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(54) **COPPER ALLOY AND METHOD FOR PRODUCING COPPER ALLOY**

KUPFERLEGIERUNG UND HERSTELLUNGSVERFAHREN FÜR DIE KUPFERLEGIERUNG  
ALLIAGE DE CUIVRE ET PROCÉDÉ DE FABRICATION DE CELUI-CI

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• **"Mechanical Properties of Intermetallic  
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Copper or Nickel - Hardness as a function of  
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## Description

## Technical Field

**[0001]** The present invention relates to a copper alloy having the high strength and high electrical conductivity which is applied to a lead frame, a connector, a terminal material and the like for electric and electronic instruments and a process for producing a copper alloy, which produces this copper alloy.

## Background Art

**[0002]** Conventionally, in materials requiring electrical conductivity and spring property such as various terminals such as a lead frame and the like, a connector, a relay or a switch and the like of electronic instruments, inexpensive brass has been applied to utilities setting a high value on the manufacturing cost. On the other hand, in utilities setting a high value on a mechanical nature such as spring property and the like, phosphorus bronze has been applied thereto. Further, in addition to spring property, nickel silver has been applied to utilities setting a high value on corrosion resistance.

**[0003]** However, with weight saving, thinning and miniaturization of electronic instruments and parts thereof in recent years, if these materials are used, the necessary strength cannot be sufficiently satisfied under the current circumstances.

**[0004]** In recent years, in materials requiring electrical conductivity and spring property of various terminals and the like of electronic instruments, in place of the conventional solid-solution strengthening alloy, a representative of which is phosphorus bronze, brass and the like, a use amount of an aging hardening-type copper alloy is increasing, from a view point of the high strength and high electrical conductivity.

**[0005]** An aging hardening-type copper alloy is a copper alloy which, by aging-treating a supersaturated solid solution which has been solution-treated, contributes to improvement in strength property such as a proof stress or a spring limit value by uniform precipitation of fine particles, and improvement in electrical conductivity by decrease in a solid solution element amount.

**[0006]** Therefore, as a material satisfying demand of weight saving of electronic instruments and parts thereof, and high strengthening of materials, which are becoming severe increasingly, for example, an aging hardening-type copper alloy such as a Cu-Ni-Si alloy (Colson) and beryllium copper is used.

**[0007]** Additionally, as weight saving, and high strengthening of materials, improvement by a manufacturing process using a Cu-Ni-Si alloy (Colson) as a copper alloy responding to electronic instruments has been also tried. For example, Patent Literature 1 discloses a copper alloy material containing 1.0 to 5.0 mass% of Ni, 0.2 to 1.0 mass% of Si, 1.0 to 5.0 mass% of Zn, 0.1 to 0.5 mass% of Sn, and 0.003 to 0.3 mass% of P, with the remainder consisting of Cu and incidental impurities, which is obtained by a first cold rolling step of cold rolling to a thickness which is 1.3 to 1.7-fold of an objective final plate thickness, a first heat-treating step of heating a material after the first cold rolling to 700 to 900°C and, thereafter, cooling the material to 300°C or lower at a temperature lowering rate of 25°C or more per minute, a second cold rolling step of cold-rolling a material after the first heat treatment to a final plate thickness, a second heat-treating step of heating a material after the second cold rolling to 400 to 500°C, and holding it for 30 minutes to 10 hours, and a step of heating and holding a material after the second heat treatment at 400 to 550°C for 10 seconds to 3 minutes while a tensile force is applied in a longitudinal direction. However, a manufacturing step becomes complicated, and it is difficult to realize reduction in the manufacturing cost.

**[0008]** Improvement by addition of other metal elements utilizing this Cu-Ni-Si (Colson) alloy is disclosed (see Patent Literatures 2 to 4). For example, Patent Literature 2 describes a copper alloy for electronic materials containing Ni: 1.0 to 4.5 mass%, Si: 0.50 to 1.2 mass%, and Cr: 0.0030 to 0.3 mass% (provided that a weight ratio of Ni and Si is  $3 \leq \text{Ni/Si} \leq 5.5$ ), with the remainder being composed of Cu and incidental impurities, in which a Cr-Si compound having a size of 0.1  $\mu\text{m}$  or more and 5  $\mu\text{m}$  or less, which is dispersed in a material is such that an atomic concentration ratio of Cr relative to Si in the dispersed particle is 1 to 5, and a dispersion density thereof is  $1 \times 10^6/\text{mm}^2$  or less. However, this alloy improves the strength of a Ni-Si intermetallic compound, and there is a limit regarding the high strength and high electrical conductivity.

**[0009]** Further, a copper alloy in which a Cr-Si, Ni-P-Fe obtained by adding Fe to Ni-P, or Ni-Ti intermetallic compound, being an intermetallic compound different from a Ni-Si intermetallic is precipitated, is disclosed (see Patent Literatures 5 to 7). For example, Patent Literature 7 describes a copper alloy for electric and electronic instruments containing 1 to 3 mass% of Ni and 0.2 to 1.4 mass% of Ti, in which a ratio (Ni/Ti) of a mass percentage of the Ni and the Ti is 2.2 to 4.7, containing 0.02 to 0.3 mass% of one or both of Mg and Zr, and 0.1 to 5 mass% of Zn, with the remainder consisting of Cu and incidental impurities, in which the copper alloy contains at least one of an intermetallic compound consisting of Ni, Ti and Mg, an intermetallic compound consisting of Ni, Ti and Zr, or an intermetallic compound consisting of Ni, Ti, Mg, and Zr, a distribution density of the intermetallic compounds is  $1 \times 10^9$  to  $1 \times 10^{13}/\text{mm}^2$ , the tensile strength is 650 MPa or more, electrical conductivity is 55 IACS% or more, and a stress relaxation ratio when held at 150°C for 1000 hours is 20% or less.

Patent Literature 8 discloses a beryllium-free precipitation hardenable copper alloy comprising 2-9% by weight nickel, 0.05-2% by weight of aluminium, chromium and silicon, with the balance being copper and impurities. The copper alloy possesses sufficient electrical conductivity to be useful in electrical applications.

## Citation List

### Patent Literatures

#### [0010]

Patent Literature 1: JP-A-2007-070651

Patent Literature 2: JP-A-2009-242921

Patent Literature 3: JP-A-2010-090408

Patent Literature 4: JP-A-2008-266787

Patent Literature 5: JP-A-2007-126739

Patent Literature 6: JP-A-2001-335864

Patent Literature 7: JP-A-2006-336068

Patent Literature 8: GB 2051127 A

Patent Literature 9: DE 42 26 692 A1

Patent Literature 10: JP H04 099140

Patent Literature 11: JP H03 126829

Patent Literature 12: GRYZIECKI JANUSZ ET AL: "The role of microadditions in the kinetic change of precipitation during the aging process of nickel-aluminium bronze", ARCHIVES OF METALLURGY, vol. 48, no. 3 (2003-01-01), pages 245-259

### Summary of Invention

#### Technical Problem

**[0011]** However, in any copper alloy, the high strength and high electrical conductivity which are possessed together are insufficient for a recent demand.

**[0012]** Then, the present invention was done in view of the aforementioned problems, and an object thereof is to provide a copper alloy which is excellent in workability in spite of the high strength, and is of high electrical conductivity, and a process for producing such the copper alloy.

**[0013]** Another object of the present invention is to provide a copper alloy which is excellent in workability in spite of the high strength, and has high electrical conductivity, and which can control physical property, and a process for producing such the copper alloy.

#### Solution to Problem

**[0014]** As the characteristic of the present invention which is the means to solve the aforementioned problems, the present inventors studied in order to obtain a high strength copper alloy and, as a result, found out that it is effective to finely precipitate a  $\gamma'$  phase of the  $L1_2$  structure with  $Ni_3Al$  in a parent phase of the FCC structure, in a Cu-Ni-Al alloy. Further, it was found out that the copper alloy is further highly strengthened by adding Si.

**[0015]** According to the present invention there is provided a high strength copper alloy of the FCC structure as defined in claim 1.

**[0016]** Therefore, the copper alloy of the present invention is a copper alloy including Ni, Al and Si in which a  $\gamma'$  phase of the  $L1_2$  structure is precipitated at an average particle diameter of 100 nm or less, and an area fraction of the  $\gamma'$  phase of 5 to 40%, with  $Ni_3(A1, Si)$ , wherein an atom positioned at a corner is Al and Si, and an atom positioned at a face centre is Ni, in a parent phase of the copper alloy, and the high strength copper alloy has an electrical conductivity of 8.5 IACS or more, and has a Vickers hardness of 220 Hv or more.

**[0017]** Further features of the invention are described in the claims, which define the invention.

**[0018]** The process for producing a high strength copper alloy of the present invention is characterized in that raw materials are integrated, melted and mixed, and hot-worked and cold-worked and, thereafter, the mixture is solution heat-treated in a range of 700 to 1020°C for 0.1 to 10 hours and, thereafter, this is aging-treated in a range of 400 to 650°C and 0.1 to 48 hours.

**[0019]** Further, the process for producing a high strength copper alloy of the present invention is further characterized in that, before or after the aging treatment, cold working at a working rate of 10 to 95% is performed.

## Advantageous Effects of Invention

**[0020]** High electrical conductivity was studied by the copper alloy of the present invention which is the means to solve the problems and, as a result, it was found out that both of the strength and electrical conductivity are satisfied in a region A and a region B. In the region A, a high strength copper alloy having, particularly, high electrical conductivity and excellent workability can be obtained and, in the region B, particularly, a high strength copper alloy having the high strength can be obtained.

**[0021]** Further, high electrical conductivity was studied by the process for producing a copper alloy of the present invention and, as a result, in the region A and the region B, a copper alloy satisfying both of the strength and electrical conductivity can be produced.

