

DESCRIPTION

COPPER STRAND FOR BONDING WIRE AND METHOD FOR PRODUCING

COPPER STRAND FOR BONDING WIRE

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TECHNICAL FIELD

[0001]

The present invention relates to a copper strand (semi-wrought copper wire) for a bonding wire used for producing a bonding wire having a wire diameter of 180 μm or less, and a method for producing the copper strand (semi-wrought copper wire) for a bonding wire.

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The present application claims priority on Japanese Patent Application No. 2011-161036 filed on July 22, 2011, the content of which is incorporated herein by reference.

15

BACKGROUND ART

[0002]

In general, in a semiconductor device having a semiconductor element mounted therein, the semiconductor element and a lead are connected to each other with a bonding wire as described above. Hitherto, as the bonding wire, an Au wire has been mainly used from the viewpoint of wire drawability, conductivity, and the like. However, since Au is expensive, a bonding wire made of Cu has been provided as the bonding wire replacing the Au wire.

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[0003]

Here, since Cu is harder than Au, there is concern that a ball formed at the tip end

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of a wire during bonding may break, for example, an Al wiring film formed on the surface of a Si semiconductor element. In addition, since Cu has a lower elongation than that of Au, there is a problem in that an appropriate wire loop shape cannot be maintained.

Therefore, for example, in Patent Documents 1 and 2, a bonding wire made of Cu by using ultra-pure copper (6NCu) having a purity of 99.9999 mass% or higher is suggested. In addition, in Patent Document 3, a bonding wire made of Cu by adding a small amount of Ti, Zr, Hf, V, Cr, and B is suggested.

[0004]

However, as described in Patent Documents 1 and 2, in the case where the ultra-pure copper (6NCu) having a purity of 99.9999 mass% or higher is used, a refining process is needed to obtain the ultra-pure copper (6NCu). Therefore, there is a problem in that the manufacturing cost is greatly increased.

In addition, the bonding wire described in Patent Document 3 is still harder than that made of Au and has a lower elongation. Therefore, properties thereof are insufficient to replace the Au wire.

Moreover, in recent years, a reduction in the wire diameter of a bonding wire made of a Cu wire is required, and workability by which wire breaking does not occur is required for a semi-wrought copper wire for a bonding wire.

PRIOR ART DOCUMENT

Patent Documents

[0005]

Patent Document 1: Japanese Unexamined Patent Application, First Publication No. S62-111455

Patent Document 2: Japanese Unexamined Patent Application, First Publication

No. H04-247630

Patent Document 3: Japanese Examined Patent Application, Second Publication

No. H04-012623

5 DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

[0006]

The present invention has been made taking the foregoing circumstances into consideration, and an object thereof is to provide a semi-wrought copper wire for a bonding wire having low hardness, high elongation, and excellent workability, and a method for producing the semi-wrought copper wire for a bonding wire.

Means for Solving the Problems

[0007]

15 In order to accomplish the object, there is provided a semi-wrought copper wire for a bonding wire according to an aspect of the present invention, which is a semi-wrought copper wire for forming a bonding wire having a wire diameter of 180 μm or less, wherein a diameter of the semi-wrought copper wire is in a range of 0.15 mm or more and 3.0 mm or less, the semi-wrought copper wire has a composition that contains one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements such that a total content thereof is in a range of 0.0001 mass% or more and 0.01 mass% or less, with a remainder being copper and unavoidable impurities, and a special grain boundary ratio ($L\sigma/L$) which is a ratio of a special grain boundary length $L\sigma$ to a total crystal grain boundary length L measured by an EBSD method is in a range of 50% or more.

[0008]

The semi-wrought copper wire for a bonding wire has the composition that contains one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements such that a total content thereof is in a range of 0.0001 mass% or more
 5 and 0.01 mass% or less, with a remainder being copper and unavoidable impurities.

Therefore, S contained in the copper reacts with the above-mentioned elements and forms a compound. Accordingly, the effect of S is reduced; and thereby, low recrystallization temperature and low hardness can be achieved.

In addition, the special grain boundary ratio ($L\sigma/L$) which is the ratio of the
 10 special grain boundary length $L\sigma$ to the total crystal grain boundary length L measured by the EBSD method is in a range of 50% or more. Therefore, it is possible to enhance elongation and workability while maintaining low hardness.

[0009]

In addition, crystal grain boundaries and special grain boundaries are specified by
 15 an EBSD measuring apparatus which uses a field emission type scanning electron microscope, and the total crystal grain boundary length L and the special grain boundary length $L\sigma$ are calculated. From the calculated lengths, the special grain boundary ratio ($L\sigma/L$) in this aspect is obtained.

The crystal grain boundary is defined as the boundary between adjacent two
 20 crystals in which the difference in orientation azimuth between the crystals is in a range of 15° or higher as a result of two-dimensional cross-section observation.

