

[Document Name] Description

[Title of Invention] CORROSION-RESISTANT ALUMINUM ALLOY
BONDING WIRE

[Technical Field]

[0001]

The present invention relates to an aluminum alloy bonding wire for connecting an electrode on a semiconductor device that is used under a high temperature environment to an external electrode, in particular, a bonding wire of a semiconductor device that is used under a high temperature environment, such as that of an aircraft, an electric vehicle, or a ship, in which intergranular corrosion, which is caused by humidity of the operation environment, is prevented from occurring to improve the durability and reliability of the bonding wire.

[Background Art]

[0002]

In a bonding pad on a semiconductor device of, for example, silicon (Si), silicon carbide (SiC), or gallium nitride (GaN), an electrode on a substrate equipped with such a semiconductor device, or a lead frame, a material such as aluminum (Al), copper (Cu), or nickel (Ni) is mainly used.

These electrodes on substrates are optionally plated with a noble metal, such as gold (Au) or silver (Ag), or nickel (Ni). Hereinafter, these are collectively referred to as "aluminum pad" unless otherwise specified.

In order to connect the aluminum pad of a

semiconductor device to an electrode such as a lead frame by ultrasonic bonding, an aluminum alloy fine wire prepared using high-purity aluminum (Al) having a high conductivity of 60% or more is used.

Such an aluminum alloy fine wire usually has a circular cross-section having a wire diameter of 50 to 500 μm . An ultrafine wire having a wire diameter of less than 50 μm or a fine wire having a wire diameter of larger than 500 μm is also used depending on application. In addition, fine wires (tape) having rectangular cross-sections, like that the above-mentioned fine wires are flattened, are also used.

[0003]

When such an aluminum (Al) alloy fine wire prepared using high-purity aluminum (Al) is used under a high-temperature high-humidity environment (atmosphere), in particular, when the wire is used as a wiring material of a semiconductor device that is used in, for example, an aircraft, an automobile, or a ship, a problem of difficulty in maintaining and securing durability and reliability under such an environment arises.

[0004]

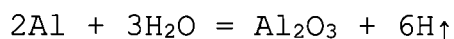
As examples of wiring materials having a relatively low resistivity, a relatively high mechanical strength, and also an excellent heat resistance, the following aluminum alloys in which nickel (Ni) is solid-soluted in aluminum (Al) are known.

Japanese Patent Laid-Open Publication No. S59-56737

(Patent Literature 1 described below) discloses an aluminum (Al) fine wire for bonding "that is characterized in that either or both of nickel (Ni) and copper (Cu) elements are added to high-purity Al in an amount of 0.005 to 0.2 wt%, i.e., 0.005 to 0.2 wt% of Ni, 0.005 to 0.2 wt% of Cu, or 0.005 to 0.2 wt% of Ni and Cu in total".

[0005]

It is well described for the corrosion mechanism of high-purity aluminum having a purity of 99.99% or more in high-temperature pure water having a temperature of 150°C or more such that it should be considered that the following chemical reaction:



is caused between aluminum and water. "A part of the hydrogen generated in this reaction is converted into molecules at the surface of aluminum to escape as H₂ gas and to thereby only increase the gas pressure in the container. However, another part of the hydrogen diffuses through alumina as atomic hydrogen and penetrates and diffuses along grain boundaries of aluminum and is then converted into H₂ molecules to increase the pressure. As a result, intergranular fracture is caused in the aluminum matrix, which also causes breakage of the alumina coating along this fracture to allow additional infiltration of water. Consequently, a reaction between aluminum and water is caused again to generate atomic hydrogen, which further penetrates into the matrix. This process is repeated and eventually cracking is caused from the grain boundaries to

collapse the matrix (Aluminum Handbook, edited by The Japan Institute of Light Metals: Non-Patent Literature 1 described below)".

