Low Temperature Alloy Development for Electronics Assembly

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Overview

1. Drivers
2. Existing Low Temp. Alloy Systems
3. Project Goals
4. Test Methodology
5. Approach, Results & Conclusions
6. Summary
7. Next Steps

Drivers for Low Temp. Alloy

Low Temp Alloy & Solder Paste enable:
-Use of Low Tg PCBs,
-Low Temp. compatible Components
- Reduced waste and Scrap (dross)

Low Temp. Solders enables elimination of Wave Soldering process, reduces exposure to thermal excursion, thereby increasing Long Term Reliability

Elimination of Wave Soldering Operation helps in reduced Labor and Equipment Maintenance Cost

Reduction in Energy Costs

Significant reduction in Reflow Cycle time.

Elimination of one full set-up enables higher throughput

Existing Low Temp. Alloys

- Sn-Bi and Sn-In are the most common lead-free low temperature alloys typically used in electronic assemblies.
- Sn-Bi systems are preferred as compared to Indium containing alloys which tend to be more costly.
- Sn42Bi58 and Sn42Bi57.6Ag0.4 are the most commonly used alloys in PCB assembly and other electronic applications.
- In this paper, we present details of a very systematic study to further improve properties of Sn42Bi58 based alloys.
- Methodology, Test Methods, Results and Discussions are covered for the new alloys that were developed.

Project Goals

- New Low Temp. Alloys were developed, through elemental additions, to improve mechanical strength, fatigue life and drop shock resistance.
- Effect of these elemental additions on the new alloys was evaluated using:
  - Alloy strength,
  - Ductility,
  - Thermal conductivity,
  - Copper dissolution,
  - Creep properties, and
  - Bulk and interfacial microstructure stability

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Test Methodology – Thermal Analysis

Properties	Test Method/Equipment	Standard
THERMAL ANALYSIS		
Liquidus and Solidus temperature	DSC (Differential Scanning Calorimeter)	ASTM E794 standard
Coefficient of Thermal Expansion	TMA (Thermal Mechanical Analyzer)	RT-500C standard
Thermal conductivity (K)	Thermal diffusivity (α) of the material	Internal SOP

Test Methodology – Wettability & Solderability

Properties	Test Method/Equipment	Standard
WETTABILITY & SOLDERABILITY		
Cu-Dissolution	Measured by the time taken for a wire to break under load when immersed in solder. Copper dissolution is calculated from the time that takes for the copper to dissolve	
Wetting Balance	Rhesca Solder Checker	JIS Z 3198-4 standard

Test Methodology – Mechanical Properties

Properties	Test Method/Equipment	Standard
MECHANICAL PROPERTIES		
Tensile Test (Ultimate Strength, Yield Strength, Elastic Modulus & Elongation)	Instron Universal Testing Machine	ASTM E8 Tensile Test Standard
Creep Test	ATS Creep Machine	Internal SOP
SOLDER JOINT IMC		
Solder Joint Microstructure	Cross-section	Internal SOP
Intermetallic Thickness	SEM Analysis	Internal SOP

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Thermal Properties - Approach

- Narrow solidus and liquidus temperature range is desirable for soldering process.
- It also helps in Solder Joint Cosmetics

- CTE value provides info of how a solder joint integrity will behave under thermal fatigue.
- Formation of IMC compounds characterizes the nature of the metallurgical bond, but due to their brittle nature they can also lead to joint failure when there is an excessive mismatch between the CTE of solder and board/components.

Increasing thermal conductivity, is a difficult approach, as it depends not only on the conductivity of the added elements but also on how they affect the alloy microstructure and the final conductive paths

Approach: Develop Low Temp Alloy with desired Thermal properties

Results & Discussions

Alloys	Melting Temp (ºC)	CTE (ppm/ºC)	Thermal Conductivity (W/m.K)
Sn42 Bi58	138.1	16.7	21.6
Sn42Bi57.6Ag0.4	137.4	17.1	24.5
Alloy A	138.6	16.7	25.6
Alloy B	138.5	17.1	25.5
Alloy C	137.4	17.6	24.6

New Low Temp Alloys have melting temperature very close to Sn42Bi58 alloy (~138C)

