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iNEMI Statement of Work
Board Assembly TIG

Lead-Free Nano-Solder Project

The Application of Nanotechnology to Suppress Non-Lead Solder Reflow Temperature

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Purpose:

The phenomenon of melting point depression of nanoscale metal particles has been studied since the 1960s, when it was noticed that extremely thin evaporated particles of metal have a lower melting point than the bulk material.[1] Tin evaporated particles and gold nano-scale particles were studied by [2] Buffat and Borel, who demonstrated well over 50% melting point depression, compared to the bulk melting point of gold. More recently, [3, 4, and 5] have developed alternate experimental methods such as nano-calorimetry and measured the latent heat of fusion as a function of temperature. This new calorimetric technique has been developed where nano-Joules of heat can be measured. Based on these nano-calorimetry studies, a simple expression was developed by [4] that relates melting point to particle size:

$T_m(r) = 156.6 - (220/r)$

where $T_m(r)$ is the melting temperature in degrees Centigrade and r is the radius of the particle in nanometers. This equation reveals that significant melting point suppression happens when the particle radius approaches the sub-20 nanometer range. Several technical challenges remain such as:

- Development of methods to produce uniform and sub-20 nanometer tin particles
- Well-dispersed and un-agglomerated tin metal particles
- Oxide-free particles (or novel fluxes to reduce tin oxide)
- Demonstrate the melting point suppression of a non-lead solder (paste)

Background and Motivation:

Nanotechnology encompasses many diverse disciplines to enable the manipulation of matter at the atomic level, enabling radical new approaches to material property enhancement and synthesis. It has been suggested that it will be the basis for waves of creative destruction and major economic revolutions. Nano-material solutions have the potential to augment and enhance traditional reliability solutions, make our products better, enable new product concepts, and disrupt industry.

Environmentally preferred materials and products necessitate the need for higher melting point no-lead solder alloys for electronic components/printed wiring board interconnects. These higher melting point alloys result in higher processing temperatures. Currently, non-lead solder alloys such as Sn/Ag/Cu have a liquidus in the range of 220 C and higher. The higher melting point solder composition results in higher reflow process temperatures well above the liquidus, typically above 240 C. The higher reflow temperatures can negatively affect product reliability due to higher residual stresses in PWB assemblies; require tougher qualification requirements for components, and sometimes a significant change in the manufacturing processes.

Scope of Work:

Phase 1: Develop and Demonstrate a Nano-Solder Paste

1.1 Produce nano-scale powder

a) Fabricate Ag, Sn, Cu nano-powder (<= 100 nM, by synthesis, plasma, oxide reduction, grinding…)
b) Fabricate nano-alloy (comprising of e.g. Ag, Sn, Cu…) powders (<= 100 nM, by synthesis, plasma, oxide reduction, grinding…)
c) Identify and apply means to prevent agglomeration
d) Measure melting / fusion temperatures of individual powders and alloys under controlled conditions
   d.1) Assess if volume is sufficient to form a solder joint
e) Characterize size vs. reactivity vs. oxidation vs. process

1.2 Explore and understand melting phenomena

a) Experimentally characterize physical phenomena: DSC, ESEM, nano-calorimetry, etc…
b) Thermodynamic simulation: particle-particle interaction and system of particles
c) Nano-scale simulation: particle-particle interaction and system of particle interaction
d) Identify mechanism of phenomena

1.3 Methods to improve oxidation resistance (i.e., novel flux systems)

Explore different flux systems or additives to protect the powders and enable soldering.

a) Identify and apply known techniques, do they work?
b) Oxidation prevention during particle synthesis, post synthesis…
c) Identify novel methods, such as coatings….
d) Characterize size vs. reactivity vs. oxidation vs. process using flux systems in 1.3a to 1.3c

1.4 Identify final material system(s) and demonstrate reduced melting point

a) Quantify temperature reduction
b) Can a prototype solder joint (SMT such as leaded, area array…) be made
c) Identify remaining technical challenges
d) Proceed to Phase 2: Go/No-Go decision

Far Future

Phase 2: Demonstrate Manufacturability of a Solder Joint Based on a Nano-Solder System
Phase 3: Nano-Solder System Joint Reliability
Phase 4: Manufacturing Equipment

Schedule:

TBD

Resources Required from Participants:

- One Man Month/Year
- Shared project costs of up to $1000 per member

References:

1) C. R. M. Wronski, "The Size Dependence of the Melting Point of Small Particles of Tin," *Brit J. Appl. Phys*., 1967, Vol. 18, pp1731 to 1737.
2) Ph. Buffat and J. P. Borel, "Size Effect on the Melting Temperature of Gold Particles," *Physical Review A*, Vol. 13, No. 6, June 1976, pp 2287-2298.
3) S. L. Lai, J. Y. Guo, V. Petrova, G. Ramanath, L. H. Allen, "Size-Dependent Meeting Properties of Small Tin Particles: Nanocalorimetric Measurements," *Physical Review Letters*, Vol. 77, No. 1, pp.99-102, July, 1996.
4) Leslie H. Allen, "Nanocalorimetry Studies of Materials: Melting Point Depression and Magic Nanostructures," NNUN Abstracts 2002/Materials, Physics, Process & Characterization, p 40.
5) M. Zhang, M. Yu. Efremov, F. Schiettekatte, E. Olson, A. T. Kwan, S. L. Lai, T. Wisleder, J. E. Greene, L. H. Allen, "Size Dependent Melting Point Depression of Nanostructures: Nanocalorimetric Measurements," *Physical Review B*, Vol. 62, No. 15, October 2000, pp. 10548-10557.