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DESCRIPTION

Title of Invention:

LEAD-FREE AND ANTIMONY-FREE SOLDER ALLOY, SOLDER BALL, AND
SOLDER JOINT

Technical Field

[0001] The present invention relates to a lead-free and antimony-free solder alloy, a solder ball, and a solder joint.

Background Art

[0002] In recent years, electronic devices are required to have higher integration, larger capacity, and higher speed. For example, a semiconductor package such as QFP (Quad Flat Package) is used, and high integration and high functionality at the semiconductor chip level are being pursued. In manufacture of QFP, a packaging process of die bonding a silicon chip cut from a silicon wafer to a lead frame is employed.

[0003] In QFP, which is obtained by bonding microelectrodes such as BGA (Ball Grid Array), a solder joint is formed by die bonding the silicon chip and the lead frame with a solder alloy. A back metal, for example, having a Ni layer as the outermost layer is formed on the silicon chip, in order to improve the wettability with the solder and improve the adhesive strength. However, when the Ni layer being the outermost layer is in contact with molten solder, the Ni layer melts into the molten solder and Ni leaching occurs. Here, a barrier layer such as Ti is usually formed on the back metal to suppress Ni from diffusing into the silicon chip. When Ni leaching progresses and the Ti layer is exposed, the back metal repels the molten solder without wetting, because the wettability of the solder alloy to Ti is very poor. Moreover, even if a little of the Ni layer remains, Ni atoms diffuse into the molten solder and Ti hardly diffuses into the Ni. Therefore, the number of voids increases at the atomic level at an interface between the Ti layer as the barrier layer and the Ni layer, and the adhesive strength at the interface between the little remaining Ni layer and the Ti layer is extremely reduced. As a result, the bonded section after die bonding may be inferior in impact resistance and heat cycle resistance. Thus, retaining the Ni layer of the back metal is extremely important in die bonding.

[0004] Further, in a microelectrode such as BGA, solder bumps are formed by using solder balls. When solder balls are used, adhesive flux is applied to the microelectrode and solder

balls are placed on the electrode coated with flux. After that, the solder balls are melted by heating in a reflow furnace, and the molten solder wets the microelectrode, so that solder bumps are formed on the microelectrodes. Thus, when solder balls are used, wettability with the electrode is required.

5 [0005] Conventionally, Sn-Ag-Cu solder alloys have been widely used, and are used in the form of solder balls as well as for die bonding. However, when this solder alloy is used, it may be necessary to improve heat cycle resistance, impact resistance, and discoloration resistance among various requirements in recent years. Therefore, in order to improve these characteristics, various studies have been made on Sn-Ag-Cu solder alloys that have been
10 widely used conventionally.

[0006] For example, Patent Document 1 discloses an Sn-Ag-Cu solder alloy containing Ni as an optional element as well as Ge and the like as a selective essential element. It is disclosed that this solder alloy exhibits heat cycle resistance when it contains Ni, and exhibits impact resistance and/or discoloration resistance when it contains Ge.

15 Citation List

Patent Document

[0007] Patent Document 1: Japanese Patent No. 4144415 B2

20 Summary of Invention

Technical Problem

[0008] As described above, the solder alloy disclosed in Patent Document 1 is an excellent alloy that can simultaneously achieve the three kinds of effects, i.e. impact resistance, discoloration resistance, and heat cycle resistance. However, there seems to be room for
25 further improvement with regard to alloy design.

[0009] Although each element has its specific significance to be added to the solder alloy, since a solder alloy is an integrated object formed by combination of all constituent elements and the constituent elements influence each other, the constituent elements need to be contained in a well-balanced manner as a whole. For the solder alloy as described in Patent Document
30 1, it seems that the contents of each constituent element are individually optimized, and are sufficient for obtaining the effects as described in Patent Document 1 at the time of filing the Patent Document 1. However, in order to make a solder alloy containing the same constituent elements adapt to recent demands, it is necessary to individually optimize the content of each

constituent element such that each property can be simultaneously improved, and further, the constituent elements need to be contained in a well-balanced manner.

[0010] In the invention described in Patent Document 1, an alloy design is conducted on the assumption that a solder ball is placed on a microelectrode such as BGA. In addition, even when the solder alloy disclosed in Patent Document 1 is used for die bonding with a large bonding area, breakage due to external stress cannot be ignored. Therefore, when soldering is performed by using an Sn-Ag-Cu-Ni-Ge solder alloy, improvement in shear strength is required. Furthermore, paste applied to an electrode on a substrate and the solder ball on the BGA may not be commingled during melting, so that fusion failure may occur in which a boundary between the paste and the solder ball remains. This is a serious bonding defect and therefore must be suppressed.

[0011] As described above, due to recent higher integration, larger capacity, and higher speed of electronic devices, a solder alloy that can be applied not only to BGA but also to die bonding used in QFP has been required.

[0012] An objective of the present invention is to provide a lead-free and antimony-free solder alloy, a solder ball, and a solder joint that have improved shear strength obtained by grain minuteness at a bonded interface and can suppress fusion failure.

