

SOLDER HIERARCHY FOR LEAD FREE SOLDER JOINT

BACKGROUND OF THE INVENTION

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This invention relates to a lead free solder structure for the assembly of electronic components, and more particularly, to a lead free solder hierarchy for use in a second level solder connection in electronic components such as joining an electronic module to a circuit card or board.

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The use of solder to join components in an electronic assembly is well known in the art. There are a variety of electronic components which require connection to other electronic components or to other levels of packaging. Typical examples are second level surface mount technology where column grid arrays (CGA) or ball grid arrays (BGA) are used to form an interconnection between a circuit board and an electronic module assembly such as a semiconductor chip attached to a multilayer ceramic (MLC) substrate.

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The module assemblies are connected to the board or card by joining solder balls or columns to the substrate bottom surface metallurgy (BSM). The module is subsequently joined to the board or card in what is referred to as a second level assembly.

For various environmental reasons the industry is moving to a lead free solder strategy for component assembly. The current lead free interconnect solution is to use Tin/Silver/Copper eutectic as the joining alloy for both the module and card side joints. This alloy is used because most of the higher melting alloys have other problems associated with them. For example, Tin
5 Antimony (235-240°C) has environmental issues regarding oxides of antimony.

The current solution to a lead free system is to use the same solder alloy (Sn/Ag/Cu of a specific composition, such as 3.8Ag,0.7Cu, balance Sn) on both the module and card or board side column joints. This has two significant problems associated with it. First is that the column
10 may tilt or collapse during second level assembly because the fillet on the module side will undergo melting. Joining of Cu columns with Sn, Ag and Cu (SAC) on the module bottom surface metallurgy BSM pad and SAC paste on the card side causes modules to fall over during joining at 235°C. SAC eutectic melts at 217°C. Second, the card rework process becomes much more involved because during module removal from the card almost all of the columns will
15 remain on the card and then have to be painstakingly removed prior to rejoin. Rework of modules from the card would leave many columns behind on the card. This is extremely messy and time consuming in manufacturing production. Another problem is that no readily available alloy exists with a melting temperature between 220°C and 260°C that does not have associated environmental, process or reliability issues.

20 The present invention solves these problems by creating a solder melting hierarchy for

second level assembly. The present invention provides an off-eutectic concentration of SnCu or SnAg that adds sufficient intermetallics to the module BSM fillet to satisfy the following requirements: The material must reflow and wet at the standard joining temperatures from 235°C to 260°C to satisfy all lead free solder applications. The material must stabilize the module BSM joint to prevent modules from falling over during joining to the card or circuit board. The material must remain cohesive during card or board rework to insure as many columns as possible stay attached to the module and are not left behind on the card or board.

The present invention discloses the use of off-eutectic lead free solder alloys containing two or more of the following: tin, silver, copper. These off-eutectic compositions contain secondary intermetallic phases which melt at a temperature above 280°C and add substantial structural support to the module BSM joint. The present invention achieves the desired temperature hierarchy in the module/Column BSM joint which allows for card or board attach without the assistance of a mechanical standoff and module removal/rework from the card or board whereby the majority of columns remain attached to the module BSM. This eliminates the problems involved when the same solder is used on both the module side and card side pads. Without a solder temperature hierarchy, all or most of the columns remain on the card or board through rework creating a very labor intensive exercise in preparing the site for the rejoin of a new module. The invention is the use of different alloys to create a stable structure during initial card join and subsequent module/card rework to prevent column collapse.

This material solution can also replace the single melt Sn, Ag and Cu (SAC) solder ball planned for lead free BGA. These and other purposes of the present invention will become more apparent after referring to the following description considered in conjunction with the accompanying drawings.

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BRIEF SUMMARY OF THE INVENTION

The purposes and advantages of the present invention have been achieved by providing a lead free solder hierarchy structure for use in second level packaging assembly. In one
10 embodiment an off-eutectic solder composition of between 90.0 - 99.0% Sn, between 10.0 - 1.0% Cu, and having inter-metallics with a melting temperature above 280°C, is used for the module side connection. In a preferred embodiment the off-eutectic solder composition is about 93.0% Sn, 7.0% Cu and has dispersed grains of SnCu inter-metallic phase structure.

