

[Title of Document] Description

[Title of Invention] GOLD (Au)-DISPERSED COPPER WIRE FOR BALL BONDING

[Technical Field]

[0001]

The present invention relates to a gold (Au)-dispersed copper wire for ball bonding which is suitable for connecting an IC chip electrode used for a semiconductor device to a board such as an outer lead, and in particular, relates to a coated copper wire which is capable of giving a stable molten ball even when the coated copper wire is an extra fine wire having a wire diameter of 15 μm or less.

[Background Art]

[0002]

In general, a method called ball bonding is employed for the first bonding of a coated copper bonding wire to an electrode, and a method called wedge bonding is employed for the second bonding of the coated copper bonding wire to a wiring on a circuit wiring board for a semiconductor, respectively. In the above-described first bonding, a true sphere called a free air ball (FAB) is formed at the tip of the bonding wire by a system called an electronic-flame-off (EFO) system, which supplies the arc input heat to the tip of the coated copper bonding wire in order to melt the tip part, and which thereafter solidifies the molten

materials by utilizing the surface tension. Then, the coated copper bonding wire and an aluminum pad on a chip are bonded together by pressure joining the initial ball and the above-described electrode by applying ultrasonic waves while heating the initial ball and the electrode to a temperature within the temperature range from 150°C to 300°C (see Figure 1).

[0003]

In this regard, the first bonding in which a molten ball is formed is generally conducted by a free air ball system which comprises spark discharging at the tip of the bonding wire while blowing a gas which mainly contains nitrogen, a nitrogen gas which contains 5% of hydrogen and the like to the bonding wire in order to suppress the oxidation of copper and forming the molten ball. This system or the molten ball formed by this system is called as a FAB.

[0004]

Conventionally, as a palladium (Pd)-coated copper wire for connecting an IC chip electrode of a semiconductor device and an external lead, "a bonding fine wire for a semiconductor comprising a coating layer made of Pd or a Pd alloy directly or via an intermediate layer on the outer periphery of a core wire made of Cu or a Cu alloy" has been proposed in Japanese Utility Model Application Laid-Open Publication No. Sho 60-160554 (Patent Literature 1 described hereinafter).

Thereafter, a practical palladium (Pd)-coated copper wire has been proposed as "a bonding wire comprising a core material and a coating layer formed on the core material, in which the core material is constituted of a material other than gold having micro Vickers hardness of 80 Hv or less, and in which the coating layer is constituted of a metal having a melting point higher than that of the core material by 300°C or more and an oxidation resistance higher than that of copper" in Japanese Patent Application Laid-Open Publication No. 2004-014884 (Patent Literature 2 described hereinafter). In addition, this bonding wire has been introduced in SEI TECHNICAL REVIEW, No.160, issued on March 2002 titled "Development of Bonding Wire". There are also some patent applications (Japanese Patent Application Laid-Open Publication No. 2010-272884 and the like) relating to the analyses of the boundary surface of the core material and the coating layer.

[0005]

However, such a copper wire coated with pure palladium (Pd) on which palladium (Pd) is exposed has exhibited very severe wear of a wire drawing die as well as a poor unwinding property of the wire, and therefore, it has been a material unsuitable for mass production. In addition, even though the copper wire coated with pure palladium (Pd) is mass-produced, there has been a problem that the molten ball becomes unstable

when the FABs are formed repeatedly. In other words, the copper wire coated with pure palladium (Pd) has a problem that the molten ball tends to take a spear shape when the molten ball is formed.

[0006]

Accordingly, Japanese Patent Application Laid-Open Publication No. 2005-167020 (Patent Literature 3 described hereinafter) has proposed an invention of a bonding wire, which comprises a coating layer made of palladium (Pd) and an outermost layer made of gold (Au), in which a melting point of the outermost layer made of gold (Au) is lower than that of the coating layer made of palladium (Pd), and in which the thickness of the coating layer made of gold (Au) is smaller than that of the coating layer made of palladium (Pd) and not larger than 0.002 times the wire diameter (Claim 8 of the publication). In addition, with regard to a usual FAB, a system, in which an angle between the end of a bonding wire and the end of a discharge torch is within 60 degrees from a wire lengthwise direction, and in which a ball portion is formed by creating arc discharge between the discharge torch and the end of the wire, is employed in order to connect the ball portion on an electrode. It has been confirmed that the shape of a FAB becomes stable due to the fact that the tip of the arc discharge reaches gold (Au) at the shortest distance, by using the above-described wire

coated with gold (Au) as the outermost layer (see Japanese Patent Application Laid-Open Publication No. 2011-146754).

