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(71) Applicant: **POSCO Co., Ltd**
Gyeongsangbuk-do 37859 (KR)

(72) Inventors:
• **PARK, Semin**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
• **KWON, Min Serk**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

(74) Representative: **Meissner Bolte Partnerschaft**
mbB
Patentanwälte Rechtsanwälte
Postfach 86 06 24
81633 München (DE)

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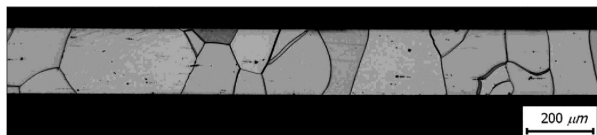
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention includes: a step of manufacturing a cold-rolled sheet including, in wt%, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, and a balance being Fe and other inevitable impurities; a first coating step of coating a Si diffusion composition including a Si

compound onto a surface of the cold-rolled sheet; a first drying step of drying the Si diffusion composition; a second coating step of coating a Si diffusion composition onto a surface of the dried steel sheet; a second drying step of drying the Si diffusion composition; and a step of diffusion annealing the cold-rolled sheet.

FIG. 1



Description**[Technical Field]**

5 **[0001]** An embodiment of the present invention relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present invention relates to a non-oriented electrical steel sheet in which Si is diffused from a surface of a steel sheet into an interior of the steel sheet to improve magnetic properties and simultaneously improve insulation properties, and a method for manufacturing the same.

10 **[Background Art]**

[0002] A non-oriented electrical steel sheet used as a core material for electronic devices is required to have high magnetic flux density and low iron loss in accordance with high efficiency and miniaturization of devices. As the magnetic flux density increases, the amount of the core required to realize the same performance decreases, thereby enabling miniaturization of electrical devices, and as the iron loss decreases, energy loss decreases, and thus securing these characteristics is essential for manufacturing a high-efficiency motor.

[0003] The iron loss causing energy loss includes hysteresis loss and eddy current loss, and in the case of a high-efficiency motor having a high operating frequency of electronic devices, the influence of the eddy current loss increases. The eddy current loss is heat generation caused by an eddy current generated when a magnetic field is induced in the core, and to reduce this, a method of increasing a content of a specific resistance element, such as Si or Al, inside the electrical steel sheet is generally effective. In addition, when the Si content is increased above a specific level, magnetostriction causing noise is reduced to zero and magnetic permeability is increased to a maximum, thereby making it possible to manufacture an electrical steel sheet having excellent high-frequency characteristics.

25 **[0004]** However, as the Si content increases, ductility of the electrical steel sheet significantly decreases, so that there is a limit in that it is difficult to manufacture a thin electrical steel sheet by a conventional rolling process.

[0005] In order to overcome the limitations of the rolling process, a technology has been proposed for manufacturing an electrical steel sheet in which the Si content in the steel sheet is increased by diffusing Si using SiCl_4 gas on the surface of the steel sheet after cold rolling is completed. However, this method uses SiCl_4 gas, which is highly toxic and chemically unstable, and has a facility limitation in that it must be produced under a high vacuum condition, making it difficult to produce an electrical steel sheet having a width of 500 mm or more. In addition, a by-product gas such as FeCl_2 is generated under a high vacuum condition, which is environmentally harmful and causes a problem of inferior insulation properties, so a fundamental solution is required.

35 **[Disclosure]****[Technical Problem]**

40 **[0006]** An embodiment of the present invention provides a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present invention provides a non-oriented electrical steel sheet in which Si is diffused from a surface of a steel sheet into an interior of the steel sheet to improve magnetic properties and simultaneously improve insulation properties, and a method for manufacturing the same.

[Technical Solution]

45 **[0007]** A non-oriented electrical steel sheet according to an embodiment of the present invention includes, in wt%, Si: 4.0 to 7.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, and a balance being Fe and inevitable impurities, wherein an unreacted residual composition layer is present on a surface thereof in an amount of 5 area% or less. Here, the unreacted residual composition layer is a residual Si composition layer that has not participated in diffusion, and includes 90 wt% or more of Si.

[0008] A surface roughness (Ra) of the steel sheet may be 0.3 μm to 1.0 μm .

[0009] ΔSi , defined as a difference $([\text{S-M}_{\text{Si}}]-[\text{C-M}_{\text{Si}}])$ between a Si content $[\text{CM}_{\text{Si}}]$ at a sheet thickness center position ($t/2$) and a maximum Si content $[\text{S-M}_{\text{Si}}]$ in a region from the surface of the non-oriented electrical steel sheet to 5% of a total thickness in an inward direction, may be 0.1 wt% or more.

55 **[0010]** ΔAl , defined as a difference $([\text{S-M}_{\text{Al}}]-[\text{C-M}_{\text{Al}}])$ between a Al content $[\text{CM}_{\text{Al}}]$ at a sheet thickness center position ($t/2$) and a maximum Al content $[\text{S-M}_{\text{Al}}]$ in a region from the surface of the non-oriented electrical steel sheet to 5% of a total thickness in an inward direction, may be 0.1 wt% or more.

[0011] The non-oriented electrical steel sheet according to the embodiment of the present invention may further

include one or more of C: 0.005 wt% or less (excluding 0%), N: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), Nb: 0.005 wt% or less (excluding 0%), and V: 0.005 wt% or less (excluding 0%).

[0012] The non-oriented electrical steel sheet according to the embodiment of the present invention one or more of P: 0.1 wt% or less (excluding 0%), Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Sn: 0.1 wt% or less (excluding 0%), Sb: 0.1 wt% or less (excluding 0%), Ni: 0.05 wt% or less (excluding 0%), and Zn: 0.01 wt% or less (excluding 0%).

[0013] The non-oriented electrical steel sheet according to the embodiment of the present invention may further include one or more of Bi: 0.200 wt% or less (excluding 0%), Pb: 0.200 wt% or less (excluding 0%), Ge: 0.200 wt% or less (excluding 0%), and As: 0.200 wt% or less (excluding 0%).

[0014] The non-oriented electrical steel sheet according to the embodiment of the present invention may further include one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0015] Another embodiment of the present invention provides a method for manufacturing a non-oriented electrical steel sheet, including: a step of manufacturing a cold-rolled sheet including, in wt%, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, and a balance being Fe and other inevitable impurities; a first coating step of coating a Si diffusion composition including a Si compound onto a surface of the cold-rolled sheet; a first drying step of drying the Si diffusion composition; a second coating step of coating a Si diffusion composition onto a surface of the dried steel sheet; a second drying step of drying the Si diffusion composition; and a step of diffusion annealing the cold-rolled sheet.

[0016] The Si diffusion composition may further include an Al compound, and includes 100 parts by weight of the Si compound and 1 to 50 parts by weight of the Al compound as a solid content.

[0017] The Si diffusion composition may further include 10 to 1000 parts by weight of a ceramic powder including an oxide, a nitride, a carbide, or an oxynitride containing at least one component selected from Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba.

[0018] An average particle size of the Si compound may be 1 to 850 nm.

[0019] An average particle size of the Al compound may be 1 to 1000 nm.

[0020] An average particle size of the ceramic powder may be 8 to 2500 nm.

[0021] A coating amount of the Si diffusion composition in each of the first and second coating steps may be 0.1 to 300 g/m².