Solution to Problem

[0013] A solder alloy is composed of two or more kinds of elements, and the effects of these element kinds may individually affect the properties of the entire solder alloy. However, as described above, because all the constituent elements constitute an integrated object, the constituent elements are related to each other. The present inventors have focused on alloy design by which shear strength is improved and fusion failure is suppressed so that the alloy design can be applied not only to BGA but also to QFP even for the same constituent elements as the solder alloy according to Patent Document 1. Specifically, under reconsideration of the significance of adding each of the constituent elements, the present inventors conducted a detailed search for composition under consideration of the balance of each of the constituent elements.

[0014] Further, conventionally, in a case where Pb is used for a substrate and then landfilled, acid rain may cause Pb to elute and flow into groundwater. Then, it may affect the human body by accumulating in livestock and humans from groundwater. Therefore, Pb is designated as a regulated substance by the RoHS Directive. Furthermore, in recent years, for environmental and health reasons, there has been a growing demand to avoid the use of not

only Pb but also Sb that may improve the heat-cycling properties of Sn-based solder alloys. Thus, alloy compositions have been studied to achieve the desired properties in a lead-free and antimony-free condition.

[0015] First, a study was made on fusion failure that should not occur in soldering. The occurrence of the fusion failure is attributed to a state of the solder ball on the side of BGA and the paste on the side of the substrate. If a thick Sn oxide film is formed on at least one of the solder ball and the paste, solder alloys thereof will poorly commingle with each other during melting, and a boundary between the solder ball and the paste is thus formed after cooling. One means of removing the oxide film on each surface may be to use flux. Even if the flux is used, however, it is difficult to completely remove the oxide film, and the wettability deteriorates due to the remaining oxide film.

[0016] However, even though the paste contains flux, it is difficult to both remove the oxide film and improve the wettability. In addition, since the volume of the solder ball is several times larger than that of solder powder used for the paste, it is more reasonable to solve the problem of fusion failure on the side of the solder ball than on the side of the paste.

[0017] A study was conducted to suppress the occurrence of fusion failure in the alloy composition on the side of the solder ball. In the Sn-Ag-Cu-Ni-Ge solder alloy, in order to suppress generation of an Sn oxide film on the surface thereof, it is necessary to appropriately adjust the Ge content to an optimum range. Ge is common as an element that incorporates oxygen in the atmosphere to form germanium oxide. Germanium oxide is formed as a hard and brittle oxide film on the surface of the molten solder. However, this oxide film is easily destroyed by the convection of the molten solder itself and also by the external pressure applied to the molten solder at the time when the chip is placed on the molten solder. Therefore, the fusion of the solder ball and the solder powder in the paste is promoted. In addition, if Ag, Cu, and Ni contents are appropriately balanced, ΔT is in an appropriate range. Furthermore, the solder powder for the paste is fused with the solder ball on BGA by adjusting the viscosity of the molten solder.

[0018] In view of these, detailed research has been conducted on the fact that the fusion is attributed to the balance between Ag, Cu, and Ni contents and Ge content in the Sn-Ag-Cu-Ni-Ge solder alloy. As a result, it was found that fusion failure does not occur when these balances are within a predetermined range.

[0019] The present inventors also studied minuteness of intermetallic compounds formed at a bonded interface to prevent the occurrence of fusion failure and to improve the bonding strength of the solder joint. In order to form a compound of Cu and Sn formed at the bonded

interface, the content ratio of Cu and Sn needs to be within a predetermined range. In addition, in the compound of Cu and Sn, the minuteness of the compound is achieved by replacing a part of Cu with Ni. More specifically, when a solder joint is formed with a solder alloy containing Cu and Ni, an intermetallic compound layer with a minute crystal structure more than Cu_6Sn_5 is formed because $(\text{Cu},\text{Ni})_6\text{Sn}_5$ is formed at the bonded interface. Therefore, the bonding strength of the solder joint is improved by an improvement in the strength of the intermetallic compound. The present inventors have focused on Ge as an element that easily concentrates on the surface of a solder alloy and dissolves in Ni to distort the crystal structure of the compound. When Ge is a predetermined amount, Ge dissolves in Ni in the compound, the crystal structure of the compound is distorted, and $(\text{Cu},\text{Ni})_6\text{Sn}_5$ is solid-solution strengthened.

[0020] As a result of the keen study conducted focusing on the above, it was found that in the Sn-Ag-Cu-Ni-Ge solder alloy, the contents of each constituent element are within a predetermined range and the Sn, Cu, Ni, and Ge satisfy a prescribed relationship, so that the bonding strength is improved by minuteness of the compounds. Then, it was found that Ag, Cu, Ni, and Ge can satisfy the suppression of fusion failure at the same time by also satisfying the prescribed relationship, as described above.

The present invention obtained from these finding is as follows.

[0021] (1) A lead-free and antimony-free solder alloy having an alloy composition consisting of, by mass%, 0.1 to 4.5% of Ag, 0.20 to 0.85% of Cu, 0.005 to 0.090% of Ni, and 0.0005 to 0.0090% of Ge with the balance being Sn,

wherein the alloy composition satisfies the following relations (1) and (2):

$$0.006 \leq (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023 \quad \text{Relation (1)}$$

$$(\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.89 \quad \text{Relation (2)}$$

wherein Ag, Cu, Ni, Ge, and Sn in the relations (1) and (2) each represent the contents (mass%) in the alloy composition.

