

[Document name]

Specification

[Title of the invention]

Copper–Rhodium Alloy Wire for Connecting Semiconductor Device

[Technical field]

[0001]

The present invention relates to a copper alloy wire useful for connecting a pad electrode to an external electrode on a semiconductor device by means of a hybrid bonding method utilizing ultrasonic wave and thermal compression, and in particular to a copper–lean rhodium alloy wire wherein rhodium is dissolved in a copper (Cu) of a purity of 99.995 mass % or higher.

[Background technology]

[0002]

With the heightening of the gold price in recent years copper alloy wire is regaining more spot light as a substitution for the 4N–pure gold alloy wire.

The hybrid bonding method utilizing ultrasonic wave and thermal compression conventionally used to bond a copper alloy wire consists of heating and melting an end of a copper alloy bonding wire on an aluminum pad in an atmosphere kept non–oxidizing such as nitrogen gas atmosphere and hydrogen mixed nitrogen gas atmosphere, by means of an arc heat input and making a molten ball by virtue of surface tension at the end of the wire, and then pressing down the wire ball upon an electrode of a semiconductor device heated to 150 – 300 degrees C by means of a carbide tool whereby the copper alloy wire and the aluminum pad are bonded together by the load of the pressing and the ultrasonic vibration energy from the carbide tool. The effects of the ultrasonic wave bonding are promotion of the deformation of the copper alloy wire whereby the bonding area is enlarged, and breakage and removal of an oxide film of a thickness of 50 – 100 nanometers (nm) formed over the surface of the copper alloy wire whereby metallic atoms such as copper (Cu) are exposed in the downward face, and thereby a plastic flow is created in the interface between the opposed faces of the wire and the bonding pad which works to increase the area of closely bonded interface and thus attain inter–atomic bonding between the two bodies.

Conventionally, there have been copper alloy wires which contain copper (Cu) and a noble metal in a state of solid solution such as ones described below; however, owing to the high prices of the noble metals the amount of the latter added is limited. As a result, the properties of the copper (Cu) matrix itself emerge through the oxidized surface film, and during the first bonding the dynamic strength is increased as the work hardening occurs during the plastic flow of the wire ball when it is bonded by

pressure at the time of the ultrasonic wave bonding, and if the ball becomes too hard chip cracking may occur and when a conditioning heat treatment is conducted at a high temperature in order to avoid the chip cracking, the static strength of the copper alloy becomes too low and as the result the wire may not be able to describe a properly shaped bonding loop.

Thus, a problem with the conventional copper alloy is that it is not possible to maintain a balanced dynamic strength and pliancy (toughness) as is required of a bonding wire while maintaining a constant static strength of it. Another problem was that, at the time of the second bonding, the resultant bondability was bad owing to the non-uniformity of the oxide concentration.

[0003]

An example of such a copper alloy wire is described in Japanese Patent Application Publication S61-020693 (hereinafter referred to as IP Publication 1). Nominally, this contains a noble metal such as gold (Au), but in substance magnesium (Mg), hafnium (Hf) or other base metallic element is added to the copper by 0.001 – 2 weight % whereby “H, O, N and C are fixed in the alloy and thereby generation of H₂, O₂, N₂ and CO gases are restricted” (Page 2 upper right column of IP Publication 1). However, when the content of the base metallic elements amounts to percent order, the hardness become too high and the molten ball tends to be too hard to avoid chip cracking.

[0004]

Also, there is Japanese Patent Application Publication 2008-085320 (hereinafter referred to as IP Publication 2). This relates to a copper alloy bonding wire for semiconductor device characterized by comprising a high purity copper containing at least one of Mg and P in a total amount of 10 – 700 mass ppm, at least one of Ag, Pd, Pt and Au in a total amount of 10 – 5,000 mass ppm, and oxygen in an amount of 6 – 30 mass ppm (Claim 2 of IP Publication 2), and the goal of the invention was to improve the shape of the bonded ball and the bonding strength by controlling the oxygen of the oxide film formed over the wire ball surface. However, as the ball bonding shape and the bonding strength are improved through softening, that is, lowering the hardness and static strength, the same problem arises as stated above, that is, the resulting bonding loop is not properly shaped.

