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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) A non-oriented electrical steel sheet according to an embodiment includes Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, by weight, with the remainder being Fe and inevitable impurities.

ΔAl , defined as difference ([S-MAI]-[C-MAI]) between an Al content [C-MAI] at the center position of

the sheet thickness ($t/2$) and a maximum Al content [S-MAI] in an area from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction is 0.1 wt% or more, a sheet structure has a single-phase ferrite structure, and an average ferrite grain size is 100 to 300 μm .

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Description**(a) Field of the Invention**

[0001] One embodiment of the present invention relates to a Si diffusion composition, a non-oriented electrical steel sheet, and a method for manufacturing the same. Specifically, one embodiment of the present invention relates to a non-oriented electrical steel sheet having an improved magnetism by diffusing Si and Al from the surface of the steel sheet to the interior of the steel sheet, and a method for manufacturing the same.

(b) Description of the Related Art

[0002] Non-oriented electrical steel sheets used as core materials for electronic devices are required to have high magnetic flux density and low iron loss as devices become more efficient and miniaturized. The higher the magnetic flux density, the less iron core is required to achieve the same performance, which enables the miniaturization of the electrical devices. The lower the iron loss, the smaller the energy loss, so securing the above characteristics is essential for manufacturing high-efficiency motors. The iron loss, which causes an energy loss, consists of a hysteresis loss and an eddy current loss, and the influence of the eddy current loss increases in high-efficiency motors with high operating frequencies of the electronic devices. The eddy current loss is a heat generation caused by an eddy current that occur when a magnetic field is induced in the core, and to reduce this, it is generally effective to increase the content of resistivity elements such as Si or Al inside the electrical steel sheet. In addition, when the Si content is increased above a certain level, the magnetostriction, which is the cause of noise, decreases to 0 and the permeability increases to the maximum, making it possible to manufacture the electrical steel sheets with the excellent high-frequency characteristics. However, as the Si content increases, the ductility of the electrical steel sheet decreases significantly, making it difficult to manufacture a thin-film electrical steel sheet using a conventional rolling process. To overcome the limitations of this rolling process, a technology has been proposed to manufacture the electrical steel sheets with increased Si content in the steel sheet by diffusing Si onto the surface of the cold-rolled steel sheet using SiCl_4 gas. However, this method has many problems that need to be overcome commercially, such as the limitation of an equipment that must be produced under high vacuum conditions because it uses SiCl_4 gas, which is highly toxic and chemically unstable. In addition, under high vacuum conditions, by-product gases such as FeCl_2 are generated, which is environmentally harmful and has poor insulation properties, so a fundamental solution is needed.

SUMMARY OF THE INVENTION**[Technical Problem]**

[0003] In one embodiment of the present invention, an Si diffusion composition, a non-oriented electrical steel sheet, and a method for manufacturing the same are provided. Specifically, one embodiment of the present invention aims to provide a non-oriented electrical steel sheet and a method for manufacturing the same, wherein a magnetism is improved by diffusing Si and Al from the surface of the steel sheet to the interior of the steel sheet.

[Technical Solution]

[0004] A non-oriented electrical steel sheet according to an embodiment includes Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, by weight, with the remainder being Fe and inevitable impurities.

[0005] ΔAl , defined as a difference $([\text{S-MAI}]-[\text{C-MAI}])$ between an Al content $[\text{C-MAI}]$ at the center position of the sheet thickness ($t/2$) and a maximum Al content $[\text{S-MAI}]$ in an area from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction may be 0.1 wt% or more,

[0006] The non-oriented electrical steel sheet according to an embodiment, a sheet structure may have a single-phase ferrite structure, an average ferrite grain size may be 100 to 300 μm .

[0007] The maximum Si content in the region from the surface to 5% of the total thickness in the inner direction may be 4 to 8 wt%, and the Si content at the center position ($t/2$) of the sheet thickness may be 0.01 to 7.0 wt%.

[0008] A ΔSi defined as a difference $([\text{S-MSi}]-[\text{C-MSi}])$ between a Si content $[\text{C-MSi}]$ at the center position ($t/2$) of the thickness of the sheet and a maximum Si content $[\text{S-MSi}]$ in a region from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction may be 0.1 wt% or more.

[0009] A surface roughness R_a of the non-oriented electrical steel sheet may be 1.00 μm or less.

[0010] The non-oriented electrical steel sheet according to an embodiment further include at least one of C, N, S, Ti, Nb, and V, each in an amount of 0.005 wt% or less.

[0011] The non-oriented electrical steel sheet according to an embodiment further include at least one of P: 0.1 wt%

or less, Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Sn: 0.1 wt% or less, Sb: 0.1 wt% or less, Ni: 0.05 wt% or less, and Zn: 0.01 wt% or less.

[0012] The non-oriented electrical steel sheet according to an embodiment further include 0.200 wt% or less of each or a combination of Bi, Pb, Ge and As. .

[0013] The non-oriented electrical steel sheet according to an embodiment further include at least one of Mo: 0.03 wt% or less, B: 0.0050 wt% or less, Ca: 0.0050 wt% or less, and Mg: 0.0050 wt% or less.

[0014] According to one embodiment of the present invention, a Si diffusion composition for an electrical steel sheet includes a Si powder and an Al alkoxide, wherein the Al alkoxide is expressed as $\text{Al(OR)}_n(\text{R})_{3-n}$, wherein R is an alkyl group having 1 to 4 carbon atoms or an alkenyl group having 2 to 4 carbon atoms, and n is an integer of 1 to 3.

[0015] The Si diffusion composition may further include a ceramic powder including an oxide, nitride, carbide or oxynitride including at least one selected from Li, B, Ca, Sr, Mg, Al, Si, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn and Ba as a component.

[0016] The Si diffusion composition may include 10 to 70 wt% of the Si powder, 1 to 20 wt% of the Al alkoxide, and the remainder ceramic powder as a solid component.

[0017] The average particle size of the Si powder may be from 1 to 850 nm.

[0018] The average particle size of the ceramic powder may be from 8 to 2500 nm.

[0019] A method for manufacturing a non-oriented electrical steel sheet according to one embodiment of the present invention includes manufacturing a cold-rolled sheet including, in wt%, Si: 0.01 to 3.5%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities; applying a Si diffusion composition including Si powder and Al alkoxide to the cold-rolled sheet; and diffusion annealing the cold-rolled sheet.

[0020] The diffusion annealing is performed at a soaking temperature of 850°C to 1,250°C for 30 to 600 minutes.

[0021] The amount of the Si diffusion composition coated in coating the Si diffusion composition is 0.1 to 300g/m².

[0022] The temperature is increased in a temperature range of 20 to 700°C at a speed of 5 to 50°C/hr prior to the above-mentioned diffusion annealing step.

[0023] In the diffusion annealing, the annealing is performed in an atmosphere having an oxidation capacity ($\text{PH}_2\text{O}/\text{PH}_2$) 6.4 or less.

[0024] Manufacturing the cold rolled sheet may include manufacturing a hot-rolled sheet by hot-rolling a slab including, by weight %, Si: 0.01 to 3.5%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities; and cold rolling the hot-rolled sheet to manufacture a cold-rolled sheet.

[Advantageous Effects]

[0025] The non-oriented electrical steel sheet according to one embodiment of the present invention has an excellent high-frequency iron loss and an insulation property at the same time.

[0026] The method for manufacturing the non-oriented electrical steel sheet according to one embodiment of the present invention provides the environmentally friendly manufacturing method in which no by-product gases harmful to the environment are generated during the manufacturing process, etc.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0027] It will be understood that, although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Thus, a first element, component, region, layer, or section described below could be termed a second element, component, region, layer, or section without departing from the teachings of the present invention.

[0028] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and "comprising", when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups.

