

SOLDER ALLOY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a solder alloy, and in particular, relates to a solder alloy preferably used for automatic soldering according to a jet stream system (wave soldering).

2. Description of the Related Art

In general, assembly of electronics is carried out such that various types of elements are soldered onto interconnecting patterns printed on substrates. For such soldering procedures, solder metals are most widely used as a means for electrical connection. However, conventional solders are not generally used as a means for mechanical fixing because they do not have enough metallic strength, for example, as compared with iron (Fe).

With the recent development of high density packaging, solders used for soldering and packaging are expected to fix elements, in other words, to have mechanical strength. Thus, the soldered portions receive larger stress and this frequently causes trouble in the electronics. Therefore, solder alloys which have excellent electrical characteristics and high mechanical connection strength are in demand. It is also required that the soldering procedure

can be applied to the present mass production process. Given these requirements, numerous ternary to quinary solder alloys composed of tin (Sn), lead (Pb), and other metals have been conventionally proposed for obtaining strong solder alloys.

However, none of such solder alloys can be employed instead of eutectic solders because they have unbalanced characteristics such that although the strength increases, practical operation efficiency decreases. Additionally, since strength is defined from only one aspect in the above, the actual improvement greatly differs from the required improvement in view of the entire strength characteristics. For example, even when the fatigue strength with respect to the thermal stress is improved, the mechanical impact strength decreases, and practical application is thereby prevented. Furthermore, the proposed alloy compositions of prior art have broad ranges so that large characteristic differences occasionally appear between the resulting alloys within a compositional range; thus industrially effective ranges are not clear.

As is mentioned above, recently solders are required to have higher mechanical strength, in addition to the electrical properties, and also, the soldering procedure must be applied to the present mass production process. However, if tensile strength of a solder alloy composition

is improved by raising the hardness, brittleness increases and results in a decline in fatigue strength, and also, wetting (i. e., readiness to form a connecting metal over the metallic surface to be soldered), which is one of the fundamental properties of soldering, significantly deteriorates; thus the solder alloy cannot be employed for the present mass-production process. Moreover, when compositions of the solder alloys are modified for avoiding fracture due to metal slip or for improving creep strength, their melting points are elevated and the operation temperatures for soldering are inevitably raised. Considering such excessive heat damage, special designs or selection of elements are required, disadvantageously limiting the application of the solder alloys.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a solder alloy which has wide application and which can improve the strength of the connecting portions between elements without altering the present electronics designs or the packaging equipment.

A solder alloy according to the present invention is characterized in that it contains 64 to 66% of Sn by weight, 0.8 to 1.5% of silver (Ag) by weight, 0.3 to 1.0% of antimony (Sb) by weight, 0.1 to 0.25 % of copper (Cu) by

weight, and the balance being Pb.

A solder alloy of the present invention is prepared by adding three types of metals, i. e., Ag, Sb, and Cu, to a Sn-Pb binary alloy, which is used as the base metal, according to the above composition. The resulting solder alloy exhibits high mechanical strength and can be employed instead of generally used eutectic solders. Furthermore, this solder alloy has wide application such that it can be used in an automatic soldering apparatus according to wave soldering. Moreover its solderability and strength characteristics are well-balanced. Therefore, mechanical strength of the soldered joints in electronics can be improved without changing present designs or packaging equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A to 1C are diagrams illustrating a thermal fatigue test employed as a method for evaluating the characteristics of a solder alloy incorporated in an embodiment of the present invention; figure 1A is a plan view of a substrate to be soldered, figure 1B is a side view of lead pins to be soldered, and figure 1C is a side view showing the lead pins soldered to the substrate;

figures 2A to 2C are diagrams illustrating a creep characteristic evaluation method as a method for evaluating

the characteristics of the solder alloy incorporated in the embodiment of the present invention; figure 2A is a side view of a test piece (solder alloy), figure 2B is a side view of a test apparatus at the time of starting loading, and figure 2C is a side view of the test apparatus after stopping the load application;

figure 3 is a graph showing the result obtained from the solder alloy by the apparatus shown in figures 2;

figures 4A and 4B are diagrams showing a mechanical fatigue test as a method for evaluating the characteristics of the solder alloy incorporated in the embodiment of the present invention; figure 4A is a plan view of a test substrate and figure 4B is a side view of a lead pin;

figures 5A and 5B are diagrams showing a compressive/tensile test apparatus employed in the mechanical fatigue test; figure 5A is a side view of the test apparatus in the compressive mode and figure 5B is a side view of the test apparatus in the tensile mode;