[0005]

As is seen from the above examples, the conventional copper alloy bonding wires were result of the efforts of improving the bonding properties of the copper (Cu) bonding wire by adding relatively small amounts of metallic elements.

As the result, although the static strength of the bonding wire has been lowered the dynamic strength has become so high that, even if chip cracking does not occur

during the ball bonding, “aluminum splash,” which is that the aluminum pad is distorted and torn off, and also with the lowering of the static strength, leaning takes place and thus a balanced pliancy (toughness) required for a bonding wire to use free air ball (FAB) is not achieved. Incidentally, the free air ball (FAB) is usually formed in a hydrogen mixed nitrogen gas atmosphere, but occasionally it is formed in an inert atmosphere comprising 100 % nitrogen, etc.

[Prior art publications]

[IP Publications]

[0006]

[IP Publication 1]

(Japanese) Patent Application Publication S61-020693 (1986)

(Japanese) Patent Application Publication 2008-085320

[Summary of the invention]

[Problems the invention seeks to solve]

[0007]

It is an object of the present invention to provide a copper alloy bonding wire which does not invite aluminum splash, chip cracking or leaning at the time of first bonding when the molten ball of the copper alloy wire is bonded to the aluminum pad by means of ultrasonic wave, and which is capable of creating an excellent second bonding having a high bondability during the second bonding.

[Means to solve the problems]

[0008]

The present inventors paid attention to rhodium (Rh), which had not be considered for use for the reason of its high price even compared to many of other noble metallic elements, and they tried to solve the above-described problems by alloying the copper (Cu) with a small amount of it. Furthermore, in this project of making a Cu-Rh alloy wire, they also paid attention to sulfur (S) which had been neglected as an impurity to copper (Cu), and eventually they came up with a finding that the reason why sulfur (S) induces aluminum splash and chip cracking during ball bonding is that sulfur (S) separates in the surface of copper (Cu) ball during the formation of the molten ball and creates a high concentration area there, and this area undergoes work hardening accompanying the plastic flow as the ball is collapsed by ball bonding, whereby the so-called dynamic strength is increased and the loads on the pad electrode and the chip are thus augmented.

On the other hand, sulfur itself is helpful to restrict the work hardening unless its concentration is not high.

Also, in the study of Cu-Rh alloys, the inventors also paid attention to oxygen (O) which works on the dynamic strength of copper during the formation of collapsed ball.

Thus, in order to avoid segregation of sulfur (S) in the surface of the copper (Cu) ball at the time of the formation of the molten ball, they fixed sulfur in the copper (Cu) matrix by first dissolving a metallic element rhodium (Rh) and a predetermined amount of non-metallic element oxygen (O) in copper (Cu). As the result, even when the molten ball was bonded by hybrid of ultrasonic wave and thermal compression, there occurred no work hardening and the dynamic strength did not increase when the wire was deformed. It was also possible to control the static strength of the bonding wire by controlling the hardness of the bonding wire after drawing at a rate of 4 % to a certain range by means of conditioning heat treatment.

[0009]

A copper-rhodium alloy wire used for ball bonding for semiconductor device according to the present invention, therefore, is such that in the copper-rhodium alloy wire for semiconductor device comprising rhodium and the balance copper (Cu) having a purity of 99.995 mass % or higher, rhodium (Rh) is dissolved in a high purity copper matrix in an amount of 0.1 – 1.5 mass % as a metallic element, and so are sulfur (S) and oxygen (O) as non-metallic elements in amounts of 1.0 – 10 mass ppm and 10 – 150 mass ppm, respectively.

