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(19) **United States**(12) **Patent Application Publication**
KATO et al.(10) **Pub. No.: US 2008/0101979 A1**(43) **Pub. Date: May 1, 2008**(54) **HEXAGONAL Z-TYPE FERRITE SINTERED
BODY AND MANUFACTURING METHOD
THEREOF****Publication Classification**(51) **Int. Cl.****C22C 38/00** (2006.01)**B22F 3/00** (2006.01)(52) **U.S. Cl.** **420/8; 419/26**

(57)

ABSTRACT

The ferrite sintered body of the present invention is a hexagonal Z-type ferrite sintered body having a high permeability and a low anisotropy of permeability, comprising a c-axis-oriented plane in which a degree of orientation $fc_{\perp}$ is not less than 0.4, said degree of orientation being given as $fc_{\perp} = \Sigma I(HK0) / \Sigma I(HKL)$, when $I(HKL)$ is the integrated intensity of a diffraction peak represented by an index (HKL) in an X-ray diffraction pattern of which measurement range is $2\theta = 20$ to 80° , wherein the degree of orientation $fc_{\parallel}$ calculated from $fc_{\parallel} = I(0018) / I(110)$ in an X-ray diffraction is not less than 0.3 in at least two planes which are perpendicular to the aforementioned c-axis-oriented plane and are perpendicular to each other. Where $\Sigma I(HKL)$ is the sum of integrated intensity of all the diffraction peaks of hexagonal Z-type ferrite.

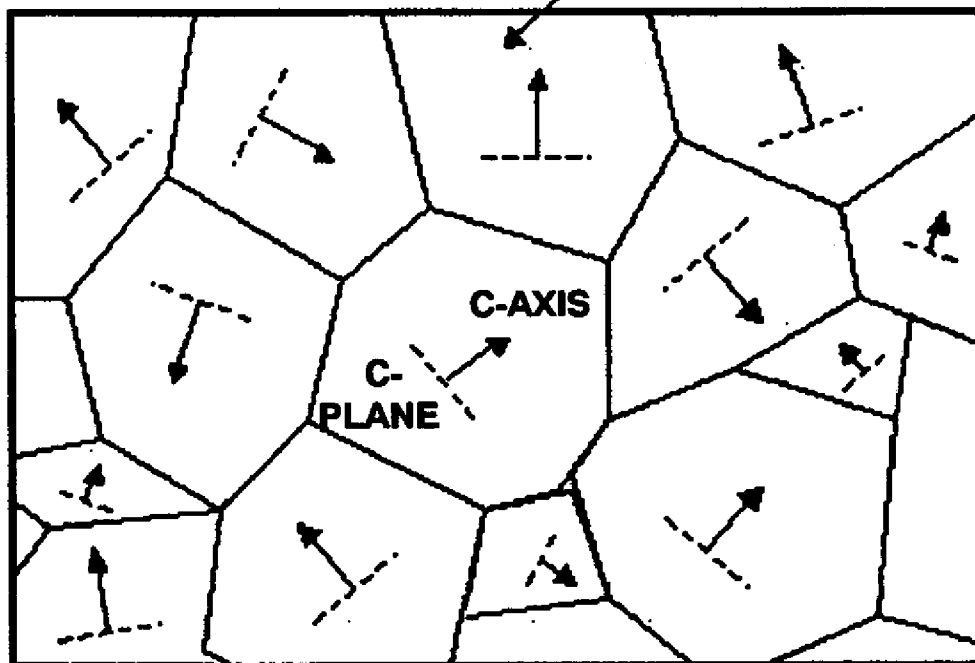
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CRYSTAL GRAIN OF Z-TYPE FERRITE

