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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)
• **LIM, Namsuk**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

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

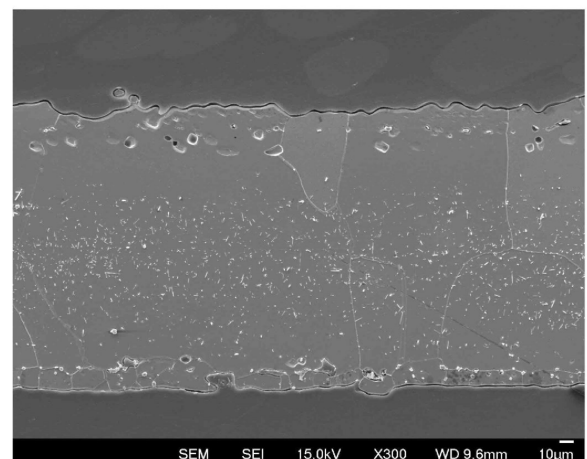
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) A non-oriented electrical steel sheet according to an embodiment of the present invention includes, by wt%, Si: 4.0 to 7.0%, Al:0.001 to 3.0%, and Mn: 0.03 to 2.0% with the balance Fe and inevitable impurities, wherein AlN is included in the steel sheet, and the AlN has an average particle size of 2.5 to 6.5 μ m.

FIG. 1



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Description**[Technical Field]**

[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 and a method for manufacturing the same, in which Si is diffused from a surface of the steel sheet into the interior of the steel sheet to improve magnetic properties and simultaneously improve mechanical strength.

[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 the increasing efficiency and miniaturization of devices. When the magnetic flux density is higher, a smaller amount of core material is required to achieve the same performance, thereby enabling miniaturization of the electrical device. In addition, when iron loss is lower, energy loss is reduced, and thus securing such characteristics is essential for manufacturing a high-efficiency motor.

[0003] Iron loss, which causes energy loss, is composed of hysteresis loss and eddy current loss. In addition, in a high-efficiency motor for electronic devices operating at a high frequency, the influence of eddy current loss is increased. Eddy current loss is heat generated by eddy currents induced in the steel sheet when a magnetic field is applied thereto. In order to reduce the eddy current loss, it is generally effective to increase the content of resistivity-increasing elements such as Si or Al in the electrical steel sheet. In addition, when the Si content is increased to a predetermined level or higher, magnetostriction, which causes noise, is reduced to zero, and permeability is maximized, thereby enabling the manufacture of an electrical steel sheet having excellent high-frequency characteristics.

[0004] However, as the Si content increases, the ductility of the electrical steel sheet is significantly reduced, making it difficult to manufacture a thin electrical steel sheet by a conventional rolling process.

[0005] In order to overcome the limitation of a rolling process described above, a technique has been proposed in which Si is diffused by using SiCl_4 gas on a surface of a cold-rolled steel sheet, thereby manufacturing an electrical steel sheet having an increased Si content in the steel sheet. However, this method uses SiCl_4 gas, which is highly toxic and chemically unstable, and thus has limitations in that production needs to be carried out under high vacuum conditions, making it difficult to manufacture electrical steel sheets having a width of 500 mm or more. In addition, under high vacuum conditions, a by-product gas such as FeCl_2 may be generated, which is environmentally harmful and cause deterioration of insulating characteristics, and thus there is a need for a fundamental solution to these problems.

[Disclosure]**[Technical Problem]**

[0006] An embodiment of the present invention is to provide a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, an embodiment of the present invention is to providing a non-oriented electrical steel sheet having improved magnetic properties and enhanced mechanical strength by diffusing Si from a surface of the steel sheet into the interior thereof, and a method for manufacturing the same.

[Technical Solution]

[0007] A non-oriented electrical steel sheet according to an embodiment of the present invention includes, by wt%, Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0% with the balance Fe and inevitable impurities, wherein AlN is included in the steel sheet, and the AlN has an average particle size of 2.5 to 6.5 μm .

[0008] An area ratio of AlN occupying a cross-section of the steel sheet is 1.0% or more.

[0009] An area ratio of AlN at a position ranging from $1/3 \times t$ to $2/3 \times t$ of the entire thickness t of the steel sheet is 3.0% or more.

[0010] ΔSi , which is defined as a difference between an Si content [C-MSi] at a center position ($t/2$) of the sheet thickness and a maximum Si content [S-MSi] in a region extending from a surface of the non-oriented electrical steel sheet to a depth corresponding to 5 % of the total thickness thereof in the inward direction, i.e., ([S-MSi] - [C-MSi]), may be 0.1 wt% or more.

[0011] ΔAl , which is defined as a difference ([S-MAI] - [C-MAI]) between a maximum Al content [S-MAI] in a surface portion extending from a surface of the non-oriented electrical steel sheet to a depth of 5% of the total thickness thereof and the Al content [C-MAI] at a center position ($t/2$) of the sheet thickness, may be 0.1 wt% or more.

[0012] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include one or more of C: 0.005 wt% or less (excluding 0%), N: 0.030 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%).

[0013] 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.

[0014] The non-oriented electrical steel sheet according to an 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.

[0015] The non-oriented electrical steel sheet according to an 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.

[0016] A manufacturing method of a non-oriented electrical steel sheet according to an embodiment of the present invention includes: preparing a cold-rolled steel sheet containing, by weight %, 0.3 to 4.0% of Si, 0.001 to 2.0% of Al, and 0.03 to 2.0% of Mn, with the balance being Fe and inevitable impurities; applying a Si diffusion composition containing a Si compound onto a surface of the cold-rolled steel sheet; drying the Si diffusion composition; and performing diffusion annealing on the cold-rolled steel sheet.

[0017] In the diffusion annealing, the atmospheric pressure may be 1.8 atm or more.

[0018] The Si diffusion composition may further include an Al compound, and contains, on a solid basis, 100 parts by weight of the Si compound and 10 to 50 parts by weight of the Al compound.

[0019] The Si diffusion composition may further include a ceramic powder including an oxide, a nitride, a carbide, or an oxynitride containing at least one element selected from among Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba as a constituent element.

[0020] An average particle diameter of the Si compound may be 1 to 850 nm.

[0021] An average particle diameter of the Al compound may be 8 to 2500nm.

[0022] An average particle diameter of the ceramic powder may be 8 to 2500nm.

[0023] In the applying, a coating amount of the Si diffusion composition may be 0.1 to 300 g/m².

[0024] In each of first diffusion annealing and second annealing, a temperature range of 300 to 400°C before soaking may be heated at a rate of 5 to 50°C/hr.

[0025] In the diffusion annealing, a soaking temperature is 950 to 1200 °C.

[0026] In the diffusion annealing, a soaking time may be 2.8 to 10 hours.

[0027] In the diffusion annealing, the atmosphere may include 99 vol% or more of N₂.

[Advantageous Effects]

[0028] The non-oriented electrical steel sheet according to an embodiment of the present invention exhibits both excellent magnetic flux density and excellent high-frequency iron loss.

[0029] The manufacturing method of the non-oriented electrical steel sheet according to an embodiment of the present invention does not generate an environmentally harmful by-product gas during a manufacturing process and the like, thereby providing an environmentally friendly manufacturing method.

[0030] The non-oriented electrical steel sheet according to an embodiment of the present invention exhibits excellent mechanical strength due to the presence of AlN in the steel sheet.

[Description of the Drawings]

[0031]

FIG. 1 shows a scanning electron microscope (SEM) image obtained by analyzing a cross-section of the non-oriented electrical steel sheet manufactured in Example 1.

FIG. 2 is an enlarged photo of FIG. 1.

FIGS. 3 and 4 are energy dispersive spectroscopy (EDS) elemental mapping images of Al in the white rectangle shown in FIG. 2.

[Mode for Invention]

[0032] Terms such as "first," "second," and "third" may be used herein to describe various elements, components, regions, layers, and/or sections, but such elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer, or section from

another element, component, region, layer, or section. Accordingly, a first element, component, region, layer, or section described below may be referred to as a second element, component, region, layer, or section without departing from the scope of the present invention.

[0033] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to limit the present invention. As used herein, singular forms include plural forms as well, unless the context clearly indicates otherwise. The term "comprising" as used herein specifies the presence of stated features, regions, integers, steps, operations, elements, and/or components, but does not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, components, and/or combinations thereof.