[0010]

Also, the copper-rhodium alloy wire used for ball bonding for semiconductor device according to the present invention is such that in the copper-rhodium alloy wire for semiconductor device comprising rhodium and the balance copper (Cu) having a purity of 99.995 mass % or higher, rhodium (Rh) is dissolved in the high purity copper matrix in an amount of 0.1 – 1.5 mass % as a metallic element, and so are sulfur (S), oxygen (O) and phosphor (P) as non-metallic elements in respective amounts of 1.0 – 10 mass ppm, 10 – 150 mass ppm, and 1 – 10 mass ppm.

[0011]

Owing to its relative costliness even among the noble metals, rhodium (Rh) has not been considered as a positive additive to be dispensed in copper (Cu) based wire, etc. on an order of %, and therefore its effectiveness as an additive element had not been known.

However, rhodium (Rh) does not oxidize as fast as copper (Cu). Also, it is thought that rhodium (Rh) has a stronger avidity to sulfur (S) than copper (Cu) does. On account of this, when rhodium (Rh) is used in a copper-rich alloy, rhodium (Rh) restricts the movement of sulfur (S) in the copper (Cu) matrix as well as that of oxygen (O), whereby separation of sulfur (S) in the surface of the molten ball even as the latter is formed is restricted. As a result, even when the molten ball is deformed, if a certain amount of rhodium (Rh) is contained, the work hardening triggered by the surface segregation of sulfur (S) does not occur, and aluminum splash is thereby

checked. Also, rhodium (Rh) restricts oxidation of copper (Cu), and has an effect of thinning the copper oxide film over the surface of the bonding wire so that the second bondability of the bonding wire is improved.

In the present invention, the content of rhodium (Rh) is specified 0.1 – 1.5 mass %, because if less than 0.1 %, it is not possible to prevent surface segregation of sulfur (S), and if greater than 1.5 mass %, the strengthening effect owing to rhodium's alloying occurs and the dynamic strength becomes too high and thus aluminum splash as well as chip cracking would occur. It is preferable to dissolve rhodium (Rh) in an amount of 0.3 – 1.2 mass % so as to stabilize the bonding properties of the bonding wire of the present invention, or more preferably 0.4 – 0.8 mass %.

[0012]

In the present invention, sulfur (S) is added in a very small amount of 1.0 – 10 mass ppm so that the pliancy (toughness) of the bonding wire is secured and thus leaning defect is eradicated. If sulfur content is smaller than 1.0 mass ppm, it is not possible to secure such pliancy (toughness), and if beyond 10 mass ppm, sulfur would undergo surface segregation during the ball bonding and aluminum splash becomes easy to occur.

Also, sulfur triggers dynamic recrystallization as the Cu–Rh alloy wire is deformed on the occasion of bonding the molten ball, and consequently as the work hardening takes place relatively weakly even when the wire undergoes plastic deformation, the possibility of incurring aluminum splash becomes lower than in the case of sulfur-less Cu–Rh alloy bonding wire.

[0013]

Also, in the present invention oxygen (O) is added by 10 – 150 mass ppm, and this is in order to control the movement of sulfur (S) in the copper (Cu) matrix as well as that of rhodium (Rh). If the oxygen (O) content is less than 10 mass ppm, this effect is not obtained, and if the oxygen content is greater than 150 mass ppm, it becomes easier for the oxide film to form over the ball surface at the time of molten ball formation.

[0014]

Furthermore, according to the present invention, it is preferable if phosphor (P) is dissolved in the copper (Cu) matrix in an amount of 1 – 10 mass ppm. If phosphor exists in the copper (Cu) matrix by 1 – 10 mass ppm, the oxygen (O) movement is restricted, and the pliancy (toughness) of the bonding wire is increased. If phosphor is less than 1 mass ppm, this effect is not obtained, and if it is more than 10 mass ppm, the balance with sulfur and oxygen (O) is lost.