## Brief Description of Drawings

**[0022]** Fig. 1 is a photograph of a transmission electron microscope in which an upper side shows a crystal structure  $L1_2$  of a precipitate according to electron beam diffraction, and a lower shows the state of a precipitate.

## Description of Embodiments

**[0023]** A best mode for carrying out the present invention will be explained below based on the drawing. In addition, a so-called person skilled in the art easily changes or modifies the present invention within the scope of the patent claims to create other embodiments. These change and modification are included in the patent claims, and the following explanation is an example of a best mode of the present invention, and does not limit the patent claims.

**[0024]** The copper alloy of the present invention is a copper alloy of the FCC structure containing Ni: 3.0 to 29.5 mass%, Al: 0.5 to 7.0 mass%, and Si: 0.1 to 1.5 mass%, with the remainder consisting of Cu and incidental impurities, in which a  $\gamma'$  phase of the  $L1_2$  structure is precipitated at an average particle diameter of 100 nm or less with  $Ni_3Al$  including Si, in a parent phase of the copper alloy. The  $L1_2$  structure can be confirmed, for example, by an arrangement structure of an electron beam diffraction image.

**[0025]** Fig. 1 is a photograph of a transmission electron microscope in which an upper side shows a crystal structure  $L1_2$  of a precipitate by electron beam diffraction, and a lower side shows the state of a precipitate.

**[0026]** In addition, the present photograph is a composition of Ni: 12.3 mass%-Al: 1.0 mass%-Si: 0.3 mass%-Cu, and the composition has been subjected to solution treatment: 900°C 10 minutes-cold working 30%-aging treatment 500°C 6 hours.

**[0027]** As in Fig. 1, electron beam diffraction is directed to a regular phase having a diffraction plane 110. That is, the  $\gamma'$  phase is an intermetallic compound, and has a regularized FCC structure in which an atom positioning at a corner is Al and Si, and an atom positioning at a face center is Ni.

**[0028]** Further, as described later, in a lower photograph of Fig. 1, it is seen that the  $\gamma'$  phase of the  $L1_2$  structure is finely precipitated.

**[0029]** Since these copper of a parent phase having the FCC structure and  $\gamma'$  phase having the  $L1_2$  structure are both of the FCC structure, they are good in integrity, they contribute to improvement in the strength and, at the same time, a solute element concentration of a parent phase is decreased by precipitating the  $\gamma'$  phase, and they also contribute to improvement in electrical conductivity.

**[0030]** The copper alloy of the present invention is a copper alloy while it has the FCC structure. The FCC structure is a structure in which metal elements are laminated most closely, and is suitable as a parent phase alloy of the high strength and high electrical conductivity. Therefore, copper having the FCC structure is excellent in workability, and an objective shape can be easily made.

**[0031]** In the copper alloy of the present invention, inclusion of Ni: 3.0 to 29.5 mass%, Al: 0.5 to 7.0 mass%, and Si: 0.1 to 1.5 mass% is necessary for satisfying the high intensity and high electrical conductivity.

**[0032]** Ni and Al precipitate an intermetallic compound of  $Ni_3Al$  to form a  $\gamma'$  phase in Cu of a parent phase. Further, since Al and Si together with Ni form a  $Ni_3$  (Al, Si) intermetallic compound, Al and Si together are required at an amount adapted for this system, and form not a system of  $Ni_3Al$  or  $Ni_3Si$  alone, but one  $Ni_3$  (Al, Si) intermetallic compound while it resides in mixture at a corner of the FCC structure in the  $L1_2$  type.

**[0033]** The  $\gamma'$  phase having the  $L1_2$  structure in the copper alloy of the present invention is an intermetallic compound, and has a regularized FCC structure in which an atom positioning at a corner is Al and Si, and an atom positioning at a face center is Ni.

**[0034]** Since these copper of a parent phase having the FCC structure and  $\gamma'$  phase having the  $L1_2$  structure are both of the FCC structure, they are good in integrity, contribute to improvement in the strength and, at the same time, a solute element concentration of a parent phase is decreased by precipitating the  $\gamma'$  phase, and they also contribute to improvement in electrical conductivity.

**[0035]** Further, to explain in detail, since the  $\gamma'$  phase of the  $L1_2$  structure belongs to the GCP (Geometrically close packing) phase, has ductility due to a closed packed structure thereof, and further, is high in integrity, a  $\gamma+\gamma'$  structure is formed, in which a  $\gamma'$  phase being a fine structure is precipitated, thereby, a copper alloy having high workability with toughness can be obtained.

**[0036]** This  $\gamma'$  phase is precipitated finely and spherically in a  $\gamma$  phase containing mainly copper being parent phase. Since the  $\gamma'$  phase is spherical, a highly workable copper alloy with toughness can be obtained without stress concentration at an interface between the  $\gamma'$  phase and the  $\gamma$  phase.

**[0037]** Further, by controlling an average particle diameter of the  $\gamma'$  phase small, it is possible to improve the strength more. By reducing an average particle diameter of the  $\gamma'$  phase, a pinning site of moving rearrangement is increased in the number, and the high tensile strength can be obtained.

**[0038]** Further, the  $\gamma'$  phase is an intermetallic compound, its own hardness is high, and the tensile strength is also high. Therefore, by preventing rearrangement from moving in the  $\gamma'$  phase, it can contribute to a hardness and the tensile strength of a copper alloy.

**[0039]** Further, generally, electrical conductivity is lowered as a concentration of a solute element which forms a solid solution in copper, but since a solute element concentration in a parent phase is decreased as compared with the solutionized state of a  $\gamma$  monophase by heat-treating an alloy at a low temperature to precipitate a  $\gamma'$  phase, precipitation of the  $\gamma'$  phase also contributes to improvement in electrical conductivity. In addition, since electrical conductivity of the  $\gamma'$  phase is lower than electrical conductivity of pure Cu, movement of electrons is reduced by a portion corresponding to a volumetric ratio occupied by this  $\gamma'$  phase, but high electrical conductivity can be maintained by adopting an area fraction of a suitable amount of the  $\gamma'$  phase.

**[0040]** Therefore, when formulated into a copper alloy, the copper alloy greatly contributes to mechanical property such as a hardness, the tensile strength and the like without considerably deteriorating ductility such as cold workability and the like, and as a second phase having the effect of improving electrical conductivity, the  $\gamma'$  phase is suitable. Thereupon, the area fraction of the  $\gamma'$  phase is 5 to 40%.

**[0041]** This area fraction can be obtained by comparing an area of each metal structure of a certain cross section of a copper alloy. In addition, usually, regarding an area fraction and a volume fraction, if areas of sections when two three dimensional-objects are cut with a plane parallel with a certain plane are equal in accordance with Cavalieri principle, volumes of two three dimensional-objects are equal. Therefore, there is no problem that this area fraction is grasped as a volume fraction.

**[0042]** In addition, the area fraction can be measured with a metal microscope, an electron microscope (SEM, TEM), EPMA (X-ray analysis apparatus) or the like.

**[0043]** Further, the average particle diameter of this  $\gamma'$  phase is 100 nm or less. A smaller average particle diameter is preferable, but it is difficult to control a practical precipitation size finer than 1 nm due to coarsening by heat treatment, and when the size is 1 nm or more and 100 nm or less, the sufficient strength can be obtained.

**[0044]** An average particle diameter of the  $\gamma'$  phase is obtained by measuring diameters of a plurality of  $\gamma'$  phases by image analysis from structural observation with an electron microscope, and averaging them.

**[0045]** Thereupon, an intermetallic compound such as  $Ni_2$  (Al, Si), NiAl,  $Ni_5Si_2$  and the like other than the  $\gamma'$  phase of an intermetallic compound of  $Ni_3Al$  is precipitated by added Ni, Al and Si, in some cases.

**[0046]** However,  $Ni_2$  (Al, Si) is smaller in a precipitation amount as compared with that of  $Ni_3$  (Al, Si), and influences little on a mechanical nature and an electric nature of a copper alloy.

**[0047]** An intermetallic compound of a  $\beta$  phase represented by NiAl is precipitated. This  $\beta$  phase is of the B2 structure of the BCC regular structure, but a compositional range at which precipitation occurs, is narrow, and if precipitated, an amount thereof is smaller as compared with that of  $Ni_3$  (Al, Si), and the  $\beta$  phase influences little on a mechanical nature and an electric nature of a copper alloy.

**[0048]** Further, an intermetallic compound of  $Ni_5Si_2$  is precipitated in some cases. This  $Ni_5Si_2$  is also smaller in a precipitation amount as compared with that of  $Ni_3$  (Al, Si), and influences little on a mechanical nature and an electric nature of a copper alloy.

**[0049]** However, precipitation of a number of respective intermetallic compounds other than the  $\gamma'$  phase of  $Ni_3$  (Al, Si) influences on a mechanical nature and an electric nature of a copper alloy, but does not influence thereon more than  $Ni_3$  (Al, Si). However, by combining these all precipitated products, the copper alloy of the present invention is established.

**[0050]** Si has the effect of reducing a concentration of a solute element in a matrix, and has the effect of increasing a volume fraction of the  $\gamma'$  phase and, at the same time, enhancing electrical conductivity. For this reason, the  $\gamma'$  phase, by becoming an intermetallic compound of  $Ni_3$  (Al, Si), is excellent in the strength and electrical conductivity as compared with a single substance of  $Ni_3Al$ . It is preferable that an amount ratio of Al and Si is in a range of Al/Si=1 to 5. This is because when the Al/Si ratio is less than 1, other compounds influencing on reduction in ductility and electrical conductivity, in addition to the  $\gamma'$  phase, are precipitated, and when the ratio is more than 5, a volume fraction of the  $\gamma'$  phase is insufficient, reduction in a concentration of a solute element in a matrix is also insufficient, and increase in the strength and electrical conductivity is not sufficiently obtained.

