources.

Making the electronic components and electronic appliances lightweight, thin, and compact is also a rapid and never-ending trend. As a result, semiconductor elements have been highly integrated and electronic components have been mounted on a printed circuit board in high density.

Consequently, the overcrowded integrated or mounted electronic elements and signal lines come into intimate contact with each other, and thereby high frequency noises are more readily induced in collaboration with the effect of high speed signal processing. It is also highly probable that generation and leakage of such high frequency noises cause malfunctions due to interference among the elements.

The problem of transmission of extraneous radiation from power supply lines to the active elements has been pointed out in recent years in electronic integrated elements and wiring boards. A countermeasure comprising inserting a component such as a decoupling capacitor having a lumped constant in the power line is employed for solving the problems described above.

However, the signal passage itself functions like a component having a lumped constant in the high speed integrated electronic elements or wiring boards because the generated noise involves harmonic components. Therefore, conventional countermeasures against the noise based on the circuitry having a lumped constant have become ineffective.

Accordingly, it is an object of the present invention to provide a soft magnetic material effective for countermeasures against extraneous radiation in the semiconductor elements and electronic circuits to be operated at high speed.

It is another object of the present invention to provide a composite magnetic material as a magnetic loss material that can simply and effectively cope with high frequency extraneous radiation arising in a wide frequency range.

DISCLOSURE OF THE INVENTION:

According to the present invention, there is provided a soft magnetic powder comprising a uniform composition which has a particle diameter distribution curve with a single maximum value without any other peaks and

troughs, and having two kinds of anisotropic magnetic fields having mutually different intensities.

In the present invention, it is preferable that the soft magnetic powder has a specific surface area of $0.3 \text{ m}^2/\text{g}$ or more. It is also preferable that the soft magnetic powder has a non-zero magnetostrictive constant at least in the vicinity of the surface of the powder particles.

The soft magnetic powder may comprise flat shape powder particles.

According to the present invention, there is also provided a composite magnetic material comprising a soft magnetic powder and a binder for binding the soft magnetic powder, and having two magnetic resonance points in two mutually different frequency regions.

In the present invention, the soft magnetic powder may be oriented and aligned in the composite magnetic material according to the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS:

Fig. 1 is a graph showing the particle diameter distribution curve of the magnetic powder to be used in the present invention;

Fig. 2 illustrates an apparatus for evaluating the electromagnetic interference suppressing effect of the composite magnetic material according to the present invention;

Fig. 3 shows μ -f characteristics of the sample No. 1 in one embodiment of the present invention;

Fig. 4 shows μ -f characteristics of the sample No. 2 in one embodiment of the present invention;

Fig. 5 shows μ -f characteristics of the sample No. 3 in one embodiment of the present invention;

Fig. 6 shows μ -f characteristics of the sample No. 4 in one embodiment of the present invention;

Fig. 7 shows μ -f characteristics of the sample No. 5 in one embodiment of the present invention;

Fig. 8 shows μ -f characteristics of the sample No. 6 in one embodiment of the present invention;

Fig. 9 shows μ -f characteristics of the sample No. 7 in one embodiment of the present invention; and

Fig. 10 shows μ -f characteristics of the sample No. 8 in one embodiment of the present invention.

BEST MODE FOR EMBODYING THE INVENTION:

The principle of the present invention will be described first.

The inventors of the present invention have invented a composite magnetic material having a large magnetic loss at high frequencies, and have found a method for effectively suppressing extraneous radiation generated from the semiconductor elements and electronic circuitry by disposing the composite magnetic material in the vicinity of the extraneous radiation sources.

With respect to the attenuation mechanism of extraneous radiation taking advantage of such magnetic loss, recent studies have shown that equivalent resistance components are added to the electronic circuit that serves as an extraneous radiation source. The magnitude of the equivalent resistance component and the frequency region that is affected by the magnitude of the equivalent resistance component depend on the magnetic loss term μ'' and its frequency dispersion range.

A larger μ'' value and dispersion of μ'' corresponding to the magnitude of the extraneous radiation are required for achieving larger attenuation of the extraneous radiation. However, since the frequency distribution of the extraneous radiation extends over a wide frequency range in most cases, frequency dispersion of the μ'' value involved in usual magnetic loss materials

cannot sufficiently compensate the extraneous radiation.

The present invention is carried out to solve such current problems as described above.