[0007]

As described above, a palladium (Pd)-coated copper wire which is further coated with gold (Au) tends to exhibit good wettability with a FAB and the molten ball tends to stick to an unmelted wire at the root portion. Accordingly, a gold (Au)-coated wire which has been subjected to "continuous wire drawing until the final film thickness reaches 1 to 9 nm" has been developed thereafter (Japanese Patent Application Laid-Open Publication No. 2012-036490 (Patent Literature 4 described hereinafter)). However, when the bonding wire is subjected to continuous wire drawing by using a diamond die, the die tends to wear, and the wire diameter tends to increase, and therefore, the coating layer made of gold (Au) in the order of nanometer tends to fluctuate. Accordingly, when trying to control the film thickness of the coating layer made of gold (Au) which is the outermost layer in the order of several nanometers (nm), the maintenance and control of the final die tends to be difficult and extremely time-consuming works have been required for replacing a die and the like.

[0008]

On the other hand, a technique relating to a gold (Au)-coating film as the outermost layer which utilizes

Stranski-Krastanov growth by which palladium of an intermediate layer infiltrates into an ultra-thin gold layer such that a minute gold phase and a palladium phase grow in three-dimension, has been developed (Japanese Patent Application Laid-Open Publication No. 2013-131654 (Patent Literature 5 described hereinafter)). This technique is to cause to grow a film made of palladium (Pd) in a mountain shape on the gold (Au)-coating film by utilizing the fact that the atomic radius of Au is similar to that of Pd. The relationship between the thickness of the gold (Au)-coating film and that of the palladium (Pd) layer is important for this technique.

[0009]

However, when the gold (Au)-coating films are fluctuated due to the die wear, the fluctuation tends not to be capable of being followed by the relationship between the thicknesses, and therefore, the palladium (Pd) film tends not to grow or the gold (Au)-coating film tends to be dispersed into the palladium (Pd) layer. Further, when the final diamond die is broken, the trace of the die is transferred to the wire and remains in a shape of a stripe groove, and then the relatively thick gold (Au)-coating layer tends to remain. Accordingly, when a molten ball is formed by a FAB, the molten ball tends to creep up along the unmelted gold (Au)-coating layer in a shape of a stripe groove, and tends to stick to the wire, and therefore, there

has still remained the problem that the molten ball tends not be stable.

[Citation List]

[Patent Literature]

[0010]

[PTL 1] Japanese Utility Model Application Laid-Open
Publication No. Sho 60-160554

[PTL 2] Japanese Patent Application Laid-Open
Publication No. 2004-014884

[PTL 3] Japanese Patent Application Laid-Open
Publication No. 2005-167020

[PTL 4] Japanese Patent Application Laid-Open
Publication No. 2012-036490

[PTL 5] Japanese Patent Application Laid-Open
Publication No. 2013-131654

[Summary of Invention]

[Technical problem]

[0011]

The present invention has been made in order to solve the above-described problem of creeping up of a molten ball along a wire, the molten ball being formed by the EFO of a mass-produced bonding wire, and therefore, an object of the present invention is to provide a gold (Au)-dispersed copper wire for ball bonding, which is capable of forming a stable molten ball under the same

discharge condition, regardless of whether the wire is produced by using a whole new diamond die obtained immediately after the start of mass production or the wire is produced by using a die obtained immediately before the replacement after conducting the wire drawing for 100,000 meters or more.