**[0051]** Therefore, by adopting a range of Al: 0.5 to 7.0 mass%, and Si: 0.1 to 1.5 mass% to precipitate the  $\gamma'$  phase, a compositional region excellent in the high strength, high electrical conductivity, and workability can be obtained.

**[0052]** Further, the copper alloy of the present invention has a compositional range containing Ni: 3.0 to 14.0 mass%, Al: 0.5 to 4.0 mass%, and Si: 0.1 to 1.5 mass%, and has electrical conductivity of 8.5 IACS% or more.

**[0053]** By adopting this compositional range to precipitate the  $\gamma'$  phase of 100 nm or less, electrical conductivity can be made to be 8.5 IACS% or more.

**[0054]** By making electrical conductivity 8.5 IACS% or more, the copper alloy as a copper alloy having high electrical conductivity is applied to a lead frame, a connector, a terminal material and the like of electronic instruments and the like.

**[0055]** Further, in the copper alloy of the present invention, by adopting this compositional range to precipitate the  $\gamma'$  phase of 100 nm or less, further, cold workability can be made to be 10 to 95%.

**[0056]** Cold workability is defined as a reduction ratio of a maximum thickness at which rolling is possible with no cracking without performing annealing in the case of rolling implemented at a temperature of 20°C, and is defined as a maximum area reduction ratio at which wire drawing is possible with no cracking without performing annealing in the case of wire drawing.

**[0057]** Since a  $\text{Ni}_3$  (Al, Si) intermetallic compound of the  $\gamma'$  phase has lower workability than that of pure Cu, a working ratio cannot be increased by a portion corresponding to a ratio of a volume occupied by this  $\text{Ni}_3$  (Al, Si) intermetallic compound.

**[0058]** Therefore, by adopting a compositional range containing Ni: 3.0 to 14.0 mass%, Al: 0.5 to 4.0 mass%, and Si: 0.1 to 1.5 mass%, a precipitation amount of the  $\gamma'$  phase can be controlled to adjust cold workability at 10 to 95% while electrical conductivity is maintained high.

**[0059]** When cold workability is less than 10%, there is a problem that a material having an objective shape cannot be made. When cold workability exceeds 95%, there is a problem that a burden on a facility is great. Therefore, cold workability is preferably in a range of 10 to 95%, further preferably 20 to 90%.

**[0060]** By adjusting cold workability at 10 to 95%, the copper alloy as a copper alloy having the high strength is applied to a lead frame, a connector, a terminal material and the like of electronic instruments and the like.

**[0061]** Further, in the copper alloy of the present invention, addition amounts of Ni, Al and Si are in a region A surrounded by four points of (Al: 2.0 mass%, Ni: 3.0 mass%), (Al: 4.0 mass%, Ni: 9.5 mass%), (Al: 1.5 mass%, Ni: 14.0 mass%), and (Al: 0.5 mass%, Ni: 5.0 mass%), in a Ni vs Al equivalent view represented by Al equivalent (mass%) = (Al mass% + 1.19Si mass%) and Ni mass%.

**[0062]** The copper alloy of the present invention can afford high electrical conductivity and high cold workability by residing in a range of this region A and adopting 5 to 20% of a volume fraction at which the  $\gamma'$  phase is precipitated.

**[0063]** In a range of this region A, since electrical conductivity of approximately 10 to 25 IACS% can be obtained, and cold workability of 10 to 95% can be obtained, the copper alloy as a contact material can reduce abrasion even when the material is contacted and sliding-rubbed frequently.

**[0064]** Therefore, the copper alloy can be applied to a lead frame, a connector, a terminal material and the like of electronic instruments and the like, as a copper alloy having high electrical conductivity and high cold workability.

**[0065]** Further, in the copper alloy of the present invention, Ni: 9.5 to 29.5 mass%, Al: 1.5 to 7.0 mass%, and Si: 0.1 to 1.5 mass% are contained, and a Vickers hardness is in a range of 220 to 450 Hv.

**[0066]** By adding a high amount of Ni to increase a volume and an area occupied by the  $\gamma'$  phase, a Vickers hardness can be enhanced.

**[0067]** In this case, by adjusting a volume fraction at which the  $\gamma'$  phase is precipitated, at 20 to 40%, this can contribute to the strength represented by a Vickers hardness on copper.

**[0068]** Thereupon, an average particle diameter of the  $\gamma'$  phase is preferably 100 nm or less like the above. A smaller average particle diameter is preferable, but it is difficult to perform practical precipitation completely uniformly, and the sufficient strength can be obtained at an average particle diameter of 1 nm or more and 100 nm or less, and 30 nm or less is more preferable.

**[0069]** In addition, in the copper alloy of the present invention, since as electrical conductivity in this compositional range, electrical conductivity of approximately 7 to 15 IACS% can be obtained, abrasion is little, and durability is good, the copper alloy can stand use for a long term, even when applied to a lead frame, a connector, a terminal material and the like of electronic instruments and the like, by possession of a high Vickers hardness together..

**[0070]** In addition, the copper alloy of the present invention is in a region B surrounded by four points of (Al: 4.0 mass%, Ni: 9.5 mass%), (Al: 7.0 mass%, Ni: 16.0 mass%), (Al: 2.5 mass%, Ni: 29.5 mass%), and (Al: 1.5 mass%, Ni: 14.0 mass%), in a Ni vs Al equivalent view represented by Al equivalent (mass%) = (Al mass% + 1.19Si mass%) and Ni mass%.

**[0071]** The copper alloy of the present invention can further have the high strength represented by a Vickers hardness by residing in a range of this region B and adjusting a volume fraction at which the  $\gamma'$  phase is precipitated, at 25 to 40%. This is derived from that the  $\gamma'$  phase is an intermetallic compound, and the strength is very high. However, when an area ratio of the  $\gamma'$  phase is increased, there is a demerit that electrical conductivity is reduced.

**[0072]** Therefore, by residing in a range of this region B, the copper alloy can be also provided with a high Vickers hardness, while high electrical conductivity is obtained.

**[0073]** Thereby, the copper alloy can be widely applied to a lead frame, a connector, a terminal material and the like of electronic instruments and the like.

**[0074]** Further, in the copper alloy of the present invention, further, a total amount of 0.01 to 5.0 mass% of one or two or more elements selected from the group consisting of Co, Ti, Sn, Cr, Fe, Zr, Mg and Zn can be contained as an addition element.

**[0075]** Since Co, Ti, Cr and Zr stabilize the  $\gamma'$  phase and promote precipitation thereof, they contribute to improvement in the strength, and since they also have the effect of decreasing a concentration of a solute element in Cu, they also contribute to improvement in electrical conductivity.

**[0076]** Since Sn, Mg and Zn have the effect of improving stress relaxation resistance property and, at the same time, dissolve in Cu, they contribute to improvement in the strength.

**[0077]** Fe has the effect of miniaturization of a crystal grain by dispersion of a fine grain of Fe in Cu, and contributes to improvement in the strength and improvement in heat resistance.

**[0078]** An addition amount of an addition element is so that selected one or two more addition elements are contained at a total amount of 0.01 to 5.0 mass%. When a total amount of selected one or two or more addition elements is less than 0.01 mass%, there is a problem that this does not contribute to improvement in electrical conductivity and improvement in the strength, for a copper alloy. Further, when a total amount of addition elements exceeds 5.0 mass%, this contributes to improvement in electrical conductivity and improvement in the strength, but there is a problem that it becomes impossible to control electric property such as electrical conductivity and the like, and mechanical property such as a Vickers hardness and the like in a suitable range.

**[0079]** The copper alloy of the present invention can further contain a total amount of 0.001 to 0.5 mass% of one or two or more elements selected from the group consisting of C, P and B as an addition element.

**[0080]** C is thought to have the effect on miniaturization of a crystal grain, and contributes to improvement in the strength. Further, C reduces solid solubility of a solute element in Cu, and contributes to improvement in electrical conductivity.

**[0081]** P is used as a deoxidant, has the effect of decreasing a concentration of impurities of Cu, and contributes to improvement in electrical conductivity.

**[0082]** B has the effect of suppressing growth of a crystal grain and, therefore, has the effect of miniaturizing a crystal grain to improve the strength. B can improve heat resistance.

**[0083]** An addition amount is such that selected one or two or more addition elements are contained at a total amount of 0.001 to 0.5 mass%. When a total amount of addition elements is less than 0.001 mass%, there is a problem that addition elements do not contribute to improvement in electrical conductivity and improvement in the strength, for a copper alloy. On the other hand, when a total amount of addition elements exceeds 0.5 mass%, there is a problem that addition elements contribute to improvement in electrical conductivity and improvement in the strength, but it becomes impossible to control electric property such as electrical conductivity and the like and mechanical property such as a Vickers hardness and the like in a suitable range.

**[0084]** Further, in the process for producing a copper alloy of the present invention, raw materials are integrated, melted, mixed and cast and, thereafter, the cast product is formed into a shape such as a plate material, a wire material, a tube material and the like by hot working such as hot forging and, if necessary, cold working such as cold rolling, cold wire drawing and the like. Then, the formed material is heat-treated in a range of 700 to 1020°C and 0.1 to 10 hours and, thereafter, aging-treated in a range of 400 to 650°C and 0.1 to 48 hours.