[0015]

In the bonding wire of the present invention, the concentrations of oxygen (O), sulfur (S) and phosphor (P) are on the order of several mass ppm, and as such they are close to the level of the so-called unavoidable impurities originating from the raw materials for the wire, so that it is necessary to suppress the concentrations of other unavoidable impurities as low as possible. As will be seen from Comparative Examples 3 and 6 hereinafter described, many of these unavoidable impurities affect the static strength and the dynamic strength of the wire, and thereby thwart or mask the effects of the ingredients constituting the present invention.

Therefore, it is necessary to secure the purity of the starting copper (Cu) to be 99.995 mass % or higher, that is, to suppress the overall concentration of the unavoidable impurities to be less than 50 mass ppm in order to contain the effects of these impurities.

Examples of the impurity elements existing in the copper (Cu) of a purity of 99.995 mass % of the present invention include silver (Ag), iron (Fe), nickel (Ni), lead (Pb), tin (Sn), antimony (Sb), arsenic (As), bismuth (Bi) and chromium (Cr).

It is preferable that the purity of copper (Cu) is 99.997 mass % or higher so as to further the dynamic strength and pliancy (toughness) of the copper (Cu) matrix. In the present invention, if the starting copper (Cu) has a purity of 99.995 mass % or higher and the content of rhodium (Rh) is contained between 0.1 and 1.5 mass %, non-metallic elements sulfur (S) and oxygen (O) would dissolved in the metallic matrix by 1.0 – 10 mass ppm and 10 – 150 mass ppm, respectively, whereby the above-described performance is carried out.

[0016]

In the present invention, it is preferable that the Vickers hardness of the copper-rhodium alloy wire measured after continuous wire drawing at a rate of 4 % and conditioning heat treatment is 75 – 100 Hv. The reason for this is that as the rhodium dosage is on percent order, if the hardness of the copper-rhodium alloy wire is increased, the static strength and dynamic strength of the copper-rhodium alloy wire after the continuous wire drawing would become easy to increase, and as a result aluminum splash and consequently chip cracking become easy to occur.

Preferably, Vickers hardness is 75 – 85 Hv.

The temperature for the intermediately conducted heat treatment can be selected in response to the composition of the ingredients of the copper-rhodium alloy wire. If the intermediate heat treatment is conducted, it is preferable, in general, that it is

done in a non-oxidizing atmosphere at 400 – 900 degrees C for 20 – 120 minutes, and more preferably at 500 – 650 degrees C for 30 – 50 minutes.

The conditioning heat treatment is conducted at a higher temperature and for a duration of short time period (no more than several seconds).

Since the wire is continuously drawn cold before the conditioning heat treatment, the conditioning heat treatment can produce a uniform fine recrystallization copper (Cu) matrix tissue. The grain size of the fine recrystallization tissue is determined by the wire drawing rate (rate of reduction in the area of cross section) and the kind of conditioning heat treatment conducted. Incidentally, it is all right to conduct a heat treatment for the purpose of relieving stress from the as-drawn wire.

[0017]

It is preferable that the continuous wire drawing is conducted in a manner such that the wire diameter becomes 90 % or more reduced from that before the cold continuous wire drawing. This facilitates the formation of after-drawn tissue of the bonding wire. More preferably, the cold drawing rate is 99 % or higher. It is preferable that the continuous wire drawing is done through a molding die, and more preferably through a diamond die. By virtue of this, it becomes easier to obtain a thin and fine recrystallization tissue aligned concentrically.

[0018]

In the second bonding, it is preferable that the lead frame used is one plated with a noble metal.

This noble metal plating is preferably a soft metal plating using a metal like gold (Au) or silver (Ag), or a three-layer plating consisting of gold (Au)/palladium (Pd)/nickel (Ni) in this order from the surface. It is more preferable if Vickers hardness of the plating is nearly equal to that of the bonding wire. In particular, it is possible to first measure the hardness of the plating in terms of knoop hardness, and approximate it toward Vickers hardness of the bonding wire.