[0022] Before soaking in each of the first diffusion annealing step and the second annealing step, a temperature range of 300 to 400°C can be increased at a rate of 5 to 50°C/hr.

[0023] In one of the first coating step and the second coating step, a coating direction of the Si diffusion composition may form an angle of 80 to 100° with a rolling direction.

[0024] In the first coating step, a coating direction may form an angle of -10 to 10° with a rolling direction, and in the second coating step, a coating direction of the Si diffusion composition may form an angle of 80 to 100° with the rolling direction.

[0025] A cooling rate after drying in each of the first drying step and the second drying step may be 20°C/sec or more.

[0026] A soaking temperature in the step of diffusion annealing may be 800 to 1200°C.

[Advantageous Effects]

[0027] A non-oriented electrical steel sheet according to an embodiment of the present invention has excellent magnetic flux density and high-frequency iron loss.

[0028] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention provides an eco-friendly manufacturing method that does not generate a by-product gas harmful to the environment during a manufacturing process or the like.

[0029] A non-oriented electrical steel sheet according to an embodiment of the present invention has excellent surface characteristics because a residual unreacted composition does not exist in a surface layer thereof.

[Description of the Drawings]

[0030]

FIG. 1 is an optical microscope photograph analyzing a cross section of a non-oriented electrical steel sheet manufactured in Example 1.

FIG. 2 is an optical microscope photograph analyzing a cross section of a non-oriented electrical steel sheet

manufactured in Comparative Example 11.

[Mode for Invention]

[0031] 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, they are not limited thereto. These terms are only used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Therefore, a first part, component, area, layer, or section to be described below may be referred to as second part, component, area, layer, or section within the range of the present invention.

[0032] The terminologies used herein are used just to illustrate a specific exemplary embodiment, but are not intended to limit the present invention. An expression used in the singular encompasses an expression of the plural, unless it has a clearly different meaning in the context. It will be further understood that the term "comprises" or "includes", used in this specification, specifies stated properties, regions, integers, steps, operations, elements, and/or components, but does not preclude the presence or addition of other properties, regions, integers, steps, operations, elements, components, and/or groups.

[0033] When referring to a part as being "on" or "above" another part, it may be positioned directly on or above the other part, or another part may be interposed therebetween. In contrast, when referring to a part being "directly above" another part, no other part is interposed therebetween.

[0034] Unless otherwise defined, all terms used herein, including technical or scientific terms, have the same meanings as those generally understood by those with ordinary knowledge in the field of art to which the present invention belongs. Terms defined in commonly used dictionaries are further interpreted as having meanings consistent with the relevant technical literature and the present disclosure, and are not to be construed as having idealized or very formal meanings unless defined otherwise.

[0035] Unless otherwise stated, % represents wt%, and 1 ppm is 0.0001 wt%.

[0036] In an embodiment of the present invention, inclusion of an additional element means replacing the balance of iron (Fe) by an additional amount of the additional elements.

[0037] Hereinafter, embodiments of the present invention will be described in detail so that those skilled in the art to which the present invention pertains may easily carry out the invention. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure.

[0038] A non-oriented electrical steel sheet according to an embodiment of the present invention includes, in wt%, Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 3.0%, with the balance being Fe and inevitable impurities.

[0039] First, the reason for limiting the components of the non-oriented electrical steel sheet will be described.

Si: 4.0 to 7.0 wt%

[0040] Silicon (Si) serves to increase the specific resistance of the material and reduce iron loss, so it must be added in relatively large amounts. As the Si content increases, eddy current loss is reduced, thereby lowering iron loss at a high frequency. Particular, when Si is contained in an amount of 6.0 wt% or more, magnetostriction causing noise is reduced to zero and magnetic permeability is increased to a maximum, thereby making it possible to manufacture an electrical steel sheet having excellent high-frequency characteristics. However, when the Si content is 4 wt% or more, ductility of the electrical steel sheet is remarkably reduced, so that there is a limitation in that it is difficult to manufacture the electrical steel sheet through a conventional rolling process.

[0041] In an embodiment of the present invention, Si is added in an amount of 4 wt% or more into the steel sheet by diffusing Si from a surface of the steel sheet toward an interior of the steel sheet. When the amount of Si in the steel sheet is too small, it is difficult to expect the effects caused by Si described above. When too much Si is contained, workability may deteriorate when the electrical steel sheet is processed into a product such as a motor. Due to the diffusion of Si from the surface toward the interior in an embodiment of the present invention, a Si concentration gradient may exist in a thickness direction of the steel sheet, and unless otherwise described, the Si content in the steel sheet means an average content in the thickness direction. The average content means a content assuming that Si in the steel sheet is uniformly distributed in the thickness direction of the steel sheet. More specifically, Si may be contained in an amount of 4.5 to 6.5 wt%.

[0042] In a non-oriented electrical steel sheet, a maximum Si content may be 4.0 to 8.0 wt% in a region from the surface of the non-oriented electrical steel sheet to 5% of a total thickness in an inward direction, and a Si content at a sheet thickness center position ($t/2$) may be 0.3 to 7.5 wt%.

[0043] In an embodiment of the present invention, since a steel sheet containing a high concentration of Si is manufactured by diffusing Si from the surface of the steel sheet into the interior thereof, a concentration gradient may occur in the thickness direction of the steel sheet. That is, the maximum Si content in a region (that is, a surface

portion) from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inward direction may be 4.0 to 8.0 wt%. If the Si content is low in the surface portion, it means that sufficient Si has not been diffused, and thus an improvement in high-frequency iron loss through the high-concentration Si may not be sufficiently obtained. If the Si content is too high, it means that a large amount of Si exists only in the surface portion and has not diffused into the interior of the steel sheet, and in this case as well, the improvement in high-frequency iron loss through the high-concentration Si may not be sufficiently obtained. The maximum Si content means the highest Si content when measuring the Si concentration of the surface portion in the thickness direction. The maximum Si content may be measured by an Electron Probe Micro-Analyzer (EPMA) or a Scanning Electron Microscope/Energy-dispersive X-ray spectroscopy (SEM/EDX), which are non-destructive analysis methods. More specifically, the maximum Si content in the surface portion may be 4.5 to 7.5 wt%.

[0044] The sheet thickness center position means a half position of the total sheet thickness. Hereinafter, it is referred to as a center portion. If the Si content is low in the center portion, it means that sufficient Si has not been diffused, and thus an improvement in high-frequency iron loss through the high-concentration Si may not be sufficiently obtained. If the Si content is too high in the center portion, a problem of deteriorated workability may occur. More specifically, the Si content in the center portion may be 2.5 to 6.0 wt%.

[0045] ΔSi , defined as a difference $([S-M_{Si}]-[C-M_{Si}])$ between a Si content $[CM_{Si}]$ at the sheet thickness center position ($t/2$) and a maximum Si content $[S-M_{Si}]$ in the region from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inward direction, may be 0.1 wt% or more. When a difference in Si content between the center portion and the surface portion appropriately exists, high-frequency iron loss and workability may be further improved. More specifically, ΔSi may be 0.5 to 3.0 wt%.