Against such a reaction mechanism, it is believed that the use of an aluminum alloy in which nickel is solid-soluted described in Patent Literature 1 converts atomic hydrogen (H), which is apt to move in crystalline structure, into H₂ by the catalytic function of nickel on the surface layer and that consequently, atomic hydrogen (H) is inhibited from penetrating into the crystalline structure of aluminum to improve the corrosion resistance. [0006]

In addition, regarding the effects of, for example, nickel (Ni) added to high-purity aluminum, Non-Patent Literature 1 describes that "it is known that the presence of a second phase NiAl₃ formed by addition of nickel in an amount of about 1% significantly improves the corrosion resistance in high-temperature water (in the middle paragraph on page 1278)", and Patent Literature 1 describes that "Ni and Cu each enhance the bonding properties and corrosion resistance of Al, ... (omission of a middle part of the text) ... an amount larger than 0.2 wt% makes the Al line hard, which involves a harmful effect of causing pellet cracking during ultrasonic joining (lines 2 to 7 on page 2)".

[0007]

However, in recent years, nickel (Ni) has been recognized as a material that has a risk of adversely

affecting the environment for health. Accordingly, the use is restricted in some applications, and it is predicted that the range of the restriction be further extended in the future.

Meanwhile, aluminum alloy fine wires are demanded to be used in semiconductors that are required to have resistance to heat of 100°C to 200°C, in particular; power semiconductors that are used in, for example, air conditioners, solar power generation systems, hybrid vehicles, or electric vehicles. It is believed that the application range of the fine wire will increasingly extend in the future. The temperature in the operating conditions for such power semiconductors is higher than that for usual semiconductor devices. For example, in the power semiconductors to be mounted on vehicles, aluminum alloy fine wires are usually required to withstand the junction temperature of up to 100°C to 150°C. In an apparatus that is used under such a high temperature environment, pure-aluminum fine wires made of high-purity aluminum (Al) only, which is apt to soften, have not been practically used.

[0008]

Accordingly, in these fields, it has been demanded to develop an aluminum alloy fine wire that is nickel (Ni) free and has higher corrosion resistance than those of nickel (Ni)-containing aluminum alloy fine wires under a high-temperature and high-humidity environment.

[Citation List]

[Patent Literature]

[0009]

[Patent Literature 1] Japanese Patent Laid-Open
Publication No. S59-56737

[Non-Patent Literature]

[0010]

[Non-Patent Literature 1] "Aluminum Handbook" edited
by The Japan Institute of Light Metals, Asakura Publishing
Co., Ltd., 2003, pp. 1278-1280, "(a) Corrosion resistance
of aluminum and its alloys to water"

[Summary of Invention]

[Technical Problem]

[0011]

It is a technical object of the present invention to
provide an aluminum alloy fine wire having softness that is
substantially the same as that of pure-aluminum alloy fine
wires made of high-purity aluminum (Al) only and thereby
not causing cracking of semiconductor chips during wire
bonding and exhibiting corrosion resistance that is
equivalent to or higher than that of conventional nickel
(Ni)-containing aluminum alloy fine wires under a high-
temperature and high-humidity environment and thereby not
causing intergranular corrosion cracking.

[Solution to Problem]

[0012]

The present invention relates to an aluminum alloy
bonding wire comprising high-purity aluminum having a
purity of 99.99% by mass or more and 10 to 200 ppm by mass
of rhodium (Rh) and/or palladium (Pd), wherein

the rhodium and/or palladium element is forcibly solid-soluted to form a dispersed phase of an intermetallic compound with aluminum in an aluminum matrix;

the aluminum matrix has a grain size of 10 to 100 μm ;

the high-purity aluminum has a purity of 99.998% by mass or more;

the dispersed phase of the intermetallic compound with aluminum is formed by heat treatment at 200°C to 300°C after a continuous wire drawing process;

the bonding wire is ultrasonically joined;

the bonding wire has a wire diameter of 50 to 500 μm ;
and

the bonding wire is used at 80°C to 300°C or 150°C to 250°C.

[0013]

In the alloy of the present invention, rhodium (Rh) and palladium (Pd) that are added to the alloy in a small amount are solid-soluted in an aluminum matrix and form a dispersed phase of an intermetallic compound with aluminum as a second phase at the grain boundaries in the aluminum matrix in a usual wire-producing process shown in Examples described below.