**[0085]** The process for producing a copper alloy of the present invention has (a) a step of integrating, melting and mixing Ni: 3.0 to 29.5 mass%, Al: 0.5 to 7.0 mass%, Si: 0.1 to 1.5 mass% and Cu to form a copper alloy material as an ingot, (b) a step of performing solution treatment of heat-treating the copper alloy material at a temperature in a range of 700°C to 1020°C for a time in a range of 0.1 to 10 hours, after the material is formed by hot working and, if necessary, cold working, and (c) a step of performing aging treatment of heating the copper alloy material after solution treatment at a temperature in a range of 400°C to 650°C for a time in a range of 0.1 to 48 hours.

**[0086]** In the (a) step of forming a copper alloy material, as a raw material of a copper alloy, a total amount of 0.01 to 5.0 mass% of one or two or more elements selected from the group consisting of Co, Ti, Sn, Cr, Fe, Zr, Mg and Zn can be also further added as an addition element. Further, as raw material of a copper alloy, a total amount of 0.001 to 0.5 mass% of one or two or more elements selected from the group consisting of C, P and B can be also added.

**[0087]** In melting and mixing, in order to prevent decrease in Al and Si due to oxidation, for example, a deoxidant such as calcium boride and the like may be used, a bubbling treatment may be performed using an argon gas or a nitrogen gas, or melting may be performed in vacuum in a vacuum container. A method of melting is not particularly limited, but a raw material may be heated at a temperature of a melting point of a copper alloy raw material or higher using the known apparatus such as a high frequency melting furnace and the like.

**[0088]** In the (b) step of performing solution treatment, a copper alloy material is heat-treated at a temperature in a



range of 700°C to 1020°C for a time in a range of 0.1 to 10 hours. Thereby, a solid solution in which added alloy elements are uniformly homogenized in a parent phase of Cu without segregation is attained. A method of heating is not particularly limited, but heating may be performed according to the known method.

**[0089]** By this solution treatment, Ni, Al, Si and the like are dispersed homogeneously, thereby, the  $\gamma'$  phase having a fine average particle diameter of 100 nm or less can be precipitated by aging treatment described later.

**[0090]** In the (c) step of performing aging treatment, a copper alloy material is aging-treated at 400 to 650°C, for a time in a range of 0.1 to 48 hours. The  $\gamma'$  phase cannot be precipitated at lower than 400°C and/or for shorter than 0.1 hour. At higher than 650°C and/or for longer than 48 hours, a problem arises that the  $\gamma'$  phase is grown, an average particle diameter exceeds 100 nm, and desired electrical conductivity and working ratio cannot be obtained. Therefore, in order to obtain desired electrical conductivity and hardness, such the aging treatment becomes essential requirement.

**[0091]** Further, the process for producing a high strength copper alloy of the present invention is further characterized in that, before or after the aging treatment, cold working of 10 to 95% is performed.

**[0092]** In the process for producing a high strength copper alloy of the present invention, in addition to the aforementioned production steps, further, (d) a step of subjecting the copper alloy material to cold working of 10 to 95% before or after the aging treatment is provided.

**[0093]** By cold-working a copper alloy material before aging treatment, a lattice defect such as a crystal grain boundary, rearrangement, a lamination defect and the like is formed to miniaturize and working-cure a crystal grain and, at the same time, thereafter, disperse and precipitate a number of  $\gamma'$  phases of  $\text{Ni}_3(\text{Al}, \text{Si})$ , thereby, an average particle diameter of the  $\gamma'$  phase can be made to be 100 nm or less and, at the same time, a temperature of aging treatment can be lowered, and a time of aging treatment can be shortened. A method of cold working is not particularly limited, but the method may be performed by the known method such as rolling with a roller and the like.

**[0094]** Further, since by cold-working a copper alloy material after aging treatment, rearrangement, a lamination defect and the like can be introduced to working-cure the material, the material can be highly strengthened.

**[0095]** Thereupon, working is performed at a working ratio in a range of 10 to 95%. When the working ratio is less than 10%, introduction of a defect is little, and the aforementioned effect of working is not sufficiently obtained. When the working ratio exceeds 95%, a burden on a processing facility becomes great, raising a problem.

**[0096]** After these steps, in order to impart spring property, low temperature aging may be performed in a range of 100 to 400°C. A method of low temperature aging is not particularly limited, but the method can be performed according to the known method.

**[0097]** Since a copper alloy obtained by such the production process can precipitate a sufficient amount of a fine  $\gamma'$  phase while suppressing coarsening of a  $\gamma'$  phase of the  $\text{L}_{12}$  structure precipitating in a copper alloy, electric property such as electrical conductivity and the like, and mechanical property such as cold workability, a Vickers hardness and the like can be easily controlled.

## Examples

(Copper alloy Nos. 1 to 57)

**[0098]** In a range of the copper alloy of the present invention, copper alloy materials of compositions of Examples 1 to 57 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast).

(Compositions of Examples 1 to 57)

**[0099]**

[Table 1-1]

Alloy No.	Ni (mass%)	Al (mass%)	Si (mass%)
1	3	1.8	0.5
2	5	2.5	0.1
3	5	1.3	0.7
4	5	0.3	0.7
5	7.5	2.8	0.75
6	7.5	1.8	0.5

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(continued)

Alloy No.	Ni (mass%)	Al (mass%)	Si (mass%)
7	7.5	0.8	0.5
8	9.5	3.7	0.1
9	10	2.5	1
10	10	2.8	0.7
11	10	2.3	0.5
12	10	1.9	0.3
13	10	1.4	0.2
14	10	0.9	0.2
15	14	1.4	0.3
16	13	2.8	0.2
17	13	2.5	0.5
18	13	2	1
19	13	2	0.75
20	13	1.8	0.2
21	13	1.5	0.5
22	13	1	1
23	13	1	0.7
24	15	4.4	0.5
25	15	3.4	0.1
26	15	1.7	0.7
27	16	6.2	0.7
28	17.5	5.1	0.75
29	17.5	4.4	0.5
30	17.5	3.4	0.5

[Table 1-2]

Alloy No.	Ni (mass%)	Al (mass%)	Si (mass%)
31	17.5	1.8	1
32	20	3.8	1
33	20	3.2	0.7
34	20	2.4	0.5
35	20	2.1	0.3
36	22.5	4.3	0.2
37	22.5	3.8	0.2
38	22.5	3.1	0.3
39	22.5	2.4	0.5
40	22.5	1.9	0.5

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(continued)

Alloy No.	Ni (mass%)	Al (mass%)	Si (mass%)
41	25	3.4	0.5
42	25	2.4	0.5
43	25	1.9	0.5
44	29.5	1.9	0.5
45	3	0.5	0.4
46	5	3.5	0.4
47	5	5.0	0.8
48	10	3.2	1.5
49	10	7.0	0.1
50	15	0.9	0.1
51	20	0.7	0.3
52	25	0.5	0.4
53	25	4.0	0.8
54	25	5.0	0.8
55	25	6.0	0.8
56	29.5	0.9	0.1
57	29.5	5.0	0.8

**[0100]** Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0101]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0102]** Electrical conductivity, workability, a Vickers hardness at each composition thereupon are shown.

(Results of electrical conductivity, workability, Vickers hardness)

**[0103]**

[Table 2-1]

Alloy No..	Electrical conductivity	Workability	Hardness
1	20.8	○	170
2	17.5	○	240
3	22.5	○	225
4	25.3	○	178
5	14.8	○	290
6	17.9	○	285
7	20.7	○	255
8	13.7	×	300
9	13.6	×	307
10	14.4	○	312
11	15.0	○	318

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(continued)

Alloy No..	Electrical conductivity	Workability	Hardness
12	15.8	○	302
13	17.2	○	270
14	17.8	○	217
15	14.8	○	285
16	12.6	○	351
17	12.7	○	369
18	14.1	○	392
19	13.1	○	381
20	14.5	○	331
21	14.5	○	355
22	15.7	○	350
23	14.2	○	295
24	10.8	×	390
25	12.5	○	395
26	14.1	○	348
27	6.8	×	365
28	8.2	×	385
29	9.2	×	400
30	11.3	Δ	390

[Table 2-2]

Alloy No..	Electrical conductivity	Workability	Hardness
31	13.3	○	345
32	9.2	×	393
33	10.5	Δ	352
34	12.2	Δ	320
35	12.8	Δ	305
36	8.0	×	340
37	8.5	×	335
38	9.8	Δ	325
39	11.2	Δ	318
40	11.5	Δ	307
41	7.8	×	320
42	9.1	×	308
43	10.0	×	285
44	6.9	×	260
45	35.0	○	150

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(continued)

Alloy No..	Electrical conductivity	Workability	Hardness
46	14.1	○	265
47	10.1	○	180
48	13.3	○	260
49	6.2	○	220
50	14.8	○	145
51	13.6	○	140
52	11.5	○	130
53	6.8	○	330
54	6.2	○	385
55	5.9	○	345
56	7.3	○	120
57	5.2	○	320

Examples 1, 4, 14, 41, 44, 45, 47 and 49-57 do not belong to the present invention. From Table 2-1 and Table 2-2, it is seen that electric property such as electrical conductivity and the like, and mechanical property such as cold workability, a Vickers hardness and the like can be controlled in a range of the copper alloy of the present invention.

**[0104]** Thereafter, a  $\gamma'$  phase of the  $L_{12}$  structure was precipitated in a parent phase of the FCC structure via production heat treatment condition steps shown in Table 3.