[0029] It will be understood that when an element such as a layer, film, region, or substrate is referred to as being "on" or "over" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present.

[0030] Although not defined otherwise, all terms including technical terms and scientific terms used in this specification have the same meanings as those commonly understood by a person having ordinary skill in the art to which the

present invention pertains. Terms defined in a common dictionary are construed as having meanings that comply with related technical documents and disclosed contents, and are not to be construed as having idealized or very official meanings unless defined otherwise.

[0031] Also, unless otherwise specified, % means weight%, and 1 ppm is 0.0001 weight%.

[0032] In one embodiment of the present invention, an inclusion of an additional element means including the remainder of iron (Fe) in an amount equivalent to the additional amount of the additional element.

[0033] Hereinafter, embodiments of the present invention will be described in detail so that a person having ordinary knowledge in the technical field to which the present invention pertains can easily implement the present invention. However, the present invention may be implemented in various different forms and is not limited to the embodiments described herein.

[0034] A non-oriented electrical steel sheet according to one embodiment of the present invention includes, by a weight (wt%), Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities.

[0035] First, the reason for the limitation of the composition of the non-oriented electrical steel sheet is described.

Si: 4.0 to 7.0 wt%

[0036] Silicon (Si) should be added in relatively large quantities because it increases the resistivity of the material and reduces iron loss. As the Si content increases, an eddy current loss may be reduced, which may lower an iron loss at high frequencies. In particular, when Si is included in an amount of 6.0 wt% or more, a magnetostriction, which is a cause of a noise, is reduced to 0 and a permeability increases to the maximum, making it possible to manufacture the electrical steel sheets with excellent high-frequency characteristics. However, when the Si content exceeds 4 wt%, the ductility of the electrical steel sheet decreases significantly, making it difficult to manufacture the electrical steel sheet by using a conventional rolling process.

[0037] In one embodiment of the present invention, Si is diffused from the surface of the steel sheet into the interior of the steel sheet to add Si in an amount of 4 wt% or more into the steel sheet. If there is too little Si in the steel sheet, it is difficult to expect the effect due to Si mentioned above. If too much Si is included, a processability may be poor. In one embodiment of the present invention, due to the diffusion of Si from the surface to the interior, a concentration gradient of Si may occur in the direction of the thickness of the steel sheet, and unless otherwise specified, the Si content in the steel sheet means the average content in the direction of the thickness. The average content refers to the content assuming that Si within the steel sheet is uniformly distributed in the thickness direction of the steel sheet. Specifically, Si may be from 4.5 wt% to 6.5 wt%.

[0038] The maximum Si content in a region from the surface to the inner direction of the non-oriented electrical steel sheet to 5% of the total thickness may be 4.0 to 8.0 wt%, and the Si content at the center position of the sheet thickness ($t/2$) may be 0.03 to 7.0 wt%.

[0039] In one embodiment of the present invention, the steel sheet including the high concentration of Si is manufactured by diffusing Si from the surface of the steel sheet to the interior of the steel sheet, so that the concentration gradient can occur in the direction of the thickness of the steel sheet. That is, the maximum Si content in a region from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction (i.e., the surface portion) can be 4.0 to 8.0 wt%. If the Si content in the surface area is low, it means that the sufficient Si has not been diffused, and the improvement in the high-frequency iron loss through the high-concentration Si may not be sufficiently obtained. If the Si content is too high, it means that Si exists in large quantities only on the surface and has not diffused into the steel sheet, which also means that the improvement in high-frequency iron loss through high-concentration Si may not be sufficiently achieved. The maximum Si content refers to the highest Si content when measuring the Si concentration at the surface in the thickness direction. The maximum Si content may be measured by non-destructive analysis methods such as an electron probe micro-analyzer (EPMA) or a scanning electron microscope/energy-dispersive, an X-ray spectroscopy (SEM/EDX). More specifically, the maximum Si content in the surface area may be 4.3 to 7.5 wt%.

[0040] The center position of the sheet thickness refers to the position at the half of the total thickness of the sheet. Hereinafter, it is referred to as the center. If the Si content in the center is low, it means that the sufficient Si has not been diffused, and the improvement in the high-frequency iron loss through high-concentration Si may not be sufficiently obtained. If the Si content in the core is too high, it may cause problems in machinability for motors. More specifically, the Si content in the center may be 2.0 to 4.0 wt%.

[0041] ΔSi , defined as the difference $[S-M_{Si}]-[C-M_{Si}]$ between the Si content $[C-M_{Si}]$ at the center position of the sheet thickness $t/2$ and the maximum Si content $[S-M_{Si}]$ in the region from the surface to the inner direction of the non-oriented electrical steel sheet to 5% of the entire thickness, may be 0.1 wt% or more. When there is an appropriate difference in the Si content between the center and the surface, it is advantageous in terms of the high-frequency iron loss and the processability. More specifically, ΔSi may be from 0.5 to 7.9 wt%. More specifically, ΔSi may be from 1.0

to 4.0 wt%.

[0042] As described above, in one embodiment of the present invention, Si in the Si powder in the Si diffusion composition is diffused by a diffusion annealing, thereby increasing the Si content, and the steel sheet before the Si diffusion may include less Si than described above. Specifically, a slab and a cold rolled steel sheet before the diffusion may include 0.01 to 3.5 wt% of Si. If there is too little Si in the slab and the cold rolled sheet before the diffusion, the amount of Si required for the diffusion increases, the diffusion annealing takes a long time, the efficiency is not high, and the difference in the Si content by the sheet thickness becomes large, making it difficult to obtain the appropriate high-frequency iron loss. If there is too much Si in the slab and the cold rolled steel sheet before the diffusion, the steel sheet may be broken or defects may occur in the steel sheet during the cold rolling process. More specifically, the Si in the slab and the cold rolled steel sheet before the diffusion may be from 0.3 wt% to 3.3 wt%. More specifically, the Si content in the slab and the cold rolled steel sheet before the diffusion may be 2.0 wt% to 3.0 wt%.

Al: 0.001 to 3.0 wt%

[0043] Aluminum (Al) increases the resistivity of the material and plays a role in reducing the high-frequency iron loss. In one embodiment of the present invention, the resistivity of the material may be sufficiently increased through the diffusion of Si, so that the addition of Al may be unnecessary. However, adding Al may further improve high-frequency iron loss. However, if too much Al is added, the iron loss may deteriorate and the surface quality may deteriorate due to the formation of an aluminum silicate complex. In one embodiment of the present invention, due to the Al diffusion from the surface to the interior, a concentration gradient of Al may occur in the direction of the thickness of the steel sheet, and unless otherwise specified, the Al content in the steel sheet means the average content in the direction of the thickness. More specifically, Al may be included in an amount of 0.01 to 2.5 wt%. More specifically, Al may be included in an amount of 0.1 to 2.0 wt%.

[0044] In one embodiment of the present invention, the steel sheet including a high concentration of Si is manufactured by diffusing Al together with Si, so that the concentration gradient may occur in the direction of the thickness of the steel sheet.

[0045] ΔAl , defined as the difference $[\text{S-M}_{\text{Al}}] - [\text{C-M}_{\text{Al}}]$ between the Al content $[\text{C-MAl}]$ at the center position of the sheet thickness ($t/2$) and the maximum Al content $[\text{S-MAl}]$ in the region from the surface of the non-oriented electrical steel sheet to 5% of the entire thickness in the inner direction, may be 0.1 wt% or more. When there is an appropriate difference in the Al content between the center and the surface, the high-frequency iron may be further improved. More specifically, ΔAl may be 0.1 to 2.9 wt%. More specifically, it may be 0.5 to 2.5 wt%.

