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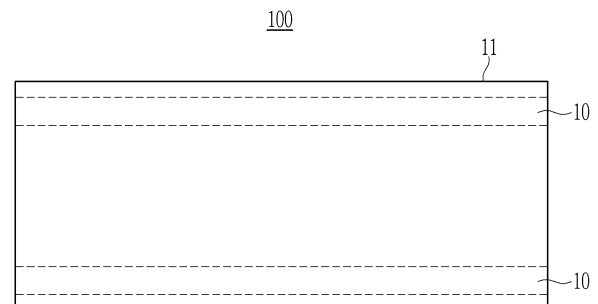
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) A non-oriented electrical steel sheet according to an embodiment of the present invention includes Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, Sn: 0.001 to 0.08%, Sb: 0.001 to 0.08%, and B: 0.0002 to 0.0007% by weight, and including the balance being Fe and unavoidable impurities, wherein, when measuring an element content in a steel sheet thickness direction in a surface portion in a range of 0.3 to 1 μm from a steel sheet surface toward the inside, a weight ratio of an Al content to Si at a point where the Al content is maximum is 25 or less, and when the steel sheet before and after stress relief annealing is measured through EBSD, a difference in maximum intensity of $\langle 111 \rangle$ is 3 or less.

FIG. 1



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Description**[Technical Field]**

5 **[0001]** An embodiment of the present invention relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present invention relates to a non-oriented electrical steel sheet and a method for manufacturing the same, in which segregation of B, Sn, and Sb is utilized and conditions in a cold-rolled sheet annealing process are controlled to densely enrich Al and Si in a surface region, thereby reducing a difference in maximum intensity of a <111>//ND texture before and after stress-relief annealing (SRA), and simultaneously improving mechanical strength and magnetic properties.

[Background Art]

15 **[0002]** A non-oriented electrical steel sheet is primarily used in a motor that converts electrical energy into mechanical energy, and an excellent magnetic property of the non-oriented electrical steel sheet is required in order to achieve high efficiency during such energy conversion. In particular, as an environmentally friendly vehicle driven by an electric motor rather than an internal combustion engine has recently attracted increasing attention, demand for a non-oriented electrical steel sheet used as a core material for a driving motor has increased. Accordingly, there is a growing need for the non-oriented electrical steel sheet having both excellent magnetic property and high strength.

20 **[0003]** A motor core may be divided into a stator core and a rotor core, and in order to satisfy demands for downsizing and increased output of an HEV drive motor and the like, a non-oriented electrical steel sheet used for the stator core is strongly required to exhibit excellent magnetic properties, including high magnetic flux density and low iron loss.

25 **[0004]** In addition, as a means for achieving downsizing and increased output of the HEV drive motor and the like, the rotational speed of the motor tends to increase. However, because an HEV drive motor generally has a large outer diameter, a substantial centrifugal force acts on the rotor core, and, depending on a motor structure, there may be an extremely narrow portion referred to as a rotor core bridge portion. Accordingly, a non-oriented electrical steel sheet used for the rotor core is also required to possess high mechanical strength.

30 **[0005]** Therefore, with respect to characteristics required for a non-oriented electrical steel sheet used in the motor core, high strength in addition to excellent magnetic properties is required for rotor-core applications, whereas high magnetic flux density and low iron loss are required for stator-core applications. As described above, even when the same non-oriented electrical steel sheet is used in a motor core, the properties required for the rotor core and the stator core differ significantly. Nevertheless, from the standpoint of improving material yield and the like during manufacture of a motor core, it is desirable to simultaneously obtain a rotor-core material and a stator-core material from the same steel sheet material and thereafter stack the respective core materials to assemble a rotor core or a stator core.

[Disclosure]**[Technical Problem]**

40 **[0006]** An embodiment of the present invention provides a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, an embodiment of the present invention provides a non-oriented electrical steel sheet and a method for manufacturing the same, in which segregation of B, Sn, and Sb is utilized and conditions of a cold-rolled sheet annealing process are controlled to densely enrich Al and Si in a surface region, thereby reducing a difference in maximum intensity of a <111>//ND texture before and after stress-relief annealing (SRA), and simultaneously improving mechanical strength and magnetic properties.

[Technical Solution]

50 **[0007]** A non-oriented electrical steel sheet according to an embodiment of the present invention includes Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, Sn: 0.001 to 0.08%, Sb: 0.001 to 0.08%, and B: 0.0002 to 0.0007% by weight, and including the balance being Fe and unavoidable impurities, wherein, when measuring an element content in a steel sheet thickness direction in a surface portion in a range of 0.3 to 1 μm from a steel sheet surface toward the inside, a weight ratio of an Al content to Si at a point where the Al content is maximum is 25 or less.

55 **[0008]** When the steel sheet before and after stress relief annealing is measured through EBSD, a difference in maximum intensity of <111>//ND is 3 or less.

[0009] When measuring the element content in the steel sheet thickness direction in the surface portion, a maximum Al content may be 2.0 wt% or more.

[0010] When measuring the element content in the steel sheet thickness direction in the surface portion, the Si content at the point where the Al content is maximum may be 0.5 wt% or more.

[0011] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include S: 0.005 wt% or less (excluding 0%), and satisfying Formula 1 below:

[Formula 1]

$$0.7 \leq ([\text{Sn}] + [\text{Sb}] + [\text{S}] \times 10)/([\text{B}] \times 100) \leq 5.2$$

[0012] (In Formula 1, [Sn], [Sb], [S], and [B] represent contents (wt%) of Sn, Sb, S, and B, respectively.)

[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 (excluding 0%), C: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0014] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include one or two or more of Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 wt% individually or in total.

[0015] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include one or more of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

[0016] 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 (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0017] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention includes: manufacturing a hot-rolled steel sheet by hot-rolling a slab including Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, Sn: 0.001 to 0.08%, Sb: 0.001 to 0.08%, and B: 0.0002 to 0.0007% by weight, and including the balance being Fe and unavoidable impurities; manufacturing a cold-rolled sheet by cold-rolling the hot-rolled steel sheet; cold-rolled sheet annealing for annealing the cold-rolled sheet; and stress relief annealing the cold-rolled sheet annealed steel sheet.

[0018] When the steel sheet before and after the stress relief annealing is measured through EBSD, a difference in maximum intensity of <111>/ND is 3 or less.

[0019] The cold-rolled sheet annealing has a soaking temperature of 750 °C to 850 °C, a hydrogen fraction in an atmosphere of 10 to 35 vol%, and a dew point of the atmosphere of -55 to -15 °C.

[0020] The slab may further include S: 0.005 wt% or less (excluding 0%), and satisfies Formula 1 below:

[Formula 1]

$$0.7 \leq ([\text{Sn}] + [\text{Sb}] + [\text{S}] \times 10)/([\text{B}] \times 100) \leq 5.2$$

[0021] (In Formula 1, [Sn], [Sb], [S], and [B] represent contents (wt%) of Sn, Sb, S, and B, respectively.)

[0022] The slab may further include one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0023] The slab may further include one, or two or more of Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 wt% individually or in total.

[0024] The slab may further include one or more of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

[0025] The slab may further include one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0026] After the cold-rolled sheet annealing, stress removal annealing for annealing the annealed sheet at 750 to 850 °C may further be included.

