Specification

Title of the Invention:
Gold-Platinum-Palladium Alloy Bonding Wire

Technical Field

[0001]
The present invention relates to gold-platinum-palladium alloy bonding wire suitable in connecting substrates including IC chip electrodes and external leads used in semiconductor devices, and especially relates to gold-platinum-palladium alloy bonding wire for encapsulation with halogen-free epoxy resin, which is used under conditions of high temperatures like automobiles and high speed devices.

Background of the Invention

[0002]
Conventionally, gold alloy wires used to connect semiconductor devices including IC chip electrodes and external leads for automobile use are demanded to be dependable in their connection durability, and for the reason of high dependability, gold-palladium alloy wire which consists of gold by about 99 mass % and includes palladium by 0.5 - 1.2 mass % is frequently used. A gold alloy wire like this is connected at its one end to a pure aluminum pad or an aluminum alloy pad on an IC chip electrode by means of a thermo compression-ultrasonic hybrid bonding method, and is connected at the other end to an external lead wire or the like on a substrate, and thereafter the bonding area is encapsulated with an epoxy resin to complete a semiconductor device. Such pure aluminum pad and aluminum alloy pad are formed normally by means of vacuum deposition or the like.

[0003]

The surrounding environment in which the semiconductor devices for automotive vehicles are used tend to have temperatures higher than normal environment for the reason of that the devices are used inside or in the vicinity of engine room of the vehicles. It is known that a conventional high connection performance gold-palladium alloy bonding wire has a connection dependability better than a pure gold bonding wire made of 99.99 mass % pure gold when tested in a high temperature storage test (HTS) wherein an encapsulation resin containing a halogen element is used. In some cases, for example, a wire is required to endure a temperature of 175 degrees C for 2,000 to 4,000 hours or so. In a use environment like this, it is important to secure the connection strength for a long term between the gold-palladium alloy bonding wire and a pad electrode. As bonding wires satisfying this there are known: a gold alloy bonding wire composed of Ca by 0.0003 - 0.003 weight %, Mg by 0.0005 - 0.01 weight %, at least one of Pt, Pd and Cu by 0.01 - 2.0 weight % and the balance being Au and inevitable impurities (Claim 1 of IP Publication 1); a gold alloy bonding wire, for a high temperature semiconductor device which is equipped with a pad of aluminum metal or aluminum alloy, the wire being composed of palladium by 0.5 - 0.7 mass %, platinum by 0.1 - 0.3 mass % and balance gold having a purity of 99.999 mass % or higher (Claim 1 of IP Publication 2); and a gold alloy bonding wire for use when halogen-containing epoxy resin is used as an encapsulant resin, the wire containing manganese by 0.005 - 0.5 weight %, palladium by 0.005 - 1.0 weight %, platinum by 0.01 - 2.0 weight %, and at least one of calcium, beryllium and rare earth elements by a total of 0.0005 - 0.05 weight % (Claim 5 of IP Publication 3).

[0004]
In recent years, epoxy encapsulant resins that contain little halogen elements are used widely on account of environmental consideration. When such epoxy encapsulant resin is used, a conventional high connection performance gold-palladium alloy

bonding wire does not always show superior connection performance to that of 99.99 mass % pure gold bonding wire in high temperature storage test, and there were occasions on which a gold-palladium alloy bonding wire failed to show a better result than a pure gold bonding wire.

It has become a customary practice in the case of IC packages for automotive vehicles to conduct a screening of the semiconductor devices without resin encapsulation through the high temperature storage test, which comprises a pulling test after leaving the devices for 1000 hours at 175 degrees C. When a test like this high temperature storage test is conducted on non-capsulated devices, the interface between the bonding wire at the first bonding part and the aluminum pad would deteriorate promptly in the case of a conventional high connection performance gold-palladium alloy bonding wire, and the result would sometimes show that its high temperature connection reliability is inferior to that of the pure gold bonding wire.

