

CLAIMS:

1. A lead-free solder alloy comprising:
 - from 2.5 to 5 wt. % silver;
 - 5 from 0.01 to 5 wt. % bismuth;
 - from 1 to 7 wt. % antimony;
 - from 0.01 to 2 wt. % copper;
 - one or more of:
 - up to 6 wt. % indium,
 - 10 up to 0.5 wt. % titanium,
 - up to 0.5 wt. % germanium,
 - up to 0.5 wt. % rare earths,
 - up to 0.5 wt. % cobalt,
 - up to 5.0 wt. % aluminium,
 - 15 up to 5.0 wt. % silicon,
 - up to 0.5 wt. % manganese,
 - up to 0.5 wt. % chromium,
 - up to 0.5 wt. % iron,
 - up to 0.5 wt. % phosphorus,
 - 20 up to 0.5 wt. % gold,
 - up to 1 wt. % gallium,
 - up to 0.5 wt. % tellurium,
 - up to 0.5 wt. % selenium,
 - up to 0.5 wt. % calcium,
 - 25 up to 0.5 wt. % vanadium,
 - up to 0.5 wt. % molybdenum,
 - up to 0.5 wt. % platinum, and
 - up to 0.5 wt. % magnesium;
 - optionally up to 0.5 wt. % nickel; and
 - 30 the balance tin together with any unavoidable impurities.

2. The solder alloy of claim 1, comprising from 2.8 to 4.5 wt.% silver, preferably from 3 to 4 wt.% silver.
3. The solder alloy of claim 1 or claim 2, comprising from 1.0 to 4.0 wt.%
5 bismuth, preferably from 2.0 to 4.0 wt.% bismuth, more preferably from 2.5 to 4 wt.% bismuth, even more preferably from 2.8 to 4 wt.% bismuth, still even more preferably from 3 to 4 wt.% bismuth.
4. The solder alloy of any preceding claim, comprising from 1.0 to 6.5 wt.%
10 antimony, preferably from 2 to 6 wt.% antimony, more preferably from 3 to 6 wt.% antimony, even more preferably from 3.1 to 6 wt.% antimony, still even more preferably from 3.2 to 6 wt.% antimony.
5. The solder alloy of any preceding claim, comprising from 0.3 to 1.2 wt.%
15 copper, and preferably from 0.4 to 0.8 wt.% copper.
6. The solder alloy of any preceding claim, comprising from 0.001 to 0.4 wt.% nickel, preferably from 0.01 to 0.3 wt.% nickel, more preferably from 0.02 to 0.2 wt.% nickel.
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7. The solder alloy of any preceding claim, comprising from 0.001 to 5.5 wt.% indium, preferably from 0.02 to 4 wt.% indium, more preferably from 0.5 to 3 wt.% indium.
8. The solder alloy of any preceding claim, comprising from 0.001 to 0.3 wt.%
25 titanium, preferably from 0.005 to 0.2 wt.% titanium, more preferably from 0.007 to 0.05 wt.% titanium.
9. The solder alloy of any preceding claim, comprising from 0.001 to 0.3 wt.%
30 germanium, preferably from 0.001 to 0.1 wt.% germanium, more preferably from 0.001 to 0.02 wt.% germanium.

