

Description

ALUMINUM ALLOY WIRE FOR POWER SEMICONDUCTOR DEVICE

Technical Field

[0001] The present invention relates to an aluminum alloy wire to be used for connecting an electrode on a semiconductor element and an external electrode to each other by ultrasonic bonding and, particularly, to an aluminum alloy wire for power semiconductor device.

Background Art

[0002] A bonding pad formed on a semiconductor element such as silicon (Si), silicon carbide (SiC) and gallium nitride (GaN) is usually formed on an electrode of the semiconductor element as a film of a high purity aluminum (Al) metal having purity of 99.99 mass% or more or an Al-0.3 to 1.5 mass% Si alloy by vapor deposition or sputtering. An aluminum alloy wire is used for ultrasonic bonding between the aluminum pad of the semiconductor element and a lead frame or the like. As the aluminum alloy wire, a round wire having a wire diameter of 50 to 500 μm is generally used, and a very thin wire having a wire diameter of less than 50 μm or a wire having a wire diameter larger than 500 μm is used in some cases. A flat square wire (tape) which is obtained by flattening any one of the above-mentioned wires is sometimes used for semiconductor devices.

In the ultrasonic bonding employed for the aluminum alloy wire, a superhard tool is pressed against the aluminum alloy wire, so that the aluminum alloy wire is bonded to the aluminum pad by way of a pressing load and energy of ultrasonic wave vibration from the superhard tool. The effects of the ultrasonic wave application include enlargement of a bonding area for promoting modification of the aluminum alloy wire and achievement of interatomic bonding between the aluminum alloy wire and the aluminum pad while progressively enlarging newly-formed surfaces which are in close contact with each other by exposing metal atoms of aluminum (Al) and the like at a lower surface through destruction and removal of a surface oxide film of about 5 to 10 nm formed on the aluminum alloy wire and by generating a plastic flow on an interface between the lower surface and the bonding pad contacting the lower surface.

As aluminum alloy wires in which a small amount of iron (Fe) is contained in aluminum (Al), the following examples are known. However, when the content of high purity aluminum (Al) as a raw material is increased, mechanical strength of the aluminum alloy wire having wire diameter of 50 to 500 μm is deteriorated, thereby raising problems such as a difficulty in forming a loop as a bonding wire and detachment and disconnection of the bonding wire from the aluminum pad due to thermal shock in the case where the semiconductor element is used as a power

semiconductor after the ultrasonic bonding. Particularly, in the fields where the use of a power semiconductor is desired, such as the fields of air conditioners, solar power generation systems, hybrid vehicles, electric vehicles, and the like, the semiconductor element is heated due to a large current supplied thereto, and a bonding portion between the wire and the electrode pad is heated to a considerable degree. Also, it has been noted that heat stresses which are generated by heating and cooling when the power is turned on and off act on the bonding portion to gradually deteriorate a bonding interface. In order to suppress the deteriorations to the smallest possible levels, various AlFe alloy bonding wires have been developed.

[0003] JP 8-8288 A1 (listed as Patent Literature 1 below) proposes firm bonding between an Al-0.02 wt% Fe alloy wire having diameter of 500 μm and an electrode pad which is an aluminum pad or an Al-Si alloy film by ultrasonic wire bonding by way of a large load and an ultrasonic wave, and takes advantage of prevention of recrystallization during current supply which is enabled by an increase in recrystallization temperature attained by incorporation of a small amount of Fe into aluminum and of suppression of development of crack which is enabled by a reduction in heat stress acting on an crystal grain boundary attained by a large crystal grain size of 50 μm or more (paragraph 0010 of Patent Literature 1).

However, along with the increase in crystal grain size, mechanical strength of the bonding wire per se is lowered to undesirably increase an amount of plastic strain exerted on the wire during a heat cycle test. Accordingly, the effect of reducing grain boundary and the effect of increased strain amount cancel each other out, and, therefore, thermal shock reliability of the bonding wire having large crystal grain size is in fact not improved so much.

[0004] Also, JP 2008-311383 A1 (listed as Patent Literature 2 below) discloses a wire having a diameter of 300 μm which is obtained by forming a 99.99 wt% (4N) high purity Al-0.2 wt% Fe alloy ingot, eliminating wire drawing processing strain by annealing a drawn wire at 300°C for 30 minutes, followed by quenching, and softening to an ultrasonic bonding-applicable level in accordance with power modules (paragraph 0017 of Patent Literature 2) and describes that aging of the above-obtained wire at 100°C to 200°C for 1 minute to 1 hour after ultrasonic bonding enables to suppress development of a crack which is generated on a bonding portion due to repetitive supply of a large current during use even when a maximum operation temperature is 200°C (paragraphs 0015 and 0017 of Patent Literature 2).