[0046] As described above, in an embodiment of the present invention, Si within a Si compound in a Si diffusion composition is diffused by diffusion annealing to increase a Si content, and a steel sheet prior to the Si diffusion may contain a smaller amount of Si than that described above. Specifically, the slab and the cold-rolled sheet prior to the diffusion may contain 2.0 to 3.5 wt% of Si. If there is too little Si in the slab and the cold-rolled sheet before the diffusion, an amount of Si required for the diffusion increases, and a long period of time is required for the diffusion annealing, which results in low efficiency, and a difference in the Si content for each sheet thickness becomes large, making it difficult to obtain an appropriate high-frequency iron loss. If there is too much Si in the slab and the cold-rolled sheet before the diffusion, the steel sheet may be broken or defects may occur in the steel sheet during a cold rolling process. More specifically, Si in the slab may be 2.3 to 3.3 wt%.

Al: 0.001 to 3.0 wt%

[0047] Aluminum (Al) serves to increase resistivity of a material to decrease high-frequency iron loss. In an embodiment of the present invention, since the resistivity of the material may be sufficiently increased through the diffusion of Si, the addition of Al may be unnecessary. However, as Al is added, the high-frequency iron loss may be additionally improved. On the other hand, if too much Al is added, an aluminum silicate-based composite may be formed, which may deteriorate iron loss and surface quality. More specifically, Al may be included in an amount of 0.01 to 2.0 wt%. Due to the diffusion of Al from the surface toward the interior in an embodiment of the present invention, a Al concentration gradient may exist in a thickness direction of the steel sheet, and unless otherwise described, the Al content in the steel sheet means an average content in the thickness direction. More specifically, Al may be included in an amount of 0.1 to 1.5 wt%.

[0048] In an embodiment of the present invention, since a steel sheet containing a high concentration of Si is manufactured by diffusing Al together with Si, an Al concentration gradient may occur in the thickness direction of the steel sheet.

[0049] ΔAl , defined as a difference $([S-M_{Al}]-[C-M_{Al}])$ between a Al content $[CM_{Al}]$ at the sheet thickness center position ($t/2$) and a maximum Al content $[S-M_{Al}]$ in the region from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inward direction, may be 0.1 wt% or more. When a difference in Al content between the center portion and the surface portion appropriately exists, high-frequency iron loss may be further improved.

[0050] The maximum Al content in a region (that is, a surface portion) from the surface of the non-oriented electrical steel sheet to 5% of the total thickness in the inward direction may be 0.1 to 3.0 wt%. If the Al content is low in the surface portion, it means that sufficient Al has not been diffused, and thus an improvement in high-frequency iron loss through the Al diffusion may not be sufficiently obtained. If the Al content is too high, it means that a large amount of Al exists only in the surface portion and has not diffused into the interior of the steel sheet, and in this case as well, the improvement in high-frequency iron loss through the Al diffusion may not be sufficiently obtained. The maximum Al content means the highest Al content when measuring the Al concentration of the surface portion in the thickness direction. The maximum Al content may be measured by GOD, FTIR, wet analysis, TEM-GDS, and SEM-GDS methods. More specifically, the maximum Al content in the surface portion may be 0.5 to 1.0 wt%.

[0051] The Al content in the center portion may be 0.001 to 2.0 wt%. If the Al content is low in the center portion, it

means that sufficient Al has not been diffused, and thus an improvement in high-frequency iron loss through the Al diffusion may not be sufficiently obtained. If the Al content in the center portion is too high, a problem of deterioration in magnetic flux density may occur. More specifically, the Al content in the center portion may be 0.5 to 1.0 wt%.

[0052] As described above, in an embodiment of the present invention, Al in an Al compound within a Si diffusion composition is diffused by diffusion annealing, so that the Al content increases, and the steel sheet before the Al diffusion may contain a smaller amount of Al than that described above

Specifically, the slab and the cold-rolled sheet before diffusion may contain 0.001 to 2.0 wt% of Al. If there is too little Al in the slab and the cold-rolled sheet before the diffusion, an amount of Al required for the diffusion increases, and a long period of time is required for the diffusion annealing, which results in low efficiency, and a difference in the Al content for each sheet thickness becomes large, making it difficult to obtain an appropriate high-frequency iron loss. If there is too much Al in the slab, Al oxides may aggregate at some positions, which may cause cracking during a rolling operation. More specifically, Al in the slab and the cold-rolled sheet before diffusion may be 0.001 to 1.8 wt%. More specifically, Al in the slab and the cold-rolled sheet before diffusion may be 0.01 to 1.0 wt%.

Mn: 0.03 to 3.0 wt%

[0053] Manganese (Mn) improves the iron loss by increasing the specific resistance of the material and serves to form a sulfide. 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 [111] texture, which is unfavorable for magnetism, and cause a rapid decrease in magnetic flux density. In an embodiment of the present invention, unlike Si and Al, Mn does not diffuse from the surface portion to the center portion, but diffuses from the center portion to the surface portion. This is because volatilization of Mn proceeds at the surface during the Si diffusion annealing process, and thus Mn diffuses from the center portion to the surface portion. As the amount of Mn decreases and the amount of Si increases, a phase transformation occurs. As the phase transformation occurs, diffusion proceeds from the surface to the inside, creating an environment favorable for forming an orientation of <100>ND, which is similar to the diffusion direction. More specifically, Mn may be 0.05 to 2.0 wt%.

[0054] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include one or more 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 at 0.1 wt% or less

[0055] Phosphorus (P) is a grain boundary segregation element, and if added in excessive amounts, it may delay recrystallization, thereby deteriorating the strength uniformity in the rolling direction and the direction perpendicular to the rolling direction. More specifically, P may be 0.005 to 0.03 wt%.

Cu: 0.005 to 0.200 wt%

[0056] Copper (Cu) serves to form sulfides together with Mn. If Cu is further added, if too little Cu is added, (Cu·Mn) S may be finely precipitated and magnetism may be degraded. If too much Cu is added, high temperature brittleness occurs, which may form cracks during casting or hot rolling. Specifically, Cu may be included in an amount of 0.01 to 0.100 wt%.

Cr: 0.010 to 0.50 wt%

[0057] Chromium (Cr) serves to improve iron loss by increasing specific resistance. If too little Cr is added, the effect of increasing specific resistance may not be sufficient. If too much Cr is included, the magnetic flux density may deteriorate. More specifically, the lower limit of Cr may be 0.05 wt%, or may include 0.30 wt%.

Sn: 0.10 wt% or less

[0058] Tin (Sn) is added as a segregating element at grain boundaries to suppress nitrogen diffusion through grain boundaries, suppress {111} texture that is detrimental to magnetism, and increase favorable {100} texture, thereby improving magnetic properties. If too much Sn is added, grain growth is hindered, which reduces magnetism and results in poor rolling properties. Therefore, Sn may be added within the above-mentioned range. More specifically, Sn may be included in an amount of 0.005 to 0.08 wt%.

Sb: 0.10 wt% or less

[0059] Antimony (Sb) is added as a segregating element at grain boundaries to suppress nitrogen diffusion through grain boundaries, suppress {111} texture that is detrimental to magnetism, and increase favorable {100} texture, thereby improving magnetic properties. If too much Sb is added, grain growth is hindered, which reduces magnetism and results in poor rolling properties. Therefore, Sb may be added within the above-mentioned range. More specifically, Sb may be included in an amount of 0.005 to 0.08 wt%.