[0034] When an element is referred to as being "on" or "over" another element, it may be directly on or over the other element, or intervening elements may be present therebetween. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present.

[0035] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meanings as commonly understood by one of ordinary skill in the art to which the present invention pertains. Terms defined in commonly used dictionaries should be interpreted as having meanings consistent with their meanings in the context of the relevant art and the present disclosure, and should not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0036] Unless otherwise specified, "%" refers to weight percent, and 1 ppm corresponds to 0.0001 weight percent.

[0037] In an embodiment of the present invention, the meaning of further including an additional element means including the additional element by replacing iron (Fe), which is the balance, by the added amount of the additional element.

[0038] Hereinafter, an embodiment of the present invention will be described in detail such that those skilled in the art can easily carry out the present 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 invention.

[0039] A non-oriented electrical steel sheet according to an embodiment of the present invention includes, by weight percent (wt%), Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, and includes the balance being Fe and inevitable impurities.

[0040] Hereinafter, the reasons for limiting the composition of the non-oriented electrical steel sheet will be described.

Si: 4.0 to 7.0 wt%

[0041] Silicon (Si) serves to increase the resistivity of a material, thereby reducing iron loss, and thus is preferably added in a relatively large amount. As the Si content increases, eddy current loss decreases, thereby reducing iron loss at a high frequency. In particular, when Si is contained in an amount of 6.0 wt% or more, magnetostriction, which is a cause of noise, decreases to substantially zero, and magnetic permeability increases to its maximum, thereby enabling a production of an electrical steel sheet having excellent high-frequency characteristics. However, when the Si content is 4 wt% or more, the ductility of the electrical steel sheet is significantly reduced, resulting in a limitation in that the electrical steel sheet is difficult to manufacture using a conventional rolling process.

[0042] In an embodiment of the present invention, Si is diffused from a surface of the steel sheet into the inside of the steel sheet, such that the steel sheet contains 4 wt% or more of Si. When the content of Si inside the steel sheet is excessively small, it is difficult to obtain the above-stated effect of Si. When the Si content is excessively high, there is a problem in that the workability of the electrical steel sheet deteriorates when the electrical steel sheet is processed into a product such as a motor. In an embodiment of the present invention, due to the diffusion of Si from the surface toward the inside of the steel sheet, a concentration gradient of Si may exist in a thickness direction of the steel sheet. Unless otherwise specified, the Si content in the steel sheet refers to an average Si content in the thickness direction of the steel sheet. The average content refers to a content value calculated under an assumption that Si is uniformly distributed in the steel sheet along the thickness direction thereof. More specifically, Si may be included in an amount of 4.5 to 6.5 wt%.

[0043] A maximum content of Si in a region extending from the surface of the non-oriented electrical steel sheet to a depth corresponding to 5 % of the total thickness in the inward direction thereof, and a Si content at a center position ($t/2$) of the sheet thickness may be 0.3 to 7.5 wt%.

[0044] In an embodiment of the present invention, a steel sheet containing a high concentration of Si is produced by diffusing Si from the surface of the steel sheet into the inside thereof, and thus a concentration gradient may be formed in the thickness direction of the steel sheet. That is, the maximum Si content in a region (i.e., a surface portion) extending from the surface of the non-oriented electrical steel sheet to a depth corresponding to 5% of the total thickness thereof in the inward direction may be 4.0 to 8.0 wt%. When the Si content in the surface portion is low, it indicates that a sufficient amount of Si has not been diffused into the steel sheet, and thus improvement in high-frequency iron loss through the high concentration of Si may not be sufficiently achieved. When the Si content in the

surface region is excessively high, it means that a large amount of Si is present only in the surface portion and has not been sufficiently diffused into the interior of the steel sheet. In this case as well, the improvement in high-frequency iron loss through the high concentration of Si may not be sufficiently achieved. The maximum Si content refers to the highest Si content measured in the surface portion along the thickness direction of the steel sheet. The maximum Si content may be measured using an electron probe micro-Analyzer (EPMA) or a scanning electron microscope/energy-dispersive X-ray spectroscopy (SEM/EDS), which are non-destructive analysis methods. More specifically, the maximum Si content in the surface portion may be 4.5 to 7.5 wt%.

[0045] A center position of the sheet thickness refers to a position corresponding to one-half of the total thickness of the sheet. Hereinafter, it will be referred to as a center portion. When the Si content at the center position of the sheet thickness is low, it indicates that Si has not been sufficiently diffused into the interior of the steel sheet, and therefore the improvement in high-frequency iron loss obtainable by the high concentration of Si may not be sufficiently achieved. When the Si content at the center position of the sheet thickness is excessively high, workability may be deteriorated. More specifically, the Si content at the center portion may be 2.5 to 6.0 wt%.

[0046] ΔSi , defined as a difference between the Si content [C-MSi] at a center position ($t/2$) of the sheet thickness and a maximum Si content [S-MSi] in a region extending from the surface of the non-oriented electrical steel sheet to a depth corresponding to 5 % of the total thickness thereof in the inward direction, i.e., ([S-MSi] - [C-MSi]), may be 0.1 wt% or more. When an appropriate difference in Si content exists between the center portion and the surface portion, high-frequency iron loss characteristics and workability may be further improved. More specifically, ΔSi may be 0.5 to 5.0 wt%. More specifically, ΔSi may be 2.0 to 4.8 wt%.

[0047] As described above, in an embodiment of the present invention, Si contained in a Si compound of the Si diffusion composition is diffused into the steel sheet during diffusion annealing, thereby increasing the Si content of the steel sheet. Accordingly, the steel sheet prior to Si diffusion may contain a smaller amount of Si than the Si content described above. Specifically, Si may be included in an amount of 2.0 to 3.5 wt% in the slab and the cold-rolled steel sheet before Si diffusion. When the Si content in the slab and the cold-rolled steel sheet before Si diffusion is excessively low, the amount of Si required for diffusion increases, and a prolonged diffusion annealing time is required, resulting in poor process efficiency. In addition, a difference in Si content across the thickness of the steel sheet becomes large, making it difficult to obtain desirable high-frequency iron loss. When the Si content in the slab and the cold-rolled steel sheet before Si diffusion is excessively high, the steel sheet may fracture during the cold-rolling process, or defects may be generated in the steel sheet. More specifically, the content is Si in the slab may be 2.3 to 3.3 wt%.

Al: 0.001 to 3.0 wt%

[0048] Aluminum (Al) serves to increase resistivity of a material, thereby reducing high-frequency iron loss. In an embodiment of the present invention, since the resistivity of the material can be sufficiently increased through Si diffusion, the addition of Al may be unnecessary. However, as the content of Al increases, high-frequency iron loss may be further improved. However, when Al is added in an excessive amount, an aluminum silicate-based composite may be formed, resulting in deterioration of iron loss and surface quality. More specifically, Al may be included in an amount of 0.01 to 2.0 wt%. In an embodiment of the present invention, due to the diffusion of Al from the surface toward the interior of the steel sheet, a concentration gradient of Al may exist in the thickness direction of the steel sheet. Unless otherwise specified, the Al content in the steel sheet refers to an average Al content in the thickness direction of the steel sheet. More specifically, Al may be included in an amount of 0.1 to 1.5 wt%.

[0049] In an embodiment of the present invention, a steel sheet containing a high concentration of Si is produced by diffusing Al together with Si, and thus a concentration gradient of Al may be formed in the thickness direction of the steel sheet.

[0050] ΔAl , which is defined as a difference ([S-MAI] - [C-MAI]) between the maximum Al content [S-MAI] in the surface portion extending from the surface of the non-oriented electrical steel sheet to a depth of 5% of the total thickness thereof and the Al content [C-MAI] at the center position ($t/2$) of the sheet thickness, may be 0.1 wt% or more. When an appropriate difference in Al content exists between the center portion and the surface portion, high-frequency iron loss may be further improved.