[0046] The maximum Al content in the region (i.e., the surface portion) from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction may be 1.0 to 4.0 wt%. If the Al content in the surface portion is low, it means that the sufficient Al has not been diffused, and the improvement in the high-frequency iron loss through the Al diffusion may not be sufficiently achieved. If the Al content is too high, it means that Al exists only in the large quantity on the surface and has not diffused to the inside of the steel sheet, which also means that the improvement in the high-frequency iron loss through the Al diffusion may not be sufficiently achieved. The maximum Al content refers to the highest Al content when measuring the Al concentration at the surface portion in the thickness direction. The maximum Al content may be measured by non-destructive analysis methods such as an electron probe micro-analyzer (EPMA) or a scanning electron microscope/energy-dispersive, X-ray spectroscopy (SEM/EDX). More specifically, the maximum Al content in the surface portion may be 1.5 to 3.5 wt%.

[0047] The Al content at the center position ($t/2$) of the sheet thickness may be 0.001 to 2.9 wt%. If the Al content in the center is low, it means that the sufficient Al has not been diffused, and the improvement in the high-frequency iron loss through the Al diffusion may not be sufficiently achieved. If the Al content in the center is too high, the iron loss may be poor due to the formation of aluminum silicate complexes, and the surface quality may be poor. More specifically, the Al content in the center may be 0.005 to 2.0 wt%.

[0048] As described above, in one embodiment of the present invention, Al in the Al alkoxide in the Si diffusion composition is diffused by a diffusion annealing, thereby increasing the Al content, and the steel sheet before the Al diffusion may include less Al than described above. Specifically, the slab and the cold rolled sheet before the diffusion may include 0.001 to 3.0 wt% of Al. If there is too little Al in the slab and the cold rolled sheet before the diffusion, the amount of Al required for the diffusion increases, the diffusion annealing takes a long time, the efficiency is not high, and the difference in the Al content by the sheet thickness becomes large, making it difficult to obtain the appropriate high-frequency iron loss. If there is too much Al in the slab, problems with the magnetism and surface roughness may occur. More specifically, Al in the slab and the cold rolled sheet before the diffusion may be 0.005 to 2.0 wt%.

Mn: 0.03 to 2.0 wt%

[0049] Manganese (Mn) increases the resistivity of the material, thereby improving the iron loss and forming sul-

fides. If too little Mn is added, fine MnS may precipitate, which may deteriorate the magnetism. If too much Mn is added, it may promote the formation of a {111} grain structure, which is unfavorable for the magnetism, and cause a rapid decrease in a magnetic flux density. In one embodiment of the present invention, Mn does not diffuse unlike Si and Al, and there may be no concentration difference between the surface portion and the center of the steel sheet. That is, the difference in the content between the surface portion and the center of the steel sheet may be 0.01 wt% or less. More specifically, Mn may be from 0.1 to 1.5 wt%.

[0050] The non-oriented electrical steel sheet according to one embodiment of the present invention may further include at least one of P: 0.1 wt% or less, Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Sn: 0.1 wt% or less, Sb: 0.1 wt% or less, Ni: 0.05 wt% or less, and Zn: 0.01 wt% or less.

P: 0.1 wt% or less

[0051] Phosphorus (P) is a grain boundary segregation element, and if it is added in too large a quantity, it may delay a recrystallization and deteriorate a strength uniformity in a rolling direction and a direction perpendicular to the rolling. More specifically, P may be from 0.0001 to 0.1 wt%. More specifically, it may be 0.001 to 0.05 wt%.

Cu: 0.005 to 0.200 wt%

[0052] Copper (Cu) plays a role in forming sulfides together with manganese. If too little Cu is added, (Cu·Mn)S may be finely precipitated, which may deteriorate the magnetism. If too much Cu is added, high-temperature brittleness may occur, which may cause a crack formation during a casting or a hot rolling. More specifically, Cu may be 0.010 to 0.100 wt%.

Cr: 0.010 to 0.50 wt%

[0053] Chromium (Cr) plays a role in improving the iron loss by increasing the resistivity. If too little Cr is added, the resistivity-increasing effect may not be sufficient. If too much Cr is included, the magnetic flux density may decrease. More specifically, Cr may be 0.02 to 0.30 wt%.

Sn: 0.10 wt% or less

[0054] Tin (Sn) is added to suppress the diffusion of nitrogen through grain boundaries as a segregating element in the grain boundaries, suppress a texture{111} that is detrimental to the magnetism, and increase a texture {100} that is advantageous to improve magnetic properties. If too much Sn is added, it hinders a grain growth, which reduces the magnetism and makes the rolling properties poor. Therefore, Sn may be added within the above-mentioned range. More specifically, Sn can be 0.001 to 0.10 wt%. More specifically, it may be 0.005 to 0.08 wt%.

Sb: 0.1 wt% or less

[0055] Antimony (Sb) is added to suppress the diffusion of nitrogen through grain boundaries as a segregating element at the grain boundaries, suppress the {111} texture that is detrimental to the magnetism, and increase the {100} texture that is advantageous to improve magnetic properties. If too much Sb is added, the grain growth is hindered, which reduces the magnetism and makes the rolling properties poor. Therefore, Sb may be added within the above-mentioned range. More specifically, Sb may be 0.001 to 0.10 wt%. More specifically, it may be 0.005 to 0.08 wt%.

Ni: 0.05 wt% or less

[0056] Nickel (Ni) reacts with impurity elements to form fine sulfides, carbides, and nitrides, which may have a detrimental effect on the magnetism. More specifically, Ni may be 0.0001 to 0.050 wt%. More specifically, Ni may be 0.001 to 0.030 wt%.

Zn: 0.01 wt% or less

[0057] Zinc (Zn) may act as an impurity and reduce the magnetism when the content is excessive. Therefore, Zn may be further added within the above-mentioned range. More specifically, Zn may be 0.0001 to 0.01 wt%. More specifically, Zn may be 0.001 to 0.008 wt%.

[0058] The non-oriented electrical steel sheet according to one embodiment of the present invention may further

include 0.200 wt% or less of one or more types of Bi, Pb, Ge, and As, individually or in a combined amount.

[0059] When the aforementioned elements are additionally added, they are segregated at the grain boundaries, thereby alleviating a stress concentration at the grain boundaries during a cold rolling, thereby suppressing a recrystallization of <111>ND orientation grain in a recrystallization annealing of a subsequent process, thereby improving the magnetic flux density. If these are added appropriately, the aforementioned effects may be additionally obtained, but if they are included in too much, a large amount of segregation may occur, thereby inhibiting a grain growth and resulting in the lower magnetic flux density and iron loss. More specifically, it may include one or more of Bi, Pb, Ge and As, each or a combined amount of 0.0001 to 0.200 wt%. More specifically, it may include 0.001 to 0.100 wt% of each or a combined amount of one or more of Bi, Pb, Ge, and As.

[0060] The non-oriented electrical steel sheet according to one embodiment of the present invention may further include at least one of Mo: 0.03 wt% or less, B: 0.0050 wt% or less, Ca: 0.0050 wt% or less, and Mg: 0.0050 wt% or less.

[0061] Since these may react with C, S, N, etc., which are inevitably included, to form fine carbides, nitrides, or sulfides, which may adversely affect the magnetism, the upper limit may be limited as described above.

[0062] More specifically, Mo may be 0.0001 to 0.03 wt%. More specifically, Mo may be 0.001 to 0.02 wt%.

[0063] B, Ca, or Mg may each be included in an amount of 0.0001 to 0.050 wt%. More specifically, B, Ca, or Mg may each be included in an amount of 0.001 to 0.030 wt%.

Other impurities

[0064] In addition to the elements mentioned above, unavoidable mixed impurities such as carbon (C), sulfur (S), nitrogen (N), titanium (Ti), niobium (Nb), and vanadium (V) may be included.