[0005]
The conventional high connection performance gold-palladium alloy wire is designed to retard the diffusion of the gold-aluminum bonding area in the aluminum pad interface by means of adding palladium more than platinum, whereby formation of an inter-metallic compound, which causes deterioration of the bonding part of the molten ball, is restricted. However, it is thought that this measure of restricting the formation of the inter-metallic compound excessively retards the diffusion of the gold and aluminum at the gold-aluminum junction and this in turn results in a failure of securing sufficient bonding strength that would have otherwise been secured by diffusion and, as a result, a deterioration of the interface takes place in the gold-aluminum junction. For this reason, it has been a reality that gold palladium-based alloy bonding wires have not been used for IC packages for automotive vehicles and semiconductor devices sealed with halogen-free epoxy

encapsulant resin.

[0006]
IP Publication 1:
Japanese Patent Application Publication H09-321075(1997)
IP Publication 2:
Japanese Patent Application Publication 2011-155129
IP Publication 3:
Japanese Patent Application Publication H10-321075(1998)

Disclosure of the Invention

Problems the Invention seeks to solve

[0007]
It is an object of the present invention to provide a gold-platinum-palladium alloy bonding wire for use with semiconductor devices for automotive vehicles, which exhibits excellent connection performance reliability when connected to an aluminum pad even if the semiconductor device encapsulated with a resin is used in severe environments such as high temperature, high humidity and high pressure.

It is another object of the present invention to provide a gold-platinum-palladium alloy bonding wire for use with semiconductor devices for automotive vehicles, which exhibits excellent connection performance reliability when connected to an aluminum pad such that even in a case wherein an epoxy resin free of halogen elements such as bromine is used, the durability throughout high temperature exposure and the capability of maintaining electric properties despite high temperature exposure are excellent.

Means to solve the Problems

[0008]

The present invention seeks to appropriately control the diffusion of the gold-aluminum junction across the aluminum pad interface and at the same time seeks to restrict the production or growth of inter-metallic compound, which causes deterioration of bonding part of a molten ball, even on occasions where an epoxy resin free of halogen elements is used, by means of including platinum, which is more expensive than palladium, by about 1 mass % or less as a main component element in gold, and including palladium by 0.5 mass % or smaller as a subcomponent element. In the case of a conventional bonding wire wherein palladium is included in gold by about 1 mass %, the diffusion in the bonding part of the aluminum pad is excessively restricted so that when it is subjected to a high temperature storage (HTS), it is thought the bonding wire undergoes deterioration at the aluminum pad interface, especially when an epoxy resin free of halogen elements is used.

[0009]
The inventors of the present invention also sought to appropriately control the diffusion of the gold-aluminum junction across the aluminum pad interface and at the same time sought to improve the mechanical properties of the bonding wire and the circularity of the depressed ball by means of adding infinitesimal amount of aluminum and co-doping calcium or magnesium whereby they are dispersed finely throughout the gold-platinum-palladium alloy matrix. The mechanical properties and depression circularity of the bonding wire are improved further through infinitesimal addition of beryllium, lantern, or rare earth elements such as cerium.

[0010]
One kind of gold-platinum-palladium alloy bonding wire for semiconductor devices to solve the problems of the present invention is a bonding wire composed of platinum by 0.5 - 0.7 mass %, palladium by 0.1 - 0.3 mass %, aluminum by 10 – 30 mass ppm, at least one of calcium and magnesium by 10 - 60 mass ppm

in sum, and a balance, which is gold of a purity of 99.999 mass % or greater.

[0011]
Another kind of gold-platinum-palladium alloy bonding wire for semiconductor devices to solve the problems of the present invention is a bonding wire composed of platinum by 0.4 - 1.2 mass %, palladium by 0.01 - 0.5 mass %, aluminum by 10 - 30 mass ppm, at least one of calcium and magnesium by 10 - 60 mass ppm in sum, beryllium plus at least one selected from rare earth elements by 1 - 30 mass ppm in sum, and a balance, which is gold of a purity of 99.999 mass % or greater.

[0012]
(Gold-platinum-palladium alloy)
A gold-platinum-palladium alloy of the present invention is an alloy consisting of a completely uniform solid solution composed of platinum by 0.4 - 1.2 mass %, palladium by 0.01 - 0.5 mass %, and a balance, which is gold of a purity of 99.999 mass % or greater.

In the present invention, the reason why platinum is adopted as a main element and palladium as a subcomponent element is to suitably control the speed of the diffusion which takes place at the junction between the gold and aluminum on a pure aluminum pad or an aluminum alloy pad to thereby suppress the deterioration of the bonding interface during a high temperature storage.