[0051] The maximum Al content in a region extending from the surface of the non-oriented electrical steel sheet to a depth corresponding to 5% of the total thickness thereof in the inward direction (i.e., a surface region) may be 0.1 to 3.0 wt%. When the Al content in the surface portion is excessively low, it means that Al has not been sufficiently diffused into the steel sheet, and therefore the improvement in high-frequency iron loss obtainable by Al diffusion may be insufficient. When the Al content in the surface portion is excessively high, it indicates that a large amount of Al is present only in the surface portion and has not been sufficiently diffused into the interior of the steel sheet, and therefore the improvement in high-frequency iron loss obtainable through Al diffusion may not be sufficiently achieved. The maximum Al content refers to the highest Al content among Al contents measured in the surface portion of the

steel sheet along the thickness direction thereof. The maximum Al content may be measured using GOD, FTIR, wet analysis, TEM-GDS, or SEM-GDS. More specifically, the maximum content of Al in the surface portion may be 0.5 to 1.0 wt%.

[0052] The Al content at the center portion may be 0.001 to 2.0 wt%. When the Al content at the center position of the sheet thickness is excessively low, it indicates that Al has not been sufficiently diffused into the steel sheet, and therefore the improvement in high-frequency iron loss obtainable through Al diffusion may not be sufficiently achieved. When the Al content at the center position of the sheet thickness is excessively high, magnetic flux density may be degraded. More specifically, the maximum content of Al in the surface portion may be 0.5 to 1.0 wt%.

[0053] As described above, in an embodiment of the present invention, Al contained in an Al compound of the Si diffusion composition is diffused into the steel sheet during diffusion annealing, thereby increasing the Al content of the steel sheet. Accordingly, the steel sheet prior to Al diffusion may contain a smaller amount of Al than the Al content described above. Specifically, the Al may be included in an amount of 0.001 to 2.0 wt% in the slab and the cold-rolled steel sheet before Si diffusion. When the Al content in the slab and the cold-rolled steel sheet before Al diffusion is excessively low, the amount of Al required for diffusion increases and the diffusion annealing time is prolonged, thereby reducing process efficiency. Furthermore, a difference in Al content depending on the thickness direction of the steel sheet increases, making it difficult to achieve desirable high-frequency iron loss. When the Al content in the slab is excessively high, Al oxides may agglomerate at local positions, causing cracking during rolling. More specifically, the content of Al in the slab and the cold-rolled steel sheet before diffusion may be 0.001 to 1.8 wt%. More specifically, the content of Al in the slab and the cold-rolled steel sheet before diffusion may be 0.01 to 1.0 wt%.

Mn: 0.03 to 3.0 wt%

[0054] Manganese (Mn) serves to increase the resistivity of a material, thereby improving iron loss, and also serves to form a sulfide. When the Mn content is excessively low, MnS may precipitate in a fine form, thereby deteriorating magnetic properties. When the Mn content is excessively high, the formation of a [111] texture, which is unfavorable to magnetic properties, may be promoted, resulting in a sharp decrease in magnetic flux density. In an embodiment of the present invention, unlike Si and Al, Mn is not diffused from the surface portion toward the center portion, but rather from the center portion toward the surface portion. This is because Mn volatilizes from the surface during the Si diffusion annealing process, causing Mn to diffuse from the center portion toward the surface portion. As the amount of Mn decreases and the amount of Si increases, a phase transformation occurs. As a phase transformation proceeds, diffusion progresses from the surface toward the interior of the steel sheet, thereby creating an environment favorable for the formation of a <100>ND texture, which has an orientation similar to the diffusion direction

[0055] More specifically, Mn may be included in an amount of 0.05 to 2.0 wt%.

[0056] 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: 0.1 wt% or less

[0057] Phosphorus (P) is a grain boundary segregation element, and when added in an excessive amount, may delay recrystallization, thereby deteriorating the uniformity of strength between a rolling direction and a direction perpendicular thereto

[0058] More specifically, P may be included in an amount of 0.005 to 0.03 wt%.

Cu: 0.005 to 0.200 wt%

[0059] Copper (Cu) may serve to form a sulfide with Mn. When Cu is further added, an excessively low Cu content may cause fine (Cu,Mn)S precipitates to form, thereby deteriorating magnetic properties. When the Cu content is excessively high, high-temperature embrittlement may occur, which may cause cracks during continuous casting or hot-rolling. More specifically, Cu may be included in an amount of 0.01 to 0.100 wt%.

Cr: 0.010 to 0.50 wt%

[0060] Chromium (Cr) serves to improve iron loss by increasing the resistivity. When the Cr content is excessively low, the effect of increasing the resistivity may be insufficient. When the Cr content is excessively high, magnetic flux density may deteriorate. More specifically, a lower limit of Cr may be 0.05 wt%, 0.30 wt%.

Sn: 0.10 wt% or less

[0061] Tin (Sn) is a grain boundary segregation element and is added to suppress diffusion of nitrogen through a grain boundary, suppresses a {111} texture that is detrimental to magnetic properties, and increases a favorable {100} texture, thereby improving magnetic characteristics. When the Sn content is excessively high, grain growth may be inhibited, thereby deteriorating magnetic properties and rollability. Therefore, Sn may be added within the above-described range. More specifically, Sn may be included in an amount of 0.005 to 0.08 wt%.

Sb: 0.10 wt% or less

[0062] Antimony (Sb), as a grain boundary segregation element, is added to suppress diffusion of nitrogen along a grain boundary, suppresses formation of a {111} texture that is detrimental to magnetic properties, and promotes formation of a favorable {100} texture, thereby improving magnetic characteristics. When the Sb content is excessively high, grain growth may be inhibited, resulting in deterioration of magnetic properties and rolling characteristics. Therefore, Sb may be added within the above-described range. More specifically, Sb may be included in an amount of 0.005 to 0.08 wt%.

Ni: 0.05 wt% or less

[0063] Nickel (Ni) may react with impurity elements to form fine sulfides, carbides, and nitrides, which may adversely affect magnetic properties. More specifically, Ni may be included in an amount of 0.005 to 0.03 wt%.

Zn: 0.01 wt% or less

[0064] Zinc (Zn), when present in an excessive amount, may act as an impurity and thereby deteriorate magnetic properties. Therefore, Zn may be added within the above-described range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

[0065] The non-oriented electrical steel sheet according to an 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.

[0066] When additionally added, the above-described elements segregate at grain boundaries and alleviate stress concentration at the grain boundaries during cold-rolling. As a result, recrystallization of grains having a <111>ND orientation is suppressed during a subsequent recrystallization annealing process, thereby improving magnetic flux density. When appropriately added, the above-described elements can provide the aforementioned effects. However, when included in an excessive amount, excessive segregation may occur, thereby suppressing grain growth and consequently deteriorating magnetic flux density and iron loss. More specifically, the non-oriented electrical steel sheet may further contain 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%.

[0067] The non-oriented electrical steel sheet according to an embodiment of the present invention may further contain 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.

[0068] These elements may react with inevitably contained elements such as C, S, and N to form fine carbides, nitrides, or sulfides, which may adversely affect magnetic properties. Accordingly, the upper limits thereof may be restricted as described above. More specifically, the non-oriented electrical steel sheet may further include one or more of Mo: 0.001 to 0.01 weight, 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 impurity

[0069] In addition to the above-described elements, inevitably incorporated impurities such as carbon (C), sulfur (S), nitrogen (N), titanium (Ti), niobium (Nb), and vanadium (V) may be included.

[0070] Nitrogen (N) combines with Ti, Nb, and V to form nitrides, thereby deteriorating grain growth characteristics. In the case of nitrogen (N), when diffusion annealing is performed for an extended period in an N₂ atmosphere at a high pressure, external nitrogen may penetrate into the steel sheet, such that the N content in the steel sheet may become higher than that before the annealing process.

[0071] Carbon (C) may react with N, Ti, Nb, V, and the like to form fine carbides, thereby inhibiting grain growth and domain movement.

[0072] Sulfur (S) forms a sulfide, thereby deteriorating grain growth characteristics.

[0073] When such impurity elements are further included, the non-oriented electrical steel sheet may further include

one or more of C: 0.005 wt% or less (excluding 0%), N: 0.030 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, the non-oriented electrical steel sheet may further include one or more of C: 0.001 to 0.003 wt%, N: 0.001 to 0.030 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%.