[Advantageous Effects]

[0027] The non-oriented electrical steel sheet according to an embodiment of the present invention exhibits excellent mechanical strength after cold-rolled sheet annealing and excellent high-frequency iron loss characteristics after

stress relief annealing.

[0028] The non-oriented electrical steel sheet according to an embodiment of the present invention enables both a rotor core and a stator core to be manufactured from the same steel sheet, thereby providing a high material yield.

5 [Description of the Drawings]

[0029]

FIG. 1 schematically illustrates a cross-section of a steel sheet according to an embodiment of the present invention.

FIG. 2 is a schematic view of a graph showing Al concentration and Si concentration for each steel sheet thickness according to an embodiment of the present invention.

15 [Mode for Invention]

[0030] 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.

[0031] 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.

[0032] 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.

[0033] Unless otherwise specified, "%" refers to weight percent, and 1 ppm corresponds to 0.0001 weight percent.

[0034] 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.

[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] 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.

[0037] A non-oriented electrical steel sheet according to an embodiment of the present invention includes, by weight percent (wt%), Si: 1.5 to 5.0 %, Al: 0.1 to 2.0 %, Mn: 0.1 to 2.0 %, Sn: 0.001 to 0.08 %, Sb: 0.001 to 0.08 %, and B: 0.0002 to 0.0007 %, and includes the balance being Fe and inevitable impurities.

[0038] Hereinafter, the reasons for limiting the composition of the non-oriented electrical steel sheet will be described.

Si: 1.5 to 5.0 wt%

[0039] Silicon (Si) serves to increase the resistivity of a material, thereby reducing iron loss, and to increase strength through solid-solution strengthening. When the content of Si is excessively low, the effect of reducing iron loss and strength enhancement may be insufficient. When Si is added in an excessive amount, the brittleness of the material increases, which may cause strip breakage during coiling and cold rolling, thereby significantly reducing rolling productivity. Therefore, Si may be included in an amount of 1.5 to 5.0 wt%. More specifically, Si may be included in an amount of 2.0 to 4.5 wt%. More specifically, Si may be included in an amount of 3.0 to 4.0 wt%. More specifically, Si may be included in an amount of 3.0 to 3.8 wt%.

Al: 0.1 to 2.0 wt%

[0040] Aluminum (Al) serves to reduce iron loss and rolling property by reducing the resistivity of a material, and improves workability during cold rolling. When Al is added in an excessively small amount, it may be difficult to obtain an effect of reducing high-frequency iron loss, and a precipitation temperature of AlN may be lowered such that nitrides are finely formed, thereby deteriorating magnetic properties. When Al is added in an excessive amount, an excessive amount of nitrides may be formed, thereby deteriorating magnetic properties and causing problems throughout steelmaking and continuous casting processes, which may significantly reduce productivity. Accordingly, Al may be included in an amount of 0.1 wt% to 2.0 wt%. More specifically, Al may be included in an amount of 0.3 wt% to 1.9 wt%. More specifically, Al may be included in an amount of 0.3 wt% to 1.5 wt%.

Mn: 0.1 to 2.0 wt%

[0041] Manganese (Mn) serves to increase the electrical resistivity of the material, thereby improving iron loss, and also promotes the formation of a sulfide. When the Mn content is excessively low, a sulfide may be formed in an excessively fine form, resulting in deterioration of magnetic properties. On the other hand, when the Mn content is excessively high, a fine MnS precipitate may be excessively formed, and the formation of a {111} texture, which is unfavorable to magnetic properties, may be promoted, thereby causing a significant reduction in magnetic flux density. Accordingly, Mn may be included in an amount of 0.1 to 2.0 wt%. More specifically, Mn may be included in an amount of 0.2 to 1.6 wt%. More specifically, Mn may be included in an amount of 0.3 to 1.5 wt%.

Sn: 0.001 to 0.080 wt%

[0042] Tin (Sn) may segregate to a grain boundary and a surface to improve the texture of a material and suppress surface oxidation, and thus may be added to improve magnetic properties. When the added amount of Sn is excessively small, the effect may not be sufficient. When Sn is added too much, grain boundary segregation becomes severe, deteriorating surface quality, and hardness increases, which causes cold-rolled sheet breakage, potentially decreasing rollability. Therefore, Sn may be added within the aforementioned range. More specifically, it may be included in an amount of 0.01 to 0.08 wt%. More specifically, it may be included in an amount of 0.03 to 0.05 wt%.

Sb: 0.001 to 0.080 wt%

[0043] Antimony (Sb) segregates to a grain boundary and a surface to improve the texture of a material and suppress surface oxidation, and thus may be added to improve magnetic properties. When the added amount of Sb is too small, the effect may be insignificant. When Sb is added too much, grain boundary segregation becomes severe, deteriorating surface quality, and hardness increases, which causes cold-rolled sheet breakage, potentially decreasing rollability. Therefore, Sb may be added within the aforementioned range. More specifically, it may be included in an amount of 0.01 to 0.08 wt%. More specifically, it may be included in an amount of 0.03 to 0.05 wt%.

B: 0.0002 to 0.0007 wt%

[0044] Boron (B) is an element with a very strong tendency for segregation in steel, and may segregate even with a small amount to significantly affect the formation of an oxide layer on the surface. In the case of B, in particular, it may segregate on the surface by competing with segregation elements such as S, Sn, and Sb, and accordingly, the degree of formation of the oxide layer on the surface varies, allowing nitrides to be formed immediately below the surface layer. Therefore, the content of B may be included in an amount of 0.0002 to 0.0007 wt%. More specifically, it may be included in an amount of 0.0003 to 0.0006 wt%.

[0045] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include S: 0.005 wt% or less (excluding 0%), and satisfy Equation 1.

[Formula 1]

$$0.7 \leq ([\text{Sn}] + [\text{Sb}] + [\text{S}] \times 10)/([\text{B}] \times 100) \leq 5.2$$

[0046] (In Formula 1, [Sn], [Sb], [S], and [B] represent the contents (wt%) of Sn, Sb, S, and B, respectively.)

S: 0.0050 wt% or less

[0047] Sulfur (S) forms a fine sulfide inside a base material to suppress grain growth and weaken iron loss, and thus a lower content is preferable, and when the content is too high, it may combine with Mn or the like to suppress grain growth or increase the degree of deterioration of magnetic properties after processing. More specifically, S may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, it may be included in an amount of 0.0010 to 0.0035 wt%.

[0048] Meanwhile, among components of a non-oriented electrical steel sheet, Sn, Sb, S, and B, which are components capable of changing the behavior of an oxide layer by segregating on the surface, tend to compete with each other for segregation on the surface, and although S or Sn/Sb are unrelated because their existing methods in the steel lattice are different, B has a competitive relationship with S or Sn/Sb. Therefore, in order to reduce nitrides on the surface, it is necessary to satisfy Formula 1, which is a relationship between the contents of S, Sn, Sb, and B elements capable of controlling oxidation by segregating on the surface. More specifically, the value of Formula 1 may be 1.0 to 5.0.

