

[Document Name] Description

[Title of Invention] Bonding Wire for High Speed Signal

[Technical Field]

[0001]

The present invention relates to a bonding wire for high speed signal lines which connects a pad electrode of a semiconductor element to a lead electrode on a wiring board and, particularly, to a bonding wire for high speed signal lines which uses a frequency of 1 to 15 GHz.

[Background Art]

[0002]

In recent years, along with the development of production technique of semiconductor devices, a semiconductor integrated circuit device for high speed signal line using an ultrahigh frequency exceeding a band of several GHz has increasingly been incorporated into a mobile phone or the like. For high frequency transmission, in general, a high purity gold bonding wire having purity of 99.99 mass% or more has heretofore been used. However, when a semiconductor element for high speed/ultrahigh speed signal lines using ultrahigh frequency is connected to a wiring electrode or the like by using the ordinary bonding wire in a band of several GHz to ten or so GHz, an ultrahigh frequency signal flows through a superficial

layer of the bonding wire to undesirably increase high frequency resistance. Therefore, the use of the high purity gold bonding wire can be the cause of reductions of receiver sensitivity, transmission output, and the like.

[0003]

Accordingly, instead of the high purity gold (Au) having a specific electric resistance value of $2.4 \mu\Omega\text{cm}$, a wire of a high purity silver (Ag) having purity of 99.99% and a specific electric resistance value of $1.6 \mu\Omega\text{cm}$ or the like was considered. However, in the course of production of the bonding wire including melting, casting, washing, and continuous wire drawing, the bulk high purity silver (Ag) wire is too soft to be put into practice. Also, silver (Ag) is sulfurized in the atmosphere to form a silver sulfide (Ag_2S) film on a superficial layer of the bonding wire, resulting in hard molten ball, thereby causing a drawback of impairing a ball bonding property of a free air ball (FAB). Accordingly, the pure silver bonding wire has not been used for high frequency transmission in which the high frequency signal flows through the superficial layer of several micrometers, and, though JP-A-57-21830 proposed Ag-Pd alloy wire, only a pure silver bonding wire with pure gold plating has been put into practice as seen in JP-A-2003-59963 (Patent Literature

1 listed below). The reason for the failure in putting the pure silver bonding wire into practice in this way is the difficulty in forming a stable molten ball rather than the difficulty in using the pure silver bonding wire as a high speed signal line using ultrahigh frequency. More specifically, when the molten ball is formed for use in ball bonding by a free air ball (FAB), the rigid silver sulfide (Ag_2S) formed on the wire surface hardens the molten ball to cause chip breakage or the like in first bonding.

[0004]

On the other hand, an Ag-Au binary system alloy bonding wire which is obtainable by adding 10000 to 55000 mass ppm (1 to 5.5 mass%) of Au and 1 to 100 mass ppm of Bi to Ag without lowering specific electric resistance to a value not more than $3.1 \mu\Omega\text{cm}$ which is similar to a widely used Au wire having purity of 99% has been developed for the purpose of using specific electric resistance of Ag having high electro conductivity, and an Ag-Au-Pd ternary system alloy bonding wire which is obtainable by adding 20000 mass ppm or less of Pd to the wire has been developed [JP-A-2012-49198 (Patent Literature 2 listed below)]. The reason why the added amount of Pd is set to 20000 mass ppm (2 mass%) or less is described as "hardness of the ball is

increased when the added amount exceeds 20000 mass ppm, leading to a pad damage during ball bonding" (see paragraph 0021 of Patent Literature 2).

[0005]

Also, a ball bonding wire which is characterized by comprising 5 to 500 wtppm in total of at least two elements selected from Ca, Cu, Gd, and Sm and 0.5 to 5.0 wt% in total of at least one element selected from Pd and Au, with the balance being Ag and inevitable impurities has been disclosed [JP-A-2012-151350 (Patent Literature 3 listed below)]. However, the bonding wire (W) is the one which is used for connecting a Ni/Pd/Au-coated electrode of a semiconductor element to a conductor wiring of a circuit wiring board by the ball bonding method, not the one to be used for bonding an Al alloy (Al-Si-Cu or the like) pad electrode. This is because "a bonding portion between Al and Ag is subject to corrosion [see paragraph 0015 of JP-A-2012-151350 (Patent Literature 3 listed below)].

[0006]

Further, a bonding wire "comprising silver (Ag) as a main component and at least one species selected from 10000 to 90000 mass ppm of gold (Au), 10000 to 50000 mass ppm of palladium (Pd), 10000 to 30000 mass ppm of copper (Cu), and 10000 to 20000 mass ppm of nickel (Ni) with a content of

chlorine (Cl) being less than 1 mass ppm" has been disclosed [JP-A-2012-99577 (Patent Literature 4 listed below)]. However, as Patent Literature 4 describes that the bonding wire "has reflectance of 95% or more for light of wavelengths of 380 to 560 nm to be effectively used for a white LED using blue light emission" (see paragraph 0010 of Patent Literature 4), the bonding wire is used for LEDs and thus has the different object and effect from the bonding wire for high speed signal lines.