[0074] In addition, other inevitably incorporated impurities may be included. The inevitable impurities are impurities introduced during a steelmaking process and a manufacturing process of the non-oriented electrical steel sheet. Since such impurities are well known in the art, a detailed description thereof will be omitted. In an embodiment of the present invention, the addition of elements other than the above-described alloying elements is not excluded, and such elements may be included in various amounts and forms within a range that does not depart from the technical spirit of the present invention. When additional elements are included, the additional elements are included by replacing a corresponding amount of the balance Fe.

[0075] The non-oriented electrical steel sheet according to an embodiment of the present invention contains AlN in the steel sheet, and the AlN has an average particle diameter of 2.5 to 6.5 μm . According to an embodiment of the present invention, by forming AlN having a relatively large particle diameter, the mechanical strength of the steel sheet, particularly the hardness thereof, may be improved. When the hardness of the non-oriented electrical steel sheet is increased, mechanical durability of a motor core manufactured therefrom may be improved, which is advantageous in terms of service life. When the average particle diameter of the AlN is excessively small, the desired improvement in mechanical strength may not be sufficiently achieved. If the average particle diameter of the AlN is excessively large, although sufficient mechanical strength may be secured, magnetic properties may be deteriorated due to the presence of the AlN. More specifically, an average particle diameter of AlN may be 3.0 to 6.0 μm .

[0076] AlN is present in the steel sheet in the form of particles formed by agglomeration of Al and N elements, and refers to a portion in which the contents of Al and N are higher than those in the steel sheet matrix. Determination of AlN and measurement of the particle diameter thereof may be performed by analyzing an SEM image of a cross-section (RD plane or TD plane) including a thickness direction (ND direction) of the steel sheet using image analysis software. In order to prevent errors caused by measurement deviations, images are obtained from at least five specimens, with three images taken from each specimen, and an arithmetic mean value thereof is calculated and used. The particle diameter of the AlN is calculated as a diameter of a circle having an area equivalent to that of the AlN particle. The average refers to an arithmetic mean. In addition, due to limitations in measurement accuracy, only a particle having a particle diameter of 0.5 μm or more is regarded as AlN.

[0077] In an embodiment of the present invention, an area occupied by AlN in a cross-section of the steel sheet may be 1.0% or more. As described above, by forming a large amount of AlN, the mechanical strength of the steel sheet, particularly the hardness thereof, may be improved. More specifically, the area occupied by AlN may be 1.1 to 5.0%. More specifically, the area occupied by AlN in a cross-section including the entire thickness of the steel sheet may be 1.2 to 2.5%.

[0078] In an embodiment of the present invention, due to the high pressure employed during diffusion annealing, N_2 may diffuse to the center portion ($t/2$) of the steel sheet, and a large amount of AlN may be formed at the center portion ($t/2$) of the steel sheet. More specifically, the area occupied by AlN present in a region from $1/3 \times t$ to $2/3 \times t$ of the total thickness t of the steel sheet may be 3.0% or more of the area of the region from $1/3 \times t$ to $2/3 \times t$. As described above, by forming a large amount of AlN at the center portion ($t/2$) of the steel sheet, the mechanical strength of the steel sheet, particularly the hardness thereof, may be improved. More specifically, it may be 3.1 to 7.0 %.

[0079] The non-oriented electrical steel sheet according to an embodiment of the present invention exhibits excellent high-frequency iron loss due to the diffusion of Si. Specifically, iron loss ($W_{0.5/20k}$) may be 22.0W/kg or less. In this case, the iron loss is measured based on a steel sheet thickness of 0.2 mm. The iron loss ($W_{0.5/20k}$) refers to the iron loss measured when a magnetic flux density of 0.5 T is induced at a frequency of 20,000 Hz. The iron loss may be measured using an Epstein test method or a single sheet tester (SST) method. More specifically, iron loss ($W_{0.5/20k}$) may be 13.0W/kg to 22.0W/kg.

[0080] In an embodiment of the present invention, not only iron loss characteristics but also magnetic flux density is simultaneously excellent. Specifically, the magnetic flux density (B_{25}) may be 1.46T or more. Specifically, the magnetic flux density (B_{25}) may be 1.50 to 1.65T.

[0081] In an embodiment of the present invention, not only magnetic properties but also mechanical strength are excellent. More specifically, the steel sheet may have a hardness (Hv) of 120 or more. More specifically, it may be 120 to 180.

[0082] A manufacturing method of the non-oriented electrical steel sheet according to an embodiment of the present invention includes: preparing a cold-rolled steel sheet containing, by weight %, 0.3 to 4.0% of Si, 0.001 to 2.0% of Al, and 0.03 to 2.0% of Mn, with the balance being Fe and inevitable impurities; applying a Si diffusion composition containing a Si compound onto a surface of the cold-rolled steel sheet; drying the Si diffusion composition; and performing diffusion annealing on the cold-rolled steel sheet.

[0083] Hereinafter, each step will be described in detail.

[0084] First, a cold-rolled steel sheet is prepared, the cold-rolled steel sheet containing, by weight %, 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. Since alloying components of the cold-rolled steel sheet are the same as those described above, redundant descriptions thereof will be omitted.

[0085] The method of manufacturing the cold-rolled steel sheet is not particularly limited. For example, the method may include hot-rolling a slab containing, by weight %, Si: 0.3 to 4.0%, Al: 0.001 to 2.0%, and Mn: 0.03 to 2.0% to prepare a hot-rolled steel sheet, and cold-rolling the hot-rolled steel sheet to prepare the cold-rolled steel sheet.

[0086] First, a slab is manufactured. Since the reasons for limiting the contents of the respective components in the slab are the same as those for limiting the composition of the non-oriented electrical steel sheet described above, repeated descriptions thereof will be omitted. Since the composition of the slab is not substantially changed during manufacturing processes, such as hot-rolling, hot-rolled steel sheet annealing, and cold-rolling, which will be described later, the composition of the slab is substantially the same as that of the cold-rolled steel sheet. In addition, during the diffusion annealing process, only Si, Al, and N are diffused. Accordingly, the alloy composition of the non-oriented electrical steel sheet may be the same as that of the cold-rolled steel sheet with respect to components other than Si, Al, and N.

[0087] Prior to preparing the hot-rolled steel sheet, the slab may be heated to 1,100°C or higher. Specifically, the slab may be charged into a reheating furnace and heated to a temperature of 1,100 to 1,250 °C. When the slab is heated to a temperature exceeding 1,250 °C, precipitates may be re-dissolved and subsequently precipitated finely after hot-rolling. More specifically, the slab heating temperature may be 1100 °C to 1200 °C.

[0088] The heated slab is hot-rolled to a thickness of 1.5 to 4.0 mm to prepare a hot-rolled steel sheet. Since the method according to an embodiment of the present invention further includes a preliminary cold-rolling process prior to the cold-rolling process, a non-oriented electrical steel sheet having an appropriate thickness may be manufactured even when the hot-rolled steel sheet has a relatively large thickness. More specifically, a thickness of the hot-rolled plate may be 1.5 mm to 3.5 mm.

[0089] The preparing the hot-rolled steel sheet may include finish rolling at a temperature of 850°C or higher.

[0090] When the finish rolling temperature during hot-rolling is excessively low, the rolling load increases, thereby deteriorating hot-rolling workability. In addition, a large amount of deformed structure may remain in the hot-rolled steel sheet, which may cause an increase in rolling load during a subsequent process, such as preliminary cold-rolling. In addition, during intermediate annealing, recrystallization of grains having a <111>//ND orientation may be promoted from the deformed structure, thereby deteriorating the magnetic flux density. Accordingly, the higher the finish rolling temperature of the hot-rolling process, the better. More specifically, the finish rolling temperature may be 850 to 1,000°C.

[0091] The preparing the hot-rolled steel sheet may include coiling at a temperature of 600 to 800°C. The hot-rolling process may further include rough rolling prior to the finish rolling process.

[0092] When the coiling temperature is excessively low, recovery and recrystallization of the deformation structure formed during hot-rolling may not sufficiently occur. In addition, the cooling load may increase in order to rapidly cool the steel sheet to the low temperature, and difficulties may arise in coiling the excessively cooled coil. Conversely, when the coiling temperature is excessively high, recovery and recrystallization may be promoted. However, additional oxidation due to atmospheric oxygen may occur while the steel sheet remains in a coiled state, thereby causing the formation of a thicker scale and giving rise to grain boundary oxidation. Grain boundary oxidation in the hot-rolled steel sheet may promote grain boundary corrosion during a subsequent pickling process, thereby increasing the possibility of generation of a surface streak defect and causing severe wear of rolling roll. More specifically, the winding temperature may be 650 to 750 °C.