In addition, the special grain boundary is a corresponding grain boundary in which a Σ value crystallographically defined based on the CSL theory (Kronberg et al.: Trans. Met. Soc. AIME, 185, 501 (1949)) satisfies $3 \leq \Sigma \leq 29$, and is defined as a crystal

grain boundary in which an intrinsic corresponding position lattice azimuth defect Dq in the corresponding grain boundary satisfies $Dq \leq 15^\circ / \Sigma^{1/2}$ (D. G. Brandon: Acta Metallurgica. Vol. 14, p. 1479, (1966)).

[0010]

5 In the semi-wrought copper wire for a bonding wire according to the aspect of the present invention, it is preferable that the total content of the additional elements be in a range of 0.0003 mass% or more and 0.002 mass% or less.

In this case, recrystallization temperature can be reliably suppressed to be low and hardness can be lowered.

10 [0011]

In addition, it is preferable that regarding contents of Fe, Pb, and S which are the unavoidable impurities, the content of Fe be in a range of 0.0001 mass% or less, the content of Pb be in a range of 0.0001 mass% or less, and the content of S be in a range of 0.005 mass% or less.

15 By specifying the contents of the impurities as described above, recrystallization temperature can be reliably suppressed to be low and hardness can be reduced.

[0012]

20 It is preferable that the number of acid-insoluble residues having particle sizes of 30 μm or more, which are obtained by heating and dissolving 100 g of the semi-wrought copper wire for a bonding wire in a nitric acid solution, be in a range of 1000 or less.

In this case, the particle sizes of the acid-insoluble residues that are present in the semi-wrought copper wire for a bonding wire are small, and the number thereof is small. Therefore, it is possible to suppress occurrence of wire breaking during wire drawing when a bonding wire is produced.

25 [0013]

It is preferable that an amount of the acid-insoluble residues obtained by heating and dissolving the semi-wrought copper wire for a bonding wire in the nitric acid solution be in a range of 0.00015 mass% or less.

In this case, the abundance ratio of the acid-insoluble residues present in the semi-wrought copper wire for a bonding wire is small. Therefore, it is possible to suppress occurrence of wire breaking during wire drawing when a bonding wire is produced.

[0014]

A method for producing a semi-wrought copper wire for a bonding wire according to an aspect of the present invention is a method for producing the above-described semi-wrought copper wire for a bonding wire, and the method includes: a molten copper generating process of generating molten copper by adding one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements to a copper raw material having a purity of 99.99 mass% or higher and 99.998 mass% or lower; a continuous casting process of continuously producing an ingot by supplying the molten copper to a belt-wheel type continuous casting machine; and a continuous rolling process of continuously rolling the produced ingot under a condition where an initial temperature is in a range of 800°C or higher.

[0015]

According to the method for producing the semi-wrought copper wire for a bonding wire, the copper raw material so-called 4NCu having a purity of 99.99 mass% or higher and 99.998 mass% or lower is used. Therefore, compared to the case where 6NCu is used, the manufacturing cost of the semi-wrought copper wire for a bonding wire can be greatly reduced.

Moreover, the continuous rolling process of continuously rolling the produced

ingot under the condition where the initial temperature is in a range of 800°C or higher is included. Therefore, the special grain boundary ratio ($L\sigma/L$) in the semi-wrought copper wire for a bonding wire can be in a range 50% or more.

[0016]

5 In addition, a method for producing a semi-wrought copper wire for a bonding wire according to another aspect of the present invention is a method for producing the above-described semi-wrought copper wire for a bonding wire and the method includes: a molten copper generating process of generating molten copper by adding one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements to a
10 copper raw material having a purity of 99.99 mass% or higher and 99.998 mass% or lower; a casting process of producing an ingot by pouring the molten copper into a mold; an extrusion process of producing an extruded wire by extruding the obtained ingot under a condition where an initial temperature is in a range of 800°C or higher; a processing and annealing process of repeatedly subjecting the obtained extruded wire to either one of
15 rolling or wire drawing, and annealing; and a light rolling process of performing rolling at a rolling reduction rate of 5% or more and 25% or less to achieve a final wire diameter of 0.15 mm or more and 3.0 mm or less.

[0017]

According to the method for producing the semi-wrought copper wire for a
20 bonding wire, the copper raw material so-called 4NCu having a purity of 99.99 mass% or higher and 99.998 mass% or lower is used. Therefore, compared to the case where 6NCu is used, the manufacturing cost of the semi-wrought copper wire for a bonding wire can be greatly reduced.

Moreover, the method includes the processing and annealing process of
25 repeatedly subjecting the extruded wire to either one of rolling or wire drawing, and

annealing, and the light rolling process of performing rolling at a rolling reduction rate of 5% or more and 25% or less to achieve a final wire diameter of 0.15 mm or more and 3.0 mm or less. Therefore, the special grain boundary ratio ($L\sigma/L$) in the semi-wrought copper wire for a bonding wire can be in a range of 50% or more.