[0049] 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 (excluding 0%), C: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

P: 0.1 wt% or less

[0050] Phosphorus (P) not only serves to increase the specific resistance of a material but also may improve magnetic flux density as a grain boundary segregation element. However, when P is added too much, the brittleness of the steel sheet increases, leading to poor weldability. More specifically, P may be included in an amount of 0.0001 to 0.0500 wt%. More specifically, P may be included in an amount of 0.0010 to 0.0200 wt%.

C: 0.005 wt% or less

[0051] Carbon (C) causes magnetic aging and combines with other impurity elements to generate carbides, which hinders grain boundary or magnetic domain wall movement, potentially deteriorating magnetic properties. More specifically, C may be included in an amount of 0.0001 to 0.003 wt%.

Ti: 0.005 wt% or less

[0052] Titanium (Ti) has a very strong tendency to form precipitates in steel, and may deteriorate iron loss by forming fine carbides, nitrides, or sulfides inside the base material to suppress grain growth and magnetic domain wall movement. More specifically, Ti may be included in an amount of 0.0001 to 0.0030 wt%.

N: 0.005 wt% or less

[0053] Nitrogen (N) not only forms fine AlN precipitates inside the base material but also forms fine precipitates by combining with other impurities to suppress grain growth and magnetic domain wall movement, potentially worsening iron loss. More specifically, N may be included in an amount of 0.0001 to 0.0030 wt%.

[0054] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include one, or two or more of Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 wt% individually or in total.

Bi, Pb, Ge, and As

[0055] When bismuth (Bi), lead (Pb), germanium (Ge), and arsenic (As) are additionally added, they segregate at grain boundaries to alleviate stress concentration at grain boundaries during cold rolling, thereby suppressing recrystallization of <111>//ND oriented grains in recrystallization annealing, which is a subsequent process, and thus improving magnetic flux density. When they are appropriately added, the aforementioned effects may be additionally obtained, but when they are included too much, a large amount of segregation occurs, suppressing grain growth, which may rather result in poor magnetic flux density and iron loss. More specifically, one, or two or more of Bi, Pb, Ge, and As may be further included in an amount of 0.010 to 0.150 wt% individually or in total.

[0056] The non-oriented electrical steel sheet according to an embodiment of the present invention may further include one or more of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

Cu: 0.005 to 0.200 wt%

[0057] Copper (Cu) serves to form sulfides together with Mn. When Cu is further added, when it is added too little, (Cu·Mn)S may finely precipitate, potentially deteriorating magnetic properties. When Cu is added too much, hot shortness occurs, which may form cracks during continuous casting or hot rolling. More specifically, Cu may be included in an amount of 0.01 to 0.10 wt%.

Cr: 0.01 to 0.50 wt%

[0058] Chromium (Cr) serves to improve iron loss by increasing the specific resistance. When Cr is added too little, the effect of increasing specific resistance may not be sufficient. When Cr is included too much, magnetic flux density may decrease. More specifically, Cr may be included in an amount of 0.050 to 0.20 wt%.

Ni: 0.05 wt% or less

[0059] Nickel (Ni) may adversely affect magnetic properties by reacting with impurity elements to form fine sulfides, carbides, and nitrides. More specifically, Ni may be included in an amount of 0.001 to 0.030 wt%.

Zn: 0.01 wt% or less

[0060] When the content of zinc (Zn) is excessive, it may act as an impurity and deteriorate magnetic properties. Therefore, Zn may be further added within the aforementioned range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

Co: 0.05 wt% or less

[0061] Cobalt (Co) does not form precipitates of fine size that decrease the magnetic properties of a steel sheet, but increases high-temperature strength, which may make the shape of a coil poor after hot rolling.

[0062] 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 (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.0050 wt% or less (excluding 0%), Te: 0.0100 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

Mo: 0.030 wt% or less

[0063] When molybdenum (Mo) is added in an excessive amount, the effect of improving the texture may decrease by suppressing the segregation of segregation elements. Therefore, Mo may be included in an amount of 0.03 wt% or less. The lower limit thereof is not particularly limited, but since it serves to improve the texture by segregating on the surface and grain boundaries, 0.001 wt% or more may be included. More specifically, Mo may be included in an amount of 0.001 to 0.010 wt%. More specifically, Mo may be included in an amount of 0.005 to 0.010 wt%..

V: 0.0050 wt% or less

[0064] Vanadium (V) has a very strong tendency to form precipitates in steel, and deteriorates iron loss by forming fine carbides or nitrides inside a base material to suppress grain growth and magnetic domain wall movement. Therefore, the V content may be 0.0050 wt% or less, respectively. The lower limit thereof is not particularly limited, but may be 0.0003 wt% due to steelmaking costs. That is, V may be included in an amount of 0.0003 to 0.0050 wt%. More specifically, V may be included in an amount of 0.0003 to 0.0030 wt%.

Ca: 0.0050 wt% or less

[0065] Calcium (Ca) has a very strong tendency to form precipitates in steel, and deteriorates iron loss by forming fine sulfides inside a base material to suppress grain growth and magnetic domain wall movement.

Nb: 0.0050 wt% or less

[0066] Niobium (Nb) has a very strong tendency to form precipitates in steel, and deteriorates iron loss by forming fine carbides or nitrides inside a base material to suppress grain growth and magnetic domain wall movement. There-

fore, the Nb content may be 0.0050 wt% or less. The lower limit thereof is not particularly limited, but may be 0.0003 wt% due to steelmaking costs. That is, Nb may be included in an amount of 0.0003 to 0.0050 wt%. More specifically, Nb may be included in an amount of 0.0003 to 0.0030 wt%.

5 Zr: 0.0050 wt% or less

[0067] When zirconium (Zr) is added in an excessive amount, it may cause deterioration of magnetic properties through the formation of inclusions in steel and the like. Therefore, Zr may be included in an amount of 0.005 wt% or less. The lower limit thereof is not particularly limited, but may be 0.0001 wt% due to steelmaking costs. That is, Zr may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, 0.0005 to 0.0030 wt% may be included.

Te: 0.0100 wt% or less

[0068] Tellurium (Te) diffuses into an oxide layer on the surface of a hot-rolled coil to increase the friction coefficient between the oxide layer and a rolling work roll, while being concentrated below the oxide layer to improve hardness, and thus may be added to cause the oxide layer crushed during rolling to fall off without being pressed into the base material. When the added amount of Te is too small, the effect may be insignificant. When Te is added too much, the oxide layer easily falls off and a base material comes into direct contact with a work roll, reducing the effect, and a deformation band is excessively generated in the steel sheet during cold rolling, potentially developing a {111}/ND texture unfavorable for magnetic properties. More specifically, 0.0001 to 0.007 wt% of tellurium may be included.

Mg: 0.0050 wt% or less

[0069] Magnesium (Mg) is an element that mainly combines with S to form sulfides, and may affect an oxide layer on a surface of base iron. Therefore, Mg may be included in an amount of 0.0050 wt% or less. The lower limit thereof is not particularly limited, but may be 0.0001 wt% due to steelmaking costs. That is, Mg may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, 0.0005 to 0.0030 wt% may be included.