[Solution to Problem]

[0012]

The present inventors have found that there is a metastable region which makes it possible for gold (Au) of the outermost layer to be innumerably scattered on the coating layer made of palladium (Pd) and to be dispersed/aligned in a granular state, by an appropriate final refining heat treatment when the film thickness of the surface layer made of gold (Au), which is the outermost layer, is made to be thin to a certain extent. This metastable region can be considered to be a metallic bond among gold (Au), which is a bond obtained by thermally relaxing a mutual mechanical bond among gold (Au) atoms which is stretched in the extremely thin surface layer made of gold (Au). This metastable region is also determined mainly by the wire diameter of the wire and the surface property of palladium (Pd) to be coated. The width of the temperature range which is suitable for this metastable region is relatively narrow. For example, when the temperature is raised only by +50°C above the starting temperature of the metastable region, this metastable

region disappears, and gold (Au) at the outermost layer is embedded in the coating layer made of palladium (Pd). In addition, the temperature range which is suitable for the metastable region varies depending on whether the coating layer made of palladium (Pd) has been obtained by dry plating, or alternatively, the coating layer made of palladium (Pd) has been obtained by wet plating by using a cyanogen plating bath or a non-cyanogen-based plating bath. The present inventors have completed the present invention based on these findings.

[0013]

The gold (Au)-dispersed copper wire for ball bonding which solves the problems of the present invention is a gold (Au)-dispersed copper wire for ball bonding, having: a palladium (Pd)-coated copper wire for ball bonding having a wire diameter of 10 to 25 μm , in which the palladium (Pd)-coated copper wire for ball bonding has a core material made of a copper alloy containing copper (Cu) with a purity of 99.9 mass% or more, and in which the palladium (Pd)-coated copper wire for ball bonding has a coating layer made of palladium (Pd) and a surface layer made of gold (Au) formed thereon, characterized in that the theoretical film thickness obtained by the chemical analysis of gold (Au) in the surface layer made of the gold (Au) is 0.1 nanometer (nm) or more and 10 nanometers (nm) or less, and that the distribution of gold (Au) observed by the surface

analysis using an electron probe microanalyzer (EPMA) is such that fine particles of the gold (Au) are distributed on the coating layer made of the palladium (Pd) in an innumerably scattered manner.

[0014]

Preferable embodiments of the present invention are as follows. It is preferable that the copper alloy contains 3 mass ppm or more and 500 mass ppm or less of phosphorus (P). In addition, it is preferable that the copper alloy contains 50 mass ppm or more and 500 mass ppm or less of gold (Au). Further, it is preferable that the copper alloy contains 0.2 mass ppm or more and 100 mass ppm or less of metal elements other than phosphorus (P) and gold (Au). Furthermore, it is preferable that the copper alloy contains 3 mass ppm or more and 500 mass ppm or less of phosphorus (P), 50 mass ppm or more and 500 mass ppm or less of gold (Au), 0.2 mass ppm or more and 100 mass ppm or less of other metal elements and less than 1,000 ppm in total of these elements. Additionally, it is preferable that the theoretical film thickness is 2 nanometers (nm) or less.

[0015]

In the present invention, "theoretical film thickness" is a concept which is introduced because the film thickness of the surface layer made of gold (Au), which is the outermost layer, cannot be actually measured as described above. Accordingly,

the ratio of gold (Au) to the whole bonding wire is obtained by chemical analysis according to the weight analysis method. Then, the film thickness is calculated from the obtained value by assuming that the section of the bonding wire is a perfect circle and that gold (Au) uniformly coats an outermost surface of the wire diameter. Since the surface of an actual bonding wire is uneven in a nano-scale order, there may be some cases where the value of the theoretical film thickness is smaller than the atomic radius of gold (Au).

[0016]

In addition, "chemical analysis" refers to an analysis method for obtaining the concentration of gold (Au) in a solution in which the whole gold (Au)-dispersed copper wire is dissolved, by employing a high-frequency inductively coupled plasma (ICP) emission spectrophotometric analysis method - an electron probe microanalyzer (EPMA)). Meanwhile, the expression "layer" used in each of the expressions "coating layer" and "surface layer" of gold (Au) as the outermost layer is used for describing the range where the fine particles of gold (Au) are present as "layer", for the sake of convenience.