15 In another embodiment an off-eutectic solder composition of between 80.0 - 96.0% Sn, between 20.0 - 4.0% Ag; and having inter-metallics with a melting temperature above 280°C is used for the module side connection. In a preferred embodiment the off-eutectic solder composition is about 82.0% Sn, 18.0% Ag and has dispersed grains of SnAg inter-metallic phase structure. In another preferred embodiment the off-eutectic solder composition is about 88.0%
20 Sn, 12.0% Ag and has dispersed grains of SnAg inter-metallic phase structure.

In another aspect of the present invention the off-eutectic solder composition is used to provide a method for creating a solder melting hierarchy for second level lead free solder assembly.

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BRIEF DESCRIPTION OF THE DRAWINGS

The features of the invention believed to be novel and the elements characteristic of the invention are set forth with particularity in the appended claims. The Figures are for illustration purposes only and are not drawn to scale. The invention itself, however, both as to organization and method of operation, may best be understood by reference to the detailed description which follows taken in conjunction with the accompanying drawings in which:

Figures 1a - 1f represent a first method to provide a lead free solder hierarchy for use in second level assembly.

Figures 2a - 2e represent a second method to provide a lead free solder hierarchy for use in second level assembly.

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Figure 3 is a schematic cross section of a lead free BGA structure according to the present

invention.

DETAILED DESCRIPTION OF THE INVENTION

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The purposes of the present invention have been achieved by providing a solder melting hierarchy for second level assembly.

10 The need for a solder melting hierarchy is driven by the fact that card assembly houses are moving towards a common solution for lead free solders for attachment of modules to cards or circuit boards. However, the joining temperature cannot be higher than is allowed by the top surface metallurgy (TSM) structure. The industry trend toward a card side solder of eutectic 95.5Sn/3.8Ag/0.7Cu (or close to that composition) means that an off- eutectic composition with an inter-metallic phase structure with a liquidus temperature higher than the ternary eutectic 15 temperature of 95.5Sn/3.8Ag/0.7Cu solder (hereafter referred to as "SAC") in the card solder paste is desirable. The SAC eutectic temperature is 217°C. An off eutectic composition will allow an inter-metallic phase structure to exist in the module side fillet during card join. Such an inter-metallic phase structure, which is evidence of incomplete liquification, is critical in eliminating the issues of tilt and collapse during assembly.

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Similarly, the inter-metallic phase structure will aid in card rework by providing a more

cohesive BSM joint thereby allowing removal of the columns from the cards, without simultaneous removal from the module. Examples of such off-eutectic solder alloys which have shown outstanding results are 82Sn/18Ag and 93Sn/7Cu.

5 The present invention is directed to alloys of SnCu (Tin/Copper) and SnAg (Tin/Silver). In the case of Tin/Copper, where the eutectic alloy composition is 99.3% Sn and 0.7% Cu (227°C), the alloys evaluated were 97Sn/3Cu and 93Sn/7Cu. In card joining at 235°C with a 97Sn/3Cu alloy encouraging results were obtained but improvements were necessary to achieve a more robust card join and rework process. In card joining at 235°C with a 93Sn/7Cu alloy, all
10 modules remained upright without the need for any rework. In contrast, previous card joining attempts at 235°C, using SAC as both the module and card side solder paste, resulted in all modules falling over. The only alternative was to use standoffs attached to the corner of the module for physical support of the modules.

15 The eutectic composition for Tin/Silver was 96.5%Sn/3.5%Ag at 221°C. The off-eutectic alloy compositions evaluated were 90Sn/10Ag, 88Sn/12Ag and 82Sn/18Ag. In card joining at 235°C with a 90Sn/10Ag alloy encouraging results were obtained, but again improvements were necessary to achieve a more robust card join and rework process. In card joining with the 88Sn/12Ag alloy, all modules survived a 235°C card join reflow. In card joining with the
20 82Sn/18Ag alloy, all modules remained upright during a 245°C reflow.

Therefore, for second level solder assembly with a reflow of 235°C the preferred off-eutectic solder alloy is either 93Sn/7Cu, 88Sn/12Ag or 82Sn/18Ag. For second level assembly with reflow requirements of 245°C or higher the preferred off-eutectic solder alloy is 82Sn/18Ag. These off-eutectic solder alloys form the inter-metallic phase structure during attachment to the module BSM. In the case where the off-eutectic solder alloy is 93Sn/7Cu, the inter-metallics are Cu_6Sn_5 and Cu_3Sn . In the case where the off-eutectic solder alloy is 88Sn/12Ag or 82Sn/18Ag the inter-metallics are Ag_3Sn . It will be apparent to those skilled in the art that higher card join reflow temperatures may require the use of off-eutectic solder alloys, with higher concentrations of intermetallic phase structure.

