

DESCRIPTION

PALLADIUM (PD)-COATED COPPER WIRE FOR BALL BONDING

[Field]

[0001]

The present invention relates to a palladium (Pd)-coated copper wire for ball bonding, the wire being suitable for connecting an IC chip electrode to an external lead or the like on a substrate in a semiconductor device. More specifically, the present invention relates to an ultra-fine coated copper wire having a diameter of 15 μm or smaller and capable of forming a molten ball uniform in shape.

[Background]

[0002]

Generally, a process called ball bonding is employed for first bonding of a coated copper bonding wire to an electrode, and a process called wedge bonding is employed for second bonding of the coated copper bonding wire to wiring on a semiconductor wiring circuit board. The first bonding is performed as follows: an electronic flame-off (EFO) process is employed to apply arc welding heat input to the tip of the coated copper bonding wire so as to melt the tip, the resulting molten tip is allowed to coagulate using surface tension to form a sphere called a free air ball (FAB) at the tip of the bonding wire, and then, while heat is applied for maintaining the temperature at 150 to 300°C and ultrasonic energy is applied, the initial ball and the electrode are pressed into adherence so as to achieve bonding of the wire to an aluminum pad on a chip.

[0003]

The FAB herein refers to the molten ball that is formed at the tip of the coated copper bonding wire by application of a spark discharge to the tip of the bonding wire extending from the tip of a bonding tool while a non-oxidizing gas or a reducing gas, such as nitrogen or nitrogen-hydrogen, is sprayed to the tip of the bonding wire.

[0004]

Conventionally, various coated copper wires have been developed for connecting an IC chip electrode and an external lead in a semiconductor device. For example, as a palladium (Pd)-coated copper wire, which was produced by coating with solid palladium (Pd) in the early stage of development, Japanese Patent Application Publication No. 2004-014884 (JP 2004-014884 A) describes in its paragraph 0020 that "electroplating was carried out on a Cu bonding wire having purity of 99.9995% and a diameter of 200 μm , and, as a result, a Pd-plated coating having a thickness of 0.8 μm was formed. The resulting plated wire was drawn to give a Pd-plated Cu bonding wire in which a diameter of the center Cu part (core) was 25 μm , a thickness of the Pd-plating was 0.1 μm , and Microvickers hardness of the core was 77".

[0005]

However, the solid palladium (Pd)-coated copper wire having exposed palladium (Pd) causes rapid wear of a drawing die, is not easily loosened, and is therefore not suitable for mass production. The solid palladium (Pd)-coated copper wire has another, unobvious problem in that FABs or molten balls that are continuously formed in mass production are not uniform in shape.

[0006]

For the purpose of preventing exposure of palladium (Pd), various coating materials for use with the palladium (Pd) coating have been developed and suggested. For example, Japanese Patent Application Publication No. 2012-39079 (JP 2012-39079 A) (listed below as Patent Literature 1) discloses an invention that is "a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a copper (Cu) or copper-alloy core, a palladium (Pd) coating, and a surface layer, and having a wire diameter of 10 to 25 μm , in which the palladium (Pd) coating has a thickness of 0.001 to 0.02 times greater the wire diameter, the core contains at least one of zirconium (Zr), tin (Sn), vanadium (V), boron (B), and titanium (Ti) in an amount of 0.5 to 99 ppm by mass with the remainder being made up of copper (Cu) having purity of 99.9% by mass or higher, and the surface layer is an outermost coating layer formed of gold (Au), silver (Ag), copper (Cu), or an alloy of these, has been subjected to continuous drawing through a diamond die to have a final theoretical thickness of 1 to 7 nm, and has a thickness of 1/8 times or less the thickness of the palladium (Pd) coating".

[0007]

Japanese Patent Application Publication No. 2010-225722 (JP 2010-225722 A) (listed below as Patent Literature 2) discloses an invention that is "a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a core predominantly composed of copper (Cu) and having two coatings on the core, in which the core is composed of an alloy of copper (Cu) and 1 to 500 ppm by mass of phosphorus (P), and the coating consists of a palladium (Pd) or platinum (Pt) coating and a gold (Au) skin layer".