[0017]

Further, the reason why it is defined that the distribution of the above-described fine particles of gold (Au) is characterized as being distributed in an innumerably

scattered manner observed by the surface analysis using an electron probe microanalyzer (EPMA) is that when a fine particle of the gold (Au) is large to a certain degree, the fine particle of the gold (Au) can be visually confirmed, but there are some fine particles which are too small to be visually confirmed. Meanwhile, with regard to the fine particle of the gold (Au) which is large to a certain degree when being observed by the surface analysis using an electron probe microanalyzer (EPMA), it has been found that Pd is not detected at the position where the fine particle of the gold (Au) is detected, by the same analysis on the distribution of Pd (see Figure 2 and Figure 3). [0018]

In the gold (Au)-dispersed copper wire for ball bonding according to the present invention, it is defined that the theoretical film thickness of the gold (Au) observed by the chemical analysis is 0.1 nanometer (nm) or more and 10 nanometers (nm) or less. The reason why the upper limit is defined to be 10 nanometers (nm) or less is that the film thickness of the outermost layer which is the coating layer made of gold (Au) is not present as a thickness of "layer" having a so-called thickness, and that there is a requirement that "fine particles of the gold (Au) are distributed on the coating layer made of the palladium (Pd) in an innumerably scattered manner". A FAB is stabilized because spark discharge reaches

these fine particles of gold (Au), since the electroconductivity of gold (Au) is higher than that of palladium (Pd). In addition, it is thought that the chemical activity of fine particles of gold (Au) is also stabilized by changing the properties of the stretched layer of gold (Au) until gold (Au) takes a state of fine particles of gold (Au).
[0019]

When the film thickness of the coating layer made of gold (Au) exceeds 10 nanometers (nm), the destination of spark discharge tends to be fluctuated because of the unevenness of the film thickness, and therefore, FABs tend to be unstable. Further, as a result of the thermal growth of the film of palladium (Pd) due to refining heat treatment and the like, the film thickness of the coating layer made of gold (Au) tends further to be fluctuated. The reason why the lower limit is defined to be 0.1 nanometer (nm) or more is to make the fine particles of gold (Au) be distributed on the coating layer made of palladium (Pd) in an innumerably scattered manner. When the film thickness of the coating layer made of gold (Au) is less than the lower limit, the fine particles of gold (Au) cannot be distributed in an innumerably scattered manner.

[0020]

When there is a position where fine particles of gold (Au) are not scattered on the coating layer made of palladium (Pd),

the destination of spark discharge tends to be fluctuated, and therefore, FABs tend to be unstable. Here, the state where fine particles of gold (Au) are "innumerably scattered" refers to a state where fine particles of gold (Au) are also dispersed on a stripe-shaped groove which is a trace of a die. By the final heat treatment at an appropriate temperature, gold (Au) atoms coated in the outermost layer are assembled two-dimensionally, and then fine particles are formed. When the temperature of the final heat treatment is higher than such an appropriate temperature, gold (Au) atoms tend to be dispersed in the coating layer made of palladium (Pd), and then so-called diffusion phenomena occur, and as a result, fine particles of gold (Au) disappear.

[0021]

The reason why the theoretical film thickness is defined to be preferably 2 nanometers (nm) or less is as follows.

In general, when the film thickness of gold (Au) obtained by the depth direction analysis which uses an Auger Spectroscopy analyzer becomes thick enough to be actually measured, that is, the film thickness of gold (Au) is in a several-hundred nanometer order, a molten ball tends to get wet with a gold (Au) film on the surface of the wire which is positioned at the root portion of the molten ball, and as a result, the molten ball creeps up along the surface of the unmelted wire due to the

surface tension of the molten ball. In other words, so called a bunch of grapes phenomenon tends to be observed. On the other hand, when the actually measured value of the film thickness of gold (Au) becomes 50 nanometers (nm) or less, that is, within the range of the theoretical film thickness, such a bunch of grapes phenomenon tends not to be observed.

[0022]

However, even when the film thickness is within a range of 50 nanometers (nm) or less, the phenomenon that fine particles of gold (Au) are innumerably scattered tends not to be observed after the final refining heat treatment, in the case where the theoretical film thickness of gold (Au) is within a large thickness range, and as a result, the control of the film thickness of gold (Au) becomes difficult. Accordingly, in order for fine particles of gold (Au) to be innumerably scattered in a stable manner even when the wire is subjected to wire drawing for a long period of time by using one final diamond die, it is better for the film thickness of gold (Au) to be thinner. Accordingly, it is defined that the theoretical film thickness of gold (Au) is preferably 2 nanometers (nm) or less.