10. The solder alloy of any preceding claim, comprising from 0.002 to 0.3 wt.% rare earths, preferably from 0.003 to 0.05 wt.% rare earths.
11. The solder alloy of any preceding claim, comprising from 0.01 to 0.2 wt.% cobalt, preferably from 0.01 to 0.2 wt.% cobalt, more preferably from 0.02 to 0.1 wt.% cobalt.
12. The solder alloy of any preceding claim, comprising from 0.001 to 3 wt.%, preferably from 0.005 to 2 wt.% of aluminum, more preferably from 0.01 to 1.5 wt.% aluminum, even more preferably from 0.015 to 1 wt.% aluminum, still more preferably from 0.02 to 0.08 wt.% aluminum.
13. The solder alloy of any preceding claim, comprising from 0.001 to 3 wt.% silicon, preferably from 0.005 to 2 wt.% of silicon, more preferably from 0.01 to 1.5 wt.% silicon, even more preferably from 0.015 to 1 wt.% silicon, still more preferably from 0.02 to 0.08 wt.% silicon.
14. The solder alloy of any preceding claim, comprising one or more of:
from 0.001 to 0.5 wt. % chromium,
from 0.01 to 0.5 wt.% of iron,
from 0.001 to 0.5 wt.% of phosphorus,
from 0.001 to 0.5 wt.% of gold,
from 0.2 to 0.8 wt.% of gallium,
from 0.001 to 0.5 wt.% of tellurium,
from 0.001 to 0.5 wt.% of selenium,
from 0.001 to 0.5 wt.% of calcium,
from 0.001 to 0.5 wt.% of vanadium,
from 0.001 to 0.5 wt.% of molybdenum,
from 0.001 to 0.5 wt.% of platinum, and
from 0.001 to 0.5 wt.% of magnesium.

15. The solder alloy of any preceding claims, comprising from one to three elements, preferably one or two elements, more preferably two elements selected from nickel, titanium, germanium, indium, manganese, rare earths, cobalt, aluminium, silicon, chromium, iron, phosphorus, gold, gallium, tellurium,
5 selenium, calcium, vanadium, molybdenum, platinum and magnesium, preferably selected from nickel, titanium, germanium, indium, manganese, rare earths, cobalt, silicon, iron and gallium.
16. The solder alloy of any preceding claim, comprising nickel and one of
10 titanium, germanium, indium, manganese, rare earths, cobalt, aluminium, silicon, chromium, iron, phosphorus, gold, gallium, tellurium, selenium, calcium, vanadium, molybdenum, platinum and magnesium, preferably selected from nickel, titanium, germanium, indium, manganese, rare earths, cobalt, silicon, iron and gallium.
17. The solder alloy of any preceding claim, wherein the wt.% of antimony is greater than the wt.% of bismuth.
18. The solder alloy of any preceding claim, wherein the sum of the wt.% of
20 antimony and the wt.% of bismuth is greater than or equal to 6.5.
19. The solder alloy of any preceding claim consisting of:
from 2.5 to 4 wt.% silver;
from 2.8 to 4.2 wt.% bismuth;
25 from 3.2 to 6.2 wt.% antimony;
from 0.4 to 0.8 wt.% copper;
from 0.04 to 0.18 wt.% nickel;
one of:
from 0.007 to 0.05 wt.% titanium,
30 from 0.001 to 0.02 wt.% germanium, and
from 0.005 to 0.01 wt.% manganese; and
the balance tin together with any unavoidable impurities,

wherein:

the wt. % of antimony is greater than the wt. % of bismuth, and

the sum of the wt. % of antimony and the wt. % of bismuth is greater than or equal to 6.5.

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20. The solder alloy of claim 1, wherein the solder alloy comprises:

from 3 to 5 wt. % silver;

from 0.01 to 0.2 wt. % bismuth;

from 4 to 6 wt. % antimony;

10 from 0.3 to 1 wt. % copper;

one or more of:

up to 6 wt. % indium,

up to 0.5 wt. % titanium,

up to 0.5 wt. % germanium,

15 up to 0.5 wt. % rare earths,

up to 0.5 wt. % cobalt,

up to 5.0 wt. % aluminium,

up to 5.0 wt. % silicon,

up to 0.5 wt. % manganese,

20 up to 0.5 wt. % chromium,

up to 0.5 wt. % iron,

up to 0.5 wt. % phosphorus,

up to 0.5 wt. % gold,

up to 1 wt. % gallium,

25 up to 0.5 wt. % tellurium,

up to 0.5 wt. % selenium,

up to 0.5 wt. % calcium,

up to 0.5 wt. % vanadium,

up to 0.5 wt. % molybdenum,

30 up to 0.5 wt. % platinum,

up to 0.5 wt. % magnesium; and

the balance tin together with any unavoidable impurities.