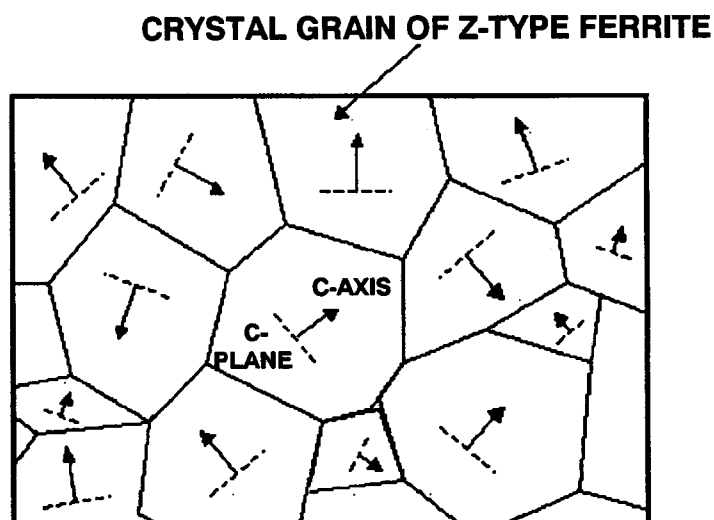


FIG.1

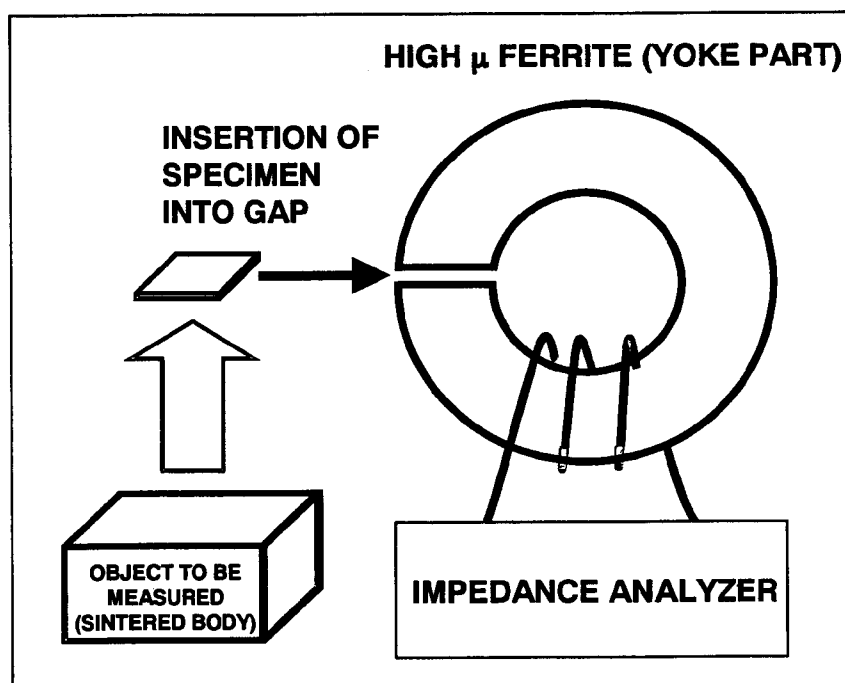


FIG.2

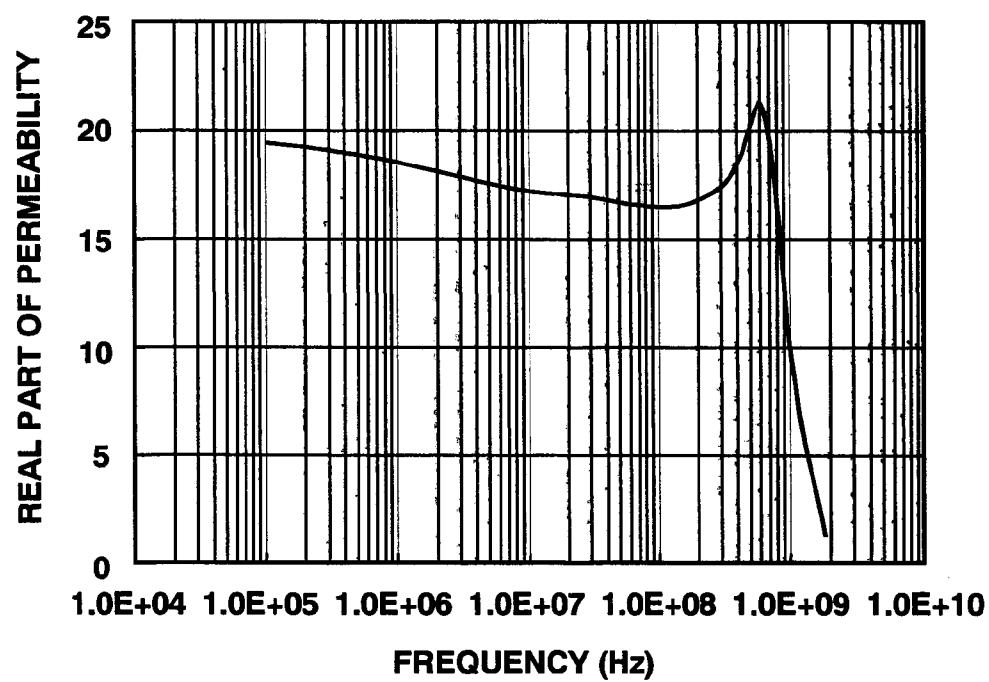


FIG.3

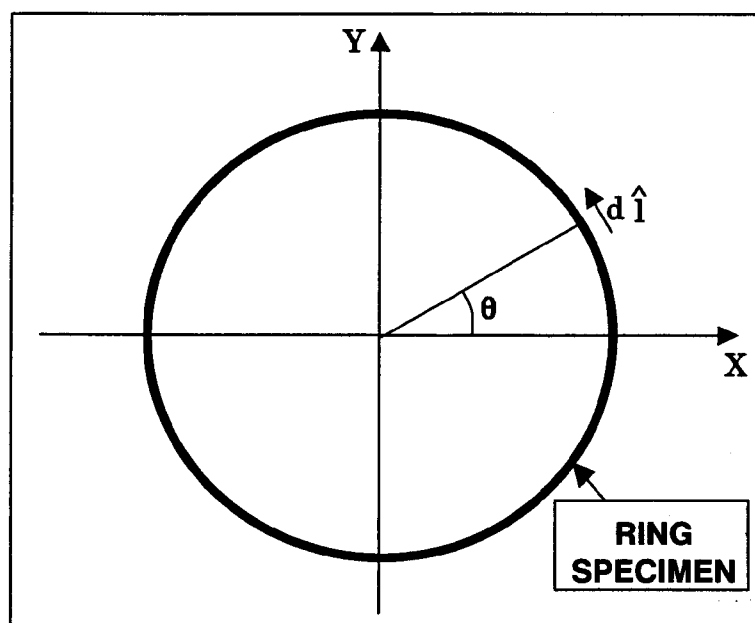


FIG.4

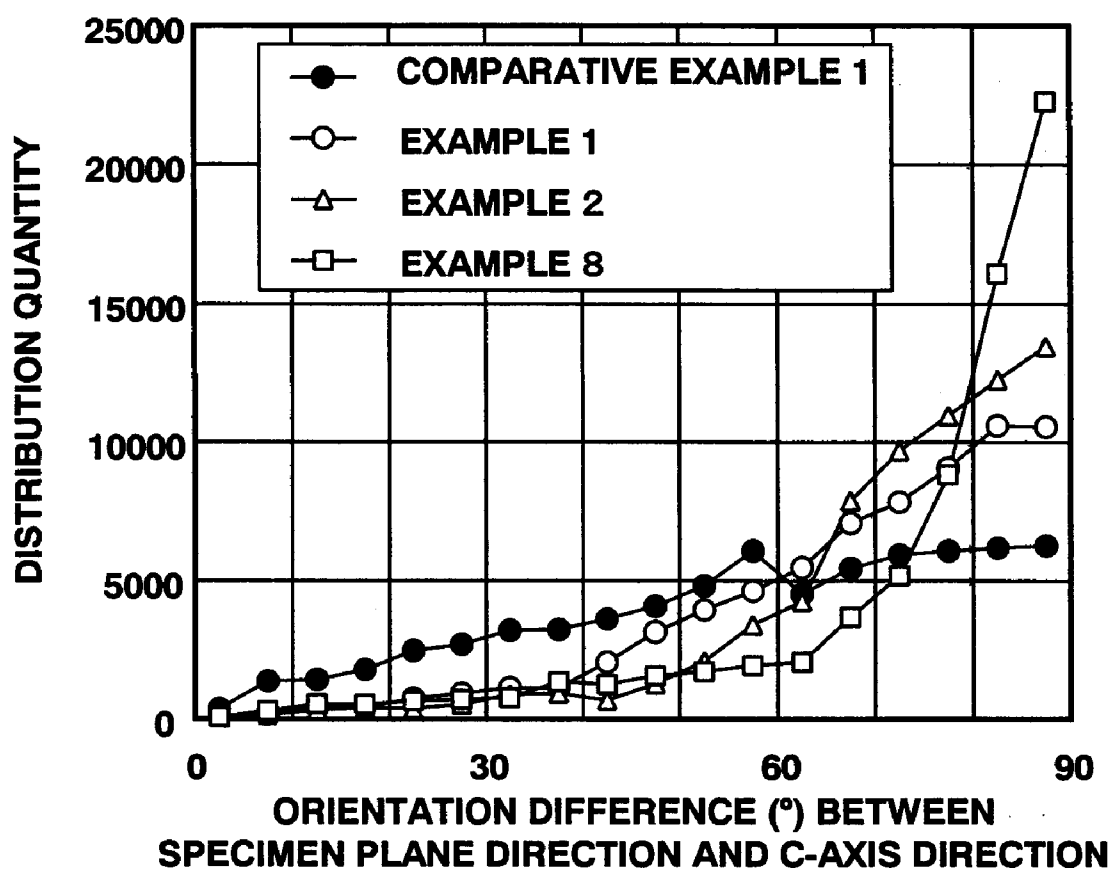


FIG.5

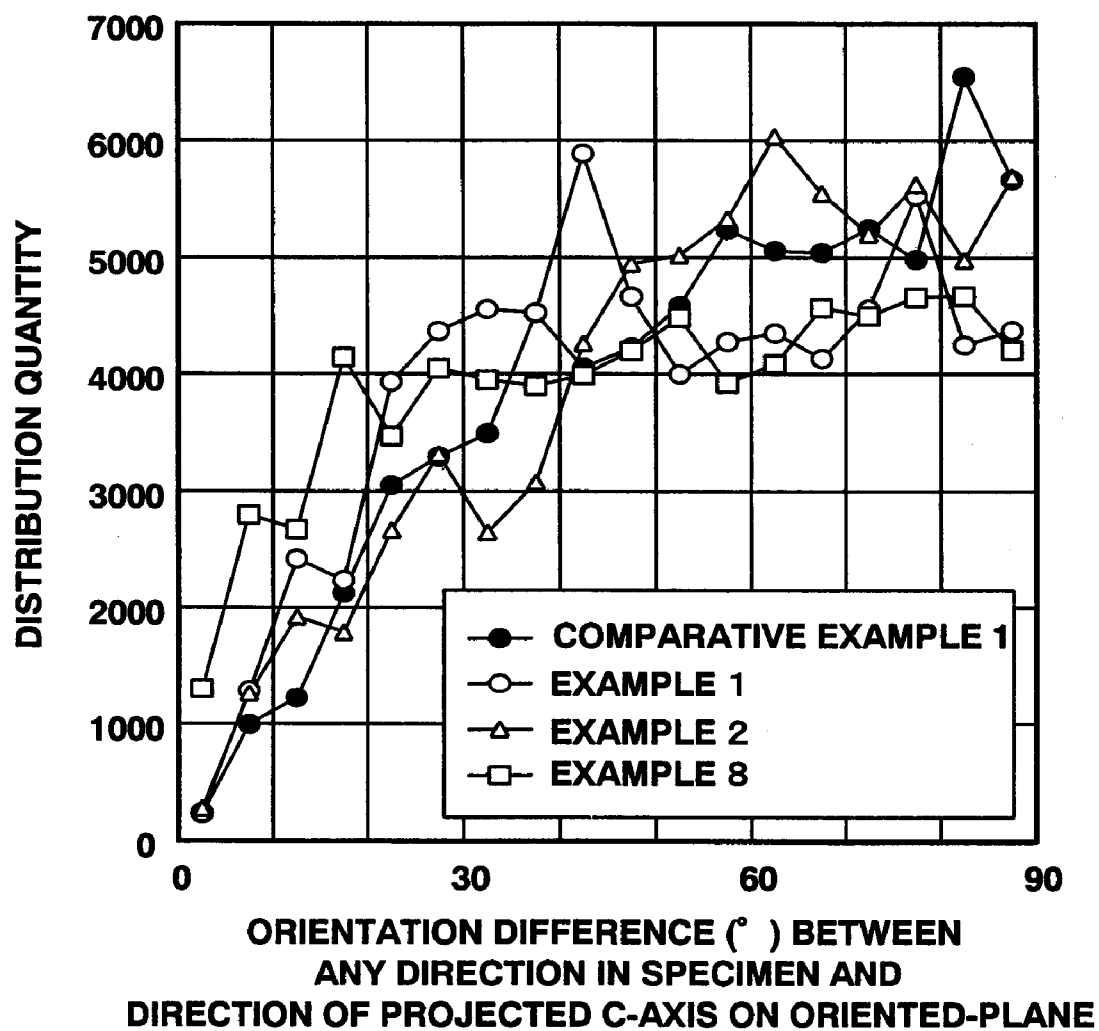


FIG.6

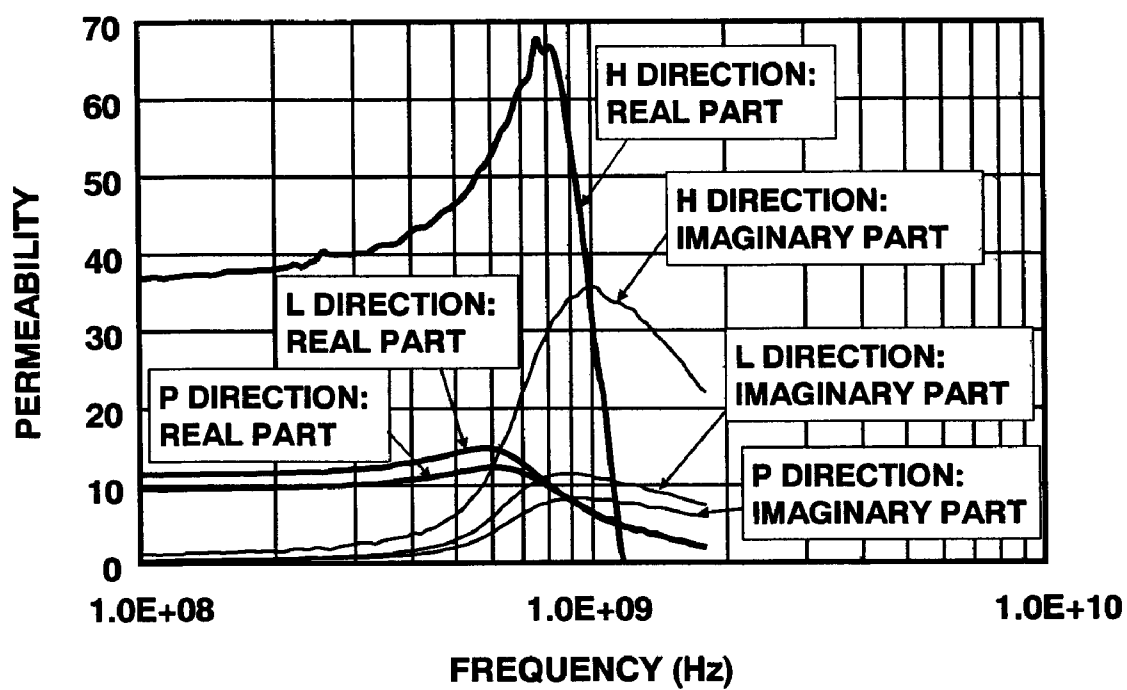


FIG.7

HEXAGONAL Z-TYPE FERRITE SINTERED BODY AND MANUFACTURING METHOD THEREOF

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to high frequency magnetic materials, and particularly to a hexagonal Z-type ferrite used for electronic components such as choke coils and noise removal elements or electromagnetic wave absorbers in a high frequency band of several MHz to several GHz.

[0003] 2. Description of the Related Art

[0004] Recently, as the frequency of signals for mobile phones, wireless LANs, Personal computers, etc. increases, there is a growing need for devices used in equipment, which can be used at high frequencies. For such a need, since spinel ferrites, which have been conventionally used, have a frequency limit called Snoek's limit in high frequency bands, it will become difficult to use them. Under the circumstances, hexagonal ferrites having a hexagonal crystal structure have been investigated as a high frequency material which overcomes such frequency limit.

[0005] Among hexagonal ferrites, particularly Z-type ferrites containing Co are known to have a relatively high permeability and to exhibit excellent high frequency characteristics. Moreover, since Z-type ferrites containing Co have an easy magnetization plane, an operation to align the c-axes of crystal grains by means of a rotating magnetic field applied from outside during forming can be performed (hereinafter, this operation is referred to as plane orientation, and the plane to which this operation is performed is referred to as oriented plane). By performing plane orientation, it is possible to increase the permeability in the oriented plane.

[0006] Japanese Patent Publication No. 35-11280 (patent Document 1) discloses that plane orientation of Z-type ferrite can be performed by applying a rotating magnetic field. Japanese Patent Laid-Open No. 48-97091 (patent Document 2) describes that a high level of plane orientation can be attained by applying a magnetic field from orthogonal two directions and also by using a hygroscopic mold so that disordering of the orientation is reduced. Further, WO2004/097863 (patent Document 3) discloses a Z-type ferrite which is subjected to plane orientation by rotating a metal die in a static magnetic field.

[0007] In the above mentioned patent Documents 1 to 3, there are descriptions that it is possible to obtain a sintered body in which z-type ferrite crystal is plane-oriented.

[0008] However, the inventions described in patent Documents 1 and 2 will lead to the complexity of apparatuses and processes relating to forming thereby causing a problem in productivity. Moreover, besides the aspect of productivity, they may not necessarily be adequate in the aspect of the application of those materials to devices. For example, patent Document 2 describes that although owing to the plane orientation a high permeability of more than 30 is obtained in the oriented plane, the direction perpendicular to the oriented plane becomes a hard magnetization direction exhibiting a low permeability of not more than 3.

[0009] That is, it is considered that all the plane-oriented Z-type ferrite sintered bodies described in patent Documents 1 to 3 are a sintered body which includes a low permeability

direction. For example, patent Document 2 discloses in Table 1, a ferrite which has a permeability μ of 1.5 in a direction perpendicular to the easy magnetization plane. Its permeability of this direction does not differ much from the permeability of vacuum of 1, and thus it is speculated that the ferrite does not substantially function as a magnetic body for the concerned direction.

[0010] Thus, since such a plane-oriented Z-type ferrite is applicable only to the formation of two-dimensional magnetic paths, it cannot be helped that the application range of such material has been quite limited. That is, such an extreme anisotropy will impose severe limitation in designing an inductance element.

SUMMARY OF THE INVENTION

[0011] In view of the above described problems, it is an object of the present invention to provide a hexagonal Z-type ferrite which has a high permeability in a specific direction as well as has a high permeability in directions other than the concerned direction thus offering a good balance of permeability and a method of manufacturing thereof.

[0012] The present invention is a hexagonal Z-type ferrite sintered body, characterized in that a c-axis-oriented plane in which a degree of orientation $fc_{\perp}$ is not less than 0.4, the degree of orientation being given as $fc_{\perp} = \Sigma I(HK0) / \Sigma I(HKL)$, where $\Sigma I(HKL)$ is the sum of integrated intensity of all the diffraction peaks of hexagonal Z-type ferrite, and $\Sigma I(HK0)$ is the sum of integrated intensity of all the diffraction peaks of (HK0) for which $L=0$ (where $I(HKL)$ is the integrated intensity of a diffraction peak represented by an index (HKL)) in an X-ray diffraction pattern of which measurement range is $2\theta=20$ to 80° , wherein the degree of orientation $fc_{\parallel}$ calculated from $fc_{\parallel} = I(0018) / I(110)$ in an X-ray diffraction is not less than 0.3 in at least two planes which are perpendicular to the aforementioned c-axis-oriented plane and are perpendicular to each other.

[0013] According to such configuration, it is possible to provide a hexagonal Z-type ferrite sintered body which has a high permeability as well as a small anisotropy of permeability.

[0014] The degree of orientation $fc_{\perp}$ is more preferably not less than 0.45. Moreover, the degree of orientation $fc_{\parallel}$ is more preferably not less than 0.5.

[0015] Further, the present invention is a hexagonal Z-type ferrite sintered body, which has a c-axis-oriented plane of which an average orientation difference θ_{AV} represented as $\theta_{AV} = \Sigma \theta n(\theta) / \Sigma n(\theta)$ is not less than 65° in the orientation analysis by EBSP (Electron Back Scattering Pattern) (where, θ indicates the orientation angle difference between the direction perpendicular to the orientation analysis plane of a hexagonal Z-type ferrite sintered body and the c-axis direction of hexagonal Z-type ferrite at the measurement position of EBSP, and $n(\theta)$ represents the number of measurement points to indicate the aforementioned θ . Moreover, $\Sigma \theta n(\theta)$ and $\Sigma n(\theta)$ represent the summation of $\Sigma \theta n(\theta)$ and $n(\theta)$ in the interval of 0 to 90° , respectively), and a value SD/n_{AV} which is given by dividing a standard deviation SD given by $SD = \{\Sigma (I(\phi) - n_{AV})^2 / m\}^{1/2}$ by an average value of the number of measurement points given by $n_{AV} = \Sigma I(\phi) / m$, is not more than 0.6 (where, ϕ is the positive acute angle which is the orientation difference between the projection direction of

c-axis direction to the aforementioned orientation analysis plane and one straight line in the aforementioned orientation analysis plane. $I(\phi)$ represents the number of measurement points to indicate the orientation difference ϕ , and m represents the number of dividing points in the interval of 0 to 90°).