[0023]

In addition, in the gold (Au)-dispersed copper wire for ball bonding according to the present invention, in general,

the coating layer made of noble metals constituted by gold (Au) and palladium (Pd) has a thickness of 1 micrometer (μm) or less, and this thickness can be mostly neglected compared to the wire diameter of the bonding wire which is 10 to 25 μm . Accordingly, even though a molten ball is formed by the FAB, the molten ball is not affected by the film thickness of the coating layer. However, the presence of this oxidation resistant coating layer made of palladium (Pd) prevents a copper wire, which is a core material, from being oxidized by oxygen in the atmospheric air. Accordingly, by using the gold (Au)-dispersed copper wire for ball bonding according to the present invention, a molten ball takes a shape of a true sphere and is joined to an aluminum pad, in the same manner as a conventionally known copper wire having a core material composition composed of a copper alloy which contains copper (Cu) having a purity of 99.9 mass% or more.

[0024]

Meanwhile, the object of the present invention cannot be achieved when a wire is coated with a coating material made of a noble metal such as palladium (Pd) and gold (Au) after the wire is subjected to the wire drawing until the final wire diameter is reached. This is because, the final coating layer cannot fill in an irregular vertically long groove, and therefore, the surface layer made of gold (Au) having the theoretical film thickness according to the present invention cannot be formed.

In order to form an extremely thin surface layer according to the present invention, it is generally required to reduce the diameter by 1/10 or more in terms of the diameter of the wire in the wire drawing step, though the degree of the reduction of the diameter also depends on a combination of a core material and a coating material.

[0025]

In addition, since the surface layer according to the present invention which forms innumerably scattered patterns of fine particles of gold (Au) is extremely thin, this surface layer will not be destroyed by using a normal wire drawing speed and a normal degree of the reduction of the diameter, once the surface layer is formed. Accordingly, the innumerably scattered patterns of fine particles of gold (Au) having a desired theoretical thickness can be formed easily by adjusting a temperature and a time period of the refining heat treatment appropriately.

[0026]

The copper alloy of the core material is normally a copper alloy containing copper (Cu) with a purity of 99.9 mass% or more including desired additive elements. In the case of a copper alloy containing copper (Cu) with a purity of 99.9 mass% or more, when phosphorus (P) or gold (Au) is selected, remaining metal components other than phosphorus (P) and gold (Au) can be

appropriately determined, considering existing alloys of prior art techniques. With regard to the purity of a copper alloy base material, a copper alloy containing copper (Cu) with a purity of 99.99 mass% or more is preferable, and a copper alloy containing copper (Cu) with a purity of 99.999 mass% or more is especially preferable. In addition, kinds of additive elements are appropriately determined depending on the kinds and uses of a required semiconductor, and a combination, an adding amount and the like of additive elements can also be appropriately determined depending on the thermal/mechanical properties which are required for a bonding wire.

[0027]

It is known that a stable FAB can be formed when phosphorus (P) is present in copper (Cu) of a core material (Japanese Patent Application Laid-Open Publication No. 2010-225722 and International Publication No. WO 2011/129256). Accordingly, when the above-described copper alloy contains phosphorus (P), it is preferable that the copper alloy contains 3 mass ppm or more and 500 mass ppm or less of phosphorus (P).

[0028]

Further, when gold (Au) is present in copper (Cu) of a core material, it becomes easier for fine particles of gold (Au) which are innumerably scattered at the outermost layer to be taken into the inside of a molten ball, and fine particles of

gold (Au) at the outermost layer are more preferentially dispersed into copper (Cu) of a core material than into the coating layer made of palladium (Pd). As a result, in the case where gold (Au) is present in copper (Cu) of a core material, a relatively strong effect of preventing the formation of an Au/Cu intermetallic compound at the bonded interface with an aluminum pad is exhibited, compared to the case where gold (Au) is absent. On the other hand, since gold (Au) is expensive, a large amount of gold (Au) cannot be added. Accordingly, when the above-described copper alloy contains gold (Au), it is preferable that the copper alloy contains 50 mass ppm or more and 500 mass ppm or less of gold (Au).

[0029]

Meanwhile, each of the extremely thin surface layer and the coating layer on the surface of the wire according to the present invention disappears upon the FAB joining during the first bonding, and also disappears at the joining position upon the ultrasonic bonding during the second bonding.