Ni: 0.05 wt% or less

[0060] Nickel (Ni) may react with impurity elements to form fine sulfides, carbides, and nitrides, which may have a detrimental effect on magnetism. More specifically, Ni may be included in an amount of 0.005 to 0.03 wt%.

Zn: 0.01 wt% or less

[0061] If the content of zinc (Zn) is excessive, it may act as an impurity and deteriorate magnetism. Therefore, Zn may be further added within the above-mentioned range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

[0062] The non-oriented electrical steel sheet according to the embodiment of the present invention may further include one or more of Bi: 0.200 wt% or less, Pb: 0.200 wt% or less, Ge: 0.200 wt% or less, and As: 0.200 wt% or less.

[0063] The aforementioned elements, when additionally added, segregate at grain boundaries, thereby alleviating stress concentration at grain boundaries during cold rolling, thereby suppressing recrystallization of <111>ND oriented grains in the subsequent recrystallization annealing 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, inhibiting grain growth and resulting in lower magnetic flux density and iron loss. More specifically, it may further include one or more of Bi: 0.001 to 0.100 wt%, Pb: 0.001 to 0.100 wt%, Ge: 0.001 to 0.100 wt%, and As: 0.001 to 0.100 wt%.

[0064] The non-oriented electrical steel sheet according to the embodiment of the present invention may further include one or more of Mo: 0.03 wt% or less, B: 0.0050 wt% or less, Ca: 0.0050 wt% or less, Zr: 0.005 wt% or less, Te: 0.01 wt% or less, and Mg: 0.0050 wt% or less.

[0065] Since these may react with C, S, N, and the like, which are inevitably included, to form fine carbides, nitrides, or sulfides, which may adversely affect magnetism, the upper limit may be limited as described above. More specifically, it may further include one or more of Mo: 0.001 to 0.01 wt%, B: 0.0010 to 0.0030 wt%, Ca: 0.0010 to 0.0030 wt%, Zr: 0.0010 to 0.0030 wt%, Te: 0.0010 to 0.0050 wt%, and Mg: 0.0010 to 0.0050 wt%.

Other Impurities

[0066] In addition to the aforementioned elements, inevitably mixed impurities such as carbon (C), sulfur (S), nitrogen (N), titanium (Ti), niobium (Nb), and vanadium (V) may be included.

[0067] N combines with Ti, Nb, and V to form nitrides and serves to reduce grain growth.

[0068] C reacts with N, Ti, Nb, and V to form fine carbides, which hinder grain growth and magnetic domain movement.

[0069] S forms sulfides, which degrade grain growth.

[0070] When the impurity elements are further included in this manner, it may further include one or more of C: 0.005 wt% or less (excluding 0%), N: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), Nb: 0.005 wt% or less (excluding 0%), and V: 0.005 wt% or less (excluding 0%). More specifically, it may further include one or more of C: 0.001 to 0.003 wt%, N: 0.001 to 0.005 wt%, S: 0.001 to 0.005 wt%, Ti: 0.001 to 0.005 wt%, Nb: 0.001 to 0.005 wt%, and V: 0.001 to 0.005 wt%.

[0071] In addition, impurities that are inevitably mixed may be included. The inevitable impurities are impurities mixed in the steel-making and the manufacturing process of the non-oriented electrical steel sheet, which are widely known in the field, and thus a detailed description thereof will be omitted. In the embodiment of the present invention, the addition of elements other than the above-described alloy components is not excluded, and various elements may be included within a range that does not hinder the technical concept of the present invention. When the additional elements are further included, they replace the balance of Fe.

[0072] In the non-oriented electrical steel sheet according to the embodiment of the present invention, an unreacted residual composition layer may be present on a surface thereof in an amount of 5 area% or less. In the embodiment of the present invention, Si is diffused from the surface to the inside of the steel sheet using a Si diffusion composition. When the Si diffusion composition is used, the unreacted residual composition inevitably exists even if the reaction

proceeds for a long time, and when a large amount of the unreacted residual composition is present, the surface characteristics of the steel sheet deteriorate, which adversely affects the adhesion between steel sheets and a stacking factor. In order to remove the unreacted residual composition, a pickling method may be considered; however, in this case, the surface roughness of the steel sheet may be further worsened. The unreacted residual composition layer is distinguished from the surface of the steel sheet outside the unreacted residual composition layer in that the unreacted residual composition layer contains 90 wt% or more of Si. The unreacted residual composition layer means an area fraction with respect to the area of the surface of the steel sheet. More specifically, the unreacted residual composition layer may be included in an amount of 0.1 to 3 area%.

[0073] In the embodiment of the present invention, the Si diffusion composition is applied a plurality of times in a divided manner and dried, so that a phenomenon in which the unreacted residual composition naturally falls off is utilized by using a difference between a thermal expansion coefficient of the unreacted residual composition on the surface and a thermal expansion coefficient of internally diffused iron. Through this, the unreacted residual composition layer attached to the surface is removed as much as possible. The unreacted residual composition layer may be distinguished from other steel sheets in terms of having a Si content of 90 wt% or more.

[0074] The surface roughness (Ra) of the steel sheet may be 0.30 μm to 1.00 μm . As described above, when pickling is performed to remove the unreacted residual composition, the surface roughness increases, which adversely affects the adhesion between steel sheets and the stacking factor. When Si is diffused using the Si diffusion composition, some roughness may be inevitably formed. More specifically, the surface roughness (Ra) of the steel sheet may be 0.33 μm to 0.75 μm .

The surface roughness (Ra) may be measured using a surface roughness tester.

[0075] The non-oriented electrical steel sheet according to the embodiment of the present invention has excellent high-frequency iron loss due to the diffusion of Si. Specifically, the iron loss ($W_{10/1000}$) may be 45.0 W/kg or less. In this case, the iron loss is based on a thickness of 0.2 mm. The iron loss ($W_{10/1000}$) is iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 1000 Hz. The iron loss may be measured by an Epstein test method or a single sheet test method. More specifically, the iron loss ($W_{10/1000}$) may be 25.00W/kg to 35.00W/kg.

[0076] In addition, the iron loss ($W_{5/2000}$) thereof may be 16.5W/kg or less. In this case, the iron loss is based on a thickness of 0.2 mm. The iron loss ($W_{5/2000}$) is iron loss when a 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 10.0 W/kg to 15.0 W/kg.

[0077] In the embodiment of the present invention, not only the iron loss but also the magnetic flux density is simultaneously excellent. Specifically, the magnetic flux density (B_{25}) may be 1.46 T or more. Specifically, the magnetic flux density (B_{25}) may be 1.50 to 1.65 T.

[0078] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention includes: a step of manufacturing a cold-rolled sheet including, in wt%, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, and a balance of Fe and unavoidable impurities; a first coating step of applying a Si diffusion composition containing a Si compound onto a surface of the cold-rolled sheet; a first drying step of drying the Si diffusion composition to form a Si diffusion coating layer; a second coating step of applying a Si diffusion composition containing a Si compound onto the Si diffusion coating layer; a second drying step of drying the Si diffusion composition; and a step of diffusion-annealing the cold-rolled sheet.

[0079] Hereinafter, respective steps will be specifically described.

[0080] First, a cold-rolled sheet including, in wt%, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, with the balance being Fe and inevitable impurities is manufactured. Since the alloy components of the cold-rolled sheet are the same as those described above, a redundant description thereof will be omitted.