Therefore, platinum is included by 0.4 - 1.2 mass % and palladium by 0.01 - 0.5 mass %. Preferably the total amount of platinum and palladium is 0.6 - 1.3 mass %.

[0013]
Individually, it is preferable that platinum content is 0.4 - 0.8 mass %, and palladium content is 0.05 - 0.4 mass %, and it

is more preferable that platinum content is 0.5 - 0.7 mass % and palladium content is 0.1 - 0.3 mass %. A mass ratio of platinum to palladium is preferably 2 - 4 and more preferably 2.5 - 3.5.

The reason why a gold having a purity of 99.999 mass % or higher is used as the balance is that by so limiting the amount of the inevitable impurities to less than 10 mass ppm, the role of the infinitesimal additive elements including aluminum and calcium or magnesium is better effected.

[0014]
In the present invention, the aluminum content is chosen to be 10 - 30 mass ppm.

Aluminum forms an inter-metallic compound with gold, so that it is in general not used in a pure gold bonding wire or gold-platinum alloy bonding wire. However, in the case of gold-platinum-palladium alloy bonding wire of the present invention, it improves the mechanical strength of the bonding wire and owing to a synergism with calcium or magnesium it helps sustain the high pull strength even when the wire is let to sit in a high temperature place.

If the aluminum content is less than 10 mass ppm, the above-mentioned effects are not obtained, and when it exceeds 30 mass ppm, the circularity of depressed ball becomes poor. Therefore, the aluminum content is chosen to be 10 - 30 mass ppm. Preferably the aluminum is contained by 16 - 24 mass ppm.

[0015]
In the present invention, at least one of calcium and magnesium is contained in a summed amount of 10 - 60 mass ppm.

In general, calcium and magnesium are thought as elements which improve mechanical strength and depressed ball circularity of

the bonding wire to which they are added. In the case of the gold-platinum-palladium alloy bonding wire of the present invention, as a result of giving rise to synergism with aluminum, calcium works to improve the mechanical strength of the bonding wire and magnesium works to improve the circularity of the depressed ball of the bonding wire.

However, when at least one of calcium and magnesium exists in an amount less than 10 mass ppm in sum, the above-mentioned effects are not obtained, and if the sum exceeds 60 mass ppm, the mechanical strength of the bonding wire becomes so high that the aluminum pad undergoes breakage. Therefore, at least one of calcium and magnesium is included by 10 - 60 mass ppm in sum. It is preferable that the summed content of calcium and magnesium is 10 - 30 mass ppm, and it if more preferable that both of them are contained in a total amount of 16 - 24 mass ppm.

[0016]
In the present invention, beryllium plus at least one selected from rare earth elements are contained by 1 - 30 mass ppm in sum.

In general, beryllium and rare earth elements are considered as elements that enhance the mechanical strength of the bonding wire. In the case of the gold-platinum-palladium alloy bonding wire of the present invention, as a result of giving rise to synergism with aluminum and calcium or magnesium, beryllium or rare earths work to improve the mechanical strength of the bonding wire and improve the circularity of the depressed ball of the bonding wire at the first bonding.

[0017]
It is preferable that beryllium in an amount of 1 - 20 mass ppm and rare earth elements in an amount of 1 - 60 mass ppm are co-doped. The rare earth components preferably include

lantern by 1 - 30 mass ppm or cerium by 1 - 30 mass ppm, and it is more preferable that lantern in an amount of 1 - 30 mass ppm and cerium in an amount of 1 - 30 mass ppm are co-doped. Preferable combinations are 6 - 14 mass ppm of beryllium plus 1 - 30 mass ppm of lantern plus 1 - 30 mass ppm of cerium, and 1 - 20 mass ppm of beryllium plus 10 - 30 mass ppm of lantern plus 1 - 30 mass ppm of cerium; a more preferable combination is 1 - 20 mass ppm of beryllium plus 1 - 30 mass ppm of lantern and 10 - 30 mass ppm of cerium; a still more preferable combination is 6 - 14 mass ppm of beryllium plus 10 - 30 mass ppm of lantern plus 10 - 30 mass ppm of cerium; a most preferable combination is 6 - 14 mass ppm of beryllium plus 14 - 26 mass ppm of lantern plus 14 - 26 mass ppm of cerium,.