In view of the fact that the bonding wire is not subjected to any solution treatment and is simply subjected to "annealing at 300°C for 30 minutes, followed by quenching" (corresponding to "refining heat treatment" of

the present invention), too, it is considered that it is intended to improve the thermal shock reliability of the bonding wire by increasing the crystal grain size as in the wire of JP 8-8288 A1 (listed as Patent Literature 1 below), but the reliability is not improved so much due to a reduction in strength of the wire.

On the other hand, since the wire becomes too hard with the use of an Al-Cu alloy, it is necessary to increase a bonding load, thereby causing generation of chip crack in a Si chip for high temperature semiconductor during ultrasonic bonding.

[0005] Also, the invention described in JP 2011-252185 A1 (listed as Patent Literature 3 below) provides an Al alloy conductive wire in which iron (Fe), silicon (Si), and copper (Cu) coexist in aluminum (Al), wherein a length in longitudinal direction of a precipitate formed of Fe in an Al-Si-Cu alloy matrix is controlled so as to obtain the Al alloy conductive wire which is excellent in elongation and tensile strength while maintaining conductivity required for a conductive wire, and the Al alloy conductive wire is used for wire harnesses, battery cables, and the like (paragraph 0013, etc. of Patent Literature 3).

In Examples of Patent Literature 3, a die-casted Al alloy is subjected to wire drawing processing to attain $\phi 5.65$ mm, followed by a solution treatment at 550°C for 3 hours, and the wire is cooled by water cooling after the solution treatment and then is subjected to cold wire

drawing processing to attain $\phi 0.33$ mm. It is described that the Al alloy wire is subjected to a heat treatment at 230°C to 240°C.

However, with the Al-Si-Cu alloy matrix, the wire per se becomes too hard like the Al-Cu alloy matrix of JP 2008-311383 A1 (listed as Patent Literature 2 below) and undesirably causes a chip crack during ultrasonic bonding when the wire is bonded as a bonding wire for a high temperature semiconductor. Further, since conductivity (IACS) is considerably lowered to 55% to 61% from the appropriate range of 62% or more, large heat generation is entailed to raise a risk of shortening a life of the semiconductor element. JP 4843745 B1 (listed as Patent Literature 4 below) has the same drawback as JP 2011-252185 A1 (listed as Patent Literature 3 below).

[0006] As described above, the conventional bonding wires for high temperature semiconductors are proposed for the purpose of prevention of the disconnection from the bonding interface which can be caused by thermal shock. The disconnection prevention is attained by preventing the chip breakage during ultrasonic bonding owing to the coarsening of the crystal grain boundary in the aluminum (Al) matrix.

Since silicon having the remarkably small thermal expansion coefficient ($3.5 \times 10^{-6}/^{\circ}\text{C}$) and aluminum having large thermal expansion coefficient ($24.3 \times 10^{-6}/^{\circ}\text{C}$) are combined on the bonding portion of the electrode pad and the aluminum alloy wire on the semiconductor element, and

since the bonding portion is heated due to the large current supply during operation of the semiconductor and thus exposed to the highest temperature, a large thermal stress is exerted on the bonding interface between the electrode pad and the aluminum alloy wire. As a result, a crack is developed in a peripheral portion of the bonded wire to cause the problem of detachment of the wire in a short time.

More specifically, in the conventional aluminum alloy wires, sub-grains attributable to the thermal shock strain are formed in the aluminum matrix due to the difference in thermal expansion coefficient between the aluminum alloy wire and the silicon chip even in the case where the aluminum matrix having large crystal grains is used, and the crack runs in the aluminum alloy wire along the sub-grains, thereby leaving the drawback of detachment of aluminum alloy wire from the silicon chip unsolved.

[0007] Therefore, the inventors had developed a bonding wire obtained from an AlFe alloy by forced solid solution treatment (JP Patent Application No. 2012-134004). The application proposes an aluminum alloy wire which is obtained by forcedly dissolving iron (Fe) into aluminum (Al) as a solid solution, wherein an Al_3Fe intermetallic compound is successfully formed to enable the aluminum alloy wire to endure a bonding portion temperature generally of 100°C to 150°C and 150°C to 200°C at maximum.

However, since it is difficult to uniformly and

finely disperse the Al_3Fe intermetallic compound in a stable fashion in the aluminum (Al) matrix, a fluctuation in quality of the bonding wires has been caused by a slight difference in conditions of the forced solid solution treatment. Therefore, in the fields of application of the power semiconductor which requires heat resistance against repetitive heating at 100°C to 200°C, since the semiconductor element is heated due to the large current supplied to the circuit to cause considerable heating of the bonding wire, the slight wire quality fluctuation has greatly influenced on a bonding property.

Citation List

[0008]

Patent Literature 1: JP 8-8288 A1

Patent Literature 2: JP 2008-311383 A1

Patent Literature 3: JP 2011-252185 A1

Patent Literature 4: JP 4843745 B1 (JP 2011-256464

A1)

Summary of Invention

Technical Problem

[0009] An object of the present invention is to provide an aluminum alloy wire which enables to prevent chip breakage in ultrasonic bonding to an aluminum pad, prevents strength of a bonding interface of the aluminum alloy wire and the aluminum pad after the bonding from becoming unstable in the case where a high temperature thermal shock test is

repeated, and has a strong crystalline structure which prevents detachment of the aluminum alloy wire from the aluminum pad.