[0065] N combines with Ti, Nb, and V to form nitrides and plays a role in reducing the grain growth.

[0066] C reacts with N, Ti, Nb, V, etc. to form fine carbides, which hinder the grain growth and a domain movement.

[0067] S forms sulfides, which impairs the grain growth.

[0068] In this case, when the impurity elements are further included, one or more of C, S, N, Ti, Nb, and V may be each included at 0.005 wt% or less. More specifically, at least one of C, S, N, Ti, Nb and V may each be contained in an amount of 0.0001 wt% to 0.005 wt%. More specifically, more specifically, at least one of C, S, N, Ti, Nb and V may each be contained in an amount of 0.0005 wt% to 0.003 wt%.

[0069] In addition, unavoidable mixed impurities may be included. As for the unavoidable impurities, they are impurities mixed in during a steelmaking stage and the manufacturing process of the non-oriented electrical steel sheet, and since this is widely known in the field, a detailed description is omitted. In one embodiment of the present invention, addition of elements other than the alloy components described above is not excluded, and may be included in various ways within a range that does not harm the technical idea of the present invention. If the additional elements are included, they are included to replace the remainder, Fe.

[0070] The non-oriented electrical steel sheet according to one embodiment of the present invention may have a steel structure of a single phase ferrite, and an average grain diameter of the ferrite may be 100 to 300 μm . If the average ferrite grain diameter is too large, an eddy current loss, which is a loss caused by an induced current, may increase, resulting in the poor magnetism. If the average ferrite grain diameter is too small, a hysteresis loss, which is an energy used to move the magnetic domain walls, increases, which may result in the poor magnetism. More specifically, it may be 120 to 280 μm . More specifically, it may be 150 to 250 μm . These properties may be obtained by controlling the temperature and time of the ceramic diffusion annealing. This is specifically explained in relation to the manufacturing method of the non-oriented electrical steel sheet. The ferrite single phase means that more than 99 area% of the crystal grains in the steel sheet are ferrite, and the remainder may be amorphous, austenite, pearlite, FeSi with B2 structure, Fe₃Si with DO3 structure, etc. The area % of the ferrite single phase may be obtained by taking an optical microscope photograph and analyzing the image. To reduce errors, more than 10 non-overlapping random locations on the steel sheet may be selected, a sample area of 1600 $\mu\text{m} \times 1200 \mu\text{m}$ or more may be taken and then averaged to be used for a judgment. The average grain diameter of the ferrite may be measured in the direction parallel to the normal plane perpendicular to the thickness direction of the steel sheet.

[0071] Meanwhile, in one embodiment of the present invention, due to the difference in the Si and Al concentrations in the central and surface portions, the grain diameters of the ferrite may be different in the central and surface portions. Specifically, the average ferrite grain diameter at the center position ($t/2$) of the sheet thickness may be 100 to 500 μm , and the average ferrite grain diameter in the region from the surface to 5% of the total thickness in the inward direction may be 10 to 100 μm . More specifically, the average ferrite grain diameter at the center position ($t/2$) of the sheet thickness may be 200 to 480 μm , and the average ferrite grain diameter at the position of 5% of the total thickness from the surface in the inward direction may be 15 to 90 μm . The grain diameter at the specific thickness location may be measured on a plane parallel to a rolling plane (an ND plane).

[0072] In this way, the difference in the ferrite grain diameter at the center position ($t/2$) of the sheet thickness and at

the position of 5% of the total thickness from the surface in the inward direction may be 100 to 450 μm . More specifically, it may be 150 to 400 μm .

[0073] The non-oriented electrical steel sheet according to one embodiment of the present invention has the excellent high-frequency iron loss due to the diffusion of Si and Al. Specifically, the iron loss ($W_{10/1000}$) may be 70.0 W/kg or less based on the thickness of 0.3 mm. The iron loss ($W_{10/1000}$) is the iron loss when the magnetic flux density of 1.0 T is induced at a frequency of 1000 Hz. The iron loss may be measured using an Epstein method or a single sheet test (SST). More specifically, the iron loss ($W_{10/1000}$) is 40 to 65 W/kg based on the thickness of 0.3 mm. Additionally, the iron loss ($W_{10/1000}$) can be 55.0 W/kg or less based on the thickness of 0.2 mm. More specifically, the iron loss ($W_{10/1000}$) is 20 to 53 W/kg based on the thickness of 0.2 mm. Additionally, $W_{10/1000}$ may be less than 35.0 W/kg based on the thickness of 0.1 mm. More specifically, $W_{10/1000}$ may be 10.0 to 33.0 W/kg based on the thickness of 0.1 mm.

[0074] Additionally, the iron loss ($W_{5/2000}$) may be less than 16.5 W/kg based on the thickness of 0.2 mm. The iron loss ($W_{5/2000}$) is the iron loss when the magnetic flux density of 0.5 T is induced at a frequency of 2000 Hz. More specifically, the iron loss ($W_{5/2000}$) may be 5.0 W/kg to 15.5 W/kg based on the thickness of 0.2 mm. Additionally, the iron loss ($W_{5/2000}$) may be less than 7.3 W/kg based on the thickness of 0.1 mm. The iron loss ($W_{5/2000}$) is the iron loss when the magnetic flux density of 0.5 T is induced at a frequency of 2000 Hz. More specifically, the iron loss ($W_{5/2000}$) may be 2.0 W/kg to 7.0 W/kg based on the thickness of 0.1 mm.

[0075] In one embodiment of the present invention, not only the iron loss but also the magnetic flux density is excellent at the same time. Specifically, the magnetic flux density (B_{25}) may be 1.46 T or more. Specifically, the magnetic flux density (B_{25}) may be 1.55 to 1.70 T.

[0076] In one embodiment of the present invention, by appropriately diffusing Al inward from the surface of the steel sheet, the insulation properties are excellent. Specifically, the insulation may be 200 to 900 mA or more. The insulation may be measured using a Franklin insulation tester. The insulation may be between 250 and 850 mA.

[0077] In one embodiment of the present invention, by appropriately using the Si diffusion composition, the roughness of the steel sheet may be reduced and the surface condition may be manufactured in a good manner. Specifically, the roughness R_a of the steel sheet surface may be 1.00 μm or less. The roughness R_a of the steel sheet surface may be measured using a confocal laser scanning microscopy. More specifically, the roughness may be between 0.10 μm and 1.00 μm . More specifically, it may be 0.20 to 0.95 μm .

[0078] The Si diffusion composition for the electrical steel according to one embodiment of the present invention includes Si powder and Al alkoxide.

[0079] The Si diffusion composition includes 10 to 70 wt% of the Si powder as a solid content. In one embodiment of the present invention, the solid content means a weight of each compound after heating it at 180°C for 20 minutes or more and removing all volatile matter.

[0080] If too little Si powder is included, the Si diffusion does not occur sufficiently, making it difficult to sufficiently achieve the desired high-frequency iron loss improvement. If too much Si powder is included, too much Si will be diffused within the steel sheet, which may cause problems with the processability when the steel sheet is later processed into products such as motors. More specifically, the Si powder may be from 15 wt% to 60 wt%.

[0081] The Si powder may include one or more of a pure Si, a Si alloy, a silicon wafer, and polycrystalline silicon. More specifically, it may be a Si alloy including 90 wt% or more of Si.

[0082] The average particle size of the Si powder may be from 1 to 850 nm. If the particle size of the Si powder is too small, the particles may clump together during a slurry mixing, causing surface defects. If the particle size of the Si powder is too large, it may be difficult to be uniformly coated to the surface of the steel sheet, and Si may not diffuse smoothly into the steel sheet. The average particle size of the Si powder may be an average particle size relative to the number of particles, and may be measured using a particle size analyzer (PSA) using a laser diffraction.