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Effects of the Invention

[0018]

According to the aspect of the present invention, the semi-wrought copper wire for a bonding wire having low hardness, high elongation, and excellent workability, and
10 the method for producing the semi-wrought copper wire for a bonding wire can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

15 FIG. 1 is an explanatory view of a continuous casting and rolling apparatus used when a semi-wrought copper wire for a bonding wire in an embodiment of the present invention is produced.

FIG. 2 is a flowchart of a method for producing the semi-wrought copper wire for a bonding wire in the embodiment of the present invention.

20 FIG. 3 is a flowchart of a method for producing the semi-wrought copper wire for a bonding wire in another embodiment of the present invention.

FIG. 4 is a graph showing evaluation results of acid-insoluble residues in
Invention Example 1.

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EMBODIMENTS OF THE INVENTION

[0020]

Hereinafter, a semi-wrought copper wire for a bonding wire and a method for producing the semi-wrought copper wire for a bonding wire according to an embodiment of the present invention will be described.

5 [0021]

The semi-wrought copper wire for a bonding wire according to this embodiment is used as a material to produce a bonding wire having a wire diameter of 180 μm or less, and more preferably, a wire diameter of 20 μm or more and 180 μm or less.

In addition, the diameter of the semi-wrought copper wire for a bonding wire
10 according to this embodiment is in a range of 0.15 mm or more and 3.0 mm or less.

[0022]

The semi-wrought copper wire for a bonding wire has a composition that contains one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements such that the total content thereof is in a range of 0.0001 mass% or more and
15 0.01 mass% or less, with a remainder being copper and unavoidable impurities.

Preferably, the total content of the one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements is in a range of 0.0003 mass% or more and 0.002 mass% or less.

In addition, regarding the contents of Fe, Pb, and S which are the unavoidable
20 impurities, the content of Fe is in a range of 0.0001 mass% or less, the content of Pb is in a range of 0.0001 mass% or less, and the content of S is in a range of 0.005 mass% or less.

Here, the rare-earth elements include Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

[0023]

25 The special grain boundary ratio ($L\sigma/L$) of the semi-wrought copper wire for a

bonding wire is in a range of 50% or more. Here, the special grain boundary ratio is the ratio of a special grain boundary length $L\sigma$ to the total crystal grain boundary length L .

Crystal grain boundaries and special grain boundaries are specified by an EBSD measuring apparatus which uses a field emission type scanning electron microscope, and

5 the total crystal grain boundary length L and the special grain boundary length $L\sigma$ are calculated. The special grain boundary ratio is obtained from the calculated lengths.

That is, in the semi-wrought copper wire for a bonding wire in this embodiment, the special grain boundaries are present at a proportion higher than that of typical crystal grain boundaries.

10 The crystal grain boundary is defined as the boundary between adjacent two crystals in which the difference in orientation azimuth between the crystals is in a range of 15° or higher as a result of two-dimensional cross-section observation.

In addition, the special grain boundary is a corresponding grain boundary in which a Σ value crystallographically defined based on the CSL theory (Kronberg et al.:

15 Trans. Met. Soc. AIME, 185, 501 (1949)) satisfies $3 \leq \Sigma \leq 29$, and is defined as a crystal grain boundary in which an intrinsic corresponding position lattice azimuth defect Dq in the corresponding grain boundary satisfies $Dq \leq 15^\circ / \Sigma^{1/2}$ (D. G. Brandon: Acta Metallurgica. Vol. 14, p. 1479, (1966)).

[0024]

20 In addition, the number of acid-insoluble residues having particle sizes of $30 \mu\text{m}$ or more, which are obtained by heating and dissolving 100 g of the semi-wrought copper wire for a bonding wire in this embodiment in a nitric acid solution, is in a range of 1000 or less. Furthermore, the abundance ratio of the above-mentioned acid-insoluble residues is in a range of 0.00015 mass% or less.

[0025]

The evaluation of the acid-insoluble residues is performed by the following procedures.

First, a predetermined amount (100 g) of a specimen is sampled from the semi-wrought copper wire for a bonding wire of which the surface is washed, and the specimen is heated and dissolved in a heated nitric acid solution. The solution is cooled to the room temperature and is thereafter filtered by a filter to collect residues.

The filter that collects the residues is weighed, and the residue mass of the residues is measured. In addition, the ratio of the amount of the residues (residue mass) to the amount of the specimen (the semi-wrought copper wire for a bonding wire) is calculated. As a result, the amount (abundance ratio) of the acid-insoluble residues obtained by heating and dissolving the semi-wrought copper wire for a bonding wire in the nitric acid solution is measured.

Next, the filter that collects the acid-insoluble residues is observed by a scanning electron microscope, and an SEM photograph thereof is taken. The SEM photograph is subjected to image analysis to measure the sizes and the number of the residues. In addition, the number of the residues having particle sizes of 30 μm or more is obtained. As a result, the number of acid-insoluble residues having particle sizes of 30 μm or more, which are obtained by heating and dissolving 100 g of the semi-wrought copper wire for a bonding wire in the nitric acid solution, is measured.