Effects of the Invention

[0018]
As described above, the gold-platinum-palladium alloy bonding wire of the present invention produces dependable connection between its molten ball and a pure aluminum pad or an aluminum alloy pad, and sustains good circularity in depressed ball, and even when it is let to sit at a place of high temperatures, a void in the connection interface at the first bonding would not enlarge and evolve so that a stable and reliable connection is maintained, and the pull strength is kept high. Furthermore, the bonding wire of the gold-platinum-palladium alloy of the present invention does not show deterioration at the bonding interface of first bonding even if it is sealed with an epoxy resin free of halogen elements and let to sit at a place of high temperatures, so that the electric connection does not undergo deterioration.

A best mode for practicing the Invention

[0019]
[Embodiment]

A gold-platinum-palladium alloy having a component composition as shown in the left half of Table 1 (the purity of gold being 99.9999 mass % or higher) was cast by melting and was subjected to an anneal heat treatment after it was roughly drawn, and then it was continuously drawn to a final thinness of 20 micrometer-diameter, and thus 20-micrometer-diameter gold-platinum-palladium alloy bonding wires 1 - 27 of the present invention (hereinafter referred to as "inventive wire(s)") were obtained; and comparative gold-platinum-palladium alloy bonding wires outside the scope of the compositions of the present invention and conventional gold-palladium alloy bonding wires were also made, which are designated as wires 28 - 36 (collectively referred to as "comparative wire(s)").

[0020]
These inventive wires 1 - 27 and comparative wires were tested for their wire strengths. Thereafter, each wire was set in a wire bonder manufactured by Kulick & Soffa (product name: Maxμm ultra), and a free air ball (FAB) was made with an aim of 40 μm on a 70-μm-square aluminum alloy pad made of aluminum-0.5 mass % copper alloy installed on a semiconductor IC chip, and bonding was conducted under the conditions of heating temperature 200 degrees C, loop length 5 mm, loop height 220 μm, depressed ball diameter 48 μm, and depressed ball height 14 μm, and the dispersion in the circularity was evaluated. Then the wire was let to sit for 1,000 hours at 175 degrees C, and a pull test was conducted on the bonding wire. Further the bonded sample was sealed with a resin and let to sit for 4,000 hours at 175 degrees C, and thereafter electric resistance was measured.

[0021]
[Evaluation method of wire strength]
With respect to each alloy composition, a 100-mm-long sample was pulled at a rate of 10 mm/min in a Tensilon-type tension

testing machine (Model name: UTM-2), and the tension as of the time of breakage was measured. The measurement was done at five points and the average value was used for evaluation. The results of the evaluation are shown in the right half of Table 1.

[0022]

[Evaluation method of the circularity of the depressed ball]

With respect to each alloy composition, a 100-time bonding was performed on an evaluation-purpose IC chip, and the lengths of the depressed ball in direction X (orthogonal to the ultrasonic wave application direction) and in direction Y (the ultrasonic application direction) were measured and their ratio was used for evaluation. The results of the evaluation are shown in the right half of Table 1.

[0023]

[Pull strength]

With respect to each alloy composition, a bonding was conducted upon a test-purpose IC chip using a wire bonder, and a pull test was performed immediately above the first bond site at 100 points using a universal-type Bond Tester Series 4000 manufactured by Dega Technology Inc., and a pull strength measurement was conducted. Thereafter, the same bonding sample was let to sit for 1,000 hours at 175 degrees C, and again pull strength measurement was conducted at 100 points. The pull strength was evaluated in terms of the lowering of pull strength through the high temperature exposure and whether or not detachment of the first boding part occurred. The results of the evaluation of the pull strength are shown in the right half of Table 1.

[0024]

[Electric resistance]

With respect to each alloy composition, a bonding was conducted upon a test-purpose IC chip using a wire bonder, and the

resulting assembly was sealed with an epoxy resin free of halogen elements (product name: GE-7470C, manufactured by NITTO DENKO CORPORATION), and a sample for measurement of electric resistance was obtained. The measurement of electric resistance was conducted by means of an equipment "SourceMeter (model 2004)," manufactured by Keithley Instruments Inc., using a test purpose IC sockets and an automatic measurement system constructed exclusively for the test purpose. The measurement procedure adopted was in accordance with a so-called direct current four-terminal method.