[0008]

Japanese Patent Application Publication No. 2013-131654 (JP 2013-131654 A) (listed below as Patent Literature 3) discloses an invention that is "a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a copper (Cu) or copper-alloy core, an intermediate coating composed of palladium (Pd) having purity of 99% by mass or higher, and a surface coating comprising the intermediate coating, and having a wire diameter of 10 to 25 μm , in which a surface layer of a side of the intermediate coating to serve as a bonding interface has a mixed layer formed thereon by thermal growth of the palladium (Pd) and gold (Au) having purity of 99.9% by mass or higher, the mixed layer has been subjected to hydrogen diffusion treatment on its palladium surface, and the mixed layer has a cross-section thickness measured by scanning electron microscopy of not greater than 5 nm on average".

[0009]

These three coated copper wires having as thin a gold (Au) skin layer as possible aim to achieve characteristics similar to those of the solid palladium (Pd)-coated copper wire having an outermost palladium (Pd) layer coating.

[0010]

However, as in the case of the solid palladium (Pd)-coated copper wire, the copper wires coated with the skin layer of gold (Au) or the like do not form a molten ball uniform in shape. In other words, neither of the coating that has "the skin layer (having a thickness) of not greater than 5 nm (Japanese Patent Application Publication No. 2010-225722 (JP 2010-225722 A) (listed below as Patent Literature 2))" nor "the palladium (Pd) coating (that) has a thickness of 0.001 to 0.02 times greater the wire diameter,... the

outermost coating layer... a final theoretical thickness of 1 to 7 nm... (Japanese Patent Application Publication No. 2012-39079 (JP 2012-39079 A) (listed below as Patent Literature 1))" form a molten ball or an FAB uniform in shape at the time of first bonding and, as a result, do not achieve constant bond strength at the time of first bonding.

[Citation List]

[Patent Literature]

[0011]

[Patent Literature 1]: Japanese Patent Application Publication No. 2012-39079 (JP 2012-39079 A)

[Patent Literature 2]: Japanese Patent Application Publication No. 2010-225722 (JP 2010-225722 A)

[Patent Literature 3]: Japanese Patent Application Publication No. 2013-131654 (JP 2013-131654 A)

[Summary]

[Technical Problem]

[0012]

The present invention has been devised so as to solve the problem described above that mass production of bonding wire by the EFO process yields a molten ball not uniform in shape. An object of the present invention is to provide a palladium (Pd)-coated copper wire for ball bonding that is easily loosened and can form a molten ball uniform in shape.

[Solution to Problem]

[0013]

Research conducted by the inventors of the present invention has proven that irregularities of molten balls are not attributed to the thickness of a coating but to the properties of an unmelted surface of a coated copper wire immediately above each molten ball. In other words, during the process of formation of the molten ball by the EFO

process at the time of first bonding of the bonding wire, metal that is melted in the early stage wets and goes up on the surface of the tip part of the bonding wire to increase the volume of the melted portion, and the surface tension of the melted portion eventually causes the molten ball to become a sphere.

[0014]

It has also been found for the above solid palladium (Pd)-coated copper wire that a die rapidly wears to yield an irregular surface shape of the bonding wire, the volume of the molten ball is accordingly not uniform with respect to a given amount of heat input energy applied thereto, and therefore the molten ball does not become a sphere, leading to variable bond strength. It has also been found that the irregular surface shape causes the solid palladium (Pd)-coated copper wire to be not easily loosened. For these reasons, the bonding properties of the solid palladium (Pd)-coated copper wire are inferior to the bonding properties of a copper wire coated with a skin layer of gold (Au) or the like.

[0015]

Research conducted by the inventors of the present invention has also proven the following. In the copper wire coated with a skin layer of gold (Au) or the like, an area of an outermost surface thickly covered with gold (Au) or the like has surface properties attributable to gold (Au) or the like and has molten ball wettability that is high enough for the molten ball to go up too high. Meanwhile, an area of the outermost surface thinly covered with gold (Au) or the like has surface properties attributable to a palladium (Pd) coating or the like and has insufficient molten ball wettability. Because of this

situation, the amount of molten ball that is wet and goes up on the surface of the wire to which the molten ball will be formed varies, and therefore the molten ball fails to become a sphere, leading to variable bond strength.