[0007]

[Patent Literature 1] JP-A-2003-59963

[Patent Literature 2] JP-A-2012-49198

[Patent Literature 3] JP-A-2012-151350

[Patent Literature 4] JP-A-2012-99577

[Disclosure of Invention]

[Problems to be Solved by Invention]

[0008]

An object of the present invention is to provide an Ag-Pd-Au-based alloy bonding wire for high speed signal lines which enables improvements in bonding properties of a free air ball (FAB) by segregating a high concentration pure silver layer and a low concentration gold alloy layer (hereinafter referred to as "high concentration pure silver layer") on a surface of the bonding wire of the Ag-Pd-Au-

based alloy and forming the segregated high concentration pure silver layer having an even thickness, and simultaneously realizes prevention of formation or progress of silver sulfide into an inside for a certain period and transmission of stable ultrahigh frequency signals of a band of several GHz and the like even when left to stand in the atmosphere.

[Means for Solving Problems]

[0009]

One of the bonding wires for high speed signal lines for solving the problems of the present invention is an Ag-Pd-Au-based alloy bonding wire which is configured to connect a pad electrode of a semiconductor element to a lead electrode on a wiring board by a free air ball (FAB) and comprises an additional trace element, wherein the bonding wire is a ternary alloy comprising 2.5 to 4.0 mass% of palladium (Pd) and 1.5 to 2.5 mass% of gold (Au), with the balance being silver (Ag) having purity of 99.99 mass% or more, a surface of the bonding wire comprises a continuously cast surface of which a diameter is reduced after continuous casting, a cross-section of the bonding wire comprises a surface segregation layer and a core material, and the surface segregation layer is a high concentration pure silver layer comprising an alloy region

where a content of the silver (Ag) is gradually increased and a content of the gold (Au) is gradually reduced as compared to the core material.

[0010]

Another one of the bonding wires for high speed signal lines for solving the problems of the present invention is an Ag-Pd-Au-based alloy bonding wire which is configured to connect a pad electrode of a semiconductor element to a lead electrode on a wiring board by a free air ball (FAB) and comprises an additional trace element, wherein the bonding wire is a ternary system alloy comprising 2.5 to 4.0 mass% of palladium (Pd), 1.5 to 2.5 mass% of gold (Au), and 5 to 300 mass ppm in total of at least one additional trace element of rhodium (Rh), iridium (Ir), ruthenium (Ru), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), indium (In), silicon (Si), germanium (Ge), beryllium (Be), bismuth (Bi), selenium (Se), cerium (Ce), yttrium (Y), lanthanum (La), calcium (Ca), and europium (Eu), with the balance being silver (Ag) having purity of 99.99 mass% or more, a surface of the bonding wire comprises a continuously cast surface of which a diameter is reduced after continuous casting, a cross-section of the bonding wire comprises a surface segregation layer and a core material, and the surface

segregation layer is a high concentration pure silver layer comprising an alloy region where a content of the silver (Ag) is gradually increased and a content of the gold (Au) is gradually reduced as compared to the core material.

[0011]

According to one preferred embodiment of the Ag-Pd-Au-based alloy bonding wire for high speed signal lines for solving the problems of the present invention, the high speed signal has a frequency of 1 to 15 GHz.

[0012]

According to another preferred embodiment of the Ag-Pd-Au-based alloy bonding wire for high speed signal lines for solving the problems of the present invention, the pad electrode is an aluminum (Al) metal having purity of 99.9 mass% or more or an aluminum (Al) alloy comprising 0.5 to 2.0 mass% of silicon (Si) or copper, with the balance being aluminum (Al) having purity of 99.9 mass% or more.

[0013]

According to another preferred embodiment of the Ag-Pd-Au-based alloy bonding wire for high speed signal lines for solving the problems of the present invention, the pad electrode is an electrode pad comprising a surface layer of gold (Au), palladium (Pd), or platinum (Pt).

[0014]

The Ag-Pd-Au-based alloy bonding wire for high speed signal lines for solving the problems of the present invention is subjected to diameter reduction at a cross-section reduction ratio of 99% or more by using a diamond die as is the case with a pure gold bonding wire and is successively subjected to cold wire drawing, and then mechanical properties of the bonding wire are adjusted by a refining heat treatment. Since a temperature is low and a treatment time is short in the refining heat treatment, the surface segregation layer of the high concentration pure silver layer does not disappear.