(2) A lead-free and antimony-free solder alloy having an alloy composition consisting of, by mass%, 0.1 to 4.5% of Ag, 0.20 to 0.85% of Cu, 0.005 to 0.090% of Ni, and 0.0005 to 0.0090% of Ge with the balance being Sn,

wherein the alloy composition satisfies the following relations (1) and (2):

$$0.003 < (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023 \quad \text{Relation (1)}$$

$$0.57 \leq (\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.89 \quad \text{Relation (2)}$$

wherein Ag, Cu, Ni, Ge, and Sn in the relations (1) and (2) each represent the contents (mass%) in the alloy composition.

[0022] (3) The lead-free and antimony-free solder alloy according to (1) or (2) above, wherein the alloy composition contains 0.0005 to 0.0045% of Ge by mass%.

(4) The lead-free and antimony-free solder alloy according to any one of (1) to (3) above, wherein the alloy composition contains one or more selected from the group consisting of Mn, Pd, P, Au, Pt, Cr, Fe, Co, V, Mo, and Nb each with an upper limit of 0.01% by mass%.

[0023] (5) A solder ball comprising the lead-free and antimony-free solder alloy according to any one of (1) to (4) above.

(6) The solder ball according to (5) above, having an average particle diameter of 1 to 1000 μm .

(7) The solder ball according to (5) or (6) above, having a sphericity of 0.95 or more.

(8) The solder ball according to (5) or (6) above, having a sphericity of 0.99 or more.

[0024] (9) A ball grid array formed using the solder ball according to any one of (5) to (8) above.

(10) A solder joint comprising the lead-free and antimony-free solder alloy according to any one of (1) to (4) above.

[0024a] In one aspect, there is provided a lead-free and antimony-free solder alloy having an alloy composition consisting of, by mass%:

0.1 to 4.5% of Ag,

0.20 to 0.85% of Cu,

0.005 to 0.090% of Ni, and

0.0005 to 0.0090% of Ge,

optionally one or more selected from the group consisting of Mn, Pd, P, Au, Pt, Cr, Fe, Co, V, Mo, and Nb each with an upper limit of 0.01%,

with the balance being Sn,

wherein the alloy composition satisfies the following relations (1) and (2):

$0.005 \leq (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023$ relation (1)

$(\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.49$ relation (2)

wherein Ag, Cu, Ni, Ge, and Sn in the relations (1) and (2) each represent the contents (mass%) thereof in the alloy composition.

[0024b] In another aspect, there is provided a lead-free and antimony-free solder alloy having an alloy composition consisting of, by mass%,

0.1 to 4.5% of Ag,

0.20 to 0.85% of Cu,

0.005 to 0.090% of Ni,
 0.0005 to 0.0090% of Ge, and
 optionally one or more selected from the group consisting of Mn, Pd, P, Au, Pt, Cr,
 Fe, Co, V, Mo, and Nb each with an upper limit of 0.01%,
 5 with the balance being Sn,
 wherein the alloy composition satisfies the following relations (1) and (2):

$$0.003 < (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023 \quad \text{relation (1)}$$

$$0.57 \leq (\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.89 \quad \text{relation (2)}$$
 wherein Ag, Cu, Ni, Ge, and Sn in the relations (1) and (2) each represent the contents
 10 (mass%) thereof in the alloy composition.

Description of Embodiments

[0025] The present invention is described in more detail below. In the present description,
 "%" relating to the solder alloy composition refers to "mass%" unless otherwise specified.

15 [0026] 1. Alloy Composition
 (1) 0.1 to 4.5% of Ag

Ag is an element that improves the strength of the solder alloy by precipitating minute
 Ag_3Sn at the grain boundaries. If the Ag content is less than 0.1%, the effect of adding Ag is
 20 not sufficiently exhibited. In terms of the lower limit, the Ag content is 0.1% or more,
 preferably 0.5% or more, more preferably 1.0% or more, even more preferably 1.2% or more,
 and particularly preferably 2.0% or more, and most preferably 2.5% or more. On the other
 hand, if the Ag content is too large, coarse Ag_3Sn is precipitated, whereby the strength
 deteriorates. In terms of the upper limit, the Ag content is 4.5% or less, preferably 4.0% or
 25 less, more preferably 3.5% or less, even more preferably 3.2% or less, and particularly
 preferably 3.0% or less.

[0027] (2) 0.20 to 0.85% of Cu

Cu is an element that can suppress Cu leaching and enable precipitation strengthening
 by Cu_6Sn_5 . If the Cu content is less than 0.20%, since the precipitated amount of Cu_6Sn_5 is
 30 small and a brittle SnNi compound is precipitated, the solder alloy itself becomes brittle. In

terms of the lower limit, the Cu content is 0.20% or more, preferably 0.3% or more, even more preferably 0.4% or more, and particularly preferably 0.5% or more. On the other hand, if the Cu content is more than 0.85%, the liquidus temperature of the solder alloy is high and the solder alloy is difficult to melt. In terms of the upper limit, the Cu content is 0.85% or less, preferably 0.80% or less, more preferably 0.75% or less, and even more preferably 0.70% or less.

