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

(57) A non-oriented electrical steel sheet according to one embodiment of the present disclosure, in a weight percent, includes Si: 2.0% to 5.0%, C: 0.005% or less (excluding 0%), and a remainder being Fe and unavoidable impurities, wherein a surface of a steel plate includes at least 95% of a total area of crystal

grains, wherein a ratio (D2/D1) of the diameter of the circumscribed circle (D1) to the diameter of the inscribed circle (D2) is 0.5 or greater, and a difference between a Si content at a depth of 20 μm from the surface of the steel sheet and the Si content at a depth of 100 μm is 1.0 weight% or more.

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**Description****[Technical Field]**

5 **[0001]** One embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, the disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same, which includes a plurality of cold rolling and a decarburization annealing process between the cold rolling, and improves a magnetism in a rolling direction by diffusing Si from the outside to the inside. **(b)**

**[Background Art]**

**[0002]** A non-grain oriented electrical steel sheet is used as a material for an iron core in rotating equipment such as motors and generators, and stationary devices such as small transformers, and plays an important role in determining an energy efficiency of electrical devices

15 **[0003]** Recently, the use of high-efficiency motors has increased significantly due to stricter motor efficiency regulations. To improve the efficiency of such motors, iron losses or copper losses must be reduced. These iron and copper losses are significantly affected by the magnetic properties of the electrical steel sheets used as the motor core material. Therefore, motor manufacturers are trending toward using low-iron-loss electrical steel sheets instead of conventional high-iron-loss electrical steel sheets. To reduce the copper loss, methods such as lowering a design magnetic flux density compared to an existing one or lowering an excitation current at a design magnetic flux are used, but to use the latter method, it is necessary to increase the magnetic flux density of the electrical steel sheet. In particular, the electrical steel sheets with high magnetic flux density have the advantage of being able to increase a torque, so motors that are frequently switched on and off have the advantage of being able to produce a large output in a short time. To manufacture the electrical steel sheets with high magnetic flux density, the Si content must be lowered; however, there is a problem of high iron loss due to the low content of Si, an element that increases a resistivity. Therefore, it is necessary to develop the electrical steel sheets with characteristics of the low iron loss and the high magnetic flux density. In terms of the structural aspects of the motor, the torque in a radial motor typically occurs in proportion to the product of the square of the rotor diameter and the length of the cylindrical stator. Therefore, in order to increase the torque, the length of the motor's cylindrical stator is increased, which leads to the problem of the overall motor volume increasing. Meanwhile, unlike a conventional radial motor structure, a stator and a rotor of an axial flux motor are arranged parallel to each other in an axial direction, so that a magnetic force is transmitted axially through the stator to the rotor to generate the torque, and the magnitude of the torque is proportional to the cube of the diameter of the cylindrical rotor. In other words, it may be described as a structure capable of generating high torque even in a small space. Since the magnetic force generated by the current applied to the stator is transmitted to the rotor magnet in the axial direction, the application of the magnetic material with particularly excellent magnetic properties in one direction is required. The conventional oriented electrical steel is a soft magnetic material with excellent magnetic properties in the rolling direction, composed of grains having the so-called Goss orientation, which is  $\{110\}<001>$  of an orientation of the steel sheet. These oriented electrical steel sheets are manufactured by heating the slab, then rolling to a final thickness through hot rolling, hot-rolled sheet annealing, and cold rolling, followed by primary recrystallization annealing and high-temperature annealing for secondary recrystallization formation. Because MgO is coated on the surface after a decarburization annealing and a metal oxide layer (also called a base coating layer) with  $\text{Mg}_2\text{SiO}_4$  as the main component is formed during high-temperature annealing, unlike a non-oriented electrical steel sheets used in conventional motor cores, the problem of the mold being damaged during a stamping process occurs due to the metal oxide layer on the surface. In addition, the conventional oriented electrical steel has a high fraction of Goss grains, so while it exhibits excellent unidirectional characteristics when applied to the axial flux motor, the strength of the magnetic field lines perpendicular to the rolling direction is weakened. Consequently, when used for the axial flux motor, there is a problem of a reduced motor efficiency.

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

50 **[0004]** One embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, the disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same, which includes a plurality of cold rolling and a decarburization annealing process between the cold rolling, and improves the magnetism in the rolling direction by diffusing Si from the inside to the outside.