A soft magnetic powder that offers a required intensity of anisotropic magnetic field (H_k) within a wide frequency region should be developed in order to cope with the extraneous radiation extending over a wide frequency range. One method for obtaining such a magnetic powder is to mix plural magnetic powders each having different intensity of anisotropic magnetic field (H_k) with each other. However, the inventors have found a simpler method for obtaining a magnetic powder comprising a single component but having two mutually different intensities of anisotropic magnetic fields (H_k).

The soft magnetic powder according to the present invention comprises a uniform composition and exhibits a particle diameter distribution curve with a single maximum value without any other peaks and troughs as well as two anisotropic magnetic fields with different intensities with each other. The soft magnetic powder contains flat shape particles having a specific surface area of $0.3 \text{ m}^2/\text{g}$. The composition in the vicinity of the surface of the particles has a magnetostrictive constant of larger than zero.

The composite magnetic powder comprises a soft magnetic powder and a binder, and has two magnetic resonances in two mutually different frequency regions. The soft magnetic powder particles are oriented and aligned in the composite magnetic powder.

The magnetic powder according to the present invention is based on the discovery of differentiation of the powder characteristics (differentiation into non-uniform particles) obtained by grinding a raw magnetic material comprising a uniform composition into a powder having a prescribed level or more of specific surface area. Details of this phenomenon are reported in S. Yoshida et. al., J. Appl. Phys., Vol. 85, No. 8, p4636 - 4638 (1999).

Two mutually different intensities of anisotropic magnetic fields (H_k) are exhibited when the raw magnetic material comprising a uniform composition has a prescribed level or more of specific surface area. The reason will be described below.

The intensities of the diamagnetic magnetic field and eddy current flowing in the particles among the magnetic factors in the soft magnetic powder depend on the configuration of the powder particles. For example, it is difficult for the isotropic magnetic powder prepared by an atomizing method to obtain good magnetic properties in a high frequency region because the ferromagnetic magnetic field ascribed to the configuration of the powder particles becomes isotropic while exhibiting eddy current magnetic loss at a relatively low frequency region.

When the powder having an isotropic configuration of the particles is mechanically ground, on the other hand, magnetic permeability is largely improved as the configuration of the powder particles is progressively flattened by mechanical grinding. This is, because the diamagnetic magnetic field along the flattened surface of the particles is remarkably reduced, in addition to the largely reduced eddy current loss by a surface film effect due to the short length across the flattened surface, or reduced thickness, of the powder particles. Improvement of permeability is considered to be the synergetic effect of the two effects above.

Cracks are generated on the flattened particle surface to change the powder into a finer powder comprising flat particles, when this mechanical grinding of the powder is further proceeded. The specific surface area of the powder increases in proportion to the grinding time when the powder particles are flattened by mechanical grinding. This means that a flat magnetic powder having a different specific surface area can be obtained by changing the grinding time.

Alternatively, a flat powder having a different specific surface area can be also obtained by changing the particle diameter or the specific surface area of the starting powder material.

The inventors of the present invention have manufactured various flat powders having respective specific surface areas with respect to representative soft magnetic powders of Fe-Si-Al and Ni-Fe alloys, and they have investigated their magnetic properties. The inventors have found that additional magnetic resonance appears at higher frequency regions when the surface area exceeds a prescribed level. In other words, magnetic resonance due to larger magnetic anisotropy appears in addition to existing magnetic resonance appearing at a frequency depending on the composition, particle configuration, and residual stress. While expression of this phenomenon is facilitated to a certain extent by the magnitude of the magnetostrictive constant arising from the composition of the magnetic material, it can be recognized at a specific surface area of 0.3 m²/g or more in the flat powder with a composition of Fe-Si-Al and Ni-Fe as a representative soft magnetic metal.

This phenomenon is essentially different from the phenomenon observed when a configuration factor such as distribution of the particle diameter or aspect ratio of the particles in the flattened magnetic powder is represented by a binomial distribution for some reasons, for example when two kinds of powders having mutually different anisotropic magnetic fields (H_k) are mixed together. In other words, the phenomenon according to the present invention is that each of curves of complex permeabilities μ' and μ'' has two peaks in μ -F characteristics. The phenomenon is also essentially different from the phenomenon appearing by mixing two kinds of powders having different surface compositions from each another, because the volume in the vicinity of the surface of the powder particles is not negligible relative to the total volume of the powder.

The proportion of the surface area per unit mass, or the specific surface area, is a predominant factor for expressing two magnetic resonance points conjectured to be ascribed to surface magnetic anisotropy. However, the extent of the surface area for expressing the two resonance points are different depending on the other factors that cause surface magnetic anisotropy such as the magnitude of magnetoelastic effect or magnetostrictive constant, and the degree of residual stress in the powder. Accordingly, it is difficult to identify the critical surface area.