[0016] According to such configuration, it is possible to provide a hexagonal Z-type ferrite sintered body which has a high permeability and a small anisotropy of permeability.

[0017] Further, the aforementioned hexagonal Z-type ferrite sintered body is principally composed of BaO, CoO, and Fe_2O_3 and preferably has a Ba-rich composition deviating from the stoichiometric composition $\text{Ba}_3\text{CO}_2\text{Fe}_{24}\text{O}_{41}$ of a hexagonal Z-type ferrite. Use of a Ba-rich composition makes it possible to achieve high densification.

[0018] Further, the aforementioned hexagonal Z-type ferrite sintered body preferably has a sintered body density of not less than $5.0 \times 10^3 \text{ kg/m}^3$. Configuring the sintered body density in such range contributes to the improvement of permeability. A sintered body density of not less than $5.0 \times 10^3 \text{ kg/m}^3$ is preferable to obtain a permeability of not less than 40. In this aspect, the sintered body density is more preferably not less than $5.1 \times 10^3 \text{ kg/m}^3$.

[0019] Furthermore, in the aforementioned hexagonal Z-type ferrite sintered body, the ratio of $\mu_{\parallel}/\mu_{\perp}$ is preferably not more than 0.6 at 100 kHz and/or 100 MHz for permeability $\mu_{\parallel}$ of at least two directions which are in parallel with the aforementioned c-axis-oriented plane and intersect with each other at right angles, where $\mu_{\perp}$ is a permeability perpendicular to the aforementioned c-axis-oriented plane, and $\mu_{\parallel}$ is a permeability parallel with the aforementioned c-axis-oriented plane.

[0020] Lowering of ratio $\mu_{\parallel}/\mu_{\perp}$ means a better orientation and also means that a high $\mu_{\perp}$ can be achieved. The aforementioned permeability ratio is more preferably not more than 0.4. Further the aforementioned ratio $\mu_{\parallel}/\mu_{\perp}$ is preferably not less than 0.1.

[0021] When crystal orientation increases, the permeability in the direction parallel with the c-axis-oriented plane decreases. If the difference between the permeability in the direction perpendicular to the c-axis-oriented plane and the permeability in the direction parallel with the c-axis-oriented plane becomes excessively large, it becomes difficult to use the direction along the c-axis-oriented plane as the magnetic path direction, leading to serious limitation to the magnetic circuit design.

[0022] Particularly, in a conventional plane orientation in which c-axis is aligned in one of directions in the c-axis-oriented plane, the ratio $\mu_{\parallel}/\mu_{\perp}$ for the concerned direction and permeability becomes very small, making it substantially difficult to use the concerned direction as a magnetic path.

[0023] Moreover, a value by a gap method in which measurement is made by inserting a hexagonal Z-type ferrite sintered body specimen into a gap provided in a ring specimen having a known permeability is used for the permeability at 100 kHz, and a value by a ring method as described below is used for the permeability at 100 MHz. These measurement methods will be described in detail below.

[0024] Further, in the aforementioned hexagonal Z-type ferrite sintered body, the permeability in the direction perpendicular to the aforementioned c-axis-oriented plane at 100

kHz is preferably not less than 30. In order to configure a high inductance element, the aforementioned permeability is more preferably not less than 35, and further preferably not less than 40. Furthermore, in order to configure an inductance element which exhibits a high inductance at high frequencies, the permeability at 100 MHz is preferably not less than 30, and more preferably not less than 35.

[0025] Further, in the aforementioned hexagonal Z-type ferrite sintered body, the permeability at 100 kHz of at least two directions which are parallel with the c-axis-oriented plane and intersect with each other at right angles is preferably not less than 8.

[0026] In the present invention, although permeability becomes particularly high in the direction perpendicular to the c-axis-oriented plane, according to the aforementioned configuration, a high permeability is exhibited even in directions parallel with the c-axis-oriented plane. Therefore, directions parallel with the c-axis-oriented plane can also be used as the magnetic path direction.

[0027] Exhibiting a high permeability in at least two directions which are parallel with the c-axis-oriented plane and intersect with each other at right angles means that the anisotropy of permeability in the concerned in-plane directions is small. According to such configuration, it is possible to provide a hexagonal Z-type ferrite sintered body which has a low anisotropy of permeability and a high flexibility of design. The permeability in the direction parallel with the c-axis-oriented plane at 100 kHz is more preferably not less than 10. Furthermore, the permeability in the direction parallel with the c-axis-oriented plane at 100 MHz is more preferably not less than 8.

[0028] Further, the aforementioned hexagonal Z-type ferrite sintered body preferably has a machined surface. Having a machined surface will result in a configuration in which a portion at an end of the sintered body where orientation is disordered has been removed, and thereby contributes to increasing permeability, and restraining the variation of the permeability.

[0029] Further, the method of manufacturing the hexagonal Z-type ferrite sintered body according to the present invention is characterized by comprising the steps of: forming a hexagonal Z-type ferrite powder which has a specific surface area of 800 to 4000 m^2/kg in a uniaxial magnetic field to obtain a green body; and sintering the aforementioned green body. According to such method, it is possible to provide a hexagonal Z-type ferrite sintered body which has a high permeability and a low anisotropy of permeability.

[0030] Further, in the aforementioned method of manufacturing the hexagonal Z-type ferrite sintered body, it is preferable to perform forming after mixing the aforementioned hexagonal Z-type ferrite powder with water to make a slurry, so that the concentration of hexagonal Z-type ferrite powder in the aforementioned slurry is not more than 70% by weight. According to the aforementioned configuration, it is possible to achieve a higher orientation. The aforementioned concentration is preferably not more than 65% by weight.

[0031] Further, in the aforementioned method of manufacturing the hexagonal Z-type ferrite sintered body, it is preferable to perform forming after stirring the aforementioned hexagonal Z-type ferrite powder in a die cavity while apply-

ing a magnetic field. According to the concerned configuration, it is possible to realize an even higher orientation.

[0032] Further, in the aforementioned method of manufacturing the hexagonal Z-type ferrite sintered body, the aforementioned hexagonal Z-type ferrite powder is preferably obtained by pulverizing a hexagonal Z-type ferrite sintered body. Since such hexagonal Z-type ferrite powder has little secondary phase and its crystal grains have fully grown, it is easily oriented and therefore is advantageous.

[0033] According to the present invention, it is possible to provide a hexagonal Z-type ferrite which has a high permeability in a specific direction, and has a high permeability even in directions other than the concerned direction, thus offering a good balance of permeability and a method of manufacturing thereof. By using the ferrite sintered body of the present invention, it becomes possible to provide high quality choke coils, inductors, and magnetic wave absorbers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] FIG. 1 is a conceptual view to show a state in which the c-axes of crystal grains are oriented toward the observed plane;

[0035] FIG. 2 is a conceptual view to show the measurement method by a gap method;

[0036] FIG. 3 shows the frequency dependency of permeability of a hexagonal Z-type ferrite sintered body according to a conventional dry process;

[0037] FIG. 4 shows the definition of r , θ , and a line element in a ring specimen;

[0038] FIG. 5 shows the distribution of the orientation difference between the c-axis orientation and the perpendicular direction to the specimen plate plane;

[0039] FIG. 6 shows the distribution of the orientation difference between the direction in which c-axis direction is projected onto the specimen plate plane (observed plane) and a specific direction on the specimen plate plane (observed plane); and

[0040] FIG. 7 shows the frequency characteristics of complex permeability in H, L, and P directions of example 4.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Hereinafter, the present invention will be described by way of embodiments in detail, but the present invention will not be limited by those embodiments.

[0042] The ferrite sintered body used as the material for the present invention can be manufactured by a typical powder metallurgy method applied to the manufacturing of ferrites, unless particularly specified in the present invention. The typical powder metallurgy method is as follows.

[0043] For example, raw materials are mixed by a wet ball mill, and then calcined using an electric furnace etc. to obtain calcined powder. Further, the resultant calcined powder is pulverized using a wet ball mill etc. and the resultant pulverized powder is formed by a press machine and then is fired by using an electric furnace etc. to obtain a hexagonal Z-type ferrite sintered body.

[0044] In the present invention, the pulverized powder to be subjected to the above described forming is fabricated for

example as follows. The sintered body obtained as described above is crushed by using a jaw crusher, a disk mill, etc. to obtain a coarse powder. The resultant coarse powder is pulverized by using a vibration mill, a ball mill, a jet mill, etc. to obtain a fine powder. The resultant fine powder is added with water to form a slurry and is pressed while applying a magnetic field using a metal die which is devised such that a magnetic flux is introduced in its molding cavity. The resultant green body is dried and thereafter resintered to obtain a ferrite sintered body. This manufacturing method will be described in more detail below.

[0045] Hereinafter, the hexagonal Z-type ferrite sintered body according to the present invention will be specifically described.

[0046] A hexagonal Z-type ferrite is typically represented by $\text{Ba}_3\text{CO}_2\text{F}_{24}\text{O}_{41}$. A hexagonal Z-type ferrite sintered body is a sintered body containing such a hexagonal Z-type ferrite phase. It is possible to partially replace part of Ba with Sr, or part of Co with at least one of Cu, Zn, and Ni. The hexagonal Z-type ferrite sintered body may partially contain a secondary phase such as hexagonal ferrite phases (W phase, Y phase, and M phase) other than the above described Z phase, a spinel phase, BaFe_2O_4 phase, etc.

[0047] Further, a hexagonal Z-type ferrite sintered body is principally composed of BaO, CoO, Fe_2O_3 , and preferably has a Ba-rich composition deviating from the stoichiometric composition $\text{Ba}_3\text{CO}_2\text{Fe}_{24}\text{O}_{41}$ of hexagonal Z-type ferrite. It is considered that deviating from the stoichiometric composition $\text{Ba}_3\text{CO}_2\text{Fe}_{24}\text{O}_{41}$ may result in the generation of a secondary phase, and a Ba-rich composition is likely to result in a BaFe_2O_4 phase. This BaFe_2O_4 phase will contribute to increasing the sintered body density, while it will not significantly affect the magnetic orientation since it is a nonmagnetic phase even when it grows into a secondary phase. Thus, since it is possible to increase the sintered body density while maintaining a high orientation, the above Ba-rich composition is preferable to obtain a hexagonal Z-type ferrite having a high permeability.

[0048] In order to obtain a high sintered body density, it is preferable to contain as principal components 17 to 21% by mole of BaO, 6 to 13% by mole of CoO, and Fe_2O_3 as the balance. Further, it is preferable to contain 0.05 to 1.0% by mass of Li in terms of Li_2CO_3 with respect to the above described composition. Containing the above described principal components and the above described Li are preferable for the high densification of a sintered body.

[0049] Further, Li and in addition Si may be contained in combination. When Li in conjunction with Si is contained, a specific synergetic effect of increasing the sintered body density and the permeability. Although even a small amount of Si exhibits a combining effect with Li and the effect of increasing volume resistivity, when it is less than 0.05% by mass in terms of SiO_2 , there is substantially no such effect, and on the other hand, when it exceeds 0.5% by mass, the volume resistivity will no longer be improved, and the permeability and sintered body density will be caused to decrease; therefore, a range of 0.05 to 0.5% by mass is preferable. By adding the above described range of Si in combination with Li, it is possible to achieve an effect of increasing initial permeability due to the containment of Li, while maintaining a sintered body density of not less than $4.95 \times 10^3 \text{ kg/m}^3$ and a volume resistivity of not less than $10^4 \text{ } \Omega \cdot \text{m}$. Further, in order to

increase the volume resistivity, 0.05 to 5% by mass of Mn in terms of Mn_3O_4 as a bivalent metal ion may be contained.

[0050] Next, the configuration of the hexagonal Z-type ferrite sintered body relating to the present invention will be described in more detail. The hexagonal Z-type ferrite sintered body according to the present invention has a magnetic orientation as described below.