[0028] (3) 0.005 to 0.090% of Ni

Ni is an element that can control a liquidus temperature of the solder alloy and suppress Ni leaching similarly to Cu. If the Ni content is less than 0.005%, the effect of adding Ni is difficult to exhibit. In terms of the lower limit, the Ni content is 0.005% or more, preferably 0.01% or more, more preferably 0.02% or more, even more preferably 0.025% or more, even yet more preferably 0.03% or more, particularly preferably 0.04% or more, and most preferably 0.05% or more. On the other hand, if the Ni content is more than 0.090%, the liquidus temperature of the solder alloy is high and the solder alloy is difficult to melt. In terms of the upper limit, the Ni content is 0.090% or less, preferably 0.080% or less, more preferably 0.075% or less, and even more preferably 0.070% or less.

[0029] (4) 0.0005 to 0.0090% of Ge

Ge is an element that can suppress fusion failure and Ni leaching. When Ge is not contained, tin oxide is formed on the surface of the molten solder. Tin oxide is strong and hard to break. On the other hand, Ge added to the solder alloy reacts with O in the atmosphere to form a hard and brittle oxide film on the surface of the molten solder. Because this oxide film is brittle, it is easily destroyed by the convection of the molten solder itself or the external force applied from the chip at the time when the chip is placed. Therefore, the formation of the oxide film of Sn is inhibited, and the oxide film is not retained on the surface of the molten solder. Contrary to the oxide film of Sn, the fusion of the solder ball and the solder powder in the paste is promoted.

[0030] In addition, Ge is an element that can be dissolved in Ni of $(\text{Cu,Ni})_6\text{Sn}_5$ formed at the bonded interface to suppress Ni leaching. Because $(\text{Cu,Ni})_6\text{Sn}_5$ is formed at the bonded interface, the crystal structure of this compound is distorted by Ge, so that the migration of Ni in the compound is suppressed and the migration of Ni to the solder alloy is inhibited. When Ge is not contained, the crystal structure of $(\text{Cu,Ni})_6\text{Sn}_5$ is maintained in an aligned state, then Ni at the bonded interface diffuses into the solder alloy, and Ni leaching occurs.

[0031] When the Ge content is less than 0.0005%, tin oxide is produced, the crystal structure of $(\text{Cu,Ni})_6\text{Sn}_5$ is not distorted, and the above effect is difficult to be exhibited. In terms of

the lower limit, the Ge content is 0.0005% or more, preferably 0.002% or more, more preferably 0.003% or more, even more preferably 0.0035% or more, and particularly preferably 0.004% or more. On the other hand, if the Ge content is too large, the liquidus temperature is high and the solder alloy is difficult to melt. In terms of the upper limit, the Ge content is 0.0090% or less, preferably 0.0082% or less, more preferably 0.0080% or less, even more preferably 0.0075% or less, even yet more preferably 0.0060% or less, particularly preferably 0.0050% or less, and most preferably 0.0045% or less.

[0032] (5) Comprising One or More Selected from the Group Consisting of Mn, Pd, P, Au, Pt, Cr, Fe, Co, V, Mo, and Nb Each with an Upper Limit of 0.01%

The solder alloy according to the present invention can comprise one or more selected from Mn, Pd, P, Au, Pt, Cr, Fe, Co, V, Mo, and Nb, each with an upper limit of 0.01% as an optional element. These elements can improve mechanical properties.

[0033] (8) Balance: Sn

The balance of the solder alloy according to the present invention is Sn. In addition to the above-described elements, unavoidable impurities may be contained. Even if unavoidable impurities are contained, it does not affect the above-mentioned effects. Specific examples of the unavoidable impurities include As and Cd. Furthermore, although the present invention is lead-free and antimony-free, it does not exclude the inclusion of Pb and Sb as unavoidable impurities. If In is contained, the wettability deteriorates, and it is better not to contain it. Furthermore, Mn does not have to be contained because it is oxidized during the production of the solder alloy and it is difficult to produce the solder alloy.

[0034] (6) Relation (1)

The present invention satisfies the following relation (1):

$$0.003 < (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023 \quad \text{Relation (1)}$$

In the above relation (1), Ag, Cu, Ni, and Ge each represent the contents (mass%) in the alloy composition.

[0035] If the relation (1) is satisfied, fusion failure is suppressed. Ag, Cu, and Ni form compounds with Sn as described above. If the contents of Ag, Cu, and Ni increase, ΔT increases because the liquidus temperature rises. In addition, the compounds of these elements with Sn grow during melting and solidification to increase the viscosity of the molten solder, and the fusion of the solder powder in the paste and the solder ball on BGA is inhibited. On the other hand, if the contents of these elements are too small, a hard and brittle oxide film of Ge will be thickly covered because the Ge content becomes relatively too large, whereby fusion failure occurs. When the relation (1) is satisfied, the formation of the oxide film of Sn

is inhibited, and the oxide film is not retained on the surface of the molten solder. Contrary to the oxide film of Sn, the fusion of the solder ball and the solder powder in the paste is promoted.