[0026]

Next, a method for producing the semi-wrought copper wire for a bonding wire in this embodiment will be described.

The semi-wrought copper wire for a bonding wire in which the ratio ($L\sigma/L$) of the total special grain boundary length $L\sigma$ of the special grain boundaries to the total crystal

grain boundary length L of the crystal grain boundaries is in a range of 50% or more is produced by a continuous casting and rolling method or an ingot extrusion method.

[0027]

In this embodiment, an example in which a continuous casting and rolling
5 apparatus 10 illustrated in FIG. 1 is used is described.

The continuous casting and rolling apparatus 10 illustrated in FIG. 1 includes a melting furnace 11, a holding furnace 12, a casting trough 13, a belt-wheel type continuous casting machine 30, a continuous rolling device 15, and a coiler 18.

[0028]

10 In this embodiment, as the melting furnace 11, a shaft furnace which includes a cylindrical furnace body is used. A plurality of burners (not illustrated) are arranged in the circumferential direction in the lower part of the furnace body and are arranged in a multi-stage form in the vertical direction. Electrolytic copper which is a raw material is inserted from the upper part of the furnace body. The electrolytic copper is melted by
15 combustion of the burners; and thereby, molten copper is continuously produced.

[0029]

The holding furnace 12 temporarily stores the pure molten copper produced in the melting furnace 11 while being held at a predetermined temperature and sends a constant amount of the molten copper to the casting trough 13.

20 [0030]

The casting trough 13 sends the molten copper sent from the holding furnace 12 to a tundish 20 disposed above the belt-wheel type continuous casting machine 30. The casting trough 13 is sealed by, for example, an inert gas such as Ar or a reducing gas. In addition, in the casting trough 13, a stirring device (not illustrated) for stirring the molten
25 copper using the inert gas is provided.

[0031]

In the tundish 20, an element adding device 21 for adding elements to the sent molten copper is provided. In addition, a pouring nozzle 22 is disposed on the end side of the flowing direction of the molten copper in the tundish 20. The molten copper in the
5 tundish 20 is supplied to the belt-wheel type continuous casting machine 30 via the pouring nozzle 22.

The belt-wheel type continuous casting machine 30 includes a casting wheel 31 having a groove formed in the outer peripheral surface, and an endless belt 32, which revolves and moves to come into contact with a part of the outer peripheral surface of the
10 casting wheel 31. The molten copper supplied via the pouring nozzle 22 is poured into a space formed between the groove and the endless belt 32 and is cooled; and thereby, a bar-like ingot 40 is continuously casted.

[0032]

In addition, the belt-wheel type continuous casting machine 30 is connected to the
15 continuous rolling device 15. The continuous rolling device 15 continuously rolls the bar-like ingot 40 produced from the belt-wheel type continuous casting machine 30; and thereby, a copper rough-drawn wire 50 having a predetermined outside diameter is produced. The copper rough-drawn wire 50 produced from the continuous rolling device 15 passes through a washing and cooling device 16 and a flaw detector 17 and is coiled by
20 the coiler 18.

[0033]

Next, the method for producing the semi-wrought copper wire for a bonding wire using the belt-wheel type continuous casting machine 30 is described by using FIGS. 1 and 2.

25 First, a copper raw material (so-called 4NCu) having a purity of 99.99 mass% or

higher and 99.998 mass% or lower is charged in the melting furnace 11 and is melted to obtain molten copper (melting process S01). In the melting process S01, an air-fuel ratio of the plurality of burners of the shaft furnace is adjusted to make the inside of the melting furnace 11 have a reducing atmosphere.

5 [0034]

The molten copper obtained by the melting furnace 11 is sent to the tundish 20 via the holding furnace 12 and the casting trough 13.

Here, the molten copper that passes through the casting trough 13 sealed by the inert gas or reducing gas is stirred by the above-mentioned stirring device. Thereby, the
10 reaction between the molten copper and the inert gas or reducing gas is accelerated.

[0035]

Next, by the element adding means (device) 21, one or more elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements are continuously added to the molten copper in the tundish 20 (element adding process S02). Thereby, molten copper
15 is generated in which the total content of the one or more elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements is adjusted to be in a range of 0.0001 mass% or more and 0.01 mass% or less, and more preferably in a range of 0.0003 mass% or more and 0.002 mass% or less.

[0036]

20 The molten copper having the adjusted components is supplied to the belt-wheel type continuous casting machine 30 via the pouring nozzle 22, and the bar-like ingot 40 is continuously produced (continuous casting process S03). Here, in the continuous casting process S03, the space between the groove of the casting wheel 31 and the endless belt 32 forms a trapezoidal shape. Therefore, the bar-like ingot 40 having a substantially
25 trapezoidal cross-sectional shape is produced.