CTE of new alloys similar to other Sn-Bi alloys

Thermal conductivity of alloy A is identical to Sn42Bi57.6Ag0.4, whereas for alloys B & C it increases about 18%, which suggests that the conductive path remains unaltered despite the alloying additives

Wetting Balance - Results

Alloys	t_0 (sec)	F_{max} (mN)
Sn42 Bi58	1.62	3.63
Sn42 Bi57.6Ag0.4	1.42	3.82
Alloy A	1.32	3.77
Alloy B	1.07	3.72
Alloy C	1.26	3.76

- Zero wetting time (t_0) and Maximum wetting force (F_{max}) are almost identical for all three alloys, which indicates an identical wetting behavior under test conditions.

Cu-Dissolution - Approach

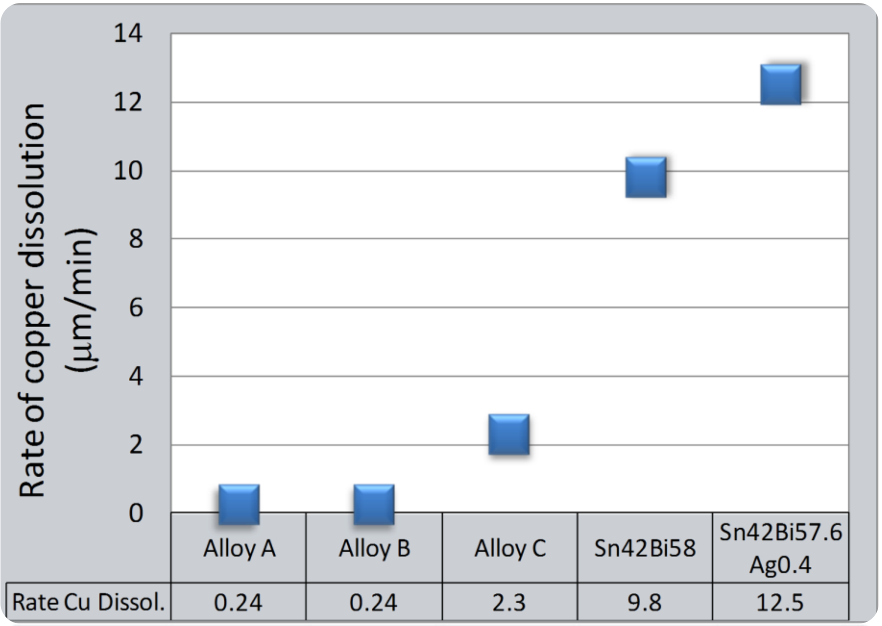
Alloys with a high Sn and Ag contents and higher melting point, have a higher tendency to dissolve copper

Higher copper dissolution in a given solder results in excessive formation of Cu_6Sn_5 intermetallic phase

Due to its brittleness, these intermetallics yield poor mechanical reliability of the solder joints, impacting performance

Approach: Develop an alloy with low Cu dissolution, to avoid deterioration of the solder joint

Cu-Dissolution - Results



- Due to a secondary alloy addition, Alloy C, which also contains Ag, still shows much lower copper dissolution (2.3µm/min).
- Alloy A and B have very low rate of copper dissolution (0.24µm/min), which is about 40.8 times lower than of Sn42Bi58 and 83 times lower than Sn42Bi57.1Ag0.9 alloys.

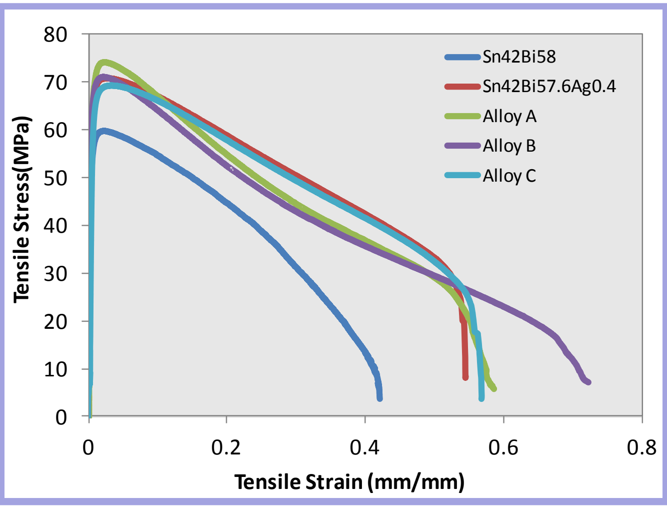
Mechanical Properties – Approach for Tensile Properties