[0019]

In the present invention, it is possible to have the copper-rhodium alloy wire coated with a 0.5 – 40 nm-thick noble metal layer, because this has an effect of restricting oxidation like in the case of a conventional high purity copper (Cu) wire coated with a noble metal such as palladium (Pd). The 0.5 – 40 nm-thick noble metal layer (converted value by drawing ratio) is suitably prepared by means of magnetron sputtering using platinum (Pt) or palladium (Pd). These noble metallic layers are so thin that they do not interfere with the bonding characteristics of the copper-rhodium alloy wire.

[Effects of the invention]

[0020]

In the bonding wire of the present invention, the non-metallic elements sulfur (S) and oxygen (O) are fixed in the copper– rhodium (Cu–Rh) matrix so that the sulfur (S) does not segregate in the surface as the molten ball is deformed at the time of the first bonding, and hence the dynamic strength does not increase, and the unit load imposed by the wire upon the chip as the plastic deformation proceeds does not become large, and hence it is possible to prevent the aluminum splash and leaning. Also, with the copper–rhodium alloy wire of the present invention, it is possible to describe a good bonding loop by virtue of the pliancy (toughness) of the bonding wire, and thus the second bondability becomes good, too.

Also, the bonding wire of the present invention does not oxidize as readily as rhodium (Rh) or copper (Cu), and is dissolved in the copper (Cu) matrix uniformly so that it is possible to fix the oxygen (O) in the copper (Cu) matrix and thus there occur little aluminum splash and chip cracking, which are caused by the oxidation in the oxygen–rich surface as the molten ball is formed.

[Examples to embody the invention]

[0021]

Alloys of Examples 1 – 30 were made in accordance with the ingredient compositions shown in Table 1, by dissolving certain amounts of sulfur (S) and oxygen (O) and also phosphor (P) as the case may be in a starting copper (Cu) comprising a predetermined amount of rhodium (Rh) and the balance copper (Cu) of a purity of 99.995 mass %, and each alloy was melted and made into a copper–rhodium alloy preform wire of a diameter of 10 mm by continuous drawing.

As Comparative Examples 1 – 6, preform wires were prepared in the similar manners as in the above Examples, except that in one case oxygen was added in an amount of 375 mass ppm but no rhodium (Rh) was added to the high purity copper (Cu) of a purity of 99.999 mass %, and then in other cases the purity of copper (Cu), and/or dosages of rhodium (Rh), sulfur (S), oxygen (O) and phosphor (P) are varied, or in a case the wire is coated with a 600–nm thick palladium (Pd) layer.

These preform wires after being continuously molded were continuously drawn cold without going through an intermediate annealing and were made into bonding wires of a diameter of 20 micrometers. Incidentally, conditioning heat treatment was conducted in both Examples and Comparative Examples at 500 degrees C for one second, except that as conventional examples the wires of Comparative Examples 1 and 2 which do not contain Rh received the conditioning heat treatment at 550 degrees C for one second.

The thickness of the coating layer was measured as of the time it was wet-plated on a preform wire of a diameter of 10 mm and the measured value was proportioned by the drawing rate so as to obtain the final thickness of the coating layer.

For the measurement of Vickers hardness of the bonding wire after the conditioning heat treatment, a Vickers hardness tester (MVK-G3 manufactured by Akashi Corporation) was used. The Vickers hardness values in Table 1 are those values taken of the bonding wires after being drawn by the rate of 4 %.