[0051] An X-ray diffraction is conducted on a specific plane of the sintered body, the degree of orientation will be determined as described below. First, in an X-ray diffraction pattern on one plane of the hexagonal Z-type ferrite sintered body, the sum of integrated intensity of all the diffraction peaks caused by the hexagonal Z-type ferrite included in the measurement range of $2\theta=20$ to 80° is calculated as $\Sigma I(\text{HKL})$, and the sum of integrated intensity of the diffraction peaks of all the planes (HK0) of which $L=0$, included in the above described range is calculated as $\Sigma I(\text{HK0})$.

[0052] That is, $\Sigma I(\text{HKL})$ is obtained by integrating diffraction peaks of hexagonal Z-type ferrite over entire 2θ from 20° to 80° . Moreover, $I(\text{HKL})$ represents an integrated intensity of the diffraction peaks from the lattice plane represented by an index (HKL). In this case, with the peak angle of diffraction line of (HKL) plane being $\theta(\text{HKL})$, a value obtained by integrating from $\theta(\text{HKL})-0.4^\circ$ to $\theta(\text{HKL})+0.4^\circ$ is used as $I(\text{HKL})$.

[0053] From the above described $\Sigma I(\text{HKL})$ and $\Sigma I(\text{HK0})$, the degree of orientation $fc_\perp$ is defined. The degree of orientation $fc_\perp$ is given as $fc_\perp = \Sigma I(\text{HK0}) / \Sigma I(\text{HKL})$. The larger value of this degree of orientation $fc_\perp$, i.e. the larger value of the denominator $\Sigma I(\text{HK0})$ means that there are more crystal grains of which c-axis is oriented toward the concerned plane, in the plane on which X-ray diffraction is being conducted. Among hexagonal Z-type ferrites, in the case of the composition represented by $\text{Ba}_3\text{CO}_2\text{Fe}_{24}\text{O}_{41}$, since the direction perpendicular to the c-axis (i.e. C-plane) is an easy magnetization plane, the fact that there are more crystal grains of which c-axis is oriented toward the concerned plane means that the permeability in the direction perpendicular to the concerned plane becomes higher.

[0054] Supposing that the above described degree of orientation $fc_\perp$ is not less than 0.4, the permeability becomes higher in the direction perpendicular to the plane on which X-ray diffraction is being performed, and it becomes possible to obtain for example a permeability of not less than 30 at a frequency of 100 kHz. In the present invention, the plane which has such a degree of orientation is referred to as a "c-axis-oriented plane." More preferably, the degree of orientation $fc_\perp$ is not less than 0.45 to attain a permeability of not less than 35. Moreover, it is preferable to have a permeability of not less than 30 even at 100 MHz. It is preferable that c-axes of more crystal grains are oriented toward the direction of the plane on which X-ray diffraction is being conducted. FIG. 1 shows, as an ideal state, a state in which c-axes of all the crystal grains are oriented toward the plane on which X-ray diffraction is being conducted.

[0055] As seen from FIG. 1, the C-plane of each crystal grain is perpendicular to the plane on which X-ray diffraction is being conducted. In this case, as long as the C-plane which is an easy magnetization plane, is perpendicular to the plane on which X-ray diffraction is being conducted, the permeability in the direction perpendicular to the plane on which

X-ray diffraction is being conducted will become high in whichever direction c-axis is oriented.

[0056] In this case, the state in which the direction of c-axis is also oriented in a fixed direction, corresponds to the case of the plane oriented state as disclosed in patent Document 1. However, in the point that C-planes are parallel with the direction perpendicular to the plane on which X-ray diffraction is being conducted, since there is no difference between the state of FIG. 1 and the plane oriented state, there will be no difference of permeability in principle in the concerned direction. On the contrary, aligning c-axes in a fixed direction will make the permeability in the concerned fixed direction to be extremely low.

[0057] In this respect, the present invention has adopted the state in which C-planes are oriented in a direction perpendicular to the plane on which X-ray diffraction is being conducted (C-planes are parallel with the concerned direction), and c-axes are randomly oriented in the direction of the plane perpendicular to the concerned direction. As such an index, a degree of orientation $fc_\parallel$ calculated from $fc_\parallel = I(0018) / I(110)$ in an X-ray diffraction in two planes which are perpendicular to the above described c-axis-oriented plane (corresponds to the plane on which X-ray diffraction is being conducted) and are perpendicular to each other (herein after referred to as perpendicular planes) is adopted and the concerned degree of orientation $fc_\parallel$ is configured to be not less than 0.3.

[0058] The larger value of the concerned degree of orientation $fc_\parallel$ means that there are more crystal grains of which c-axes are oriented in the direction perpendicular to the above described perpendicular planes. This condition is satisfied at least in the two perpendicular planes, which ensures that c-axes are randomly oriented. Such an orientation mode corresponds to an orientation mode possessed by a sintered body formed by applying a uniaxial magnetic field, i.e. a direct-current static magnetic field of a predetermined direction. By doing this, it is possible to obtain a high permeability in a direction parallel with the c-axis-oriented plane without being biased to a specific direction.

[0059] It is one feature of the present invention that with the above described configuration, it is possible to increase the permeability in the direction perpendicular to the c-axis-oriented plane, while maintaining the permeability in the direction of c-axis-oriented plane, by adjusting the degree of orientation fc to be within a predetermined range. By adjusting the degree of orientation $fc_\parallel$ to be not less than 0.4, it is possible to make the ratio of the permeability at 100 kHz in the direction parallel with the c-axis-oriented plane to the permeability at 100 kHz in the direction perpendicular to the c-axis-oriented plane to be not more than 0.6, in at least two directions which are parallel with the c-axis-oriented plane and are perpendicular to each other.

[0060] Especially, when a high permeability is required, it is preferable to increase the permeability in the perpendicular direction to the c-axis-oriented plane by adjusting the above described permeability ratio to be not more than 0.4, and further to be not more than 0.3. On the other hand, by providing the above described orientation mode, it becomes possible to make the above described ratio to be not less than 0.1 in at least two directions which are parallel with the c-axis-oriented plane and are perpendicular to each other. Also by making it to be not less than 0.15 for the ratio with respect to the permeability in the direction perpendicular to the c-axis-

oriented plane, it is possible to provide a hexagonal Z-type ferrite sintered body which exhibits an excellent balance of permeability.

[0061] The configuration relating to the above described permeability ratio may be fulfilled at 100 MHz instead of, or in addition to 100 kHz.

[0062] It is possible to obtain a permeability of not less than 8 at 100 kHz in the direction parallel with the c-axis-oriented plane. By having such a high permeability also in the direction parallel with the c-axis-oriented direction, it is possible to use the concerned direction as a magnetic path direction.

[0063] Further, it is preferable to have a permeability of not less than 8 at 100 MHz. In the case of plane orientation, it may be possible to satisfy the condition that $fc_{\parallel}$ is not less than 0.3 in a plane which is perpendicular to the c-axis-oriented plane (a plane in the plane orientation direction), but is not possible to satisfy the condition that $fc_{\parallel}$ is not less than 0.3 in two planes which are perpendicular to each other.

[0064] More preferably, the concerned degree of orientation $fc_{\parallel}$ is not less than 0.5. Although, $fc_{\parallel}$ may be not less than 0.3 in two planes which are perpendicular to the above described c-axis-oriented plane and are perpendicular to each other, more preferably $fc_{\parallel}$ is not less than 0.3 in three planes which form an angle of 120° or in larger number of planes. It is more preferable that $fc_{\parallel}$ is not less than 0.3 in any plane perpendicular to the above described c-axis-oriented plane.

[0065] The hexagonal Z-type ferrite sintered body may comprise a c-axis-oriented plane which satisfies the above described conditions. Such a plane may be a sintered body surface or inside a sintered body. When it is inside a sintered body, it may be exposed by cutting or grinding a sintered body to evaluate the above described degree of orientation.

[0066] When the sintered body is a rectangular solid, X-ray diffraction may be conducted on one of the surfaces thereof to evaluate the degree of orientation $fc_{\perp}$, and when as the result of that the concerned plane becomes a c-axis-oriented plane, the degree of orientation $fc_{\parallel}$ may be evaluated on two other surfaces which are perpendicular to the c-axis-oriented plane and perpendicular to each other. Moreover, a hexagonal Z-type ferrite sintered body which has a small anisotropy of permeability and a good magnetic balance can be understood as described below. That is, an orientation analysis by an electron back scattering pattern (EBSP) in a scanning electron microscope (SEM) may be used. In such an orientation analysis, since an inclination amount of the c-axis of a crystal grain with respect to the direction perpendicular to the orientation analysis plane of a sintered body can be observed, the orientation state of crystal grains can be evaluated.

[0067] In such an orientation analysis, the following calculation is performed:

$$\theta_{AV} = \Sigma \theta n(\theta) / \Sigma n(\theta) \quad (\text{Equation 1})$$

[0068] Where θ is the orientation angle difference between the direction perpendicular to the orientation analysis plane of the hexagonal Z-type ferrite sintered body and the c-axis direction of the hexagonal Z-type ferrite at the measurement point of the EBSP, and $n(\theta)$ represents the number of measurement points to indicate the above described θ . Moreover, $\Sigma \theta n(\theta)$ and $\Sigma n(\theta)$ indicates the summation of $\theta n(\theta)$ and $n(\theta)$ respectively for all θ in the interval of 0 to 90°.

[0069] Configuring the above described average orientation difference θ_{AV} to be not less than 65°, C-planes are oriented in the direction perpendicular to the orientation analysis plane to provide a hexagonal Z-type ferrite having a good permeability in the concerned direction. In such a case, c-axes will be oriented in the direction parallel with the above described orientation analysis plane and the above described orientation analysis plane becomes a c-axis-oriented plane.

[0070] Moreover, when the value SD/n_{AV} , which represents the standard deviation given by Equation 3 divided by the average of the number of measurement points given by Equation 2, is not more than 0.6, it is ensured that c-axes are randomly oriented in the direction parallel with the c-axis-oriented plane:

$$n_{AV} = \Sigma I(\phi) / m \quad (\text{Equation 2})$$

(where, ϕ represents an angle when the orientation difference between the projection direction of c-axis direction to the above described orientation analysis plane and “one straight line” in the above described orientation analysis plane forms a positive acute angle. $I(\phi)$ represents the number of measurement points to indicate orientation difference ϕ , and m represents the number of dividing points in the interval of 0 to 90°.)

$$SD = \{\Sigma (I(\phi) - n_{AV})^2 / m\}^{1/2} \quad (\text{Equation 3})$$

[0071] Furthermore, the above described “one straight line” may be any one in the above described orientation analysis plane. By doing this way, it is possible to obtain a high permeability in the direction parallel with the c-axis-oriented plane. Since the value of SD increases as the number of measurement points increases, an index which is divided by n_{AV} which corresponds to an average number of measurement points is used as the index so that the results of EBSP analysis of a different number of measurement points can be compared.

[0072] n_{AV} is preferably set to be about 4000. By making the average orientation difference θ_{AV} to be not less than 65°, and SD/n_{AV} to be not more than 0.6, it is possible to configure such that a permeability is not less than 30 at 100 kHz in the perpendicular direction to the c-axis-oriented plane, a permeability is not less than 8 at 100 kHz in the direction parallel with the c-axis-oriented plane and the ratio of the permeability in the direction parallel with the c-axis-oriented plane to the permeability in the direction perpendicular to c-axis-oriented plane is not less than 0.15. The aforementioned ratio is more preferably not less than 0.20.

[0073] Moreover, the evaluation of EBSP may be performed at a span of 1 μm by using a beam of a diameter of 1 μm . Although the analysis area may be selected within a range of 0.01 to $0.3 \times 10^{-6} \text{ m}^2$ depending on the average diameter of crystal grains so that not less than 40 crystal grains are included in the analysis area, in this invention, an analysis area of $0.16 \times 10^{-6} \text{ m}^2$ is adopted as a general purpose condition to perform orientation analysis.

[0074] In order to increase the magnitude of permeability, the density of hexagonal Z-type ferrite sintered body is preferably not less than $4.7 \times 10^3 \text{ kg/m}^3$. A sintered body density of not less than $5.0 \times 10^3 \text{ kg/m}^3$ is more preferable to obtain a permeability of not less than 40. Further preferably, the sintered body density is not less than $5.1 \times 10^3 \text{ kg/m}^3$. Though there is no specific upper limit, it is preferably less than

$5.25 \times 10^3 \text{ kg/m}^3$ since coarse grains tend to be generated as the sintered body density increases.

[0075] As described so far, the hexagonal Z-type ferrite of which permeability is improved by the improvement of orientation is also advantageous in the frequency characteristics of permeability compared with the case in which the permeability is improved by controlling other factors such as the composition and structure.

[0076] When improving the permeability by controlling another factor, since magnetic anisotropy and the like also change, the frequency characteristics will be degraded thereby causing the permeability to decrease at lower frequencies.