**[Technical Solution]**

**[0005]** A non-oriented electrical steel sheet according to one embodiment of the present disclosure, in a weight percent, includes Si: 2.0% to 5.0%, C: 0.005% or less (excluding 0%), and a remainder being Fe and unavoidable impurities, wherein a surface of a steel plate includes at least 95% of a total area of crystal grains, wherein a ratio (D2/D1) of the diameter of the circumscribed circle (D1) to the diameter of the inscribed circle (D2) is 0.5 or greater, and a difference between a Si content at a depth of 20  $\mu\text{m}$  from the surface of the steel sheet and the Si content at a depth of 100  $\mu\text{m}$  is 1.0 weight% or more.

**[0006]** A ratio of crystal grains having a particle diameter of 30  $\mu\text{m}$  to 500  $\mu\text{m}$  may be 80 area% or more.

**[0007]** The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include Mn: 0.1 wt% or less and S: 0.005 wt% or less

**[0008]** A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present disclosure includes manufacturing a hot-rolled steel sheet by hot-rolling a slab including, in weight percent, Si: 0.3% to 2.5%, C: 0.05% to 0.4%, and a remainder being Fe and unavoidable impurities; performing a first cold rolling of the hot-rolled steel sheet; decarburizing and annealing the first cold-rolled steel sheet; secondary cold rolling the steel sheet after the decarburization annealing is completed; a cold-rolled sheet annealing of annealing the steel sheet after the second cold rolling is completed; forming a Si coating layer by coating a composition including a Fe-Si powder onto the annealed steel sheet; and a diffusion annealing of annealing the steel sheet with the Si coating layer formed thereon for 8 to 45 minutes.

**[0009]** The slab may further include Mn: 0.1 wt% or less and S: 0.005 wt% or less.

**[0010]** A hot rolled sheet annealing of the hot-rolled steel sheet may be further included, and the hot-rolled sheet annealing may include a decarburization process.

**[0011]** The hot-rolled sheet annealing may be performed by annealing at a temperature of 850°C to 1000°C and a dew point temperature of 70°C or lower.

**[0012]** The decarburization annealing may be performed by annealing at a temperature of 750°C to 1000°C and a dew point temperature of 25°C to 70°C.

**[0013]** The decarburization annealing may include a first decarburization annealing of annealing at a dew point temperature of 25°C to 70°C and a second decarburization annealing of annealing at a dew point temperature of -10°C to 20°C.

**[0014]** The decarburization annealing may be performed by annealing in an austenite single-phase region or in a region where a complex phase of ferrite and austenite exists.

**[0015]** A carbon content may be 0.005 weight% or less in the steel sheet after the decarburization annealing.

**[0016]** The decarburization annealing and the secondary cold rolling may be repeated two or more times.

**[0017]** The first cold rolling and the second cold rolling may be performed under a reduction rate of 50 to 70% each.

**[0018]** The cold-rolled sheet annealing may include a first cold-rolled sheet annealing at a temperature of 850°C to 1000°C and a dew point temperature of 70°C or lower, and a second cold-rolled sheet annealing at a temperature of 1000°C to 1200°C and an atmosphere of H<sub>2</sub> 50 volume% or more.

**[0019]** After the cold-rolled sheet annealing, the method may further include pickling using an aqueous acid solution of 5 to 50 weight% at a temperature of 50 to 100°C for 20 to 100 seconds.

**[0020]** The composition may further include MgO in forming the Si coating layer.

**[0021]** In forming the Si coating layer, the Fe-Si powder may include 20 to 80 weight% of Si.

**[0022]** In the diffusion annealing, a soaking temperature may be 1050 to 1200°C.

**[Advantageous Effects]**

**[0023]** The non-oriented electrical steel sheet according to one embodiment of the present disclosure has excellent magnetism in all directions and simultaneously excellent magnetism in the rolling direction, thereby making it particularly useful for axial flux motors.

**[0024]** In addition, since it may be manufactured through a continuous process, a manufacturing time may be relatively shortened and a productivity may be improved.

**[Mode for Invention]**

**[0025]** It will be understood that, although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Thus, a first element, component, region, layer, or section described below could be termed a second element, component, region, layer, or section without departing

from the teachings of the present disclosure.

**[0026]** The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and "comprising", when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups.

**[0027]** It will be understood that when an element such as a layer, film, region, or substrate is referred to as being "on" or "above" another element, it can be directly on or above the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements there.

**[0028]** If not defined differently, all the terminologies including the technical terminologies and scientific terminologies used herein have meanings that are the same as ones that those skilled in the art generally understand. The terms defined in dictionaries should be construed as having meanings corresponding to the related prior art documents and those stated herein, and are not to be construed as being ideal or official, if not so defined.