However, the surface area that permit the two magnetic resonance points to appear seems to be reduced as the powder has a larger anisotropic magnetoelastic effect. Consequently, the two resonance points are often observed at a relatively small surface area since a substantially large residual stress is conjectured to be caused by grinding in the mechanically ground and flattened powder.

In summary, two different intensities of anisotropic magnetic fields (H_k) are expressed and wide band μ'' -dispersion characteristics are obtained in the present invention, by specifying a critical surface area in the soft magnetic powder having a uniform composition and particle diameter distribution.

The starting materials to be used in the present invention will be described hereinafter. Representative examples of the soft magnetic powder to be used in the present invention comprises a powder of a metallic soft magnetic material such as a Fe-Al-Si alloy (sendust), Fe-Ni alloy (permalloy) or an amorphous alloy prepared by granulating by grinding processing, extension processing, or atomization granulation.

Powders of oxide soft magnetic materials such as spinel type ferrite, planar type ferrite, hematite, magnetite, and maghemite may be also used in the present invention.

Chlorinated polyethylene that is excellent in flexibility and fire resistance may be used for the binder as a sub-material for obtaining the composite magnetic material according to the present invention, because the composite magnetic material is used in the vicinity of the electronic circuitry. Organic binders available other than the chlorinated polyethylene include thermoplastic resins and thermoplastic elastomers such as a polyester resin, polyethylene resin, chlorinated polyvinyl resin, polyvinyl butylal resin, polyurethane resin, cellulose resin, ABS resin, ethylene-vinyl acetate copolymer, acrylonitrile-butadiene based rubber, styrene-butadiene based rubber and silicon rubber, and heat curable resins such as an epoxy resin, a phenol resin, an amide resin, and an imide resin.

The resins other than those described above may be also used for the binder according to the present invention, so long as the resins are thermoplastic resins and heat curable resins having appropriate adhesive property and flexibility.

The kneading and dispersing methods of the constitution elements are not particularly restricted for obtaining the composite magnetic material in the present invention. A preferable method may be selected, if necessary, based on the property of the binder used and the ease of the manufacturing steps.

Examples of the present invention will be described hereinafter. Powders of the Fe-Al-Si alloy comprising, by weight, 9.8% Si, 5.9% Al, and balance of Fe, and a powder of the Fe-Ni alloy comprising, by weight, 80% Ni and 20% Fe were used as the flat-shaped soft magnetic powders in these examples. An attriter and a pin-mill were used for elongating and grinding these alloys into flat-shaped powders. The magnetite powder was used as an example of an irregular-shaped soft magnetic powder.

For preparing the composite magnetic powder from the soft magnetic powders, a paste was first formed by weighing and mixing 90% by weight of the

soft magnetic powder, 10% by weight of chlorinated polyethylene resin as a binder and 50% by weight of toluene. Then, the paste was applied as a film by a doctor blade method, and the film was cured at 85°C for 24 hours after heat-pressing.

(Example 1)

Three kinds of powders of the Fe-Al-Si alloy having different specific surface areas with the compositions described above were prepared. The specific surface areas of these samples as measured by the BET method were 0.67 m²/g, 1.33 m²/g and 0.17 m²/g, respectively.

Fig. 1 shows the particle diameter distribution of the Fe-Al-Si alloy powder with the surface area of 0.67 m²/g. The particle diameter distribution curve shown in the graph has a single maximum value without any other peaks and troughs, indicating that the alloy powder has a unimodal particle diameter distribution. The particle diameter distribution curves of the other alloy powders also show similar patterns. An assay of the powder suggested that the surface of the particles of the alloy powder contains an excess amount of iron as compared with the bulk composition of the starting material.

These alloy powders were formed into sheets of the composite magnetic materials by the method as described above to subject them to evaluation of their characteristics. The samples comprising the alloy powders with the specific surface areas of 0.67 m²/g, 1.33 m²/g and 1.33 m²/g were termed as the sample Nos. 1, 2, and 3, respectively, for convenience.

These samples were assayed using a vibration sample type magnetometer and a scanning type electron microscope. The easy axis of magnetization and the direction of orientation of the particles were found to lay on the sample face from the assay results. For verifying the performance of these composite magnetic materials, magnetic permeability-frequency (μ -f) characteristics and suppressing effects of electromagnetic interference of these

samples were investigated. In the measurements of the μ -f characteristics, μ' and μ'' of the complex permeability were determined by measuring impedance of each sample of the composite magnetic material formed into a toroidal shape after inserting it into a test fixture for forming a one-turn coil.