figure 6 is a diagram, partially in cross section, showing the structure of an impact strength test apparatus used for evaluating the characteristics of the solder alloy incorporated in the embodiment of the present invention;

figure 7 is a diagram showing a system construction employed for evaluating the solderability (wetting) of the solder alloy incorporated in the embodiment of the present

invention;

figure 8 is a graph showing the result of the solderability (wetting) evaluation carried out by the system of figure 7;

figure 9 is a graph illustrating the effects of the Sn content in the solder alloy of the embodiment of the present invention on the solderability (wetting) and thermal fatigue characteristics;

figure 10 is a diagram illustrating an automatic soldering apparatus according to wave soldering; and

figure 11 is a radar chart showing the characteristics of the solder alloy incorporated in the embodiment of the present invention in comparison with those of a conventional eutectic solder.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The above and other objects, features and advantages of the present invention will be better understood from the following detailed description of the preferred embodiment taken in conjunction with the accompanying drawings.

The soldering strength of a high strength solder alloy incorporated in this embodiment is improved by adding Ag, Sb, and Cu to a binary alloy, composed of Sn and Pb, according to the composition shown in Table 1.

Table 1

Element	Content (% by weight)
Sn	65.0
Pb	33.2
Ag	1.0
Sb	0.6
Cu	0.2

In such a solder alloy prepared by adding three types of metals (i. e., Ag, Sb, and Cu) to the Sn-Pb binary alloy, each of the metal contents per se, as well as mechanical strength, largely affects the soldering operation efficiency. Therefore, to determine the optimum content for each metal while considering the interaction with other metals, the required characteristics (indexes for evaluation) were classified into 11 criteria (see figure 11) and quantified corresponding to the required practical characteristics. An alloy showing well-balanced results over all the evaluation criteria was regarded to be excellent. According to such a principle, the above composition was determined, and a solder alloy, which has larger mechanical strength and which is usable instead of

generally employed eutectic solders, was thereby obtained. Test methods, as quantifying methods for the solder strength, will be explained below: By employing the following methods, it can be judged whether the soldering procedure is applicable to the present mass-production process or not, and further, whether the improvements in various types of strengths are meaningful or not.

Figures 1A to 1C are diagrams explaining a method for evaluating the thermal fatigue characteristic. Figure 1A illustrates a substrate 10, figure 1B shows a resin element to be loaded on the substrate 10, and figure 1C shows the substrate 10 on which the element 11 is loaded by soldering. According to this method, soldered joints 12 receive lateral cyclic stress corresponding to the thermal stress pattern applied thereto, because the coefficient of thermal expansion of the material (nylon resin) of the element 11 differs from that of the material (phenolic sheet) of the substrate 10. The thermal fatigue strength is indicated by the number of cycles applied until the soldered joints 12 fracture. The magnitude of the stress varies according to the element pitch or the distance L between the lead pins 11a of the element 11. Hereinafter, the test carried out while employing a large element pitch (22.5 mm) and the test using a small element pitch (10 mm) are referred to as "high strain thermal fatigue test" and "low strain thermal

fatigue test", respectively. Other conditions for the substrate 10 and the element 11 are shown in figure 1. In the solder alloy of this embodiment, the high strain thermal fatigue characteristic and the low strain thermal fatigue characteristic were improved by approximately 60% and 290%, respectively, as compared with those of the eutectic solder.

Figures 2A to 2C illustrate the method for evaluating the high-temperature creep characteristic. According to this method, the creep characteristic is evaluated as follows: a test sample (solder alloy 21) shown in figure 2A is held by a pair of chucks 22a and 22b, as is shown in figures 2B and 2C, and after applying a 1.0 kg load to the solder alloy 21 at a displacement rate of 10 mm/min, the decline behavior is shown by a curve ($F(t)$) of figure 3, and the time ($\tau_{0.3}$) when a load cell 23 receives a 0.3 kg load is read so as to evaluate the creep characteristic. The test is carried out at 100°C. In the solder alloy of this embodiment, the creep characteristic was improved by approximately 140% as compared with that of the eutectic solder.

Figures 4A, 4B, 5A, and 5B illustrate a method of mechanical fatigue test. This test is carried out as follows: after soldering a lead pin 42 shown in figure 4B to a testing substrate 41 shown in figure 4A, very small displacement cycles (each 0.1 mm) are applied thereto by a

compressive/tensile apparatus 50 shown in figures 5A and 5B. The fatigue strength is evaluated by the number of cycles applied until fracture occurs in the direction perpendicular to the lead portion.