[0022]

(Bonding conditions of hybrid method utilizing thermal compression and ultrasonic wave)

The wire diameter of the copper alloy wire was 20 micrometers and the loop length of 7 mm and the loop height was 200 micrometers. Using a fully automatic bonder of MAXXAM PLUS TYPE manufactured by K & S Corporation, a copper alloy wire was ball-bonded on a 0.8-micrometer-thick film of aluminum-copper alloy (Al plus 0.5 mass % Cu) plated over a chip (0.5 mm thick). The bonding conditions were such that the frequency was 120 kHz, FAB making condition, load and ultrasonic condition were arranged such that in the first bonding the diameter of FAB became 1.8 times the wire diameter, the diameter of the collapsed ball became 2.5 times the wire diameter and in the second bonding conditions were adjusted arbitrarily so as to bring about a favorable bonding, and with regard to all of the 100 samples the first bonding and the second bonding were conducted under the same conditions. The capillary used was one made by SPT Corporation which met the wire size.

[0023]

Next, with regard to each copper-rhodium alloy wire as bonded, aluminum splash test, leaning test and second bonding quality test were conducted.

[0024]

(Aluminum splash test)

Each bonded sample wire was observed from above through an optical microscope (a measuring microscope STM6 manufactured by Olympus.), at a magnification ratio of 20, to see if the aluminum pad around the bond area was thermally deformed and detached. This aluminum splash test provides a reference for the FAB hardness relevant to the making of molten ball in the state of FAB and squashing it. In both cases of Examples and Comparative Examples, each wire was observed at 100 sites and if even one aluminum splash was found the wire was rated as X and if none was found the rating was O; in both cases of Examples and Comparative Examples there was observed no chip cracking.

[0025]

(Leaning test)

The angle from the imaginary line which extends passing through the bonding points of the first bonding and the second bonding by which the loop peak of the bonding wire leans was measured with respect to 100 wire pieces using the optical microscope (the measuring microscope STM6 manufactured by Olympus.) and the standard deviation (σ) thereof was obtained. Samples whose standard deviation (σ) in leaning was 5 micrometers or smaller were given a credit of excellence (◎), and if the standard deviation (σ) in leaning was in the range of 5 – 10 micrometers the credit of goodness (○) was given, and if the standard deviation (σ) in leaning was over 10 micrometers, the credit of defectiveness (×) was given.

[0026]

(Second bondability test)

A 10-micrometer thick nickel layer was electrically plated over a copper (Cu) plate, and over this was plated similarly a one-micrometer-thick palladium (Pd) layer, and finally a 0.5-micrometer-thick gold (Au) layer was plated in an autocatalytic manner on the top and thus a lead base substrate was prepared. While heating this lead substrate at 175 degrees C, a copper rhodium wire was wedge bonded onto the substrate, and a pull test was conducted with the bonding wire. The result of whether there was a detachment of the second bond was used to estimate the quality of the second bond. When the mechanical strength was 7.0 gf or greater the credit of ◎ was given; when the mechanical strength was 6.5 – 7.0 gf the credit was ○; when the mechanical strength was only 6.0 – 6.5 gf the credit was △; and when the mechanical strength was 6.0 gf or smaller the credit was ×.

[0027]

Table 1 shows the compositions of the wires of Examples and Comparative Examples, whether or not a coating layer is provided, Vickers hardness, and results of the tests conducted on these wires.

Incidentally, the concentration of oxygen was measured by means of combustion method (using an oxygen/nitrogen analyzer TC-436AR manufactured by LECO).

Table 1 (Cu-Rh)