[0036] In terms of the lower limit, the relation (1) needs to be more than 0.003 and is preferably 0.004 or more, more preferably 0.005 or more, even more preferably 0.006 or more, and particularly preferably 0.007 or more, and most preferably 0.008 or more. In terms of the upper limit, the relation (1) needs to be less than 0.023, preferably 0.022 or less, more preferably 0.021 or less, even more preferably 0.020 or less, even yet more preferably 0.019% or less, particularly preferably 0.018 or less, and most preferably 0.016 or less, and may be 0.014% or less, 0.013% or less, 0.011% or less, and 0.009% or less.

[0037] (7) Relation (2)

The present invention satisfies the following relation (2):

$$(\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.89 \quad \text{Relation (2)}$$

In the above relation (2), Cu, Ni, Ge, and Sn each represent the contents (mass%) in the alloy composition.

In the Sn-Ag-Cu-Ni-Ge solder alloy according to the present invention, the balance between the contents of Cu, Ni, Ge, and Sn needs to be considered in order to improve shear strength simultaneously.

[0038] In order to improve the bonding strength of the solder joint, minuteness of the intermetallic compound formed at the bonding interface is necessary, where external stress is concentrated. The reason is that the stress is dispersed to the grain boundaries by making the compound minute. In order to form a compound of Cu and Sn at the bonded interface, the content ratio of Cu and Sn needs to be within a predetermined range. In addition, minute $(\text{Cu}, \text{Ni})_6\text{Sn}_5$ is formed by replacing a part of Cu with Ni, and Ge dissolves in Ni and distorts the crystal structure of the compound. Thus it is presumed that the bonding strength is improved by solid solution strengthening of $(\text{Cu}, \text{Ni})_6\text{Sn}_5$. Accordingly, it is presumed that in the Sn-Ag-Cu-Ni-Ge solder alloy, Sn, Cu, Ni, and Ge satisfy the prescribed relationship, so that the bonding strength is improved by minuteness and solid-solution strengthened of the compound.

[0039] In addition, the occurrence of Ni leaching can also be suppressed by satisfying the relation (2). In order to suppress the Ni leaching, it is necessary to suppress diffusion of Ni at the bonded interface. In order to suppress the diffusion of Ni, the migration of Ni into the solder alloy should be inhibited. Here, it is presumed that $(\text{Cu}, \text{Ni})_6\text{Sn}_5$ is formed at the bonded interface, and the crystal structure of the compound is further distorted by containing Ge, which dissolves in Ni, in a well-balanced manner, and the diffusion of Ni is suppressed.

[0040] In terms of the upper limit, the relation (2) is less than 0.89, preferably 0.88 or less, more preferably 0.84 or less, even more preferably 0.83 or less, even yet more preferably 0.81 or less, particularly preferably 0.80 or less, and most preferably 0.79 or less, and may be 0.73 or less. In terms of the lower limit, the relation (2) is not particularly limited, but from the viewpoint of suppressing Ni leaching and sufficiently improving shear strength, it is preferably more than 0.25, more preferably 0.32 or more, even more preferably 0.34 or more, even yet more preferably 0.36 or more, particularly preferably 0.37 or more, and most preferably 0.44 or more, and may be 0.49 or more, 0.57 or more, 0.63 or more, and 0.71 or more.

[0041] Consequently, the solder alloy according to the present invention needs to satisfy the relations (1) and (2) in order to achieve both suppression of fusion failure and improvement in shear strength. As a result thereof, Ni leaching can also be suppressed.

[0042] (8) ΔT

It is preferable that ΔT of the solder alloy according to the present invention is within a predetermined range because the solid-liquid coexistence region is narrow, and an increase in the viscosity of the molten solder can be suppressed. The range of ΔT is preferably 100°C or less, more preferably 70°C or less, and even more preferably 40°C or less.

[0043] 3. Solder Ball

The lead-free and antimony-free solder alloy according to the present invention is most suitable for the form of solder balls used for BGA. The sphericity of the solder ball is preferably 0.90 or more, more preferably 0.95 or more, and most preferably 0.99 or more. The sphericity is determined by various methods such as the least squares circle method (LSC method), the minimum zone circle method (MZC method), the maximum inscribed circle method (MIC method), and the minimum circumscribed circle method (MCC method). In the present invention, the sphericity of the solder ball is measured using a CNC image measuring system (Ultra Quick Vision ULTRA QV350-PRO measuring device manufactured by Mitutoyo Corporation) using the minimum zone circle method (MZC method). In the present invention, the sphericity represents a deviation from the true sphere, and for example, the sphericity is an arithmetic mean value calculated when the diameter of each of 500 balls is divided by the major axis. The closer the value of the sphericity is to the upper limit of 1.00, the closer it is to a true sphere.