[0083] More specifically, the lower limit of the average particle size of the Si powder may be 10 nm to 800 nm.

[0084] The Si diffusion composition includes 1 to 20 wt% of Al alkoxide as a solid content. Al alkoxide serves as an Al raw material that diffuses Al within the steel sheet, and plays a role in ensuring a stability of a slurry mixture and ensuring a uniform quality. If too little Al alkoxide is included, the stability of the slurry mixture may become deteriorated. If too much Al alkoxide is included, the viscosity of the slurry mixture increases, which may cause problems in terms of a surface quality. More specifically, the lower limit of Al alkoxide may be 1.5 wt% to 16.0 wt%.

[0085] Al alkoxide is expressed as $\text{Al}(\text{OR})_n(\text{R})_{3-n}$, where R is an alkyl group having 1 to 4 carbon atoms or an alkenyl group having 2 to 4 carbon atoms, and n is an integer from 1 to 3. More specifically, each R may be an alkyl group having 1 to 4 carbon atoms, and n may be 3. More specifically, each R may be an alkyl group having 2 to 4 carbon atoms. More specifically, it may be aluminum tri-i-propoxide or aluminum tri-n-butoxide.

[0086] When Al oxide or nitride, i.e. Al_2O_3 or AlN , is included instead of Al alkoxide, a problem of a poor surface roughness may occur.

[0087] The Si diffusion composition may further include a ceramic powder including oxide, nitride, carbide or oxynitride including at least one selected from Li, B, Ca, Sr, Mg, Al, Si, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn and Ba as a

component. The ceramic powder plays a role in controlling the amount of the coated slurry and regulating the Si diffusion rate of the final steel sheet.

[0088] The ceramic powder may be included as a remainder of the Si powder and Al alkoxide as a solid component. That is, it may include 10 to 89 wt% as the solid component.

[0089] If too little ceramic powder is included, problems may occur in securing the amount of the coating. If too much ceramic powder is included, the slurry viscosity increases, which may cause problems in terms of the surface defects. More specifically, the ceramic powder may be present in the amount of 20 wt% to 70 wt%.

[0090] The ceramic powder may be at least one of Al_2O_3 , SiO_2 , TiO_2 , $\text{MgO} \cdot \text{Al}_2\text{O}_3$, $\text{MgO} \cdot \text{TiO}_2$, $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, $\text{ZrO}_2 \cdot \text{SiO}_2$, TiN , CrN , SrTiO_3 , MgAl_2O_4 , Y_2O_3 , FeTiO_3 and $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$.

[0091] The average particle size of the ceramic powder may be from 8 to 2500 nm. If the particle size of the ceramic powder is too small, problems may arise in securing a sufficient coating amount. If the particle size of the ceramic powder is too large, the viscosity increases, the surface quality deteriorates, and the Al diffusion into the steel sheet may not occur smoothly. More specifically, the average particle size of the ceramic powder may be 10 nm to 2000 nm.

[0092] The Si diffusion composition may further include a solvent in addition to the aforementioned components. The solvent enables the Si diffusion composition to be coated uniformly. If the solvent is too little, the coating of the Si diffusion composition may not be easy. If there is too much solvent, the viscosity of the Si diffusion composition may be too low, making it difficult to coat the sufficient amount of the composition onto the steel sheet. The solvent may be included in the amount of 10 to 1500 parts by a weight per 100 parts of the solid component. More specifically, the solvent may be included in the amount of 20 to 1300 parts by a weight. The solvent may include at least one of water and alcohol.

[0093] In addition to the Si powder, Al alkoxide, ceramic powder, and solvent described above, the Si diffusion composition may further include additional components, which are not excluded in one embodiment of the present invention. Examples of additional ingredients may include orthophosphoric acid, sodium silicate, and a fluoride ion solution. When the additional components are included, the content ratio of the aforementioned Si powder, Al alkoxide, and ceramic powder is understood to be a ratio to the total sum of the Si powder, Al alkoxide, and ceramic powder, not to the entire Si diffusion composition.

[0094] A method for manufacturing the non-oriented electrical steel sheet according to one embodiment of the present invention includes manufacturing a cold-rolled sheet including, in wt%, Si: 0.01 to 3.5%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities; coating a Si diffusion composition including the Si powder and the Al alkoxide to the cold-rolled sheet; and diffusion-annealing the cold-rolled sheet.

[0095] Below, each step is explained in detail.

[0096] First, the cold-rolled sheet is manufactured including, in weight %, Si: 0.01 to 3.5%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities. Since the alloy composition of the cold rolled sheet is the same as that described above, redundant explanation is omitted.

[0097] The method for manufacturing a cold-rolled sheet is not particularly limited, and may include hot-rolling a slab including, in wt%, Si: 0.01 to 3.5%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities, to manufacture a hot-rolled sheet; and cold-rolling the hot-rolled sheet to manufacture a cold-rolled sheet.

[0098] First, the slab is manufactured. The reason for limiting the addition ratio of each composition within the slab is the same as the reason for limiting the composition of the non-oriented electrical steel sheet described above, so a repeated explanation is omitted. Since the composition of the slab does not substantially change during the manufacturing processes such as the hot rolling, the hot-rolled sheet annealing, and the cold rolling described later, the composition of the slab and the composition of the cold-rolled sheet are substantially the same. In addition, only Si and Al are diffused in the diffusion annealing process, and the alloy composition of the non-oriented electrical steel sheet may be the same as that of the remaining components except for Si and Al.

[0099] The slab may be heated to 1100°C or higher prior to manufacturing the hot rolled sheet. Specifically, the slab is placed in a furnace and heated to 1100 to 1250°C. When being heated at a temperature exceeding 1250°C, the precipitates may be re-dissolved and finely precipitated after the hot rolling. More specifically, the slab heating temperature may be between 1150°C and 1200°C.

[0100] The heated slab is hot rolled to 1.5 to 4.0 mm to produce a hot-rolled sheet. In one embodiment of the present invention, a preliminary cold rolling before the cold rolling may be also included, so that even if the thickness of the hot-rolled sheet is relatively thick, the non-oriented electrical steel sheet of an appropriate thickness may be manufactured. More specifically, the thickness of the hot rolled sheet may be from 1.8 mm to 3.5 mm.

[0101] Manufacturing the hot rolled sheet may include finish-rolling at a temperature of 850°C or higher.

[0102] If the hot rolling finishing temperature is too low, the rolling load increases and the hot rolling workability deteriorates. In addition, a lot of deformation structures remain in the hot-rolled steel sheet, which may cause the increase in the rolling load during the subsequent preliminary cold rolling process. In addition, during an intermediate annealing, the recrystallization of <111>/ND orientation grains from the deformation structure is promoted, resulting in

a lower magnetic flux density. Therefore, the higher the hot rolling finishing rolling temperature, the better, and more specifically, the finishing rolling temperature may be 870 to 1000°C.

[0103] Manufacturing the hot rolled sheet may include winding at a temperature of 600 to 800°C. A rough rolling may also be included prior to the final rolling.

[0104] If the temperature is controlled too low during the winding, the recovery and recrystallization of the hot-rolled deformation structure will not occur well, and the cooling load will increase in order to quickly cool the steel sheet to a low temperature, which may make it difficult to wind the supercooled coil. Conversely, if the temperature is too high, the recovery and recrystallization may be promoted, but an additional oxidation by an atmospheric oxygen may occur while being coiled, which may cause a thicker scale formation and a grain boundary oxidation problem. The grain boundary oxidation of the hot-rolled sheet promotes a grain boundary corrosion during a subsequent pickling process, which increases a possibility of surface stripe defects and may cause a severe wear of the rolling rolls. Therefore, the winding temperature may be between 620°C and 770°C.