(Production condition)

**[0105]**

[Table 3]

Heat treatment working condition	
1	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)
2	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-aging precipitation treatment (500°C, 6 hours)
3	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-aging precipitation treatment (500°C, 12 hours)
4	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-aging precipitation treatment (500°C, 18 hours)
5	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-cold rolling (rolling reduction 30%)
6	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-cold rolling (rolling reduction 30%)-aging precipitation treatment (500°C, 6 hours)
7	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-cold rolling (rolling reduction 30%)-aging precipitation treatment (500°C, 12 hours)
8	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-cold rolling (rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours)
9	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-aging precipitation treatment (500°C, 6 hours)-cold rolling (rolling reduction 30%)
10	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-aging precipitation treatment (500°C, 12 hours)-cold rolling (rolling reduction 30%)
11	Hot rolling (900°C)-solutionizing (900°C, 10 minutes)-aging precipitation treatment (500°C, 18 hours)-cold rolling (rolling reduction 30%)
12	As-cast

(continued)

	Heat treatment working condition	
5	13	Hot rolling (900°C)

The examples produced by production conditions 1, 5, 12 and 13 do not belong to the present invention.

**[0106]** In Table 4, electrical conductivity and a Vickers hardness at each production condition in Table 3 are shown using copper alloys of compositions of Nos. 16 to 23 as a copper alloy.

(Results of electrical conductivity and Vickers hardness under production condition)

**[0107]**

[Table 4]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness		
Alloy No.	6.6	97	10.0	233	10.0	261	11.2	269	6.8	260	12.0	335	11.2	339	12.6	351	10.1	308	12.3	330	11.8	360	9.2	243	7.6	123
	8.6	104	9.7	253	11.1	286	10.9	300	7.0	233	12.8	366	12.6	368	12.7	369	10.6	323	10.0	361	11.7	346	8.5	291	6.8	150
	7.6	141	11.6	297	12.1	325	12.4	309	8.3	308	11.9	362	14.7	392	14.1	392	10.5	362	12.4	368	13.5	389	8.1	355	8.1	198
	7.0	127	11.0	304	12.2	311	13.5	315	7.5	234	12.1	367	13.0	358	13.1	381	10.8	348	11.8	341	12.9	336	10.9	308	7.2	157
	7.5	91	11.1	221	11.7	268	12.0	300	8.1	220	9.7	325	13.6	323	14.5	331	12.4	314	11.9	361	12.9	357	9.6	197	8.0	103
	8.3	143	11.1	245	8.9	282	14.4	293	7.7	240	9.9	363	13.8	358	14.5	355	11.2	336	10.6	364	13.2	358	9.0	257	8.2	137
	8.7	139	11.3	280	12.9	299	15.1	331	9.4	254	12.0	336	16.0	349	15.7	350	13.3	333	14.2	354	14.6	361	11.8	334	8.4	167
	7.9	150	11.3	262	12.8	275	11.9	282	8.8	213	12.1	309	13.3	279	14.2	295	12.2	316	11.8	319	12.8	316	10.8	306	7.9	122

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**[0108]** As seen from this Table 4, under all heat treatment working conditions other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Copper alloy Nos. 58 to 70)

**[0109]** Then, addition elements were added. Copper alloy materials of compositions of Examples 58 to 70 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast).

(Composition of addition elements)

**[0110]**

[Table 5-1]

Alloy No.	Ni (mass%)	Al (mass%)	Si (mass%)	Cu (mass%)
58	6	1.2	0.64	Remainder
59	13	1.2	0.5	Remainder
60	13	1	1	Remainder
61	13	2	1	Remainder
62	13	1	1	Remainder
63	13	1	1	Remainder
64	13	1	1	Remainder
65	13	2	1	Remainder
66	13	2	1	Remainder
67	13	2	1	Remainder
68	13	1	1	Remainder
69	13	2	1	Remainder
70	13	2	1	Remainder

[Table 5-2]

Alloy No.	Addition element (mass%)
58	B:0.01
59	B:0.01
60	Co:0.2
61	Ti:0.5
62	Sn:0.5
63	Cr:0.5
64	Zr:0.5
65	Fe:0.5
66	Mg:0.5
67	Zn:0.5
68	P:0.1
69	C:1
70	B:0.05



**[0111]** Thereafter, a  $\gamma'$  phase of the L1<sub>2</sub> structure was precipitated in a parent phase of Cu of the FCC structure.

**[0112]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

5 **[0113]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0114]** As seen in Table 6, under production condition of the production process of the present invention, under all of heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

10 (Results of electrical conductivity and Vickers hardness)

**[0115]**

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[Table 6]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness
58	9.7	87	15.8	135	16.5	140	16.8	152	9.5	155	17.3	233	17.6	249	17.8	260	16.3	225	16.7	237	17.1	242	15.0	243	14.8	218
59	7.5	185	10.0	285	10.5	279	10.9	283	7.3	245	9.2	360	13.3	348	14.5	355	11.5	330	12.6	364	13.1	350	9.4	222	9.1	263
60	8.0	143	11.4	280	12.6	241	12.9	299	7.8	215	12.9	326	14.2	315	14.2	301	12.6	320	13.1	309	13.8	304	12.3	265	8.9	121
61	8.1	136	13.0	264	10.4	270	15.4	282	7.6	203	14.9	309	15.2	313	13.4	288	10.1	308	11.2	300	13.7	289	11.0	265	7.3	135
62	9.0	142	12.0	274	12.4	237	14.9	273	8.4	218	13.4	285	16.6	281	19.2	273	14.0	289	14.9	287	15.2	276	11.5	251	8.2	142
63	8.0	120	12.7	244	14.3	251	14.5	250	7.9	197	14.8	286	16.6	246	17.4	231	12.8	295	15.4	268	14.9	255	11.8	255	8.2	130
64	9.2	137	13.9	270	15.7	274	16.2	232	8.3	218	15.2	270	18.0	236	19.0	207	14.0	301	15.3	290	17.2	268	9.8	306	9.8	137
65	6.0	125	10.2	254	10.8	267	11.8	277	6.6	206	11.7	300	12.5	294	12.7	280	10.8	300	11.1	301	11.2	286	8.2	220	5.9	124
66	7.3	148	10.2	278	12.5	283	13.6	286	8.1	201	12.7	315	13.3	311	14.2	302	11.9	308	12.7	306	12.7	309	7.9	282	8.7	136
67	7.6	134	11.6	273	12.8	296	14.1	293	7.8	231	13.4	327	14.8	325	14.8	322	10.9	306	14.0	297	12.8	301	8.8	253	7.9	166
68	8.7	129	12.5	242	14.3	251	15.6	257	9.1	183	15.2	284	15.6	266	16.5	247	13.4	265	14.0	265	15.3	262	9.9	288	8.9	121
69	8.2	121	13.2	267	13.5	257	14.2	270	8.4	204	14.8	283	16.2	269	16.9	219	12.9	294	13.6	285	14.0	274	9.6	314	9.6	161
70	7.5	137	15.1	266	13.2	271	13.8	274	6.7	204	13.5	301	14.9	302	13.6	298	10.7	305	12.8	302	12.4	294	10.2	298	8.3	145

(Copper alloy Nos. 71 to 76)

**[0116]** Then, Sn was added as an addition element.

**[0117]** Copper alloy materials of compositions of Examples 71 to 76 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0118]** Compositions of Examples 71 to 76 are shown in the following Table 7.

[Table 7]

Alloy No.	Addition element (mass%)
71	Sn:0.2
72	Sn:0.2
73	Sn:1.0
74	Sn:0.2
75 (62)	Sn:0.5
76	Sn:1.0
*71~73 Ni13Al2Si1 *74~76 Ni13Al1Si1	

**[0119]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0120]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0121]** As seen from Table 8, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more.

**[0122]** Further, under all heat treatment working conditions essentially including aging treatment other than treatment working conditions 1, 5, 6, 7, 8, 12 and 13, a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0123]**

[Table 8]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13		
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness			
Alloy No.	71	9.7	138	13.8	256	14.1	247	16.0	249	8.3	191	13.5	231	15.1	199	16.4	186	12.7	239	11.8	252	12.2	231	9.2	262	9.2	137
	72	7.8	116	12.2	247	13.1	252	13.5	239	7.8	187	13.4	239	14.2	208	15.0	206	11.8	262	12.4	251	13.8	261	9.7	273	8.1	137
	73	6.9	129	12.4	253	14.9	229	14.6	220	8.7	197	13.4	207	14.6	190	14.6	211	12.6	262	12.5	261	13.5	256	9.6	295	7.8	135
	74	9.7	142	14.2	267	15.2	271	15.9	272	8.0	206	16.1	305	17.5	283	18.9	282	13.6	293	15.3	274	15.3	282	11.4	266	9.2	158
	75	9.0	142	12.0	274	12.4	237	14.9	273	8.4	218	13.4	285	16.6	281	19.2	273	14.0	289	14.9	287	15.2	276	11.5	251	8.2	142
	76	8.6	150	14.4	274	14.2	269	14.8	262	8.1	222	16.6	285	15.7	268	15.1	253	11.9	289	13.0	282	14.0	276	11.7	297	9.4	163

(Copper alloy Nos. 77 to 82)

**[0124]** Then, as an addition element, Ti was added.

**[0125]** Copper alloy materials of compositions of Examples 77 to 82 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0126]** Compositions of Examples 77 to 82 are shown in the following Table 9.

