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

(72) Inventors:
• **LIM, Namsuk**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
• **RYU, Hanjin**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

- **KWON, Min Serk**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
- **KIM, Donghwi**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
- **CHOI, Heonjo**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
- **JUNG, Hongwook**
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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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) A non-oriented electrical steel sheet includes, as wt%, 0.3 to 7.0% of Si, 0.001 to 3.0% of Al, and 0.03 to 2.0% of Mn, includes a balance of Fe and inevitable

impurities, includes an oxide layer in an internal direction of the steel sheet on a surface of the steel sheet, and a thickness of the oxide layer is 7.0 μm or less.

EP 4 826 018 A1

Description**[Technical Field]**

5 **[0001]** The present disclosure relates to a non-oriented electrical steel sheet and a manufacturing method thereof. In detail, the present disclosure relates to a non-oriented electrical steel sheet for diffusing Si into a steel sheet on a steel sheet surface, suppressing formation of an oxide layer, and increasing magnetism, and a manufacturing method thereof.

10 **[Background 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. When the Si content is increased above a certain level, the magnetostriction, which is the cause of noise, decreases to 0 and the investment rate 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 the gas of SiCl_4 . However, this method uses the gas of SiCl_4 , which is highly toxic and chemically unstable, and has a limit of device that must be produced in a high vacuum condition so it is difficult to manufacture the electrical steel sheet with the width of 500 mm or more. 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.

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

[0003] The present disclosure attempts to provide a non-oriented electrical steel sheet and a manufacturing method thereof. In detail, the present disclosure attempts to provide a non-oriented electrical steel sheet for diffusing Si into a steel sheet on a steel sheet surface, suppressing formation of an oxide layer, and increasing magnetism, and a manufacturing method thereof.

[Technical Solution]

45 **[0004]** An embodiment of the present disclosure provides a non-oriented electrical steel sheet including: as wt%, 0.3 to 7.0 % of Si, 0.001 to 3.0 % of Al, and 0.03 to 2.0 %, and including a balance of Fe and inevitable impurities, wherein an oxide layer is included in an internal direction of a steel sheet on a surface of the steel sheet, and a thickness of the oxide layer is 7 μm or less.

[0005] A content of oxygen may be 0.0030 to 0.0150 wt% for the entire thickness of the steel sheet.

50 **[0006]** ΔSi defined as a difference ($[\text{S-M}_{\text{Si}}] - [\text{C-M}_{\text{Si}}]$) between the content of Si $[\text{C-M}_{\text{Si}}]$ on a center position of the sheet thickness $t/2$ and the content of Si $[\text{S-M}_{\text{Si}}]$ in a region up to 25% of the entire thickness in an internal direction from the surface of the non-oriented electrical steel sheet may be 0.1 wt% or more.

[0007] The content of Si $[\text{C-M}_{\text{Si}}]$ on the center position of the sheet thickness $t/2$ may be 0.3 to 5.5 wt%.

55 **[0008]** The non-oriented electrical steel sheet may further include at least one of 0.005 wt% or less of C (excluding 0%), 0.005 wt% or less of N (excluding 0%), 0.005 wt% or less of S (excluding 0%), 0.005 wt% or less of Ti (excluding 0%), 0.005 wt% or less of Nb (excluding 0%), and 0.005 wt% or less of V (excluding 0%).

[0009] The non-oriented electrical steel sheet may further include at least one of 0.1 wt% or less of P (excluding 0%), 0.005 to 0.2 wt% of Cu, 0.01 to 0.5 wt% of Cr, 0.1 wt% or less of Sn (excluding 0%), 0.1 wt% or less of Sb (excluding 0%), 0.05 wt% or less of Ni (excluding 0%), and 0.01 wt% or less of Zn (excluding 0%).

[0010] The non-oriented electrical steel sheet may further include at least one of 0.200 wt% or less of Bi (excluding 0%), 0.200 wt% or less of Pb (excluding 0%), 0.200 wt% or less of Ge (excluding 0%), and 0.200 wt% or less of As (excluding 0%).

[0011] The non-oriented electrical steel sheet may further include at least one of 0.03 wt% or less of Mo (excluding 0%), 0.0050 wt% or less of B (excluding 0%), 0.0050 wt% or less of Ca (excluding 0%), 0.005 wt% or less of Zr (excluding 0%), 0.01 wt% or less of Te (excluding 0%), and 0.0050 wt% or less of Mg (excluding 0%).

[0012] Another embodiment of the present disclosure provides a method for manufacturing a non-oriented electrical steel sheet including: manufacturing a cold rolled plate including, as wt%, 0.3 to 5.5% of Si, 0.001 to 2.0% of Al, and 0.03 to 2.0% of Mn, and including a balance of Fe and inevitable impurities; applying a Si diffused composition including a compound of Si on a surface of the cold rolled plate; drying the Si diffused composition; and diffusion annealing the cold rolled plate, wherein an applied amount of the Si diffused composition is 5 to 100g/m² in the applying, an atmosphere includes 98 volume% or more of hydrogen, and a dew point is -25 °C or less in the diffusion annealing.

[0013] An applied amount of the Si diffused composition may be 5 to 100g/m².

[0014] An atmosphere may include 98 volume% or more of hydrogen, and a dew point may be -25 °C or below in the diffusion annealing.

[0015] Regarding the compound of Si, a volume of particles in a range of 0.1 to 10 μm is 95% or more of the entire volume.

[0016] A soaking temperature may be 950 to 1100 °C in the diffusion annealing.

[0017] A soaking time may be 1 to 10 hours in the diffusion annealing.

[Advantageous Effects]

[0018] According to the embodiment of the present disclosure, the non-oriented electrical steel sheet has excellent magnetic flux density and high frequency iron loss.

[0019] According to the embodiment of the present disclosure, the method for manufacturing a non-oriented electrical steel sheet does not generate by-product gas harmful to environments such as the manufacturing process, and is an environment-friendly manufacturing method.

[Mode for Invention]

[0020] 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. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of the present disclosure.

[0021] The technical terms used herein are to simply mention a particular embodiment and are not meant to limit the present disclosure. An expression used in the singular encompasses an expression of the plural, unless it has a clearly different meaning in the context. It is to be understood that terms such as "including", "having", etc., are intended to indicate the existence of specific features, regions, numbers, stages, operations, elements, components, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other specific features, regions, numbers, operations, elements, components, or combinations thereof may exist or may be added.