[0016]

The inventors of the present invention continued their research, and, as a result, have found that when the palladium (Pd)-coated copper wire having a thin solid palladium (Pd) coating or a thin collective coating of a gold (Au) coating and a palladium (Pd) coating is left under certain temperature conditions for a certain period of time, copper (Cu) in the core penetrates from immediately below the coating through the coating to exude to all over the outermost surface at a predetermined thickness. In other words, the inventors of the present invention have found a novel phenomenon of the tunnel effect in bonding wire.

[0017]

The tunnel phenomenon is further confirmed by a change in color on the surface of the bonding wire before and after the phenomenon of the tunnel effect. The tunnel phenomenon is also confirmed by the formation of a void (a cavity) inside the core immediately below the coating of the coated copper wire when the coated copper wire is left in the same manner as above for a longer period of time. The copper (Cu) thus exuded to the outermost surface of the palladium (Pd)-coated copper wire is immediately bonded to oxygen in the atmosphere to form stable copper oxide on the surface of the palladium (Pd)-coated copper wire. It should be noted that wire having a void (a cavity) formed therein obviously fails to exhibit properties of a bonding wire.

[0018]

Therefore, the palladium (Pd)-coated copper wire has surface properties attributable not to the solid palladium (Pd) coating or the gold (Au) skin layer but to the newly formed copper oxide layer. On the other hand, when left in the atmosphere at room temperature for a month, the copper (Cu)-exuded layer formed of copper (Cu) exuded due to the tunnel phenomenon does not increase in volume and no change is observed in the thickness of the copper oxide layer thus formed. This indicates that the presence of the solid palladium (Pd) coating prevented sulfidation and oxidation from proceeding into the copper (Cu) core. The ultra-thin copper oxide layer formed by the tunnel phenomenon covers the entire surface of the bonding wire, which is supported by a photograph of the surface shown in Fig. 2 below, and is not affected by the cross-sectional shape of the palladium (Pd)-coated copper wire or the surface properties of the coating.

[0019]

It is known that the presence of the solid palladium (Pd) coating yields much concentration of palladium (Pd) in a lower layer of the spherical molten ball. It is also known that when this molten ball is bonded to an aluminum pad, oxidation of copper (Cu) at a bonding interface can be delayed due to the presence of a CuAl intermetallic compound. These facts mean that the presence of the copper oxide layer can yield constant wettability of the molten ball to the wire, and the spherical molten ball to be obtained can be uniform in shape. Therefore, the concentrated part of palladium (Pd) can be consistently maintained, and, as a result, first bonding of the palladium (Pd)-coated copper wire of the present invention to an aluminum pad can proceed stably.

[0020]

The inventors of the present invention have conducted various experiments, and, as a result, have found that the rate of exuding is affected, for example, by the material of the core, the material and the thickness of the coating, and the rate of decrease in the cross section area at the time of drawing. In other words, the thickness of the copper oxide layer can be optimized, as needed, by selecting the type of the copper (Cu) or copper-alloy core, the thicknesses of the palladium (Pd) coating and the gold (Au) skin layer, and the thickness of a diffusion layer. In summary, the thickness of the copper oxide layer can be optimized at nanoscale, as needed, in accordance with the type of the coated copper wire.

[0021]

An object of the present invention is to provide a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire being capable of forming a spherical molten ball uniform in shape at the time of first bonding. Another object of the present invention is to provide a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire exhibiting constant bond strength at the time of FAB bonding as first bonding. Yet another object of the present invention is to provide a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire being easily loosened.

[0022]

An embodiment of the palladium (Pd)-coated copper wire for ball bonding that achieves an object of the present invention is a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a

copper (Cu) or copper-alloy core and a palladium (Pd) coating formed on the core and having a wire diameter of 10 to 25 μm , the palladium (Pd)-coated copper wire including a solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating, and a copper (Cu)-exuded layer formed of copper (Cu) exuded from the core, the copper (Cu)-exuded layer being formed on the palladium (Pd) coating, the surface of the copper (Cu)-exuded layer having been oxidized.