The compressive/tensile apparatus 50 is composed of: a base 51 for loading the test substrate 41; and a compressive/tensile mechanism 52. A side face of the base 51 has a fixing section 51a for fixing the test substrate 41. The compressive/tensile mechanism 52 has an eccentric cam 53 positioned above the base 51. This eccentric cam 53 is rotatable around an axis 53a. An arm 55 having a weight 54 on one end is provided above the base 51. The arm 55 is rotatable around an axis 55a and one of its end is detachable from the eccentric cam 53. Another arm 56 is further provided above the base 51. The arm 56 is rotatable around an axis 56a. A weight 57 is fixed to one end of the arm 56. A side portion of one end of the arm 56 has an engaging portion 58. The upper portion of one end, which does not have the weight 54, of the arm 55 can be engaged in the lower portion of the engaging portion 58. The other end of the arm 56 has an engaging portion 59. The engaging portion 59 is held by a holder 61 attached to a vertical pole 60 which is vertically movable. The lower end of the vertical pole 60 has a substrate mounting section 62, in which the lead pin 42 is fixed by a fixing screw 62b while

the upper portion of the lead pin 42 is held between the vertical pole 60 and a fixing plate 62a.

According to the compressive/tensile apparatus 50, when the eccentric cam 53 is at the bottom dead center, it is detached from the end of the arm 55, as is shown in figure 5A. Therefore, the arm 55 rotates counterclockwise due to the weight 54 so that the other end of the arm 55 pushes up one end (which has the weight 57) of the arm 56 against the weight 57 via the engaging portion 58. The arm 56 thereby rotates clockwise around the axis 56a and pushes down the vertical pole 60 via the engaging portion 59. Thus, the soldered joint 43 between the test substrate 41 and the lead pin 42 receives a certain amount of compressive stress (5 kgf in this embodiment). When the eccentric cam 53 further rotates and reaches the top dead center, the eccentric cam 53 is brought into contact with the end of the arm 55, as is shown in figure 5B. Therefore, the arm 55 is pushed up clockwise against the weight 54 so that the other end of the arm 55 is detached from the arm 56. The arm 56 thereby rotates counterclockwise around the axis 56a and pushes up the vertical arm 60 via the engaging portion 59. Thus, the soldered joint 43 between the test substrate 41 and the lead pin 42 receives a certain amount of tensile stress (5 kgf in this embodiment). The compressive stress and tensile stress are alternately applied according to the same manner as the

above.

According to this compressive/tensile apparatus 50, stress (compressive stress and tensile stress) can be applied without changes in ambient temperature, thus the failure mode due to the vibration proof or brittleness can be evaluated without influence of the thermal fatigue. In the solder alloy incorporated in this embodiment, mechanical fatigue strength was improved by approximately 40% as compared with that of the eutectic solder.

Furthermore, after soldering the lead pin 42 shown in figure 4B to the test substrate 41 shown in figure 4A, the strength with respect to the mechanical impact load was also evaluated. In other words, after soldering the lead pin 42, an impact load was applied to the lead pin 42 by dropping a steel ball using an impact strength test apparatus shown in figure 6, and the applied impact load required for fracturing the soldered joint 43 was defined as the impact resistance load.

The impact strength test apparatus 60 has a steel support 67 formed in an approximately cylindrical shape on a base 61. On the support 67, a cylindrical housing 62 is formed from a plastic material. The support 67 has a lead pin container recess 67a. The test substrate 41 is placed on the top face of the support 67 such that the lead pin container recess 67a accommodates the end of the lead pin 42

with the soldered joint 43 being above the support 67. The center of the lead pin 42 is positioned at the center of the housing 62. The soldered joint 43 and the lead pin 42 are connected to a measuring device (e. g., a peak holding type recorder) via lead line 66a and 66b, respectively, so as to measure the electrical resistance between the soldered joint 43 and the lead pin 42. A horizontal arm 64 is arranged in the upper portion inside the housing 62 and extends outside. The tip of the horizontal arm 64 has an electro-magnetic chuck 64a which can hold or drop a steel ball 63 according to the "on" or "off" operation. The horizontal arm 64 is fixed to a pole 65 set up outside the housing 62. The mounting position of the horizontal arm 64 to the pole 65 is changeable so as to alter the height of the steel ball 63.