[0077] On the contrary, when improving the permeability by controlling the orientation, since magnetic anisotropy does not change, there will be less effect on the frequency characteristics. Therefore, the hexagonal Z-type ferrite relating to the present invention has an excellent frequency characteristics and, for example, the value of permeability at 1 GHz may be made to be 30% to 80% of the value of permeability at 100 MHz.

[0078] In the viewpoint of improvement of frequency characteristics of permeability, the average crystal grain diameter of the sintered body is preferably within a range of 4 to 50 μm . For example, the change rate $(=100 \times (\mu_{100\text{MHz}} - \mu_{1\text{GHz}}) / \mu_{100\text{MHz}})$ of the real part of a complex permeability at 1 GHz, $\mu_{1\text{GHz}}$, with respect to a permeability (the real part of complex permeability) at 100 MHz, $\mu_{100\text{MHz}}$, will be reduced. Such change rate may be not more than 40%. As the result, a high permeability can be obtained even at a high frequency of about 1 GHz. It is possible to make the permeability at 1 GHz to be not less than 25.

[0079] Here, the grain diameter of the sintered body is calculated in such a way that with the longest (maximum diameter) of the lines which can be drawn inside the observed crystal grain being a long axis, and the longest of the lines which can be drawn perpendicular to the long axis inside the crystal grain being a short axis, an average of the short axis and the long axis is the crystal grain diameter for individual grain. An average crystal grain diameter may be determined by evaluating and averaging 100 arbitrary grains.

[0080] The above described hexagonal Z-type ferrite sintered body is obtained by using for example the below described method of manufacturing a hexagonal Z-type ferrite sintered body. That is, a hexagonal Z-type ferrite sintered body is obtained through a forming step to form hexagonal Z-type ferrite powder having a specific surface area of 800 to 4000 m^2/kg in a uniaxial magnetic field to obtain a green body, and a sintering step to sinter the concerned green body.

[0081] Typically, finely pulverized ferrite powder is used to improve the sinterability. On the contrary, in the method of manufacturing a hexagonal Z-type ferrite sintered body relating to the present invention, the specific surface area of hexagonal Z-type ferrite powder is controlled to be 800 to 4000 m^2/kg . This will realize a high orientation and a high permeability. When the above described specific surface area is too small, the sintered body density will not be increased, and orientation is also low. On the other hand, when the specific surface area is too large, orientation will be reduced and coarse grains are likely to be generated.

[0082] Usable forming methods include press forming, extrusion forming, injection forming, and the like, but particularly preferable is simple, press forming. In the case of

press forming, an axial magnetic field forming process in which the magnetic field application direction and the pressing direction are parallel, and a transverse magnetic field forming process in which the magnetic field application direction and the pressing direction are perpendicular can be used, but to obtain high orientation, the lateral magnetic field forming process is preferable.

[0083] Moreover, orientation is performed by forming in a magnetic field. As the method of applying a magnetic field, a uniaxial magnetic field as described above, that is, a direct-current static magnetic field applied in a predetermined direction may be used. An application method in which the application direction or angle of a magnetic field changes in time, such as a rotating magnetic field is not suitable. Forming by the application of a uniaxial magnetic field makes it possible to obtain the hexagonal Z-type ferrite sintered body relating to the present invention described above, in which C-planes of crystal grains are oriented so as to be parallel with magnetic field application direction, and c-axis directions are in a random state in the plane perpendicular to the magnetic field application direction.

[0084] Moreover, although forming can be performed by means of a dry forming which utilizes dried powder, in order to increase orientation, it is preferable to use a wet forming which utilizes a slurry obtained by mixing hexagonal Z-type ferrite powder with a medium such as water. The kind of water as the medium is not specifically limited, and for example service water may be used.

[0085] Further, it is possible to reduce impurity ions by using ion exchanged water or distilled water. Although the slurry for forming may be produced by mixing dry pulverized powder with water, the slurry after wet pulverization may be preferably used as it is as the slurry for forming without being subjected to a drying process. Such method will make it possible to achieve an even higher degree of orientation.

[0086] The slurry concentration, that is, the weight proportion of hexagonal Z-type ferrite powder in the slurry may be not more than 85% by weight. This is because, when it is higher than 85% by weight, friction between grains increases, and rotation of grains becomes insufficient thereby causing decline of the degree of orientation. For example, from the viewpoint of achieving a high orientation such as a degree of orientation $\text{fc}_\perp$ of not less than 0.5, it is more preferable to perform forming with the concentration of hexagonal Z-type ferrite powder in the above described slurry being not more than 70% by weight. More preferably, the slurry concentration is not more than 65% by weight.

[0087] On the other hand, the slurry concentration is preferably not less than 50% by weight. This is because, when it is less than 50% by weight, it takes much time for dewatering during forming thereby reducing the productivity. By stirring and thereafter forming the above described hexagonal Z-type ferrite powder in a dried powder state or in a slurry state in a die cavity under the application of a magnetic field, it becomes possible to loosen the agglomeration of hexagonal Z-type ferrite powder thereby further increasing the degree of orientation.

[0088] Moreover, in the case of a wet forming of slurry through pressurization, the method of feeding the slurry may be injecting the slurry by pressure into a die cavity under the application of a magnetic field, or charging the slurry into a die cavity and thereafter applying a magnetic field. The medium in the slurry is removed through a water drain hole or a clearance formed in the cavity, during pressurization. The

hexagonal Z-type ferrite powder after forming, that is, the green body is to be subjected to sintering after being sufficiently dried.

[0089] Although the above described hexagonal Z-type ferrite powder can be obtained by performing calcining in a powder state and pulverizing it as with a common process, the method of pulverizing a hexagonal Z-type ferrite sintered body is preferable in the viewpoint of pulverizability. In order to achieve orientation, the grains constituting hexagonal Z-type ferrite powder are preferably single crystals. In this respect, since grains have grown in the sintered body, pulverizing the concerned sintered body will make it possible to obtain powder containing a large number of grains which are single crystals.

[0090] Therefore, the method of pulverizing a hexagonal Z-type ferrite sintered body to obtain powder is a process for preparing powder preferable for orientation in a magnetic field. In this case, the average crystal grain diameter of the hexagonal Z-type ferrite sintered body to be subjected to such pulverization is preferably 5 to 200 μm .

[0091] Moreover, although forming can be performed by using hexagonal Z-type ferrite powder obtained by pulverizing the powder after calcining as in a normal process, it is also preferable in this case that the average crystal grain diameter of hexagonal Z-type ferrite in the powder after calcining is 5 to 200 μm .

[0092] Furthermore, in any case including the method of obtaining powder by pulverizing a hexagonal Z-type ferrite sintered body and the method of using hexagonal Z-type ferrite powder obtained by pulverizing the powder after calcining, it is preferable that the powder to be subjected to forming contains substantially no hexagonal M-type ferrite phase. This is because the hexagonal M-type ferrite phase exhibits uniaxial anisotropy, in which c-axis is an easy magnetization axis, and tends to be oriented in the uniaxial direction of applied magnetic field, thereby producing an orientation state (plane orientation) different from the orientation state relating to the present invention, even if it turns into a hexagonal Z-type ferrite phase during sintering.

[0093] Here, the expression "contains substantially no hexagonal M-type ferrite phase" means that the ratio of the intensity of the (006) peak which is the peak of hexagonal M-type ferrite to the intensity of the (1016) peak which is the peak of maximum intensity of hexagonal Z-type ferrite phase is not more than 5% in an X-ray diffraction. Further, the powder subjected to the forming is preferably hexagonal Z-type ferrite which contains substantially neither Y-type ferrite nor spinel ferrite.

[0094] The expression "contains substantially neither Y-type ferrite nor spinel ferrite" means that the ratio of the intensity of the (0012) peak of Y-type ferrite to the intensity of the (1016) peak which is the peak of maximum intensity of hexagonal Z-type ferrite is not more than 5%, and the ratio of the intensity of the (440) peak of spinel ferrite to the same is not more than 7%.

[0095] The hexagonal Z-type ferrite sintered body, which is obtained through forming in a magnetic field as described above, may have a disorder of orientation near the surfaces thereof. Therefore, removing the surface by machining will increase the portion of a high degree of orientation in the entire sintered body, and is advantageous in obtaining a high permeability. Also removing the surface by machining will lead to the suppression of the variation in the orientation, and

therefore in the permeability in the sintered body. The machining may be performed on at least part of the sintered body. Surface machining either by grinding or by cutting will remove the surface area.

EMBODIMENTS

[0096] First, Fe_2O_3 , BaCO_3 , and CO_3O_4 were weighed such that the composition of principal components are 70.2% by mole of Fe_2O_3 , 18.8% by mole of BaO and 11.0% by mole of CoO . Then, Mn_3O_4 , Li_2CO_3 and SiO_2 were added such that their proportions to the principal components are: 3.0% by mass of Mn_3O_4 , 0.4% by mass of Li_2CO_3 and 0.13% by mass of SiO_2 and were mixed for 16 hours in a wet ball mill. In this respect, Mn_3O_4 , Li_2CO_3 , and SiO_2 may be added during pulverization which is performed after calcining.

[0097] Next, the mixture was calcined at 1100° C. for 2 hours in the atmosphere. The calcined powder was pulverized for 18 hours in a wet ball mill. The resultant pulverized powder was added with a binder (PVA) and granulated. After granulation, it was pressed and then sintered at 1300° C. for 3 hours in an oxygen atmosphere.

[0098] The resultant sintered body was crushed by a jaw crusher and then coarsely pulverized in a disk mill to obtain a coarsely pulverized powder. Further, powder fabricated by pulverizing the coarsely pulverized powder in a stamp mill, powder fabricated by pulverizing the resultant coarsely pulverized powder by a vibration mill, and powder fabricated by pulverizing the powder pulverized by the vibration mill in a ball mill are obtained respectively. In this process, the pulverization time of the ball mill was varied to obtain powders having a different particle diameter (powder 1 to 5). These powders were nearly of single Z-type phase, and all of the intensity ratios of (0012) peak of Y-type ferrite, (006) peak of M-type ferrite, and (440) peak of spinel ferrite with respect to (0016) peak of Z-type ferrite were not more than 3%.

[0099] Moreover, the specific surface areas of these pulverized powders were measured by a gas absorption method (BET method) using Macsorb Model-1201. Further, powders 1 to 5 were added with water to obtain slurries of which powder concentration was 73% by weight, and the resultant slurries were wetly formed in a magnetic field. The forming pressure was 87.5 MPa, and a magnetic field of 848 kA/m was applied in the direction perpendicular to the press direction. The resultant green body was resintered in the same condition as described above, and the sintered body density was measured by a water substitution method. The obtained powder characteristics and sintered body density are shown in Table 1.

TABLE 1

	Pulverization method	specific	Sintered
		surface area of powder (BET value) m^2/kg	body density $\times 10^3$ kg/m^3
Powder 1	Pulverize coarsely-pulverized powder by stamp mill	200	4.2
Powder 2	Pulverize coarsely-pulverized powder by vibration mill (medium pulverized powder)	1080	4.6

TABLE 1-continued

	Pulverization method	specific surface area of powder (BET value) m ² /kg	Sintered body density ×10 ³ kg/m ³
Powder 3	Pulverize intermediately- pulverized powder for 2 hrs 50 min by ball mill	2350	5.0
Powder 4	Pulverize intermediately- pulverized powder for 4 hrs by ball mill	3560	5.2
Powder 5	Pulverize intermediately- pulverized powder for 18 hrs by ball mill	6450	5.25

[0100] It is seen from these results that the finer the powder is, the larger the density of resultant sintered body becomes. Here it is also confirmed that powder 1 has an insufficient sintered body strength and therefore not suitable for practical uses, and powder 5 in which coarse grains were generated is not suitable for practical uses as well.

[0101] Selecting the powders 2, 3, 4 which had a sintered body density of not less than 4.5×10^3 kg/m³ and from which a sintered body having an excellent strength was obtained, sintered bodies were further fabricated by varying the forming conditions as shown below. The powders were added with water such that the slurry concentration was 73% by weight, and wetly formed in a uniaxial magnetic field. Here, the forming pressure was 87.5 MPa, and the magnetic field was applied in the direction perpendicular to the press direction. The applied magnetic field was within a range of 0 to 848 kA/m.

[0102] The resultant green body was resintered in the same condition as described above to obtain a cubic sintered body of about 10 mm sides. The specimen was cut in such a way to obtain a cut plane of which normal corresponds to the magnetic field application direction of the sintered body, and X-ray diffraction (XRD) analysis was conducted on the cut plane to evaluate the degree of orientation $fc_{\perp}$.