[0037]

The bar-like ingot 40 is supplied to the continuous rolling device 15 to be subjected to rolling; and thereby, the copper rough-drawn wire 50 having a predetermined outside diameter (in this embodiment, a diameter of 8 mm) is produced (continuous rolling process S04). In the continuous rolling process S04, rolling is performed at a temperature of 400°C to 900°C. In this embodiment, an initial temperature during rolling is set to be in a range of 800°C or higher. The initial temperature during rolling is preferably in a range of 800°C or higher and 1050°C or lower.

[0038]

The copper rough-drawn wire 50 produced from the continuous rolling device 15 passes through the washing and cooling device 16 and the flaw detector 17 and is coiled by the coiler 18. The washing and cooling device 16 washes and cools the surface of the copper rough-drawn wire 50 produced from the continuous rolling device 15 with a cleaner such as alcohol. In addition, the flaw detector 17 detects flaws of the copper rough-drawn wire 50 sent from the washing and cooling device 16.

[0039]

Next, the obtained copper rough-drawn wire 50 is subjected to wire drawing so as to achieve a final wire diameter of 0.15 mm or more and 3.0 mm or less (in this embodiment, a diameter of 0.9 mm) (wire drawing process S05).

In addition, after the above-described wire drawing process S05, a recrystallization heat treatment is performed at a temperature of 150°C or higher and 250°C or lower (finishing heat treatment process S06). In this embodiment, a heat treatment is performed in an atmosphere at 220°C for two hours.

In the above-described procedures, the semi-wrought copper wire for a bonding

wire in this embodiment is produced.

[0040]

The semi-wrought copper wire for a bonding wire in this embodiment is further subjected to a drawing process to be processed into a fine wire having a diameter of 180
5 μm or less, and the fine wire is used as a bonding wire.

[0041]

The semi-wrought copper wire for a bonding wire in this embodiment having the above properties has a composition that contains one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements such that the total content thereof
10 is in a range of 0.0001 mass% or more and 0.01 mass% or less, with a remainder being copper and unavoidable impurities. More preferably, the total content of the additional elements is in a range of 0.0003 mass% or more and 0.002 mass% or less. Therefore, S contained in the copper forms a compound with the above-mentioned additional elements. Accordingly, the effect of S is reduced; and thereby, low recrystallization temperature and
15 low hardness can be achieved.

[0042]

In addition, the special grain boundary ratio ($L\sigma/L$) of the semi-wrought copper wire for a bonding wire in this embodiment is in a range of 50% or more. In addition, crystal grain boundaries and special grain boundaries are specified by the EBSD
20 measuring apparatus which uses the field emission type scanning electron microscope, and the total crystal grain boundary length L and the special grain boundary length $L\sigma$ are calculated. In addition, the special grain boundary ratio is obtained from the calculated lengths. In the case where the special grain boundary ratio is high, the consistency of the crystal grain boundaries in the entire structure is enhanced, and dislocations are less likely
25 to be accumulated. Therefore, it is possible to enhance elongation and workability while

maintaining low hardness.

[0043]

In addition, the number of acid-insoluble residues having particle sizes of 30 μm or more, which are obtained by heating and dissolving 100 g of the semi-wrought copper wire for a bonding wire in this embodiment in the nitric acid solution, is in a range of 1000 or less. Furthermore, the amount (abundance ratio) of the acid-insoluble residues is in a range of 0.00015 mass% or less.

As described above, the particle sizes of the acid-insoluble residues are small, the number thereof is small, and the abundance ratio thereof is suppressed. Therefore, it is possible to suppress wire breaking when the semi-wrought copper wire for a bonding wire is subjected to wire drawing to be processed into the bonding wire.

[0044]

In addition, according to the method for producing the semi-wrought copper wire for a bonding wire in this embodiment, the copper raw material so-called 4NCu having a purity of 99.99 mass% or higher and 99.998 mass% or lower is used. Therefore, compared to the case where 6NCu is used, the manufacturing cost of the semi-wrought copper wire for a bonding wire can be greatly reduced.

Moreover, the production method includes the continuous casting process S03 of continuously producing the bar-like ingot 40 using the belt-wheel continuous casting machine 30, and the continuous rolling process S04 of continuously rolling the produced bar-like ingot 40 under the condition where the initial temperature is in a range of 800°C or higher. Therefore, the special grain boundary ratio ($L\sigma/L$) of the produced semi-wrought copper wire for a bonding wire can be in a range of 50% or more.

[0045]

While the embodiments of the present invention have been described above, the

present invention is not limited thereto and can be appropriately modified without departing from the features of the present invention.

In this embodiment, the semi-wrought copper wire for a bonding wire is produced by using the belt-wheel type continuous casting machine in the description, but the present invention is not limited thereto.

[0046]

For example, as illustrated in FIG. 3, the semi-wrought copper wire for a bonding wire having a special grain boundary ratio ($L\sigma/L$) of 50% or more may be produced by performing a molten copper generating process S11, a casting process S12, a hot extrusion process S13, a processing and annealing process S14, and a light rolling process S15.

In the molten copper generating process S11, molten copper is obtained by adding one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements to a copper raw material (so-called 4NCu) having a purity of 99.99 mass% or higher and 99.998 mass% or lower.