**[0029]** Unless particularly mentioned, % refers to wt%, and 1 ppm is 0.0001 wt%.

**[0030]** In an exemplary embodiment of the present disclosure, a further inclusion of an additional element means that an additional amount of the additional element is included in place of iron (Fe), which is a balance.

**[0031]** Hereinafter, exemplary embodiments of the present disclosure will be described in detail so as to be easily practiced by a person skilled in the art to which the present disclosure pertains. 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.

**[0032]** A method for manufacturing a non-oriented electrical steel sheet according to one embodiment of the present disclosure includes a step of: hot rolling a slab including, in weight percent, Si: 0.3% to 2.5%, C: 0.05% to 0.4%, and the remainder being Fe and unavoidable impurities to produce a hot-rolled steel sheet; a step of first cold rolling the hot-rolled steel sheet; a step of decarburizing and annealing the steel sheet that was first cold rolled; a step of second cold rolling the steel sheet after the decarburizing and annealing is completed; a cold-rolled sheet annealing step of annealing the steel sheet after the second cold rolling is completed; a step of forming a Si coating layer by coating a composition including Fe-Si powder onto the steel sheet after the annealing is completed; and a diffusion annealing step of annealing the steel sheet with the Si coating layer formed thereon for 8 to 45 minutes.

**[0033]** Below, each step is explained in detail.

**[0034]** First, the slab is hot-rolled.

**[0035]** The slab may include, in weight percent, Si: 0.3% to 2.5%, C: 0.05% to 0.4%, and the remainder being Fe and unavoidable impurities.

**[0036]** The reason for limiting the composition is as follows. The reason for limiting the composition is as follows.

**[0037]** Si improves an iron loss by lowering a magnetic anisotropy of the electrical steel sheet and increasing a resistivity. If the Si content is too low, the iron loss is inferior, and if it is too high, a brittleness increases. Accordingly, the Si content in the non-oriented electrical steel sheet after the annealing step of the slab and cold-rolled sheet may be 0.3% to 2.5% by weight. More specifically, the Si content may be 0.5 to 2.0 weight%. More specifically, the Si content may be 1.0 to 1.8 weight%.

**[0038]** The carbon (C) content in the slab may be 0.1 to 0.4 weight% because, during the decarburization annealing, a process is required for the C in the center to escape to the surface layer so that the Goss grains in the surface layer diffuse to the center. More specifically, the content of C in the slab may be 0.15 to 0.3 weight%. In addition, the carbon content in the final non-oriented electrical steel sheet manufactured after the decarburization is completed may be 0.0050 weight% or less. More specifically, it may be 0.003 weight% or less.

**[0039]** The slab may further include Mn: 0.1 wt% or less and S: 0.005 wt% or less.

**[0040]** Mn and S form MnS precipitates, hindering the growth of Goss grains that diffuse into the center during the decarburization process. Therefore, it is preferable not to add Mn and S. However, considering the amount inevitably incorporated during the steelmaking process, Mn and S in the non-oriented electrical steel sheet after the slab and final annealing step may be controlled to Mn: 0.1 wt% or less and S: 0.005 wt% or less, respectively.

**[0041]** The remainder includes Fe and unavoidable impurities. As for unavoidable impurities, they are those introduced during the steelmaking stage and the manufacturing process of the non-oriented electrical steel sheet; since this is widely known in the field, a detailed explanation is omitted. Specifically, since components such as Al, N, Ti, Mg, and Ca react with oxygen in the steel to form oxides, it is necessary to strongly inhibit them, so each component may be managed to be 0.005 weight% or less. In one embodiment of the present disclosure, the addition of elements other than the aforementioned alloy components is not excluded and may be included in various ways within a range that does not impair the technical concept of the present disclosure. If additional elements are included, the remainder Fe is replaced.

**[0042]** The slab may be heated before the hot rolling. The slab heating temperature may be 1050°C to 1350°C, which is higher than a normal heating temperature. When the temperature is high during the slab reheating, there is a problem in that the hot-rolled structure becomes coarse, which has an adverse effect on the magnetism. However, the method for manufacturing the non-oriented electrical steel sheet according to one embodiment of the present disclosure has a higher carbon content than a conventional method, so the hot-rolled structure does not become coarse even if the slab reheating temperature is high, and it is advantageous during the hot rolling by reheating at a higher temperature than in the usual case. However, if the reheating temperature is too high, the solubility of precipitates such as TiN and AlN increases, and as a large number of fine precipitates are distributed during the cooling, they hinder the growth of crystal grains on the surface.