[0023]

Another embodiment of the palladium (Pd)-coated copper wire for ball bonding that achieves an object of the present invention is a palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a copper (Cu) or copper-alloy core, having a palladium (Pd) coating and a gold (Au) skin layer on the core, and having a wire diameter of 10 to 25 μm , the palladium (Pd)-coated copper wire including a copper (Cu)-exuded layer, the copper (Cu)-exuded layer being formed on the gold (Au) skin layer, a surface of the copper (Cu)-exuded layer having been oxidized, and a solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating.

[0024]

The palladium (Pd)-coated copper wire for ball bonding of the present invention has the "solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating" or the "solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating".

This structure has been devised in order that appropriate heat treatment causes the tunnel effect and then copper (Cu) in the core becomes exposed on the entire skin layer.

[0025]

In other words, copper (Cu) in the copper (Cu) or copper-alloy core, after having passed through the solid palladium (Pd) layer solely consisting of solid palladium (Pd), has high surface activity when exuded from the palladium (Pd) coating or when exuded from the gold (Au) skin layer, and copper (Cu) thus exuded covers the entire surface of the bonding wire at a uniform thickness. Copper (Cu) thus exuded is oxidized on its surface by oxygen in the atmosphere, but oxygen enters only to a limited depth. The effect of the tunnel phenomenon is assumed to occur only when the palladium (Pd) coating of the coated copper wire is ultra-thin.

[0026]

After being exuded from the gold (Au) skin layer, copper (Cu) intensely reacts with oxygen in the atmosphere. However, before having passed through and being exuded from the solid palladium (Pd) layer solely consisting of solid palladium (Pd), copper (Cu) consumes oxygen in the gold (Au) skin layer. Palladium (Pd) allows penetration of hydrogen but does not allow penetration of oxygen, and therefore the palladium (Pd) coating having a certain thickness does not allow penetration of oxygen. Therefore, as shown in Fig. 1, copper (Cu) exuded from the gold (Au) skin layer can inhibit penetration of oxygen beyond a certain depth, namely beyond the solid palladium (Pd) layer solely consisting of solid palladium (Pd), and, as a result, can control molten ball wettability. For this reason, the palladium (Pd)-coated copper wire for ball bonding of the

present invention has the "solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating" as an essential constituent element thereof.

The solid palladium (Pd) layer solely consisting of solid palladium (Pd) refers to an area having a palladium content of 100%, as determined by Auger analysis conducted to quantify palladium (Pd), copper (Cu), gold (Au), and oxygen (O).

[0027]

The copper oxide layer refers to a mixed layer of copper (Cu) and oxygen located at a certain nanoscale depth from the surface. In the absence of the copper oxide layer, the molten ball or the FAB goes up on the surface of the wire, while in the presence of the mixed layer of copper (Cu) and oxygen, this phenomenon of the FAB going up on the surface of the wire is not observed. In the case of the palladium (Pd)-coated copper wire having the gold (Au) skin layer, for example, the presence of copper oxide formed on the unmelted surface of the wire as seen in Fig. 1 lowers the surface tension of the molten ball compared to the surface tension of the gold (Au) skin layer and consequently the molten ball does not readily become as wet as previously. This low surface tension does not allow the molten ball to go up on the unmelted surface of the wire, and therefore the resulting molten ball can be uniform in shape.

[0028]

In the present invention, the thickness of a layer was observed by analysis on an Auger spectrophotometer in the depth direction and the concentration of palladium (Pd) in the coating and the concentration of gold (Au) in the skin layer were determined as follows. The palladium (Pd)-

coated copper wire as a whole was dissolved, and the concentration of palladium (Pd) or gold (Au) in the resulting solution was determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The thickness determined on an Auger spectrophotometer is based on a silicon (Si) etch rate and therefore does not completely agree with the thickness determined by ICP analysis.