According to the impact strength test apparatus 60, the soldered joint 43 and lead pin 42 are connected to the measuring device via lead lines 66a and 66b after placing the test substrate 41 on the support 67 with the soldered joint 43 positioned facing upward. The electro-magnetic chuck 64a set up at the tip of the horizontal arm 64 is then turned "off" to allow the steel ball 63 to have a free fall along the center line of the housing 62, as is indicated by the arrow, so that an impact occurs with the upper end of the lead pin 42 by the collision of the steel ball 63, as is indicated by the dotted line in the figure. The impact load

applied to the lead pin 42 is transmitted to the soldered joint 43 and it changes the electrical resistance between the soldered joint 43 and the lead pin 42. The change in electrical resistance is measured by the measuring device 66 and shown on a display not illustrated in the figure. The resistance at the time of applying the impact load is indicated by a momentary peak. Since internal fracture of the soldered joint 43 varies according to the magnitude of the impact load, changes in electrical resistance differ correspondingly. A quantitative evaluation of the mechanical strength of the soldered joint 43 is thereby enabled.

The amount of the applied impact load is changed by altering the falling height. In the solder alloy incorporated in the embodiment of the present invention, impact resistance strength was improved by approximately 10% as compared with that of the eutectic solder.

The interfacial strength between the lead pin 42 and the soldered joint 43 was also evaluated. In other words, after forming the soldered joint 43 on the lead pin 42, a tensile test was carried out on the soldered joint 43 at a tensile stress of 2 mm/min, and the thus-obtained fracture strength was defined as the interfacial strength. As a result, in the solder alloy incorporated in the embodiment of the present invention, interfacial strength was improved

by approximately 25% as compared with that of the eutectic solder.

Figure 7 shows the construction of a wetting evaluation system. A solder bath 70 of this system can vertically move by a motor 71. The temperature of a test sample 70a (melted solder) contained in the solder bath 70 is adjusted by a heater not shown in the figure via a controller 72. The controller 72 is composed of: a temperature adjusting section 721 for maintaining the test sample 70a at a certain temperature (e. g., 240°C); and a driving control section 722 for controlling the driving of the motor 71. Above the solder bath 70, a copper wire (diameter: 0.6 mm) 74 for wetting detection is suspended from a load cell 73. When the solder bath 70 is lifted, the copper wire 74 is immersed into the test sample 70a, as is indicated by a two-dot chain line in the figure. The buoyancy F applied to the copper wire 74 is detected by the load cell 73 and then displayed on a recorder 76 after being amplified by a buoyancy detecting amplifier 75.

Figure 8 illustrates an example of the measurement results displayed on the recorder 76. As is shown in this figure, from the initial time ($t = 0$ and buoyancy $F = 0$) when the copper wire 74 is immersed into the test sample 70a, the copper wire 74 receives an upward force F (shown as downward in figure 8). After reaching a constant value, the

buoyancy F gradually declines corresponding to the wetting of the solder, and returns to buoyancy $F = 0$ after a certain time period (t_1). The time period required for returning to the buoyancy $F = 0$ is defined as the wetting time. The shorter the wetting time becomes, the better the wetting. This system employs a so-called wetting balance method and the rate of soldering can be evaluated as an index (wetting).

Although numerous alloys with improved strength have been conventionally proposed as substitutes for eutectic solders having the most generally used composition (63% of Sn and 37% of Pb by weight), they are not put into practical use widely. The following study was conducted to obtain an alloy compositional range within which strength can be improved while minimizing a decline in solderability (wetting) as compared with generally used eutectic solders, which decline increases the fraction detractive of products.

The effects of the blending ratio on low strain thermal fatigue and wetting were examined for determining the compositional ratio of Sn and Pb of the base metal in a solder alloy. Figure 9 shows the obtained relationship between the Sn content in solder alloys composed of Sn and Pb and the number of cycles until crack occurrence due to low strain thermal fatigue. According to this figure, although low strain thermal fatigue is improved with a rise

in Sn, wetting deteriorates. In compositions having 66% or more Sn by weight, wetting largely deteriorates, and there is a possibility that the same solderability as that of the eutectic solders cannot be ensured. Therefore, the optimum Sn content was determined to be 64 to 66% by weight and 65% was employed for this embodiment.

Next, the blending ratio of the additional elements will be explained. Table 2 shows the effects of Ag content on the creep characteristic.

Table 2

Ag content in Sn ₆₅ Pb ₃₅ alloy (% by weight)	Creep time $\tau_{0.3}$ (sec.)
0.0	45
0.5	54
0.8	85
1.0	97
1.5	130
2.0	155

From this table, it is understood that when the Ag content is 0.8% by weight, a remarkable effect on the creep characteristic appears and the creep time increases corresponding to a rise in the Ag content. When the Ag content is 2% by weight, the increasing effect on creep time seems to start declining. Since Ag is an expensive metal, it is preferable to have the above effect by the least possible Ag content. Therefore, the optimum Ag content was set to 0.8 to 1.5% by weight, and 1.0% by weight was employed in this embodiment.

Table 3 shows the effects of Sb content on low strain thermal fatigue, mechanical fatigue, and wetting.