[0070] The balance includes Fe and unavoidable impurities. The unavoidable impurities are impurities that are mixed in during the steelmaking step and the manufacturing process of the non-oriented electrical steel sheet, and since these are widely known in the field, detailed descriptions thereof will be omitted. An embodiment of the present invention does not exclude the addition of elements other than the aforementioned alloy components, and various elements may be included within a range that does not impair the technical idea of the present invention. When an additional element is further included, it is included by replacing Fe, which is the balance.

[0071] As described above, in an embodiment of the present invention, by appropriately adjusting the alloy components of the steel sheet and adjusting the conditions in the cold-rolled sheet annealing process, Al and Si are densely concentrated in the surface portion, and thus mechanical strength and magnetic properties can be improved at the same time.

[0072] FIG. 1 schematically illustrates a cross-section of a steel sheet according to an embodiment of the present invention. As illustrated in FIG. 1, a surface portion 10 may exist in a range of 0.3 to 1 μm from a steel sheet surface 11 toward the inside. In FIG. 1, an example in which the surface portion 10 exists on both surfaces of the steel sheet is described, but it is also possible for the surface portion 10 to exist on only one surface of the steel sheet.

[0073] In an embodiment of the present invention, when measuring the element content in a thickness direction with respect to the surface portion 10, a weight ratio of the Al content to Si at a point where the Al content is maximum may be 25 or less.

[0074] When an insulating coating exists on a surface of an electrical steel sheet to be described later, the surface portion 10 may be in a range of 0.3 to 1 μm in an inward direction based on a surface 11 of a steel sheet substrate, excluding an insulating coating.

[0075] The element content in the thickness direction may be measured through a glow discharge spectrometer (GDS), and in order to reduce error according to a measurement position, it may be measured at intervals of at least 2 cm and obtained as an average with three surrounding points. FIG. 2 illustrates an example of Al and Si contents in the thickness direction.

[0076] The surface portion 10 contains a larger amount of Al and Si than the inside of the steel sheet due to the enrichment of Al and Si. In this case, by adjusting the diffusion amount of Al and Si, the weight ratio of the Al content to Si ($\text{Al}_{\text{max}}/\text{Si}_{\text{maxAl}}$) at the point where the Al content is maximum can be adjusted to 25 or less. If the weight ratio of the Al content to Si ($\text{Al}_{\text{max}}/\text{Si}_{\text{maxAl}}$) at the point where the Al content is maximum is too large, an Al-enriched layer develops excessively strongly, and thus peeling between the base material and a coating layer may occur. More specifically, the weight ratio of the Al content to Si ($\text{Al}_{\text{max}}/\text{Si}_{\text{maxAl}}$) at the point where the Al content is maximum within the surface portion 10 may be 1.0 to 15.0.

[0077] When measuring the element content in the steel sheet thickness direction in the surface portion 10, the maximum Al content may be 2.0 wt% or more. When the maximum Al content (Al_{max}) is too small, it means that Al enrichment within the surface portion 10 does not occur densely, and as a result, many fine inclusions are formed inside the steel sheet by N_2 , O_2 , and the like, introduced from the external air, which may adversely affect magnetic properties. More specifically, when measuring the element content in the steel sheet thickness direction in the surface portion 10, the maximum Al content (Al_{max}) may be 2 to 15 wt%.

[0078] In addition, when measuring the element content in the steel sheet thickness direction in the surface portion 10, when measuring the element content in the steel sheet thickness direction in the surface portion 10, the Si content (Si_{maxAl}) at the point where the Al content is maximum may be 0.5 wt% or more. When the Si content (Si_{maxAl}) is too small, it means that Si enrichment within the surface portion 10 does not occur densely, and as a result, many fine inclusions or precipitates are formed inside the steel sheet by N_2 , O_2 , and the like introduced from the external air, which may adversely affect magnetic properties. More specifically, when measuring the element content in the steel sheet thickness direction in the surface portion 10, the Si (Si_{maxAl}) content may be 0.5 to 4 wt%.

[0079] In an embodiment of the present invention, by appropriately concentrating Si and Al in the surface portion 10, development of surface fine nitrides due to internal oxidation and N penetration is prevented, thereby making the change in $\langle 111 \rangle // ND$ before and after SRA small. Specifically, when the steel sheet before and after stress relief annealing is measured through EBSD, the difference in maximum intensity of $\langle 111 \rangle // ND$ is 3.0 or less. $\langle 111 \rangle // ND$ refers to grains whose $\langle 111 \rangle$ direction is parallel to the rolling direction of the steel sheet within 15° . The maximum intensity of $\langle 111 \rangle // ND$ before SRA is lower than the maximum intensity of $\langle 111 \rangle // ND$ after SRA. More specifically, the difference in maximum intensity of $\langle 111 \rangle // ND$ may be 0.5 to 2.8. The stress relief annealing may be performed by annealing at 750 to 850 °C. The time may be 40 to 120 minutes. More specifically, the change in the maximum intensity of $\langle 111 \rangle // ND$ before and after the annealing may be measured by annealing at 800 °C for 120 minutes. The maximum intensity of $\langle 111 \rangle // ND$ is measured through EBSD, and can be obtained by measuring an area of at least 10 mm² on at least 8 sheets of the TD surface of the steel sheet. The maximum intensity of $\langle 111 \rangle // ND$ before SRA may be 5.0 to 10.0. More specifically, it may be 5.0 to 8.0.

[0080] As described above, in an embodiment of the present invention, by appropriately concentrating Si and Al in the surface portion 10, magnetic properties can be improved. Specifically, the non-oriented electrical steel sheet according to an embodiment of the present invention may have a B_{50} of 1.63 to 1.68 T.

[0081] In addition, in an embodiment of the present invention, the iron loss ($W_{10/400}$) of the non-oriented electrical steel sheet based on a thickness of 0.25 mm may be 12.5 W/kg or less. Iron loss ($W_{10/400}$) is an iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz. More specifically, the iron loss ($W_{10/400}$) of the non-oriented electrical steel sheet may be 10.0 to 12.0 W/kg.

[0082] In addition, an embodiment of the present invention is excellent in mechanical strength as well. More specifically, the yield strength may be 480 MPa or more and 570 MPa or less. The yield strength may be measured by a tensile test.

[0083] In addition, an embodiment of the present invention has a small change in magnetic flux density before/after stress relief annealing. Specifically, the stress relief annealing may be annealing maintained at 750 °C to 850 °C for 40 to 120 minutes. More specifically, it may be maintained at 800 °C for 120 minutes. In this case, a difference in magnetic flux density B_{50} may be 0.03 T or less.

[0084] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention includes: manufacturing a hot-rolled steel sheet by hot-rolling a slab; manufacturing a cold-rolled sheet by cold-rolling the hot-rolled steel sheet; cold-rolled sheet annealing for annealing the cold-rolled sheet; and stress relief annealing the cold-rolled sheet annealed steel sheet.

[0085] Hereinafter, each step will be described in detail.

[0086] First, the slab is hot-rolled.

[0087] Since an alloy component of the slab have been described in the alloy components of the aforementioned non-oriented electrical steel sheet, duplicate descriptions will be omitted. Since the alloy component does not substantially change during the manufacturing process of the non-oriented electrical steel sheet, the alloy component of the non-oriented electrical steel sheet and the slab are substantially the same.