[0015]

(Main Added Element)

In the present invention, silver (Ag) having purity of 99.99 mass% or more is used as the balance silver (Ag) in order to evenly generate the surface segregation layer of the alloy having the large silver (Ag) content on an entire periphery of the wire. When the purity is lower, a thickness of the surface segregation layer of the alloy having the high silver (Ag) content can be fluctuated due to influences of impurities.

[0016]

In the case of a pure silver bonding wire, since a sulfide is more stable than an oxide, formation of the sulfide is

undesirable. In conventional pure silver bonding wires, superficial silver (Ag) on a surface of high purity silver (Ag) in the atmosphere is turned into ions, and the ions become a sulfide when bound to hydrogen sulfide in the atmosphere. The sulfide initially forms an unstable silver sulfide layer on the pure silver wire surface, and the silver sulfide layer proceeds into the inside of the pure silver bonding wire and gradually grows to secure a rigid silver sulfide (Ag_2S) film of several nanometers on the surface of the pure silver bonding wire. What is worse, it is considered that a sulfurized compound existing on the superficial layer moves along a crystal grain boundary to progress further into the inside of the pure silver bonding wire, thereby extending the rigid silver sulfide (Ag_2S) film.

[0017]

In the case of a bulk Ag-Pd-Au alloy obtained by alloying pure silver (Ag) with palladium (Pd) and gold (Au), formation of the silver sulfide layer in the high concentration pure silver layer is more suppressed than in the pure silver bonding wire. Further, in the case of the Ag-Pd-Au-based alloy of the present invention, since the gold (Au) concentration is gradually increased as approaching from the superficial layer to the inside of the

core material, and the content of palladium (Pd) and gold (Au) in the core material is 4.0 to 6.5 mass%, the progress of the silver sulfide (Ag_2S) film formed on the surface into the inside can be delayed.

[0018]

The content of palladium (Pd) is set to the value larger than the content of gold (Au) in the bonding wire made of the Ag-Pd-Au-based alloy in order to form an Ag-Pd matrix which is nobler than a silver (Ag) matrix with respect to sulfurization resistance and to form the surface segregation layer made of gold (Au) which is much nobler in the Ag-Pd matrix.

[0019]

In the present invention, the predetermined amount of palladium (Pd) is added in order to delay the progress of sulfurization. In the case of using the bonding wire in a humid environment or the like, the bonding wire surface is subject to sulfurization, and, therefore, the wire which is made of the Ag-Pd-Au-based alloy and has sulfurization resistance per se is required. When the palladium (Pd) content is 2.5 mass%, the formation of the rigid silver sulfide (Ag_2S) film on the surface of the pure silver bonding wire can be delayed. In contrast, when the palladium (Pd) content exceeds 2.5 mass%, high frequency

properties are a little deteriorated due to a reduction in silver concentration, resulting in an inappropriate ultrahigh frequency signal line. However, since the high concentration pure silver layer is formed, the palladium content may be up to 4.0 mass% in practical use.

[0020]

Also, since palladium (Pd) is an alloying element which considerably increases hardness, hardness of a molten ball in formation of a free air ball (FAB) is increased when the palladium (Pd) content is 2.5 mass% or more, possibly leading to chip breakage in the ball bonding (see paragraph 0021 of Patent Literature 2). However, since the high concentration pure silver layer having a low melting point is provided by increasing the gold (Au) content, the problem is solved insofar as the palladium (Pd) content is in the range of 4.0 mass% or less. The palladium (Pd) concentration is substantially constant in the high concentration pure silver layer and the core material.

[0021]

In the present invention, the alloying element of gold (Au) has a higher specific gravity than silver (Ag) and palladium (Pd) and, therefore, exhibits a surface segregation effect on the Ag-Pd-based alloy matrix. Since the surface segregation high concentration pure silver

layer utilizes a surface phenomenon between a solid phase and a gas phase of a dilute alloy, the high concentration pure silver layer is capable of evenly forming a layer having a constant width around an entire periphery of the bonding wire. When the wire is viewed in a direction from the surface to the center, the concentration of the alloying element of gold (Au) is gradually increased (lower curve of Fig. 1) along with the gradual reduction (upper curve in Fig. 1) of the silver (Ag) concentration in the high concentration pure silver layer. Accordingly, two regions, namely, the region of the high concentration pure silver layer having the relatively high silver (Ag) concentration and the region of the core material having the relatively low silver concentration exist in the wire. Therefore, even when the unstable silver sulfide layer is formed on the wire surface having the high silver concentration, owing to the synergy between the existence of the two regions and the existence of the alloying elements [palladium (Pd) and gold (Au)] which are nobler than silver (Ag), it is possible to delay the progress of the sulfur compound on the silver alloy surface into the inside and to delay the formation of the rigid silver sulfide (Ag_2S) film on the silver alloy surface during a period in which the bonding wire is left to stand after the

production until it is used as a signal line.