The dispersed phase of the intermetallic compound with aluminum is formed as a uniform dispersed phase in an alloy matrix by adding a predetermined amount of Rh and/or Pd to an aluminum alloy, melting and then solidifying the mixture, heat-treating the resulting ingot at a temperature near the melting point to forcibly solid-solute Rh and/or

Pd in the alloy matrix, and allowing the Rh and/or Pd to precipitate as an intermetallic compound at grain boundaries in a thermal refining process that is performed after a continuous wire drawing process (see Fig. 3).

The mechanism of corrosion prevention by the dispersed phase of the intermetallic compound under a high-humidity environment is believed to be that atomic hydrogen (H) generated by the above-mentioned chemical reaction at the surface layer as in the above-described prior art is converted into H_2 by the catalytic function and is thereby prevented from penetrating from the surface layer into the inner matrix and further that the intermetallic compound dispersed at the grain boundaries as a second phase similarly converts the atomic hydrogen penetrating through the grain boundaries into H_2 and thereby effectively inhibits the atomic hydrogen from penetrating into the inside of the grain boundary.

Fig. 3 shows the state of the intermetallic compound precipitated as a second phase at the grain boundaries in the aluminum alloy matrix.

The corrosion state of a high-purity aluminum wire not containing Rh or Pd under a high-humidity environment is, as shown in Fig. 2, that cracks are formed from the enlarged alumina film on the surface into the inner aluminum matrix to accelerate corrosion. On the other hand, the state in an example of the present invention is, as shown in Fig. 1, that a uniform thin alumina layer formed on the surface is maintained and no cracks due to

corrosion occur in the aluminum alloy matrix under the alumina layer.

[Advantageous Effects of Invention]

[0014]

In the corrosion-resistant aluminum alloy bonding wire of the present invention, in which rhodium (Rh) and/or palladium (Pd) is added to an aluminum alloy matrix, atomic hydrogen (H) formed by a reaction with aluminum under a high-temperature and high-humidity environment is inhibited from penetrating and diffusing into the alloy matrix to prevent intergranular corrosion in the matrix.

As a result, corrosion resistance under a high-temperature and high-humidity environment is exhibited, and also the hardness of the wire can be reduced by means of the alloy composition to prevent chip cracking, and substantially the same electrical conductivity as that of high-purity aluminum is maintained.

[Brief Description of Drawings]

[0015]

[Fig. 1] Fig. 1 shows a cross-section of an aluminum alloy fine wire in Example 3 of the present invention after a corrosion resistance test.

[Fig. 2] Fig. 2 shows a cross-section of an aluminum alloy fine wire in Comparative Example 1 after a corrosion resistance test.

[Fig. 3] Fig. 3 is a TEM observation photograph showing an intermetallic compound (indicated by an arrow) precipitated at the grain boundaries of an aluminum alloy

fine wire cross-section in Example 8 of the present invention.

[Description of Embodiment]

[0016]

As Examples of the present invention and Comparative Examples, aluminum alloy element wires having a diameter of 5 mm were produced by melting aluminum alloys having compositions shown in Table 1, producing aluminum alloy ingots having a diameter of 300 mm by continuous casting, rolling each of the ingots with a grooved roll, and performing a wire drawing process.

Subsequently, the element wire was continuously drawn in water until a predetermined wire diameter was obtained. The wire was finally treated with heat of 200°C to 300°C for 1 hour for refining annealing to give a bonding wire having a predetermined diameter. Rhodium (Rh) and palladium (Pd) forcibly solid-soluted by the heat treatment for refining annealing precipitate as intermetallic compounds with aluminum to form a second phase of the alloy matrix at the grain boundaries and thereby form a dispersed phase in the aluminum alloy matrix.

An Al-50 ppm Ni alloy wire was similarly produced and was used as a conventional example.

The drawing process may involve an intermediate heat treatment as necessary and may be appropriately coordinated with consideration for wire properties and the intermetallic compound forming conditions.