Solution to Problem

[0010] The inventors investigated the detachment from a bonding interface between aluminum (Al) of an aluminum pad and aluminum (Al) of a bonding wire caused by a thermal shock test to find that the cause of destruction of the bonding interface is fatigue failure. The inventors further pursued the cause of the fatigue failure to find that the problem resides in a solid solution state of iron (Fe) of which only 0.052% (520 ppm) is dissolved as a solid solution in an aluminum (Al) matrix at 650°C. More specifically, it was found that, when iron (Fe) has a considerably low solid solubility limit, iron (Fe) is precipitated in aluminum (Al) upon slow cooling in a process step of melting and casting an aluminum (Al)-iron (Fe) alloy ingot and, thus, is not dissolved to the solid solubility limit to deteriorate strength of the aluminum alloy wire.

[0011] In order to solve the above-described problem, iron (Fe) is forcedly dissolved into aluminum as a solid solution by a solution heat treatment at an intermediate wire diameter and a following quenching treatment. The iron which is forcedly dissolved as a solid solution prevents coarsening of a wire crystal structure during bonding and a thermal shock test, thereby enabling to

prevent the fatigue failure.

[0012] Also, the inventors investigated the cause of the unstableness in the thermal shock test to find that the cause of unstableness is a precipitation form of an AlFe compound. More specifically, the uniformly distributed fine AlFe compound makes crystal grains finer to improve strength of the wire, thereby contributing to the prevention of fatigue failure. On the other hand, the fine AlFe compound serves as a core around which recrystallization grains are generated, resulting in a reduction in recrystallization temperature. The inventors confirmed that the reduction in recrystallization temperature is the cause of the unstableness in thermal shock test results.

Though wire strength which suppresses the fatigue failure in combination with the effect of the uniformly dispersed fine AlFe compound is ensured in the prior application (JP Patent Application No. 2012-134004) by maintaining a Fe content within the range of 0.2 to 2.0 mass% and dissolving Fe as a solid solution in a matrix to the solid solubility limit by the above-described forced solid solution treatment, it was confirmed that, even when the Fe content is lower than the lower limit, it is possible to ensure satisfactory resistance against a thermal shock by adding Si under the conditions that a predetermined amount of Fe is dissolved as a solid solution in the matrix.

Therefore, the inventors stabilized the recrystallization temperature by suppressing the iron (Fe) content to equal to or lower than the above-specified range and maintaining a ratio between a Fe precipitation amount and a Fe solid solution amount within a predetermined range and, further, improved the strength by adding a very small amount of Si, thereby successfully achieving stabilization of thermal shock results.

[0013] An aluminum alloy wire for power semiconductor device according to the present invention is an aluminum alloy wire which comprises iron (Fe) and silicon (Si) with the balance being a high purity aluminum (Al) alloy and is used for ultrasonic bonding to an aluminum pad of a semiconductor element, wherein the aluminum alloy wire is an alloy comprising 0.01 to 0.2 mass% of iron (Fe), 1 to 20 mass ppm of silicon (Si) with the balance being aluminum (Al) having purity of 99.997 mass% or more and has a microstructure having an average crystal grain diameter of 5 to 12 μm .

[0014] Examples of impurity elements in aluminum (Al) having purity of 99.997 mass% or more according to the present invention include transition metal elements such as copper (Cu), manganese (Mn), magnesium (Mg), zinc (Zn), and titanium (Ti), alkali metal elements, alkali earth metal elements, and the like. The purity of aluminum (Al) may preferably be 99.997 mass% or more, more preferably 99.999 mass% or more, in order to promote work softening of the

aluminum alloy wire. Also, purity of the aluminum (Al) relative to the entire alloy of the aluminum alloy wire may preferably be 99.99 mass% or more (an amount of metal impurities as a whole is less than 100 mass ppm), more preferably 99.995 mass% or more (an amount of metal impurities as a whole is less than 50 mass ppm).

[0015] According to the present invention, a content of iron (Fe) is within the range of 0.01 to 0.2 mass% as one of the requirements. Iron (Fe) is dissolved in an amount only of several hundreds of ppm as a solid solution into the aluminum (Al) matrix and is uniformly and finely precipitated as fine particles in the aluminum (Al) matrix after melting and casting. However, when the iron (Fe) content exceeds the range of 0.24 mass%, problems such as chip breakage caused by too high strength and unstable thermal shock test results caused by a reduction in recrystallization temperature can occur.

On the other hand, when the iron (Fe) content is less than 0.01 mass%, mechanical strength of the bonding wire becomes unsatisfactory, and the recrystallization temperature is lowered, thereby making it difficult to endure the thermal shock test. Therefore, the range of iron (Fe) content is set to 0.01 to 0.24 mass%. However, in order to attain satisfactory bonding property to the aluminum pad and to endure repetitive thermal shocks, the content of iron (Fe) may preferably be lowered to 0.015 to 0.1 mass%.