In the casting process S12, the molten copper is poured into a mold to obtain an ingot having a diameter of 200 mm to 400 mm.

In the hot extrusion process S13, the ingot is extruded under the condition where an initial temperature is in a range of 800°C or higher; and thereby, an extruded wire is obtained. The initial temperature during the extrusion is preferably in a range of 800°C or higher and 1050°C or lower.

In the processing and annealing process S14, the extruded wire is repeatedly subjected to either one of rolling or wire drawing, and annealing. The annealing is performed whenever a cross-section reduction ratio reaches 80% or more.

In the light rolling process S15, rolling is performed at a rolling reduction rate of

5% or more and 25% or less to achieve a final wire diameter of 0.15 mm or more and 3.0 mm or less.

EXAMPLES

5 [0047]

(Example 1)

Hereinafter, results of an evaluation test on the semi-wrought copper wire for a bonding wire in this embodiment described above will be described.

By the method illustrated in the flowchart of FIG. 2, semi-wrought copper wires
10 for a bonding wire of Invention Examples 1 to 5 and Comparative Examples 1 and 2 were produced. Specifically, molten copper was obtained by adding additional elements shown in Table 1 to 4NCu. The molten copper was poured into a belt-wheel type continuous casting machine, and continuous casting and rolling was performed thereon. Furthermore, wire drawing and a finishing heat treatment were performed to produce a
15 semi-wrought copper wire for a bonding wire having a diameter of 0.9 mm.

By the method illustrated in the flowchart of FIG. 3, semi-wrought copper wires for a bonding wire of Invention Examples 6 to 10 and Comparative Examples 3 and 4 were produced. Specifically, molten copper was obtained by adding additional elements shown in Table 1 to 4NCu. An ingot having a diameter of 240 mm was produced from
20 the molten copper. The ingot was subjected to hot extrusion at 800°C to produce an extruded wire having a diameter of 8 mm. The extruded wire was repeatedly subjected to rolling and annealing to produce a semi-wrought copper wire having a diameter of 1 mm. Thereafter, the semi-wrought copper wire was subjected to rolling at a rolling reduction rate of 10%. Next, a finishing heat treatment was performed at 220°C to
25 produce a semi-wrought copper wire for a bonding wire having a diameter of 0.9 mm.

A semi-wrought copper wire for a bonding wire of a related art example was produced by the following method. First, molten copper was obtained by adding 0.0030 mass% of Zr to 4NCu. An ingot having a diameter of 240 mm was produced from the molten copper. The ingot was subjected to hot extrusion at 800°C to produce an
5 extruded wire having a diameter of 8 mm. The extruded wire was subjected to wire drawing. Next, a finishing heat treatment was performed at 220°C to produce a semi-wrought copper wire for a bonding wire having a diameter of 0.9 mm.

In addition, the obtained semi-wrought copper wires for a bonding wire of Invention Examples 1 to 10, Comparative Examples 1 to 4, and the related art example
10 were subjected to wire drawing to produce bonding wires having a diameter of 180 μm .

[0048]

(Special Grain Boundary Ratio)

Special grain boundary ratios (L_{σ}/L) of the obtained semi-wrought copper wires for a bonding wire of Invention Examples 1 to 10, Comparative Examples 1 to 4, and the
15 related art example were measured by the following method.

Mechanical polishing was performed on each specimen using waterproof abrasive paper and diamond abrasive grains. Next, finishing polishing was performed using a colloidal silica solution.

In addition, crystal grain boundaries and special grain boundaries were specified
20 by an EBSB measuring apparatus (S4300-SEM manufactured by Hitachi, Ltd., OIM Data Collection manufactured by EDAX/TSL Inc.) and an analysis software (OIM Data Analysis ver. 5.2 manufactured by EDAX/TSL Inc.), and a total crystal grain boundary length L and a special grain boundary length L_{σ} were calculated. Accordingly, the average crystal grain size and the special grain boundary length ratio were analyzed.

Details of the measuring method are described below.

First, by using a scanning electron microscope, individual measurement points in a measurement range of the specimen surface were irradiated with electron beams, and the specimen surface was two-dimensionally scanned with the electron beams. By azimuth analysis by electron backscatter diffraction, a crystal grain boundary was defined between the adjacent measurement points in which the azimuth difference between the measurement points was in a range of 15° or more.

The total grain boundary length (the total length of all the crystal grain boundaries) L of the crystal grain boundaries in the measurement range was measured.

In addition, the position of a crystal grain boundary at which the interface between adjacent crystal grains was the special grain boundary was identified, and the total grain boundary length (the total length of all the special grain boundaries) $L\sigma$ of the special grain boundaries was measured. In addition, the ratio $L\sigma/L$ of the measured special grain boundary length $L\sigma$ to the total grain boundary length L of the crystal grain boundaries was obtained as a special grain boundary ratio ($L\sigma/L$).