[0029]

In the palladium (Pd)-coated copper wire for ball bonding of the present invention, the copper alloy that composes the core is preferably a copper alloy containing copper (Cu) having purity of 99.9% by mass or higher and is particularly preferably a copper alloy containing copper (Cu) having purity of 99.99% by mass or higher. The composition of the remainder can be selected, as needed, referring to alloys in prior art. Additive elements are selected, as needed, depending on the type and the use of a semiconductor to fabricate. The combination and the added amounts of the additive elements can also be selected, as needed, depending on the mechanical properties required of the bonding wire.

[0030]

Preferably, a component element of the copper (Cu)-exuded layer is detectable to a depth of not less than 0.5 nm and not greater than 30 nm below the surface of the wire. The reasons for this are as follows. When the thickness of the copper (Cu)-exuded layer is less than 0.5 nm, the volume of the copper (Cu)-exuded layer may not be enough to completely fill many longitudinal grooves, if formed by a drawing die, on the surface of the wire, leading to an irregular thickness of the copper (Cu) layer exposed on the

surface layer and then an irregular thickness of the copper oxide layer. When the thickness of the copper (Cu)-exuded layer is greater than 30 nm, a void (a cavity) may be formed inside the bonding wire, which may impair looping characteristics and other properties of the bonding wire. For these reasons, the numerical value of the thickness of the copper (Cu)-exuded layer is limited to the range from not less than 0.5 nm to not greater than 30 nm. The range of the thickness is more preferably not less than 1 nm and not greater than 25 nm and is most preferably not less than 3 nm and not greater than 20 nm.

[0031]

In the palladium (Pd)-coated copper wire for ball bonding of the present invention, the thickness of each of the coating itself and a coating consisting of the surface layer and the coating is several hundred nanometers, which is practically negligible relative to the wire diameter of the bonding wire, which is 10 to 25 μm . For this reason, the thickness of the coating does not affect the molten ball or the FAB. The presence of the oxidation-resistant palladium (Pd) coating prevents oxidation of the core even though the copper oxide layer exists on the coating. As a result, the palladium (Pd)-coated copper wire for ball bonding of the present invention that has the same copper (Cu) or copper-alloy core formation as that of a well-known wire forms a spherical molten ball ready for bonding to a pad.

[0032]

It should be noted that the objects of the present invention described above cannot be successfully achieved when the wire is coated with a coating material of a noble metal such as palladium (Pd) or gold (Au) after drawing is

performed to the final wire diameter. This is because the resulting final coating cannot adequately fill the irregular longitudinal grooves and therefore the copper oxide skin layer of the present invention cannot be formed. For the ultra-thin skin layer of the present invention to be formed, the diameter of the wire generally must be reduced to 1/10 or smaller the original diameter depending on the combination of the core and the coating material. Such an ultra-thin, mosaic or bumpy pattern thus formed as the ultra-thin skin layer on the surface of the core does not become distorted at an ordinary drawing speed and an ordinary ratio of diameter reduction. Therefore, by suitably regulating the temperature and the time of tempering heat treatment that is carried out for not longer than 1 second, the copper (Cu)-exuded layer having a predetermined thickness and a layer composed of oxygen having penetrated through the surface of the exuded layer can be easily formed.

[0033]

The ultra-thin surface layer and the coating formed on the surface of the wire according to the present invention both disappear at the time of FAB bonding as first bonding, and also disappear at a portion subjected to ultrasonic bonding as second bonding.

[Advantageous Effects of Invention]

[0034]

According to the palladium (Pd)-coated copper wire for ball bonding of the present invention, the ultra-thin exuded layer of copper (Cu) and oxygen having a predetermined thickness can be uniformly formed on the surface of the palladium (Pd)-coated copper wire, and therefore the shape of the molten ball or the FAB at the time of first bonding

does not vary. As a result, the palladium (Pd)-coated copper wire for ball bonding can be formed further thinner and finer than conventional wires. Accordingly, an aluminum pad to be used can be small in area and the diameter of the ball can be decreased, which can allow high density wiring with the palladium (Pd)-coated copper wire. In addition, according to the palladium (Pd)-coated copper wire of the present invention, oxygen penetration through the surface of the wire is blocked by the palladium (Pd) coating or the palladium (Pd) coating and the gold (Au) skin layer, and therefore oxidation of copper alloy in the core is effectively prevented.