The preferred volume of off-eutectic solder alloy will depend on the size of the contact pad and the size of the interconnect feature, i.e., ball, column, etc. The volume preferred for each off-eutectic solder composition described above is in the range of between about 2,000 to 7,000 cubic mils. The BSM contact pads were 32 mils in diameter and the column diameter was 10 mils. In the evaluations discussed above the lead free columns used were copper columns. However, the present invention is not limited to use with copper columns. The present solder hierarchy is also applicable to standard kovar (NiFe) alloys with a readily solderable plated coating, and alloys of Ni, Co, Cu, and Pt. Similarly, the present invention is also compatible with lead free solder balls or lead free solder connections in general.

It will be apparent to those skilled in the art that the additions of small amounts of a third,

or even a fourth element, to the disclosed Tin/Copper and Tin/Silver off-eutectic alloys would not effect the hierarchy structure and such additions are therefore within the scope of the disclosed invention. The elements added would have to readily form an intermetallic compound with Tin as does the Copper and Silver. Examples of possible additional elements include
5 Nickel, Cobalt and Gold as Nickel/Tin, Cobalt/Tin and Gold/Tin are well known Tin intermetallics.

The present invention is also not limited to a column interconnect. It is also applicable to "springs", "connectors", "s-connectors", "c-connectors", "cantilever beams", and just about any
10 assembly where a member is hard joined on both sides, ie, ceramic and card sides. The present invention allows the use of acceptable lead-free alloy systems, with the additional advantage of a temperature hierarchy, without the need for mechanical standoffs to aid in the joining/rework processes.

15 A preferred method is illustrated with reference to Figure 1a which shows a circuit chip 10 attached to a top side of an electronic module 20. Bottom surface metallurgy (BSM) pads 30 are provided on the bottom surface of the module 20. A preform boat 40, typically made of graphite, contains openings 50 which are arrayed to coincide with the position of the BSM pads 30 on the module 20. The off-eutectic solder preforms 60 of the present invention are then placed
20 in the boat openings 50. The module 20 is then positioned on the boat 40 such that the BSM pads 30 are in contact with the off-eutectic solder preforms 60. The resulting module/boat assembly is

then heated to the required reflow temperature, typically between 235°C and 245°C, whereby the solder preforms **60** are reflowed onto the BSM pads **30**. The module/boat assembly is then cooled resulting in the BSM pads **30** being coated with the off-eutectic solder alloy.

5 Referring now to Figure 1b the module **20** after reflow is shown. The resulting off-eutectic coated BSM pads are commonly referred to as solder bumps **70**. Referring to Figure 1c a second boat **80**, typically made of graphite, contains openings **90** which are arrayed to coincide with the position of the solder bumps **70**. Lead free solder columns, in this example copper columns **100**, are placed in the boat openings **90**.

10 Referring to Figure 1d the module **20** is positioned on the boat **80** such that the solder bumps **70** are in contact with the ends of the columns **100**. The resulting module/boat assembly is then heated to the required reflow temperature. For copper columns up to 260°C, and preferably 250°C. Depending on the particular solder hierarchy used this reflow temperature could be over
15 350°C. The solder bumps **70** reflow on the ends of the columns **100** and after cooling form the module side solder fillets which adhere the columns **100** to the module **20**.

20 Referring now to Figure 1e the module **20** is shown with columns **100** attached by the resulting inter-metallic phase structure **110** of the present invention. Referring now to Figure 1f the resulting module **20** with columns **100** attached is now assembled to a circuit board or card **120**. The circuit board **120** has electrical contact pads **140**. SAC solder paste **130** is applied to the

contact pads **140**. The columns **100** are placed on the board **120** so that the free ends of the columns **100** are in contact with the SAC solder paste **130**. The module/board assembly is then heated to reflow the SAC solder paste on the column ends. Upon cooling the reflowed SAC solder paste forms the solder joint which adheres the columns to the board **120**. This resulting module/board assembly comprises the solder hierarchy between the module and board side joints of the present invention.