[0016]

According to the present invention, a wire diameter of the aluminum alloy wire may preferably be 50 to 500 μm . An aluminum alloy wire having a wire diameter less than 50 μm is not usable for large current power semiconductors for use in electric vehicles, while it is difficult to perform ultrasonic bonding to the aluminum pad when the wire diameter exceeds 500 μm . The diameter of the aluminum alloy wire may be appropriately selected depending on a power semiconductor device in which the aluminum alloy wire is to be used.

[0017] According to the present invention, the aluminum pad may preferably be an Al-Si alloy pad since components thereof are the same as those of the bonding wire. A content of silicon (Si) may preferably be 0.5 to 1.5 mass%, more preferably 0.8 to 1.2 mass%.

According to the present invention, continuous wire drawing may preferably be die drawing, particularly preferably diamond die wire drawing. The die wire drawing enables to uniformly disperse and arrange the iron (Fe) particles in a concentric fashion.

The aluminum alloy wire after the continuous wire drawing is subjected to a final refining heat treatment with a predetermined tension being applied thereto.

[0018] The size of a grain boundary of a fine recrystallization structure is changed depending on a temperature and a time of the refining heat treatment, and

the temperature and the time of the refining heat treatment vary depending on an reduction in area of the wire drawing processing and are not uniquely defined. According to the present invention, the refining heat treatment is performed after the continuous wire drawing in such a manner that the wire after the continuous wire drawing is directly subjected to the heat treatment under a non-oxidizing atmosphere, preferably under a reductive atmosphere. A temperature range for attaining the recrystallization of the aluminum alloy wire of the present invention may preferably be 350°C to 500°C, more preferably 380°C to 430°C. Examples of a heating method of the heat treatment include heating in an electric furnace, Joule heating, heating with light irradiation, water vapor heating, and the like.

[0019] When the aluminum alloy wire after the wire drawing processing is subjected to water cooling after the refining heat treatment (final heat treatment), voids and the like are formed on a surface of the aluminum alloy wire to cause heat generation of an ultrasonic wave around the voids and the like, thereby making it easier to attain the ultrasonic bonding of the aluminum alloy wire to the aluminum pad. The ultrasonic bonding is more facilitated by adding water-soluble alcohol such as ethanol and isobutyl alcohol to water for cooling.

On the other hand, intermetallic compound particles of iron (Fe) and aluminum (Al) precipitated by the melting

and casting are uniformly and finely dispersed into the aluminum (Al) matrix by the wire drawing processing to enhance, owing to a pinning effect, mechanical strength of the aluminum (Al) matrix and to prevent coarsening of the fine recrystallization structure otherwise caused by heating. The iron (Fe)-aluminum (Al) intermetallic compound particles are considered to be FeAl_3 or FeAl_6 .

[0020] Hardness of the bonding wire according to the present invention may preferably be 22 to 28 Hv, more preferably 23 to 27 Hv, in terms of Vickers hardness. From the viewpoint of chip breakage during ultrasonic bonding, the hardness of the wire is generally preferred to be as low as possible. However, since the bonding wire of the present invention is used for power semiconductors and is therefore repetitively subjected to high temperature thermal shock, the Vickers hardness of 22 to 28 Hv is required. Also, purity of the aluminum (Al) is necessarily 99.997 mass% or more and may preferably be 99.999 mass% or more.

[0021] According to the present invention, a content of silicon (Si) is within the range of 1 to 20 mass ppm as one of the requirements. When the silicon (Si) content is above the range of 200 mass ppm, strength of the bonding wire is increased too much, and such strength leads to susceptibility to chip breakage. On the other hand, when the silicon (Si) content is less than 1 mass ppm, mechanical strength of the bonding wire becomes

unsatisfactory. Therefore, the range of silicon (Si) content is set to 1 to 20 mass ppm. However, in order to attain a satisfactory bonding property to the aluminum pad and to endure the repetitive thermal shock, the content of silicon (Si) may preferably be 2 to 10 mass ppm.

[0022] According to the present invention, a Fe precipitation amount may preferably be 7 times or less, more preferably 3 times or less, of a Fe solid solution amount. Fe has the effect of increasing the recrystallization temperature when it is dissolved into Al as a solid solution, but, in the case where Fe is precipitated, the FeAl compound serves as a core for the recrystallization to undesirably reduce the recrystallization temperature. Since the bonding wire is repetitively exposed to a high temperature in the thermal shock test, a material having low recrystallization temperature is softened during the thermal shock test to be susceptible to a thermal fatigue failure.