[0093] After the preparing the hot-rolled steel sheet, the method may further include annealing the hot-rolled steel sheet at a temperature in the range of 600 to 1,100°C. When the annealing temperature of the hot-rolled steel sheet is excessively low, a recrystallized structure may not be formed or may grow only to a limited extent, resulting in an insufficient improvement in magnetic flux density, and, when the annealing temperature is excessively high, magnetic properties may instead deteriorate, and rolling workability may be reduced due to deformation of the sheet shape. More specifically, the hot-rolled plate annealing temperature may be 750 to 1000 °C.

[0094] The hot-rolled steel sheet annealing process may be performed, as necessary, to increase orientations favorable for magnetic properties, and may be omitted if desired. The annealing method is not particularly limited, and annealing may be performed in either a batch mode or a continuous mode.

[0095] The hot-rolled steel sheet obtained through hot-rolling may be subjected to pickling, if necessary.

[0096] Next, the hot-rolled steel sheet is pickled and cold-rolled to a predetermined sheet thickness. Although a reduction ratio may vary depending on the thickness of the hot-rolled steel sheet, cold-rolling may be performed at a reduction ratio of 70 to 95 % such that the final thickness becomes 0.10 to 0.65 mm. In order to achieve the desired reduction ratio, cold-rolling may be performed once, or may be performed two or more times with intermediate anneal-

ing therebetween. More specifically, the reduction ratio may be 75 to 90 %. The thickness of the cold-rolled steel sheet may be 0.15 to 0.35 mm.

[0097] Next, in the applying, a Si diffusion composition containing a Si compound is applied to the cold-rolled steel sheet.

[0098] The Si compound is not particularly limited as long as it is capable of diffusing Si into the steel sheet through prolonged annealing. More specifically, the Si compound may include one or more selected from among pure Si, a Si alloy, a Si oxide, a Si nitride, a Si carbide, and a silane compound. In addition, one or more of FeSi, Fe₃Si, Fe₃Al, and FeAl may be included.

[0099] More specifically, pure Si, a Si alloy, and Fe₃Si may be included.

[0100] The Si compound may have an average particle size of 1 to 850 nm. When the particle size of the Si compound is excessively small, the particles may agglomerate with one another during slurry mixing, thereby causing surface defects. When the particle size of the Si compound is excessively large, uniform application onto the surface of the steel sheet may become difficult, and thus diffusion of Si into the interior of the steel sheet may not proceed smoothly. The average particle size of the Si compound refers to the average particle size with respect to the number of compound particles, and may be measured using a particle size analyzer (PSA) based on a laser diffraction method. More specifically, the average particle size of the Si compound may be 10 to 500 nm. More specifically, it may be 20nm to 100nm.

[0101] The Si diffusion composition may further include an Al compound, and may contain, on a solid basis, 100 parts by weight of the Si compound and 10 to 50 parts by weight of the Al compound. In an embodiment of the present invention, the term "solid content" refers to the weight of each compound after heating the compound at 180 °C for 20 minutes or longer to remove substantially all volatile components.

[0102] The Al compound serves to improve insulation properties, enhance bonding with the Si compound, and promote the formation of intermetallic compounds. When the content of the Al compound is excessively low, the above-described effects may not be sufficiently achieved. When the content of the Al compound is excessively high, a large number of Al-containing inclusions may be formed, thereby deteriorating magnetic properties. More specifically, the Al compound may be included in an amount of 15 to 30 parts by weight.

[0103] Any Al compound may be used without particular limitation, provided that it is capable of diffusing Al into the interior of the steel sheet. For example, the Al compound may include pure Al, an aluminum alkoxide, or the like.

[0104] The average particle size of the Al compound may be 1 to 1,000 nm. When the particle size of the Al compound is excessively small, agglomeration among the Al compound particles may occur. When the particle size of the Al compound is excessively large, diffusion of Al into the interior of the steel sheet may not proceed smoothly. More specifically, the lower limit of the average particle size of the Al compound may be 5 nm. More specifically, the average particle size of the Al compound may be 5 to 750 nm.

[0105] The Si diffusion composition may further include a ceramic powder including an oxide, a nitride, a carbide, or an oxynitride containing at least one element selected from among Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba as a constituent element. The ceramic powder serves to control the coating amount of the slurry and determine the Si content of the final steel sheet.

[0106] The ceramic powder may be included in an amount of 10 to 1,000 parts by weight on a solid content basis. When the content of the ceramic powder is excessively low, it may be difficult to secure a sufficient coating amount. When the content of the ceramic powder is excessively high, the viscosity of the slurry may increase, thereby causing problems associated with surface defects. More specifically, the ceramic powder may be included in an amount of 20 to 500 parts by weight.

[0107] The ceramic powder may be one or more selected from among Al₂O₃, TiO₂, MgO·Al₂O₃, MgO·TiO₂, 3Al₂O₃·2SiO₂, ZrO₂·SiO₂, TiN, CrN, SrTiO₃, MgAl₂O₄, Y₂O₃, FeTiO₃, and Li₂O·Al₂O₃·SiO₂.

[0108] The average particle size of the ceramic powder may be 8 to 2,500 nm. When the particle size of the ceramic powder is excessively small, it may be difficult to secure a sufficient coating amount. When the particle size of the ceramic powder is excessively large, the viscosity of the slurry may increase and surface quality may deteriorate, such that diffusion of Si into the interior of the steel sheet may not proceed smoothly. More specifically, the average particle size of the ceramic powder may be 10 to 1,500 nm.

[0109] The Si diffusion composition may further include a solvent in addition to the above-described components. The solvent enables the Si diffusion composition to be uniformly applied. When the amount of the solvent is excessively small, application of the Si diffusion composition may not be easy. When the amount of the solvent is excessively large, the viscosity of the Si diffusion composition may become excessively low, making it difficult to apply a sufficient amount of the composition onto the steel sheet. The solvent may be included in an amount of 10 to 1,500 parts by weight based on 100 parts by weight of the Si compound. More specifically, the solvent may be included in an amount of 50 to 1,000 parts by weight. The solvent may include one or more selected from among water and an alcohol.

[0110] In addition to the above-described components, the Si diffusion composition may further include an additional

component, and such an additional component is not excluded from the scope of an embodiment of the present invention. Examples of the additional components may include phosphoric acid, sodium silicate, and a fluoride ion solution.

[0111] In the applying, a coating amount of the Si diffusion composition may be 0.1 to 300 g/m². In this case, the coating amount is based on solid content. When the coating amount is excessively low, sufficient diffusion of Si may not occur, making it difficult to sufficiently achieve the effects obtained by Si diffusion. When the coating amount is excessively high, workability may deteriorate.

[0112] As the coating method, the Si diffusion composition may be applied using a roll coater, a brush, or the like. From the viewpoint of productivity, the Si diffusion composition may be applied using a roll coater.

[0113] After the applying, the drying includes drying the Si diffusion composition to form a Si diffusion coating layer. The drying temperature may be any temperature sufficient to remove the solvent contained in the Si diffusion composition, and may specifically be 300 to 850°C. The drying time may be 10 seconds to 180 seconds. More specifically, the drying temperature may be 500 to 800°C. The drying time may be 15 to 150 seconds. After drying at the drying temperature, cooling may be performed at a cooling rate of 20°C/s or more. By performing such rapid cooling, spontaneous detachment of unreacted residual composition may be induced. The cooling range may extend from the drying temperature to 100°C.

[0114] Next, the cold-rolled steel sheet is subjected to diffusion annealing. In this process, Si and Al are diffused into the interior of the steel sheet from the Si diffusion composition applied to the surface of the cold-rolled steel sheet.

[0115] Prior to the diffusion annealing, the steel sheet may be heated through a temperature range of 20 to 700 °C at a heating rate of 5 to 50 °C/hr. By heating at such a relatively low heating rate, a steel sheet having uniform quality may be obtained. When the heating rate is excessively low, the process time may be unnecessarily prolonged, resulting in reduced productivity. When the heating rate is excessively high, the above-described effects may not be sufficiently achieved. More specifically, the steel sheet may be heated at a heating rate of 10 to 30°C/hr.