[Table 9]

Alloy No.	Addition element (mass%)
77	Ti:0.2
78(61)	Ti:0.5
79	Ti:1.0
80	Ti:0.2
81	Ti:0.5
82	Ti:1.0
*77~79 Ni13Al2Si1 *79~82 Ni13Al1Si1	

**[0127]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0128]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0129]** As seen from Table 10, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0130]**

[Table 10]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13		
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness			
Alloy No.	77	10.1	213	14.9	283	15.4	288	15.7	272	9.4	231	15.2	302	16.1	292	14.9	279	14.6	290	15.5	275	14.2	273	10.4	295	6.9	151
	78	8.1	136	13.0	264	10.4	270	15.4	282	7.6	203	14.9	309	15.2	313	13.4	288	10.1	308	11.2	300	13.7	289	11.0	265	7.3	135
	79	7.9	226	11.6	293	12.7	291	11.9	279	7.4	239	12.1	305	14.1	286	12.6	284	11.6	275	12.9	270	12.7	277	9.3	276	7.2	171
	80	10.6	163	15.3	234	15.7	239	15.9	228	10.5	206	16.0	254	16.3	237	18.3	234	14.1	247	15.1	241	15.5	234	12.0	287	8.4	148
	81	10.1	168	15.8	242	15.8	229	16.4	233	10.2	205	16.7	265	16.7	247	16.6	244	14.6	244	14.7	242	16.0	243	12.0	266	8.0	143
	82	10.1	183	14.4	255	15.7	249	15.6	264	8.9	204	14.1	271	16.4	261	14.9	256	12.8	249	13.3	247	14.2	241	10.0	252	7.7	138

(Copper alloy Nos. 83 to 88)

**[0131]** Then, as an addition element, Zr was added.

**[0132]** Copper alloy materials of compositions of Examples 83 to 88 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0133]** Compositions of Examples 83 to 88 are shown in the following Table 11.

[Table 11]

Alloy No.	Addition element (mass%)
83	Zr:0.2
84	Zr:0.5
85	Zr:1.0 0
86	Zr:0.2
87 (64)	Zr:0.5
88	Zr:1.0 0
*83~85 Ni13Al2Si1 *86~88 Ni13Al1Si1	

**[0134]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0135]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0136]** As seen from Table 12, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0137]**

[Table 12]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13		
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	
Alloy No.	83	9. 4	145	15. 3	282	11. 7	277	13. 2	281	8. 2	208	10. 8	299	15. 2	284	15. 2	284	12. 9	306	13. 0	299	13. 6	314	9. 2	281	5. 9	170
	84	8. 3	184	12. 4	295	13. 4	285	13. 2	292	8. 2	232	13. 8	321	14. 4	313	14. 3	303	12. 3	312	13. 0	316	13. 0	309	10. 0	283	6. 4	167
	85	10. 2	169	15. 5	255	15. 7	253	15. 1	248	11. 0	196	15. 4	264	16. 2	258	17. 6	245	14. 2	265	14. 7	254	13. 4	260	10. 2	283	7. 9	130
	86	8. 6	188	13. 0	279	12. 8	279	13. 4	277	8. 8	223	13. 3	319	13. 9	303	13. 9	284	11. 3	299	13. 3	293	12. 9	292	10. 2	262	7. 5	162
	87	9. 2	137	13. 9	270	15. 7	274	16. 2	232	8. 3	218	15. 2	270	18. 0	236	19. 0	207	14. 0	301	15. 3	290	17. 2	268	9. 8	306	9. 8	137
	88	8. 9	167	13. 7	263	13. 7	258	14. 7	252	8. 8	209	13. 3	266	15. 1	252	16. 5	239	14. 0	265	14. 8	259	15. 0	254	9. 9	259	7. 0	140



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(Copper alloy Nos. 89 to 94)

**[0138]** Then, as an addition element, Cr was added.

**[0139]** Copper alloy materials of compositions of Examples 89 to 94 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0140]** Compositions of Examples 89 to 94 are shown in the following Table 13.

[Table 13]

Alloy No.	Addition element (mass%)
89	Cr:0.2
90	Cr:0.5
91	Cr:1.0
92	Cr:0.2
93 (63)	Cr:0.5
94	Cr:1.0
*89~91 Ni13Al2Si1 *92~94 Ni13Al1Si1	

**[0141]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0142]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0143]** As seen from Table 14, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0144]**

[Table 14]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness
Alloy No.																										
89	7.8	187	12.8	282	13.3	295	13.6	286	7.7	225	12.8	303	13.6	297	14.3	292	12.2	297	12.7	285	13.4	299	4.4	252	7.2	152
90	6.9	179	12.5	288	14.3	267	13.7	282	7.2	228	13.2	313	14.3	286	15.4	301	12.3	289	12.4	307	13.9	285	9.1	279	6.3	161
91	6.8	194	11.8	285	13.9	304	14.5	281	7.3	224	13.0	321	14.1	321	14.8	314	11.2	313	13.2	300	13.7	294	9.0	252	6.4	154
92	9.1	168	14.1	251	14.6	245	15.2	249	9.2	203	15.0	266	15.8	239	16.8	211	14.0	250	15.1	256	15.1	246	10.5	277	7.8	126
93	8.0	120	12.7	244	14.3	251	14.5	250	7.9	197	14.8	286	16.6	246	17.4	231	12.8	295	15.4	268	14.9	255	11.8	255	8.2	130
94	7.2	170	13.4	286	14.3	279	15.0	269	7.6	219	16.0	277	15.8	274	15.6	281	12.3	275	14.8	264	13.8	273	9.3	251	7.1	150

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(Copper alloy Nos. 95 to 100)

[0145] Then, as an addition element, Fe was added.

[0146] Copper alloy materials of compositions of Examples 95 to 100 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

[0147] Compositions of Examples 95 to 100 are shown in the following Table 15.

[Table 15]

Alloy No.	Addition element (mass%)
95	Fe:0.2
96 (65)	Fe:0.5
97	Fe:1.0
98	Fe:0.2
99	Fe:0.5
100	Fe:1.0
*95~97 Ni13Al2Si1 *98~100 Ni13Al1Si1	

[0148] Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction ratio 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

[0149] Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

[0150] As seen from Table 16, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Result of electrical conductivity and Vickers hardness)

[0151]

[Table 16]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Alloy No.	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity
95	9.0	183	13.4	274	13.8	275	14.4	272	8.9	227	14.4	299	15.0	271	14.2	276	14.0	318	14.0	269	14.8	287	9.6	287	6.0	169
96	6.0	125	10.2	254	10.8	267	11.8	277	6.6	206	11.7	300	12.5	294	12.7	280	11.1	300	11.1	301	11.2	286	8.2	220	5.9	124
97	7.0	210	11.8	280	12.6	260	12.6	267	6.7	223	12.6	307	13.0	290	13.0	287	11.5	277	11.5	281	12.6	274	8.3	260	5.7	169
98	7.4	185	12.0	236	15.5	231	13.6	230	9.5	196	14.7	258	15.9	241	16.1	231	15.5	249	15.5	255	14.8	243	12.6	287	7.4	139
99	9.1	157	13.5	236	14.3	234	14.3	233	9.1	203	11.6	260	15.5	246	15.3	233	14.9	244	14.9	249	14.6	248	11.1	281	7.1	122
100	9.2	163	14.4	238	15.8	231	15.2	212	7.9	201	14.1	256	13.9	252	14.2	244	13.4	246	13.4	256	12.6	240	8.6	268	6.8	157

(Copper alloy Nos. 101 to 106)

**[0152]** Then, as an addition element, P was added.

**[0153]** Copper alloy materials of compositions of Examples 101 to 106 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0154]** Compositions of Examples 101 to 106 are shown in the following Table 17.

[Table 17]

Alloy No.	Addition element (mass%)
101	P:0.01
102	P:0.05
103	P:0.1
104	P:0.01
105	P:0.05
106 (68)	P:0.1
*101~103 Ni13Al2Si1	
*104~106 Ni13Al1Si1	

**[0155]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0156]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0157]** As seen from Table 18, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0158]**

[Table 18]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness		
Alloy No.	9.5	170	15.3	275	16.1	287	16.2	277	10.6	210	14.5	297	15.2	254	18.6	269	14.6	295	15.7	290	16.1	274	11.1	275	8.0	139
	7.8	179	12.1	266	13.1	275	14.3	279	7.8	206	12.5	307	14.0	289	14.8	293	12.0	281	12.7	278	14.2	285	9.4	277	6.4	161
	7.1	150	13.0	261	12.9	279	14.1	277	8.6	213	12.4	299	13.5	291	15.0	290	13.1	283	15.6	265	14.7	288	10.5	285	7.6	134
	10.3	147	14.0	238	15.8	238	15.5	234	8.5	181	15.3	266	16.1	248	16.8	239	15.2	255	15.4	249	16.2	244	10.8	278	8.2	127
	10.1	145	14.3	247	15.6	252	16.7	245	9.1	186	14.6	274	13.6	261	12.8	249	11.8	258	14.7	255	13.4	258	11.4	265	8.2	118
	8.7	129	12.5	242	14.3	251	15.6	257	9.1	183	15.2	284	15.6	266	16.5	247	13.4	265	14.0	265	15.3	262	9.9	288	8.9	121

(Copper alloy Nos.107 to 112)

**[0159]** Then, as an addition element, Zn was added.

**[0160]** Copper alloy materials of compositions of Examples 107 to 112 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0161]** Compositions of Examples 107 to 112 are shown in the following Table 19.