[0022]

Since high purity gold (Au) is subject to surface segregation on the high purity Ag-Pd alloy matrix, when continuous casting is performed by adding palladium (Pd) and gold (Au) to high purity silver (Ag), the high concentration pure silver layer including the high silver (Ag) concentration region and the low gold (Au) concentration region in the form of a doughnut is formed in the vicinity of a superficial layer. By performing cold continuous wire drawing under water-cooling or the like while maintaining the high concentration layer in a production process of a bonding wire, a diameter of the high concentration layer is reduced in proportion to a wire diameter of a thin wire. Thus, the high concentration pure silver layer is usable for high frequency signals of several gigahertzes (Hz) or more.

[0023]

In the case of subjecting a continuously cast wire having a diameter of 8 mm to diameter reduction to obtain a bonding wire of 20 μm (cross-section reduction ratio: 99.9% or more), the high concentration silver (Ag) layer which is several nanometers or less from a surface of the bonding wire theoretically remains on a superficial part. Actually,

when a wire having a diameter of 20 μm was obtained from a continuously cast wire having a diameter of 8 mm by wire drawing, the high concentration pure silver layer shown in Fig. 1 including the high silver (Ag) concentration region (upper curve in Fig. 1) and the low gold (Au) concentration region (lower curve in Fig. 1) was observed.

[0024]

In general, the high frequency signal of several GHz flows through a surface layer of about 1 μm , and it has been considered that the high frequency signal approaches to the surface as the frequency is increased. Therefore, when the high silver (Ag) concentration layer exists in the surface layer, an amount of signals is increased, and a signal waveform is stabilized, as compared to the conventional bonding wires which do not have the high concentration layer.

[0025]

When the range of palladium (Pd) is 2.5 to 4.0 mass%, it is possible to prevent the chip breakage of the molten ball of FAB and to attain stable bonding properties insofar as the range of gold (Au) is 1.5 to 2.5 mass%.

[0026]

(Additional Trace Element)

To the Ag-Pd-Au-based alloy of the present invention, 5 to 300 mass ppm in total of at least one of rhodium (Rh), ruthenium (Ru), iridium (Ir), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), manganese (Mn), indium (In), silicon (Si), germanium (Ge), tin (Sn), beryllium (Be), bismuth (Bi), selenium (Se), cerium (Ce), titanium (Ti), yttrium (Y), calcium (Ca), lanthanum (La), europium (Eu), and antimony (Sb) may be added. These additional trace elements do not change the surface segregation layer of the Ag-Pd-Au-based alloy but is effective for bonding properties of an Ag-Pd-Au-based alloy bonding wire having no high concentration pure silver layer. Therefore, the additional trace elements are adopted to the Ag-Pd-Au-based alloy bonding wire of the present invention. More specifically, the additional trace elements are effective for bondability, particularly for long-term stability, between a molten ball and a pad electrode of an aluminum (Al) metal or an aluminum (Al) alloy. Also, when the element(s) of rhodium (Rh), ruthenium (Ru), iridium (Ir), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), manganese (Mn), indium (In), silicon (Si), germanium (Ge), tin (Sn), beryllium (Be), bismuth (Bi), selenium (Se), cerium (Ce), titanium (Ti), yttrium (Y), calcium (Ca), lanthanum (La), europium (Eu),

and antimony (Sb) is/are added to the Ag-Pd-Au-based alloy within the specified range, flexibility of the bonding wire is enhanced without impairing the shape of FAB. However, the effects of the addition are not exhibited when the total amount of the elements is less than 5 mass ppm, and crystal grains of a molten ball in forming FAB becomes excessively hard to cause chip breakage when the total amount exceeds 300 mass ppm. Accordingly, the range of at least one of rhodium (Rh), ruthenium (Ru), iridium (Ir), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), manganese (Mn), indium (In), silicon (Si), germanium (Ge), tin (Sn), beryllium (Be), bismuth (Bi), selenium (Se), cerium (Ce), titanium (Ti), yttrium (Y), calcium (Ca), lanthanum (La), europium (Eu), and antimony (Sb) was set to 5 to 300 mass ppm in total. Since the total amount of the additional trace elements is usually 100 mass ppm or less in ordinary bonding wires, the total amount of the additional trace elements may preferably be 5 to 100 mass ppm.

[0027]

The pad electrode may preferably be the one comprising a surface layer of gold (Au), palladium (Pd), or gold (Au), or platinum (Pt). This is because the Ag-Pd-Au ternary alloy and Ag-Pd-Au ternary system alloy bonding

wires of the present invention have a good bondability to such an electrode pad by FAB due to the low melting point high concentration pure silver layer.