[0022] When a part is referred to as being "on" another part, it may be directly on the other part or intervening parts may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements therebetween.

[0023] 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 disclosure belongs. Such terms as those defined in a generally used dictionary are to be interpreted to have the meanings equal to the contextual meanings in the relevant field of art, and are not to be interpreted to have idealized or excessively formal meanings unless clearly defined in the present application.

[0024] Unless mentioned in a predetermined way, % represents wt%, and 1 ppm is 0.0001 wt%.

[0025] In an embodiment of the present disclosure, "further including an additional element" signifies including the additional element in substitute for iron (Fe) that is a remainder.

[0026] An embodiment of the present disclosure will be described more fully hereinafter so that a person skilled in the art may easily realize the same. 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.

[0027] The non-oriented electrical steel sheet may include, in wt%, 0.3 to 7.0% of Si, 0.001 to 3.0% of Al, and 0.03 to

2.0% of Mn, and may include balance of Fe and inevitable impurities.

[0028] A reason of limiting components of the non-oriented electrical steel sheet will now be described.

Si: 0.3 to 7.0 wt%

[0029] Silicon (Si) increases resistivity of a material and reduces iron loss so it must be added in a relatively large quantity. As the content of Si increases, eddy current loss may be reduced, and the iron loss at a high frequency may be reduced. Particularly, when Si is included in an amount of 6.0 wt% or more, magnetostriction, which is a cause of a noise, is reduced to 0 and an investment ratio increases to the maximum, making it possible to manufacture the electrical steel sheets with excellent high-frequency characteristics. However, when the content of Si is equal to or greater than 4 wt%, ductility of the electrical steel sheet is substantially reduced, so it is difficult to manufacture the electrical steel sheet according to the conventional rolling process.

[0030] Si is diffused into the steel sheet on a surface of the steel sheet to increase Si in 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 a very big amount of Si is included, workability of the electrical steel sheet is degraded when it is processed as a product such as a motor. Due to the diffusion of Si to the interior from the surface, a concentration gradient of Si may be generated in the thickness direction of the steel sheet, and unless otherwise specified, the Si content in the steel sheet may signify the average content in the thickness direction. 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. In detail, it may include 2.5 to 6.5 wt% of Si. In detail, it may include 3.5 to 6.0 wt% of Si.

[0031] The content of Si in a region up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet may be 4.0 to 8.0 wt%, and the content of Si at a center position ($t/2$) of the sheet thickness may be 0.3 to 5.5 wt%. In detail, content of Si in a region up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet may be 4.1 to 7.0 wt%, and the content of Si at the center position ($t/2$) of the sheet thickness may be 0.4 to 3.5 wt%.

[0032] 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 may be generated in the direction of the thickness of the steel sheet. That is, the content of Si in the region (i.e., surface portion) up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet may be 4.0 to 8.0 wt%. If the content of Si in the surface portion is low, it means that the sufficient Si is not diffused, and the improvement of the high-frequency iron loss through the high concentration of Si may not be sufficiently obtained. If the content of Si is too high, it means that a large quantity of Si exists on the surface and is not diffused into the steel sheet, so the improvement of the high-frequency iron loss through the high concentration of Si may not be sufficiently achieved. The content of Si represents an average content of Si in the thickness direction in the surface portion when the concentration of Si of the surface portion is measured in the thickness direction. The content of Si 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). In detail, the content of Si on the surface portion may be 4.1 to 7.0 wt%. The surface portion includes an oxide layer, and the oxide layer is included in the surface portion when the content of Si is calculated.

[0033] The center position of the thickness of the sheet refers to the position at the half of the total thickness of the sheet. It will be referred to as the center portion. If the content of Si in the center portion is low, it means that the sufficient Si is not diffused, and the improvement in the high-frequency iron loss through high-concentration of Si may not be sufficiently obtained. If the content of Si is very high in the center portion, workability may be reduced. In detail, the content of Si in the center portion may be 0.3 to 5.5 wt%. In detail, the content of Si in the center portion may be 0.4 to 3.5 wt%.

[0034] ΔSi defined as the difference ($[S-M_{Si}]-[C-M_{Si}]$) between the content of Si $[C-M_{Si}]$ at the center position of the sheet thickness ($t/2$) and the content of Si $[S-M_{Si}]$ in the region up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet may be 0.1 wt% or more. When there is an appropriate difference in the content of Si between the center portion and the surface, the high-frequency iron loss and the processability may be further improved. In detail, ΔSi may be 1.0 to 6.0 wt%. In detail, ΔSi may be 2.0 to 5.8 wt%.

[0035] As described, Si in a compound of Si in a diffused composition of Si is diffused by a diffusion annealing, thereby increasing the content of Si, and a less amount of Si compared to what is described above may be included in the steel sheet before Si is diffused. In detail, a slab and a cold rolled plate before it is diffused may include 0.3 to 5.5 wt% of Si. If there is too little Si in the slab and the cold rolled sheet before its diffusion, the amount of Si required for diffusion increases, the diffusion annealing takes a long time, the efficiency is not high, and the difference in the content of Si by the sheet thickness becomes large, making it difficult to obtain the appropriate high-frequency iron loss. If there is a very big amount of Si in the slab and the cold rolled plate before its diffusion, the steel sheet may be

broken or defects may be generated in the steel sheet during the cold rolling process. In detail, Si in the slab may be 0.4 to 3.5 wt%.

Al: 0.001 to 3.0 wt%

[0036] Aluminum (Al) lowers the high-frequency iron loss by increasing resistivity of the material. The resistivity of the material may be sufficiently increased through the diffusion of Si, so the addition of Al may be unnecessary. Adding more Al may further improve high-frequency iron loss. If a very big amount of Al is added, iron loss and surface quality deterioration may be generated due to the formation of a silicic acid aluminum-based composite material. In detail, 0.01 to 2.0 wt% of Al may be included. Due to diffusion of Al from the surface to the interior, a concentration gradient of Al may exist in the thickness direction of the steel sheet, and unless otherwise noted, the content of Al in the steel sheet refers to the average content in the thickness direction. In detail, an amount of 0.1 to 1.5 wt% of Al may be included.

[0037] The steel sheet including a high concentration of Si is manufactured by diffusing Al together with Si, so a concentration gradient of Al may be generated in the direction of the steel sheet thickness.