[0088] Specifically, the slab includes Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, Sn: 0.001 to 0.08%, Sb: 0.001 to 0.08%, and B: 0.0002 to 0.0007% by weight, with the balance being Fe and unavoidable impurities.

[0089] Since other additional elements have been described in the alloy components of the non-oriented electrical steel sheet, duplicate descriptions will be omitted.

[0090] Before hot-rolling the slab, it may be heated. The heating temperature of the slab is not limited, but the slab may be heated to 1200 °C or less. When the slab heating temperature is too high, a precipitate such as AlN and MnS existing in the slab is re-dissolved and then finely precipitates during hot rolling and annealing, which may suppress grain growth and decrease magnetic properties.

[0091] Next, the slab is hot-rolled to manufacture a hot-rolled sheet. A thickness of the hot-rolled sheet may be 1.0 to

4.5 mm. In the manufacturing the hot-rolled sheet, a finish rolling temperature may be 800 °C or more. Specifically, it may be 850 to 950 °C. The hot-rolled sheet may be wound at a temperature of 600 °C or more. More specifically, the thickness of the hot-rolled sheet may be 1.5 to 4.3 mm.

[0092] After manufacturing the hot-rolled steel sheet, subsequent steps may be performed while scales existing on the hot-rolled steel sheet remain. That is, after hot rolling, removal of scales such as pickling, shot blasting, or surface grinding is omitted, and subsequent steps may be performed. Since the friction between a rolling work roll and the steel sheet increases due to cold rolling with the pickling process omitted, shear deformation is applied simultaneously with plane strain during rolling, and thus a specific orientation develops during recrystallization annealing. In an embodiment of the present invention, scale refers to a portion where elements such as Fe, Al, and Si on the surface of a steel sheet combine with oxygen to form a phase different from that of a base material. The scale remaining means that a scale with a thickness of at least 1 μm remains on the hot-rolled sheet. In this case, the scale thickness means a sum of a scale thicknesses generated on both surfaces of the steel sheet. When the remaining scale thickness is too thin, the effect of the scale remaining may not be sufficiently exhibited. Even through the scale thickness is thicker, the effect is not improved, and there is a problem that the yield of the steel sheet decreases. More specifically, a scale with a thickness of 0.1 to 1 μm may remain.

[0093] After manufacturing the hot-rolled sheet, annealing the hot-rolled sheet may be additionally included. The hot-rolled sheet annealing temperature may be 950 to 1150 °C. The time may be 10 to 300 seconds. The hot-rolled sheet annealing may be omitted if necessary.

[0094] Next, the hot-rolled steel sheet is cold-rolled to manufacture a cold-rolled sheet. In this case, cold rolling may be performed at a reduction ratio of 70 to 90%. When the reduction ratio is too low, deformation energy accumulated in the rolled steel sheet is small, making it difficult to recrystallize in a subsequent annealing process, and thus a rolled structure remains, which may cause a problem in improving magnetic flux density and iron loss. Conversely, when the reduction ratio is too high, recrystallization of <111>//ND oriented grains is promoted in the subsequent annealing process and the grain size becomes fine, which may cause problems of poor magnetic flux density and increased iron loss. More specifically, the reduction ratio may be 58 to 67%. The cold rolling may use a Tandem cold rolling mill for continuously cold-rolling a steel sheet using a plurality of rolling stands, or a Reverse rolling mill for discontinuously cold-rolling using 12 or more stages of rolling rolls. In addition, one-time cold rolling or two or more times of cold rolling with intermediate annealing in between may be performed. The final rolling thickness may be 0.1 mm to 0.35 mm.

[0095] Next, the cold-rolled sheet is annealed.

[0096] The cold-rolled sheet annealing has a soaking temperature of 750 °C to 850 °C, a hydrogen fraction in an atmosphere of 10 to 35 vol%, and a dew point of the atmosphere of -40 to -10 °C.

[0097] When the soaking temperature is too low, initial recrystallization does not sufficiently occur, which may cause a problem of a high <111>//ND fraction. When the soaking temperature is too high, strength decreases and the degree of iron loss improvement after SRA may fall. More specifically, the soaking temperature may be 760 to 820 °C.

[0098] When the hydrogen fraction in the atmosphere is too low, the atmosphere in an annealing furnace changes to an oxidizing atmosphere, which may cause a problem of oxidation. When the hydrogen fraction is too high, there is a risk of explosion in the annealing furnace. More specifically, the hydrogen fraction in the atmosphere may be 15 to 30 vol%. Others besides hydrogen may be oxygen and nitrogen. More specifically, 65 to 90 vol% of nitrogen may be included.

[0099] When the dew point of the atmosphere is too low, an appropriate Si/Al enrichment layer is not formed, and thus nitrogen penetrates, which may cause a problem of forming fine nitrides. When the dew point of the atmosphere is too high, a problem of strong oxidation of the surface may occur. More specifically, the dew point of the atmosphere may be -50 to -30 °C.

[0100] The annealing time may be 50 to 120 seconds.

[0101] After cold-rolled sheet annealing, an insulating coating may be formed. The insulating coating may be treated with an organic, inorganic, or organic-inorganic composite coating, and it is also possible to treat with other insulating coating agents.

[0102] In addition, after the cold-rolled sheet annealing, stress relief annealing the cold-rolled sheet annealed steel sheet may be further included. After cold-rolled sheet annealing, the electrical steel sheet may be punched and laminated, and by removing stress generated in this process, the magnetic properties of the steel sheet may be further improved. Specifically, the stress relief annealing may be performed by annealing at 750 to 850 °C. The annealing time may be 40 to 120 minutes.

[0103] Hereinafter, the present invention will be described in more detail through examples. However, these examples are only for illustrating the present invention, and the present invention is not limited thereto.

Example 1

[0104] A slab was manufactured with components including Table 1, Table 2, and the balance Fe and unavoidable

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impurities. This was heated to 1150 °C and hot-rolled at a finishing temperature of 900 °C to manufacture hot-rolled sheets having a thickness of 1.8 mm.

[0105] Thereafter, the hot-rolled sheet was annealed at 1000 °C for 180 seconds, and cold-rolled to a final thickness of 0.25 mm. The cold-rolled steel sheet was annealed under the conditions summarized in Table 2 below.

[0106] A surface of the manufactured non-oriented electrical steel sheet was analyzed by GDS, and the results are shown in Table 3.

[0107] Magnetic flux density and iron loss were measured with a single sheet tester by cutting specimens of width 60 mm × length 60 mm × 5 sheets for each specimen, and the values are shown.

[0108] In this case, $W_{10/400}$ is an iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz. B_{50} means a magnetic flux density induced in a magnetic field of 5000 A/m.

[0109] In addition, the manufactured non-oriented electrical steel sheet was subjected to stress relief annealing at 800 °C for 60 minutes. . Thereafter, B_{50} was measured and shown in Table 3.

[0110] In addition, the maximum intensity of <111>/ND before/after stress relief annealing and the difference thereof were measured by EBSD and are shown in Table 3.