[0081] The method for manufacturing the cold-rolled sheet is not particularly limited, and may include a step of hot-rolling a slab including, in wt%, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0% to manufacture a hot-rolled sheet; and a step of cold-rolling the hot-rolled sheet to manufacture a cold-rolled sheet.

[0082] First, a slab is manufactured. The reason for limiting the addition ratio of each composition in the slab is the same as the reason for limiting the composition of the non-oriented electrical steel sheet described above, so a repeated description will be omitted. Since the composition of the slab is not substantially changed during manufacturing processes such as hot rolling, hot-rolled sheet annealing, and cold rolling, which will be described later, the composition of the slab and the composition of the cold-rolled sheet are substantially identical. In addition, in the diffusion annealing process, only Si and Al diffuse, and the alloy composition of the non-oriented electrical steel sheet may be identical to the remaining components except for Si and Al.

[0083] Before the step of manufacturing the hot-rolled sheet, the slab may be heated to 1100°C or higher. Specifically, the slab is fed into a heating furnace and heated to 1100 to 1,250°C. When heated at a temperature exceeding 1250 °C, a precipitate may be redissolved, and it may be finely precipitated after the hot-rolling. More specifically, the slab heating temperature may be 1100°C to 1200°C.

[0084] The heated slab is hot-rolled to 1.5 to 4.0 mm to produce a hot-rolled sheet. Since the embodiment of the present invention also includes a step of preliminary cold rolling before cold rolling, a non-oriented electrical steel

sheet having an appropriate thickness may be manufactured even if the thickness of the hot-rolled sheet is relatively thick. More specifically, the thickness of the hot-rolled sheet may be 1.5 mm to 3.5 mm.

[0085] The step of manufacturing the hot-rolled sheet may include a step of finish rolling at a temperature of 850°C or higher.

[0086] If the hot rolling finish rolling temperature is too low, a rolling load increases, thereby degrading hot rolling workability. In addition, a lot of deformation structures remain in the hot-rolled steel sheet, which may cause an increase in the rolling load during the subsequent preliminary cold rolling process. In addition, during intermediate annealing, 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 finish rolling temperature, the better, and more specifically, the finish rolling temperature may be 850 to 1000°C.

[0087] The step of manufacturing the hot-rolled sheet may include a step of coiling at a temperature of 600 to 800°C. A step of rough rolling may also be included before the step of finish rolling.

[0088] If the temperature is controlled too low during the step of the winding, recovery and recrystallization of the hot-rolled deformation structure will not occur well, and the cooling load will increase 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, recovery and recrystallization may be promoted, but additional oxidation by atmospheric oxygen may occur while wound, which may cause thicker scale formation and grain boundary oxidation problems. The grain boundary oxidation of the hot-rolled sheet promotes grain boundary corrosion during the subsequent pickling process, which increases the possibility of surface stripe defects and severe wear of the rolling roll. More specifically, the winding temperature may be 650 to 750°C.

[0089] After the step of manufacturing the hot-rolled sheet, a step of annealing the hot-rolled sheet in 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, while if the annealing temperature is too high, the magnetic properties may deteriorate, and the rolling workability may deteriorate due to deformation of the sheet shape. More specifically, the annealing temperature of the hot-rolled sheet may be 750 to 1000 °C.

[0090] The hot-rolled sheet annealing is performed in order to increase the orientation favorable to magnetism as required, and it may be omitted. The annealing form is not particularly limited, and batch or continuous annealing is possible.

[0091] The hot-rolled hot-rolled sheet may be pickled as needed.

[0092] Next, the hot-rolled sheet is pickled and cold-rolled to a predetermined thickness. Although It may be applied differently depending on the thickness of the hot-rolled sheet, but the cold-rolling may be performed so that the final thickness thereof becomes 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 rollings with intermediate annealing may be performed. More specifically, the reduction ratio may be 75 to 90%. The thickness of the cold-rolled sheet may be 0.15 to 0.35 mm.

[0093] Next, in the first coating step, a Si diffusion composition including a Si compound is coated on the cold-rolled sheet.

[0094] As the Si compound, any material capable of diffusing Si into the steel sheet through a long period of annealing may be used without limitation. Specifically, it may include one or more of pure Si, a Si alloy, an oxide, nitride, or carbide of Si, and a silane compound. In addition, it may include one or more of FeSi, Fe₃Si, Fe₃Al, and FeAl.

[0095] More specifically, it may include pure Si, a Si alloy, and Fe₃Si.

[0096] The average particle size of the Si compound may be 1 to 850 nm. If the particle size of the Si compound is too small, problems may arise where they aggregate with each other during slurry mixing, causing surface defects. If the particle size of the Si compound is too large, uniform coating on the surface of the steel sheet may be difficult, so that Si diffusion into the steel sheet may not be smoothly performed. The average particle size of the Si compound is an average particle size with respect to the number of compound particles, and may be measured with a particle size analyzer (PSA) using a laser diffraction method. More specifically, the average particle size of the Si compound may be 10 nm to 500 nm. More specifically, it may be 20 nm to 100 nm.

[0097] The Si diffusion composition further includes an Al compound, and may include 100 parts by weight of the Si compound and 10 to 50 parts by weight of the Al compound as a solid content. In the embodiment of the present invention, the solid content means a weight in a state in which volatile components are completely removed by heating each compound at 180°C for 20 minutes or longer.

[0098] The Al compound serves to improve insulation properties, increase bonding with the Si compound, and allow intermetallic compounds to be better formed. When too little Al compound is included, it may be difficult to properly obtain the aforementioned effects. When too much Al compound is included, a large number of Al inclusions are formed, which may cause a problem of poor magnetic properties. More specifically, the Al compound may be included in an amount of 15 to 30 parts by weight.

[0099] As the Al compound, any material capable of diffusing Al into the steel sheet may be used without limitation. For example, there may be pure Al, aluminum alkoxide, and the like.

[0100] The average particle size of the Al compound may be 1 to 1000 nm. If the particle size of the Al compound is too small, a problem of agglomeration of the Al compounds may occur. If the particle size of the Al compound is too large, Al diffusion into the steel sheet may not be smoothly performed. More specifically, the lower limit of the average particle size of the Al compound may be 5 nm. The upper limit of the average particle size of the Al compound may be 750 nm.

[0101] The Si diffusion composition may further include a ceramic powder including an oxide, nitride, carbide, or oxynitride, including at least one component selected from Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba. The ceramic powder serves to control a slurry coating amount and determine a Si content of a final steel sheet.

[0102] The ceramic powder may be included in an amount of 10 to 1000 parts by weight as a solid content. If too little ceramic powder is included, a problem may occur in terms of securing a coating amount. If too much ceramic powder is included, a viscosity of the slurry increases, which may cause a problem in terms of surface defects. More specifically, the ceramic powder may be included in an amount of 20 to 500 parts by weight.

[0103] The ceramic powder may be one or more of Al_2O_3 , 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 $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$.

[0104] The average particle size of the ceramic powder may be 8 to 2500 nm. If the particle size of the ceramic powder is too small, a problem may occur in securing a sufficient coating amount. If the particle size of the ceramic powder is too large, the viscosity increases and the surface quality is degraded, so that Si diffusion into the steel sheet may not be smoothly performed. More specifically, the average particle size of the ceramic powder may be 10 nm to 1500 nm.