[0103] That is, XRD was conducted in the measurement range of $2\theta = 20$ to 80° , and in the obtained X-ray diffraction pattern, the sum of integrated intensity of all the diffraction peaks of hexagonal Z-type ferrite was determined as $\Sigma I(\text{HKL})$, and the sum of integrated intensity of all the diffraction peaks of (HK0) for which $L=0$ as $\Sigma I(\text{HK0})$. The degree of orientation was calculated from the equation: $fc_{\perp} = \Sigma I(\text{HK0}) / \Sigma I(\text{HKL})$. Where, $I(\text{HKL})$ represents a value integrated over the range from $\theta(\text{HKL}) - 0.4^\circ$ to $\theta(\text{HKL}) + 0.4^\circ$, with the peak angle of the diffraction line of (HKL) plane being $\theta(\text{HKL})$.

[0104] On the other hand, the specimen was cut so as to obtain a cut plane of which normal corresponds to the press direction and a cut plane of which normal corresponds to the direction perpendicular to the magnetic field application direction and the press direction, and XRD measurements were conducted on those cut planes to evaluate $fc_{\parallel}$. Those planes will provide the above described two planes which are perpendicular to the cut plane of which normal corresponds to the magnetic field application direction, and are perpendicular to each other. The degree of orientation $fc_{\parallel}$ defined herein

is a value which is the diffraction peak intensity generated from the lattice plane of index (0018) divided by the diffraction intensity generated from the lattice plane of index (110) of Z-type ferrite.

[0105] Hereinafter, the magnetic field application direction is referred to as H direction, the permeability in H direction as μ_H , and a plane of which normal corresponds to H direction as H-plane, and for the press direction, similarly referred to as P direction, μ_P and P-plane, and for the case of the direction perpendicular to both the magnetic field application direction and the press direction, as L direction, μ_L and L-plane.

[0106] Further, the permeability in one direction of a specimen was evaluated by the technique described below, and the concept of which is shown in FIG. 2. As shown in the figure, a ring-shape ferrite of a high μ , of which permeability had been measured in advance, was formed with a gap and provided with a winding (hereinafter, referred to as a yoke part). In the present embodiments, Mn—Zn ferrite for which $\mu_i = 8100$ at 100 kHz was used as the yoke part. As the standard specimens, non-oriented hexagonal ferrite ($\mu_{2.8}, 5.7, 12.9$), consolidated powder metal ($\mu_{45}, 60$), and spinel ferrite ($\mu_{14.0}, 19.2, 29.3, 32.8, 50.0, 55.0$), each of which had a known permeability of 0 to 60, were prepared.

[0107] Those were machined, as shown in FIG. 2, to have a sectional form which corresponds to the gap portion of the yoke part, and were inserted into the gap portion to measure inductance values at 100 kHz. Since the permeability of the standard specimen was known, the relationship between the permeability within 0 to 60 and the inductance was obtained. The correlation between the permeability and the inductance was approximated by a 6-order polynomial to obtain an approximation curve.

[0108] Here, specimens of which permeability to be measured was unknown were machined so as to be inserted in the gap portion as shown in FIG. 2, and inductance L was measured at 100 kHz. From the obtained values of inductance L, the permeability was calculated using the above described approximation curve. Hereafter, the present technique will be called a gap method.

[0109] Slurries were prepared using powders 4, 3 and 2, and were wetly formed varying the intensity of the applied magnetic field, and were sintered at 1310°C . to obtain specimens; for which XRD and permeability evaluation were conducted and the results are shown in Tables 2, 3, and 4, respectively.

[0110] Further, for comparison, a hexagonal Z-type ferrite sintered body according to a conventional dry process was prepared. The conditions before the calcination and the condition for firing were the same as those described above. Calcined powder was pulverized for 18 hours in a ball mill, and resultant pulverized powder was added with 1% by weight of PVA for granulation, and was dryly formed without magnetic field. The resultant green body was sintered at 1300°C . for 3 hours in an oxygen atmosphere.

[0111] The frequency dependence of the permeability of the resultant hexagonal Z-type ferrite sintered body is shown in FIG. 3. As seen from FIG. 3, in the case of conventional process, the permeability at 100 kHz is 19.4 and the permeability at 100 MHz is 16.6, both of which are not more than 20. Moreover, in the case of the hexagonal Z-type ferrite sintered body of the composition used in the present embodi-

ments, the permeability at 100 MHz tends to be slightly lowered with respect to the permeability at 100 kHz as shown in FIG. 3.

[0112] Table 2 shows the values of sintered body density, $fc_{\perp}$, $fc_{\parallel}$, permeability at 100 kHz of the sintered body obtained by varying the applied magnetic field in the range of 0 to 848 kA/m. Even when the applied magnetic field is 0, the permeability at 100 kHz is not less than 20, which shows that the permeability is higher than that of the hexagonal Z-type ferrite sintered body according to the conventional dry process shown in FIG. 3.

TABLE 2

	Powder used	Applied magnetic field intensity (kA/m)	Sintered body density ($\times 10^3$ kg/m ³)	Degree of orientation			Real part of H direction permeability (100 kHz)
				$f_{C//}$			
				H-plane	L-plane	P-plane	
Comp. Ex. 1	Powder 4	0	5.16	0.21	0.52	1.12	23.5
Comp. Ex. 2	Powder 4	2.5	5.16	0.25	0.38	1.02	22
Comp. Ex. 3	Powder 4	15.2	5.12	0.24	0.32	1.24	25.5
Ex. 1	Powder 4	136	5.14	0.41	0.48	1.81	32
Ex. 2	Powder 4	376	5.16	0.51	0.52	0.89	38.5
Ex. 3	Powder 4	568	5.16	0.46	0.72	1.11	40
Ex. 4	Powder 4	848	5.15	0.49	1.46	1.85	41

[0113] From this table, it is seen that when a magnetic field of not less than 136 kA/m is applied, $fc_{\parallel}$ will become not less than 0.3, and also a high permeability of H direction of not less than 30 will be obtained. Specifically, for $fc_{\perp}$ not less than 0.41, the permeability was not less than 32.

[0114] Further, the sintered body densities of examples 1 to 4 were not less than 5.1×10^3 kg/m³, and thus in all cases exhibited a high value of not less than 5.00×10^3 kg/m³. Further, for examples 2 to 4 for which $fc_{\perp}$ was not less than 0.45, high permeabilities of not less than 35 were obtained. Especially for examples 3 and 4 for which the applied magnetic field intensity was not less than 568 kA/m, a very high permeability in H direction of not less than 40 was obtained.

[0115] Further, the degree of orientation $fc_{\parallel}$ in L-plane and P-plane was, in all cases, not less than 0.3, and c-axes were randomly oriented in the directions perpendicular to the magnetic field application direction (directions parallel with the c-axis-oriented plane) showing that a hexagonal Z-type ferrite sintered body having a small anisotropy of orientation has been obtained.

[0116] Furthermore, as for the value of $fc_{\parallel}$, the value measured in P-plane exceeded the value measured in L-plane for all the specimens.

[0117] When forming is performed in a uniaxial magnetic field, it is considered in principle that the orientation in the direction perpendicular to the applied magnetic field is in a random and uniform state. However, in the case of the present embodiments, it is considered that since the powder used for the specimens contained a large amount of planar grains of

which c-axis was oriented in the direction of the normal of the plate surface, C-plane orientation took place in P-plane due to the applied pressure during forming, resulting in the increase of the peak intensity of (0018).

[0118] Therefore, in the case of press forming, among the directions perpendicular to H direction, P-plane will exhibit the highest degree of orientation $fc_{\parallel}$, and L-plane which is perpendicular to the direction concerned, will exhibit the lowest degree of orientation $fc_{\parallel}$. The fact that the degree of orientation $fc_{\parallel}$ of L-plane is still not lower than 0.3 shows that

the anisotropy of orientation is small. Further, there was a tendency that both in L-plane and P-plane, $fc_{\parallel}$ increases as $fc_{\perp}$ increases.

[0119] The reason of this is considered that as $fc_{\perp}$ increases along with the increase of applied magnetic field intensity, the tendency of H-plane intersecting with the C-plane of the crystal at right angles grows stronger, and therefore, on the contrary, the diffraction peak of C-plane is intensified in the direction perpendicular to H-plane. For applied magnetic field intensity of not less than 376 kA/m, the degree of orientation $fc_{\parallel}$ of L-plane was not less than 0.5, while the ratio of the degree of orientation $fc_{\parallel}$ of L-plane to the degree of orientation $fc_{\parallel}$ of P-plane was not less than 0.5.

[0120] Further, it is seen that when the applied magnetic field becomes not less than 700 kA/m, the degree of orientation $fc_{\parallel}$ of L-plane becomes not less than 1.0 and the ratio of the degree of orientation $fc_{\parallel}$ of L-plane to the degree of orientation $fc_{\parallel}$ of P-plane is not less than 0.7, thereby showing that the anisotropy in the direction perpendicular to the magnetic field application direction (direction parallel with the c-axis-oriented plane) has further decreased.

[0121] Table 3 shows $fc_{\perp}$ and the real part of the permeability at 100 kHz of the specimen which was fabricated using powder 3 and by varying the magnetic field in the range of 23.2 to 848 kA/m. Further, example 12 is the specimen which was prepared by stirring the powder using a stick in the cavity during application of a magnetic field before the press forming in a magnetic field.

TABLE 3

	Powder used	Slurry concentration (wt %)	Applied magnetic field intensity (kA/m)	Sintered body density ($\times 10^3$ kg/m ³)	Degree of orientation $f_{c\perp}$ (H-plane)	Real part of permeability (100 kHz) μ_H
Ex. 7	Powder 3	73	23.2	5.06	0.43	31
Ex. 8	Powder 3	73	136	5.13	0.52	43
Ex. 9	Powder 3	73	376	5.10	0.52	42.5
Ex. 10	Powder 3	73	568	5.13	0.62	41
Ex. 11	Powder 3	73	848	5.11	0.58	40.5
Ex. 12	Powder 3	73	848 (with stirring)	5.13	0.68	48.5

[0122] When powder 3 which had a larger average particle diameter than powder 4, that is, a smaller specific surface area which was not more than 2350 m²/kg was used, $f_{c\perp}$ was not less than 0.4 and the permeability was not less than 30 even in a magnetic field of 23.2 kA/m.

[0123] Further, on example 11, the permeabilities of P direction and L direction (μ_p , μ_L) were measured by a gap method to find that they were 15.5 and 20.5 respectively, indicating a high permeability of not less than 15 even in the direction perpendicular to H direction. In this case, the ratios of permeabilities (μ_L/μ_H , μ_p/μ_H) at 100 kHz were from 0.38 to 0.51, that is, within a range of not more than 0.6 and not less than 0.1, also showing that a hexagonal Z-type ferrite sintered body having a good balance of anisotropy has been obtained.

[0124] Further, in particular, stirring the slurry in a magnetic field caused the degree of orientation to increase making it possible to obtain a high value of not less than 45 for the permeability in the magnetic field application direction (H direction). Moreover, for comparison purpose, specimens were prepared by a longitudinal magnetic field forming process, in which magnetic field application direction and the pressing direction are the same, and it was found that the degree of orientation $f_{c\perp}$ thereof was decreased by amount of about 0.2 to 0.3 compared with the case of the above described lateral magnetic field forming.

[0125] The frequency characteristics of the permeability, particularly the permeability at high frequencies of not less than 100 MHz, of one direction of the oriented hexagonal Z-type ferrite was evaluated by means of the technique described below. That is, since the permeability in the direction parallel with the C-plane of the ferrite sintered body oriented by a uniaxial magnetic field cannot be readily measured with a ring-shape specimen, three ring specimens, of which the ring annular surface are parallel with H-plane, P-plane, or L-plane, were cut out, and from the measurement results of permeabilities of these ring specimens, the permeabilities of H direction, P direction, and L direction were calculated.

[0126] Before describing the evaluation method, necessary equations will be derived. The longitudinal direction and lateral direction along the plate surface of magnetic plate having an anisotropy are defined to be Y direction (for example P direction) and X direction (for example H direction) respectively, a ring specimen in which the difference between the outer diameter and inner diameter thereof is sufficiently small is cut out from the concerned magnetic

plate, and N-turn-winding was provided on the concerned ring specimen; and it is supposed that a current I is applied to the winding to measure an initial permeability. Further, let the sectional area of the ring specimen be S.

[0127] As shown in FIG. 4, when a ring specimen is defined on an origin point by θ and r, Relational expression 1 is obtained.

$$\vec{d}_l = (-r \sin \theta \cdot d\theta, r \cos \theta \cdot d\theta) \quad (\text{Relational expression 1})$$

Where

$$\vec{d}_l$$

is an infinitesimal line element vector in the tangent direction of the ring specimen.