Referring now to Figure 2a there is illustrated a second method using a screen-on column process, whereby the off-eutectic solder alloy of the present invention, in paste form, is screened onto the column array and then reflowed. This method saves one reflow step. A screening mask **200**, typically made from Mo or stainless steel, is placed on a column boat **80** containing lead free solder columns **100**. In this embodiment the column boat **80** contains fillet openings **180** or enlarged upper portions of the column openings **90**. The screening mask **200** has mask openings **150** which are arrayed to coincide with the positions of the solder columns **100**. The off-eutectic solder paste **160**, which is made of the same composition as the off-eutectic solder preforms **60**, is screened into the mask openings **150** and fillet openings **180**.

Referring now to Figure 2b, the screening mask **200** is removed and the columns **100** in the column boat **80** are left with an off-eutectic "solder paste bump" **170** on one end of the columns **100**. The geometry of this solder paste bump **170** is determined by the combination of the thickness of the screening mask **200** and by the geometry of the fillet openings **180** in the

column boat **80**.

Referring now to Figure 2c, the module **20** with BSM pads **30** is placed on the column boat **80** such that the BSM pads **30** are in contact with the off-eutectic solder paste bumps **170**.

5 The resulting module/boat assembly is then heated to the required reflow temperature. For lead free copper columns up to 245°C, and preferably 250°C. Depending on the particular solder hierarchy used this reflow temperature could be over 350°C. The off-eutectic solder paste bumps **170** reflow on the ends of the columns **100** and after cooling form the module side solder fillets which adhere the columns **100** to the module **20**.

10 Referring now to Figure 2d, the module **20** is shown with columns **100** attached with the resulting inter-metallic phase structure **110** of the present invention. Referring now to Figure 2e the resulting module **20** with columns **100** attached is now assembled to a circuit board or card **120**. The circuit board **120** has electrical contact pads **140**. SAC solder paste **130** is applied to the
15 contact pads **140**. The columns **100** are placed on the board **120** so that the free ends of the columns **100** are in contact with the SAC solder paste **130**. The module/board assembly is then heated to reflow the SAC solder paste on the column ends. Upon cooling the reflowed SAC solder paste forms the solder joint which adheres the columns to the board **120**. This resulting module/board assembly comprises the solder hierarchy between the module and board side joints
20 of the present invention.

In surviving the card attach reflow without requiring the use of standoff supports the present invention has achieved a solder hierarchy which does not exist presently. Not only is this critical to the initial card joining, but it is also very critical to card rework. With the present invention the majority (95% or more) of the columns remain attached to the module during
5 reflow/removal from the card.

While the preferred embodiments are described above, it will be appreciated by one skilled in the art that a range of off-eutectic solder compositions for the Sn/Ag and Sn/Cu and Sn/Ag/Cu systems are also within the scope of the present invention. When these off-eutectic
10 solder solutions are used on the module side, in conjunction with the "standard" National Electronics Manufacturing Initiative (NEMI) alloy in the range of 3.8 to 4.0 weight % Ag, 0.5 - 0.9 weight % Cu, balance Sn, used on the card side, a natural temperature hierarchy is achieved, greatly facilitating the process of joining and also of reworking. This occurs because the off-eutectic solder alloy contains inter-metallic compounds whose liquidus temperature are higher
15 then that of the card side solder alloy. Therefore, although there may be onset of melting, there is incomplete liquification, leading to an inter-metallic phase structure. This inter-metallic phase structure, which has higher resultant viscosity, is the key enabler for this solution. It prevents the columns, or other members, from collapsing during joining/rework processes.

20 The present invention is not limited to these compositions alone. The disclosure is to use one of these alloys, or similar compositions of the same components, to resolve the above

mentioned problems of column tilt and rework. Increasingly, card assembly houses are moving towards a common lead free solder for card side attach, and the chosen composition seems to be close to 95.5Sn/3.8Ag/0.7Cu.

5 The present invention is also not limited to the second level assembly methods described above. It will be apparent to those skilled in the art that other lead free second level assembly methods may be easily adapted to benefit from the use of the off-eutectic solder composition of the present invention. An example is illustrated in Figure 3 where the off-eutectic solder composition is used as the solder ball **190** for second level BGA assembly of the module **20**,
10 having BSM pads **30**, to the board **120**. Use of a solder ball composed of the off-eutectic composition of the present invention would achieve the same rework advantages already discussed in that most of the solder balls would remain attached to the module after rework. This will reduce the time and effort needed to clean and redress the board or card attach sites.

15 It will be apparent to those skilled in the art having regard to this disclosure that other modifications of this invention beyond those embodiments specifically described here may be made without departing from the spirit of the invention. Accordingly, such modifications are considered within the scope of the invention as limited solely by the appended claims.