[Advantageous Effects of Invention]

[0030]

According to the gold (Au)-dispersed copper wire for ball bonding according to the present invention, fine particles of gold (Au) which are innumerable scattered at the outermost layer of the bonding wire form arc discharge like a lightning rod,

between a discharge torch and the tip of the bonding wire, and therefore, the arc discharge upon the first bonding is stabilized. In addition, since this outermost layer is extremely thin, a molten ball part which is formed will not be eccentric by being wetted by the unmelted wire at the root portion. As a result, it is possible for the gold (Au)-dispersed copper wire for ball bonding to be further thinned compared to conventional copper wires.

[0031]

In addition, the area of an aluminum pad can be reduced, and therefore, high-density wiring of a gold (Au)-dispersed copper wire by using a small diameter ball is possible. Further, by using the gold (Au)-dispersed copper wire according to the present invention, an effect that the copper alloy which is the core material is not oxidized can be achieved, because the oxygen intrusion from the surface of the wire is blocked by the coating layer made of palladium (Pd) and the surface layer made of gold (Au). Furthermore, the coating layer of the gold (Au)-dispersed copper wire for ball bonding according to the present invention is extremely thin, and therefore, it is possible to obtain a stable true sphere ball regardless of material properties of the coating material, and is also possible to improve loop formation and the like.

[0032]

In addition, according to the gold (Au)-dispersed copper wire for ball bonding according to the present invention, since fine particles of gold (Au) are innumerably scattered at the outermost layer of the wire, the wire is not stuck to each other even when the wire is multiply wound. As a result, an unwinding property of the wire improves. Further, as a side benefit, slipperiness of the surface of the wire against a capillary improves. Furthermore, according to the gold (Au)-dispersed copper wire for ball bonding according to the present invention, fine particles of gold (Au) at the outermost layer of the wire do not peel off from the coating layer made of palladium (Pd). Accordingly, no oxide of copper (Cu) adheres to a capillary even when bonding is repeated many times, and therefore, the capillary is not contaminated.

[Examples]

[0033]

As a core material, copper (Cu) with a purity of 99.999 mass% or more, to which 100 mass ppm of phosphorus (P) was added or not added, was used. The core material was subjected to continuous casting, and was subjected to intermediate heat treatment ($600^{\circ}\text{C} \times \text{one hour}$), and then was subjected to rolling, and thereafter, was subjected to wire drawing to give a thick wire (with a diameter of 1.0 mm) before being coated with a coating material.

[0034]

[Table 1]

Unused die	Core material			Coating layer	Surface layer	Test results	
	5NCu	P(ppm)	Au(ppm)	Pd(nm)	Au(nm)	FAB stability	FAB eccentricity
Example 1	Reminder	0	0	80	1	○	○
Example 2	Reminder	0	0	20	1	○	○
Example 3	Reminder	0	0	60	1	○	○
Example 4	Reminder	0	0	40	1	○	○
Example 5	Reminder	20	0	60	1	○	○
Example 6	Reminder	80	0	40	1	○	○
Example 7	Reminder	0	2	20	1	○	○
Example 8	Reminder	0	8	80	1	○	○
Example 9	Reminder	40	5	60	1	○	○
Example 10	Reminder	60	7	40	1	○	○
Die used for 100,000 m	Core material			Coating layer	Surface layer	Test results	
	5NCu	P(ppm)	Au(ppm)	Pd(nm)	Au(nm)	FAB stability	FAB eccentricity
Example 11	Reminder	0	0	80	3	○	○
Example 12	Reminder	0	0	20	3	○	○
Example 13	Reminder	0	0	60	3	○	○
Example 14	Reminder	0	0	40	3	○	○
Example 15	Reminder	20	0	60	3	○	○
Example 16	Reminder	80	0	40	3	○	○
Example 17	Reminder	0	2	20	3	○	○
Example 18	Reminder	0	8	80	3	○	○
Example 19	Reminder	40	5	60	3	○	○
Example 20	Reminder	60	7	40	3	○	○
Unused die	Core material			Coating layer	Surface layer	Test results	
	5NCu	P(ppm)	Au(ppm)	Pd(nm)	Au(nm)	FAB stability	FAB eccentricity
Conventional Example 1	Reminder	0	0	200	0	×	○
Conventional Example 2	Reminder	0	0	500	200	○	×
Comparative Example 1	Reminder	0	0	100	10	○	×
Comparative Example 2	Reminder	0	0	100	0.1	×	○

[0035]

Here, the value of gold in the surface layer shown in Table 1 was calculated, as the uniform film thickness in the wire diameter of the bonding wire, from the concentration determined by dissolving about 10,000 meters of a wire with the diameter of 17 μm in aqua regia, and measuring the concentrations of gold (Au) and palladium (Pd) in this solution by a high-frequency inductively coupled plasma emission spectrophotometric analysis method (ICPS-8100 manufactured by Shimadzu Corporation). In other words, the value is the conversion value

in accordance with the chemical analysis by ICP.