[0038] ΔAl , defined as the difference $([\text{S-M}_{\text{Al}}] - [\text{C-M}_{\text{Al}}])$ between the content of Al $[\text{C-M}_{\text{Al}}]$ at the center position of the sheet thickness ($t/2$) and the content of Al $[\text{S-M}_{\text{Al}}]$ in the region up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet, may be 0.1 wt% or more. When there is an appropriate difference in the content of Al between the center portion and the surface portion, high-frequency iron loss may be further improved.

[0039] The content of Al in the region (i.e., surface portion) up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet may be 0.1 to 3.0 wt%. If the content of Al on the surface portion is low, it means that sufficient Al is not diffused, and the improvement in high-frequency iron loss through diffusion of Al may not be sufficiently achieved. If the content of Al is too high, it means that a large amount of Al exists on the surface portion and is not diffused into the steel sheet, and consequently, sufficient improvement in high-frequency iron loss through diffusion of Al may not be achieved. The content of Al represents the average content of Al in the thickness direction when measuring the concentration of Al of the surface portion in the thickness direction. The content of Al may be measured by GOD, FTIR, wet analysis, TEM-GDS, and SEM-GDS methods. In detail, the content of Al of the surface portion may be 0.5 to 1.0 wt%.

[0040] The content of Al of the center portion may be 0.001 to 2.0 wt%. If the content of Al is low in the center portion, it means that sufficient Al is not diffused, and the improvement in high-frequency iron loss through the diffusion of Al may not be sufficiently achieved. If the content of Al in the center portion is too high, a problem that magnetic flux density degrades may be generated. In detail, the content of Al in the center portion may be 0.5 to 1.0 wt%.

[0041] As previously described, Al in the compound of Al in the Si diffused composition is diffused by diffusion annealing, increasing the content of Al, and the steel sheet prior to diffusion of Al may include less Al compared to what is previously described. In detail, the cold rolled plate before slab and diffusion may include 0.001 to 2.0 wt% of Al. If there is too little Al in the slab and the cold-rolled plate before its diffusion, the amount of Al required for diffusion increases, and diffusion annealing takes a long time, resulting in low efficiency and a large difference in the content of Al depending on the plate thickness, making it difficult to obtain appropriate high frequency iron loss. If there is a very big amount of Al in the slab, Al oxide may clump in some positions and breakage may be generated during a rolling work. In detail, Al in the slab and the cold rolled plate before diffusion may be 0.001 to 1.8 wt%. In detail, Al in the slab and the cold rolled plate before its diffusion may be 0.01 to 1.0 wt%.

Mn: 0.03 to 3.0 wt%

[0042] Manganese (Mn) increases resistivity of the material to improve iron loss and forms sulfides. If too little Mn is added, fine MnS may precipitate, which may degrade magnetism. If a very big amount of Mn is added, it encourages formation of a [111] texture that is disadvantageous to magnetism, which may cause the magnetic flux density to decrease rapidly. Unlike Si and Al, Mn is not diffused to the center portion from the surface portion, but is diffused to the surface portion from the center portion. Volatilization of Mn proceeds at the surface during the diffusion annealing process of Si, causing Mn to diffuse to the surface portion from the center portion. As the amount of Mn decreases and the amount of Si increases, a phase transformation is generated. As the phase transformation is generated, diffusion proceeds to the inside from the surface, and at this time, the environment is formed in a way that is advantageous for the formation of $\langle 100 \rangle$ //ND, which is an orientation similar to the diffusion direction. In detail, Mn may be 0.05 to 2.0 wt%.

[0043] The non-oriented electrical steel sheet may further include at least one of 0.1 wt% or less of P, 0.005 to 0.2 wt% of Cu, 0.01 to 0.5 wt% of Cr, 0.1 wt% or less of Sn, 0.1 wt% or less of Sb, 0.05 wt% or less of Ni, and 0.01 wt% or less of Zn.

P: 0.1 wt% or less

[0044] If phosphorus (P) which is a grain boundary segregating element is added in an excessive amount, it may delay recrystallization and may degrade strength uniformity in a rolling direction and a vertical rolling direction. In detail, P may be 0.005 to 0.03 wt%.

Cu: 0.005 to 0.200 wt%

[0045] Copper (Cu) forms sulfides together with Mn. When Cu is further added, and if too little is added, (Cu-Mn)S may be precipitated finely, which may degrade magnetism. If a great amount of Cu is added, high-temperature brittleness is generated, which may lead to the formation of cracks during continuous casting or hot rolling. In detail, 0.01 to 0.100 wt% of Cu may be included.

Cr: 0.010 to 0.50 wt%

[0046] Chromium (Cr) improves iron loss by increasing resistivity. If a very small amount of Cr is added, the uplift effect of resistivity may not be sufficient. If a very big amount of Cr is included, the magnetic flux density may be deteriorated. In detail, the lower limit of Cr may include 0.05 wt% and 0.30 wt%.

Sn: 0.10 wt% or less

[0047] Tin (Sn) is added as a grain boundary segregating element to suppress diffusion of nitrogen through the grain boundary, thereby suppressing the {111} texture harmful to magnetism and increasing the beneficial {100} texture to improve magnetic characteristics. If a very big amount of Sn is added, it hinders grain growth, reduces magnetism, and results in poor rolling properties. Therefore, Sn may be added within the aforementioned range. In detail, Sn may include 0.005 to 0.08 wt%.

Sb: 0.10 wt% or less

[0048] Antimony (Sb) is added as a grain boundary segregation element to suppress diffusion of nitrogen through the grain boundary, thereby suppressing the {111} texture harmful to magnetism and increasing the beneficial {100} texture to improve magnetic characteristics. If a very big amount of Sb is added, it hinders grain growth, reduces magnetism, and results in poor rolling properties. Therefore, Sb may be added within the aforementioned range. In detail, Sb may include 0.005 to 0.08 wt%.

Ni: 0.05 wt% or less

[0049] Nickel (Ni) may react with impurity elements to form fine sulfides, carbides, and nitrides, which may have a harmful effect on magnetism. In detail, Ni may be included in an amount of 0.005 to 0.03 wt%.