[0105] The Si diffusion composition may further include a solvent in addition to the aforementioned components. The solvent allows the Si diffusion composition to be uniformly coated. If the solvent is too small, the coating of the Si diffusion composition may not be easy. If the solvent is too large, the viscosity of the Si diffusion composition is too low, making it difficult to coat a sufficient amount of the composition on the steel sheet. The solvent may be included in an amount of 10 to 1500 parts by weight based on 100 parts by weight of the Si compound. More specifically, 50 to 1000 parts by weight of the solvent may be included. The solvent may include one or more of water and alcohol.

[0106] In addition to the above-described components, the Si diffusion composition may further include an additional component, which is not excluded from an embodiment of the present invention. Examples of the additional component may include phosphoric acid, sodium silicate, a fluoride ion solution, and the like.

[0107] In the first coating step, a coating weight of the Si diffusion composition may be 0.1 to 300 g/m². In this case, the coating weight is on a solid basis. If the coating weight is too small, sufficient diffusion of Si is not achieved, and thus it is difficult to sufficiently achieve the effect by the Si diffusion. When the coating weight is too large, a problem of deterioration in workability may occur.

[0108] The coating may be applied by a roll coater, a brush, dipping, or the like. From the viewpoint of productivity, it may be applied using a roll coater.

[0109] In a coating direction, coating may be performed by forming an angle of -10 to 10° with a rolling direction, or by forming an angle of 80 to 100° with the rolling direction. More specifically, in the coating direction, the coating may be performed by forming an angle of -5 to 5° with the rolling direction, or by forming an angle of 85 to 95° with the rolling direction. From the viewpoint of productivity, the coating may be performed by forming an angle of -10 to 10° with the rolling direction.

[0110] After the first coating step, in the first drying step, the Si diffusion composition is dried to form a Si diffusion coating layer. The drying temperature is sufficient as long as it is a temperature capable of removing a solvent in the Si diffusion composition, and specifically, may be 300 to 850°C. The time may be 10 seconds to 180 seconds. More specifically, the temperature may be 500 to 800°C. The time may be 15 seconds to 150 seconds. After drying at the drying temperature, cooling may be performed at a cooling rate of 20°C/sec or more. By rapidly cooling in this way, the automatic detachment of the unreacted residual composition may be induced by utilizing the difference in thermal shrinkage between the steel sheet and the unreacted composition layer. The cooling range may be from the drying temperature to 100°C.

[0111] Next, in the second coating step, the Si diffusion composition is coated on the surface of the dried steel sheet. In this case, the Si diffusion composition may be the same as or different from the Si diffusion composition coated in the first coating step. The Si diffusion composition has been described above, so a redundant description thereof will be omitted.

[0112] In the embodiment of the present invention, a phenomenon is utilized in which the unreacted residual composition is naturally detached by utilizing a difference between a coefficient of thermal expansion of the unreacted residual composition on the surface and a coefficient of thermal expansion of internally diffused iron through a plurality of times of coating in the first coating step and the second coating step. Through this, the unreacted residual composi-

tion is removed as much as possible to improve surface characteristics. The coating step may be performed not only twice, but also three times or more. That is, it is also possible to repeat the step of coating and drying the Si diffusion composition three times or more.

[0113] In the second coating step, the coating weight of the Si diffusion composition may be 0.1 to 300 g/m². In this case, the coating weight is on a solid basis. If the coating weight is too small, sufficient diffusion of Si is not achieved, and thus it is difficult to sufficiently achieve the effect by the Si diffusion. When the coating weight is too large, a problem of deterioration in workability may occur.

[0114] The coating may be applied by a roll coater, a brush, dipping, or the like. From the viewpoint of productivity, it may be applied using a roll coater.

[0115] In the coating direction, the coating may be performed by forming an angle of -10 to 10° with a rolling direction, or by forming an angle of 80 to 100° with the rolling direction. More specifically, in the coating direction, the coating may be performed by forming an angle of -5 to 5° with the rolling direction, or by forming an angle of 85 to 95° with the rolling direction. In order to more easily remove the unreacted residual composition, coating may be performed by forming an angle of 80 to 100° with the rolling direction in the second coating step. In this case, bonding with the previously coated and dried Si diffusion composition is not sufficiently achieved, and a partial space exists. Accordingly, a gap opens between the unreacted slurry and the steel sheet due to a difference between the coefficient of thermal expansion of the unreacted residual composition on the surface and the coefficient of thermal expansion of the internally diffused iron, and at this time, a phenomenon occurs in which the unreacted slurry naturally detaches.

[0116] After the second coating step, in the second drying step, the Si diffusion composition is dried to form a Si diffusion coating layer. The drying temperature is sufficient as long as it is a temperature capable of removing a solvent in the Si diffusion composition, and specifically, may be 300 to 850°C. The time may be 10 seconds to 180 seconds. More specifically, the temperature may be 500 to 800°C. The time may be 15 seconds to 150 seconds. After drying at the drying temperature, cooling may be performed at a cooling rate of 20°C/sec or more. By rapidly cooling in this way, the automatic detachment of the unreacted residual composition may be induced by utilizing the difference in thermal shrinkage between the steel sheet and the unreacted composition layer. The cooling range may be from the drying temperature to 100°C.

[0117] Next, the cold-rolled sheet is subjected to diffusion annealing. In this process, Si and Al are diffused into the steel sheet from the Si diffusion composition coated to the surface of the cold-rolled sheet.

[0118] Prior to the diffusion annealing step, a temperature range of 20°C to 700°C may be heated at a rate of 5°C/hr to 50°C/hr. In this manner, a uniform quality may be obtained by increasing the temperature at a relatively slow heating rate. If the heating rate is too slow, the process time becomes unnecessarily long and productivity decreases. If the heating rate is too fast, the aforementioned effects may not be properly obtained. More specifically, the temperature may be increased at a rate of 10°C/hr to 30°C/hr.

[0119] The diffusion annealing temperature may be 850°C to 1250°C. If the diffusion annealing temperature is too low, the diffusion of Si may not be sufficiently performed, so that a desired effect may not be obtained. If the diffusion annealing temperature is too high, pores may form, which may deteriorate magnetic properties. More specifically, it may be 900°C to 1150°C.

[0120] The time may be 30 minutes to 600 minutes. If the time is too short, the diffusion of Si and Ti may not be sufficiently performed, so that a desired effect may not be obtained. If the time is too long, it may be difficult to control an amount of diffusion, and workability may deteriorate. More specifically, it may be 60 minutes to 300 minutes.

[0121] An atmosphere during the diffusion annealing may be an atmosphere including one or more of hydrogen, nitrogen, and argon. An oxidation ability (PH₂O/PH₂) of the atmosphere may be 6.4 or less. If the oxidation ability is too high, Al₂O₃ internal oxides are formed, which may deteriorate magnetic properties. Specifically, the oxidation ability (PH₂O/PH₂) of the atmosphere may be 3.0 or less. Specifically, the oxidation ability (PH₂O/PH₂) of the atmosphere may be 1.0 or less.

[0122] After the diffusion annealing, a final thickness of the steel sheet may be 0.10 mm to 0.65 mm, and the thickness may partially increase compared to the cold-rolled sheet due to the coating and diffusion of the Al diffusion composition.