	No	Starting Cu Purity(%)	Rh concentration(%)	Coating layer (nm)	S concentration (ppm)	O concentration (ppm)	P concentration (ppm)	Wire hardness (Hv)	Al splash	leaning
E X A M P L E S	1	99.999	1.1	none	5	75	0	92	○	○
	2	99.995	1.4	none	4.6	60	0	97	○	○
	3	99.995	0.9	none	9.6	90	0	88	○	○
	4	99.995	1.2	none	5.2	135	0	93	○	○
	5	99.995	0.8	none	4.4	45	0	86	○	○
	6	99.995	0.3	none	4.2	120	0	78	○	○
	7	99.995	0.6	none	4.8	30	0	83	○	◎
	8	99.995	0.4	none	7	105	0	80	○	◎
	9	99.996	1.3	none	9	75	0	95	○	○
	10	99.996	0.7	none	3	60	0	85	○	○
	11	99.996	1	none	1.4	90	0	90	○	○
	12	99.996	0.5	none	5.6	135	0	81	○	○
	13	99.996	0.1	none	4	45	0	76	○	○
	14	99.996	1.1	none	6.4	120	0	92	○	○
	15	99.999	1.4	none	3.6	30	0	97	○	○
	16	99.999	0.9	none	6.4	105	0	88	○	○
	17	99.997	1.2	none	8.8	75	0	93	○	○
	18	99.997	0.8	none	5.8	60	0	86	○	○
	19	99.997	0.3	none	5.4	90	5	78	○	○
	20	99.997	0.6	none	3.8	135	8	83	○	○
	21	99.997	0.4	none	6.2	45	7	80	○	◎
	22	99.998	1.3	none	3.4	120	3	95	○	◎
	23	99.998	0.7	none	7.8	30	4	85	○	○
	24	99.998	1	none	2.6	105	9	90	○	○
	25	99.998	0.5	none	1.8	75	6	81	○	○
	26	99.998	0.1	none	2.2	60	2	76	○	○
	27	99.999	1	Au(20)	3.8	75	0	90	○	○
	28	99.999	0.5	Au(200)	7.6	120	5	81	○	○
	29	99.995	0.2	Pd(10)	3.2	60	0	76	○	○
	30	99.995	1.4	Pd(300)	6.6	135	8	97	○	○
C O M P A R A T I V E S	1	99.9996	0	none	0	375	0	69	×	×
	2	99.999	0	Pd(600)	0	170	0	69	○	○
	3	99.99	1.8	none	7.6	60	0	90	×	○
	4	99.997	0.02	none	20	75	0	90	×	○
	5	99.995	1	none	0.2	2	0	90	○	×
	6	99.99	0.1	none	5	1200	0	100	×	○

[0028]

Comparative Example 3 has rhodium (Rh) in an amount greater than the upper limit. Therefore, the wire of Comparative Example 3 becomes too hard and aluminum splash occurs, although the concentrations of sulfur (S) and oxygen (O) are within the scope of the present invention. On the other hand, in Comparative Example 4 the concentration of rhodium (Rh) is short of the lower limit. On account of this, Comparative Example 4 sees a failure in restricting the effect of excessively existing sulfur (S), and as the result aluminum splash occurred and the quality of the second bonding was poor.

[0029]

With regard to Comparative Example 4, it is thought the lowness of the concentration of rhodium (Rh) as well as the existence of sulfur (S) caused the dynamic strength of the wire to increase so high that aluminum splash occurred. On the other hand, in Comparative Example 5 the concentrations of sulfur (S) and oxygen (O) were below the lower limits. On account of this, in Comparative Example 5 even though rhodium (Rh) existed within the scope of the invention, the concentrations of sulfur (S) and oxygen (O) were so low that the balance among these was lost and the wire became so soft that leaning resulted.

[0030]

In Comparative Example 6, the concentration of oxygen (O) was higher than the upper limit of the scope of the present invention. On account of this, in Comparative Example 6 the static strength as well as the dynamic strength grew so high that aluminum splash occurred and the quality of the second bonding was adversely affected.

[0031]

Next, in Comparative Examples 3 and 6, the starting copper (Cu) had purities that are off the scope of the present invention, and had high impurity concentrations. On account of this, it is thought, the impurities contained affected such that the ball became so hard and the static strength became so high that the wires of Comparative Examples 3 and 6 experienced aluminum splash.