Zn: 0.01 wt% or less

[0050] If the content of zinc (Zn) is excessive, it may function as an impurity and degrade magnetism. Hence, Zn may be further added within the aforementioned range. In detail, Zn may include 0.001 to 0.005 wt%.

[0051] The non-oriented electrical steel sheet may further include at least one of 0.200 wt% or less of Bi, 0.200 wt% or less of Pb, 0.200 wt% or less of Ge, and 0.200 wt% or less of As.

[0052] When the described elements are added, they segregate at the grain boundaries, thereby alleviating stress concentration at the grain boundaries during cold rolling, and suppresses recrystallization of orientation grains of <111>ND during the subsequent recrystallization annealing process, thereby improving magnetic flux density. If they are appropriately added, the aforementioned effects may be additionally obtained, however, if they are included in an excessive amount, a large amount of segregation may be generated, which suppresses grain growth and may actually result in inferior magnetic flux density and iron loss. In detail, it may further include at least one of 0.001 to 0.100 wt% of Bi, 0.001 to 0.100 wt% of Pb, 0.001 to 0.100 wt% of Ge, and 0.001 to 0.100 wt% of As.

[0053] The non-oriented electrical steel sheet may further include at least one of 0.03 wt% or less of Mo, 0.0050 wt% or less of B, 0.0050 wt% or less of Ca, 0.005 wt% or less of Zr, 0.01 wt% or less of Te, and 0.0050 wt% or less of Mg.

[0054] They may react with C, S, N, etc., which are inevitably included, to form fine carbides, nitrides, or sulfides, which may have an adverse effect on magnetism, so the upper limit may be restricted as described above. In detail, it may further include at least one of 0.001 to 0.01 wt% of Mo, 0.0010 to 0.0030 wt% of B, 0.0010 to 0.0030 wt% of Ca,

0.0010 to 0.0030 wt% of Zr, 0.0010 to 0.0050 wt% of Te, and 0.0010 to 0.0050 wt% of Mg.

Other impurities

- 5 **[0055]** In addition to the above-noted elements, inevitable impurities such as carbon (C), sulfur (S), nitrogen (N), titanium (Ti), niobium (Nb), and vanadium (V) may be included.
- [0056]** N is combined with Ti, Nb, and V to form nitrides and deteriorates grain growth. C reacts with N, Ti, Nb, V, etc. to form fine carbides, which hinder grain growth and domain movement.
- [0057]** S forms sulfide to degrade grain growth.
- 10 **[0058]** When the impurity elements are additionally included as described, at least one of 0.005 wt% or less of C (excluding 0%), 0.005 wt% or less of N (excluding 0%), 0.005 wt% or less of S (excluding 0%), 0.005 wt% or less of Ti (excluding 0%), 0.005 wt% or less of Nb (excluding 0%), and 0.005 wt% or less of V (excluding 0%) may be further included. In detail, at least one of 0.001 to 0.003 wt% of C, 0.001 to 0.005 wt% of N, 0.001 to 0.005 wt% of S, 0.001 to 0.005 wt% of Ti, 0.001 to 0.005 wt% of Nb, and 0.001 to 0.005 wt% of V may be further included.
- 15 **[0059]** In addition, inevitable impurities may be included. The inevitable impurities refer to impurities introduced during a steelmaking stage and a process for manufacturing a non-oriented electrical steel sheet, which is widely known in the field, and a detailed description will be omitted. An embodiment of the present disclosure does not exclude the addition of elements other than the aforementioned alloy component, and may include various elements within a range that does not impair the technical concept of the present disclosure. If additional elements are included,
- 20 Fe, which is the balance, is replaced and included.
- [0060]** The non-oriented electrical steel sheet includes an oxide layer in the internal direction of the steel sheet on the surface of the steel sheet, and the thickness of the oxide layer may be 7.0 μm or less. When observed with a transmission electron microscope (TEM), the oxide layer is determined to extend from the surface of the steel sheet to the maximum depth where granular oxides such as Al_2O_3 , SiO_2 , and MnO exist. Curvature may exist in the oxide layer,
- 25 and unless otherwise specified regarding thickness of the oxide layer, it refers to the average thickness of the oxide layer at the measured position.
- [0061]** In the present disclosure, during the process for applying a Si diffused composition and diffusion annealing it, an oxide layer of a certain thickness or more is inevitably formed. When annealing a cold rolled plate in a non-oxidizing atmosphere without performing a Si diffusion process, the oxide layer may be formed to be very thin that is less than 1
- 30 μm , but in this case, it is difficult to achieve the concentration gradient of Si and iron loss intended in the present disclosure. If the oxide layer is too thick, the magnetism may be degraded because of the thickness. In detail, the thickness of the oxide layer may be 1.0 to 7.0 μm . In detail, it may be 2.0 to 6.0 μm .
- [0062]** During the process for applying a Si diffused composition and diffusion annealing it, oxygen is inevitably diffused into the steel sheet. In this case, the amount of oxygen for the entire thickness of the steel sheet is concentrated in the aforementioned oxide layer, and there is almost no oxygen left at the center position of the sheet thickness. When calculating the average content of oxygen for the entire thickness of the steel sheet, it may be
- 35 0.0030 to 0.0150 wt%. When annealing the cold-rolled plate in a non-oxidizing atmosphere without performing a Si diffusion process, the content of oxygen may be controlled to a very low level, however, in this case, it is difficult to achieve the concentration gradient of Si and the iron loss intended in the present disclosure. If the amount of oxygen becomes too high, the magnetic properties may deteriorate. In detail, the content of oxygen may be 0.0050 to 0.0100 wt%.
- [0063]** The non-oriented electrical steel sheet exhibits excellent high-frequency iron loss due to the diffusion of Si and the suppression on the formation of the oxide layer. In detail, iron loss ($W_{10/1k}$) may be 53.0W/kg or less. At this time, the iron loss is based on the thickness of 0.2 mm. The iron loss ($W_{10/1k}$) is the iron loss when the magnetic flux density of 1.0T is induced at a frequency of 1000 Hz. The iron loss may be measured using the Epstein measurement method or the single sheet test (SST) method. In detail, the iron loss ($W_{10/1k}$) may be 20.0W/kg to 50.0W/kg.
- 45 **[0064]** Not only is the iron loss excellent, but the magnetic flux density is also simultaneously superior. In detail, the magnetic flux density (B_{25}) may be 1.46T or more. In detail, the magnetic flux density (B_{25}) may be 1.55 to 1.70T.
- [0065]** The method for manufacturing a non-oriented electrical steel sheet includes: manufacturing a cold rolled plate including, as wt%, 0.3 to 5.5 % of Si, 0.001 to 2.0 % of Al, and 0.03 to 2.0 % of Mn, and including a balance Fe and inevitable impurities; applying a Si diffused composition including a compound of Si to a surface of the cold rolled plate; drying the Si diffused composition; and diffusion annealing the cold rolled plate.
- 50 **[0066]** The method will now be described in detail.
- [0067]** A cold-rolled plate including, as wt%, 0.3 to 5.5 % of S, 0.001 to 2.0 % of Al, and 0.03 to 2.0 % of Mn, and including a balance of Fe and inevitable impurities is prepared. As the alloy component of the cold-rolled plate is the same as previously described, repeated descriptions will be omitted.
- 55 **[0068]** The method for manufacturing a cold rolled plate is not particularly limited and may include manufacturing a hot-rolled plate by hot rolling a slab including, as wt%, 0.3 to 5.5 % of Si, 0.001 to 2.0 % of Al, and 0.03 to 2.0 % of Mn,