[0123] The steel sheet for which the diffusion annealing is completed may further include a step of washing and drying to remove unreacted materials.

[0124] The steel sheet for which the diffusion annealing is completed may further include a step of pickling to improve surface appearance.

[0125] For the pickling, at least one of hydrochloric acid, nitric acid, sulfuric acid, and hydrofluoric acid may be used.

[0126] The steel sheet for which the diffusion annealing is completed may further include a step of plasma treatment to further improve the surface appearance.

[0127] Thereafter, a step of forming an insulating film may be further included. Since the insulating film is widely known, a detailed description thereof will be omitted. Specifically, the insulation coating layer may be formed by coating an insulating coating layer forming composition containing metal phosphate and silica as main components,

and then performing heat treatment.

[0128] Hereinafter, preferred examples of the present invention and comparative examples will be described. However, the following examples are merely preferred examples of the present invention, and the present invention is not limited to the following examples.

Experimental Example

[0129] A slab including 2.5 wt% of silicon (Si), 0.002 wt% of aluminum (Al), 0.10 wt% of manganese (Mn), 0.04 wt% of tin (Sn), 0.04 wt% of antimony (Sb), 0.013 wt% of phosphorus (P), and a balance of Fe and other unavoidable impurities was prepared.

[0130] The slab was heated at 1100°C and then hot-rolled to a thickness of 1.8 mm to prepare a hot-rolled sheet.

[0131] The hot-rolled sheet was coiled at 700°C, cooled in air, and subjected to hot-rolled sheet annealing at 1030°C for 2 minutes, followed by rapid cooling in water, pickling, and cold-rolling to a thickness of 0.20 mm to prepare a cold-rolled sheet.

[0132] A Si diffusion composition was prepared by adding 100 parts by weight of silicon powder (Si: 99.99 wt% or more) with an average particle size of 15 nm and 80 parts by weight of Al₂O₃ ceramic powder with an average particle size of 1000 nm to the surface of the cold-rolled sheet and stirring with water.

[0133] The prepared Si diffusion composition was coated to the cold-rolled sheet. In this case, the coating direction was as shown in Table 1. It was dried at 600°C for 1 minute. After drying, a cooling rate to 100°C was as shown in Table 1 below.

[0134] The Si diffusion composition was coated to the dried steel sheet. In this case, the coating direction was as shown in Table 1. It was dried at 600°C for 1 minute. After drying, a cooling rate to 100°C was as shown in Table 1 below.

[0135] The cold-rolled sheet to which the Si diffusion composition was coated was subjected to diffusion annealing at 1000°C for 1 hour.

[0136] The surface of the steel sheet for which the diffusion annealing was completed was washed with water, dried at room temperature, and then immersed in a nitric acid solution containing 0.5% hydrofluoric acid at 65°C for 12 seconds to remove unreacted materials, washed with water again, and finally dried to manufacture a non-oriented electrical steel sheet having a thickness of 0.2 mm.

[0137] The Si content of the finally manufactured steel sheet was 5.3 wt%, the Al content thereof was 1.2 wt%, Δ Si was 2.3 wt%, and Δ Al was 0.4 wt%.

[0138] The presence or absence of peeling of the unreacted layer was measured by observing a surface in a thickness direction with an optical microscope. When an area of the unreacted layer adhering to the surface of the steel sheet was 5% or less, it was expressed as "completely peeled."

[0139] When the area of the unreacted layer remained at 50% or less and more than 5%, it was indicated as "partially peeled," and when the area of the unreacted layer remained at more than 50%, it was indicated as "un-peeled."

(Table 1)

Steel Type	First coating direction	Second coating direction	First drying cooling speed (°C/sec)	Second drying cooling speed (°C/sec)
1	Rolling direction	Rolling vertical direction	20	20
2	Rolling direction	Rolling vertical direction	25	35
3	Rolling direction	Rolling vertical direction	35	25
4	Rolling direction	Rolling vertical direction	40	40
5	Rolling direction	Non-implementation	30	Non-implementation
6	Rolling vertical direction	Non-implementation	30	Non-implementation
7	Rolling direction	Non-implementation	15	Non-implementation
8	Rolling direction	Rolling direction	30	30
9	Rolling direction	Rolling direction	40	40
10	Rolling direction	Rolling vertical direction	10	30
11	Rolling direction	Rolling vertical direction	30	10

(continued)

Steel Type	First coating direction	Second coating direction	First drying cooling speed (°C/sec)	Second drying cooling speed (°C/sec)
12	Rolling vertical direction	Rolling vertical direction	30	30

(Table 2)

Steel Type	Presence or absence of peeling of unreacted residual layer	Surface roughness (Ra, μm)	B25(T)	W10/1000(W/kg)	Type
1	Peeled	0.34	1.66	32.5	Example
2	Peeled	0.42	1.60	33.2	Example
3	Peeled	0.38	1.67	31.9	Example
4	Peeled	0.53	1.67	34.7	Example
5	Unpeeled	1.23	1.47	51.2	Comparative example
6	Unpeeled	2.32	1.44	50.4	Comparative example
7	Unpeeled	2.34	1.48	53.4	Comparative example
8	Partially unpeeled	0.57	1.51	42.4	Comparative example
9	Partially unpeeled	0.65	1.55	47.2	Comparative example
10	Unpeeled	1.12	1.54	47.4	Comparative example
11	Unpeeled	0.76	1.48	46.3	Comparative example
12	Peeled	0.35	1.52	35.9	Example

[0140] As shown in Table 1 and Table 2, when the Si diffusion composition was applied twice, the application direction was appropriately controlled, and rapid cooling was performed after drying, an increase in iron loss caused by unreacted residual composition was significantly reduced, surface properties were improved, and excellent magnetic properties were confirmed. FIG. 1 shows an optical microscope analysis result of a cross-section of a steel type. As shown in FIG. 1, it can be confirmed that an unreacted residual composition layer on a surface was peeled off from the surface, and a steel sheet having low roughness was manufactured.

[0141] On the other hand, in Steel Type 5 to Steel Type 7, the Si diffusion composition was applied only once, and a large amount of unreacted residual composition was present, so that it can be confirmed that unpeeled residual composition existed, surface roughness properties deteriorated, and magnetic properties were inferior. An optical microscope analysis result of a cross-section of the steel type is shown. As shown in FIG. 2, it can be confirmed that an unreacted residual composition layer that was not peeled off existed on the surface, and a steel sheet having high roughness was manufactured.

[0142] In Steel Type 8 and Steel Type 9, although the composition was applied twice, it was applied twice only in a rolling direction, and thus it can be confirmed that a portion of the unreacted residual composition that was not peeled off existed.

[0143] In Steel Type 10 and Steel Type 11, a cooling rate after drying was low, and thus it can be confirmed that the unreacted residual composition layer existed.

[0144] The present invention may be embodied in many different forms, and should not be construed as being limited to the disclosed embodiments. In addition, it will be understood by those skilled in the art that various changes in form and details may be made thereto without departing from the technical spirit and essential features of the present invention. Therefore, it is to be understood that the above-described embodiments are for illustrative purposes only, and the scope of the present invention is not limited thereto.

Claims

1. A non-oriented electrical steel sheet, comprising:

in wt%, Si: 4.0 to 7.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, and a balance being Fe and inevitable impurities,
 wherein an unreacted residual composition layer is present on a surface thereof in an amount of 5 area% or less.