[0049]

(Hardness Test)

Next, hardnesses of the semi-wrought copper wires for a bonding wire of Invention Examples 1 to 10, Comparative Examples 1 to 4, and the related art example and the bonding wires produced from the semi-wrought copper wires for a bonding wire were measured.

In addition, a hardness test was performed based on JIS Z 2241 by using the Vickers microhardness tester MVK-700 manufactured by Akashi Corporation.

[0050]

(Elongation)

Next, the semi-wrought copper wires for a bonding wire of Invention Examples 1 to 10, Comparative Examples 1 to 4, and the related art example and the bonding wires produced from the semi-wrought copper wires for a bonding wire were subjected to a tensile test by using a Amsler vertical type tension testing machine manufactured by Akashi Corporation so as to evaluate elongation.

[0051]

(Workability)

The obtained semi-wrought copper wires for a bonding wire of Invention Examples 1 to 10, Comparative Examples 1 to 4, and the related art example were further subjected to wire drawing to produce wires having diameters of 87 μm , 50 μm , and 20 μm . The number of wire breakages during the wire drawing was evaluated.

[0052]

The evaluation results on the special grain boundary ratios ($L\sigma/L$), hardnesses, and elongations of the semi-wrought wires for a bonding wire, hardnesses and elongations of the bonding wires, and the number of wire breakages during wire drawing are shown in Table 1.

[0053]

Table 1

	Alloy composition of semi-wrought wire for bonding wire		Semi-wrought wire for bonding wire				Bonding wire		Number of breakages (Number/100 km)		
	Additional element (mass ppm)	Remainder	Special grain boundary ratio ($L\sigma/L$)	Hardness (Hv)	Elongation (%)		Hardness (Hv)	Elongation (%)	$\phi 87 \mu\text{m}$	$\phi 50 \mu\text{m}$	$\phi 20 \mu\text{m}$
Invention Example 1	Mg:5	Copper and unavoidable impurities	57	36	41		35	40	0	0	0
Invention Example 2	Mg:80	Copper and unavoidable impurities	60	39	41		36	42	0	0	1
Invention Example 3	Zr:7	Copper and unavoidable impurities	62	34	42		34	44	0	0	0
Invention Example 4	Zr:70	Copper and unavoidable impurities	65	35	42		35	41	0	0	1
Invention Example 5	Sr:8	Copper and unavoidable impurities	54	38	42		39	40	0	0	1
Invention Example 6	Ti:10	Copper and unavoidable impurities	55	33	40		36	38	0	0	0
Invention Example 7	Ba:9	Copper and unavoidable impurities	59	36	41		39	37	0	0	1
Invention Example 8	Ce:15	Copper and unavoidable impurities	52	37	40		38	39	0	0	1
Invention Example 9	Ca:3	Copper and unavoidable impurities	58	38	41		36	40	0	0	0
Invention Example 10	Ca:95	Copper and unavoidable impurities	53	37	40		38	41	0	1	1
Comparative Example 1	Zr:0.5	Copper and unavoidable impurities	41	46	35		51	38	2	9	40
Comparative Example 2	Zr:150	Copper and unavoidable impurities	42	49	30		58	32	5	13	54
Comparative Example 3	Ca:0.3	Copper and unavoidable impurities	38	44	38		53	39	3	8	35
Comparative Example 4	Ca:130	Copper and unavoidable impurities	45	54	31		57	33	7	15	58
Related art example	-	Copper and unavoidable impurities	35	48	35		43	37	3	6	38

[0054]

With regard to Invention Examples 1 to 10, it was confirmed that the special grain boundary ratios ($L\sigma/L$) were in a range of 50% or more. On the other hand, with regard to Comparative Examples 1 to 4 and the related art example, the special grain boundary ratios ($L\sigma/L$) were less than 50%. In comparison between Invention Examples 6 to 10 and the related art example, it was confirmed that it is possible to increase the special grain boundary ratio ($L\sigma/L$) by performing processing at a rolling reduction rate of 10% before subjecting the semi-wrought wire having the final wire diameter to the finishing heat treatment.

With regard to Invention Examples 1 to 10 in which the special grain boundary ratios ($L\sigma/L$) were in a range of 50% or more, it was confirmed that the hardnesses were reduced to 40 Hv or less in the state of the bonding wires having a wire diameter of 180 μm .

In addition, with regard to Invention Examples 1 to 10, it was confirmed that, compared to Comparative Examples, wire breaking was suppressed during wire drawing, and thus the wire could be drawn to have a small diameter.

[0055]

(Example 2)

Next, the residue amount of the acid-insoluble residues and the particle size distribution thereof were evaluated using the semi-wrought copper wires for a bonding wire of Invention Examples 1 to 10.

The specimen was subjected to an etching process in a nitric acid to remove impurities adhering to the surface. Next, 100 g of the specimen was weighed. The specimen was heated and dissolved in a nitric acid solution. The heating temperature

was 60°C. This operation was repeated.

Next, the solution was cooled to the room temperature and filtered by a filter to collect residues.