[0023] According to the present invention, the Fe solid solution amount may preferably be 0.01 to 0.06%. Though Fe has the effect of increasing the recrystallization temperature of Al when it is dissolved into Al as a solid solution, the recrystallization temperature increase effect is scarcely confirmed when the Fe solid solution amount is less than 0.01%. Also, electric resistance is increased when the Fe solid solution amount is too large, thereby making it difficult to attain the desired property when

such a bonding wire is used for connection of terminals. Therefore, the upper limit of the Fe solid solution amount may preferably be 0.06%.

Advantageous Effects of Invention

[0024] With the use of the aluminum alloy wire for connection in semiconductor device according to the present invention, since the bonding wire per se becomes soft due to work softening, satisfactory bonding to the aluminum pad is attained even when the bonding wire having a large wire diameter is subjected to ultrasonic bonding, and chip breakage does not occur during wedge bonding as first bonding. Also, even when the bonding wire is fatigued by repeating a high temperature-low temperature thermal shock test, thermal shock resistance similar to that of an aluminum alloy matrix is maintained owing to a work-softened structure of the high purity aluminum (Al) matrix and a pinning effect attained by the intermetallic compound particles of iron (Fe) and aluminum (Al).

More specifically, as described in Examples, in the case where a thermal shock test including 3 minutes of a high temperature (200°C) and 3 minutes of a low temperature (-50°C) is repeated, the number of times of a reduction of 20% to 30% (0.8 to 0.7) in a ratio of a shear strength after the repetition to an initial shear strength is largely improved to a value which is twice of a conventional example. Further, since the effect is based on the work-softened structure of the high purity aluminum

(Al) matrix per se, aluminum alloy wires which are produced in large scale is stably free from a fluctuation among lots of the aluminum alloy wires. Therefore, the aluminum alloy wire of the present invention is usable as an aluminum alloy wire for ultrasonic bonding which is suitable for power cycle semiconductors and the like of electric vehicles and the like which are used under a high temperature.

Brief Description of Drawings

[0025] Fig. 1 is a diagram showing a picture of a cross-section structure of an aluminum alloy wire of the present invention; and

Fig. 2 is a diagram showing a change ratio of shear strength of the aluminum alloy wire of the present invention.

Description of Embodiments

[0026] Each of aluminum alloys having compositions of Examples 1 to 29 and Comparative Examples 1 to 14 shown in Table 1 and comprising iron (Fe) with the balance being aluminum (Al) was molten and subjected to continuous casting to obtain an aluminum alloy ingot having a diameter of 300 mm. The obtained ingot was subjected to rolling using a grooved roller and then to wire drawing processing to obtain an aluminum alloy element wire having a diameter of 5 mm. The element wire was subjected to a solution

treatment at a predetermined temperature for 2 days, followed by quenching in water. Subsequently, the element wire was subjected to continuous wire drawings in water to attain predetermined wire diameters, thereby obtaining bonding wires having the predetermined wire diameters (a reduction in area was 99% or more in each of Examples).

One hundred wires of each of the above-obtained wires were bonded to an Al-1.0% Si alloy aluminum pad by ultrasonic bonding by using an ultrasonic bonding machine (REB07 manufactured by Ultrasonic Engineering Co., Ltd.) under the conditions of a frequency of 120 kHz, a load of 8000 mN, ultrasonic power of 15 W, and a bonding time of 180 ms. Also, an Al-100 ppm Ni alloy wire was used as a conventional example for reference.

[0027]

(Ultrasonic Bonding Conditions)

The wire diameters of the aluminum alloy wires were 0.1 mm, 0.3 mm, and 0.5 mm. A loop length was 8 mm, and a loop height was 1.3 mm. Ultrasonic bonding of the aluminum alloy wire to an Al-1.0% Si film (thickness: 3 m) on a Si chip (thickness: 0.2 mm) was performed by using the automatic bonder (REB07 manufactured by Ultrasonic Engineering Co., Ltd.).

A frequency as one of the bonding conditions was set to 130 kHz, and load and ultrasonic conditions were arbitrarily adjusted so that a flattened width of a first bonding part became 1.3 times of the wire diameter. The

ultrasonic bonding including first bonding and second bonding was performed on the 100 samples under the same conditions. As a superhard tool and a bonding guide, those which were in conformity with the wire sizes and manufactured by Ultrasonic Engineering Co., Ltd. were used. [0028] The bonded aluminum alloy wires were subjected to a chip breakage observation test and a thermal shock test. (Chip Breakage Observation Test)

The Al-1.0% Si pad of the sample after the bonding was dissolved with a 20% NaOH solution, and absence/presence of chip breakage was confirmed by using an optical microscope (measurement microscope "STM 6" manufactured by Olympus Corporation) at a magnification of $\times 100$. After observing 100 parts, the sample in which there was no chip breakage was evaluated as o, the sample in which chip breakage was observed in 1 to 3 parts was evaluated as Δ , and the sample in which chip breakage was observed in 4 or more parts was evaluated as x.

[0029]

(Thermal Shock Test)

A small cold and hot thermal shock apparatus "TSE-11" manufactured by ESPEC CORP. was used as a thermal shock test apparatus, and each of a high temperature of $+200^{\circ}\text{C}$ for 3 minutes and a low temperature of -50°C for 3 minutes was repeated for 10000 times.