[Table 19]

Alloy No.	Addition element (mass%)
107	Zn:0.2
108(67)	Zn:0.5
109	Zn:1.0
110	Zn <sub>1</sub> :0.2
111	Zn:0.5
112	Zn:1.0
*107~109 Ni13Al2Si1	
*110~112 Ni13Al1Si1	

**[0162]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0163]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0164]** As seen from Table 20, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0165]**

[Table 20]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Alloy No.	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity
107	8.9	189	14.8	275	15.1	275	15.2	283	9.9	232	14.1	289	16.1	271	16.2	262	14.2	285	15.4	282	15.5	272	11.1	260	7.7	181
108	7.6	134	11.6	273	12.8	296	14.1	293	7.8	231	13.4	327	14.8	325	14.8	322	10.9	306	14.0	297	12.8	301	8.8	253	7.9	166
109	8.8	179	13.5	295	14.1	287	14.2	287	9.0	231	13.9	299	15.7	283	16.1	285	12.6	285	14.2	275	14.8	278	9.4	301	6.7	198
110	9.3	160	14.6	233	15.3	233	16.0	223	9.2	187	14.4	256	15.5	233	16.1	236	13.7	233	14.7	246	14.6	250	10.5	292	7.8	135
111	9.8	142	14.3	242	15.7	236	14.7	221	10.0	188	15.7	250	15.7	238	15.8	236	14.5	257	15.2	238	12.7	235	11.3	277	7.6	138
112	9.8	157	14.6	234	13.8	229	14.6	230	9.8	191	15.0	254	14.9	247	16.2	237	15.1	234	14.7	236	12.8	238	10.1	258	6.7	147



(Copper alloy Nos. 113 to 118)

**[0166]** Then, as an addition element, Mg was added.

**[0167]** Copper alloy materials of compositions of Examples 113 to 118 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0168]** Compositions of Examples 113 to 118 are shown in the following Table 21.

[Table 21]

Alloy No.	Addition element (mass%)
113	Mg:0.2
114(66)	Mg:0.5
115	Mg:1.0
116	Mg:0.2
117	Mg:0.5
118	Mg:1.0
*113~115 Ni13Al2Si1	
*116~118 Ni13Al1Si1	

**[0169]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0170]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0171]** As seen from Table 22, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0172]**

[Table 22]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13		
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness			
Alloy No.	113	7. 7	189	13. 4	275	13. 0	288	14. 9	252	7. 6	230	13. 6	291	14. 7	288	13. 9	286	13. 5	282	13. 5	274	14. 3	281	9. 4	267	6. 6	168
	114	7. 3	148	10. 2	278	12. 5	283	13. 6	286	8. 1	201	12. 7	315	13. 3	311	14. 2	302	11. 9	308	12. 7	306	12. 7	309	7. 9	282	8. 7	136
	115	9. 9	201	14. 9	292	15. 3	275	12. 2	269	13. 4	228	12. 1	309	13. 4	291	12. 9	279	9. 8	292	12. 3	310	13. 1	302	9. 1	267	7. 9	177
	116	8. 9	156	13. 7	229	11. 3	221	10. 2	230	10. 6	195	15. 5	256	16. 4	250	15. 8	239	12. 3	245	16. 2	249	11. 5	237	10. 7	285	7. 1	131
	117	9. 4	155	14. 2	234	14. 7	235	14. 7	228	9. 1	199	14. 0	260	15. 1	238	15. 6	239	13. 9	261	14. 2	247	14. 9	245	9. 6	272	8. 1	131
	118	9. 9	170	14. 5	232	15. 4	217	15. 2	224	10. 3	229	14. 0	243	14. 9	237	14. 7	225	13. 9	258	14. 9	258	14. 1	256	11. 3	285	7. 5	144

(Copper alloy Nos. 119 to 122)

**[0173]** Then, as an addition element, B was added.

**[0174]** Copper alloy materials of compositions of Examples 119 to 122 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

**[0175]** Compositions of Examples 119 to 122 are shown in the following Table 23.

[Table 23]

Alloy No.	Addition element (mass%)
119	B:0.01
120 (70)	B:0.05
121	B:0.01
122	B:0.05
*119/120 Ni13Al2Si1	
*121/122 Ni13Al1Si1	

**[0176]** Heat treatment condition is representative production condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

**[0177]** Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

**[0178]** As seen from Table 24, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

**[0179]**

[Table 24]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness
119	8.8	161	12.1	264	12.9	282	14.5	275	8.5	213	13.5	302	14.1	299	14.8	286	12.3	290	13.1	293	14.4	284	10.0	288	7.6	152
120	7.5	137	15.1	266	13.2	271	13.8	274	6.7	204	13.5	301	14.9	302	13.6	298	10.7	305	12.8	302	12.4	294	10.2	298	8.3	145
121	9.1	129	13.4	252	14.1	241	14.9	248	9.0	149	13.6	272	15.4	256	15.8	262	16.4	255	15.0	264	17.4	254	10.6	284	7.2	106
122	8.0	151	12.6	258	15.2	264	13.9	265	10.3	190	15.4	269	16.5	265	17.4	254	14.2	265	15.8	250	16.3	289	10.8	245	8.2	135

(Copper alloy Nos. 123 to 128)

[0180] Then, as an addition element, Co was added.

[0181] Copper alloy materials of compositions of Examples 123 to 128 were integrally placed into a high frequency induction melting furnace, fused, melted and mixed. This was formulated into a cast ingot (as-cast). Thereafter, a  $\gamma'$  phase of the  $L1_2$  structure was precipitated in a parent phase of Cu of the FCC structure.

[0182] Compositions of Examples 123 to 128 are shown in the following Table 25.

[Table 25]

Alloy No.	Addition element (mass%)
123	Co:0.2
124	Co:0.5
125	Co:1.0
126 (60)	Co:0.2
127	Co:0.5
128	Co:1.0
*123~125 Ni13Al2Si1	
*126~128 Ni13Al1Si1	

[0183] Heat treatment condition is representative productive condition, and is hot rolling (900°C, rolling reduction 90%)-solutionizing (900°C, 10 minutes)-cold rolling (20°C, rolling reduction 30%)-aging precipitation treatment (500°C, 18 hours).

[0184] Electrical conductivity and a Vickers hardness at each composition thereupon are shown.

[0185] As seen from Table 26, under production condition of the production process of the present invention, under all heat treatment working conditions essentially including aging treatment other than heat treatment working conditions 1, 5, 12 and 13, electrical conductivity was 8.5 IACS% or more, and a Vickers hardness was 220 Hv or more.

(Results of electrical conductivity and Vickers hardness)

[0186]

[Table 26]

Heat treatment condition	1		2		3		4		5		6		7		8		9		10		11		12		13	
	Alloy No.	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity	Hardness	Electrical conductivity
123	7.9	160	12.5	268	14.2	267	13.5	260	7.6	213	13.1	284	14.1	273	15.0	271	12.1	281	13.5	272	13.6	278	10.6	262	8.5	140
124	7.7	141	10.8	254	12.0	262	13.7	264	7.4	208	13.3	288	14.4	283	13.1	282	10.2	277	11.2	274	11.9	263	9.5	271	8.1	135
125	6.5	152	11.0	264	11.7	270	11.9	270	5.8	213	12.0	302	14.2	289	14.0	294	10.9	288	11.3	289	11.3	293	8.1	275	6.8	140
126	8.0	143	11.4	280	12.6	241	12.9	299	7.8	215	12.9	326	14.2	315	14.2	301	12.6	320	13.1	309	13.8	304	12.3	265	8.9	121
127	7.9	113	11.9	267	13.3	235	10.7	241	7.3	175	14.2	236	16.2	207	17.5	192	12.2	265	13.6	244	13.5	230	9.9	275	7.6	123
128	7.6	121	11.8	233	12.5	227	13.4	220	7.7	184	11.3	242	11.6	226	12.9	202	11.7	254	13.1	258	13.7	240	10.5	275	6.2	123

**[0187]** Therefore, the copper alloy of the present invention is a copper alloy having a predetermined composition, which is obtained by a predetermined production process, and since the copper alloy can precipitate a sufficient amount of a fine  $\gamma'$  phase while coarsening of a  $\gamma'$  phase of the  $L1_2$  structure which is precipitated in a copper alloy is suppressed, it was seen that it can easily control electric property such as electrical conductivity and the like, and mechanical property such as cold workability, a Vickers hardness and the like.

## Claims

1. A high strength copper alloy of the FCC structure containing Ni: 3.0 to 29.5 mass%, Al: 0.5 to 7.0 mass%, and Si: 0.1 to 1.5 mass%, optionally further containing a total amount of 0.01 to 5.0 mass% of one or two or more elements selected from the group consisting of Co, Ti, Sn, Cr, Fe, Zr, Mg and Zn, as an addition element, and optionally further containing a total amount of 0.001 to 0.5 mass% of one or two or more elements selected from the group consisting of C, P and B, as an addition element with the remainder consisting of Cu and incidental impurities, wherein:

a  $\gamma'$  phase of the intermetallic compound  $Ni_3(Al, Si)$  having a structure of  $L1_2$  and an FCC is precipitated, wherein an atom positioned at a corner is Al and Si, and an atom positioned at a face centre is Ni, the average particle diameter being 100 nm or less and an area fraction of the  $\gamma'$  phase being 5 to 40% in a parent phase of the copper alloy; and

the high strength copper alloy has an electrical conductivity of 8.5 IACS% or more, and has a Vickers hardness of 220 Hv or more.

2. The high strength copper alloy according to claim 1, wherein the high strength copper alloy contains Ni: 3.0 to 14.0 mass%, Al: 0.5 to 4.0 mass%, and Si: 0.1 to 1.5 mass%, and has electrical conductivity of 10 to 25 IACS%.

3. The high strength copper alloy according to claim 1 or 2, wherein cold workability is in a range of 10 to 95%.

4. The high strength copper alloy according to claim 1, wherein the high strength copper alloy contains Ni: 9.5 to 29.5 mass%, Al: 1.5 to 7.0 mass%, and Si: 0.1 to 1.5 mass%, and has a Vickers hardness of 220 to 450 Hv and electrical conductivity of 8.5 to 15 IACS%.

5. A process for producing the high strength copper alloy according to any of claims 1 to 4, the process comprising integrating, melting, mixing, hot-working and cold-working raw materials, then, solution heat-treating the worked product in a range of 700 to 1020°C and 0.1 to 10 hours and, thereafter, aging-treating this in a range of 400 to 650°C, and 0.1 to 48 hours.