[0116] In an embodiment of the present invention, by setting the pressure of the atmosphere to a relatively high level during diffusion annealing, N₂ in the atmosphere may be diffused into the steel sheet, thereby increasing the reactivity between Al and N and allowing a large amount of AlN to be formed. Specifically, the pressure of the atmosphere may be 1.8 atm or higher. When the pressure is excessively low, it may be difficult to achieve the desired effects of promoting diffusion of N₂ and enhancing reactivity. More specifically, the pressure of the atmosphere may be 1.9 to 3.0 atm.

[0117] During the diffusion annealing process, the N content in the steel sheet may increase by 0.002 to 0.020 wt%. More specifically, it may increase by 0.005 to 0.015 wt%.

[0118] The diffusion annealing temperature may be 950 to 1,250°C. When the diffusion annealing temperature is excessively low, diffusion of Si may be insufficient, and thus the intended effects may not be achieved. If the diffusion annealing temperature is excessively high, pores may be formed, resulting in deterioration of magnetic properties. More specifically, the diffusion annealing temperature may be 980 to 1,170°C.

[0119] The diffusion annealing time may be 2.8 to 10 hours. When the diffusion annealing time is excessively short, diffusion of Si may be insufficient, and thus the desired effects may not be achieved. More specifically, the diffusion annealing time may be 2.5 to 7 hours.

[0120] The atmosphere during diffusion annealing may comprise 99 vol% or more of N₂. The atmosphere may include one or more selected from among hydrogen, oxygen, and argon. The atmosphere may have an oxidation potential (PH₂O/PH₂) of 6.4 or less. When the oxidation potential is excessively high, internal oxides of Al₂O₃ may be formed, thereby deteriorating the magnetic properties. More specifically, the atmosphere may have an oxidation potential (PH₂O/PH₂) of 3.0 or less. Specifically, the oxidation potential (PH₂O/PH₂) of the atmosphere may be 1.0 or less.

[0121] After diffusion annealing, the final thickness of the steel sheet may be 0.10 to 0.65 mm. Due to application of the Si diffusion composition and diffusion of Si and Al, the thickness of the steel sheet may be increased to some extent compared to that of the cold-rolled steel sheet.

[0122] The method may further include washing and drying the steel sheet after completion of diffusion annealing in order to remove unreacted materials.

[0123] The method may further include pickling the steel sheet after completion of diffusion annealing in order to improve the surface appearance thereof.

[0124] The pickling may use at least one acid selected from among hydrochloric acid, nitric acid, sulfuric acid, and hydrofluoric acid.

[0125] After completion of diffusion annealing, the method may further include plasma treatment of the steel sheet in order to improve the surface appearance thereof.

[0126] Thereafter, the method may further include forming an insulating coating layer. Since the insulating coating layer is widely known, a detailed description thereof will be omitted. More specifically, the insulating coating layer may be formed by applying a composition for forming an insulating coating layer containing a metal phosphate salt and

silica as main components, followed by heat treatment.

[0127] The following examples illustrate the present invention in more detail. However, the following embodiments are merely preferred embodiments of the present invention, and the present invention is not limited thereto.

5 Experimental Example

[0128] A slab formed of 2.0 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), and 0.013 wt% of phosphorus (P), with the balance consisting of Fe and inevitable impurities was prepared.

[0129] The slab was heated to 1,100°C and then hot-rolled to a thickness of 1.8 mm to produce a hot-rolled plate.

[0130] The hot-rolled plate was coiled at 700°C, cooled in air, and then subjected to hot-rolled plate annealing at 1,030°C for 2 minutes. Thereafter, the plate was quenched in water, pickled, and then cold-rolled to a thickness of 0.20 mm to produce a cold-rolled steel sheet.

[0131] A silicon diffusion composition was prepared by adding, onto a surface of the cold-rolled steel sheet, 100 parts by weight of silicon powder having an average particle diameter of 15 nm (Si: 99.99 wt% or more) and 80 parts by weight of Al₂O₃ ceramic powder having an average particle diameter of 1,000 nm, followed by stirring with water.

[0132] The prepared silicon diffusion composition was applied onto the cold-rolled steel sheet. Thereafter, drying was performed at 600°C for 1 minute.

[0133] The cold-rolled steel sheet coated with the silicon diffusion composition was subjected to diffusion annealing under the conditions shown in Table 1 below.

[0134] After completion of diffusion annealing, the surface of the steel sheet was washed with water and dried at room temperature. Thereafter, an unreacted material was removed by immersing the steel sheet in a nitric acid solution containing 0.5% hydrofluoric acid at 65°C for 12 seconds, followed by water washing and final drying, thereby producing a non-oriented electrical steel sheet having a thickness of 0.2 mm.

[0135] A size of AlN in the finally manufactured steel sheet was measured by SEM at a magnification of 5,000× or higher.

[0136] The hardness (Hv) was measured as Vickers hardness (using a 500 g load with a duration of 10 seconds).

[0137] Iron loss (W_{0.5/20k}) was measured by an Epstein test method in both the rolling direction and the direction perpendicular to the rolling direction, and the average thereof was reported.

(Table 1)

Classification	Temperature (°C)	Pressure (Atmosphere pressure)	Time (hr)	AlN average particle diameter (μm)	AlN area fraction (%)	AlN area fraction (%) in center portion	ΔSi (wt %)	Hardness (Hv)	W _{0.5/20k} (W/kg)
Comparative Example1	800	1.5	3.0	0.1	0.5	2.5	0.6	112	29.5
Comparative Example2	900	1.5	3.0	0.3	0.4	2.0	1.0	115	26.4
Inventive Example1	1000	1.5	3.0	3.0	1.2	3.2	2.2	121	16.2
Inventive Example 2	1100	1.5	3.0	3.3	2.1	3.3	3.8	132	14.5
Inventive Example 3	1150	1.5	3.0	4.2	2.3	4.3	4.5	151	15.2
Comparative Example3	1000	1.0	3.0	0.2	0.1	1.0	4.3	110	17.2
Inventive Example 4	1000	2.0	3.0	4.2	1.8	3.8	2.2	151	18.4
Inventive Example 5	1000	2.5	3.0	5.4	1.8	3.3	2.2	163	21.4
Comparative Example4	1000	1.5	0.5	0.2	0.2	1.2	0.2	118	29

(continued)

Classification	Temperature (°C)	Pressure (Atmosphere pressure)	Time (hr)	AlN average particle diameter (μm)	AlN area fraction (%)	AlN area fraction (%) in center portion	ΔSi (wt %)	Hardness (Hv)	W _{0.5/20k} (W/kg)
Comparative Example 5	1000	1.5	1.0	1.3	0.5	1.9	0.8	123	28.2
Comparative Example 6	1000	1.5	1.5	1.8	0.4	1.8	1.0	130	24.4
Comparative Example 7	1000	1.5	2.0	2.2	0.4	2.3	2.1	140	22.4
Inventive Example 6	1000	1.5	6.0	5.8	1.9	4.1	4.7	172	15.2
Comparative Example 8	1000	5.0	3.0	10.0	3.0	7.4	3.4	201	31.2

[0138] As shown in Table 1, Comparative Example 3, in which the pressure of the atmosphere during diffusion annealing was not properly controlled, exhibits almost no formation of AlN and shows a very low hardness.

[0139] In addition, Comparative Example 8, in which the pressure during diffusion annealing was excessively controlled to a high level, exhibits excessive formation of AlN, and although the hardness is high, it can be confirmed that the iron loss is deteriorated.

[0140] In Comparative Examples 1, 2, and 4 to 7, in which the temperature and time during diffusion annealing were not properly controlled, Si diffusion was not sufficiently achieved, and it can be confirmed that the iron loss is deteriorated.

[0141] FIG. 1 shows a scanning electron microscope (SEM) image obtained by analyzing a cross-section of the non-oriented electrical steel sheet manufactured in Example 1. As shown in FIG. 1, it can be confirmed that AlN is largely formed and occupies a large area. In addition, it can be confirmed that a larger amount of AlN is formed in the central portion of the steel sheet than at the surface thereof.