[0030]

(Shear Strength Test)

Shear strength of the first bonding part was measured by using Type 2400 manufactured by Dage Japan Co., Ltd. at after 1000 times, 2000 times, 5000 times, and 10000 times of the thermal shock test, and the results were compared with the initial strength. The sample in which the number of times of a reduction of 20% (0.8) in a ratio of the shear strength after the repetition to the initial shear strength was twice of the conventional example was evaluated as o, the sample in which the number was 1.5 to 2 times was evaluated as Δ, and the sample in which the number was less than 1.5 times was evaluated as x. As the conventional example, the commercially available Al-100 ppm Ni was used. A test height was 3 μm, and a test speed was 300 μm.

[0031]

(Resistivity Measurement)

Resistivity at 77 K of each of the wires was measured by using a direct current source (Type 2400 manufactured by Keithley Instruments, Inc.) and a nanovoltmeter (Type 2182 manufactured by Keithley Instruments, Inc.) by employing a DC 4-terminal method. A length of the sample was 300 mm, and a measurement current was 1 A.

[0032]

(Crystal Grain Diameter Observation)

A wire cross-section was formed by using a cross-section milling machine (IM-4000 manufactured by Hitachi High-Technologies Corporation), and a focused ion beam

processing and observation system (JIB-4000 manufactured by JEOL, Ltd.) was used for structure observation. The method of section was employed for measurement of a crystal grain diameter. As an average size of the crystal grains, an average value of the wire lengths in a horizontal direction and a vertical direction of the cross-section was used.

[0033]

(Vickers Hardness Measurement)

A Vickers hardness tester (MVK-G3 manufactured by Mitsutoyo Corporation) was used for measurement of Vickers hardness.

(Tension Test)

A tension test was conducted by using a tension tester (Autograph AG-X manufactured by Shimadzu Corporation) and under the conditions of a distance between evaluation points of 100 mm and a stroke displacement speed of 20 mm/min.

[0034]

(Recrystallization Temperature)

The wire before the refining heat treatment was subjected to heat treatments at various temperatures each in a salt bath for 30 minutes, and a heat treatment temperature which attained strength which was intermediate between the tensile strength of the wire before the heat treatment and the tensile strength of the wire after the completion of recrystallization was considered as a recrystallization temperature.

The results obtained under the above-described conditions are shown in Table 1 (Conventional Example and Comparative Examples) and Table 2 (Examples).

[Table 1]

Conventional Example and Comparative Examples

Conventional Example and Comparative Examples														
Component concentration (balance Al)			Al raw material purity (%)	Solution treatment temperature (°C)	Resistivity in liquid nitrogen (nΩ·m)	Fe solid solution amount a (%)	Fe precipitation amount b (%)	b/a	Recrystallization temperature (°C)	BFI diameter (mm)	Average crystal grain diameter (μm)	Vickers hardness (Hv)	Chip breakage	Thermal shock test
Fe (%)	Si (ppm)													
Conventional Example Al-100ppmNi			99.999	—	—	—	—	—	170	0.5	25.4	20.0	○	×
Comparative Example														
1	0.007	5	99.999	600	2.426	0.007	0	0	240	0.5	13.2	21.2	○	×
2	0.4	5	99.999	600	2.961	0.025	0.375	15	270	0.5	5.8	27.8	△	×
3	0.8	5	99.999	600	2.956	0.025	0.775	31	260	0.5	5.4	28.1	×	—
4	0.05	5	99.99	600	3.053	0.025	0.025	1	290	0.5	5.1	29.0	×	—
5	0.05	0.5	99.999	600	2.960	0.025	0.025	1	290	0.5	7.7	21.0	○	×
6	0.05	30	99.999	600	2.966	0.025	0.025	1	290	0.5	6.3	29.3	×	—
7	0.05	5	99.999	500	2.390	0.006	0.044	7.3	260	0.5	11.3	20.6	○	×
8	0.1	5	99.999	500	2.390	0.006	0.094	15.7	255	0.5	11.8	19.9	○	×
9	0.1	5	99.999	530	2.498	0.010	0.090	9	260	0.5	9.7	22.8	○	×
10	0.15	5	99.999	500	2.390	0.006	0.144	24.0	253	0.5	12.3	19.2	○	×
11	0.15	5	99.999	530	2.498	0.010	0.140	14	258	0.5	10.2	22.1	○	×
12	0.2	5	99.999	500	2.390	0.006	0.194	32.3	251	0.5	12.8	18.6	○	×
13	0.2	5	99.999	530	2.493	0.010	0.190	19	256	0.5	10.7	21.4	○	×
14	0.2	5	99.999	560	2.804	0.020	0.180	9	257	0.5	9.8	22.6	○	×

[Table 2]