[0044] The solder balls according to the present invention are used for forming bumps on electrodes and substrates of semiconductor packages such as BGA (ball grid array). The diameter of the solder ball according to the present invention is preferably in the range of 1 to

1000 μm and more preferably 50 μm or more to 300 μm . The solder ball can be manufactured by a general solder ball manufacturing method. The diameter in the present invention means the diameter measured by Ultra Quick Vision ULTRA QV350-PRO measuring device manufactured by Mitutoyo Corporation.

5 [0045] 4. Solder Joint

The solder joint according to the present invention is suitable for connection between an IC chip for a semiconductor package and its substrate (interposer), or for connection between the semiconductor package and a printed wiring board. Here, the term "solder joint" according to the present invention is defined as a connection part between an IC chip and a substrate,
10 which is connected using the above-described solder alloy according to the present invention, and the connection part includes a connection for an electrode or a connection part between a die and the substrate.

[0046] 5. Other

A bonding method using a solder alloy according to the present invention may be
15 performed according to an ordinary method e.g. using a reflow method. The heating temperature may be appropriately adjusted depending on the heat resistance of the chip or the liquidus temperature of the solder alloy. About 240°C is preferable as the heating temperature from the viewpoint of suppressing thermal damage to the chip. A melting temperature of the solder alloy for performing flow soldering may be approximately 20°C higher than the liquidus
20 temperature. In a case where bonding is conducted by using the solder alloy according to the present invention, the structure can be further made minuteness by considering a cooling rate during solidification. For example, the solder joint is cooled at a cooling rate of 2 to 3°C/s or higher. Other bonding conditions can be appropriately adjusted depending on the alloy composition of the solder alloy.

25 [0047] The solder alloy according to the present invention enables a low α -ray alloy to be produced by using a low α -ray material as a raw material therefor. When such a low α -ray-alloy is used for forming solder bumps in the periphery of memory, soft errors can be suppressed.

30 Examples

[0048] For the solder alloys constituted from alloy compositions as shown in Table 1, fusion failure and ΔT obtained from the liquidus temperature and the solidus temperature were evaluated as follows. The shear strength and Ni leaching were also evaluated.

[0049] (1) Presence or absence of fusion failure

The solder alloys as shown in Table 1 were verified for the presence or absence of fusion failure. A method for verifying them was such that the prepared solder alloys based on compositions of Examples and Comparative Examples were cast and rolled, and they were punched out into small piece members (each being 2 mm (length) × 2 mm (width) × 0.1 mm (thickness)). These small pieces were formed as plate materials having a predetermined dimension, which were put on a Cu plate on which organic solderability preservative (OSP) processing (water-soluble preflux processing) was performed and flux was applied. They were reflowed, and then the surface thereof was washed and stayed at an environment of a temperature of 125°C and humidity RH of 100% RH for 24 hours. Further, the solder balls (in the case of this example, a diameter thereof is 300 μm) which were prepared by using the solder alloy consisting of, by mass%, 3.0% of Ag and 0.5% of Cu with the balance being Sn (Sn-3.0Ag-0.5Cu) were stayed at an environment of a temperature of 125°C and humidity RH of 100% RH for 24 hours similarly to the small piece members. Next, flux was applied to samples made of the solder alloys of Examples or Comparative Examples, and the predetermined number of solder balls was put thereon. In the examples, the number of solder balls was set to be nine pieces and respective 5 plate materials were prepared. Then, after reflowing was performed, the number of fusion-failed solder balls was calculated and incidence of fusion defect was determined. The term fusion failure is defined as a state in which the small pieces and the solder balls are not bonded to each other.

When the number of the fusion failed solder balls is 0 or less, it was rated as "A"; when it was more than 0 and 10 or less, it was rated as "B"; and when it was more than 10, it was rated as "D".

[0050] (2) ΔT (K)

Each solder alloy as shown in Table 1 was prepared, and the melting temperature of the solder was measured. The measurement of the solidus temperature was performed according to JIS Z3198-1. The liquidus temperature was measured, instead of JIS Z3198-1, with a method with DSC which is similar to the measurement method for a solidus temperature according to JIS Z3198-1. ΔT (K), which is the difference between the measured liquidus temperature and solidus temperature, was determined. When ΔT (K) was 100 K or less, it was rated as "B", and when it was over 100 K, it was rated as "D".

[0051] (3) Shear strength

Solder balls with a diameter of 0.6 mm were prepared from solder compositions as shown in Table 1. These solder balls were used for soldering to a substrate with a thickness of 1.2 mm and an electrode size of 0.5 mm in diameter (Cu-OSP).

[0052] As for the soldering conditions, a flux (manufactured by SENJU METAL INDUSTRY CO., LTD.: WF-6400) was applied onto an electrode, and soldering was performed using a reflow apparatus (manufactured by SENJU METAL INDUSTRY CO., LTD.: SNR-615) under a reflow profile with a peak temperature of 245°C and a cooling rate of 2°C/s. The prepared sample was subjected to a shear strength test under the conditions of a shear rate of 1000 mm/s in a shear strength measuring device (manufactured by Nordson Dage: SERIES 4000HS).