[0105] After manufacturing the hot-rolled sheet, annealing the hot-rolled sheet at a temperature range of 600 to 1100°C may be further included. If the annealing temperature of the hot-rolled sheet is too low, the recrystallized structure is not formed or grows finely, so the effect of increasing the magnetic flux density is small. If the annealing temperature is too high, the magnetic properties may deteriorate, and the rolling workability may deteriorate due to the deformation of the sheet shape. More specifically, the hot-rolled sheet annealing temperature may be 650°C to 1050°C.

[0106] The annealing of the hot-rolled sheets is performed to increase the orientation favorable to the magnetism, and may also be omitted as needed. The annealing form is not particularly limited, and the annealing may be performed in batch or continuous manner.

[0107] The hot rolled sheet that is hot rolled may be pickled as needed.

[0108] Next, the hot-rolled sheet is pickled and cold-rolled into a desired thickness. It may be applied differently depending on the thickness of the hot-rolled sheet, but it may be cold rolled to a final thickness of 0.10 to 0.65 mm by applying a reduction ratio of 70 to 95%. To match the reduction ratio, one cold rolling or two or more cold rolling with an intermediate annealing therebetween may be performed. More specifically, the reduction ratio may be between 75% and 90%. The thickness of the cold rolled sheet may be from 0.10 mm to 0.35 mm.

[0109] Returning to the description of the method for manufacturing the non-oriented electrical steel sheet, a Si diffusion composition including the Si powder and the Al alkoxide is coated to the cold-rolled sheet. Since the Si diffusion composition is the same as described above, redundant description is omitted.

[0110] The coating amount of the Si diffusion composition may be 0.1 to 300 g/m². At this time, the coating amount is based on the solid component. If the amount of the coating is too small, the sufficient diffusion of Si and Al does not occur, making it difficult to sufficiently achieve the effect of the Si and Al diffusion. If the amount of the coating is too large, the problem of the poor processability may occur due to the increased diffusion of Si and Al.

[0111] Coating the Si diffusion composition and drying it may be further included. The drying temperature is sufficient as long as it is a temperature capable of removing the solvent within the Si diffusion composition, and can be specifically 300 to 750°C. The time may be from 10 to 60 seconds. More specifically, the temperature may be between 350°C and 700°C. The time may be between 15 and 50 seconds.

[0112] Next, the cold rolled sheet is diffusion annealed. In this process, Si and Al are diffused into the steel sheet from the Si diffusion composition applied to the surface of the cold-rolled sheet.

[0113] Before the diffusion annealing, the temperature range may be increased from 20 to 700°C at a rate of 5 to 50°C/hr. In this way, a uniform quality may be obtained by heating at a relatively slow heating rate. If the heating rate is too slow, the process time will be unnecessarily long and productivity will decrease. If the heating rate is too fast, the aforementioned effects cannot be properly obtained. More specifically, the heating rate may be 10 to 40°C/hr.

[0114] By controlling the temperature and time of the diffusion annealing, the ferrite single phase and ferrite average grain diameter may be appropriately controlled.

[0115] The diffusion annealing temperature may be between 850°C and 1250°C. If the diffusion annealing temperature is too low, the diffusion of Si and Al may not occur sufficiently, and the desired effect may not be obtained. If the diffusion annealing temperature is too high, pores may form and the magnetism may become poor. More specifically, the diffusion annealing temperature can be 900°C to 1200°C.

[0116] The time may range from 30 to 600 minutes. If the time is too short, the diffusion of Si and Al may not occur sufficiently, and the desired effect may not be achieved. If the time is too long, it may be difficult to control the diffusion amount of Si and Al, which may result in the poor processability. More specifically, the time may be between 60 and 480 minutes.

[0117] The atmosphere during the diffusion annealing may be an atmosphere including one or more of hydrogen, nitrogen or argon. The oxidation capacity ($\text{PH}_2\text{O}/\text{PH}_2$) of the atmosphere may be less than 6.4. If the oxidation capacity is too high, internal oxides of SiO_2 and Al_2O_3 may be formed, which may reduce the magnetism. Specifically, the oxidation capacity may be from 0.001 to 5.0. More specifically, the oxidation capacity may be from 0.01 to 3.0.

[0118] After the diffusion annealing, forming an insulating film may be further included. Since the insulating film is widely known, the detailed description thereof is omitted. Specifically, an insulating coating layer may be formed by coating g an insulating coating layer forming composition including a metal phosphate and silica as main components and performing a heat treatment.

[0119] Hereinafter, preferred embodiments and comparative examples of the present invention are described. However, the following examples are only preferred embodiments of the present invention, and the present invention is not limited to the following examples.

Experimental Example 1: a control of temperature and time conditions during a diffusion annealing

[0120] A slab was prepared including 2.0 wt% silicon (Si), 0.003 wt% aluminum (Al), 0.15 wt% manganese (Mn), 0.02 wt% tin (Sn), 0.01 wt% phosphorus (P), and the remainder being iron and other unavoidable impurities.

[0121] The slab was heated at 1100°C and then hot rolled to a thickness of 1.8 mm to produce a hot-rolled sheet.

[0122] After coiling the hot-rolled sheet at 700°C, it was cooled in the air, annealed at 1030°C for 2 minutes, rapidly cooled in water to be pickled, and then cold rolled to a thickness of 0.10 mm to produce a cold-rolled sheet.

[0123] A Si diffusion composition was prepared by stirring a water together with 65 wt% of silicon nanoparticles having an average particle size of 25 nm, 1 wt% of aluminum n-butoxide, and 34 wt% of Al₂O₃ ceramic powder having an average particle size of 1000 nm.

[0124] The manufactured Si diffusion composition was coated to the cold-rolled sheet in an amount of 50g/m² and dried at 650°C condition for 8 seconds.

[0125] The cold-rolled sheet coated with the Si diffusion composition was diffusion-annealed under conditions listed in Table 1 below in an atmosphere containing 50 vol% argon, 50 vol% hydrogen, and an oxidation ability of 1.22 at 900°C for 2 hours.

[0126] The surface of the steel sheet after the completion of the diffusion annealing was washed with water, dried at room temperature, and etched under an atmospheric pressure plasma condition to remove unreacted substances, thereby manufacturing the non-oriented electrical steel sheet with 0.1 mm of the thickness.

[0127] As a result of an analysis using an electron probe micro-analyzer (EPMA), it was confirmed that the average steel composition in the thickness direction of the steel sheet included Si: 7.0 wt%, Al: 0.95 wt%, Mn: 0.15 wt%, P: 0.010 wt%, Sn 0.02 wt%, and the remainder was composed of Fe and other unavoidable impurities. It was confirmed that ΔAl was 0.1 wt%.

[0128] Optical microscope photographs of the cross-sections of the steel sheets were taken and an image analysis was performed to determine whether single-phase ferrite was present.

[0129] In addition, the grain diameter of the steel sheet is used to the average particle diameter by using a line parallel to a normal plane perpendicular to the thickness direction of the steel sheet. The average ferrite grain diameter for the entire thickness of the steel sheet, the average ferrite grain diameter at the center (the center position t/2 of the sheet thickness), and the average ferrite grain diameter at the surface (the position t/20 of the sheet thickness) were measured.

[0130] The iron loss and the magnetic flux density were measured using a single sheet tester.

