[0009] Patent Document 1: International Publication No. WO 2020/135932

Patent Document 2: International Publication No. WO 2007/102588

Patent Document 3: Japanese Unexamined Patent Application Publication No. 2008-93701 A

Patent Document 4: Japanese Unexamined Patent Application Publication No. 2013-049073 A

Summary

Technical Problem

[0010] In Patent Document 1, various evaluations are made on the alloy composition containing Sn and Cu. However, evaluation is performed with an alloy composition having different constituent elements according to each evaluation item. For example, in the evaluation on die tilt, a solder alloy having constituent elements exhibiting a melting point such that it does not melt in second reflow or maintains a high viscosity even when melted is used. The void growth and the shear strength after reflow soldering performed a plurality of times are similarly evaluated with solder alloys consisting of different constituent elements.

[0011] As described above, in the invention described in Patent Document 1, constituent elements other than Sn and Cu are different according to each evaluation item, although various evaluations have been made. Therefore, an alloy composition satisfying all the evaluation items mentioned in Patent Document 1 is not disclosed. In addition, as described above, Patent Document 1 discloses that Ag may be contained. However, Ag-containing alloy compositions have not been evaluated. Therefore, in the invention described in Patent Document 1, the effect of adding Ag is not verified.

[0012] In the inventions described in Patent Document 2 and Patent Document 3, the Ni content is reduced in both the inventions to improve the properties of the joint interface, thereby improving the drop impact resistance. In the invention described in Patent Document 4, the joint interface is miniaturized by expensive rare metals.

[0013] As described above, in Patent Documents 1 to 4, a joint interface of a solder joint is studied. Improving the properties of the joint interface of the solder joint is an important

objective in solder alloys. However, even if the load on the solder joint becomes large, a fracture mode should not be such that the joint interface breaks. In the solder joint, since physical and electrical loads are mainly applied to the joint interface, it is desired that the solder joint is firmly joined at the joint interface.

[0014] As described above, evaluation of a solder joint in an extreme state is an important index for confirming that a good solder joint is formed. However, since the fracture mode is not examined in Patent Documents 1 to 4, it is unclear whether a solder joint having a good joint interface is formed.

[0015] In addition, the evaluation items studied in Patent Documents 1 to 4 are all performed after the solder joint is formed. As a property of the solder alloy before the solder joint is formed, excellent wettability of the molten solder is also important. In Patent Documents 1 to 4, wettability is mentioned, but no evaluation with a specific alloy composition is performed on wettability.

[0016] Furthermore, in bonding to a substrate such as a BGA, the shape of the solder bump needs to be appropriate as a form before the solder joint is formed. This is because when the solder bump is deformed, there is a high likelihood that some problem will occur during soldering. However, the shape of the solder bump for forming the solder joint is not studied at all in Patent Documents 1 to 4.

[0017] The solder bump is formed by melting a solder ball on an electrode, then solidifying the solder ball, and joining the solder ball to the electrode. Therefore, it is considered preferable that the surface has a substantially elliptical shape. On the other hand, a hole may be formed in the solder bump to cause unevenness on the surface, a needle-shaped intermetallic compound may protrude on the surface of the solder bump, or the shape may be an irregular shape greatly deviated from a substantially elliptical shape. Such solder bumps are likely to cause bonding defects or short circuit between the electronic component and the substrate. In recent years, due to downsizing and thinning of electronic components, bonding defects due to irregularly-shaped bumps have been increasing year by year, and thus prompt improvement is desired.

[0018] Therefore, an object of the present disclosure is to provide a solder alloy, a solder ball,

a solder preform, a solder joint, and a circuit which have excellent wettability and shear strength, as well as an appropriate fracture mode, suppressed growth of an intermetallic compound at a joint interface even after reflowing is performed a plurality of times, excellent drop impact resistance, and an appropriate bump shape.

Solution to Problem

[0019] The present inventors have studied various alloy compositions of the solder alloy disclosed in Patent Documents 2 to 4 in order to solve the problem of the present disclosure. Specifically, evaluation was performed with an Sn-1.0Ag-1.0Cu-0.1Ni solder alloy not containing Ge, which is the alloy composition of Example 10 in Patent Document 2. Consequently, it was found that an abnormality occurs in the solder bump.