Examples

	Component concentration (balance Al)		Al raw material purity (%)	Solution treatment temperature (°C)	Resistivity in liquid nitrogen (nΩm)	Fe solid solution amount a (%)	Fe precipitation amount b (%)	b : a	Recrystallization temperature (°C)	BW diameter (mm)	Average crystal grain diameter (μm)	Vickers hardness (Hv)	Chip breakage	Thermal shock test
	Fe (%)	Si (ppm)												
1	0.01	5	99.999	600	2.515	0.010	0	0	275	0.5	11.8	22.0	○	△
2	0.015	5	99.999	600	2.657	0.015	0	0	275	0.5	9.7	22.1	○	○
3	0.025	5	99.999	600	2.959	0.025	0	0	290	0.5	9.0	24.8	○	○
4	0.05	5	99.999	600	2.957	0.025	0.025	1	290	0.5	8.1	24.3	○	○
5	0.1	5	99.999	600	2.961	0.025	0.075	3	285	0.5	7.6	24.1	○	○
6	0.2	5	99.999	600	2.958	0.025	0.175	7	278	0.5	6.1	26.2	○	△
7	0.05	5	99.997	600	2.980	0.025	0.025	1	290	0.5	6.3	26.0	○	○
8	0.05	1	99.999	600	2.960	0.025	0.025	1	290	0.5	8.2	21.9	○	△
9	0.05	2	99.999	600	2.960	0.025	0.025	1	290	0.5	7.8	23.7	○	○
10	0.05	10	99.999	600	2.959	0.025	0.025	1	290	0.5	7.3	26.1	○	○
11	0.05	20	99.999	600	2.957	0.025	0.025	1	290	0.5	6.9	27.7	△	○
12	0.05	5	99.999	530	2.498	0.010	0.040	4.2	275	0.5	9.2	23.4	○	△
13	0.05	5	99.999	580	2.804	0.020	0.030	1.5	285	0.5	8.3	24.6	○	○
14	0.05	5	99.999	610	3.092	0.029	0.021	0.7	290	0.5	8.1	24.3	○	○
15	0.05	5	99.999	635	3.413	0.040	0.010	0.2	295	0.5	7.2	26.1	○	○
16	0.05	5	99.999	655	3.710	0.050	0	0.0	305	0.5	6.5	27.1	○	○
17	0.1	5	99.999	580	2.804	0.020	0.080	4.1	272	0.5	8.8	24.0	○	△
18	0.1	5	99.999	610	3.092	0.029	0.071	2.4	285	0.5	8.6	24.2	○	○
19	0.1	5	99.999	635	3.413	0.040	0.060	1.5	290	0.5	7.7	25.5	○	○
20	0.1	5	99.999	655	3.770	0.052	0.048	0.9	300	0.5	7.0	26.4	○	○
21	0.15	5	99.999	580	2.804	0.020	0.130	6.6	270	0.5	9.3	23.3	○	△
22	0.15	5	99.999	610	3.092	0.029	0.121	4.1	272	0.5	9.1	23.6	○	△
23	0.15	5	99.999	635	3.413	0.040	0.110	2.7	288	0.5	8.2	24.8	○	○
24	0.15	5	99.999	655	3.770	0.052	0.098	1.9	298	0.5	7.5	25.7	○	○
25	0.2	5	99.999	610	3.092	0.029	0.171	5.8	270	0.5	9.6	22.9	○	△
26	0.2	5	99.999	635	3.413	0.040	0.160	4.0	274	0.5	8.7	24.1	○	△
27	0.2	5	99.999	655	3.770	0.052	0.148	2.8	285	0.5	8.0	25.1	○	○
28	0.05	5	99.999	600	2.957	0.025	0.025	1	290	0.3	7.8	25.3	○	○
29	0.05	5	99.999	600	2.957	0.025	0.025	1	290	0.1	8.2	24.8	○	○

[0035] In Tables 1 and 2, Comparative Examples 1 to 3 and Examples 1 to 6 show the influence exerted by the added amount of Fe. Comparative Example 1 is too soft due to the too small Fe content and results in the poor thermal shock test result. Also, the Fe precipitation amount/Fe solid solution amount of each of Comparative Examples 2 and 3 exceeds 7 due to the too large Fe content, resulting in the large Vickers hardness and the occurrence of chip breakage.

In contrast, the Fe contents of Examples 1 and 6 are the upper limit value and the lower limit value. When the

Vickers hardness is compared with the chip breakage and the thermal shock test result, Example 1 is free from chip breakage since it is soft, but the thermal shock test result thereof is a little poorer. The Vickers hardness of Example 6 is not so large as to cause chip breakage, but, due to the large Fe content, the Fe precipitation amount of Example 6 is large, resulting in the upper limit Fe precipitation amount/Fe solid solution amount ratio. Thus, Example 6 shows the tendency of deterioration of fatigue failure property under high temperature due to the reduction in recrystallization temperature caused by the influence of the precipitated AlFe compound.

Even when the Fe content is less than the upper limit value, the Fe precipitation amount/Fe solid solution amount exceeding 7 which is caused by the high Fe precipitation amount leads to the poor thermal shock test result as can be seen in Comparative Examples 7 to 14.