and including balance Fe and inevitable impurities; and manufacturing a cold rolled plate by cold rolling the hot-rolled plate.

[0069] A slab is manufactured. The reason for limiting an addition ratio of respective compositions in the slab is the same as the reason for limiting the composition of the non-oriented electrical steel sheet described above, so the repeated descriptions will be omitted. In the manufacturing processes to be described later, such as hot rolling, hot-rolled plate annealing, and cold rolling, the composition of the slab is not substantially changed, so the composition of the slab and the composition of the cold-rolled plate are substantially the same. In the diffusion annealing process, Si and Al are diffused, and the alloy composition of the non-oriented electrical steel sheet may be identical to that of the remaining components excluding Si and Al.

[0070] The slab may be heated to 1100 °C or higher prior to manufacturing the hot-rolled plate. In detail, the slab is loaded into a furnace and is heated to 1100 to 1250 °C. When heated at a temperature that is greater than 1250 °C, the precipitate may be redissolved and may be finely precipitated after hot rolling. In detail, the slab heating temperature may be 1100 °C to 1200 °C.

[0071] The heated slab is hot-rolled to 1.5 to 4.0 mm to be manufactured into a hot-rolled plate. Pre-cold rolling prior to cold rolling is also included, so the non-oriented electrical steel sheet with an appropriate thickness may be manufactured even if the hot-rolled plate is relatively thick. In detail, the thickness of the hot-rolled plate may be 1.5 mm to 3.5 mm.

[0072] The manufacturing of a hot-rolled plate may include finishing rolling at a temperature of 850 °C or higher.

[0073] If the hot rolling finishing temperature is too low, a rolling load increases, leading to a decrease in hot rolling workability. A large amount of deformation structures remain in the hot-rolled steel sheet, which causes an increase in a rolling load during the pre-cold rolling that is a subsequent process. During intermediate annealing, recrystallization of <111>ND orientation grains from the deformed structure is promoted, resulting in a lowered magnetic flux density. Therefore, the hot rolling finishing temperature should be as high as possible, and more specifically, the finishing rolling temperature may be 850 to 1000 °C.

[0074] The manufacturing of a hot-rolled plate may include winding at the temperature of 600 to 800 °C. A rough rolling may be included before the finishing rolling.

[0075] If the temperature is controlled too low during the winding, recovery and recrystallization of the hot rolling deformed structure is not properly generated, and the cooling load increases to quickly cool the steel sheet to a low temperature, which may cause difficulties in winding the supercooled coil. Conversely, if the temperature is too high, recovery and recrystallization may be promoted, but additional oxidation by atmospheric oxygen may be generated while wound, leading to the formation of thicker scale and problems of grain boundary oxidation. The grain boundary oxidation of the hot-rolled plate promotes grain boundary corrosion during the subsequent pickling process, which increases the possibility of surface stripe defects and may cause severe wear on the rolling roll. In detail, the winding temperature may be 650 to 750 °C.

[0076] After manufacturing the hot-rolled plate, the process may further include annealing the hot-rolled plate in the temperature range of 600 to 1100 °C. If the annealing temperature of the hot-rolled plate is too low, the recrystallization structure is not formed or grows finely, resulting in a small increase in the magnetic flux density, and if the annealing temperature is too high, the magnetic characteristics may deteriorate, and rolling workability may worsen due to deformation of the plate shape. In detail, the annealing temperature of the hot-rolled plate may be 750 to 1000 °C.

[0077] Hot-rolled plate annealing is performed to increase the orientation that is advantageous to magnetism as needed, and it may be omitted. The annealing method is not particularly limited, and the annealing may be performed in a batch or continuously.

[0078] The hot-rolled plate may be pickled as needed.

[0079] The hot-rolled plate is pickled and is cold-rolled to have a predetermined plate thickness. Although it may vary depending on the thickness of the hot-rolled plate, cold rolling may be performed by applying a reduction rate of 70 to 95% to achieve a final thickness of 0.10 to 0.65 mm. To achieve the desired reduction ratio, one cold rolling or at least two cold rollings with intermediate annealing in between may be performed. In detail, the reduction rate may be 75 to 90%. The thickness of the cold-rolled plate may be 0.15 to 0.35 mm.

[0080] In the coating, a Si diffused composition including a compound of Si is applied to the cold-rolled plate.

[0081] As for the compound of Si, any material capable of diffusing Si into the steel sheet through long-term annealing may be used without restriction. Specifically, it may include at least one of pure Si, alloy of Si, oxide of Si, nitride or carbide, and silane compound. In addition, it may include at least one of FeSi, Fe₃Si, Fe₃Al, and FeAl.

[0082] In detail, it may include pure Si, alloy of Si, and Fe₃Si.

[0083] In the compound of Si, the volume occupied by particles with a particle size in the range of 0.1 to 10 μm may be more than 95% of the entire volume. If the particle size of the compound of Si is too small, problems where they coagulate with each other during slurry mixing to cause surface defects may be generated. If the particle size of the compound of Si is too large, it is difficult to achieve uniformity on the surface of the steel sheet, which may hinder smooth diffusion of Si into the steel sheet. The average particle size of the compound of Si is the average particle size

for the number of compound particles, and may be measured using a particle size analyzer (PSA) using a laser diffraction method. In detail, the volume occupied by the particles with the particle size in the range of 0.1 to 10 μm may be 99% or more of the entire volume in the compound of Si.