[0020] Therefore, the present inventors have evaluated an Sn-1.0Ag-1.0Cu-0.1Ni-0.02Ge solder alloy obtained by adding Ge to the Sn-1.0Ag-1.0Cu-0.1Ni solder alloy. As a result, abnormality of the solder bump was observed, and it was found that wettability was poor.

[0021] Next, a study was conducted focusing on the Ni content. In paragraphs 0072 and 0139 of Patent Document 2, it is explained that when the Ni content is more than 0.07%, the solder alloy before reflow is hardened to such an extent that there is no problem in practical use, and thus the drop impact resistance is poor. Meanwhile, in paragraph 0063 of the same document, it is described that Ni alleviates strain between a $(Cu, Ni)_6Sn_5$ intermetallic compound in which a part of Cu is substituted with Ni and an adjacent Cu_3Sn intermetallic compound. In view of these facts, it is presumed that the Sn-Ag-Cu-Ni-Ge solder alloy disclosed in the same document discloses only an alloy composition of 0.05% in which the Ni content is close to 0.07%.

[0022] In addition, FIGS. 3 and 4 of Patent Document 3 disclose that generation of voids cannot be suppressed when the Ni content is more than 0.05%. Further, FIG. 5 of the same document discloses that the alloy composition containing 0.03% of Ni has the same breaking elongation as that of the alloy composition containing 0.07% of Ni, and does not need to contain more than 0.05% of Ni.

[0023] Therefore, in view of these descriptions, the present inventors evaluated the alloy composition in which the Ni content was reduced to 0.05% in the Sn-Ag-Cu-Ni-Ge solder alloy.

As the result, similarly to the alloy composition in which the Ni content is 0.07%, it has been found that the shear strength is poor and abnormality occurs in the solder bump.

[0024] Additionally, since Patent Document 4 is described that the Ag content is reduced, an Sn-Ag-Cu-Ni-Ge solder alloy in which the Ag content is reduced to 0.05% was evaluated. As a result, it was found that the wettability and the shear strength were poor although the abnormality of the solder bump was reduced.

[0025] In view of these findings, in the Sn-Ag-Cu-Ni-Ge solder alloy, it is considered difficult to solve the problem of the present disclosure even in view of the conventional alloy composition and the tendency of the effects. Therefore, in order to obtain an Sn-Ag-Cu-Ni-Ge solder alloy that simultaneously satisfies all the effects mentioned in the problems of the present disclosure, the present inventors have taken a different approach from that of a conventional one and have studied an alloy composition that increases the Ni content to 0.08% or more. Further, investigations were made on detailed adjustment of contents of Ag, Cu, and Ge at the same time.

[0026] Note that, as described in paragraphs 0072 and 0139 of Patent Document 2, in view of the fact that characteristics are exhibited to such an extent that there is no problem in practical use even if the characteristics are slightly deteriorated, it is considered that it is not necessary to achieve all the objects listed in the object of the present disclosure at a level higher than necessary. For this reason, the above examination has been performed so that the effects without a problem in practical use are achieved.

[0027] As a result, it has been found that when the Ni content is increased and each constituent element is within a predetermined range, it is possible to achieve excellent wettability and shear strength, as well as an appropriate fracture mode, suppressed growth of an intermetallic compound at a joint interface even after reflowing is performed a plurality of times, excellent drop impact resistance, and appropriate bump shape, whereby the present disclosure has been completed.

The present disclosure obtained from these findings is as follows.

[0028] (0) A solder alloy having, by mass%, Ag: 0.10 to 3.00%, Cu: 0.80 to 6.00%, Ni: 0.08 to 0.60%, Ge: 0.0010 to 0.0150%, with the balance being Sn, and unavoidable impurity.

(1) A solder alloy containing, by mass%, an alloy composition consisting of Ag:

0.10 to 3.00%, Cu: 0.80 to 6.00%, Ni: 0.08 to 0.60%, Ge: 0.0010 to 0.0150%, with the balance being Sn.

[0029] (2) The solder alloy according to any one of (0) or (1) above, wherein the alloy composition further contains 0.1% or less in total of at least one of Bi, Sb, In, Zn, Ga, Mn, Cr, Co, Si, Ti, and rare earth elements.