[0035]

According to the palladium (Pd)-coated copper wire for ball bonding of the present invention, the coating is ultra-thin and therefore the ball to be obtained is spherical and uniform in shape regardless of the coating material or materials. Additionally, according to the present invention, in the presence of the palladium (Pd) coating, the copper (Cu)-exuded layer can be formed without being affected by another core component and, therefore, a known trace component that is suitable for semiconductor use can be added to copper (Cu) to form a copper alloy as the core. In addition, in the presence of the palladium (Pd) coating of the present invention, the copper (Cu)-exuded layer can be formed without being affected by another coating material and therefore, among others, loop formation can be conducted well.

[0036]

Moreover, the entire surface of the palladium (Pd)-coated copper wire for ball bonding of the present invention is evenly covered with copper (Cu) oxide, which serves as the

outermost surface of the wire, and therefore the wire is easily loosened. Smooth sliding of the wire surface within a capillary as an accompanying effect is also achieved. Furthermore, according to the palladium (Pd)-coated copper wire for ball bonding of the present invention, the copper (Cu) oxide layer is ultra-thin and therefore does not peel off. Consequently, copper (Cu) oxide does not adhere to the capillary when bonding is repeated many times, and therefore capillary contamination does not occur.

[Example 1]

[0037]

To produce the core, copper (Cu) having purity of 99.999% by mass or higher mixed with or not mixed with 100 ppm by mass of phosphorus (P) was subjected to continuous casting, and was then rolled under intermediate heat treatment (600°C, 1 hour), followed by drawing to give a thick wire (diameter: 1.0 mm) which was to be subjected to coating with a coating material.

[0038]

Then, the outer circumference of the resulting thick wire was coated with a palladium (Pd) coating and a gold (Au) skin layer shown in Table 1. The purity of gold (Au) of the skin layer was 99.999% by mass or higher, and the purity of palladium (Pd) was 99.99% by mass or higher. Subsequently, continuous wet drawing was carried out through a diamond die, followed by tempering heat treatment at 500°C for 1 second. As a result, a palladium (Pd)-coated copper wire for ball bonding having a diameter of 20 μm was obtained. The average ratio of diameter reduction was 6 to 20%, and the final drawing speed was 100 to 1000 m/minute. After coating, 0 to 2 rounds, preferably 1 or 2 rounds, of heat treatment were carried out at 200 to 600°C

for 0.01 to 120 minutes each in order to facilitate changes in the copper (Cu)-exuded layer.

[0039]

In the same manner as in Example 1 described above, a palladium (Pd)-coated copper wire (Example 2 to Example 6) as listed in the left column of Table 1 was prepared. The thicknesses of various coating materials, conditions of after-coating heat treatment, and conditions of tempering heat treatment were changed so as to control the thickness of the copper (Cu)-exuded layer.

[0040]

The values of the thickness of the skin layer and the total thickness of the coatings shown in Table 1 were determined as follows: each wire having a diameter of 20 μm and a length of ten thousand meters was dissolved in aqua regia, the concentrations of gold (Au) and palladium (Pd) in the resulting solution were determined by inductively coupled plasma atomic emission spectroscopy (on ICPS-8100 from Shimadzu Corporation), and the resulting concentrations were used to calculate the thicknesses of the skin layer and the coatings that were assumed to be evenly formed, considering the diameter of the bonding wire. This means that the values thus obtained were converted values obtained by ICP analysis. The numerical values in the column named copper (Cu)-exuded layer, the column named depth of oxygen penetration, the column named skin layer, the column named layer solely consisting of palladium (Pd), and the column named alloy layer in Table 1 were obtained as readings of the results shown in Fig. 1. These results were obtained on a scanning Auger electron microscope manufactured by VG Scientific, England (model: MICROLAB-310D) at an accelerating voltage of 10 kV and a sample

current of 20 nA. Distribution of the copper (Cu)-exuded layer on the surface of the wire analyzed on the same apparatus is shown in Fig. 2.