In general, an alloy with higher modulus will be stiffer, i.e., less flexible under tension and will have lower elongation

Develop an ideal alloy composition which will have high enough modulus with balanced ductility and elongation

Approach: Develop an alloy with an ideal composition that enables desired Tensile Properties

Mechanical Properties - Tensile Test Results



Stress-Strain Curves

Alloys	Ultimate Tensile Strength (MPa)	Elongation (%)	Elastic Modulus (GPa)
Sn42Bi58	63.6	48.2	16.5
Sn42Bi57.6Ag0.4	67.4	52.6	21.2
Alloy A	73.0	69.8	22.0
Alloy B	70.2	66.1	20.6
Alloy C	69.4	51.8	20.0

- Elastic modulus of Sn42Bi57.6Ag0.4 and alloys A, B and C is similar.
- However, Alloys A, B and C show higher Tensile Strength (5 to 8%) & Elongation.

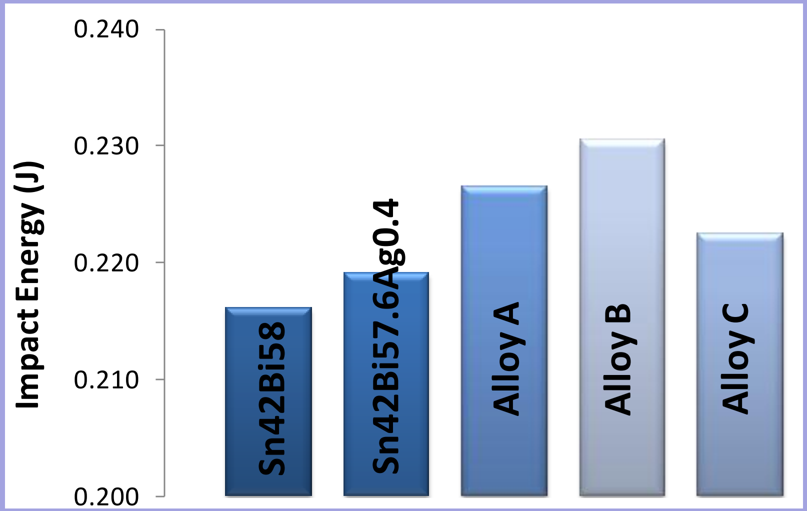
Mechanical Properties – Approach for Charpy Impact

Charpy Impact Test evaluates the ability of the alloy to absorb energy during an impact

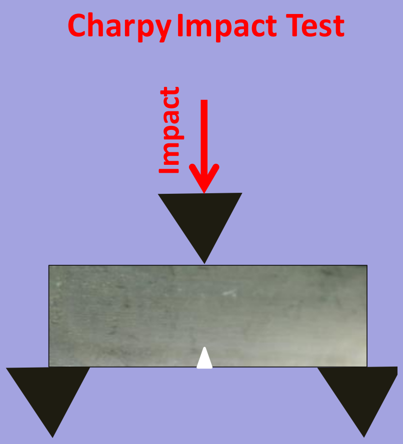
This can be a measure of alloy toughness and ductility.

Approach / Logic: Develop an alloy composition that will enable higher Impact Properties

Mechanical Properties – Charpy Impact Test Results



Impact Energy from Charpy Test



- Alloy A and B have about 5-7% higher Charpy impact energy than Sn42Bi58 and Sn42Bi57.6Ag0.4.
- Alloy C has impact energy equivalent to 0.4wt.% Ag addition.