[0128] Further, supposing that there is no leakage of magnetic flux from the ring specimen and the magnitude of magnetic flux density vector within the ring specimen is constant, following Relational expression 2 is obtained.

$$\vec{B} = (-B_0 \sin \theta, B_0 \cos \theta) \quad (\text{Relational expression 2})$$

Where

$$\vec{B}$$

is magnetic flux density vector inside the ring specimen, and

$$B_0 = |\vec{B}|$$

[0129] Supposing that permeabilities in X direction and Y direction are μ_x and μ_y respectively, following relational expression 3 is obtained.

$$\vec{H} = ((-B_0/\mu_x) \sin \theta, (B_0/\mu_y) \cos \theta) \quad (\text{Relational expression 3})$$

Where

$$\vec{H}$$

is the magnetic field vector in the ring specimen. Moreover, μ_x and μ_y as well as $\mu_{xy\text{plane}}$ as described below are in each case a relative permeability.

[0130] From the above described relational expressions 1 to 3 and the Ampere's law, following relationship is obtained.

$$B_0 = (1/\mu_x + 1/\mu_y)^{-1} \times NI/\pi r \quad (\text{Equation 4})$$

[0131] Where since the self inductance L is the ratio of linkage flux and electric current, following is obtained by using the relationship of Equation 4.

$$L = N\Phi/I = NB_0S/I = S(1/\mu_x + 1/\mu_y)^{-1} \times N^2/\pi$$

[0132] When it is in vacuum ($\mu_x = \mu_y = 1$), since $L_0 = SN^2/2\pi r$, letting the permeability observed from the ring specimen be $\mu_{xy\text{-plane}}$, the following relationship is obtained.

$$\mu_{xy\text{-plane}} = L/L_0 = 2 \times (1/\mu_x + 1/\mu_y)^{-1} \quad (\text{Equation 5})$$

[0133] Taking into consideration the relationship such as Equation 5, three kinds of ring specimens were cut out in such a way that the annular surface corresponds to H-plane, L-plane, or P-plane, and complex relative permeability ($\mu_{H\text{-plane}}$, $\mu_{L\text{-plane}}$, $\mu_{P\text{-plane}}$) from 10 MHz to 1.8 GHz was measured with an Impedance Meter 4291B (by AGILENT). The dimensions of the specimen were as follows: an outer diameter of 6.8 mm, an inner diameter of 3.2 mm, and a thickness of 1.5 mm. The permeability of each direction was calculated using the following equations from the measurements.

$$\begin{aligned} \mu_H &= \{(-1/\mu_{H\text{-plane}}) + (1/\mu_{L\text{-plane}}) + (1/\mu_{P\text{-plane}})\}^{-1} \\ \mu_L &= \{(1/\mu_{H\text{-plane}}) + (-1/\mu_{L\text{-plane}}) + (1/\mu_{P\text{-plane}})\}^{-1} \\ \mu_P &= \{(1/\mu_{H\text{-plane}}) + (1/\mu_{L\text{-plane}}) + (-1/\mu_{P\text{-plane}})\}^{-1} \end{aligned}$$

[0134] Hereinafter, this method will be referred to as a “ring method.”

[0135] Moreover, for comparison purpose, the following specimens were fabricated to measure the permeability of each direction, and others. That is, powder 2 of Table 1 was added with water in such a way that the slurry concentration was 73% by weight, and the slurry is put into a nonmagnetic die to be rotated 3 times with the die in a static magnetic field of 480 kA/m, and after the rotation, is formed with a forming pressure of 22 MPa in a static magnetic field of the same intensity. At this time, the forming pressure was applied in the direction perpendicular to the magnetic field. The resultant green body was sintered at 1350° C. in an oxygen atmosphere to obtain a sintered body (comparison example 4).

[0136] Moreover, the direction in which a magnetic field is applied during pressing for forming is referred to as H direction, the press direction as P direction, and direction perpendicular to both H direction and P direction as L direction; the planes each of which the normal corresponds to the aforementioned respective direction being referred to as H-plane, P-plane, and L-plane respectively.

[0137] Table 4 shows the sintered body density, the degrees of orientation ($f_{c\perp}$, $f_{c\parallel}$), and the values of the real part of permeability at 100 MHz for H, L, P directions determined by the ring method, for comparative examples 1 to 4 and examples 1 and 4.

[0138] Since I(0018) was observed at a very strong level, and the diffraction peak of (110) plane were obstructed by the diffraction peak of (0018) plane, $f_{c\parallel}$ of P-plane of comparative example 4 was unable to observe. However, it was obvious that $f_{c\parallel}$ exceeded 0.3. Moreover, it is seen that $f_{c\perp}$ in H-plane is not less than 0.7 and a high value of 35 can be obtained for the permeability of H direction at 100 MHz.

[0139] On the other hand, it was confirmed that $f_{c\parallel}$ in L-plane exhibited a small value of not more than 0.1 which was smaller compared to $f_{c\parallel}$ in P-plane, and c-axes were oriented concentrating in a specific direction in H-plane. Further, at this time, the permeability in P direction was as low as not more than 4.

[0140] Further, in comparative examples 1 to 3 in which the applied magnetic field intensity was low and the degree of orientation $f_{c\perp}$ was less than 0.4, the ratio of permeabilities (μ_L/μ_H , μ_P/μ_H) at 100 MHz exceed 0.6 thus showing that the permeabilities in H direction has not been sufficiently increased by orientation.

[0141] On the contrary, in example 1 in which the degree of orientation $f_{c\perp}$ was not less than 0.4, the ratio of permeabilities (μ_L/μ_H , μ_P/μ_H) was 0.39 to 0.56, the values being not more than 0.6 and not less than 0.1.

[0142] Further, in example 4, $f_{c\parallel}$ was not less than 1.4 for both L-plane and P-plane, and c-axes were randomly oriented even in the direction perpendicular to the magnetic field application direction (direction parallel with c-axis-oriented plane) showing that a hexagonal Z-type ferrite sintered body having a small anisotropy of orientation in the c-axis-oriented plane has been obtained. As the result, the permeability μ_L in L direction and the permeability μ_P in P direction were 11.5 and 9.1 respectively, confirming that each shows a high value of not less than 8. The permeability in H direction also exhibited a high value of not less than 35. Moreover, the ratios of the permeability μ_L of L direction and the permeability μ_P of P direction with respect to the permeability μ_H of H direction, that is the direction perpendicular to the c-axis-oriented plane, were 0.31 and 0.24 respectively, revealing that each exhibits a high value of not more than 0.4 and not less than 0.15 indicating a good balance of anisotropy in permeability.

[0143] Table 5 shows the sintered body density, $f_{c\perp}$, and μ_H obtained through the gap method of the specimen prepared by using powder 2.

TABLE 4

	Powder used	Sintered body density ($\times 10^3 \text{ kg/m}^3$)	Degree of orientation			Real part of permeability (100 MHz)		
			$f_{c\perp}$	$f_{c\parallel}$				
			H-plane	L-plane	P-plane	μ_H	μ_L	μ_P
Comp. Ex. 4	Powder 2	4.80	0.74	0.07	—	35.0	27.8	4.0
Comp. Ex. 1	Powder 4	5.16	0.21	0.52	1.12	15.6	17.6	10.5
Comp. Ex. 2	Powder 4	5.16	0.25	0.38	1.02	17.4	17.3	10.7
Comp. Ex. 3	Powder 4	5.12	0.24	0.32	1.24	17.9	14.7	11.3
Ex. 1	Powder 4	5.14	0.41	0.48	1.81	24.9	13.9	9.6
Ex. 4	Powder 4	5.15	0.49	1.46	1.85	37.7	11.5	9.1

TABLE 5

	Powder used	Slurry concentration (%)	Applied magnetic field intensity (kA/m ³)	Sintered body density ($\times 10^3$ kg/m ³)	Degree of orientation $f_{C\perp}$ H-plane	Real part of permeability (100 kHz) μ_H
Ex. 13	Powder 2	73	136	4.59	0.55	35
Ex. 14	Powder 2	73	848	4.60	0.61	31

[0144] It is seen that examples 13 and 14 become to exhibit a degree of orientation not less than 0.5 by the application of a magnetic field of not less than 136 kA/m, and to exhibit a permeability value of not less than 30. Further, it is also seen that in the case of using powder 2 having a specific surface area of 1080 m²/kg which is smaller than that of powder 3, the degree of orientation $f_{C\perp}$ has increased when compared with the case of using powder 3 at the same applied magnetic field intensity.

[0145] From the results of Tables 2 to 4 in which powders 2 to 4 were used, it is seen that as the specific surface area of the hexagonal Z-type ferrite powder to be subjected to forming becomes smaller, the orientation $f_{C\perp}$ becomes higher. However, even though the sintered body density is not less than 4.5×10^3 kg/m³, it is rather small, and thus the permeability is suppressed accordingly. For example, in examples 2 and 8, a permeability of not less than 38 has been obtained even for $f_{C\perp} = 0.5$ showing that when the sintered body density is not less than 4.7×10^3 kg/m³, a high permeability is more likely to be obtained.

[0146] Next, a sintered body specimen (example 15) was prepared in the same manner as in example 11 except that the slurry was not dried after pulverizing and formed as it was adjusting the slurry concentration to be 68%. Moreover, a sintered body specimen (example 16) was prepared in a condition which differed from that of the aforementioned specimen only in the composition of the principal components. The composition of principal components of example 16 is 70.6% by mole of Fe₂O₃, 17.6% by mole of BaO, and 11.8% by mole of CoO, which corresponds to the stoichiometric composition of Ba₃CO₂Fe₂₄O₄₁.

[0147] Table 6 shows sintered body density, the degree of orientation $f_{C\perp}$, and the real part of the permeability at 100 kHz for examples 15 and 16. The permeabilities were measured by the gap method.

TABLE 6

	Powder used	Slurry concentration (%)	Applied magnetic field intensity (kA/m)	Sintered body density ($\times 10^3$ kg/m ³)	Degree of orientation $f_{C\perp}$ (H-plane)	Real part of permeability (100 kHz) μ_H
Ex. 15	Powder 3	68	848	5.14	0.70	55.0
Ex. 16	Powder 3	68	848	4.95	0.74	40.0

[0148] As shown in Table 6, even example 16 which had a stoichiometric composition exhibited a high degree of orientation of not less than 0.7 and a high permeability of not less than 40. In contrast, in example 15 which had a Ba-rich

composition deviating from the stoichiometric composition, the sintered body density has increased by not less than 3%. On the other hand, the degree of orientation of example 15 exhibited only a slight decrease with respect to that of example 16. As a result, the permeability increases 30% or more and a permeability of 50 or more is obtained. Thus, it is seen that a Ba-rich composition deviating from the stoichiometric composition is preferable in increasing the density and permeability of oriented hexagonal Z-type ferrite.

[0149] Moreover, it is seen that both the degree of orientation $f_{C\perp}$ and the permeability have significantly increased in the specimen of example 15 compared with the specimen of example 11, indicating that forming the slurry after wet pulverization without drying is effective in improving the orientation.

[0150] Further, on the specimen of example 15, the real part of the permeability at 100 kHz for each H, P, and L direction μ_H , μ_L , μ_P were measured by a gap method to find that they were 55.0, 21.0 and 12.5 respectively. For the direction perpendicular to the c-axis-oriented plane, a very high permeability of not less than 50 was obtained even at 100 kHz. Moreover, a high permeability of not less than 10 was obtained also in the direction parallel with the c-axis-oriented plane, and the ratios of permeabilities (μ_L/μ_H , μ_P/μ_H) were from 0.23 to 0.38, that is, within a range of not more than 0.4 and not less than 0.1, showing that a hexagonal Z-type ferrite sintered body having a good balance of anisotropy has been obtained.

[0151] Furthermore, the real part of permeability at 100 MHz in each H, L, and P direction was evaluated by the ring method to find that they were 51.5, 11.8, and 8.1. For the direction perpendicular to the c-axis-oriented plane, a very high permeability of not less than 50 was obtained even at 100 MHz. Also, in the direction parallel with the c-axis-oriented plane, a high permeability of not less than 8 was obtained and

the ratios of permeabilities (μ_L/μ_H , μ_P/μ_H) were from 0.16 to 0.23, that is, within a range of not more than 0.4 and not less than 0.1, indicating excellent characteristics even at 100 MHz.

[0152] Next, a sintered body specimen (example 17) was prepared in the same manner as in example 15 except that the calcination was performed at 1330° C. for 3 hours in oxygen atmosphere and the calcined powder was pulverized for 22 hours to be subjected to forming. The sintered body density, the degree of orientation $fc_{\perp}$, and the real part of the permeability at 100 kHz were evaluated on the obtained specimen, and results of which are shown in Table 7. The permeability was measured by the gap method.