[0036]

Next, a coating layer made of palladium (Pd) as well as a surface layer made of gold (Au) shown in Table 1 were prepared, and the outer periphery of the thick wire was coated with them. The purity of gold (Au) of the surface layer was 99.9 mass% or more, and the purity of palladium (Pd) was 99 mass% or more. Thereafter, each of the coated thick wires was subjected to the continuous wire drawing in a wet manner by using a diamond die and was subjected to refining heat treatment of $480^{\circ}\text{C} \times 1 \text{ sec}$ to give a gold (Au)-dispersed copper wire for ball bonding with the diameter of $17 \mu\text{m}$ finally. These wires were used as Examples 1 to 20. Meanwhile, the mean degree of diameter reduction is 6 to 20%, and the final wire speed is 100 to 1,000 m/min. In addition, copper (Cu) of the core material was once subjected to heat treatment at 200 to 600°C for 0.01 to 120 min before being coated.

[0037]

(FAB Stability Test)

A FAB stability test was conducted as follows.

That is, in examples shown in the right column of Table 1, the first ball bonding by means of a FAB was conducted for each of 1,000 wires of Example 1 to Example 20, by using a fully automatic wire bonder IConn ProCu, which is manufactured by

Kulicke & Soffa, with a current value of 45 mA and a time period of arc discharge of 347 microseconds, such that a molten ball of 30 μm gave a squashed ball diameter of 40 μm on an Ag-plated lead frame (QFP-200). The result is shown in the right column of Table 1. In Table 1, the mark $\circ$ shows that there is no eccentric ball at all generated by the arc discharge, and the mark $\times$ shows that there are one or more eccentric balls generated by the arc discharge. From this test result, it is found that the gold (Au)-dispersed copper wire for ball bonding according to the present invention exhibits no fluctuation of molten balls caused by the arc discharge.

[0038]

(FAB Eccentricity Test)

A FAB eccentricity test was conducted in the same manner as the above-described FAB stability test. That is, with regard to each of 1,000 wires, the first ball bonding by means of a FAB was conducted by using a fully automatic wire bonder IConn ProCu with a current value of 45 mA and a time period of arc discharge of 347 microseconds. This result is shown in the right column of Table 1. In Table 1, the mark $\circ$ shows that there is no eccentric ball at all generated by creeping up of a molten ball, and the mark $\times$ shows that there is one or more balls like bunches of grapes generated by creeping up of molten balls. From this test result, it is found that the gold (Au)-dispersed

copper wire for ball bonding according to the present invention does not cause the generation of a ball like a bunch of grapes.

[0039]

Accordingly, with regard to each of wires of Example 1 to Example 20 of the present invention, it is found that the shape of a molten ball is extremely stable and that the area of an aluminum pad can be made smaller. Meanwhile, with regard to the gold (Au)-dispersed copper wire for ball bonding according to the present invention (each of Example 1 to Example 20), it is found that no clogging of a capillary occurs even when the bonding is repeated for more than 10,000 meters, and that the slipping property of a capillary is good. In addition, no wear was observed on the inner surface of a capillary. Further, with regard to the gold (Au)-dispersed copper wire for ball bonding according to the present invention (each of Example 1 to Example 20), the result of a test about unwinding property of each of wires was also good.

[Conventional Examples]

[0040]

A bonding wire on which only 200 nanometers (nm) of a coating layer made of palladium (Pd) was formed was used as Conventional Example 1, and a bonding wire on which 500 nanometers (nm) of a coating layer made of palladium (Pd) and 200 nanometers (nm) of a surface layer made of gold (Au) were

formed was used as Conventional Example 2. Each of these wires of Conventional Examples 1 and 2 was subjected to the FAB stability test and the FAB eccentricity test in the same manner as Examples, and as a result, the results shown in the right column of Table 1 were obtained. As apparent from the results, it is found that the wire of Conventional Example 1 is poor in the result of the FAB stability test, and that the wire of Conventional Example 2 is not satisfactory in the result of the FAB eccentricity test.