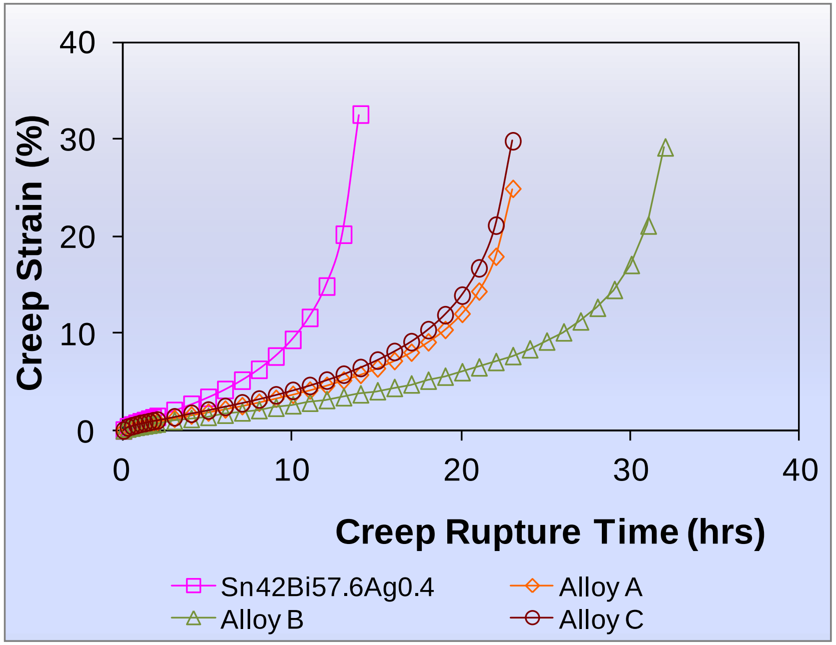
Mechanical Properties – Approach for Creep Rupture

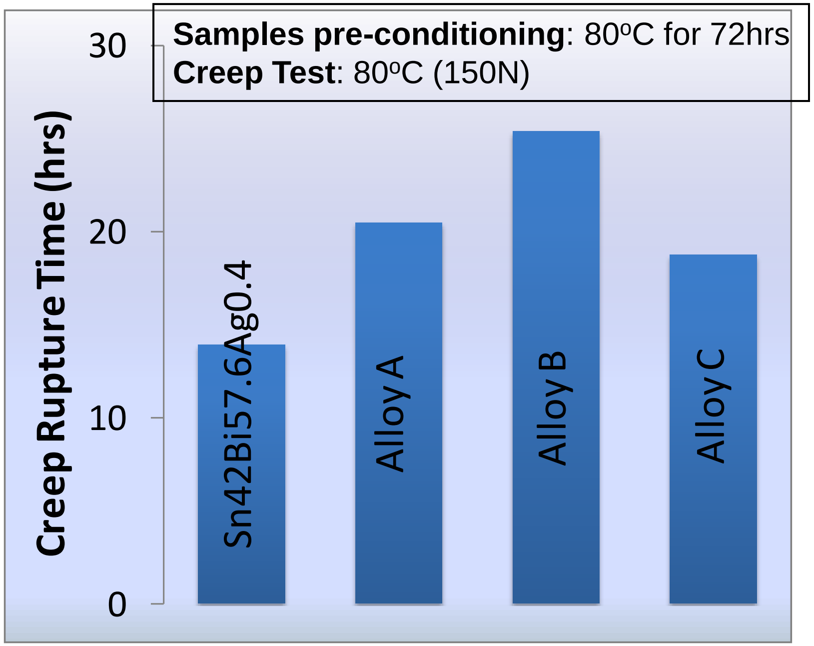
- Creep rupture time evaluates creep strength
- Creep strain evaluates the creep elongation

Elongation and Resistance are often in opposite sides of a balance, i.e., increase in strength quite often results in loss of elongation

Approach: Develop an alloy with ideal composition and ensure that the new alloys do not trade much of their elongation for strength

Mechanical Properties – Creep Rupture Results





- Remarkable improvement of creep strength with the minor alloying additions of A, B and C, resulted in 47%, 82% and 34% higher creep rupture time, respectively.
- Compared to Sn42Bi57.6Ag0.4, alloys A, B and C have equivalent elongation.