As shown in Fig. 2, an evaluation sample 15 was prepared by supporting a square sheet of the composite magnetic material 11 with a dimension of 2 mm in thickness and 200 mm in the length of edge with a copper plate 13. For evaluation of the suppressing effect of electromagnetic interference, fine loop transmission and reception antennas 19 and 21 with a loop diameter of 1.5 mm were used as a wave source element and a reception element using an electromagnetic wave source oscillator 17, respectively. A network analyzer (electromagnetic field strength measuring apparatus) 23 was used for measuring the coupling level of the performance of the composite magnetic material.

With reference to Figs. 3 and 4, both of the sample Nos. 1 and 2 show large μ'' values at high frequency regions throughout a wide band owing to realizing a pair of two resonances 31, 32 and 33, 34 in curves of μ' and μ'' , respectively. On the contrary, the μ'' value of the sample No. 3 does not spread into the wide band as shown in Fig. 5, and shows a μ -f characteristic as is usually observed in the composite magnetic materials.

These results show that, while only one resonance point is observed in the composite magnetic material using an alloy powder having a relatively small specific surface area, two magnetic resonances 31, 32 and 33, 34 are clearly observed in the composite magnetic material using an alloy powder having a relatively large surface area, although the powder exhibits a unimodal particle diameter distribution curve. Consequently, the magnetic loss term μ'' also shows two dispersions ranging over a wide band. Expression of the two resonance points becomes more evident in the alloy powder having a larger

specific surface area. In other words, the sample Nos. 1 and 2 using an alloy powder with a specific surface area of 0.1 m²/g or more have wide band magnetic loss characteristics in the high frequency region.

Distribution of μ'' and the suppression effect of electromagnetic interference in each sample will be described hereinafter. The level of the suppression effect of electromagnetic interference as used herein is defined by the signal attenuation level relative to that of the copper plate (zero dB). Table 1 shows these results.

TABLE 1

		Sample 1	Sample 2	Sample 3
μ'' distribution		wide	wide	narrow
Signal Attenuation Level	800 MHz	7.0dB	6.5dB	6.9dB
	1.9 GHz	8.0dB	7.5dB	2.5dB

Table 1 clearly shows the following effects.

While the sample Nos. 1 and 2 show good suppressing effects of electromagnetic interference at both the 800 MHz band and 1.9 GHz band, the sample No. 3 shows substantially poor suppressing effects of electromagnetic interference at 1.9 GHz band.

Accordingly, it can be appreciated that the expanding effect of μ'' distribution according to the present invention is quite effective for suppressing the extraneous radiation over a wide range of frequencies.

(Example 2)

An example using the Fe-Ni alloy powder as a soft magnetic powder will be described below. The composite magnetic materials were also prepared in this example by the same method as in Example 1 using the alloy powders comprising flat shape particles with the specific surface areas of 0.13 m²/g, 0.47

m^2/g and $0.61 \text{ m}^2/\text{g}$, respectively. All the powders are confirmed to show unimodal particle diameter distribution curves.

The samples comprising the alloy powders with the specific surface areas of $0.13 \text{ m}^2/\text{g}$, $0.47 \text{ m}^2/\text{g}$ and $0.61 \text{ m}^2/\text{g}$ were also termed as the sample Nos. 4, 5, and 6, respectively, for convenience.

The results of evaluation of the magnetic permeability characteristics of the sample Nos. 4, 5, and 6 shown in Figs. 6, 7, and 8, respectively, will be discussed below. While only one resonance point is observed in the sample No. 4 using an alloy powder with a relatively small specific surface area, two magnetic resonance points are observed in the sample Nos. 5 and 6 using alloy powders having relatively large specific surface areas, although they have a unimodal particle diameter distribution curve. In addition, the two resonance points becomes more evident as the specific surface clearly is larger. Consequently, the magnetic loss term μ'' extends over a wide band since it has two dispersion points.

(Example 3)

Use of the flat shape magnetic powder have been described in Examples 1 and 2. However, since expression of the two magnetic resonance points is thought due to magnetic anisotropy of the surface of the powder particles, the same phenomenon may be expressed when the powder comprises non-flat particles. The example is described below. A magnetite (Fe_3O_4) powder comprising irregular shape particles and a unimodal particle diameter distribution curve was prepared as the magnetic powder. Magnetic powders with specific surface areas of $0.20 \text{ m}^2/\text{g}$ and $1.3 \text{ m}^2/\text{g}$ were also used, and the samples comprising the composite magnetic materials prepared as described in Example 1 were termed as the sample Nos. 7 and 8, respectively.