21. The solder alloy of claim 1, wherein the alloy consists of from 2.8 to 3.2 wt.% silver, from 2.8 to 3.2 wt.% bismuth, from 4.5 to 5.5 wt.% antimony, from 0.3 to 0.8 wt.% copper, from 0.08 to 0.2 wt.% nickel, 0.001 to 0.01 wt.% of
5 germanium, and the balance tin together with unavoidable impurities.

22. The solder alloy of claim 1, wherein the alloy consists of from 2.8 to 3.2 wt.% silver, from 2.8 to 3.2 wt.% bismuth, from 5.5 to 6.5 wt.% antimony, from 0.3 to 0.8 wt.% copper, from 0.08 to 0.2 wt.% nickel, 0.005 to 0.02 wt.% of titanium,
10 and the balance tin together with unavoidable impurities.

23. The solder alloy of claim 1, wherein the alloy consists of from 3.1 to 3.7 wt.% silver, from 3 to 3.5 wt.% bismuth, from 3 to 3.8 wt.% antimony, from 0.4 to 0.9 wt.% copper, from 0.01 to 0.9 wt.% nickel, from 0.001 to 0.01 wt.% of
15 germanium, and the balance tin together with unavoidable impurities.

24. The solder alloy of claim 1, wherein the alloy consists of from 3.2 to 3.9 wt.% silver, from 3.5 to 4.5 wt.% bismuth, from 5.5 to 6.5 wt.% antimony, from 0.3 to 0.9 wt.% copper, from 0.05 to 0.12 wt.% nickel, 0.001 to 0.01 wt.% of
20 manganese, and the balance tin together with unavoidable impurities. (Alloy 4)

25. The solder alloy of claim 1, wherein the alloy consists of from 3.5 to 4.2 wt.% silver, from 0.01 to 0.1 wt.% bismuth, from 5 to 6 wt.% antimony, from 0.4 to 0.9 wt.% copper, from 0.001 to 0.01 wt.% of germanium, from 0.2 to 0.8 wt.%
25 indium, from 0.02 to 0.08 wt.% cobalt and the balance tin together with unavoidable impurities.

26. The solder alloy of any preceding claim in the form of a bar, a stick, a solid or flux cored wire, a foil or strip, a film, a preform, a powder or paste (powder plus
30 flux blend), solder spheres for use in ball grid array joints, a pre-formed solder piece or a reflowed or solidified solder joint, pre-applied on any solderable

material such as a copper ribbon for photovoltaic applications or a printed circuit board of any type.

27. A soldered joint comprising the solder alloy of any preceding claim.
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28. A solder paste comprising:
the solder alloy of any of claims 1 to 26, and
a solder flux.
- 10 29. A method of forming a solder joint comprising:
(i) providing two or more work pieces to be joined;
(ii) providing a solder alloy as defined in any of claims 1 to 26 or the solder
paste of claim 28; and
(iii) heating the solder alloy or solder paste in the vicinity of the work
15 pieces to be joined.
30. Use of a solder alloy of any of claims 1 to 26 or the solder paste of claim
28 in a soldering method, preferably wherein the soldering method is selected
from wave soldering, Surface Mount Technology (SMT) soldering, die attach
20 soldering, thermal interface soldering, hand soldering, laser and RF induction
soldering, soldering to a solar module, soldering of level 2 LED package-board,
solder dipping, and rework soldering.
31. A method of manufacturing the solder alloy of any of claims 1 to 26, the
25 method comprising:
providing the recited elements, and
melting the recited elements,
wherein the recited elements may be provided in the form of individual elements
and/or in the form of one or more alloys containing one of more of the recited
30 elements.