(Table 1)

	Diffusion annealing temperature (°C)	Diffusion annealing time (min)	Single-phase ferrite existence	Entire thickness ferrite average particle diameter(μ m)	Center ferrite average particle diameter(μ m)	Surface ferrite average particle diameter(μ m)	B25 (T)	W10/1k(W/kg)	W5/2 k(W/kg)
Embodiment 1-1	900	480	○	132.5	234	31	1.57	31.2	4.4
Embodiment 1-2	1000	240	○	121.5	225	18	1.59	30.8	4.5
Embodiment 1-3	1100	240	○	192.5	344	41	1.62	25.5	4.2
Embodiment 1-4	1200	60	○	224.5	381	68	1.61	29.4	4.4
Embodiment 1-5	1200	90	○	241.0	408	74	1.64	26.1	4.0
Embodiment 1-6	1200	120	○	281.5	475	88	1.63	26.6	4.1
Comparative Example 1-1	700	480	○	63.0	95	31	1.35	49.6	17.5
Comparative Example 1-2	1300	60	○	361.0	557	165	1.37	49.0	15.8
Comparative Example 1-3	900	900	○	231.5	267	196	1.41	43.1	13.8
Comparative Example 1-4	1200	900	○	438.0	527	349	1.38	47.2	14.3
Comparative Example 1-5	1300	900	X	519.5	598	441	1.47	53.3	16.5

[0131] As shown in Table 1, if the conditions are not properly controlled during the diffusion annealing process, the single-phase ferrite is not formed, the ferrite grain diameter is not properly formed, and ultimately the magnetism is poor.

5 Experimental Example 2: Al alkoxide types

[0132] A slab was prepared including 2.5 wt% silicon (Si), 0.002 wt% aluminum (Al), 0.10 wt% manganese (Mn), 0.04 wt% tin (Sn), 0.04 wt% antimony (Sb), 0.013 wt% phosphorus (P), and the remainder being iron and other unavoidable impurities.

[0133] The slab was heated at 1100°C and then hot rolled to a thickness of 1.8 mm to produce a hot-rolled sheet.

[0134] After coiling the hot-rolled sheet at 700°C, it was cooled in the air, annealed at 1030°C for 2 minutes, rapidly cooled in water to be pickled, and then cold rolled to a thickness of 0.10 mm to produce a cold-rolled sheet.

[0135] On the surface of the cold-rolled sheet, 65 parts by weight of silicon nanoparticles (Si: 99.99 wt% or more) having an average particle size of 15 nm as a solid component, 7 parts by weight of aluminum alkoxide as a solid component, and 28 parts by weight of SrTiO₃ ceramic powder having an average particle size of 1500 nm as a solid component were added and stirred with a water to prepare a Si diffusion composition. The type of Al alkoxide was changed as shown in Table 2 below and manufactured.

[0136] The manufactured Si diffusion composition was coated to the cold-rolled sheet in an amount of 50g/m² and dried at 650°C for 8 seconds.

[0137] The cold-rolled sheet coated with the Si diffusion composition was diffusion-annealed at 900°C for 2 hours in an atmosphere including 50 vol% argon, 50 vol% hydrogen, and an oxidation ability of 1.22.

[0138] The surface of the steel sheet on which the diffusion annealing was completed was washed with water, dried at room temperature, and etched under atmospheric pressure plasma conditions to remove unreacted substances, thereby manufacturing the non-oriented electrical steel sheet with 0.1 mm of the thickness.

[0139] As a result of analysis using a scanning electron microscope/energy-dispersive X-ray spectrometer, it was confirmed that the average steel composition in the thickness direction of the steel sheet included Si: 7.0 wt%, Al: 1.5 wt%, Mn: 0.15 wt%, P: 0.01 wt%, Sn 0.02 wt%, and the remainder was composed of Fe and other unavoidable impurities. It was confirmed that ΔSi was 1.3 wt% and ΔAl was 0.5 wt%.

[0140] An insulation was measured using a Franklin tester.

[0141] The iron loss and magnetic flux density were measured using a single sheet tester.

[0142] Surface characteristics were measured as an area ratio of a surface defect per a unit area through an image analysis, and were classified as excellent when it is less than 0.5%, good when it is 0.5% or more but less than 5%, fair when it is 6% or more but less than 10%, poor when it is 10% or more but less than 20%, and very poor when it is 20% or more.

[0143] A final steel sheet surface roughness characteristics according to the change of an Al alkoxide were measured using a confocal laser scanning microscopy.

(Table 2)

	Al(O R) ₃ , R	Singl e- phase ferrite existence	Entire thickness ferrite average particle diameter (μ m)	Center ferrite average particle diameter(μm)	Surface ferrite average particle diameter(μm)	Steel sheet surface roughness (μ m)	B25(T)	W10/ 1k(W /kg)	W5/2 k(W/ kg)	Surface state
Embodiment 2-1	methyl	◦	202.0	353	51	0.78	1.56	30.0	5.1	Fair
Embodiment 2-2	ethyl	◦	200.5	349	52	0.63	1.55	31.4	5.0	Good
Embodiment 2-3	n-propyl	◦	200.5	347	54	0.91	1.57	29.4	4.7	Good
Embodiment 2-4	i-propyl	◦	203.0	354	52	0.21	1.64	24.7	3.8	Excellent
Embodiment 2-5	n-butyl	◦	197.5	348	47	0.19	1.61	24.9	3.6	Excellent
Embodiment 2-6	s-butyl	◦	203.5	354	53	0.33	1.55	26.7	3.9	Good
Comparative Example 2-1	n-pentyl	◦	200.5	348	53	1.05	1.49	35.8	7.5	Poor
Comparative Example 2-2	n-hexyl	◦	201.5	355	48	1.04	1.48	40.2	9.1	Poor
Comparative Example 2-3	n-heptyl	◦	199.5	353	46	1.24	1.48	42.5	12.2	Very poor
Comparative Example 2-4	Al ₂ O ₃	◦	202.5	353	52	1.56	1.33	56.8	24.6	Very poor
Comparative Example 2-5	AlN	◦	198.5	350	47	1.44	1.37	56.6	24.3	Very poor

[0144] As shown in Table 2, when Al_2O_3 or AlN is used instead of Al alkoxide, it may be confirmed that the magnetism and the surface quality are inferior to those of the $\text{Al}(\text{OR})_3$ compound. Even when $\text{Al}(\text{OR})_3$ is used, if the carbon atoms of R exceeds 4, it may be confirmed that the carbon content increases, causing defects on the surface of the steel sheet and ultimately resulting in poor magnetism.

Experimental Example 3: Control of a Si Powder Content

[0145] A slab was prepared including 2.0 wt% silicon (Si), 0.03 wt% aluminum (Al), 0.11 wt% manganese (Mn), 0.06 wt% tin (Sn), 0.01 wt% antimony (Sb), 0.010 wt% phosphorus (P), and the remainder being iron and other unavoidable impurities.

[0146] The slab was heated at 1100°C and then hot rolled to a thickness of 2.0 mm to produce a hot-rolled sheet.

[0147] After coiling the hot-rolled sheet at 650°C, it was cooled in the air, annealed at 1055°C for 2 minutes and 30 seconds, rapidly cooled in water, to be pickled, and then cold rolled to a thickness of 0.20 mm to produce a cold-rolled sheet.

[0148] On the surface of the cold-rolled sheet, silicon nanoparticles having an average particle size of 25 nm were adjusted as shown in Table 3 below, and 10 wt% of aluminum n-butoxide and the remaining Al_2O_3 ceramic powder having an average particle size of 1000 nm were stirred with water to prepare a Si diffusion composition.

[0149] The manufactured Si diffusion composition was coated and dried at 350°C for 60 seconds.

[0150] The cold-rolled sheet coated with the Si diffusion composition was diffusion-annealed at 1150°C for 7 hours in a mixed atmosphere of 75 vol% hydrogen and 25 vol% nitrogen, with the oxidation capacity adjusted to 0.65.

[0151] The surface of the steel sheet after the completion of the diffusion annealing was washed with water, dried at room temperature, and then etched under atmospheric pressure plasma conditions to remove unreacted substances.