From the results of evaluation of magnetic permeability characteristics of the sample Nos. 7 and 8 shown in Figs. 9 and 10, it can be seen that two

resonance points are expressed in the samples using the magnetic powders having relatively small specific surface areas, although the powders have unimodal particle diameter distribution curves.

The examples as hitherto described show that additional magnetic resonance points appear at high frequency regions even in the magnetic powder having a uniform composition and unimodal particle diameter distribution curve, when the specific surface area of the magnetic powder reaches a prescribed level. This means that magnetic resonance points based on magnetic anisotropy appear in addition to the conventional magnetic resonance points that depend on the composition, shape, and residual stress.

The magnetic powder also has a uniform particle shape and unimodal particle diameter distribution curve in the present invention.

Some examples of the flat-shape fine particles of the soft magnetic metals were mainly shown in the embodiment of the present invention. However, two magnetic resonance points appearing in the powder comprising a uniform composition in the present invention are also expressed in a magnetic powder comprising irregular-shaped particles with a magnetostrictive constant of larger than zero, for example in magnetite, when the surface area reaches a certain level.

Wide band dispersion characteristics of μ'' can be obtained in the soft magnetic powder and in the composite magnetic material using the powder according to the present invention, because two magnetic resonance points appear in mutually different frequency regions even when the magnetic powder comprises a uniform composition and particle diameter distribution. This composite permeability μ'' is a magnetic loss term necessary for absorbing electromagnetic waves. A good noise suppressing effect appears when the composite permeability μ'' is large over a wide band.

The present invention provides a thin composite magnetic material effective for suppressing noises within high-frequency electronic appliances such as a mobile communication device by taking advantage of wide band composite permeability μ'' .

The composite magnetic material using the soft magnetic powder according to the present invention can be readily made to be flexible due to the characteristics of its constituting elements. Accordingly, the composite magnetic material can be formed into complex configurations and can comply with severe requirements against vibration resistance and impact resistance.

INDUSTRIAL APPLICABILITY:

As hitherto described, the soft magnetic powder and the composite magnetic material using the powder are effective materials for suppressing radiation of extraneous electromagnetic waves. The material is quite effective for protecting electronic components, particularly high speed active elements and highly integrated printed wiring boards, from noises.

CLAIMS

1. A soft magnetic powder comprising a uniform composition which has a particle diameter distribution curve with a single maximum value without any other peaks and troughs, and having two kinds of anisotropic magnetic fields having mutually different intensities.
2. A soft magnetic material according to Claim 1, having a uniform composition, a particle diameter distribution curve comprising a single maximum value without any other peaks and troughs, and a frequency variance of imaginary permeability realizing a bimodal form in a characteristic curve.
3. A soft magnetic powder according to Claim 1, having a specific surface area of $0.3 \text{ m}^2/\text{g}$ or more.
4. A soft magnetic powder according to any one of Claims 1 to 3, having a magnetostrictive constant of larger than zero at least in the vicinity of the surface of the powder particles.
5. A soft magnetic powder according to any one of Claims 1 to 4 comprising flat shape powder particles.
6. A soft magnetic powder according to any one of Claims 1 to 5 comprising a metallic soft magnetic material or an oxide soft magnetic material.
7. A soft magnetic powder according to Claim 6, wherein the metallic soft magnetic material is any one of a Fe-Al-Si alloy, Fe-Ni alloy, or an amorphous alloy, and the oxide soft magnetic material is any one of a spinel type ferrite, a planar type ferrite, hematite, magnetite or maghemite.
8. A composite magnetic material comprising a soft magnetic powder with a uniform composition having a particle diameter distribution curve comprising a single maximum value without any other peaks and troughs, and having two kinds of anisotropic magnetic fields having mutually different intensities, and a binder for binding the soft magnetic powder, the composite



magnetic material comprising two magnetic resonances in two mutually different frequency regions.

9. A composite magnetic material according to Claim 8, wherein the soft magnetic powder particles are oriented and aligned.

10. A composite magnetic material according to Claim 8 or 9, wherein the soft magnetic powder has a specific surface area of $0.3 \text{ m}^2/\text{g}$ or more.

11. A composite magnetic material according to any one of Claims 8 to 10, wherein the soft magnetic powder has a magnetostrictive constant of larger than zero at least in the vicinity of the surface of the powder particles.

12. A composite magnetic material according to any one of Claims 8 to 11, wherein the soft magnetic powder comprises flat shape powder particles.

13. A composite magnetic material according to any one of Claims 8 to 12, wherein the binder is an organic binder.