- 5 2. The non-oriented electrical steel sheet of claim 1, wherein
 a surface roughness (Ra) of the steel sheet is 0.3 μm to 1.0 μm .
- 10 3. The non-oriented electrical steel sheet of claim 1, wherein
 ΔSi , defined as a difference $([\text{S-M}_{\text{Si}}]-[\text{C-M}_{\text{Si}}])$ between a Si content $[\text{CM}_{\text{Si}}]$ at a sheet thickness center position (t/2) and a maximum Si content $[\text{S-M}_{\text{Si}}]$ in a region from the surface of the non-oriented electrical steel sheet to 5% of a total thickness in an inward direction, is 0.1 wt% or more.
- 15 4. The non-oriented electrical steel sheet of claim 1, wherein
 ΔAl , defined as a difference $([\text{S-M}_{\text{Al}}]-[\text{C-M}_{\text{Al}}])$ between a Al content $[\text{CM}_{\text{Al}}]$ at a sheet thickness center position (t/2) and a maximum Al content $[\text{S-M}_{\text{Al}}]$ in a region from the surface of the non-oriented electrical steel sheet to 5% of a total thickness in an inward direction, is 0.1 wt% or more.
- 20 5. The non-oriented electrical steel sheet of claim 1, further comprising
 one or more of C: 0.005 wt% or less (excluding 0%), N: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), Nb: 0.005 wt% or less (excluding 0%), and V: 0.005 wt% or less (excluding 0%).
- 25 6. The non-oriented electrical steel sheet of claim 1, further comprising
 one or more of P: 0.1 wt% or less (excluding 0%), Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Sn: 0.1 wt% or less (excluding 0%), Sb: 0.1 wt% or less (excluding 0%), Ni: 0.05 wt% or less (excluding 0%), and Zn: 0.01 wt% or less (excluding 0%).
- 30 7. The non-oriented electrical steel sheet of claim 1, further comprising
 one or more of Bi: 0.200 wt% or less (excluding 0%), Pb: 0.200 wt% or less (excluding 0%), Ge: 0.200 wt% or less (excluding 0%), and As: 0.200 wt% or less (excluding 0%).
- 35 8. The non-oriented electrical steel sheet of claim 1, further comprising
 one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).
9. A method for manufacturing a non-oriented electrical steel sheet, comprising:
 - 40 a step of manufacturing a cold-rolled sheet including, in wt%, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0%, and a balance being Fe and other inevitable impurities;
 a first coating step of coating a Si diffusion composition including a Si compound onto a surface of the cold-rolled sheet;
 a first drying step of drying the Si diffusion composition;
 - 45 a second coating step of coating a Si diffusion composition onto a surface of the dried steel sheet;
 a second drying step of drying the Si diffusion composition; and
 a step of diffusion annealing the cold-rolled sheet.
- 50 10. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein
 the Si diffusion composition further includes an Al compound, and includes 100 parts by weight of the Si compound and 1 to 50 parts by weight of the Al compound as a solid content.
- 55 11. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein
 the Si diffusion composition further includes 10 to 1000 parts by weight of a ceramic powder including an oxide, a nitride, a carbide, or an oxynitride containing at least one component selected from Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba.
12. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein

an average particle size of the Si compound is 1 to 850 nm.

13. The method for manufacturing the non-oriented electrical steel sheet of claim 10, wherein an average particle size of the Al compound is 1 to 1000 nm.

14. The method for manufacturing the non-oriented electrical steel sheet of claim 11, wherein an average particle size of the ceramic powder is 8 to 2500 nm.

15. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein a coating amount of the Si diffusion composition in each of the first and second coating steps is 0.1 to 300 g/m².

16. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein in one of the first coating step and the second coating step, a coating direction of the Si diffusion composition forms an angle of 80 to 100° with a rolling direction.

17. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein in the first coating step, a coating direction forms an angle of -10 to 10° with a rolling direction, and in the second coating step, a coating direction of the Si diffusion composition forms an angle of 80 to 100° with the rolling direction.

18. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein a cooling rate after drying in each of the first drying step and the second drying step is 20°C/sec or more.

19. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein a soaking temperature in the step of diffusion annealing is 800 to 1200°C.

FIG. 1

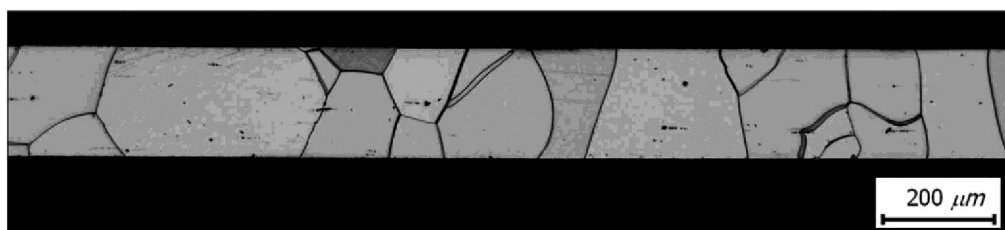
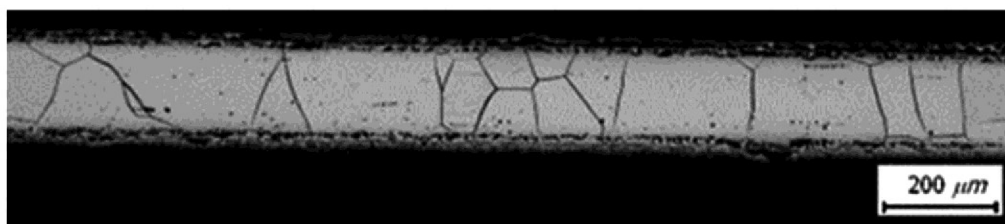


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063297

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i; C22C 38/14(2006.01)i;
C22C 38/12(2006.01)i; C22C 38/42(2006.01)i; C22C 38/58(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); B22F 3/18(2006.01); C21D 8/12(2006.01); C22C 38/00(2006.01); C23C 10/46(2006.01);
C23C 16/24(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), 확산소둔(diffusion annealing), 코팅(coating), 건조(drying), 열팽창계수(coefficient of expansion)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2004-0041773 A (POSCO) 20 May 2004 (2004-05-20) See paragraph [0062], claims 1, 3 and 12 and table 2.	1-19
A	KR 10-2005-0062195 A (POSCO) 23 June 2005 (2005-06-23) See paragraph [0058], claim 1 and table 2.	1-19
A	KR 10-1467062 B1 (HYUNDAI STEEL COMPANY) 01 December 2014 (2014-12-01) See claim 1.	1-19
A	CN 106811730 A (ANHUI ZHONGLONG ENERGY SAVING TECHNOLOGY CO., LTD.) 09 June 2017 (2017-06-09) See claims 1 and 5-6.	1-19
A	JP 2002-275601 A (DAIDO STEEL CO., LTD.) 25 September 2002 (2002-09-25) See claims 1 and 4.	1-19

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

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“O” document referring to an oral disclosure, use, exhibition or other means

“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

08 April 2025

Date of mailing of the international search report

09 April 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.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/IB2024/063297

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CN 106811730 A	09 June 2017	None	
JP 2002-275601 A	25 September 2002	None	

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