[Effect of Invention]

[0028]

Since each of the Ag-Pd-Au-based alloy bonding wires of the Ag-Pd-Au ternary alloy and the Ag-Pd-Au ternary system alloy of the present invention is capable of forming the high concentration pure silver layer with high silver (Ag) concentration suitable for high speed signal transmission without fail, and the high concentration pure silver layer and the low concentration gold (Au) layer are added to the core material of each of the Ag-Pd-Au ternary alloy and the Ag-Pd-Au ternary system alloy, they attain better bondability with a pad than conventional bonding wires and are capable of forming a stable silver alloy-rich signal layer which is suitable for transmission of high frequency signals of several GHz to ten or so GHz.

Also, since the high concentration pure silver layer of each of the Ag-Pd-Au-based alloy bonding wires of the present invention is thin, bulk mechanical strength of the wire per se is satisfactory, and the wire has an excellent loop property similar to the conventional bonding wires.

Further, as to the bonding properties including an FAB

property and the like, additional effects that a bondability a second bondability between a molten ball and a pad electrode and are more excellent than the bonding wires having no high concentration pure silver layer are attained since the low melting point high concentration pure silver layer is formed as the surface layer. Particularly, in the case where the pad electrode has the surface layer which is formed of gold (Au) palladium (Pd), or gold (Au), or platinum (Pt), bonding strength is stable.

[0029]

Since the addition amount of palladium (Pd) which influences on the mechanical strength of the bonding wire is 4.0 mass% or less and the addition amount of gold (Au) is 2.5 mass% or less in the Ag-Pd-Au-based alloy bonding wire of the present invention, crystal grains of a molten ball when forming FAB by the low melting point surface segregation layer is prevented from being excessively hard. Also, each of the Ag-Pd-Au-based alloy bonding wires of the present invention is free from chip breakage and pad peeling owing to the low melting point surface segregation layer even in the case where a soft aluminum pad formed of an aluminum (Al) metal having purity of 99.9 mass% or more or an aluminum (Al) alloy comprising 0.5 to 2.0 mass% of silicon (Si) or copper (Cu), with the balance being

aluminum (Al) having purity of 99.9 mass% or more is used. As a result, migration does not occur on the bonding interface even when the bonding wire is left to stand at a room temperature in the atmosphere for a certain period of time, thereby attaining the effect of stably transmitting high frequency signals.

[Examples]

[0030]

Ag-Pd-Au ternary alloys and Ag-Pd-Au ternary system alloys having compositions shown in Table 1 [in each of which purity of each of palladium (Pd) and gold (Au) is 99.99 mass% or more, purity of silver (Ag) is 99.999 mass% or more, and a total amount of additional trace element(s) of rhodium (Rh), ruthenium (Ru), iridium (Ir), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), manganese (Mn), indium (In), silicon (Si), germanium (Ge), tin (Sn), beryllium (Be), bismuth (Bi), selenium (Se), cerium (Ce), titanium (Ti), yttrium (Y), calcium (Ca), lanthanum (La), europium (Eu), and/or antimony (Sb) is 5 to 300 ppm] were produced. As the production method, melting was performed in the same manner as in production of ordinary pure gold bonding wires, and then continuous casting was performed in an inert atmosphere to achieve a diameter of 8 mm. Subsequently, the continuously cast

thick wire was subjected to continuous cold wire drawing in a wet manner at a cross-section reduction ratio of 99.99% or more to achieve a final wire diameter of 20 μm by using a diamond die, and a predetermined refining heat treatment was performed to obtain bonding wires (hereinafter referred to as "wires of the present invention") 1 to 21 according to the present invention each having a wire diameter of 20 μm .

Examples 1 to 9 are the wires of the present invention according to claim 1, and Example 10 to 21 are the wires of the present invention according to claim 2.

[0031]

[Table 1]

No.	Main Element mass%										Additional Trace Element mass ppm																		
	Ag	Pd	Au	Rh	Ru	Ir	Cu	Ni	Fe	Mg	Zn	Al	Mn	In	Si	Ge	Sn	Be	Bi	Se	Ce	Te	Y	Ca	La	Eu	Sb		
1	Balance	3.2	2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	20	0	0	
2	Balance	2.7	2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	Balance	2.9	1.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	Balance	3.7	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	Balance	2.6	1.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	Balance	3.4	1.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	Balance	3.8	2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	Balance	3.9	1.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	Balance	3.1	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	Balance	2.7	2.1	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	
11	Balance	3.2	1.7	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	Balance	2.9	2.3	20	0	0	0	0	0	0	20	0	0	0	0	0	20	0	0	0	0	0	0	0	20	0	0	0	
13	Balance	2.8	1.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	0	
14	Balance	3.0	1.8	0	10	10	0	0	0	0	10	10	10	0	0	0	0	0	0	40	0	0	0	0	20	0	10	0	
15	Balance	3.1	2.2	0	0	0	0	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	Balance	3.6	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	
17	Balance	3.3	2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230	0	0	0	0	0	
18	Balance	1.6	0.4	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	50	0	50	0	0	0	0	0	0	0	
19	Balance	1.8	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	280	0	0	0	
20	Balance	2.0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	
21	Balance	3.4	1.9	0	10	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	
22	Balance	2.4	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	Balance	4.1	1.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350	0	0	0	0	0	0	0	0	0	
24	Balance	2.6	2.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	Balance	3.2	2.3	0	0	0	50	50	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	
E x a m p l e																													
C o m p o s i t i o n o f e x a m p l e																													