WHAT IS CLAIMED IS:

- 1 1. An off-eutectic solder composition (60) consisting essentially of:
2 between 90.0 - 99.0% Sn;
3 between 10.0 - 1.0% Cu; and
4 having inter-metallics with a melting temperature greater than 280°C.
- 1 2. The off-eutectic solder composition (60) of claim 1, wherein said composition is
2 about:15
3 93.0% Sn;
4 7.0% Cu; and
5 having dispersed grains of SnCu inter-metallic phase structure.
- 1 3. The off-eutectic solder composition (60) of claim 2, wherein said inter-metallic
2 phase structure comprises Cu_6Sn_5 at a temperature greater than 300°C.
- 1 4. The off-eutectic solder composition (60) of claim 2, wherein said inter-metallic
2 phase structure comprises Cu_3Sn at a temperature greater than 300°C.
- 1 5. The off-eutectic solder composition (60) of claim 2, wherein said composition has a
2 volume between 2,000 and 7,000 cubic mils.
- 1 6. An off-eutectic solder composition (60) consisting essentially of:

between 80.0 - 96.0% Sn;
between 20.0 - 4.0% Ag; and
having inter-metallics with a melting temperature greater than 280°C.

7. The off-eutectic solder composition (60) of claim 6, wherein said composition is about:
82.0% Sn;
18.0% Ag; and
having dispersed grains of SnAg inter-metallic phase structure.

8. The off-eutectic solder composition (60) of claim 7, wherein said inter-metallic phase structure comprises Ag_3Sn at a temperature greater than 280°C.

9. The off-eutectic solder composition (60) of claim 7, wherein said composition has a volume between 2,000 and 7,000 cubic mils.

10. The off-eutectic solder composition (60) of claim 6, wherein said composition is about:
88.0% Sn;
12.0% Ag; and
having dispersed grains of SnAg inter-metallic phase structure.

11. The off-eutectic solder composition (60) of claim 8, wherein said inter-metallic

2 phase structure comprises Ag_3Sn at a temperature greater than 280°C .

1 12. The off-eutectic solder composition (60) of claim 10, wherein said composition
2 has a volume between 2,000 and 7,000 cubic mils.

1 13. A method for creating a lead free solder melting hierarchy for second level solder
2 assembly comprising the steps of:
3 providing an electronic module (20) having bottom surface metallurgy pads (30)
4 on a bottom surface of said electronic module (20);
5 placing off-eutectic lead free solder (60) on said bottom surface metallurgy pads
6 (30) ;
7 placing a first end of lead free columns (100) in contact with said off-eutectic lead
8 free solder (60);
9 heating said off-eutectic lead free solder (60) to reflow said off-eutectic lead free
10 solder and form module side off-eutectic lead free solder fillets (110) which adhere said
11 first end of lead free columns (100) to said bottom surface metallurgy pads (30);
12 providing a circuit board (120) having contact pads (140) on a top surface of said
13 circuit board (120) ;
14 applying a solder paste (130) to said contact pads (140);
15 placing a second end of lead free columns (100) in contact with said solder paste.
16 (130) ;
17 heating said solder paste (130) to reflow said solder paste (130) and form card side
18 solder fillets which adhere said second end of lead free columns (100) to said contact pads

19 (140) thereby creating a solder hierarchy for the second level solder assembly.

1 14. The method of claim 13 wherein said module side off-eutectic solder fillets (110)
2 have a composition of about 93.0% Sn, 7.0% Cu and have dispersed grains of SnCu
3 inter-metallic phase structure.

1 15. The method of claim 13 wherein said module side off-eutectic solder fillets (110)
2 have a composition of about 82.0% Sn, 18.0% Ag and have dispersed grains of
3 SnAg inter-metallic phase structure.

1 16. The method of claim 13 wherein said module side off-eutectic solder fillets (110)
2 have a composition of about 88.0% Sn, 12.0% Ag and have dispersed grains of
3 SnAg inter-metallic phase structure.

1 17. The method of claim 13 wherein said off-eutectic lead free solder (60) is placed on
2 said bottom surface metallurgy pads (30) as a solid off-eutectic lead free solder
3 preform.

1 18. The method of claim 13 wherein said off-eutectic lead free solder (60) is placed on
2 said second end of lead free columns (100) by screening an off-eutectic lead free
3 solder paste (160) through a screening mask.