[0142] FIGS. 2 to 4 illustrate the types of inclusions. As can be confirmed from FIGS. 3 and 4, the contents of Al and N are higher than those in the matrix, indicating that the inclusions are AlN inclusions.

[0143] The present invention is not limited to the embodiments but can be manufactured in various different forms, and those skilled in the art to which the present invention pertains will understand that the present invention can be implemented in other specific forms without changing the technical idea or essential features of the present invention. Therefore, it should be understood that the embodiments described above are illustrative in all respects and not restrictive.

Claims

1. A non-oriented electrical steel sheet comprising, by wt%, Si: 4.0 to 7.0%, Al: 0.001 to 3.0%, and Mn: 0.03 to 2.0%, with the balance Fe and inevitable impurities, wherein AlN is included in the steel sheet, and the AlN has an average particle size of 2.5 to 6.5 μm.
2. The non-oriented electrical steel sheet of claim 1, wherein: an area ratio of AlN occupying a cross-section of the steel sheet is 1.0% or more.
3. The non-oriented electrical steel sheet of claim 1, wherein: an area of AlN at a position ranging from 1/3 x t to 2/3 x t of the entire thickness t of the steel sheet is 3.0% or more.
4. The non-oriented electrical steel sheet of claim 1, wherein: ΔSi, defined as a difference between an Si content [C-MSi] at a center position (t/2) of the sheet thickness and a maximum Si content [S-MSi] in a region extending from a surface of the non-oriented electrical steel sheet to a depth corresponding to 5 % of the total thickness thereof in the inward direction, i.e., ([S-MSi] - [C-MSi]), is 0.1

wt% or more.

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

ΔAl , which is defined as a difference $([\text{S-MAl}] - [\text{C-MAl}])$ between a maximum Al content $[\text{S-MAl}]$ in a surface portion extending from a surface of the non-oriented electrical steel sheet to a depth of 5% of the total thickness thereof and the Al content $[\text{C-MAl}]$ at a center position ($t/2$) of the sheet thickness, is 0.1 wt% or more.

6. The non-oriented electrical steel sheet of claim 1, further comprising one or more of C: 0.005 wt% or less (excluding 0%), N: 0.030 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%).

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

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

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

10. A manufacturing method of a non-oriented electrical steel sheet comprising:

preparing a cold-rolled steel sheet containing, by weight %, 0.3 to 4.0% of Si, 0.001 to 2.0% of Al, and 0.03 to 2.0% of Mn, with the balance being Fe and inevitable impurities;

applying a Si diffusion composition containing a Si compound onto a surface of the cold-rolled steel sheet;

drying the Si diffusion composition; and

performing diffusion annealing on the cold-rolled steel sheet,

wherein in the diffusion annealing, the atmospheric pressure is 1.8 atm or more.

11. The manufacturing method of claim 10, wherein:

the Si diffusion composition further comprises an Al compound, and contains, on a solid basis, 100 parts by weight of the Si compound and 10 to 50 parts by weight of the Al compound.

12. The manufacturing method of claim 10, wherein:

the Si diffusion composition further comprises a ceramic powder including an oxide, a nitride, a carbide, or an oxynitride containing at least one element selected from among Li, B, Ca, Sr, Mg, Al, P, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Zr, Sn, and Ba as a constituent element.

13. The manufacturing method of claim 10, wherein:

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

14. The manufacturing method of claim 11, wherein:

an average particle diameter of the Al compound is 1 to 1000nm.

15. The manufacturing method of claim 12, wherein:

an average particle diameter of the ceramic powder is 8 to 2500nm.

16. The manufacturing method of claim 10, wherein:

in the applying, a coating amount of the Si diffusion composition is 0.1 to 300 g/m² each.

17. The manufacturing method of claim 10, wherein:

in the diffusion annealing, a soaking temperature is 950 to 1200 °C.

18. The manufacturing method of claim 10, wherein:

in the diffusion annealing, a soaking time is 2.8 to 10 hours.

- 19.** The manufacturing method of claim 10, wherein:
in the diffusion annealing, the atmosphere comprises 99 vol% or more of N₂.