E x a m p l e

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[Comparative Examples]

[0032]

Bonding wires 22 to 25 (hereinafter referred to as "comparative wire") having compositions shown in Table 1 which are out of the composition range of the present invention were produced as comparative wires in the same manner as in Examples.

The comparative wire 25 is a bonding wire without a surface segregation layer on a surface layer, which was obtained by producing a thick wire of 8 mm ϕ by continuous casting in the same manner as in Examples, subjecting the thick wire to washing with 80°C dilute nitric acid to obtain an element wire, and subjecting the element wire to continuous wire drawing (diameter reduction). Therefore, the composition range of the comparative wire 25 is within the range of the present invention, but the comparative wire 25 is different from the wires of the present invention in the step of washing with acid.

[0033]

The refining heat treatment in the present invention and Comparative Examples is the one which is performed in a tubular furnace by adjusting a temperature and a speed in the same manner as in a gold wire and for adjusting a drawing ratio to a predetermined value in measurement by

using a tensile rupture tester. The high concentration pure silver layer in the form of a doughnut which was segregated on the surface of each of the wires of the present invention did not disappear by the refining heat treatment.

[Confirmation of High Concentration Pure Silver Layer]

[0034]

The Ag-Pd-Au-based alloy having the composition of the wire 1 of the present invention was subjected to continuous casting under an inert atmosphere into a thick wire having a diameter of 8 mm. The thick wire was subjected to continuous wire drawing under water-cooling and then to the refining heat treatment to attain elongation of 4%, thereby obtaining a bonding wire having a diameter of 20 μm . Silver (Ag) and gold (Au) elements of the bonding wire were analyzed by Auger analysis in a depth direction which is a direction from the surface layer to the center. The results are shown in the schematic diagram of Fig. 1 as the upper curve and the lower curve.

As shown in the schematic diagram of Fig. 1, the gradually reducing layer of high concentration silver (Ag) exists in a region from the surface to the depth of about 10 nm, and, in contrast, the gradually increasing layer of the alloying element gold (Au) which has a low concentration exists in

the region in the wire of the present invention. Though not shown, the concentration of palladium (Pd) was substantially constant in the high concentration pure silver layer and the core material.

[Confirmation of Silver Sulfide]

[0035]

The wire 1 of the present invention was left to stand at a room temperature in the atmosphere for 30 days, and then a film thickness of silver sulfide (Ag_2S) at an outermost surface was measured by using a sulfide film thickness measurement device (QC-200, product of Cermatronics Boeki Co., Ltd.) and employing continuous electrochemical reduction. As a result, no silver sulfide (Ag_2S) film was detected. The result is shown as the red line (L-shaped curve) in Fig. 2.

[0036]

In the same manner as in the wire 1 of the present invention, the comparative wire 22 was left to stand at a room temperature in the atmosphere for 30 days, and then a film thickness of silver sulfide (Ag_2S) was measured. As a result, a silver sulfide (Ag_2S) film was detected. The result is shown as a green line (stepwise curve) in Fig. 2.

[0037]

More specifically, the graph of Fig. 2 shows temporal

voltage changes. In the case of the comparative wire 22 which formed the silver sulfide (Ag_2S) film, as shown by the green line (stepwise curve) of Fig. 2, the phenomenon that the voltage does not change occurs in the segment of -0.25 to -0.80 V despite the elapse of time in the region where the silver sulfide (Ag_2S) film exists. In contrast, in the wire 1 of the present invention, the stepwise phenomenon is not observed in the voltage segment, and the voltage changed along with the elapse of time as shown by the red line (L-shaped curve) of Fig. 2. In view of the fact that there was no region where the voltage was not changed, it was proved that the silver sulfide (Ag_2S) film was not formed in the outermost surface of the wire 1 of the present invention.

[0038]

Also, a qualitative analysis of the outermost surface of the wire 1 of the present invention was conducted by using a scanning Auger analysis device (MICROLAB-310D, product of VG Scientific Ltd.) to detect sulfur (S). The qualitative analysis result is shown in Fig. 3.