[0152] As a result of analysis using EPMA (Electron Probe Micro-Analyzer), it was confirmed that the average steel composition in the thickness direction of the steel sheet included Al: 0.9 wt%, Mn: 0.11 wt%, P: 0.010 wt%, Sn 0.06 wt%, Sb 0.01 wt%, and the remainder was composed of Fe and other inevitable impurities. ΔAl was confirmed to be 0.25 wt%.

(Table 3)

	Si po w de r (w t %)	Si con tent (wt %)	Single- phase ferrite existen ce	Entire thickness ferrite average particle diameter(μm)	Center ferrite average particle diameter(μm)	Surface ferrite average particle diameter(μm)	B2 5(T)	W 5/2 k(W/ kg)
Embodiment 4-1	10	4.0	○	195.0	375	15	1.612	15.4
Embodiment 4-2	28	5.0	○	212.5	404	21	1.573	13.7
Embodiment 4-3	49	6.0	○	223.5	422	25	1.470	8.5
Embodiment 4-4	70	7.0	○	257.5	481	34	1.462	10.9
Embodiment 4-5	55	5.5	○	236.0	445	27	1.525	9.8
Embodiment 4-6	16	4.5	○	202.0	386	18	1.579	14.7
Comparative Example 4-1	9	3.9	○	186.0	366	6	1.613	25.7
Comparative Example 4-2	75	7.1	X	282.0	523	41	1.450	17.5
Comparative Example 4-3	80	9.2	X	312.5	577	48	1.422	18.3

(continued)

	Si powder (wt %)	Si content (wt %)	Single- phase ferrite existence	Entire thickness ferrite average particle diameter(μ m)	Center ferrite average particle diameter(μ m)	Surface ferrite average particle diameter(μ m)	B2 5(T)	W 5/2 k(W/ kg)
Comparative Example 4-4	90	10.7	X	328.0	603	53	1.322	19.9

[0153] As shown in Table 3, it may be confirmed that when the content of the Si powder is very small, the ferrite grain diameter on the surface is not secured and the magnetism is poor.

[0154] When the content of the Si powder is very large, it may be confirmed that Si is not properly diffused into the center, so only the ferrite grain diameter in the center becomes very coarse in order to secure the grain diameter of the surface, ultimately confirming the poor magnetism.

[0155] The exemplary embodiments and modified examples of the present invention have been described and shown with reference to the accompanying drawings, but the present invention is not limited to the exemplary embodiments and may be manufactured in various forms. As described above, it will be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the general inventive concept, the scope of which is defined in the appended claims and their equivalents. Therefore, it should be understood that the exemplary embodiments described above are not limitative but are exemplary in all the aspects.

Claims

1. A non-oriented electrical steel sheet comprising:

Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, by weight, with the remainder being Fe and inevitable impurities,
wherein Δ Al, defined as a difference ([S-MAI]-[C-MAI]) between an Al content [C-MAI] at the center position of the sheet thickness ($t/2$) and a maximum Al content [S-MAI] in an area from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction is 0.1 wt% or more,
a sheet structure has a single-phase ferrite structure, an average ferrite grain size is 100 to 300 μ m.

2. The non-oriented electrical steel sheet of claim 1, wherein:

the maximum Si content in the region from the surface to 5% of the total thickness in the inner direction is 4 to 8 wt%, and the Si content at the center position ($t/2$) of the sheet thickness is 0.01 to 7.0 wt%.

3. The non-oriented electrical steel sheet of claim 1, wherein:

a Δ Si defined as a difference ([S-MSi]-[C-MSi]) between a Si content [C-MSi] at the center position ($t/2$) of the thickness of the sheet and a maximum Si content [S-MSi] in a region from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inner direction is 0.1 wt% or more.

4. The non-oriented electrical steel sheet of claim 1, wherein:

a surface roughness Ra of the non-oriented electrical steel sheet is 1.00 μ m or less.

5. The non-oriented electrical steel sheet of claim 1, further comprising:

at least one of C, N, S, Ti, Nb, and V, each in an amount of 0.005 wt% or less.

6. The non-oriented electrical steel sheet of claim 1, further comprising:

at least one of P: 0.1 wt% or less, Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Sn: 0.1 wt% or less, Sb: 0.1 wt% or less, Ni: 0.05 wt% or less, and Zn: 0.01 wt% or less.

7. The non-oriented electrical steel sheet of claim 1, further comprising:

0.200 wt% or less of each or a combination of Bi, Pb, Ge and As.

8. The non-oriented electrical steel sheet of claim 1, further comprising:
at least one of Mo: 0.03 wt% or less, B: 0.0050 wt% or less, Ca: 0.0050 wt% or less, and Mg: 0.0050 wt% or less.

9. A method for manufacturing a non-oriented electrical steel sheet, comprising:

manufacturing a cold rolled sheet, comprising, in weight %, Si: 0.01 to 3.5%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities;
coating a Si diffusion composition including a Si powder and an Al alkoxide to the cold rolled sheet; and
diffusion-annealing the cold rolled sheet,
wherein the Al alkoxide is expressed as $\text{Al(OR)}_n(\text{R})_{3-n}$, R is an alkyl group having 1 to 4 carbon atoms or an alkenyl group having 2 to 4 carbon atoms, and n is an integer of 1 to 3, and
the diffusion annealing is performed at a soaking temperature of 850°C to 1,250°C for 30 to 600 minutes.

10. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:
the amount of the Si diffusion composition coated in coating the Si diffusion composition is 0.1 to 300g/m².

11. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:
the temperature is increased in a temperature range of 20 to 700°C at a speed of 5 to 50°C/hr prior to the above-mentioned diffusion annealing step.

12. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:
in the diffusion annealing, the annealing is performed in an atmosphere having an oxidation capacity ($\text{PH}_2\text{O}/\text{PH}_2$) 6.4 or less.

13. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:

manufacturing the cold rolled sheet includes
manufacturing a hot-rolled sheet by hot-rolling a slab including, by weight %, Si: 0.01 to 3.5%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the remainder being Fe and unavoidable impurities; and
cold rolling the hot-rolled sheet to manufacture a cold-rolled sheet.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020325

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/04**(2006.01)i; **C22C 38/42**(2006.01)i; **C22C 38/58**(2006.01)i;
C22C 38/52(2006.01)i; **C22C 38/12**(2006.01)i; **C21D 8/12**(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02(2006.01); C21D 8/12(2006.01); C21D 9/00(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01);
C22C 38/16(2006.01); H01F 1/16(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models: IPC as above

Japanese utility models and applications for utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS (KIPO internal) & keywords: 무방향(non-oriented), 전기강판(electrical steel sheet), 확산(diffusion), 알콕사이드 (alkoxide)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-2022-0087695 A (POSCO) 27 June 2022 (2022-06-27) See paragraphs [0052] and [0156] and claims 1-2, 4, 7 and 11-13.	1-13
Y	JP 2011-006721 A (NIPPON STEEL CORP.) 13 January 2011 (2011-01-13) See claims 1 and 6.	1-8
Y	JP 2006-503189 A (POSCO) 26 January 2006 (2006-01-26) See paragraphs [0055] and [0061], claims 2, 7 and 12 and tables 6-7.	9-13
A	KR 10-2164113 B1 (POSCO CO., LTD.) 13 October 2020 (2020-10-13) See claims 1-2.	1-13
A	JP 08-269555 A (NIPPON STEEL CORP.) 15 October 1996 (1996-10-15) See claims 1-2.	1-13

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search 18 March 2025	Date of mailing of the international search report 18 March 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020325

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-1461785 B1 (POSCO et al.) 14 November 2014 (2014-11-14) See claims 1-5.	1-13

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/020325

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						WO	2020-111640	A1	04 June 2020
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