[0041]

[Table 1]

	Core	Copper (Cu)-exuded layer	Depth of oxygen penetration	Skin layer		Layer solely consisting of Pd	Total thickness of coatings	Wire diameter	Test to evaluate smooth unwinding of wire	Test to evaluate irregularities of molten balls
		(nm)	(nm)	Au (wt%)	Au (nm)	(nm)	(nm)	(μ m)		
Example Wire 1	Alloy of Cu and 100 ppm by wt of P	14	5	0.1	2.6	103	290	20	Good	Good
Example Wire 2	Alloy of Cu of 99.999% by mass or higher	6	3	0	0	217	382	20	Good	Good
Example Wire 3	Alloy of Cu and 20 ppm of Ca	20	6	0.05	1.3	72	145	20	Good	Good
Example Wire 4	Alloy of Cu and 0.5 wt% Pt	9	4	0.2	5.2	112	202	20	Good	Good
Example Wire 5	Alloy of Cu and 1.0 wt% Pd	5	3	0.1	2.6	152	324	20	Good	Good
Example Wire 6	Alloy of Cu and 10 ppm by wt of P	3	2	0.1	2.6	109	291	20	Good	Good
Comp. Wire 1	CuP alloy	0	4	0.1	2.6	100	260	20	Very Poor	Very Poor
Comp. Wire 2	Alloy of Cu of 99.999% by mass or higher	0	5	0.1	2.6	0	320	20	Very Poor	Very Poor
Comp. Wire 3	Alloy of Cu and 20 ppm Ca	40	15	0.1	2.6	55	304	20	Good	Poor

[0042]

(Test to evaluate smooth unwinding of wire)

A bonding wire having a composition shown in the left column of Table 1 was wound around a spool (50 mm in diameter), which was then rotated at a speed of 9 rotations per minute for 15 minutes so as to unwind and hang the bonding wire from a height of 30 cm. The position at which the bonding wire left the spool was used as an indicator in evaluating smooth unwinding of the bonding wire. If the position (2) at which the bonding wire (1) left the spool was within the area A as in Fig. 3, it was rated as Good, and if the position (2) was within the area B to the area D as in Fig. 4, it was rated as Very Poor. Each evaluation was carried out for 5 samples (N = 5).

[0043]

(Test to evaluate irregularities of molten balls)

Irregularities of molten balls were tested as follows.

The right column of Table 1 shows results of a test on Example Wire 1 to Example Wire 6. In the test, the wire was bonded to an Ag-plated lead frame (QFP-200) by first ball bonding using an ICONN fully-automatic ultrasonic

ribbon bonder manufactured by K&S, where a molten ball or an FAB having a diameter of 30 μm was formed and was then pressed into adherence to an area of 40 μm in diameter. The test was repeated 1,000 times. The results are shown in the right column of Table 1. If the number of eccentric balls was 10 or smaller, this was rated as Good, if the number of eccentric balls was 20 or smaller, this was rated as Poor, and if the number of eccentric balls was 21 or greater, this was rated as Very Poor. The results from the test indicate that when the thickness of the copper (Cu)-exuded layer is within the range from 0.5 to 30 nm, irregularities of molten balls fall within a preferable range.

[Comparative Example]

[0044]

Comparative Wire 1 was obtained in the same manner as in the case of Example Wire 1 except that tempering heat treatment was carried out at 400°C for 1 second. Comparative Wire 2 was obtained in the same manner as in Example 1 with tempering heat treatment carried out in the same manner as in Example 1 except that a highly pure copper alloy (a copper alloy of 99.999% by mass or higher) was used and therefore no solid palladium (Pd) layer solely consisting of solid palladium (Pd) was formed. Comparative Wire 3 was obtained in the same manner as in Example 1 with tempering heat treatment carried out in the same manner as in Example 1 except that the thickness of the copper (Cu)-exuded layer was 40 nm.

[0045]

(Test to evaluate smooth unwinding of wire)

Comparative Wire 1 to Comparative Wire 3 were subjected to the test for evaluating smooth unwinding of the wire in the

same manner as in the cases of the example wires, and results in the right column of Table 1 were obtained.