As shown in Fig. 3, it can be seen that sulfur (S) exists in the outermost surface of the wire 1 of the present invention. However, in view of the fact that no silver sulfide (Ag_2S) film was detected as is proved from the

result of Fig. 2, it is revealed that sulfur (S) of the wire 1 of the present invention reacts with silver (Ag) existing in the outermost surface but does not form any rigid silver sulfide (Ag_2S) film, and that the bonding state of such silver sulfide is unstable and is achieved by mere physical adhesion. Also, as is apparent from Fig. 3, since metal elements other than silver (Ag), such as palladium (Pd) and gold (Au), are not detected in the outermost surface of the wire 1 of the present invention, and only the high concentration silver (Ag) layer substantially exists in the outermost surface, it is proved that the bonding wire has the optimum structure as a high speed signal layer.

[Aluminum Splash Test]

[0039]

Each of the wires 1 to 21 of the present invention and the comparative wires 22 to 25 was set in a generally-used wire bonder, and free air balls (FABs) were formed on a 70 μm -square aluminum pad [having a vapor-deposited 20 nm-gold (Au) layer on its surface] formed of an Al/1.0 mass%-Si/0.5 mass%-Cu alloy on a surface of a dummy semiconductor IC (obtained by embedding a test pattern into a wafer; usually abbreviated to "TEG") under a blowing nitrogen atmosphere and with a target diameter of 38 μm .

Ball bonding was performed under the conditions of: a substrate temperature of 200°C, a loop length of 5 mm, a loop height of 220 μm , a press-bonding ball diameter of 50 μm , and a press-bonding ball height of 10 μm . As a method for measuring an amount of aluminum splash, the press-bonding ball of each of the wires was observed from right over the press-bonding ball by using a generally-used scanning electron microscope (SEM), and a position of aluminum which was most protruded from the press-bonding ball was measured by setting an outer periphery of the press-bonding ball as a base point. The symbol o indicates that the protruded aluminum amount was less than 2 μm , the symbol Δ indicates that the protruded aluminum amount was 2 μm or more and less than 4 μm , and the symbol $\times$ indicates that the protruded aluminum amount was 4 μm or more. The evaluation results of the aluminum splash test are shown in Table 2.

[0040]

[Table 2]

	No.	Evaluation Item			
		Aluminum Splash	Deteriora- tion of Signal Waveform	Ball Shear	Chip Damage
Wire of Present Invention	1	○	○	○	○
	2	○	○	○	○
	3	○	○	○	○
	4	○	○	○	○
	5	○	○	○	○
	6	○	○	○	○
	7	○	○	○	○
	8	○	○	○	○
	14	○	○	○	○
	15	○	○	○	○
	16	○	○	○	○
	17	○	○	○	○
	18	○	○	○	○
	19	○	○	○	○
	20	○	○	○	○
	21	○	○	○	○
	22	○	○	○	○
	23	○	○	○	○
	24	○	○	○	○
	25	○	○	○	○
	76	○	○	○	○
Wire Comparison	77	○	x	○	○
	78	x	x	○	x
	80	x	x	○	x
	81	○	x	○	○

[Chip Damage Test]

[0041]

Further, a chip damage of each of the samples was investigated. The column of the chip damage test was the result of melting the aluminum pad of the substrate using a sodium hydroxide solution and then observing the chip with a stereomicroscope. In "Chip Damage" of Table 2, the symbol x indicates that there was a scratch or a crack, and

the symbol o indicates that there was no scratch or crack.

[Waveform Degradation Test]

[0042]

A waveform degradation test was performed by employing the quadrupole method. The wires of the present invention and the comparative wires were used as samples (each having a wire diameter of 20 μm and a length of 100 mm). An ordinarily used function generator was used for the measurement, and a pulsed waveform of 10 GHz at 2 V was transmitted through each of the wires of the present invention and the comparative wires. A waveform was measured by using a predetermined and ordinarily used digital oscilloscope capable of measuring a pulsed waveform in a 10 GHz band and probes. An interval between the measurement probes was 50 mm. As a degree of deterioration of a signal waveform, a delay time until an output signal waveform transmitted through the wire reached an input voltage value was measured. It was confirmed that the signal delay time of the conventional pure gold wire (Ca: 15 ppm, Eu: 20 ppm, with the balance being Au of 99.999 mass%) was 20% from a test result. Therefore, as the judgment of the signal delay time, the case where the delay time was less than 20% is indicated as the symbol o, and

the case where the delay time was larger than 20% is indicated as the symbol x, in view of the conventional wire. The evaluation results of the signal waveform deterioration test of the wires of the present invention and the comparative wires are shown in Table 2.