**[0043]** The hot rolling may be used to produce the hot-rolled plate with the thickness of 1.5 to 4.0 mm by applying an appropriate rolling reduction rate at the final cold rolling step so that the final product thickness may be produced.

**[0044]** The hot rolling temperature or cooling temperature is not specifically limited, but as an example of excellent magnetic properties, the hot rolling end temperature may be set to 950°C or lower, and the cooling may be rapid with water and coiled at 600°C or lower.

**[0045]** After the hot rolling, the process may further include a step of annealing the hot-rolled steel sheet. At this time, the annealing of the hot-rolled sheet may include a decarburization process. Specifically, the hot-rolled sheet may be annealed at a temperature of 850°C to 1000°C and a dew point temperature of 70°C or lower. More specifically, it may be annealed at a dew point temperature of -70°C to 70°C. After the aforementioned annealing, an additional annealing may be performed at a temperature of 1000 to 1200°C and a dew point temperature of 0°C or lower. After performing the annealing on the hot-rolled sheet, it may be pickled.

**[0046]** Next, a cold-rolled steel sheet is manufactured by performing the first cold rolling.

**[0047]** It is known that in the manufacturing process of a common oriented electrical steel sheet, the cold rolling is effective when performed once at a high rolling rate of nearly 90%. This is because only the Goss grains among the primary recrystallized grains create an environment favorable for a grain growth. However, since the method for manufacturing a non-oriented electrical steel sheet according to one embodiment of the present disclosure does not utilize an abnormal grain growth of Goss orientation grains and instead diffuses the Goss grains inwardly from the surface layer generated by the decarburization annealing and cold rolling, it is advantageous to form a large number of Goss orientation grains distributed in the surface layer.

**[0048]** Therefore, when the cold rolling is performed at a reduction rate of 50% to 70%, a large number of Goss textures may be formed in the surface layer. More specifically, it may be 55% to 65%.

**[0049]** Next, the first cold-rolled steel sheet is decarburized and annealed. At this time, the decarburization annealing step may be performed in an austenite single-phase region or in a region where a complex phase of ferrite and austenite exists. Specifically, the annealing may be performed at a temperature of 750°C to 1000°C and a dew point temperature of 25°C to 70°C. In addition, the atmosphere may be a mixed gas atmosphere of hydrogen and nitrogen. In addition, after the decarburization annealing, the carbon content in the steel sheet may be 0.003 weight% or less.

**[0050]** During this decarburization annealing process, the grain size on the surface of the electrical steel sheet grows coarse, but the grains inside the electrical steel sheet remain as a fine structure. After such decarburization annealing, the average diameter of the crystal grains may be 150μm to 250μm. In this case, the grains are surface ferrite grains. In addition, the diameter of the crystal grain refers to a diameter of a hypothetical circle that has the same area as the crystal grain. The reference plane is a plane parallel to the rolling vertical plane (TD plane).

**[0051]** The decarburization annealing may include a first decarburization annealing of annealing at a dew point temperature of 25°C to 70°C and a second decarburization annealing of annealing at a dew point temperature of -10°C to 20°C.

**[0052]** Next, the steel sheet with the completed decarburization annealing is subjected to the secondary cold rolling. Since the second cold rolling is the same as the first cold rolling, a detailed explanation is omitted.

**[0053]** Next, the steel sheet with the completed second cold rolling is annealed as a cold-rolled sheet.

**[0054]** In the method for manufacturing the non-oriented electrical steel sheet according to one embodiment of the present disclosure, the cold rolling followed by the continuous annealing of the cold-rolled sheet may be performed.

**[0055]** In a method for manufacturing an oriented electrical steel sheet according to one embodiment of the present disclosure, the final annealing may include a first cold-rolled sheet annealing step of annealing the cold-rolled sheet at a temperature of 850°C to 1000°C and a dew point temperature of 70°C or lower, and a second cold-rolled sheet annealing step of annealing the cold-rolled sheet at a temperature of 1000°C to 1200°C and an atmosphere of H<sub>2</sub> 50 volume% or more. In addition, the atmosphere of the second cold-rolled sheet annealing stage may be H<sub>2</sub> 90 volume% or more and the dew point may be -25°C or lower.