Here, filtration was performed by using a polycarbonate filter (having pore diameter of 0.4 μm). The polycarbonate filter that collected the residues was precisely weighed in a clean room to measure the residue mass of the residues.

[0056]

In addition, the particle size distribution of the acid-insoluble residues was measured. The above-mentioned filter that collected the residues was observed by the scanning electron microscope, and an SEM image was taken. The image was sent to a personal computer, and the image was analyzed through binarization processing by an image analysis software (WinRoof Software). Then, an area on which the residue was projected was measured, and the diameter of a circle having the same area as the projection area (equivalent circle diameter) was calculated. The equivalent circle diameter was used as the particle size of the residue. The size (equivalent circle diameter) and the number of residues were measured. In addition, a graph of the particle size distribution was plotted from the data of Invention Example 1. The result is shown in FIG. 4.

[0057]

As a result of the image analysis by the WinRoof Software, it was confirmed that, when 100g of the specimen (the semi-wrought copper wire for a bonding wire) of each of Invention Examples 1 to 10 was heated and dissolved in the nitric acid solution, the number of acid-insoluble residues having particle sizes of 30 μm or more was in a range of 1000 or less. In addition, as a result of measuring the residue mass of the residues by the above-described method, it was confirmed that the mass ratios of the acid-insoluble

residues in the specimens of Invention Examples 1 to 10 were in a range of 0.00015 mass% or less.

Industrial Applicability

5 [0058]

The semi-wrought copper wire for a bonding wire in this embodiment has low hardness, high elongation, and excellent workability. Therefore, the semi-wrought copper wire in this embodiment can be appropriately applied to a manufacturing process of a Cu bonding wire used instead of an Au wire.

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Brief Description of Reference Signs

[0059]

30 belt-wheel type continuous casting machine

CLAIMS

1. A semi-wrought copper wire for a bonding wire, which is a semi-wrought copper wire for forming a bonding wire having a wire diameter of 180 μm or less,

5 wherein a diameter of the semi-wrought copper wire is in a range of 0.15 mm or more and 3.0 mm or less,

 the semi-wrought copper wire has a composition that contains one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements such that a total content thereof is in a range of 0.0001 mass% or more and 0.01 mass% or less,

10 with a remainder being copper and unavoidable impurities, and

 a special grain boundary ratio ($L\sigma/L$) which is a ratio of a special grain boundary length $L\sigma$ to a total crystal grain boundary length L measured by an EBSD method is in a range of 50% or more.

15 2. The semi-wrought copper wire for a bonding wire according to claim 1, wherein the total content of the additional elements is in a range of 0.0003 mass% or more and 0.002 mass% or less.

3. The semi-wrought copper wire for a bonding wire according to claim 1 or 2,

20 wherein, regarding contents of Fe, Pb, and S which are the unavoidable impurities, the content of Fe is in a range of 0.0001 mass% or less, the content of Pb is in a range of 0.0001 mass% or less, and the content of S is in a range of 0.005 mass% or less.

4. The semi-wrought copper wire for a bonding wire according to any one of claims 1 to

25 3,

wherein the number of acid-insoluble residues having particle sizes of 30 μm or more, which are obtained by heating and dissolving 100 g of the semi-wrought copper wire for a bonding wire in a nitric acid solution, is in a range of 1000 or less.

- 5 5. The semi-wrought copper wire for a bonding wire according to any one of claims 1 to 4,

wherein an amount of the acid-insoluble residues obtained by heating and dissolving the semi-wrought copper wire for a bonding wire in a nitric acid solution is in a range of 0.00015 mass% or less.

10

6. A method for producing the semi-wrought copper wire for a bonding wire according to any one of claims 1 to 5, the method comprising:

a molten copper generating process of generating molten copper by adding one or more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements
15 to a copper raw material having a purity of 99.99 mass% or higher and 99.998 mass% or lower;

a continuous casting process of continuously producing an ingot by supplying the molten copper to a belt-wheel type continuous casting machine; and

- a continuous rolling process of continuously rolling the produced ingot under a
20 condition where an initial temperature is in a range of 800°C or higher.

7. A method for producing the semi-wrought copper wire for a bonding wire according to any one of claims 1 to 5, the method comprising:

a molten copper generating process of generating molten copper by adding one or
25 more additional elements selected from Mg, Ca, Sr, Ba, Ra, Zr, Ti, and rare-earth elements

to a copper raw material having a purity of 99.99 mass% or higher and 99.998 mass% or lower;

a casting process of producing an ingot by pouring the molten copper into a mold;

an extrusion process of producing an extruded wire by extruding the obtained

5 ingot under a condition where an initial temperature is in a range of 800°C or higher;

a processing and annealing process of repeatedly subjecting the obtained extruded wire to either one of rolling or wire drawing, and annealing; and

a light rolling process of performing rolling at a rolling reduction rate of 5% or more and 25% or less to achieve a final wire diameter of 0.15 mm or more and 3.0 mm or

10 less.