[0017]

[Table 1]

	Raw material Al purity (% by mass)	Wire diameter (μm)	Rh (ppm)	Pd (ppm)	Ni (ppm)	Grain size (μm)	Corrosion layer thickness after PCT 1000 hr (μm)	Chip cracking during bonding
Conventional Example								
	99.99	300	0	0	50	25.1	8.1	OK
Example								
1	99.99	300	10	0	0	82.1	5.2	OK
2	99.99	300	0	10	0	73.1	8.6	OK
3	99.99	300	200	0	0	12.1	3.3	OK
4	99.99	300	0	200	0	10.3	6.1	OK
5	99.99	300	5	5	0	78.2	6.7	OK
6	99.99	300	100	100	0	11.6	4.4	OK
7	99.998	300	10	0	0	98.1	5.5	OK
8	99.998	300	200	0	0	18.3	3.1	OK
9	99.99	50	10	0	0	62.9	5.6	OK
10	99.99	500	10	0	0	90.2	4.9	OK
Comparative Example								
1	99.99	300	5	0	0	90.5	200 or more	OK
2	99.99	300	0	5	0	86.1	200 or more	OK
3	99.99	300	250	0	0	9.9	2.7	NG
4	99.99	300	0	250	0	8.2	5.3	NG

[Examples]

[0018]

Bonding wires of the following Examples produced as in the above-described process were investigated under the following conditions for the properties, such as corrosion resistance under a high-temperature and high-humidity environment.

(Ultrasonic joining conditions)

The aluminum alloy fine wires were produced so as to have a wire diameter of 0.05 mm, 0.3 mm, or 0.5 mm, a loop length of 8 mm, and a loop height of 1.3 mm.

The aluminum alloy fine wire was ultrasonically bonded to an Al-1.0% Si film (thickness: 3 μ m) on a Si chip (thickness: 0.2 mm) with a fully automatic bonder, model REBO-7, manufactured by Ultrasonic Engineering Co., Ltd.

The bonding conditions were adjusted to a frequency of 130 kHz, and the loading and ultrasonic conditions were adjusted such that the collapse width of a first junction was 1.3 times the wire diameter. All the hundred samples were subjected to first and second ultrasonic bonding under the same conditions. The ultra-hard tool and bonding guide used were those consistent with the wire and manufactured by Ultrasonic Engineering Co., Ltd.

[0019]

(Chip cracking observation test)

The samples after the bonding were subjected to dissolution of the Al-1.0% Si alloy pad with a 20% NaOH solution, and whether chip cracking occurred or not was observed with an optical microscope (STM6, a measuring microscope manufactured by Olympus Corporation) at a magnification of $\times 100$. A hundred points of each sample were observed. A sample in which no chip cracking was observed was determined to be good (OK), and a sample in which chip cracking was observed at one or more points was determined to be no good (NG).

[0020]

(Grain size observation)

A wire cross-section was prepared with a cross-section milling device (model IM-4000 manufactured by Hitachi High-Technologies Corporation), and the structure of the cross-section was observed with a focused ion beam machining observation device (model JIB-4000 manufactured by JEOL Ltd.). The grain size was measured by a method of section.

[0021]

(Corrosion resistance test)

A test was performed for 1000 hours under at 121°C and 100% RH (unsaturated) with an unsaturated highly accelerated life tester (HASTEST model IPAC-R8D) manufactured by Hirayama Manufacturing Corporation. The corrosion layer was observed by preparing a wire cross-section with a cross-section milling device (model IM-4000 manufactured by Hitachi High-Technologies Corporation) and measuring the thickness of a corrosion layer with an FE-SEM (model JSM-7800F manufactured by JEOL Ltd.).

[0022]

The results of each test are shown in Table 1.

The nickel alloy wire as a conventional example gave satisfactory results in the corrosion resistance and chip cracking prevention.

The present invention, in both cases of containing rhodium (Rh) or palladium (Pd) in a content ranging from 10 to 200 ppm by mass, achieved suitable effects equivalent to

or higher than those in the nickel alloy wire as a conventional example in the corrosion resistance and chip cracking prevention under a high-temperature and high-humidity environment.

In addition, in the cases of containing both rhodium (Rh) and palladium (Pd) in a total amount of 10 ppm by mass (No. 5) or 200 ppm by mass (No. 6), similar results were obtained.