[0053] (4) Ni leaching

A preform with a thickness of 250 μm and made of alloy composition as shown in Table 1 was mounted on a Cu lead frame. Thereafter, an IC chip having a back metal on the side of a substrate bonded surface of a silicon chip of 5 mm $\times$ 5 mm $\times$ 200 μm^t was mounted on the solder alloy. The back metal is obtained by sequentially stacking a 0.05 μm Ti layer as a barrier layer, and a 0.20 μm Ni layer. The mounting was performed in such an orientation that in the IC chip having the back metal, the Ni layer was in contact with the solder alloy. A substrate with the solder alloy and the IC chip mounted thereon was heated in a reflow furnace so that the peak temperature was 240°C, then die bonding was performed.

Then, a cross section of an obtained lead frame was zoomed up by a factor of 30000 on a SEM monitor, and an average value of a film thickness of an Ni layer was calculated from arbitrary 10 locations.

The results are shown in Table 1.

[0054]

Table 1

	Alloy Composition (mass%)						Relation (1)	Relation (2)	Fusion failure	ΔT	Comprehensive evaluation
	Sn	Ag	Cu	Ni	Ge	other					
Example 1	Bal.	0.5	0.50	0.010	0.0080		0.008	0.88	B	B	B
Example 2	Bal.	1.0	0.50	0.050	0.0040		0.006	0.73	A	B	B
Example 3	Bal.	1.0	0.70	0.010	0.0082		0.014	0.63	B	B	B
Example 4	Bal.	1.0	0.50	0.080	0.0030		0.005	0.57	A	B	B
Example 5	Bal.	2.0	0.75	0.070	0.0030		0.008	0.37	A	B	B
Example 6	Bal.	2.5	0.70	0.030	0.0040		0.013	0.49	A	B	B
Example 7	Bal.	3.0	0.50	0.005	0.0030		0.011	0.36	A	B	B
Example 8	Bal.	3.0	0.50	0.010	0.0020		0.007	0.32	A	B	B
Example 9	Bal.	3.0	0.50	0.050	0.0045		0.016	0.80	A	B	B
Example 10	Bal.	3.5	0.50	0.020	0.0035		0.014	0.57	A	B	B
Example 11	Bal.	3.5	0.50	0.070	0.0040		0.016	0.73	A	B	B
Example 12	Bal.	3.5	0.80	0.070	0.0030		0.013	0.34	A	B	B
Example 13	Bal.	4.0	0.80	0.010	0.0045		0.022	0.37	A	B	B
Example 14	Bal.	4.5	0.20	0.025	0.0020		0.009	0.88	A	B	B
Example 15	Bal.	4.5	0.80	0.060	0.0040		0.021	0.44	A	B	B
Example 16	Bal.	1.0	0.50	0.080	0.0045		0.007	0.84	A	B	B
Example 17	Bal.	2.5	0.75	0.070	0.0060		0.020	0.71	A	B	B
Example 18	Bal.	2.0	0.75	0.070	0.0075		0.021	0.88	A	B	B
Example 19	Bal.	1.2	0.50	0.050	0.0045		0.008	0.81	A	B	B
Example 20	Bal.	3.0	0.50	0.050	0.0050		0.018	0.88	A	B	B

Table 1-continued

	Alloy Composition (mass%)						Relation (1)	Relation (2)	Fusion failure	ΔT	Comprehensive evaluation
	Sn	Ag	Cu	Ni	Ge	other					
Example 21	Bal.	3.2	0.50	0.030	0.0050		0.019	0.83	A	B	B
Example 22	Bal.	3.5	0.50	0.050	0.0045	Mn:0.01	0.018	0.79	A	B	B
Example 23	Bal.	3.5	0.50	0.050	0.0045	Pd:0.01	0.018	0.79	A	B	B
Example 24	Bal.	3.5	0.50	0.050	0.0045	P:0.01	0.018	0.79	A	B	B
Example 25	Bal.	3.5	0.50	0.050	0.0045	Au:0.01	0.018	0.79	A	B	B
Example 26	Bal.	3.5	0.50	0.050	0.0045	Pt:0.01	0.018	0.79	A	B	B
Example 27	Bal.	3.5	0.50	0.050	0.0045	Cr:0.01	0.018	0.79	A	B	B
Example 28	Bal.	3.5	0.50	0.050	0.0045	Fe:0.01	0.018	0.79	A	B	B
Example 29	Bal.	3.5	0.50	0.050	0.0045	Co:0.01	0.018	0.79	A	B	B
Example 30	Bal.	3.5	0.50	0.050	0.0045	V:0.01	0.018	0.79	A	B	B
Example 31	Bal.	3.5	0.50	0.050	0.0045	Mo:0.01	0.018	0.79	A	B	B
Example 32	Bal.	3.5	0.50	0.050	0.0045	Nb:0.01	0.018	0.79	A	B	B
Comparative Example 1	Bal.	3.0	0.50	0.030	<u>0.0150</u>		<u>0.053</u>	<u>1.93</u>	D	B	D
Comparative Example 2	Bal.	2.0	0.75	0.070	0.0080		<u>0.023</u>	<u>0.93</u>	D	B	D
Comparative Example 3	Bal.	3.5	0.50	<u>0.100</u>	<u>0.1500</u>		<u>0.615</u>	<u>11.49</u>	D	D	D
Comparative Example 4	Bal.	3.5	0.50	<u>0.200</u>	<u>0.0500</u>		<u>0.210</u>	<u>7.66</u>	D	D	D
Comparative Example 5	Bal.	3.5	0.50	<u>0.200</u>	<u>0.1000</u>		<u>0.420</u>	<u>12.76</u>	D	D	D
Comparative Example 6	Bal.	1.2	0.50	0.050	<u>0.0001</u>		<u>0.000</u>	0.02	D	B	D
Comparative Example 7	Bal.	1.2	0.50	0.050	0.0005		<u>0.001</u>	0.10	D	B	D
Comparative Example 8	Bal.	1.2	0.50	0.050	0.0010		<u>0.002</u>	0.19	D	B	D
Comparative Example 9	Bal.	1.2	0.50	0.050	<u>0.0200</u>		<u>0.035</u>	<u>2.81</u>	S	B	D
Comparative Example 10	Bal.	4.5	0.85	0.005	0.0005		<u>0.003</u>	0.05	D	B	D
Comparative Example 11	Bal.	0.1	0.20	0.050	0.0005		<u>0.000</u>	0.25	D	B	D