[0036] Also, Comparative Example 4 and Example 7 show the influence of the purity of the Al material. The Vickers hardness of Comparative Example 4 is considerably high to cause the poor chip breakage and thermal shock test results. Since the purity of the Al material of Example 7 is within the range of the present invention, Examples 7 attains the Vickers hardness within the appropriate range and attains the favorable chip breakage and thermal shock test results despite the fact that the Fe content of Example 7 is the same as that of Comparative Example 4.

[0037] Comparative Examples 5 and 6 and Examples 8 to 11 show the influence exerted by the added amount of Si.

The Si added amounts deviate from the upper limit and the lower limit of the range of the present invention in Comparative Examples 5 and 6, and the upper and lower limits of the Si added amount of the present invention are confirmed by Examples 8 to 11. More specifically, the wire becomes too soft to endure the thermal shock test when the Si added amount is too small, while the wire is hardened to cause the chip breakage when the Si added amount is too large.

[0038] Comparative Examples 7 to 14 and Example 12 to 27 reveal the "effect of Fe precipitation amount/Fe solid solution amount".

Comparative Examples 7 to 14 reveal that the Fe precipitation amount/Fe solid solution amount exceeding 7 which is the upper limit of the present invention leads to the poor thermal shock test result even when the Fe content is within the range of the present invention. In contrast, Examples 12 to 27 show the comparison between the changes in Fe precipitation amount/Fe solid solution amount and the thermal shock test results, and further prove the upper and lower limits and the preferred range.

More specifically, the recrystallization temperature is lowered too much to endure the thermal shock test when the Fe precipitation amount/Fe solid solution amount is more than 7. Also, the range of the Fe precipitation

amount/Fe solid solution amount of 3 to 7 results in the thermal shock test of Δ , and the Fe precipitation amount/Fe solid solution amount of 3 or less results in the thermal shock test of $\circ$.

[0039] Examples 28 and 29 show the effect of wire diameter. The wire diameter of other examples is 0.5 mm, and the effects of the wire diameters of 0.3 mm and 0.1 mm are confirmed by Examples 28 and 29.

[0040] Fig. 1 is a diagram showing a picture of a cross-section structure of the aluminum alloy wire, and, as is determined by the indicated gauge, the grains are substantially uniform in size near an average grain diameter of 10 μm to show that the stable structure is obtained.

Fig. 2 is a diagram showing a change ratio of the shear strength of the aluminum alloy wire of the present invention, and it is confirmed that the shear strength after the reduction is about 80% of the initial value at the test cycle of 10×1000 times, and that the reliability of the bonding part is considerably improved as compared to the reduction to 30% detected with the conventional example.

Industrial Applicability

[0041] Since the aluminum alloy wire of the present invention achieves the suppressed reduction in shear strength in the repetitive thermal shock test, the aluminum alloy wire is useful as a bonding wire of power

semiconductors which are used for hybrid cars and electric vehicles or trains, wind power generators, and industrial robots.

Claims

1. An aluminum alloy wire for power semiconductor device, which is to be used for ultrasonic bonding to an aluminum pad of a semiconductor element, comprising iron (Fe) and silicon (Si) with the balance being a high purity aluminum (Al) alloy, wherein

the aluminum alloy wire is an alloy comprising 0.01 to 0.2 mass% of iron (Fe) and 1 to 20 mass ppm of silicon (Si) with the balance being aluminum (Al) having purity of 99.997 mass% or more, has a Fe solid solution amount of 0.01% to 0.06%, has a Fe precipitation amount of 7 times or less of the Fe solid solution amount, and has a microstructure having an average crystal grain size of 6 to 12 μm .

2. The aluminum alloy wire for power semiconductor device according to claim 1, wherein the purity of the balance aluminum (Al) of the aluminum alloy wire is 99.999 mass% or more.

3. The aluminum alloy wire for power semiconductor device according to claim 1, wherein the iron (Fe) content is 0.015 to 0.1 mass%.

4. The aluminum alloy wire for power semiconductor device according to claim 1, wherein purity of the aluminum (Al) relative to the entire alloy of the aluminum alloy wire is 99.99 mass% or more.

5. The aluminum alloy wire for power semiconductor device according to claim 1, wherein the aluminum pad is an

Al-Si alloy pad.

6. The aluminum alloy wire for power semiconductor device according to claim 1, wherein the iron (Fe) content is twice or more of the silicon (Si) content.

7. The aluminum alloy wire for power semiconductor device according to claim 1, wherein the aluminum alloy wire has Vickers hardness of 22 to 28 Hv.

8. The aluminum alloy wire for power semiconductor device according to claim 1, wherein a wire diameter of the aluminum alloy wire is 50 to 500 μm .

9. The aluminum alloy wire for power semiconductor device according to claim 1, wherein the Fe precipitation amount is 3 times or less of the Fe solid solution amount.