On the other hand, in the cases of containing rhodium (Rh) or palladium (Pd) in an amount of 5 ppm by mass, i.e., an amount less than 10 ppm by mass, as comparative examples, though no chip cracking occurred, the thickness of the corrosion layer was significantly high. In the cases of containing rhodium (Rh) or palladium (Pd) in an amount of 250 ppm by mass, i.e., an amount higher than 200 ppm by mass, though the corrosion resistance was satisfactory, chip cracking occurred due to the high hardness.

There is a tendency that the grain size decreases and the mechanical strength and hardness increase as the contents of rhodium (Rh) and palladium (Pd) increase. Chip cracking occurs in association with bonding when the content exceeds the range of the present invention. The limitation of the content is shown in that the grain size is reduced to be lower than the lower limit in the present invention with an increase of the content.

[0023]

Figs. 1 and 2 show photographs of wire cross-sections

of an example of the present invention and a comparative example subjected to the corrosion resistance test. Fig. 1 shows a cross-section of the aluminum alloy wire of the present invention in Example 3. The dark gray thin layer on the cross-section of a light-colored aluminum layer is the alumina layer formed on the wire surface. The uniform thin alumina layer covers the aluminum alloy surface, and no crack occurs in the inner alloy matrix.

On the other hand, in Comparative Example 1 shown in Fig. 2, a high-purity aluminum wire was subjected to a corrosion resistance test under the same conditions as those in the Example, and a cross-section thereof was photographed. It was observed that an ununiform thick corrosion layer was formed on the surface and a deep crack was formed from this corrosion layer toward the inside of the alloy matrix.

[Industrial Applicability]

[0024]

The aluminum alloy fine wire of the present invention inhibits chip cracking in ultrasonic bonding, exhibits high corrosion resistance under a high-temperature and high-humidity environment, and has high electrical conductivity and is therefore applicable to various uses, such as aircrafts, automobiles, and ships, and is expected to be spread to these uses because of the satisfactory bonding properties thereof and can contribute to industries.

CLAIMS

[Claim 1]

High corrosion-resistant aluminum alloy bonding wire comprising:
high-purity aluminum (Al) and rhodium (Rh), where the high-purity aluminum (Al) has a purity of 99.99% by mass or more, and the rhodium (Rh) is contained in an amount of 10 to 100 ppm by mass (excluding 100 ppm by mass), wherein
the rhodium (Rh) forms a dispersion phase of an intermetallic compound with aluminum in an aluminum matrix.

[Claim 2]

High corrosion-resistant aluminum alloy bonding wire comprising:
high-purity aluminum (Al), rhodium (Rh), and palladium (Pd),
where the high-purity aluminum (Al) has a purity of 99.99% by mass or more, and the rhodium (Rh) and the palladium (Pd) are contained in a total amount of 10 to 100 ppm by mass (excluding 100 ppm by mass),
wherein

the rhodium (Rh) and the palladium (Pd) form a dispersion phase of an intermetallic compound with aluminum in an aluminum matrix.

[Claim 3]

The high corrosion-resistant aluminum alloy bonding wire according to Claim 1 or 2, wherein the high-purity aluminum has a purity of 99.998% by mass or more.

[Claim 4]

The high corrosion-resistant aluminum alloy bonding wire according to Claim 1 or 2, wherein the aluminum matrix has a grain size of 10 to 100 μm .

[Claim 5]

The high corrosion-resistant aluminum alloy bonding wire according to Claim 1 or 2, wherein the dispersion phase is formed by heat treatment at 200 to 300°C after continuous wire drawing.

[Claim 6]

The high corrosion-resistant aluminum alloy bonding wire according to Claim 1 or 2, wherein the bonding wire is ultrasonically bonded.

[Claim 7]

The high corrosion-resistant aluminum alloy bonding wire according to Claim 1 or 2, wherein the bonding wire has a wire diameter of 50 to 100 μm .

[Claim 8]

The high corrosion-resistant aluminum alloy bonding wire according to Claim 1 or 2, wherein the bonding wire is used at 80 to 300°C or at 150 to 250°C.