(Table 1)

Classification	Si	Mn	Al	Sn	Sb	B	S	Formula 1
1	3.5	0.69	1.26	0.0014	0.0003	0.0003	0.0045	1.6
2	3.6	1.02	0.68	0.0057	0.0065	0.0005	0.0036	1.0
3	3.3	0.92	0.98	0.0019	0.0031	0.0003	0.0030	1.2
4	3.0	1.16	1.50	0.0035	0.0028	0.0002	0.0040	2.3
5	3.3	1.20	0.79	0.0050	0.0005	0.0003	0.0027	1.1
6	2.9	1.48	0.91	0.0037	0.0027	0.0003	0.0034	1.3
7	3.6	0.68	0.53	0.0055	0.0010	0.0005	0.0036	0.9
8	3.1	1.23	0.79	0.0032	0.0041	0.0006	0.0034	0.7
9	3.2	1.39	1.50	0.0031	0.0047	0.0005	0.0037	0.9
10	3.5	0.44	1.14	0.0059	0.0075	0.0006	0.0037	0.8
11	3.4	0.76	1.01	0.0023	0.0062	0.0006	0.0035	0.7
12	3.1	1.10	1.44	0.0062	0.0033	0.0003	0.0021	1.0
13	3.5	0.34	1.17	0.0021	0.0068	0.0004	0.0044	1.3
14	3.4	1.04	0.95	0.0047	0.0071	0.0006	0.0049	1.0
15	3.7	1.03	0.58	0.0077	0.0039	0.0006	0.0040	0.9
16	3.6	0.52	1.18	0.0013	0.0067	0.0003	0.0039	1.6
17	3.5	1.41	0.78	0.0071	0.0033	0.0003	0.0047	1.9
18	3.7	0.91	0.89	0.0015	0.0038	0.0006	0.0050	0.9
19	1.3	0.69	0.75	0.0023	0.0035	0.0003	0.0047	1.8
20	5.3	1.45	0.98	0.0057	0.0063	0.0006	0.0026	0.6
21	3.6	0.05	0.66	0.0036	0.0045	0.0002	0.0040	2.4
22	3.2	2.20	1.37	0.0014	0.0064	0.0007	0.0036	0.6
23	3.2	1.37	0.05	0.0043	0.0021	0.0005	0.0049	1.1
24	3.4	1.23	2.20	0.0016	0.0072	0.0005	0.0046	1.1
25	3.3	1.21	0.72	0.0005	0.0050	0.0003	0.0017	0.8
26	3.3	0.45	1.20	0.0790	0.0058	0.0003	0.0016	3.4
27	3.7	0.66	0.62	0.0079	0.0005	0.0002	0.0045	2.7
28	3.2	0.70	1.04	0.0004	0.0850	0.0006	0.0033	2.0
29	3.5	1.35	1.47	0.0068	0.0058	0.0001	0.0020	3.3

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(continued)

Classification	Si	Mn	Al	Sn	Sb	B	S	Formula 1
30	3.1	0.76	1.27	0.0740	0.0740	0.0010	0.0014	1.6
31	3.2	0.30	1.29	0.0028	0.0012	0.0004	0.0075	2.0
32	3.0	0.64	1.27	0.0071	0.0055	0.0007	0.0023	0.5
33	3.4	1.24	0.67	0.0750	0.0750	0.0003	0.0022	5.7
34	3.2	1.03	0.67	0.0062	0.0010	0.0006	0.0034	0.7
35	3.4	1.11	1.32	0.0045	0.0068	0.0005	0.0032	0.9
36	4.0	0.47	1.29	0.0047	0.0066	0.0003	0.0018	1.0
37	3.8	0.64	0.80	0.0016	0.0065	0.0003	0.0035	1.4
38	3.2	0.54	0.50	0.0019	0.0003	0.0006	0.0047	0.8
39	3.7	0.99	1.37	0.0043	0.0014	0.0005	0.0028	0.7

(Table 2)

Classification	Soaking temperature(° C)	Hydrogen fraction (volume%)	Dew point (° C)	Al _{max}	Si _{maxAl}	Al _{max} /Si _{maxAl}
1	830	23	-26	4.7	0.6	7.8
2	790	18	-17	5.5	0.8	6.9
3	760	20	-40	5.2	0.7	7.4
4	750	18	-36	9.4	1.2	7.8
5	750	14	-29	3.5	1.1	3.2
6	840	17	-25	12.0	2.1	5.7
7	760	24	-22	11.2	0.8	14.0
8	820	15	-35	2.6	0.5	5.2
9	780	20	-47	3.1	0.5	6.2
10	780	25	-32	8.4	1.3	6.5
11	770	30	-32	4.5	0.6	7.5
12	810	20	-29	5.4	1.1	4.9
13	840	11	-36	4.2	1.0	4.2
14	800	34	-25	6.7	0.9	7.4
15	830	35	-31	4.2	0.7	6.0
16	820	10	-34	5.3	0.9	5.9
17	790	32	-38	4.3	1.3	3.3
18	790	10	-37	3.5	0.7	5.0
19	800	26	-33	0.8	0.5	1.6
20	cold rolling not possible					
21	770	22	-10	15.8	0.4	39.5
22	770	22	-14	13.2	0.3	44.0
23	820	11	-11	12.9	0.5	25.8
24	830	14	-16	30.8	1.2	25.7
25	840	14	-40	3.7	3.8	1.0

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(continued)

	Classification	Soaking temperature(° C)	Hydrogen fraction (volume%)	Dew point (° C)	Al _{max}	Si _{maxAl}	Al _{max} /Si _{maxAl}
5	26	790	10	-23	3.3	0.1	33.0
	27	840	35	-13	13.2	0.5	26.4
	28	780	27	-34	22.8	0.6	38.0
10	29	800	17	-40	29.8	1.1	27.1
	30	810	26	-19	10.5	2.9	3.6
	31	770	30	-12	11.2	0.5	22.4
15	32	810	22	-36	16.7	0.5	33.4
	33	820	16	-33	9.8	0.3	32.7
	34	730	19	-35	1.9	0.5	3.8
	35	880	16	-18	18.7	0.7	26.7
20	36	830	5	-36	87.3	3.3	26.5
	37	800	40	-20	1.1	0.4	2.8
	38	770	31	-60	1.6	0.3	5.3
25	39	850	14	0	19.7	0.3	65.7

(Table 3)

30	Classification	B ₅₀ (Tesla)	Iron loss after SRA W _{10/400} (W/kg)	Maximum intensity of <111>/ND before SRA	B ₅₀ after SRA (Tesla)	Difference in B ₅₀ before and after SRA	Difference in maximum intensity of <111>/ND before/after SRA	Remarks
35	1	1.64	11.3	5.2	1.62	0.02	1.9	Inventive Example
	2	1.65	11.5	6.1	1.63	0.02	2.1	Inventive Example
40	3	1.64	11.2	6.3	1.63	0.01	2.4	Inventive Example
	4	1.64	10.8	6.9	1.63	0.01	1.8	Inventive Example
45	5	1.65	11.6	6.5	1.64	0.01	2.2	Inventive Example
	6	1.67	11.0	5.5	1.65	0.02	2.4	Inventive Example
50	7	1.65	11.1	6.1	1.64	0.01	1.7	Inventive Example
	8	1.65	11.4	5.6	1.63	0.02	1.9	Inventive Example
55	9	1.64	10.7	6.0	1.64	0	2.0	Inventive Example
	10	1.67	11.6	6.4	1.66	0.01	2.4	Inventive Example