[Press-Bonding Ball Shear Strength Test]

[0043]

A member and an evaluation device same as those of the aluminum splash test were used. Each of the wires of the present invention and the comparative wires was subjected to bonding on a dedicated IC chip by using a wire bonder, and shear strengths of 100 press-bonding balls in ball bonding were evaluated by using General-Purpose Bond Tester (BT) Type 4000 (product name) which is a product of Dage Japan Co., Ltd. The shear evaluation results are shown in Table 2.

[0044]

In Table 2, "Ball Shear" means a shear load value in first bonding. The symbol o indicates that the shear load value was 12 kg/mm² or more, the symbol Δ indicates that the shear load value was 10 kg/mm² or more and less than 12 kg/mm², and the symbol x indicates that the shear load value was less than 1 kg/mm² or that the press-bonding ball was detached.

[0045]

As is apparent from the results of Table 2, deterioration was not observed with all of the wires 1 to 21 of the present invention in the signal waveform deterioration test, while all of the comparative wires 22 to 25 were caused the deterioration.

Also, in the aluminum splash test, the chip damage test, and the press-bonding ball shear strength test, it is confirmed that all of the wires 1 to 21 of the present invention show the good results. In contrast, the comparative wire 22 is inferior in the poor press-bonding ball shear strength test, and that the comparative wires 23 and 24 are inferior in the aluminum splash test and the chip damage test.

[Industrial Applicability]

[0046]

The bonding wire of the present invention is optimally used for an ultrahigh frequency signal of several GHz to ten or so GHz and has usages as bonding wires for signals which are widely and suitably used for transmission of high frequency signals.

[Brief Description of Drawings]

[0047]

Fig. 1 is a sectional schematic diagram showing a distribution of a high concentration pure silver layer of the present invention, in which an upper curve indicates a silver (Ag) concentration, and a lower curve indicates a gold (Au) concentration,

Fig. 2 is a diagram showing graphs (L-shaped curve and stepwise curve) of temporal voltage changes of the wire 1 of the present invention and the comparative wire 22, and

Fig. 3 shows results of qualitative analysis of a vicinity of an outermost surface of the wire 1 of the present invention.

[Document Name] Claims

[Claim 1]

An Ag-Pd-Au-based alloy bonding wire for high speed signal lines which is configured to connect a pad electrode of a semiconductor element to a lead electrode on a wiring board by a free air ball (FAB), wherein: the bonding wire is a ternary alloy comprising 2.5 to 4.0 mass% of palladium (Pd) and 1.5 to 2.5 mass% of gold (Au), with the balance being silver (Ag) having purity of 99.99 mass% or more; a surface of the bonding wire comprises a continuously cast surface of which a diameter is reduced after continuous casting; a cross-section of the bonding wire comprises a surface segregation layer and a core material; and the surface segregation layer comprises an alloy region where a content of the silver (Ag) is gradually decreased and a content of the gold (Au) is gradually increased in a direction from an outermost surface to the core material.

[Claim 2]

An Ag-Pd-Au-based alloy bonding wire for high speed signal lines which is configured to connect a pad electrode of a semiconductor element to a lead electrode on a wiring board by a free air ball (FAB) and comprises an additional trace element, wherein: the bonding wire is a ternary system alloy comprising 2.5 to 4.0 mass% of palladium (Pd),

1.5 to 2.5 mass% of gold (Au), and 5 to 300 mass ppm in total of at least one of rhodium (Rh), iridium (Ir), ruthenium (Ru), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), indium (In), silicon (Si), germanium (Ge), beryllium (Be), bismuth (Bi), selenium (Se), cerium (Ce), yttrium (Y), lanthanum (La), calcium (Ca), and europium (Eu), with the balance being silver (Ag) having purity of 99.99 mass% or more; a surface of the bonding wire comprises a continuously cast surface of which a diameter is reduced after continuous casting; a cross-section of the bonding wire comprises a surface segregation layer and a core material; and the surface segregation layer comprises an alloy region in which a content of the silver (Ag) is gradually decreased and a content of the gold (Au) is gradually increased in a direction from an outermost surface to the core material

[Claim 3]

The bonding wire for high speed signal lines according to claim 1 or claim 2, wherein the silver (Ag) of the bonding wire has purity of 99.999 mass% or more.

[Claim 4]

The bonding wire for high speed signal lines according to claim 1 or claim 2, wherein the high speed signal has a frequency of 1 to 15 GHz.

[Claim 5]

The bonding wire for high speed signal lines according to claim 1 or claim 2, wherein the pad electrode is an aluminum (Al) metal having purity of 99.9 mass% or more or an aluminum (Al) alloy comprising 0.5 to 2.0 mass% of silicon (Si) or copper, with the balance being aluminum (Al) having purity of 99.9 mass% or more.

[Claim 6]

The bonding wire for high speed signal lines according to claim 1 or claim 2, wherein the pad electrode is an electrode pad comprising a surface layer of gold (Au), palladium (Pd), or platinum (Pt).