The electric resistance was measured with respect to 100 pairs of external leads (200 pins) before the high temperature exposure and after the high temperature exposure for 4,000 hours at 175 degrees C. When there was a pair of lead wires of which the electric resistance increased during the high temperature exposure by 20 % or more, it is judged that a fault occurred and the evaluation was based on the rate of this fault occurrence. The results of the evaluation by electric resistance measurement are shown in Table 1.

[0025]

[Table 1]

		component (mass%)		additives (mass pap)									items of evaluation			
		Au	Pt	Pd	Al	Ca	Mg	Be	Ce	La	Er	Y	wire strength	circularity of depressed ball	pull strength	electric resistance
Inventive Examples	1	balance	0.5	0.1	15	25							○	△	○	◎
	2	balance	0.6	0.2	20	20	18						○	○	◎	◎
	3	balance	0.7	0.3	25		15						△	△	◎	◎
	4	balance	0.8	0.4	12	15							○	△	○	◎
	5	balance	0.9	0.05	14		25						△	△	◎	○
	6	balance	1	0.15	16	28							○	△	◎	◎
	7	balance	1.1	0.25	18		26						△	△	◎	◎
	8	balance	0.45	0.35	20	24		5					◎	○	○	◎
	9	balance	0.55	0.45	22		22		5				△	△	○	◎
	10	balance	0.65	0.03	24		18			5			△	△	◎	○
	11	balance	0.75	0.13	26	18		23			5		○	○	◎	◎
	12	balance	0.85	0.23	28	16			27			5	○	△	◎	◎
	13	balance	0.95	0.33	13		14	10	15				△	◎	◎	◎
	14	balance	1.05	0.43	15	12		15		25			△	◎	○	◎
	15	balance	1.15	0.08	17		13	20	8	8			△	○	◎	○
	16	balance	0.48	0.18	19	17		25		10			△	◎	○	◎
	17	balance	0.58	0.28	21		19			15			△	△	◎	◎
	18	balance	0.68	0.38	23	21					15	20	◎	△	○	◎
	19	balance	0.78	0.48	25		23		23	3			△	△	○	◎
	20	balance	0.88	0.02	27		27	21	3	19			△	△	◎	○
	21	balance	0.98	0.12	15	26		3		17			◎	△	◎	◎
	22	balance	1.08	0.42	20	22		7	17				◎	○	○	◎
	23	balance	1.18	0.32	25	14	20	16	21				△	◎	◎	◎
	24	balance	0.42	0.22	16	23	18	8		23			◎	◎	○	◎
	25	balance	0.62	0.16	19	19	22	9	18	22			◎	◎	◎	◎
	26	balance	0.82	0.26	12	27	14	6	24	6			◎	○	◎	◎
	27	balance	1.12	0.36	14	13	27	18	24	18			○	○	◎	◎
Comparative Examples	28	balance	0.2	0.8	×	15	30	10		20			×	×	×	△
	29	balance	1	0.5	×	10	24						×	×	△	○
	30	balance	0.03	0.03	×	×							×	×	△	×
	31	balance	1.4	0.31	11		17						×	×	×	○
	32	balance	0.57	0.7	29	29							◎	×	×	△
	33	balance	1.13	0.005	20	15	80						×	×	◎	○
	34	balance	0.53	0.27	16	26			50				×	×	◎	◎
	35	balance	0.33	0.17	27		18	9			50		△	△	×	×
	36	balance	0.93	0.85	18	22	3	7	35	35	35	35	◎	△	×	×

[0026]
Inventive wires Nos. 1 - 7 correspond to Claim 1 invention, inventive wires Nos. 8 - 27 correspond to Claim 2 invention, inventive wires No. 2 and Nos. 23 - 27 correspond to Claim 3 invention, inventive wires No. 11 and Nos. 13 - 16 and Nos. 20 - 27 correspond to claim 4 invention, inventive wires No. 15 and No. 20 and Nos. 25 - 27 correspond to Claim 6 invention.