[0084] The Si diffused composition further includes a compound of Al, and may include 100 parts by weight of the compound of Si and 10 to 50 parts by weight of the compound of Al as solids. The solid refers to the weight of each compound when heating it to 180 °C for at least 20 minutes and removing all volatilized components.

[0085] The compound of Al improves insulation, increases bonding with the compound of Si, and facilitates formation of intermetallic compounds. If too little compound of Al is included, it may be difficult to properly obtain the aforementioned effects. If a very big amount of compound of Al is included, numerous Al inclusions may be formed, leading to a problem where magnetic properties are degraded. In detail, the compound of Al may include 15 to 30 parts by weight.

[0086] For the compound of Al, any material capable of diffusing Al into the steel sheet may be used without restriction. For example, pure Al and aluminum alkoxide may exist.

[0087] The average particle size of the compound of Al may be 1 to 1000 nm. If the particle size of the compound of Al is too small, a problem of coagulation between the compounds of Al may be generated. If the particle size of the compound of Al is too large, diffusion of Al into the steel sheet may not be smoothly generated. In detail, the lower limit of the average particle size of the compound of Al may be 5 nm. The upper limit of the average particle size of the compound of Al may be 750 nm.

[0088] The Si diffused composition may further include ceramic powder including an oxide, nitride, carbide, or oxynitride including at least one of Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba. The ceramic powder controls the applied amount of slurry and determines the content of Si in the final steel sheet.

[0089] The ceramic powder may include 10 to 1,000 parts by weight as a solid. If a very small amount of ceramic powder is included, problems may arise in terms of securing the applied amount. If a very big amount of ceramic powder is included, viscosity of the slurry increases, which may cause problems surface defects. In detail, 20 to 500 parts by weight of the ceramic powder may be included.

[0090] The ceramic powder may be at least one 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 $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$.

[0091] 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, there may be a problem in securing a sufficient applied amount. If the particle size of the ceramic powder is too large, the viscosity increases to deteriorate surface quality, which may hinder smooth diffusion of Si into the steel sheet. In detail, the average particle size of the ceramic powder may be 10 nm to 1500 nm.

[0092] The Si diffused composition may further include a solvent in addition to the aforementioned components. The solvent enables uniform application of the Si diffused composition. If the amount of solvent is too small, the application of the Si diffused composition may not be easy. If there is a very big amount of solvent, the viscosity of the Si diffused composition becomes too low, making it difficult to apply a sufficient amount of the composition onto the steel sheet. The solvent may include 10 to 1500 parts by weight for 100 parts by weight of the compound of Si. In detail, the solvent may include 50 to 1000 parts by weight. The solvent may include at least one of water and alcohol.

[0093] In addition to the aforementioned component, the Si diffused composition may include additional components, and this is not excluded from an embodiment of the present disclosure. Examples of the additional components may include phosphoric acid, sodium silicate, fluoride ion solution, etc.

[0094] In the coating, the applied amount of the Si diffused composition may be 5 to 100 g/m^2 . The applied amount is based on the solid. If the applied amount is too small, sufficient diffusion of Si is not generated so it is difficult to fully achieve the effects of diffusion of Si. If the applied amount is too high, a problem where workability is deteriorated may be generated. In detail, the applied amount may be 20 to 70 g/m^2 . In detail, the solid refers to the mass remaining after heat treatment for 9 seconds in a drying condition of 650 °C.

[0095] As an application method, it may be applied using a roller coater, a brush, etc. From a production efficiency perspective, it may be applied using a roll coater.

[0096] In the drying after the coating, the Si diffused composition is dried to form a Si diffused coating layer. The drying temperature is sufficient if it is a temperature at which the solvent in the Si diffused composition may be removed, and specifically, it may be 300 to 850 °C. The time may be 10 seconds to 180 seconds. In detail, the temperature may be 500 to 800 °C. The time may be 15 seconds to 150 seconds. After drying at a drying temperature, it may be cooled at a cooling speed of 20 °C/second or more. By rapidly cooling in this way, automatic detachment of unreacted residual composition may be induced. The cooling range may be up to 100 °C at the drying temperature.

[0097] Diffusion annealing is performed on the cold-rolled plate. In this process, Si and Al are diffused into the steel sheet from the Si diffused composition applied to the surface of the cold-rolled plate.

[0098] By appropriately controlling the atmosphere conditions during diffusion, the formation of an oxide layer in the non-oriented electrical steel sheet and the diffusion of oxygen may be suppressed to the maximum extent. In detail, during the diffusion annealing, the atmosphere includes 98 volume% or more of hydrogen, and the dew point may be

-25 °C.

[0099] In the diffusion annealing, 98,000 volume% or more of hydrogen is included. If a hydrogen fraction is too low, oxygen may react on the surface of the steel sheet, or hydrogen in the atmosphere may not react with the oxygen present in the steel sheet, so a thick oxide layer may be generated or a large amount of oxygen may penetrate into the steel sheet. In detail, it may include 98.200 to 99.999 volume%. The remainder may include at least one of nitrogen and oxygen.

[0100] In the diffusion annealing, the dew point may be -25 °C or lower. The dew point is proportional to the amount of H₂O in the atmosphere, and if the dew point is high, aqueous vapor in the atmosphere reacts with the steel sheet, forming a thick oxide layer or allowing a large amount of oxygen to penetrate into the steel sheet. In detail, the dew point may be -50 to -30 °C.

[0101] The diffusion annealing temperature may be 950 °C to 1100 °C. If the diffusion annealing temperature is too low, the diffusion of Si may not be sufficiently generated, and the desired effect may not be achieved. If the diffusion annealing temperature is too high, pores may be formed, and the magnetic properties may be degraded. In detail, it may be 950 to 1050 °C.

[0102] The time may be 1 to 10 hours. If the time is too short, diffusion of Si may not be sufficiently generated, and the desired effect may not be achieved. In detail, it may be 2 to 7 hours.

[0103] After diffusion annealing, the final thickness of the steel sheet may be 0.10 to 0.65 mm, and the thickness may be slightly increased compared to the cold rolled plate due to application of the Si diffused composition and diffusion thereof.