**[0056]** Before annealing the cold-rolled sheet, the decarburization annealing is performed, and the carbon content of the steel remains at least 40% to 60% by weight relative to the carbon content of the slab. Therefore, during the first cold-rolled sheet annealing step at the final annealing step, as carbon is released, the crystal grains formed on the surface layer diffuse inward. In the first cold-rolled sheet annealing step, the decarburization may be performed so that

the carbon content in the steel sheet becomes 0.005 weight% or less.

[0057] Subsequently, in the second cold-rolled sheet annealing step, the texture having the Goss orientation diffused in the first cold-rolled sheet annealing step grows. In the method for manufacturing a non-oriented electrical steel sheet according to one embodiment of the present disclosure, unlike a case where crystal grains are grown by a conventional abnormal grain growth, the crystal grain diameter of the Goss texture may be within 1 mm. Therefore, compared to the conventional non-oriented electrical steel sheet, it may have the texture in which a large number of Goss grains with small grain sizes exist.

[0058] The steel plate manufactured in this way may include at least 95% of the total area of the crystal grains, wherein a ratio ( $D2/D1$ ) of the diameter of the circumscribed circle ( $D1$ ) to the diameter of the inscribed circle ( $D2$ ) is 0.5 or greater on the surface of the steel plate. The crystal structure of the steel sheet will be explained in detail in relation to the non-oriented electrical steel sheet described later.

[0059] Next, the process may further include a step of pickling the steel sheet after the cold-rolled annealing is completed. The oxide layer that is naturally formed on the surface of the steel plate is removed through the pickling process. By removing the oxide layer, the diffusion of Si may be facilitated more smoothly.

[0060] The pickling step may use an aqueous acid solution of 5 to 50 weight%. In this case, the aqueous acid solution may be an aqueous solution including an inorganic acid such as hydrochloric acid, nitric acid, or sulfuric acid. If the concentration of the acid solution is too low, a proper acid washing may not be achieved. In addition, if the concentration of the acid solution is too high, the surface roughness of the steel plate becomes too high, which may adversely affect magnetism.

[0061] The pickling step can be performed at a temperature of 50 to 100°C. If the temperature is too low, a problem may arise where the pickling is not performed properly. If the temperature is too high, the problem of reoxidation may occur.

[0062] The pickling step may be performed for 20 to 100 seconds. If the time is too short, the removal of the oxide layer may not be sufficient. If the time is too long, the magnetic properties may actually deteriorate due to the nonuniformity of the pickling ability between the grain interiors and the grain sizes. More specifically, the pickling step may be performed for 25 to 50 seconds.

[0063] Next, a composition including the Fe-Si powder is coated onto the cold-rolled steel sheet that the annealing has completed to form a Si coating layer.

[0064] The composition including the Fe-Si powder may be in a form of a slurry including a solvent for an easy dispersion and surface coating of the Fe-Si powder. The solvent is not specifically limited, but it may include water or alcohol.

[0065] The Fe-Si powder includes alloy components including Fe and Si, wherein Si may be included in an amount of 20 to 80 weight%. The Fe-Si powder may be manufactured by mixing a Fe powder and a Si powder, mixing them well with a rolling mixer, placing a certain amount into a crucible, and then firing at a high temperature in a kiln where an atmosphere gas may be controlled.

[0066] The composition may further include MgO in addition to the Fe-Si powder. MgO not only acts as an annealing separator to prevent a sheet sticking caused by high temperatures during the Si diffusion within the steel sheet, but also serves as a binder to ensure that the Fe-Si powder adheres well to the steel sheet. When adding MgO, 60 to 200 parts by weight may be added per 100 parts by weight of Fe-Si.

[0067] As previously mentioned, in one embodiment of the present disclosure, the cold-rolled sheet annealing process may be operated as a continuous annealing process, and the steps of the first cold rolling and the Si diffusion annealing may be performed continuously.

[0068] Next, the steel plate with the Si coating layer formed thereon is subjected to a diffusion annealing for 8 to 45 minutes. At this time, the annealing process may be performed at a temperature of 1050 to 1200°C. The annealing time may be 8 to 45 minutes. If the annealing temperature is too low or the annealing time is too short, smooth Si diffusion may not occur. Conversely, if the annealing time is too long, a Si concentration gradient may not be properly formed in the direction of the steel sheet thickness. If the appropriate Si concentration gradient is not present, as the overall Si content of the steel sheet increases, the content of Fe, a magnetic material, decreases, causing the saturation magnetic flux density to drop. As a result, this causes the magnetic flux density to decrease even when a magnetic field strength of 5000 A/m is applied, and it may also cause the iron loss in the steel sheet to increase as the magnetic field strength increases to obtain a constant magnetization value, even when measuring the iron loss at a specific magnetization value. More specifically, the diffusion annealing time may be 10 to 30 minutes.