[0032]

Wires of Comparative Examples 1 and 2 did not contain rhodium (Rh); the wire of the Comparative Example 1 had high oxygen (O) concentration, and on account of this the dynamic strength at the time of the molten ball compression in the first bonding became too high and thus aluminum splash took place, and also the pliancy (toughness) of the wire became low and the oxygen in the wire surface adversely affected the leaning and the quality of the second bonding. Comparative Example 2 provided a palladium (Pd) coating layer and thus restricted the oxygen concentration and improved these qualities but the quality of the second bonding was not good enough.

[0033]

As opposed to the above-explained Comparative Examples, the Examples which were within the scope of the present invention showed good results with respect to the tests in aluminum splash, leaning and second bonding.

It is seen that when rhodium (Rh) content was about the middle of the range a better result was obtained, but as is seen in Examples 7, 8, 21 and 22, when the rhodium (Rh) content was 0.3 – 1.3 %, the result turned even better when there was a balance among the contents of the additives, and especially when the rhodium content was 0.4 – 0.8 mass % the result of excellent.

Also, in the present invention, as is seen in Examples 21 and 22, in addition to setting the contents of rhodium (Rh), sulfur (S) and oxygen (O) to the respective scopes, an infinitesimal amount of phosphor (P) is added to improve against the leaning and by providing a coating layer of a noble metal the bonding quality could be improved. Examples 29 and 30 show that the quality of the second bonding was improved as a result of the formation of palladium (Pd) coating layer, and thus the present invention solves the problems not only by its wire's core material but also by the coating layer material.

[Industrial usefulness]

[0034]

The present invention is useful in that by adding rhodium (Rh), which restricts atmospheric oxidation of copper (Cu), it maintains the conductivity of the copper (Cu) bonding wire, and improves the first and second bonding qualities as well as the leaning tendency, and thus provides a copper (Cu) bonding wire excellent in electrical properties for transmission of signals of semiconductor devices.

[Document name]

Scopes of the invention claimed

[Claim 1]

A copper–rhodium alloy wire for ball bonding used in semiconductor device comprising rhodium (Rh) and a balance copper (Cu) as a matrix having a purity of 99.995 mass % or higher and characterized in that in said high-purity copper (Cu) matrix are dissolved rhodium (Rh) as a metallic element in an amount of 0.1 – 1.5 mass % and sulfur (S) and oxygen (O) as non-metallic elements in respective amounts of 1.0 – 10 mass ppm and 10 – 150 mass ppm.

[Claim 2]

A copper–rhodium alloy wire for ball bonding used in semiconductor device comprising rhodium (Rh) and a balance copper (Cu) as matrix having a purity of 99.995 mass % or higher and characterized in that in said high-purity copper (Cu) matrix are dissolved rhodium (Rh) as a metallic element in an amount of 0.1 – 1.5 mass % and sulfur (S), oxygen (O) and phosphor (P) as non-metallic elements in respective amounts of 1.0 – 10 mass ppm, 10 – 150 mass ppm and 1 – 10 mass ppm.

[Claim 3]

The copper–rhodium alloy wire for ball bonding used in semiconductor device as claimed in Claim 1 or 2, characterized in that the purity of the balance copper (Cu) is 99.998 mass % or higher.

[Claim 4]

The copper–rhodium alloy wire for ball bonding used in semiconductor device as claimed in Claim 1 or 2, characterized in that Vickers hardness of the copper–rhodium alloy wire is 75 – 100 Hv.

[Claim 5]

The copper–rhodium alloy wire for ball bonding used in semiconductor device as claimed in Claim 1 or 2, characterized in that said oxygen (O) is contained in a greater amount than sulfur (S).

[Claim 6]

The copper–rhodium alloy wire for ball bonding used in semiconductor device as claimed in Claim 1 or 2, characterized in that a connective electrode of said semiconductor device is a pad plated with a noble metal.

[Claim 7]

The copper–rhodium alloy wire for ball bonding used in semiconductor device as claimed in Claim 1 or 2, characterized in that a connective electrode of said semiconductor device is a pad plated with gold (Au), silver (Ag) or palladium (Pd).