[0030] (3) The solder alloy according to any one of (0) to (2) above, wherein the alloy composition satisfies the following Relations (1) and (2):

$$0.00043 \leqq Cu \times Ni \times Ge \leqq 0.00149 \quad (1)$$

$$0.09 \leqq Ag \times Cu \times Ni \leqq 0.11 \quad (2)$$

where Ag, Cu, Ni, and Ge in Relations (1) and (2) above represent the contents (mass%) thereof in the alloy composition.

[0031] (4) A solder ball consisting of the solder alloy according to any one of (0) to (3) above.

[0032] (5) A solder preform consisting of the solder alloy according to any one of (0) to (3) above.

[0033] (6) A solder joint including the solder alloy according to any one of (0) to (3) above.

[0034] (7) A circuit including the solder according to (6) above.

[0035a] In an example of the present disclosure, there is provided a solder alloy having an alloy composition consisting of, by mass%, Ag: 0.10 to 3.00%, Cu: 0.80 to 6.00%, Ni: 0.08 to 0.60%, Ge: 0.0010 to 0.0150%, with the balance being Sn.

[0035b] In another example of the present disclosure, there is provided a solder ball consisting of the solder alloy as disclosed herein.

[0035c] In a further example of the present disclosure, there is provided a solder preform consisting of the solder alloy as disclosed herein.

[0035d] In another example of the present disclosure, there is provided a solder joint comprising the solder alloy as disclosed herein.

[0035e] In a further example of the present disclosure, there is provided a circuit comprising the solder joint as disclosed herein.

Brief Description of Drawings

[0035] FIG. 1 is a surface SEM photograph of an intermetallic compound formed at a joint interface in a solder joint produced using a solder alloy of Example 3.

FIG. 2 is a surface SEM photograph of an intermetallic compound formed at a joint interface in a solder joint produced using a solder alloy of Comparative Example 4.

Description of Embodiments

[0036] The present invention will be described in greater detail below. In this description, "%" relating to the solder alloy composition refers to "mass%" unless otherwise specified.

[0037] 1. Solder Alloy

(1) Ag:0.10 to 3.00%

Ag contributes to improvement of wettability. Further, the shear strength can be

preferably 4.00% or less, further preferably 3.00% or less, still further preferably 2.00% or less, particularly preferably 1.20% or less, most preferably 1.05% or less, or 1.00% or less.

[0042] (3) Ni:0.08 to 0.60%

Similarly to Cu, Ni contributes to improvement of shear strength and suppression of deformation of solder bumps. Further, Ni improves drop impact resistance and wettability, and can also optimize a fracture mode. When the Ni content is less than 0.08%, the effect of suppressing the growth of the intermetallic compound at the joint interface is not exhibited, and the shear strength decreases. Further, a thin compound of Ge and Ni is not formed on the surface of the molten solder, and the solder bump is deformed. In terms of the lower limit, the Ni content is 0.08% or more, preferably 0.09% or more.

[0043] On the other hand, when the Ni content is more than 0.60%, wettability is deteriorated similarly to Cu, and further, a coarse intermetallic compound is precipitated at the joint interface, the drop impact resistance and the shear strength are poor, and the fracture mode becomes inappropriate. Furthermore, since a large amount of a compound of Ge and Ni is precipitated on the surface of the molten solder, the solder bump is deformed. In terms of the upper limit, the Ni content is 0.60% or less, preferably 0.50% or less, more preferably 0.40% or less, further preferably 0.30% or less, still further preferably 0.20% or less, particularly preferably 0.12% or less, most preferably 0.11% or less, or 0.10% or less.

[0044] (4) Ge:0.0010 to 0.0150%

Ge forms a compound with Cu and Ni, and these compounds move to the surface of the molten solder. However, convection of the molten solder breaks these compounds, and cleaning of the surface of the molten solder suppresses deformation of the solder bump. When the Ge content is less than 0.0010%, the compound of Cu and Ni is not sufficiently precipitated on the surface of the molten solder, and the solder bump is deformed. In terms of the lower limit, the Ge content is 0.0010% or more, preferably 0.0020% or more, more preferably 0.0050% or more, and further preferably 0.0060% or more.

[0045] On the other hand, when the Ge content is more than 0.0150%, the compound of Cu and Ni becomes thick on the surface of the molten solder, and these compounds remain on the surface of the solder alloy during solidification, so that the solder bump is deformed. And

wettability also decreases. In terms of the upper limit, the Ge content is 0.0150% or less, preferably 0.0120% or less, more preferably 0.0100% or less, and particularly preferably 0.0080% or less.