TABLE 7

	Slurry concentration (%)	Applied magnetic field intensity (kA/m)	Sintered body density ($\times 10^3$ kg/m ³)	Degree of orientation $fc_{\perp}$ (H-plane)	Real part of permeability (100 kHz) μ_H
Ex. 17	68	848	5.05	0.66	42.0

[0153] By adopting a step of sufficiently growing grains by raising the calcining temperature and prolonging the calcining time instead of pulverizing the sintered body, it is made possible to obtain a degree of orientation $fc_{\perp}$ of not less than 0.4.

[0154] Next, on some specimens (comparative example 1, examples 1, 2, 8) among the specimens of Tables 2 to 4, the orientations of crystal grains existing in the c-axis-oriented plane (H-plane) which was the observed plane, were measured by means of EBSD (OIM version 4.6 by TSL Inc.)

[0155] An observation magnification was selected such that at least not less than 40 crystal grains were included in the EBSD observation area. The observation area was 200 $\mu\text{m} \times 800 \mu\text{m}$ ($0.16 \times 10^{-6} \text{ m}^2$), and the step interval of the beam was 1 μm . The orientation angle difference between the c-axis direction of the crystal and the perpendicular direction of specimen plate surface (observed plane) was determined for each point, based on the orientation information obtained from the measurement points, and the number of points which had the same orientation angle difference θ was counted to obtain $n(\theta)$, thereby obtaining an orientation difference distribution diagram of θ with $n(\theta)$ being the longitudinal axis. The obtained distribution diagrams of orientation difference are summarized in FIG. 5.

[0156] The results shown in FIG. 5 revealed that as the degree of orientation $fc_{\perp}$ increases, the distribution of c-axis direction becomes concentrated in the direction parallel with the c-axis-oriented plane (H-plane). From the obtained orientation difference distribution, a average orientation difference of c-axis, θ_{AV} of crystal was calculated using Equation 1. The results thereof are shown in Table 8.

TABLE 8

	Powder used	Slurry concentration (wt %)	Applied magnetic field intensity (kA/m)	Degree of orientation $fc_{\perp}$	Real part of permeability (100 kHz)	θ_{AV} (°)	SD/n_{AV}
Comp.	Powder 4	73	0	0.21	23.5	57.1	0.44
Ex. 1	Powder 4	73	136	0.41	32	68.1	0.36
Ex. 2	Powder 4	73	376	0.51	38.5	72.3	0.45
Ex. 8	Powder 3	73	848	0.68	48.5	74.4	0.21

[0157] It is seen that as the degree of orientation $fc_{\perp}$ becomes not less than 0.4, average orientation difference of c-axis, θ_{AV} becomes not less than 65° indicating that c-axes were moving close to parallel with c-axis-oriented plane. Further, at the same time, the permeability at 100 kHz by the gap method becomes not less than 30. Furthermore, it is seen that when the degree of orientation $fc_{\perp}$ increases to not less than 0.5, a high orientation in which the average orientation difference of c-axis, θ_{AV} is not less than 70° is realized. In examples 2 and 8, θ_{AV} was 72.30 and 74.40 respectively, further moving closer to parallel with c-axis-oriented plane. When θ_{AV} became not less than 70°, the permeability at 100 kHz by the gap method was not less than 35.

[0158] With ϕ being the positive acute angle which is the orientation difference between the projection direction of c-axis direction to an observed plane and one straight line in the concerned observed plane, the results are shown in FIG. 6 in which the lateral axis is ϕ , and the longitudinal axis is $I(\phi)$.

[0159] From FIG. 6, comparative example 1, examples 1, 2, and 8 in all cases exhibit a similar tendency, although there is a slight bias in the distribution of $I(\phi)$ with respect to ϕ , the value is not more than 7000 points even in the direction in which c-axis direction is observed with a highest intensity in FIG. 6 compared with the case of FIG. 5 in which the observation points at a highest intensity was more than 20000 points. The ratio is in all cases not more than 0.6 in examples and thus the level of bias is low.

[0160] Here, the values of SD/n_{AV} , which is SD calculated by Equation 3 divided by n_{AV} calculated by Equation 2, are shown in Table 8. The value of SD/n_{AV} can be used as the index of variance, which is not more than 0.6 in any of comparative example 1, examples 1, 2, and 8, confirming that the projection direction of c-axis to the c-axis-oriented plane does not exhibit strong bias. Further, particularly in example 8, SD/n_{AV} is not more than 0.21 indicating that the projection direction of c-axis to the c-axis-oriented plane is randomly distributed in the plane.

[0161] Table 9 shows the values of the degree of orientation $fc_{\perp}$ and the permeability in the case in which forming was performed by using powder 4, applying the specific magnetic field of 848 kA/m, and varying the slurry concentration. It is seen that when the slurry concentration decreases, the degree of orientation increases. When slurry concentration became not more than 65% by weight, $fc_{\perp}$ became not less than 0.6 and a high permeability exceeding 40 was obtained.

TABLE 9

	Powder used	Slurry concentration (%)	Applied magnetic field intensity (kA/m)	Sintered body density ($\times 10^3$ kg/m ³)	Degree of orientation $f_{c\perp}$ (H-plane)	Real part of permeability (100 kHz) μ_H
Ex. 4	Powder 4	73	848	5.15	0.49	41
Ex. 5	Powder 4	65	848	5.22	0.60	40
Ex. 6	Powder 4	60	848	5.18	0.71	44

[0162] FIG. 7 shows the frequency characteristics of the complex permeability of example 4 determined by the ring method in a range of 100 MHz to 1.8 GHz. It is seen from FIG. 7 that the real part of the complex permeability in H direction is not less than 30 up to 1 Hz and thus a high permeability is maintained. The permeability of 1 GHz $\mu_{1\text{GHz}}$ is maintained at not less than 80% of the permeability of 100 MHz $\mu_{100\text{MHz}}$, and the change rate thereof ($=100 \times (\mu_{100\text{MHz}} - \mu_{1\text{GHz}}) / \mu_{100\text{MHz}}$) is 20%, exhibiting a small value not more than 40%.

[0163] As so far described, according to the present invention, it is possible to provide a hexagonal Z-type ferrite which has a particularly high permeability in a specific direction and still has a high permeability in the directions other than the concerned direction thereby offering an excellent balance of permeability, and a method of manufacturing the same. Thus, by using the ferrite sintered body according to the present invention, it becomes possible to provide high quality choke coils, inductors, magnetic wave absorbers, and others.

1. A hexagonal Z-type ferrite sintered body, comprising:

a c-axis-oriented plane in which

a degree of orientation $f_{c\perp}$ is not less than 0.4, said degree of orientation being given as $f_{c\perp} = \Sigma I(\text{HK}0) / \Sigma I(\text{HKL})$, where $\Sigma I(\text{HKL})$ is the sum of integrated intensity of all the diffraction peaks of hexagonal Z-type ferrite and $\Sigma I(\text{HK}0)$ is the sum of integrated intensity of all the diffraction peaks of (HK0) for which $L=0$ in an X-ray diffraction pattern of which measurement range is $2\theta = 20$ to 80° , when $I(\text{HKL})$ is the integrated intensity of a diffraction peak represented by an index (HKL) wherein

a degree of orientation $f_{c\parallel}$ calculated from $f_{c\parallel} = I(0018) / I(110)$ in an X-ray diffraction is not less than 0.3 in at least two planes which are perpendicular to said c-axis-oriented plane and are perpendicular to each other.

2. The hexagonal Z-type ferrite sintered body according to claim 1, wherein said hexagonal Z-type ferrite sintered body is principally composed of BaO, CoO, and Fe_2O_3 , and has a Ba-rich composition deviating from the stoichiometric composition $\text{Ba}_3\text{CO}_2\text{Fe}_{24}\text{O}_{41}$ of a hexagonal Z-type ferrite.

3. The hexagonal Z-type ferrite sintered body according to claim 1, wherein a sintered body density of said hexagonal Z-type ferrite sintered body is not less than 5.0×10^3 kg/m³.

4. The hexagonal Z-type ferrite sintered body according to claim 1 wherein a ratio of $\mu_{\parallel} / \mu_{\perp}$ is not more than 0.6 at 100 kHz and/or 100 MHz for permeabilities $\mu_{\parallel}$ of at least two directions which are parallel with said c-axis-oriented plane and intersects at right angles to each other, where $\mu_{\perp}$ is a

permeability perpendicular to said c-axis-oriented plane and $\mu_{\parallel}$ is a permeability parallel with the said c-axis-oriented plane.

5. The hexagonal Z-type ferrite sintered body according to claim 1, wherein the permeability at 100 kHz in the direction perpendicular to said c-axis-oriented plane is not less than 30.

6. The hexagonal Z-type ferrite sintered body according to claim 1, wherein the permeability at 100 kHz in a direction parallel with said c-axis-oriented plane is not less than 8.

7. The hexagonal Z-type ferrite sintered body according to claim 1, wherein said hexagonal Z-type ferrite sintered body has a machined surface.

8. A hexagonal Z-type ferrite sintered body, comprising:

a c-axis-oriented plane of which an average orientation difference θ_{AV} represented as $\theta_{AV} = \Sigma \theta n(\theta) / \Sigma n(\theta)$ is not less than 65° in an orientation analysis by EBSP (Electron Back Scattering Pattern), wherein

a value SD/n_{AV} , which is given by dividing a standard deviation SD given by $SD = \{\Sigma (I(\phi) - n_{AV})^2 / m\}^{1/2}$ by an average value of the number of measurement points given by $n_{AV} = \Sigma I(\phi) / m$, is not more than 0.6 (where, θ : orientation angle difference between the direction perpendicular to the orientation analysis plane of hexagonal Z-type ferrite sintered body and the c-axis direction of the hexagonal Z-type ferrite at the measurement position of EBSP, $n(\theta)$: the number of measurement points to indicate said θ , $\Sigma \theta n(\theta)$: the summation of $\theta n(\theta)$ in the interval of 0 to 90° , $\Sigma n(\theta)$: summation of $n(\theta)$ in the interval of 0 to 90° , ϕ : the positive acute angle which is the orientation difference between the projection direction of c-axis direction to said orientation analysis plane and one straight line in said orientation analysis plane, $I(\phi)$: the number of measurement points to indicate orientation difference ϕ , and m : the number of dividing points in the interval of 0 to 90° .)

9. The hexagonal Z-type ferrite sintered body according to claim 8, wherein said hexagonal Z-type ferrite sintered body is principally composed of BaO, CoO, and Fe_2O_3 , and has a Ba-rich composition deviating from the stoichiometric composition $\text{Ba}_3\text{CO}_2\text{Fe}_{24}\text{O}_{41}$ of a hexagonal Z-type ferrite.

10. The hexagonal Z-type ferrite sintered body according to claim 8, wherein a sintered body density of said hexagonal Z-type ferrite sintered body is not less than 5.0×10^3 kg/m³.

11. The hexagonal Z-type ferrite sintered body according to claim 8, wherein a ratio of $\mu_{\parallel} / \mu_{\perp}$ is not more than 0.6 at 100 kHz and/or 100 MHz for permeabilities $\mu_{\parallel}$ of at least two directions which are parallel with said c-axis-oriented plane and intersects at right angles to each other, where $\mu_{\perp}$ is a permeability perpendicular to said c-axis-oriented plane and $\mu_{\parallel}$ is a permeability parallel with the said c-axis-oriented plane.

12. The hexagonal Z-type ferrite sintered body according to claim 8, wherein the permeability at 100 kHz in the direction perpendicular to said c-axis-oriented plane is not less than 30.

13. The hexagonal Z-type ferrite sintered body according to claim 8, wherein the permeability at 100 kHz in a direction parallel with said c-axis-oriented plane is not less than 8.

14. The hexagonal Z-type ferrite sintered body according to claim 8, wherein said hexagonal Z-type ferrite sintered body has a machined surface.

15. A method of manufacturing a hexagonal Z-type ferrite sintered body, comprising the steps of:

forming a hexagonal Z-type ferrite powder which has a specific surface area of 800 to 4000 m²/kg in a uniaxial magnetic field to obtain a green body; and

sintering said green body.

16. The method of manufacturing a hexagonal Z-type ferrite sintered body according to claim 15, wherein

forming is performed by mixing said hexagonal Z-type ferrite powder with water to make a slurry so that the concentration of the hexagonal Z-type ferrite powder in said slurry is not more than 70% by weight.

17. The method of manufacturing a hexagonal Z-type ferrite sintered body according to claim 16, wherein

forming is performed after stirring said hexagonal Z-type ferrite powder in a die cavity while applying a magnetic field.

18. The method of manufacturing a hexagonal Z-type ferrite sintered body according to claim 15, wherein

said hexagonal Z-type ferrite powder is obtained by pulverizing a hexagonal Z-type ferrite sintered body.

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