[0104] The diffused and annealed steel sheet may further include washing and drying to remove unreacted materials.

[0105] The diffused and annealed steel sheet may further include pickling to make the surface smooth.

[0106] The pickling may use at least one of hydrochloric acid, nitric acid, sulfuric acid, and hydrofluoric acid.

[0107] The diffused and annealed steel sheet may further include performing a plasma treatment to make the surface beautiful.

[0108] It may further include forming an insulating film. As the insulating film is widely known, a detailed description will be omitted. In detail, an insulating coating layer may be formed by applying an insulating coating layer forming composition made of metal phosphoric acid salt and silica as main components, and performing a heat treatment.

[0109] An embodiment and a comparative example will now be described. However, the following Example is merely a preferable embodiment of the present disclosure, and the present disclosure is not limited thereto.

Experimental Example

[0110] A slab including silicon (Si) with the concentration of Si in the steel sheet expressed in Table 2, 0.002 wt% of aluminum (Al), 0.10 wt% of manganese (Mn), 0.04 wt% of tin (Sn), 0.04 wt% of antimony (Sb), and 0.013 wt% of phosphorus (P) and including a balance of Fe and other inevitable impurities is prepared.

[0111] A hot-rolled plate is manufactured by heating the slab at 1100 °C and hot-rolling it to the thickness of 1.8 mm.

[0112] The hot-rolled plate is wound at 700 °C, is cooled in the air, is annealed at 1030 °C for 2 minutes, is quenched in water, is pickled, and is then cold-rolled to the thickness of 0.20 mm to manufacture a cold-rolled plate.

[0113] The Si diffused composition is prepared by stirring silicon powder with the average particle size of 1 μm (99.99 wt% or more of Si, 0.5 to 5 μm of particle diameter range, and 99.9 wt% or more) with water on the surface of the cold-rolled plate.

[0114] The prepared Si diffused composition is applied to the cold-rolled plate in the solid amount listed in Table 1. It is dried for 9 seconds at 650 °C.

[0115] The cold-rolled plate coated with the Si diffused composition is diffusionannealed for 2 hours under the condition of Table 1.

[0116] The diffused and annealed surface of the steel sheet is washed with water, is dried at the room temperature, is immersed in a nitric acid solution including 0.5% of hydrofluoric acid at 65 °C for 12 seconds to remove unreacted materials, is washed again with water, and is finally dried to manufacture the non-oriented electrical steel sheet with the thickness of 0.2 mm.

[0117] The comparative example 11 represents an example in which the cold-rolled plate is manufactured in the same way, a Si annealing separator is not applied, and annealing is performed for 120 seconds under the conditions summarized in Table 1.

[0118] The thickness of the oxide layer of the finally manufactured steel sheet is measured from the surface of the steel sheet to the maximum depth where granular oxides such as Al₂O₃, SiO₂, or MnO exist by using a transmission electron microscope (TEM).

[0119] The concentration of oxygen in the steel sheet is measured using ICP-MS (Inductively Coupled Plasma - Mass Spectrometry).

[0120] The concentration of Si on the center portion and surface portion is measured using a scanning electron microscope/energy-dispersive X-ray spectroscopy (SEM/EDX).

[0121] The iron loss ($W_{10/1000}$) is measured in the rolling direction and the vertical rolling direction using the Epstein measurement method, and the average of these measurements is displayed.

(Table 1)

Steel types	Applied amount of Si diffused composition (g/m ²)	Diffusion temperature (°C)	Hydrogen volume (%)	Dew point (°C)
Embodiment 1	32	1043	99.275	-39
Embodiment 2	31	1007	98.699	-35
Embodiment 3	45	1015	98.957	-38
Embodiment 4	27	1040	98.550	-37
Embodiment 5	65	1006	99.608	-35
Embodiment 6	35	1046	99.907	-37
Embodiment 7	45	955	99.775	-41
Embodiment 8	24	991	99.337	-42
Embodiment 9	56	1050	99.795	-44
Embodiment 10	24	1035	98.308	-39
Comparative Example1	24	960	50.421	-39
Comparative Example2	25	945	70.483	-38
Comparative Example3	18	970	99.993	0
Comparative Example4	3	960	99.989	-37
Comparative Example5	24	992	97.345	-43
Comparative Example6	46	710	99.986	-42
Comparative Example7	24	924	99.994	-49
Comparative Example8	130	960	99.996	-34
Comparative Example9	14	1221	99.995	-38
Comparative Example10	12	1211	99.993	-38
Comparative Example11	-	1000	99.992	-30

(Table 2)

Steel types	Concentration of Si of surface portion (wt%)	Concentration of Si of center portion (wt%)	Amount of oxygen (wt.ppm)	Thickness of oxide layer (μm)	Iron loss ($W_{10/1000}$, W/Kg)
Embodiment 1	5.6	1.6	66	4.3	36.0
Embodiment 2	6.2	1.4	75	4.8	48.4
Embodiment 3	4.4	1.9	89	2.6	44.3
Embodiment 4	5.5	0.4	55	3.8	43.5
Embodiment 5	6.5	0.9	95	5.6	37.7
Embodiment 6	5.0	1.6	72	4.4	38.2
Embodiment 7	4.1	1.0	84	3.7	45.7
Embodiment 8	4.4	0.9	84	3.7	45.8
Embodiment 9	4.4	1.2	85	3.9	48.1

(continued)

Steel types	Concentration of Si of surface portion (wt%)	Concentration of Si of center portion (wt%)	Amount of oxygen (wt.ppm)	Thickness of oxide layer (μm)	Iron loss (W10/1000 , W/Kg)
Embodiment 10	6.2	2.0	88	2.7	41.5
Comparative Example1	3.8	2.8	86	7.7	57.0
Comparative Example2	4.5	3.2	74	8.2	61.2
Comparative Example3	6.0	0.6	64	8.2	56.1
Comparative Example4	6.0	5.0	Broken	Broken	Broken
Comparative Example5	6.3	2.4	59	8.5	54.1
Comparative Example6	2.0	1.5	65	3.9	64.5
Comparative Example7	2.7	1.4	54	4.4	61.3
Comparative Example8	2.3	0.9	80	6.8	63.4
Comparative Example9	3.4	1.1	243	8.1	56.6
Comparative Example10	4.3	2.2	210	8.4	64.6
Comparative Example11	2.5	2.5	5	0.5	70.2

[0122] As expressed in Table 1 and Table 2, in the embodiment where the conditions are properly controlled during diffusion annealing, it may be confirmed that diffusion of Si is properly achieved, the thickness of the oxide layer is simultaneously suppressed, and the penetrating amount of oxygen is low, resulting in excellent iron loss.