[0046] (5) A total amount of at least one of Bi, Sb, In, Zn, Ga, Mn, Cr, Co, Si, Ti, and rare earth elements is 0.1% or less.

The solder alloy according to the present invention may contain, as an optional element, at least one of Bi, Sb, In, Zn, Ga, Mn, Cr, Co, Si, Ti, and rare earth elements in a total amount of 0.1% or less as long as the effect of the present invention is not affected. In the present invention, the rare earth element represents 17 kinds of elements obtained by combining Sc and Y belonging to Group 3 in the periodic table and 15 elements of the lanthanum group corresponding to the atomic numbers 57 to 71. In terms of the upper limit, the content of the optional element is not particularly limited, but is preferably 0.1% or less, and more preferably 0.01% or less. A lower limit is also not particularly limited, but is preferably 0.001% or more.

[0047] (6) Relations (1) and (2)

$$0.00043 \leqq Cu \times Ni \times Ge \leqq 0.00149 \quad (1)$$

$$0.09 \leqq Ag \times Cu \times Ni \leqq 0.11 \quad (2)$$

where Ag, Cu, Ni, and Ge represent the contents (mass%) of the alloy composition in Relations (1) and (2).

[0048] The solder alloy according to the present invention preferably satisfies Relations (1) and (2). When these relations are satisfied, the fracture mode is further optimized, the shear strength is further improved, the drop impact resistance is further improved even after reflowing is performed a plurality of times, the intermetallic compound precipitated at the joint interface becomes fine, and the deformation of the solder bump is also suppressed. Relation (1) is a relation composed of Cu, Ni, and Ge, which are elements that suppress the deformation of the solder bump. The Ge content is smaller than the Cu or Ni content, but Ge forms a compound with Cu or Ni and greatly affects the behavior of the alloy structure in the solidification process, and thus a small Ge amount contributes greatly to the characteristics of the solder alloy. Therefore, the content of each constituent element can be expressed as a relation directly without multiplying Ge by a coefficient.

[0049] Relation (2) is a relation composed of Ag, Cu, and Ni, which contributes to improvement of wettability and shear strength. The solder joint should not break at the joint interface, but the strength of the solder alloy itself should not be too weak. In this regard, Ag is a precipitation-strengthened element, and by satisfying Relation (2), the strength of the solder alloy itself can be improved to some extent to the extent that the fracture mode is not inappropriate. Further, Cu and Ni contribute to the formation of fine intermetallic compounds at the joint interface and the liquidus-line temperature, and thus affect the overall characteristics of the solder joint together with Ag.

[0050] These relations are obtained by mutual dependence of constituent elements. This is because the alloy is an integral body in which all constituent elements are combined, and each constituent element affects each other. As described above, the solder alloy according to the present invention that satisfies Relations (1) and (2) after being adjusted to the optimum content of each constituent element is set within a range sufficiently considering that each constituent element depends on each other. Therefore, the alloy composition in which each constituent element is within the above range and satisfies Relations (1) and (2) exhibits excellent drop impact resistance even after soldering a plurality of times, and coarsening of the intermetallic compound precipitated at the joint interface is suppressed. In addition, at the same time, excellent wettability and shear strength are obtained, the fracture mode is appropriate, and the solder bump can be suppressed from being deformed at a high level.

[0051] In terms of the lower limit, Relation (1) is preferably 0.00043 or more, more preferably 0.00060 or more, further preferably 0.00064 or more, particularly preferably 0.00072 or more, and most preferably 0.00076 or more. In terms of the upper limit, Relation (1) is preferably 0.00149 or less, more preferably 0.00120 or less, further preferably 0.00100 or less, still further preferably 0.00096 or less, particularly preferably 0.00088 or less, most preferably 0.00086 or less, or 0.00084 or less, or 0.00080 or less.

[0052] In terms of the lower limit, Relation (2) is preferably 0.09 or more, and more preferably 0.095 or more. In terms of the upper limit, Relation (2) is preferably 0.11 or less, more preferably 0.105 or less, and still more preferably 0.10 or less.

[0053] (7) Balance: Sn