Table 3

Sb content in Sn ₆₅ Ag _{1.0} Pb _{balance} alloy (% by weight)	No. cycles until crack occurrence due to low strain thermal fatigue	No. cycles until fracture occurrence due to mechanical fatigue	Wetting time (sec.)
0.0	600	-	1.7
0.3	600	10000	1.6
0.6	1000	8000	1.6
1.0	1000	7500	1.7
1.5	1000	6000	2.0
3.0	1300	5500	2.3

As is apparent from Table 3, the low strain thermal fatigue characteristic is largely improved with an increase in the Sb content, meanwhile mechanical fatigue and wetting deteriorate. Considering the balance of these three factors, the optimum Sb content was set to 0.3 to 1.0% by weight, and 0.6% by weight was employed in this embodiment.

Table 4 shows the effects of the addition of Cu. When the Cu content is 0.1% by weight, improvements in the characteristics of high strain thermal fatigue and mechanical fatigue strength become apparent, and when the content is 0.2% by weight, these characteristics are further

improved.

Table 4

Cu content in $\text{Sn}_{65}\text{Ag}_{1.0}\text{Sb}_{0.6}\text{Pb}_{\text{balance}}$ alloy (% by weight)	No. cycles until crack occurrence due to high strain thermal fatigue	No. cycles until fracture occurrence due to mechanical fatigue
0.0	100	8000
0.1	210	8800
0.2	300	10000

In particular, in an automatic soldering apparatus (wave soldering apparatus) 100 according to a jet stream system shown in figure 10, if fresh solder alloy is thrown into a solder bath 104, an abrupt change occurs in the solder alloy composition immediately after starting operation; it is also expected that such a change is preventable by the addition of Cu. In the automatic soldering apparatus 100, a substrate 101 to be soldered is placed in a dip bath 102 by a conveyor 106. The substrate 101 in the dip bath 102 is coated with a flux, and then, is heated to approximately 100°C by a pre-heater 103 so as to be rendered in an optimum condition for soldering. The

substrate 101 then passes over solder jet streams (i. e., a primary jet stream and a secondary jet stream) coming from the solder bath 104 while being in contact with the surface of the solder jet streams so as to carry out soldering. The thus-soldered substrate 101 is cooled by a cooling fan 105 and then taken out from the automatic soldering apparatus 100.

According to the automatic solder apparatus 100, in general, an intermetallic compound of Sn and Cu precipitates when the Cu content of the solder in the solder bath 104 is 0.29% or more by weight. Precipitation of such a Sn-Cu intermetallic compound roughens the surface of soldered joints and impairs solderability. Therefore, the maximum Cu content was set to 0.25% by weight and the range of the Cu content was determined to be from 0.1 to 0.25% by weight. In this embodiment, 0.2% by weight was employed.

Figure 11 is a radar chart showing the above various characteristics of the solder alloy A of this embodiment in comparison with those of a conventional solder alloy (eutectic solder) B. As is apparent from this chart and the above explanations, the solder alloy A incorporated in this embodiment has significantly improved characteristics in high strain thermal fatigue, low strain thermal fatigue, high temperature creep, mechanical fatigue, interfacial strength, and impact strength, as compared with those of the

conventional solder alloy B. Furthermore, the characteristics of fillet formation, dross (oxidized solder) generation, compositional stability, and migration resistance are almost the same as those of the conventional solder alloy B. Therefore, the solder alloy A of this embodiment has wide application such that it can be used in an automatic soldering apparatus of a jet stream system. In addition, according to the solder alloy A, the strength of the connecting portions between elements can be improved without altering present designs or packaging equipment.

As is mentioned above, according to the present invention, the solder alloy contains 64 to 66% of Sn by weight, 0.8 to 1.5% of Ag by weight, 0.3 to 1.0% of Sb by weight, 0.1 to 0.25 % of Cu by weight, and the balance being Pb. The resulting solder alloy obtains wide application such that it can be used in an automatic soldering apparatus of a jet stream system, the strength thereof can be improved without deteriorating solderability, and the strength of the connecting portion between elements can be improved without altering present designs or packaging equipment.

WHAT IS CLAIMED IS:

1. A solder alloy comprising 64 to 66% of Sn by weight, 0.8 to 1.5% of Ag by weight, 0.3 to 1.0% of Sb by weight, 0.1 to 0.25 % of Cu by weight, and the balance being Pb.

2. A solder alloy as set forth in claim 1,
wherein said solder alloy is applicable to automatic soldering such that an element to be soldered is brought in contact with the surface of a solder jet stream coming from a solder bath.