6. The process for producing the high strength copper alloy according to claim 5, wherein before or after the aging treatment, cold working at a working ratio of 10 to 95% is performed.

## Patentansprüche

1. Hochfeste Kupferlegierung der FCC-Struktur, enthaltend 3,0 bis 29,5 Masse-% Ni, 0,5 bis 7,0 Masse-% Al und 0,1 bis 1,5 Masse-% Si, gegebenenfalls ferner enthaltend eine Gesamtmenge von 0,01 bis 5,0 Masse-% von einem oder zwei oder mehr Elementen, die aus der Gruppe ausgewählt sind, welche aus Co, Ti, Sn, Cr, Fe, Zr, Mg und Zn besteht, als Zusatzelement und gegebenenfalls ferner enthaltend eine Gesamtmenge von 0,001 bis 0,5 Masse-% von einem oder zwei oder mehr Elementen, die aus der Gruppe ausgewählt sind, welche aus C, P und B besteht, als Zusatzelement, wobei der Rest aus Cu und zufälligen Verunreinigungen besteht, wobei:

eine  $\gamma'$ -Phase der intermetallischen Verbindung  $Ni_3(Al, Si)$  mit einer Struktur von  $L1_2$  und einem FCC ausgefällt wird, wobei es sich bei einem an einer Ecke positionierten Atom um Al und Si handelt und es sich bei einem im vorderen Zentrum positionierten Atom um Ni handelt, wobei der durchschnittliche Teilchendurchmesser 100 nm oder weniger beträgt und ein Flächenanteil der  $\gamma'$ -Phase in einer Ausgangsphase der Kupferlegierung 5 bis 40 % beträgt; und

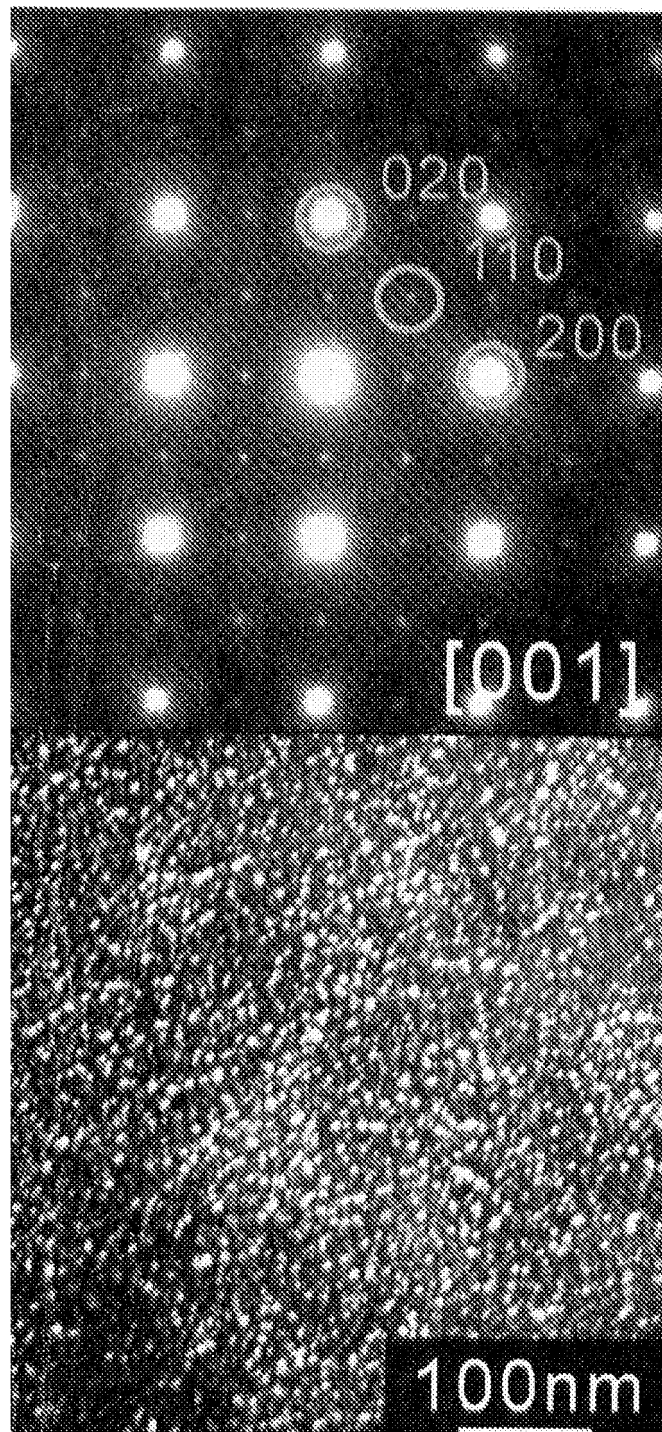
die hochfeste Kupferlegierung eine elektrische Leitfähigkeit von 8,5 IACS% oder mehr aufweist und eine Vickershärte von 220 Hv oder mehr aufweist.

2. Hochfeste Kupferlegierung nach Anspruch 1,  
wobei die hochfeste Kupferlegierung 3,0 bis 14,0 Masse-% Ni, 0,5 bis 4,0 Masse-% Al und 0,1 bis 1,5 Masse-% Si  
enthält, und eine elektrische Leitfähigkeit von 10 bis 25 IACS% aufweist.
3. Hochfeste Kupferlegierung nach Anspruch 1 oder 2,  
wobei die Kaltformbarkeit im Bereich von 10 bis 95 % liegt.
4. Hochfeste Kupferlegierung nach Anspruch 1,  
wobei die hochfeste Kupferlegierung 9,5 bis 29,5 Masse-% Ni, 1,5 bis 7,0 Masse-% Al und 0,1 bis 1,5 Masse-% Si  
enthält, und Vickershärte von 220 bis 450 Hv und eine elektrische Leitfähigkeit von 8,5 bis 15 IACS% aufweist.
5. Verfahren zum Herstellen der hochfesten Kupferlegierung nach einem der Ansprüche 1 bis 4, wobei das Verfahren  
das Einarbeiten, Schmelzen, Mischen, Heißformen und Kaltformen von Rohmaterialien, dann Lösungsglühen des  
geformten Produkts in einem Bereich von 700 bis 1020 °C und für 0,1 bis 10 Stunden und anschließendes Auslagern  
des geformten Produkts in einem Bereich von 400 bis 650 °C und für 0,1 bis 48 Stunden umfasst.
6. Verfahren zum Herstellen der hochfesten Kupferlegierung nach Anspruch 5,  
wobei vor oder nach dem Auslagern eine Kaltformung bei einem Formungsanteil von 10 bis 95 % durchgeführt wird.

## Revendications

1. Alliage de cuivre de grande résistance ayant la structure FCC contenant Ni : 3,0 à 29,5 % en masse, Al : 0,5 à 7,0  
% en masse, et Si : 0,1 à 1,5 % en masse, contenant en outre de manière facultative une quantité totale de 0,01 à  
5,0 % en masse d'un ou deux ou plus de deux éléments choisis parmi le groupe constitué de Co, Ti, Sn, Cr, Fe,  
Zr, Mg et Zn, en tant qu'élément d'ajout, et contenant en outre de manière facultative une quantité totale de 0,001  
à 0,5 % en masse d'un ou deux ou plus de deux éléments choisis parmi le groupe constitué de C, P et B, en tant  
qu'élément d'ajout, le reste étant constitué de Cu et d'impuretés accidentelles, dans lequel :  
une phase  $\gamma'$  du composé intermétallique  $Ni_3(Al, Si)$  ayant une structure de  $L1_2$  et FCC est précipitée, dans  
lequel un atome positionné à un angle est Al et Si, et un atome positionné au niveau d'un centre de face est  
Ni, le diamètre moyen des particules étant de 100 nm ou moins et une fraction de surface de la phase  $\gamma'$  étant  
de 5 à 40 % dans une phase parent de l'alliage de cuivre ; et  
l'alliage de cuivre de grande résistance a une conductivité électrique de 8,5 % IACS ou plus, et a une dureté  
Vickers de 220 Hv ou plus.
2. Alliage de cuivre de grande résistance selon la revendication 1,  
dans lequel l'alliage de cuivre de grande résistance contient Ni : 3,0 à 14,0 % en masse, Al : 0,5 à 4,0 % en masse,  
et Si : 0,1 à 1,5 % en masse,  
et a une conductivité électrique de 10 à 25 % IACS.
3. Alliage de cuivre de grande résistance selon la revendication 1 ou 2,  
dans lequel l'aptitude au façonnage à froid est dans une plage de 10 à 95 %.
4. Alliage de cuivre de grande résistance selon la revendication 1,  
dans lequel l'alliage de cuivre de grande résistance contient Ni : 9,5 à 29,5 % en masse, Al : 1,5 à 7,0 % en masse,  
et Si : 0,1 à 1,5 % en masse,  
et a une dureté Vickers de 220 à 450 Hv et une conductivité électrique de 8,5 à 15 % IACS.
5. Procédé de production de l'alliage de cuivre de grande résistance selon l'une quelconque des revendications 1 à 4,  
le procédé comprenant l'intégration, la fusion, le mélange, le façonnage à chaud et le façonnage à froid de matériaux  
bruts, puis le traitement thermique en solution du produit façonné dans une plage de 700 à 1020 °C et de 0,1 à 10  
heures et, ensuite, un traitement de vieillissement de celui-ci dans une plage de 400 à 650 °C, et de 0,1 à 48 heures.
6. Procédé de production de l'alliage de cuivre de grande résistance selon la revendication 5,  
dans lequel, avant ou après le traitement de vieillissement, un façonnage à froid à un rapport de façonnage compris  
entre 10 et 95 % est effectué.





## REFERENCES CITED IN THE DESCRIPTION

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