[0069] The non-oriented electrical steel sheet according to one embodiment of the present disclosure includes, in a weight percent, Si: 2.0% to 8.0%, C: 0.005% or less (not including 0%), and the remainder being Fe and unavoidable impurities, and includes at least 95% of the total area of the crystal grains in which the ratio ( $D2/D1$ ) of the diameter of the circumscribed circle ( $D1$ ) to the diameter of the inscribed circle ( $D2$ ) with respect to the surface of the steel sheet is 0.5 or more, and the difference between the Si content at the depth of 20  $\mu\text{m}$  from the surface of the steel sheet and the Si content at the depth of 100  $\mu\text{m}$  is at least 1.0 weight percent.

**[0070]** As the alloy composition has been explained in the aforementioned method for manufacturing the non-oriented electrical steel sheets, the redundant explanation is omitted. In one embodiment of the present disclosure, the process of diffusing Si from the outside of the steel plate is included, so that the Si content of the finally manufactured steel plate is higher than the content of the slab. As described below, the non-oriented electrical steel sheet according to one embodiment of the present disclosure has the Si concentration gradient depend on the thickness of the steel sheet, and unless specifically indicated, the Si content refers to the average Si content over the entire thickness of the steel sheet.

**[0071]** The surface of the steel plate includes at least 95% of the total area of crystal grains, wherein the ratio ( $D2/D1$ ) of the diameter of the circumscribed circle ( $D1$ ) to the diameter of the inscribed circle ( $D2$ ) is 0.5 or greater. Here, the circumscribed circle refers to the smallest imaginary circle surrounding the outside of the crystal grain, and the inscribed circle refers to the largest imaginary circle contained within the inside of the crystal grain.

**[0072]** In the texture of the non-oriented electrical steel sheet according to one embodiment of the present disclosure, the crystal grains on the surface grow into the interior of the steel sheet, thereby creating the round-shaped crystal grains. As such, due to the texture shape according to one embodiment of the present disclosure, the superior magnetism may be obtained.

**[0073]** In one embodiment of the present disclosure, and the area where the particle size of the crystal grains of the substrate may be  $30\mu\text{m}$  to  $500\mu\text{m}$  may be 80% or more on the total crystal grains. As such, the texture according to one embodiment of the present disclosure exists in a long form in the thickness direction compared to a conventional non-oriented electrical steel sheet, so that Si can diffuse smoothly even during short-term diffusion annealing. As a result, the iron loss of the non-oriented electrical steel sheet is further improved.

**[0074]** In addition, in one embodiment of the present disclosure, the magnetism may be further enhanced through the Si concentration gradient between the surface and the interior. Specifically, the difference ( $\text{Si}_{20\mu\text{m}} - \text{Si}_{100\mu\text{m}}$ ) between the Si content ( $\text{Si}_{20\mu\text{m}}$ ) at the depth of  $20\mu\text{m}$  from the surface of the steel plate and the Si content ( $\text{Si}_{100\mu\text{m}}$ ) at the depth of  $100\mu\text{m}$  is 1.00 wt% or more. More specifically, it may be 1.10 to 2.50%.

**[0075]** The Si content ( $\text{Si}_{20\mu\text{m}}$ ) at the depth of  $20\mu\text{m}$  from the surface of the steel plate may be 3.00 to 5.70 wt%, and the Si content ( $\text{Si}_{100\mu\text{m}}$ ) at the depth of  $100\mu\text{m}$  may be 2.20 to 3.50 wt%.

**[0076]** In one embodiment of the present disclosure, the non-oriented electrical steel sheet has excellent magnetism. Specifically, the average magnetic flux density ( $B_{50}$ ) in the rolling direction and the rolling vertical direction may be 1.90T or more. In addition, the average iron loss ( $W_{10/400}$ ) in the rolling direction and the rolling vertical direction may be 10.0 W/kg or less. More specifically, the magnetic flux density ( $B_{50}$ ) in the rolling direction may be 1.95 to 2.05 T. The iron loss ( $W_{10/400}$ ) in the rolling direction may be 6.5 to 9.9 W/kg.

**[0077]** The magnetic flux density ( $B_{50}$ ) refers to the magnetic flux density induced in a magnetic field of 5000 A/m. The iron loss ( $W_{15/50}$ ) is the magnitude (W/kg) of the iron loss induced under conditions of 1.0 Tesla and 400 Hz.