The underline indicates that it does not fall within the scope of the present invention.

[0055] As shown in Table 1, according to Examples 1 to 32, it was revealed that fusion failure does not occur and ΔT is in a predetermined range because the content of each constituent element and the relations (1) and (2) were satisfied for all the alloy compositions.

5 In addition, it was confirmed that the solder joints comprising the solder alloys of Examples showed higher values of shear strength than any of Comparative Examples. Furthermore, it was confirmed that the average value of the film thickness of the Ni layer was 20% or more of an initial film thickness.

[0056] On the other hand, according to Comparative Examples 1 to 11, the relation (1) was
10 not satisfied, whereby many fusion-failed solder balls were detected. In addition, the Sn-1.2Ag-0.50Cu-0.050Ni-0.0050Ge solder alloy (the numerical values are expressed in mass%; the balance is Sn and unavoidable impurities) and Sn-1.2Ag-0.50Cu-0.050Ni-0.0100Ge solder alloy (the numerical values are expressed in mass%; the balance is Sn and unavoidable impurities) had inferior shear strength of solder joints because they satisfied the relation (1) but
15 not relation (2).

CLAIMS

1. A lead-free and antimony-free solder alloy having an alloy composition consisting of, by mass%:
5 0.1 to 4.5% of Ag,
0.20 to 0.85% of Cu,
0.005 to 0.090% of Ni,
0.0005 to 0.0090% of Ge, and
optionally one or more selected from the group consisting of Mn, Pd, P, Au, Pt, Cr,
10 Fe, Co, V, Mo, and Nb each with an upper limit of 0.01%,
with the balance being Sn,
wherein the alloy composition satisfies the following relations (1) and (2):

$$0.005 \leq (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023 \quad \text{relation (1)}$$

$$(\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.49 \quad \text{relation (2)}$$
15 wherein Ag, Cu, Ni, Ge, and Sn in the relations (1) and (2) each represent the contents (mass%) thereof in the alloy composition.

2. A lead-free and antimony-free solder alloy having an alloy composition consisting of, by mass%,
20 0.1 to 4.5% of Ag,
0.20 to 0.85% of Cu,
0.005 to 0.090% of Ni,
0.0005 to 0.0090% of Ge, and
optionally one or more selected from the group consisting of Mn, Pd, P, Au, Pt, Cr,
25 Fe, Co, V, Mo, and Nb each with an upper limit of 0.01%,
with the balance being Sn,
wherein the alloy composition satisfies the following relations (1) and (2):

$$0.003 < (\text{Ag} + \text{Cu} + \text{Ni}) \times \text{Ge} < 0.023 \quad \text{relation (1)}$$

$$0.57 \leq (\text{Sn}/\text{Cu}) \times (\text{Ni} \times \text{Ge})/(\text{Ni} + \text{Ge}) < 0.89 \quad \text{relation (2)}$$
30 wherein Ag, Cu, Ni, Ge, and Sn in the relations (1) and (2) each represent the contents (mass%) thereof in the alloy composition.

3. The lead-free and antimony-free solder alloy according to claim 1 or 2, wherein, by mass%,
the alloy composition comprises 0.0005 to 0.0045% of Ge.

5

4. A solder ball comprising the lead-free and antimony-free solder alloy according to any one of claims 1 to 3.

10

5. The solder ball according to claim 4, having an average particle diameter of 1 to 1000 μm .

6. The solder ball according to claim 4 or 5, having a sphericity of 0.95 or more.

7. The solder ball according to claim 4 or 5, having a sphericity of 0.99 or more.

15

8. A ball grid array formed using the solder ball according to any one of claims 4 to 7.

9. A solder joint comprising the lead-free and antimony-free solder alloy according to any one of claims 1 to 3.