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(continued)

5	Classification	B ₅₀ (Tesla)	Iron loss after SRA W _{10/400} (W/kg)	Maximum intensity of <111>//N D before SRA	B ₅₀ after SRA (Tesla)	Difference in B ₅₀ before and after SRA	Difference in maximum intensity of <111>//ND before/after SRA	Remarks
10	11	1.64	11.8	5.4	1.63	0.01	2.4	Inventive Example
	12	1.65	11.5	4.9	1.62	0.03	1.6	Inventive Example
15	13	1.64	11.2	5.2	1.63	0.01	2.7	Inventive Example
	14	1.64	11.4	5.7	1.62	0.02	1.9	Inventive Example
20	15	1.65	11.3	6.1	1.63	0.02	2.1	Inventive Example
	16	1.63	11.6	6.7	1.63	0	2.5	Inventive Example
25	17	1.65	10.8	7.3	1.64	0.01	1.9	Inventive Example
	18	1.64	10.9	6.7	1.63	0.01	2.3	Inventive Example
30	19	1.71	18.2	5.5	1.68	0.03	3.9	Comparative Example
	20	cold rolling not possible						Comparative Example
35	21	1.63	12.8	5.4	1.60	0.03	3.3	Comparative Example
	22	1.61	13.1	6.1	1.58	0.03	4.5	Comparative Example
40	23	1.62	13.0	6.6	1.59	0.03	3.8	Comparative Example
	24	1.60	11.0	7.5	1.56	0.04	5.5	Comparative Example
45	25	1.62	12.1	6.4	1.59	0.03	3.8	Comparative Example
	26	1.63	14.1	5.8	1.60	0.03	4.5	Comparative Example
50	27	1.65	11.9	4.3	1.62	0.03	3.7	Comparative Example
	28	1.65	15.4	4.6	1.61	0.04	3.9	Comparative Example
55	29	1.62	11.5	6.1	1.58	0.04	3.6	Comparative Example
	30	1.59	13.2	8.3	1.55	0.04	4.2	Comparative Example
	31	1.65	12.0	4.8	1.63	0.02	3.2	Comparative Example

(continued)

5	Classification	B ₅₀ (Tesla)	Iron loss after SRA W _{10/400} (W/kg)	Maximum intensity of <111>//N D before SRA	B ₅₀ after SRA (Tesla)	Difference in B ₅₀ before and after SRA	Difference in maximum intensity of <111>//ND before/after SRA	Remarks
10	32	1.62	12.8	5.5	1.58	0.04	3.5	Comparative Example
	33	1.65	13.5	4.7	1.61	0.04	5.0	Comparative Example
15	34	1.63	12.6	5.8	1.59	0.04	4.4	Comparative Example
	35	1.62	12.1	6.2	1.60	0.02	3.5	Comparative Example
20	36	1.58	13.6	7.2	1.55	0.03	4.7	Comparative Example
	37	1.62	11.3	5.7	1.61	0.01	5.3	Comparative Example
25	38	1.62	13.8	6.0	1.61	0.01	3.8	Comparative Example
	39	1.59	14.5	9.1	1.55	0.04	4.2	Comparative Example

30 **[0111]** As shown in Tables 1 to 3, when the steel components are appropriately adjusted and the conditions for cold-rolled sheet annealing are appropriately adjusted, Si and Al are densely concentrated in the surface layer, and thus it can be confirmed that the difference in <111>//ND intensity before/after SRA is small, iron loss and magnetic flux density are excellent, and magnetic properties are also excellent after SRA.

35 **[0112]** On the other hand, when the steel components are not appropriately adjusted or the conditions for cold-rolled sheet annealing are not appropriately adjusted, and thus the surface layer is not appropriately formed and the difference in <111>//ND intensity before/after SRA is large, it can be confirmed that iron loss and magnetic flux density are poor or magnetic properties are significantly poor after SRA.

40 **[0113]** 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..

[Description of reference numerals]

45 100 : non-oriented electrical steel sheet 10 : surface portion,
11: steel sheet surface

50 Claims

1. A non-oriented electrical steel sheet comprising Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, Sn: 0.001 to 0.08%, Sb: 0.001 to 0.08%, and B: 0.0002 to 0.0007% by weight, and including the balance being Fe and unavoidable impurities,

55 wherein, when measuring an element content in a steel sheet thickness direction in a surface portion in a range of 0.3 to 1 μm from a steel sheet surface toward the inside, a weight ratio of an Al content to Si at a point where the Al content is maximum is 25 or less, and, when the steel sheet before and after stress relief annealing is measured through EBSD, a difference in

maximum intensity of <111>//ND is 3 or less.

2. The non-oriented electrical steel sheet of claim 1, wherein:
when measuring the element content in the steel sheet thickness direction in the surface portion, a maximum Al content is 2.0 wt% or more.
3. The non-oriented electrical steel sheet of claim 1, wherein:
when measuring the element content in the steel sheet thickness direction in the surface portion, the Si content at the point where the Al content is maximum is 0.5 wt% or more.
4. The non-oriented electrical steel sheet of claim 1, further comprising S: 0.005 wt% or less (excluding 0%), and satisfying Formula 1 below:

[Formula 1]

$$0.7 \leq ([\text{Sn}] + [\text{Sb}] + [\text{S}] \times 10)/([\text{B}] \times 100) \leq 5.2$$

(In Formula 1, [Sn], [Sb], [S], and [B] represent contents (wt%) of Sn, Sb, S, and B, respectively).

5. The non-oriented electrical steel sheet of claim 1, further comprising one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).
6. The non-oriented electrical steel sheet of claim 1, further comprising one, or two or more of Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 wt% individually or in total.
7. The non-oriented electrical steel sheet of claim 1, further comprising one or more of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).
8. The non-oriented electrical steel sheet of claim 1, further comprising one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).
9. A method for manufacturing a non-oriented electrical steel sheet, comprising:
manufacturing a hot-rolled steel sheet by hot-rolling a slab including Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, Sn: 0.001 to 0.08%, Sb: 0.001 to 0.08%, and B: 0.0002 to 0.0007% by weight, and including the balance being Fe and unavoidable impurities;
manufacturing a cold-rolled sheet by cold-rolling the hot-rolled steel sheet;
cold-rolled sheet annealing for annealing the cold-rolled sheet; and
stress relief annealing the cold-rolled sheet annealed steel sheet,
wherein the cold-rolled sheet annealing has a soaking temperature of 750 °C to 850 °C, a hydrogen fraction in an atmosphere of 10 to 35 vol%, and a dew point of the atmosphere of -55 to -15 °C, and,
when the steel sheet before and after the stress relief annealing is measured through EBSD, a difference in maximum intensity of <111>//ND is 3 or less.

10. The method of claim 9, wherein:

the slab further comprises S: 0.005 wt% or less (excluding 0%), and satisfies Formula 1 below:

[Formula 1]

$$0.7 \leq ([\text{Sn}] + [\text{Sb}] + [\text{S}] \times 10)/([\text{B}] \times 100) \leq 5.2$$

(In Formula 1, [Sn], [Sb], [S], and [B] represent contents (wt%) of Sn, Sb, S, and B, respectively).