**[0078]** Specific examples of the present disclosure are described below. However, the following examples are merely specific embodiments of the present disclosure, and the present disclosure is not limited to the following examples.

### Example 1

#### Example 1

**[0079]** A slab including Si:1.4% and C:0.09% by weight, with the remainder being Fe and unavoidable impurities, was heated at a temperature of  $1250^{\circ}\text{C}$  and then hot-rolled to a thickness of 1.6 mm, followed by a hot-rolled sheet annealing at an annealing temperature of  $900^{\circ}\text{C}$ , cooled, pickled, and then first cold-rolled with a reduction rate of 60% (0.6 mm).

**[0080]** The cold-rolled plate was subjected to a first decarburization annealing for 120 seconds at an annealing temperature of  $870^{\circ}\text{C}$  and a dew point temperature of  $60^{\circ}\text{C}$ , followed by a second decarburization annealing in a hydrogen atmosphere with a dew point temperature of  $0^{\circ}\text{C}$ , and after cooled, and then second cold-rolled with a reduction rate of 60% (0.25 mm).

**[0081]** Subsequently, during the annealing of the cold-rolled sheet, a decarburization annealing was performed for 60 seconds at a temperature of  $900^{\circ}\text{C}$  in a humid (a dew point temperature  $60^{\circ}\text{C}$ ) mixed gas atmosphere of hydrogen and nitrogen, followed by a heat treatment for 3 minutes in a 100%  $\text{H}_2$  atmosphere at  $1050^{\circ}\text{C}$ .

**[0082]** After annealing the cold-rolled sheet, it underwent a pickling process for 20 seconds using an aqueous solution of 25 wt% HCl at  $80^{\circ}\text{C}$ . After the pickling process was completed, a Fe-Si powder with a 40.5% Si content was mixed with a calcined MgO powder and ethyl alcohol and coated to the steel plate, and then annealed at  $1100^{\circ}\text{C}$  for the time specified in Table 2 below to determine the magnetic flux density and the iron loss, which are shown in Table 1.

**[0083]** The Si content by each thickness was measured using GDS.

**[0084]** The magnetic flux density (B50) and the iron loss (W10/400) were measured using a single sheet test (SST) method, and the averages were measured in the rolling direction and the rolling vertical direction and shown in Table 1.

(Table 1)

| Heat treatment time (minutes) | Si content (wt%) |              | Ratio (D2/D1) of crystal grains of 0.5 or more (area%) | B 50 (Tesla) | W 10/400 (W/Kg) |                      |
|-------------------------------|------------------|--------------|--------------------------------------------------------|--------------|-----------------|----------------------|
|                               | Surface 30um     | Center 100um |                                                        |              |                 |                      |
| 0                             | 2.03             | 2.03         | 96                                                     | 2.05         | 11.0            | Comparative material |
| 5                             | 2.43             | 2.10         | 96                                                     | 2.03         | 10.7            | Comparative material |
| 10                            | 3.43             | 2.22         | 96                                                     | 2.02         | 9.7             | Inventive material   |
| 15                            | 4.22             | 2.56         | 96                                                     | 2.01         | 9.1             | Inventive material   |
| 20                            | 4.65             | 2.66         | 96                                                     | 1.99         | 8.4             | Inventive material   |
| 25                            | 5.15             | 2.78         | 96                                                     | 1.97         | 7.5             | Inventive material   |
| 30                            | 5.66             | 3.13         | 96                                                     | 1.96         | 6.9             | Inventive material   |
| 60                            | 5.78             | 4.87         | 96                                                     | 1.88         | 7.8             | Comparative material |
| 120                           | 6.15             | 5.78         | 96                                                     | 1.85         | 8.2             | Comparative material |

**[0085]** As shown in Table 1, it may be confirmed that the iron loss is improved through the Si diffusion. However, it may be confirmed that as the diffusion time increases, the Si concentration gradient for each thickness decreases, which leads to a result where the magnetic flux density and iron loss actually become inferior.

**[0086]** The exemplary embodiments and modified examples of the present invention have been described and shown with reference to the accompanying drawings, but the present invention is not limited to the exemplary embodiments and may be manufactured in various forms. As described above, it will be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the general inventive concept, the scope of which is defined in the appended claims and their equivalents. Therefore, it should be understood that the exemplary embodiments described above are not limitative but are exemplary in all the aspects.