[0046]

(Test to evaluate irregularities of molten balls)

Comparative Wire 1 to Comparative Wire 3 were subjected to the test for evaluating irregularities of molten balls in the same manner as in the cases of the example wires, and results in the right column of Table 1 were obtained.

[0047]

The results of the test for evaluating smooth unwinding of the wire and the test for evaluating irregularities of molten balls have proven that the palladium (Pd)-coated copper wire for ball bonding of the present invention (Example Wire 1 to Example Wire 6) was smoothly unwound and formed a molten ball extremely uniform in shape such that a pad to be used can be small in area. It was also found that each of the coated copper wires of the comparative examples (Comparative Wire 1 and Comparative Wire 2) was poor in smooth unwinding of the wire, formed a molten ball with great irregularities, and did not allow first bonding to proceed consistently. It was further found that the coated copper wire as Comparative Wire 3 formed a molten ball not uniform in shape and did not allow first bonding to proceed consistently.

[0048]

Each of the palladium (Pd)-coated copper wires for ball bonding of the present invention (Example Wire 1 to Example Wire 6) were accompanied by no clogging of a capillary during repeated bonding for a length greater than ten thousand meters, proving that they smoothly slid within the capillary. No wear was observed on the interior wall of the capillary. The HAST test (130°C, 85%RH (relative

humidity)) showed that all of Example Wire 1 to Example Wire 6 had a longer lifetime and higher reliability than Comparative Wire 1 to Comparative Wire 3.

[Industrial Applicability]

[0049]

Taking the place of a conventional gold alloy wire, the palladium (Pd)-coated copper wire for ball bonding of the present invention has applications in semiconductors such as in general-purpose ICs, discrete ICs, memory ICs, and IC packages for use in LEDs and automobile semiconductors under high temperatures and high humidity where low cost fabrication is sought after.

[Reference Signs List]

[0050]

1 Bonding wire

2 Position at which bonding wire left spool

[Brief Description of Drawings]

[0051]

[Fig. 1] Fig. 1 shows results of Auger analysis on a bonding wire of the present invention in the depth direction.

[Fig. 2] Fig. 2 is a photograph of copper (Cu) distribution on the surface of a bonding wire of the present invention.

[Fig. 3] Fig. 3 illustrates smooth unwinding of a bonding wire.

[Fig. 4] Fig. 4 illustrates unsmooth unwinding of a bonding wire.

CLAIMS

[Claim 1] A palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a copper (Cu) or copper-alloy core and a palladium (Pd) coating formed on the core and having a wire diameter of 10 to 25 μm , comprising:

a solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating, and

a copper (Cu)-exuded layer formed of copper (Cu) exuded from the core, the copper (Cu)-exuded layer being formed on the palladium (Pd) coating, a surface of the copper (Cu)-exuded layer having been oxidized.

[Claim 2] A palladium (Pd)-coated copper wire for ball bonding, the palladium (Pd)-coated copper wire having a copper (Cu) or copper-alloy core, a palladium (Pd) coating on the core, and a gold (Au) coating on a surface of the palladium (Pd) coating, and having a wire diameter of 10 to 25 μm , comprising:

a copper (Cu)-exuded layer formed of copper (Cu) exuded from the core, the copper (Cu)-exuded layer being formed on the gold (Au) skin layer, a surface of the copper (Cu)-exuded layer having been oxidized, and

a solid palladium (Pd) layer solely consisting of solid palladium (Pd), the solid palladium (Pd) layer being present in the palladium (Pd) coating.

[Claim 3] The palladium (Pd)-coated copper wire for ball bonding according to claim 1 or 2, wherein a component element of the copper (Cu)-exuded layer is detectable to a depth of not less than 0.5 nm and not greater than 30 nm

below a surface of the wire.

[Claim 4] The palladium (Pd)-coated copper wire for ball bonding according to claim 1 or 2, wherein oxygen is detectable on a surface of the wire.

[Claim 5] The palladium (Pd)-coated copper wire for ball bonding according to claim 1 or 2, wherein a component element of the palladium (Pd) coating is detectable to a depth of not less than 100 nm and not greater than 500 nm below a surface of the wire.