[0027]
In the right half of Table 1, the wire strength is indicated in terms of strength measurement results such that a dual circle ◎ represents about 83.4N (8.5gf) or greater, a single circle ○ represents about 68.6N (7.0gf) or greater, a triangle △ represents about 53.9N (5.5gf) or greater and a cross × represents about 53.0N (5.4gf) or smaller, respectively.

In the right half of Table 1, the circularity of depressed ball is indicated in terms of the ratio X/Y where X and Y are diameters of a depressed ball, X and Y being orthogonal to each other, such that a dual circle represents 0.95 - 1.05, a single circle represents 0.9 - 1.10, a triangle represents 0.8 - 1.2, a cross represents either 0.79 or small or 1.21 or greater, respectively.

In the right half of Table 1, the pull strength is indicated in terms of decrement in pull strength and whether or not detachment of the first bonding section took place such that a dual circle represent a decrement of about 0 - 9.8N (0 - 1.0gf), a single circle represents a decrement of about 10.8 - 19.6N (1.1 - 2.0gf), a triangle represents a decrement of about 20.6 - 39.2N (2.1 - 4.0gf), and a cross represents a decrement of about 40.2N (4.1gf) or greater as well as a detachment of the first bonding part, respectively.

[0028]

In the right half of Table 1, the electric resistance is indicated in terms of occurrence rate of fault such that a dual circle represents 0 %, a single circle represents 0.1 - 5.0 %, a triangle represents 5.1 - 30.0 %, a cross represents 30.1 % or higher, respectively.

As is clear from the results shown in the right half of Table 1, the inventive wires had higher wire strengths, excelled in circularity of the depressed ball, experienced smaller decrement in the pull strength during the high temperature exposure, and did not show increases in electric resistance during the high temperature exposure in the case where the epoxy resin free of halogen elements was used for sealing; whereas each one the comparative wires Nos. 28 - 36 showed failure in at least one of the these properties.

Industrial Applicability

[0029]
The bonding wire of the present invention has an application to be used in a semiconductor device encapsulated with an halogen-free epoxy resin, which is used, in particular, in high temperature circumstances such as automotive vehicles and high speed devices.

Scope of the Claims

[Claim 1]
A gold-platinum-palladium alloy bonding wire composed of platinum by 0.5 - 0.7 mass %, palladium by 0.1 - 0.3 mass %, aluminum by 10 - 30 mass ppm, at least one of calcium and magnesium by 10 - 60 mass ppm in sum, and a balance, which is gold of a purity of 99.999 mass % or greater.

[Claim 2]
A gold-platinum-palladium alloy bonding wire composed of platinum by 0.4 - 1.2 mass %, palladium by 0.01 - 0.5 mass %, aluminum by 10 - 30 mass ppm, at least one of calcium and magnesium by 10 - 60 mass ppm in sum, beryllium plus at least one selected from rare earth elements by 1 - 30 mass ppm in sum, and a balance, which is gold of a purity of 99.999 mass % or greater.

[Claim 3]
A gold-platinum-palladium alloy bonding wire as claimed in Claim 1 or Claim 2 characterized by that the content of said calcium is 10 - 30 mass ppm and the content of said magnesium is 10 - 30 mass ppm.

[Claim 4]
A gold-platinum-palladium alloy bonding wire as claimed in Claim 2 characterized by that the content of said beryllium is 1 - 20 mass ppm and the content of at least one of said rare earth elements in total is 1 - 30 mass ppm.

[Claim 5]
A gold-platinum-palladium alloy bonding wire as claimed in Claim 2 characterized by that said beryllium plus at least one selected from rare earth elements consists of beryllium by 1 - 20 mass ppm and at least one of lantern and cerium by 1 - 30 mass ppm in sum.

[Claim 6]
A gold-platinum-palladium alloy bonding wire as claimed in Claim 2 characterized by that said beryllium plus at least one selected from rare earth elements consists of beryllium by 1 - 20 mass ppm, lantern by 1 - 30 mass ppm and cerium by 1 - 30 mass ppm.

[Claim 7]
A gold-platinum-palladium alloy bonding wire as claimed in Claim 1 or Claim 2 characterized by that said bonding wire is for encapsulation with halogen-free epoxy resin.