Microstructure & IMCs - Approach

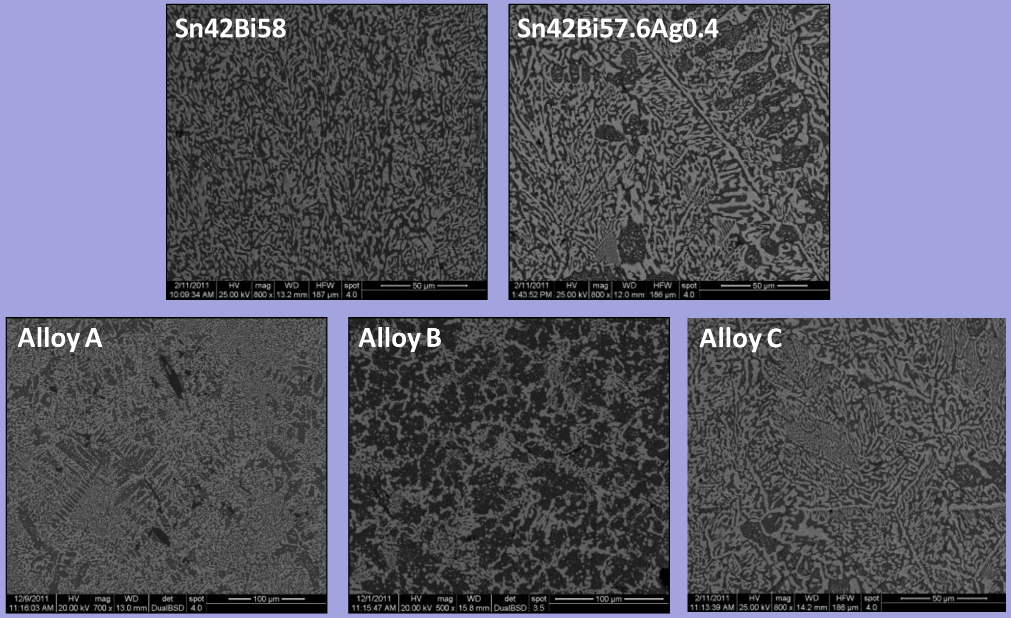
Microstructure of Sn42Bi58 bulk samples is lamellar with large continuity of the more brittle Bi-rich phase in the Sn-Bi eutectic solder

1. Break continuity of large brittle Bi phase with minor additions of alloying elements
2. Further, with minor additions contribute to precipitate strengthening of the Sn-Bi matrix

Refine alloy microstructure, thereby improving the joint strength

Approach: Engineer the microstructure with inhibitors and additives to improve the joint strength

Microstructure & IMCs Results



Microstructure refinement of new low temperature alloys

- Minor additions, as in alloys A and C result in higher microstructure refinement, and can also impact Bi nucleation that appears to form an individual phase rather than a continuous layer, as seen in alloy B.

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Summary / Conclusions

- New Low Temp Alloys A and B have the following properties, when compared to Sn42Bi57.6Ag0.4:
  - Eutectic composition, with melting point ~138^{o}C
  - CTE within specification (15-20 ppm/^{o}C)
  - 4 to 4.5% Higher thermal and electrical conductivities
  - Comparable wetting properties
  - 52X Lower Cu dissolution than Sn42Bi57.6Ag0.4
  - Superior mechanical properties
    - 5-8% Higher tensile strength
    - 4-6% Higher toughness
    - 47-82% Higher creep rupture time and equivalent creep elongation

- **Thus new alloys were developed which are low temperature, lead-free and eutectic, with superior mechanical properties, high thermal conductivity, high creep resistance and lower rate of Cu dissolution.**

Next Steps

- Thermal fatigue resistance completed (not covered in the Paper):
  - Test Conditions: TC3/NTC-C, -40 to 125^{o}C, 10min dwell.
  - 1000 Cycles completed.
  - Alloys A and B have about 25% better thermal cycling behavior than Sn57.6Bi0.4Ag.
- Drop Shock testing underway.
- Results of TC and Drop Shock will be covered in Phase 2.
- **Recommend single Low Temp. Alloy with superior mechanical properties, high thermal conductivity, high creep resistance and lower rate of Cu dissolution**

Thank you !