## Claims

1. A non-oriented electrical steel sheet, in a weight percent, including Si: 2.0% to 5.0%, C: 0.005% or less (excluding 0%), and a remainder being Fe and unavoidable impurities,

wherein a surface of a steel plate includes at least 95% of a total area of crystal grains, wherein a ratio (D2/D1) of the diameter of the circumscribed circle (D1) to the diameter of the inscribed circle (D2) is 0.5 or greater, and

a difference between a Si content at a depth of 20  $\mu\text{m}$  from the surface of the steel sheet and the Si content at a depth of 100  $\mu\text{m}$  is 1.0 weight% or more.

2. The method for manufacturing the non-oriented electrical steel sheet of claim 1, wherein: a ratio of crystal grains having a particle diameter of 30 $\mu\text{m}$  to 500 $\mu\text{m}$  is 80 area% or more.

3. The method for manufacturing the non-oriented electrical steel sheet of claim 2, further comprising Mn: 0.1 wt% or less and S: 0.005 wt% or less.

4. A method for manufacturing a non-oriented electrical steel sheet comprising

manufacturing a hot-rolled steel sheet by hot-rolling a slab including, in weight percent, Si: 0.3% to 2.5%, C: 0.05% to 0.4%, and a remainder being Fe and unavoidable impurities;  
performing a first cold rolling of the hot-rolled steel sheet;  
decarburizing and annealing the first cold-rolled steel sheet;

secondary cold rolling the steel sheet after the decarburization annealing is completed;  
a cold-rolled sheet annealing of annealing the steel sheet after the second cold rolling is completed;  
forming a Si coating layer by coating a composition including a Fe-Si powder onto the annealed steel sheet;  
and  
a diffusion annealing of annealing the steel sheet with the Si coating layer formed thereon for 8 to 45 minutes.

5        5. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the slab further includes Mn: 0.1 wt% or less and S: 0.005 wt% or less.

10      6. The method for manufacturing the non-oriented electrical steel sheet of claim 4, further comprising:  
  
a hot-rolled sheet annealing of the hot-rolled steel sheet, and  
the hot-rolled sheet annealing includes a decarburization process.

15      7. The method for manufacturing the non-oriented electrical steel sheet of claim 6, wherein:  
the hot-rolled sheet annealing is performed by annealing at a temperature of 850°C to 1000°C and a dew point  
temperature of 70°C or lower.

20      8. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the decarburization annealing is performed by annealing at a temperature of 750°C to 1000°C and a dew point  
temperature of 25°C to 70°C.

25      9. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the decarburization annealing is performed by annealing in an austenite single-phase region or in a region where  
a complex phase of ferrite and austenite exists.

30      10. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
a carbon content is 0.005 weight% or less in the steel sheet after the decarburization annealing.

35      11. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the decarburization annealing and the secondary cold rolling are repeated two or more times.

40      12. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the first cold rolling and the second cold rolling are performed under a reduction rate of 50 to 70% each.

45      13. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the cold-rolled sheet annealing includes a first cold-rolled sheet annealing at a temperature of 850°C to 1000°C  
and a dew point temperature of 70°C or lower, and a second cold-rolled sheet annealing at a temperature of  
1000°C to 1200°C and an atmosphere of H<sub>2</sub> 50 volume% or more.

50      14. The method for manufacturing the non-oriented electrical steel sheet of claim 4, further comprising:  
after the cold-rolled sheet annealing, pickling using an aqueous acid solution of 5 to 50 weight% at a temperature  
of 50 to 100°C for 20 to 100 seconds.

55      15. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
the composition further includes MgO in forming the Si coating layer.

60      16. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
in forming the Si coating layer, the Fe-Si powder includes 20 to 80 weight% of Si.

65      17. The method for manufacturing the non-oriented electrical steel sheet of claim 4, wherein:  
in the diffusion annealing, a soaking temperature is 1050 to 1200°C.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063296

## A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/00(2006.01)i; C22C 38/04(2006.01)i; C21D 8/12(2006.01)i; H01F 1/147(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 1/26(2006.01); C21D 8/12(2006.01); C21D 9/46(2006.01); C22C 33/04(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) &amp; keywords: 무방향(non-oriented), 전기강판(electrical steel sheet), 탈탄(decarbonizing), 코팅(coating), 냉간압연(cold rolling)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                              | Relevant to claim No. |
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☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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"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

"&amp;" document member of the same patent family

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**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.

**PCT/IB2024/063296**

| Patent document<br>cited in search report | Publication date<br>(day/month/year)                            | Patent family member(s) | Publication date<br>(day/month/year)   |
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