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FIG. 1

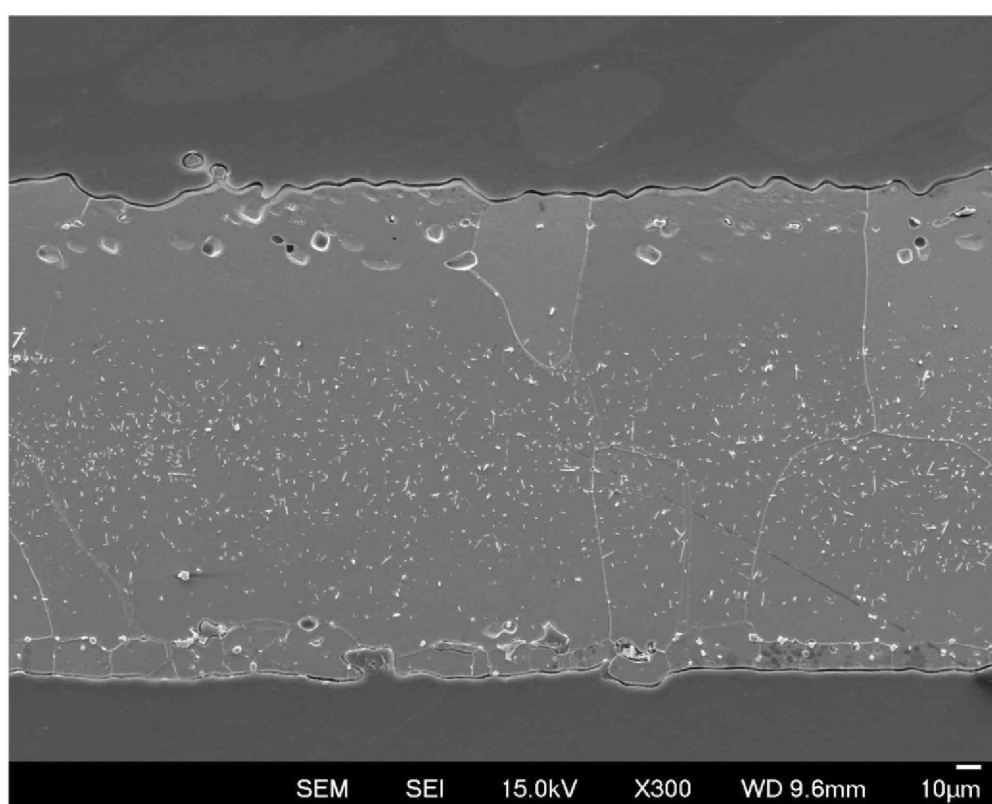


FIG. 2

Electron Image 1

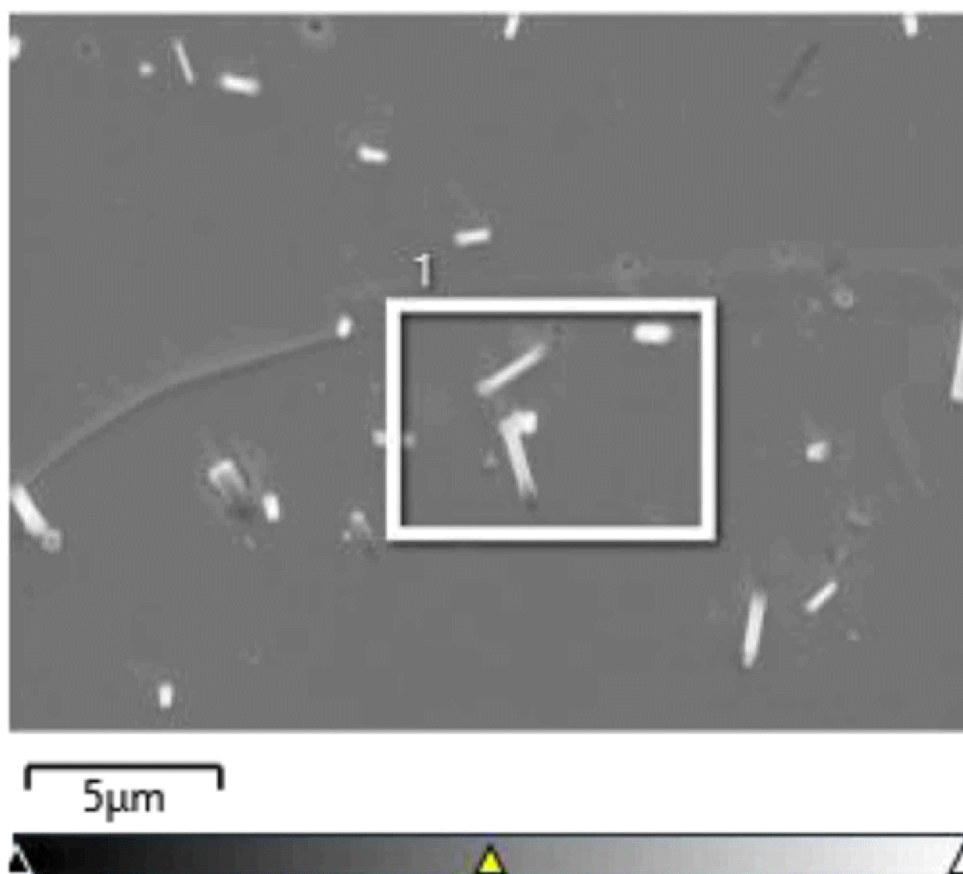


FIG. 3
Al K series

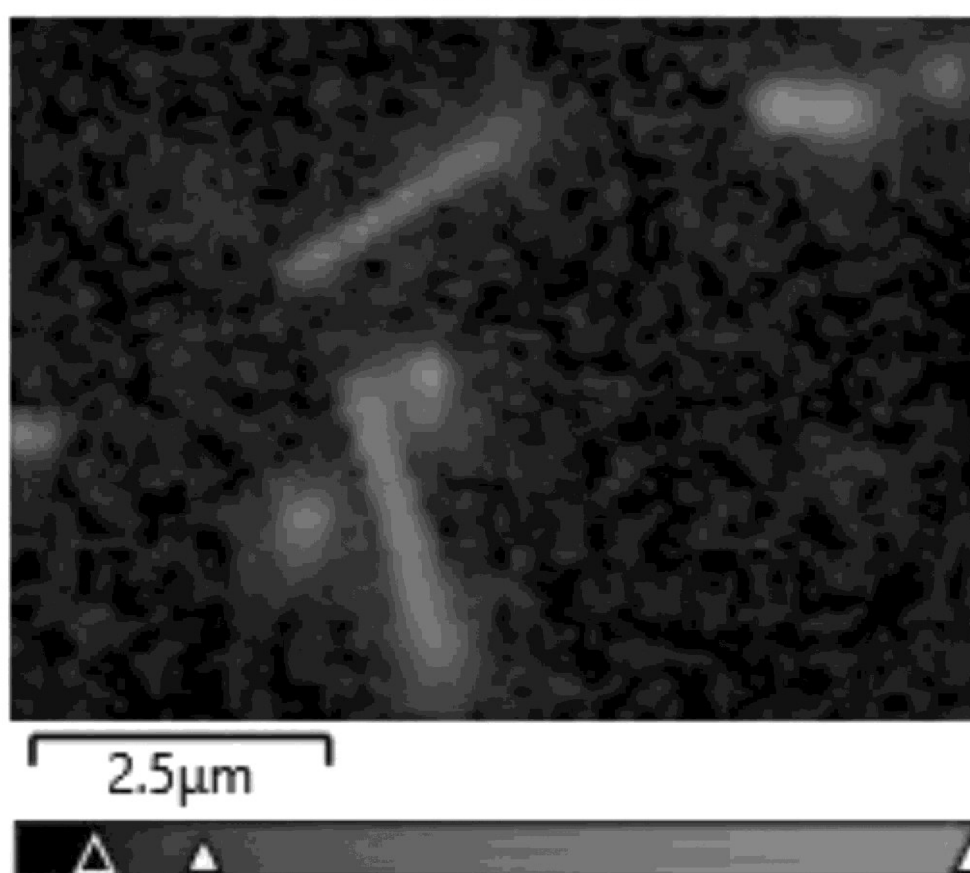
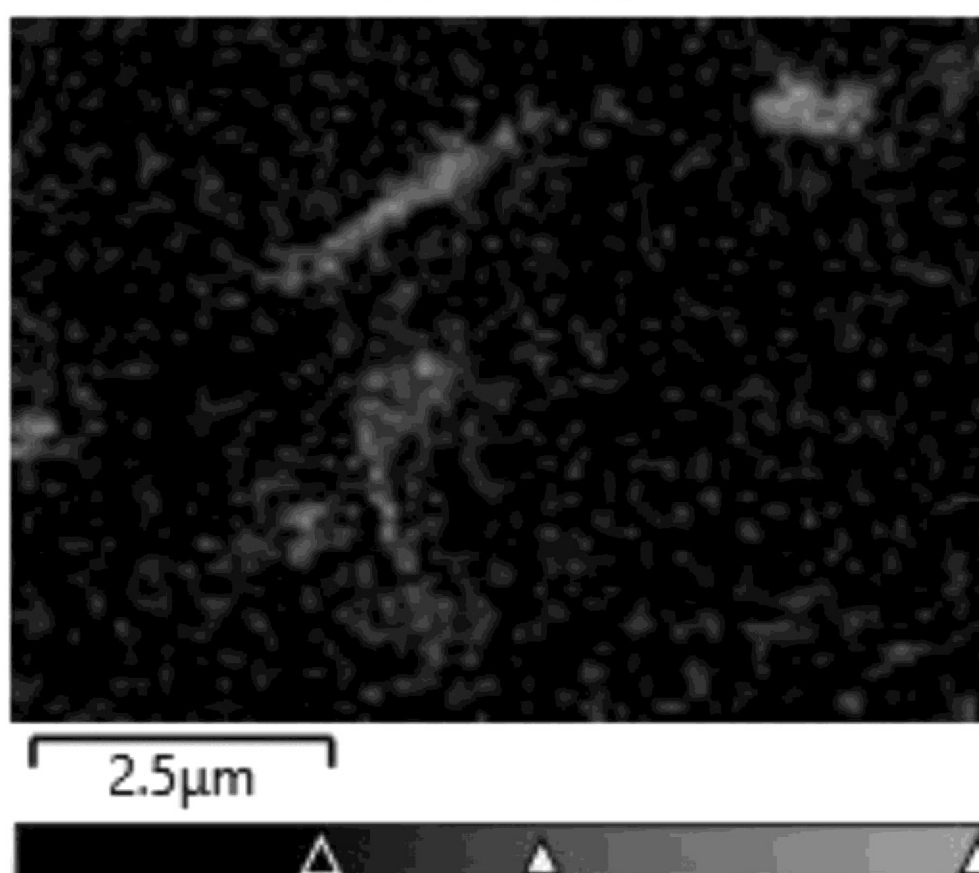


FIG. 4

N K series



INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063298

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/04**(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/58**(2006.01)i;
C22C 38/12(2006.01)i; **C21D 8/12**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02(2006.01); C21D 8/12(2006.01); C22C 38/00(2006.01); C22C 38/06(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), 분위기(atmosphere), 질화알루미늄(AIN)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2019-178372 A (NIPPON STEEL CORP.) 17 October 2019 (2019-10-17) See claims 1, 4 and 6.	1-19
A	KR 10-0711470 B1 (POSCO) 24 April 2007 (2007-04-24) See paragraphs [0011]-[0017], claims 1 and 3 and table 2.	1-19
A	KR 10-1060913 B1 (POSCO) 30 August 2011 (2011-08-30) See claims 1-4.	1-19
A	KR 10-2021-0078166 A (POSCO) 28 June 2021 (2021-06-28) See claims 1, 4 and 9.	1-19
A	KR 10-2022-0004221 A (JFE STEEL CORPORATION) 11 January 2022 (2022-01-11) See claims 1 and 6.	1-19

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

☒ See patent family annex.

* Special categories of cited documents:

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 April 2025	08 April 2025
Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208	
Facsimile No. +82-42-481-8578	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/IB2024/063298

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KR 10-1060913 B1	30 August 2011	KR 10-2005-0062195 A	23 June 2005
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