[Comparative Examples]

[0041]

A bonding wire on which 100 nanometers (nm) of a coating layer made of palladium (Pd) was formed and a layer of gold (Au) having the theoretical film thickness of 10 nanometers (nm) or 0.1 nanometer (nm) was formed, was used as Comparative Example 1 or 2, respectively. Each of these wires of Comparative Examples 1 and 2 was subjected to the FAB stability test and the FAB eccentricity test in the same manner as Examples, and as a result, the results shown in the right column of Table 1 were obtained. As apparent from the results, it is found that the wire of Comparative Example 1 is poor in the result of the FAB stability test similarly to that of Conventional Example 2, and that the wire of Comparative Example 2 is not satisfactory in the result of the FAB eccentricity test similarly to that

of Conventional Example 1.

[0042]

(HAST Test)

In addition, a HAST test (130°C × 85 RH (relative humidity)) was conducted, and though the measurement results are not shown, the wires of Example 1 to Example 20 all exhibited the life longer than those of Conventional Examples 1 and 2 as well as Comparative Examples 1 and 2, and therefore, the wires of Example 1 to Example 20 had high reliability.

[Industrial Applicability]

[0043]

The gold (Au)-dispersed copper wire for ball bonding according to the present invention is useful for semiconductor applications such as general ICs, discrete ICs, and memory ICs, as well as IC packages for LEDs which require low cost though the use is for a high-temperature and high-humidity atmosphere and IC packages for semiconductors for automobiles. Accordingly, the gold (Au)-dispersed copper wire for ball bonding according to the present invention will replace a conventional gold alloy wire.

[Brief Description of Drawings]

[0044]

[Fig. 1] Figure 1 is a schematic diagram which illustrates the arc discharge of a bonding wire.

[Fig. 2] Figure 2 is a photograph which shows the distribution of gold (Au) on the surface of the bonding wire according to the present invention.

[Fig. 3] Figure 3 is a photograph which shows the distribution of palladium (Pd) on the surface of the bonding wire according to the present invention.

[Title of Document] Claims

[Claim 1]

A gold (Au)-dispersed copper wire for ball bonding, comprising: a palladium (Pd)-coated copper wire for ball bonding having a wire diameter of 10 to 25 μm , wherein the palladium (Pd)-coated copper wire for ball bonding has a core material made of a copper alloy containing copper (Cu) with a purity of 99.9 mass% or more, and wherein the palladium (Pd)-coated copper wire for ball bonding has a coating layer made of palladium (Pd) and a surface layer made of gold (Au) formed thereon, characterized in that the theoretical film thickness obtained by the chemical analysis of said gold (Au) is 0.1 nanometer (nm) or more and 10 nanometers (nm) or less, and that the distribution of gold (Au) observed by the surface analysis using an electron probe microanalyzer (EPMA) is such that fine particles of said gold (Au) are distributed on the coating layer made of said palladium (Pd) in an innumerably scattered manner.

[Claim 2]

The gold (Au)-dispersed copper wire for ball bonding according to Claim 1, wherein the copper alloy contains 3 mass ppm or more and 500 mass ppm or less of phosphorus (P).

[Claim 3]

The gold (Au)-dispersed copper wire for ball bonding

according to Claim 1, wherein the copper alloy contains 50 mass ppm or more and 500 mass ppm or less of gold (Au).

[Claim 4]

The gold (Au)-dispersed copper wire for ball bonding according to Claim 1, wherein the copper alloy contains 0.2 mass ppm or more and 100 mass ppm or less of metal elements other than phosphorus (P) and gold (Au).

[Claim 5]

The gold (Au)-dispersed copper wire for ball bonding according to Claim 1, wherein the copper alloy contains 3 mass ppm or more and 500 mass ppm or less of phosphorus (P), 50 mass ppm or more and 500 mass ppm or less of gold (Au), 0.2 mass ppm or more and 100 mass ppm or less of other metal elements and less than 1,000 ppm in total of these elements.

[Claim 6]

The gold (Au)-dispersed copper wire for ball bonding according to Claim 1, wherein the theoretical film thickness is 2 nanometers (nm) or less.