[0123] On the other hand, if the conditions are not properly controlled during diffusion annealing, diffusion of Si is not properly generated or the oxide layer is formed to be too thick, resulting in inferior iron loss.

[0124] Comparative Example 11 is the case where the Si diffusing process is not performed, and it may be seen that the iron loss is inferior.

[0125] While this disclosure has been described in connection with what is presently considered to be practical embodiments, it is to be understood that the disclosure is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. Therefore, the embodiments described above are only examples and should not be construed as being limitative in any respects.

Claims

1. A non-oriented electrical steel sheet comprising,

as wt%, 0.3 to 7.0 % of Si, 0.001 to 3.0 % of Al, and 0.03 to 2.0 %, and including a balance of Fe and inevitable impurities,

wherein an oxide layer is included in an internal direction of a steel sheet on a surface of the steel sheet, and a thickness of the oxide layer is 7 μm or less.

2. The non-oriented electrical steel sheet of claim 1, wherein a content of oxygen is 0.0030 to 0.0150 wt% for the entire thickness of the steel sheet.

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 the content of Si $[\text{C-M}_{\text{Si}}]$ on a center position of the sheet thickness $t/2$ and the content of Si $[\text{S-M}_{\text{Si}}]$ in a region up to 25% of the entire thickness in an internal direction from the surface of the non-oriented electrical steel sheet is 0.1 wt% or more.

4. The non-oriented electrical steel sheet of claim 1, wherein the content of Si $[\text{C-M}_{\text{Si}}]$ on the center position of the sheet thickness $t/2$ is 0.3 to 5.5 wt%.

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

ΔAl defined as a difference ($[S-M_{Al}]-[C-M_{Al}]$) between the content of Al $[C-M_{Al}]$ on the center position of the sheet thickness $t/2$ and the content of Al $[S-M_{Al}]$ in a region up to 25% of the entire thickness in the internal direction from the surface of the non-oriented electrical steel sheet is 0.1 wt% or more.

- 5 **6.** The non-oriented electrical steel sheet of claim 1, further comprising
at least one of 0.005 wt% or less of C (excluding 0%), 0.005 wt% or less of N (excluding 0%), 0.005 wt% or less of S (excluding 0%), 0.005 wt% or less of Ti (excluding 0%), 0.005 wt% or less of Nb (excluding 0%), and 0.005 wt% or less of V (excluding 0%).
- 10 **7.** The non-oriented electrical steel sheet of claim 1, further comprising
at least one of 0.1 wt% or less of P (excluding 0%), 0.005 to 0.2 wt% of Cu, 0.01 to 0.5 wt% of Cr, 0.1 wt% or less of Sn (excluding 0%), 0.1 wt% or less of Sb (excluding 0%), 0.05 wt% or less of Ni (excluding 0%), and 0.01 wt% or less of Zn (excluding 0%).
- 15 **8.** The non-oriented electrical steel sheet of claim 1, further comprising
at least one of 0.200 wt% or less of Bi (excluding 0%), 0.200 wt% or less of Pb (excluding 0%), 0.200 wt% or less of Ge (excluding 0%), and 0.200 wt% or less of As (excluding 0%).
- 20 **9.** The non-oriented electrical steel sheet of claim 1, further comprising
at least one of 0.03 wt% or less of Mo (excluding 0%), 0.0050 wt% or less of B (excluding 0%), 0.0050 wt% or less of Ca (excluding 0%), 0.005 wt% or less of Zr (excluding 0%), 0.01 wt% or less of Te (excluding 0%), and 0.0050 wt% or less of Mg (excluding 0%).
- 25 **10.** A method for manufacturing a non-oriented electrical steel sheet comprising:
manufacturing a cold rolled plate including, as wt%, 0.3 to 5.5% of Si, 0.001 to 2.0% of Al, and 0.03 to 2.0% of Mn, and including a balance of Fe and inevitable impurities;
applying a Si diffused composition including a compound of Si on a surface of the cold rolled plate;
drying the Si diffused composition; and
30 diffusion annealing the cold rolled plate,
wherein an applied amount of the Si diffused composition is 5 to 100g/m² in the applying,
an atmosphere includes 98 volume% or more of hydrogen, and a dew point is -25 °C or less in the diffusion annealing.
- 35 **11.** The method of claim 10, wherein
regarding the compound of Si, a volume of particles in a range of 0.1 to 10 μm is 95% or more of the entire volume.
- 40 **12.** The method of claim 10, wherein
a soaking temperature is 950 to 1100 °C in the diffusion annealing.
- 45 **13.** The method of claim 10, wherein
a soaking time is 1 to 10 hours in the diffusion annealing.
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- 55

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063299

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 38/58(2006.01)i; C22C 38/42(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); B21B 1/22(2006.01); C21D 8/04(2006.01); C21D 8/12(2006.01); C21D 9/46(2006.01);
C22C 38/00(2006.01); C23C 24/10(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: 무방향성(non-oriented), 전자강판(electrical steel sheet), 규소(Si), 소둔
(annealing), 확산(diffusion), 산화층(oxide layer), 알루미늄(Al), 망간(Mn)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2029609 B1 (JFE STEEL CORPORATION) 07 October 2019 (2019-10-07) See paragraphs [0062], [0064], [0066], [0071] and [0074] and claims 1 and 3-4.	1-13
X	KR 10-2021-0125073 A (NIPPON STEEL CORPORATION) 15 October 2021 (2021-10-15) See claims 1-3.	1,6-9
X	KR 10-2022-0089084 A (POSCO) 28 June 2022 (2022-06-28) See claims 1-5 and 7.	1,6-9
A	JP 2006-241563 A (NIPPON STEEL CORP.) 14 September 2006 (2006-09-14) See paragraph [0019] and claims 1-2.	1-13
A	JP 2008-069412 A (NIPPON STEEL CORP.) 27 March 2008 (2008-03-27) See paragraph [0028] and claims 1 and 13.	1-13

☐ 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

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“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

14 April 2025

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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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