11. The method of claim 9, wherein:

the slab further comprises one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%),
Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

12. The method of claim 9, wherein:

the slab further comprises one, or two or more of Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 wt%
individually or in total.

13. The method of claim 9, wherein:

the slab further comprises one or more of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less
(excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

14. The method of claim 9, wherein:

the slab further comprises one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding
0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less
(excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt%
or less (excluding 0%).

15. The method of claim 9, wherein:

the stress relief annealing performs annealing at 750 to 850 °C.

FIG. 1

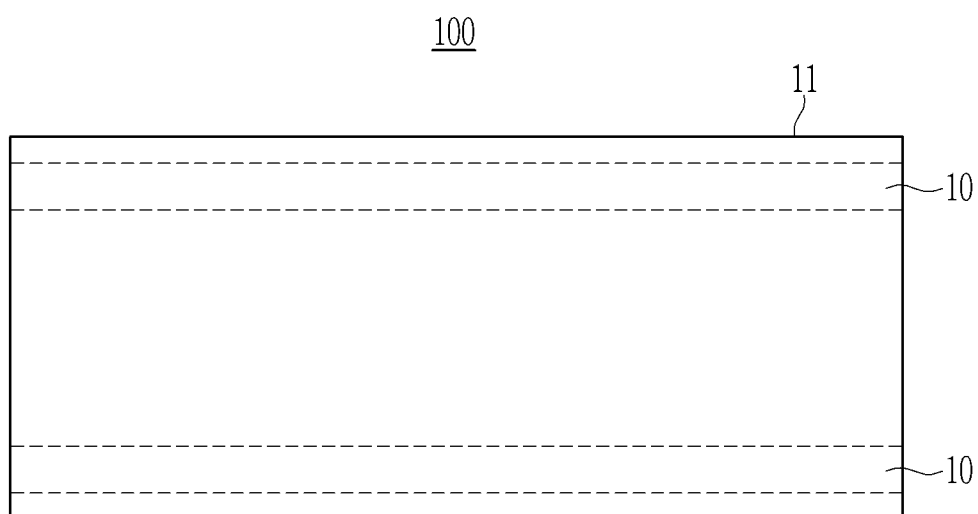
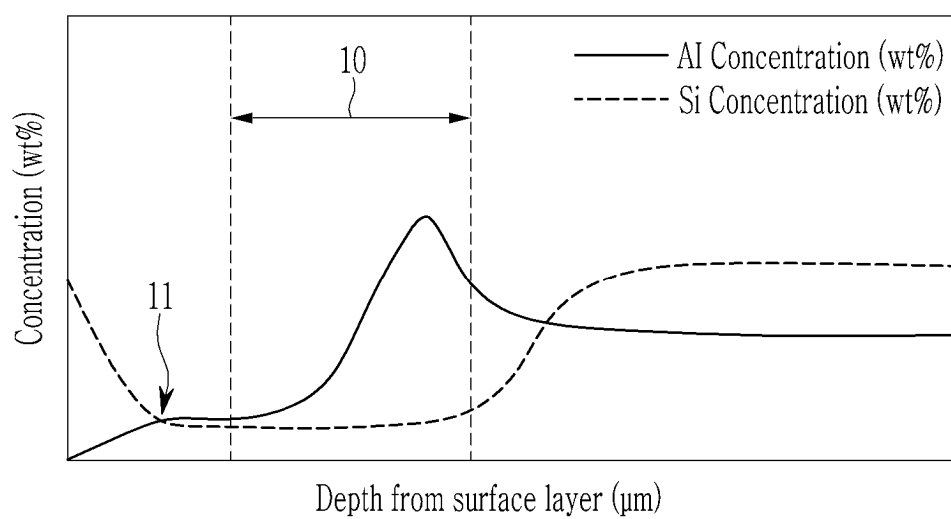


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063282

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 38/14(2006.01)i;
C22C 38/42(2006.01)i; C22C 38/58(2006.01)i; C22C 38/52(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 38/04(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) & keywords: 무방향성 전기강판(non-oriented electrical steel sheet), 응력제거소둔(stress relief annealing, SRA), 실리콘(Si, silicon), 알루미늄(Al, aluminum), 망간(Mn, manganese), 안티몬(Sb, antimony), 주석(Sn, tin), 보론(B, boron), EBSD 측정(EBSD measurement), 이슬점(dew point)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-2023-0095256 A (POSCO) 29 June 2023 (2023-06-29) See claims 1-10.	1-15
Y	KR 10-2022-0004221 A (JFE STEEL CORPORATION) 11 January 2022 (2022-01-11) See paragraphs [0079], [0121] and [0133] and claim 4.	1-15
A	CN 113969371 A (BAOSHAN IRON & STEEL CO., LTD.) 25 January 2022 (2022-01-25) See claims 1-16.	1-15
A	KR 10-1945132 B1 (JFE STEEL CORPORATION) 01 February 2019 (2019-02-01) See paragraphs [0043]-[0044].	1-15
A	KR 10-1329715 B1 (POSCO) 14 November 2013 (2013-11-14) See paragraphs [0072]-[0073] and table 2.	1-15

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

* Special categories of cited documents:

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

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

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

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 2025	14 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	
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/IB2024/063282

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Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
KR 10-2023-0095256 A	29 June 2023	CN 117377787 A	09 January 2024
		EP 4455329 A1	30 October 2024
		JP 2024-518899 A	08 May 2024
		MX 2023010391 A	22 November 2023
		US 2024-0203622 A1	20 June 2024
		WO 2023-121256 A1	29 June 2023
KR 10-2022-0004221 A	11 January 2022	CA 3137623 A1	30 December 2020
		CA 3137623 C	15 August 2023
		CN 114008224 A	01 February 2022
		EP 3992312 A1	04 May 2022
		JP 7054074 B2	13 April 2022
		KR 10-2721285 B1	23 October 2024
		MX 2021015679 A	03 February 2022
		TW 202104613 A	01 February 2021
		TW I820337 B	01 November 2023
		US 11962184 B2	16 April 2024
		US 2022-0278566 A1	01 September 2022
		WO 2020-262063 A1	30 December 2020
CN 113969371 A	25 January 2022	CN 113969371 B	20 September 2022
KR 10-1945132 B1	01 February 2019	CA 2956686 A1	04 February 2016
		CA 2956686 C	08 January 2019
		CN 106574334 A	19 April 2017
		CN 106574334 B	12 June 2018
		EP 3176279 A1	07 June 2017
		EP 3176279 B1	15 August 2018
		JP 6260800 B2	17 January 2018
		JP WO2016-017263 A1	27 April 2017
		KR 10-2017-0020481 A	22 February 2017
		MX 2017001348 A	27 April 2017
		TW 201610171 A	16 March 2016
		TW I575075 B	21 March 2017
		US 10526673 B2	07 January 2020
		US 2017-0260600 A1	14 September 2017
		WO 2016-017263 A1	04 February 2016
KR 10-1329715 B1	14 November 2013	KR 10-2013-0001533 A	04 January 2013

Form PCT/ISA/210 (patent family annex) (July 2022)