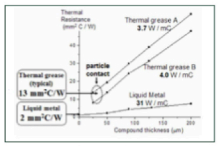
LIQUID METAL INNOVATIONS FOR HIGH-PERFORMANCE THERMAL INTERFACE MATERIALS (TIMs)

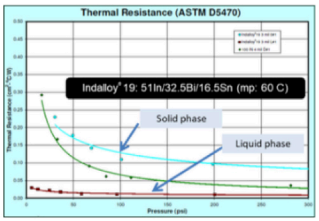
Tim Jensen, Senior Product Manager, Engineered Solder Materials, Indium Corporation

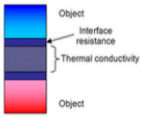
Liquid Metals as a TIM[1]

- Pros
  - Relatively high thermal conductivity
  - Excellent wetting to surfaces
  - No soldering or surface metallization needed
  - Thin bondline possible
- Cons
  - Must be contained to minimize spread elsewhere on board
  - More difficult to handle and apply



Thermal Resistance: Solid vs. Liquid

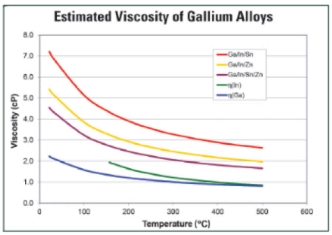




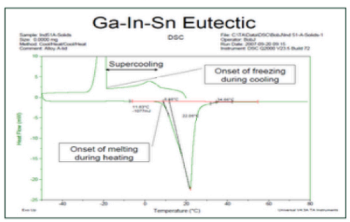
Basic Liquid Metal Properties

Metal/Alloy	Melting Point (°C)	Composition	Density (g/cm³)	Thermal Conductivity (W/mK)
Gallinstan	11	66.5Ga/20.5In/13.0Sn	6.32	25
EGaIn	16	75.5Ga/24.5In	6.35	26
EGaSn	21	91.6Ga/8.4Sn	6.01	28
Base Elemental Properties				
Indium	157	100In	7.31	87
Tin	235	100Sn	7.28	73
Gallium	30	100Ga	5.90	31

- Mixing of metals generally lowers both the melting point and thermal conductivity
- Liquid metals are high-density and low viscosity

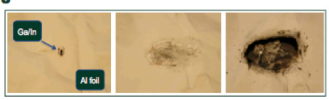


Liquid Metal Supercooling

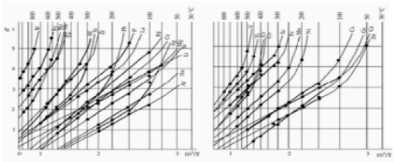


Liquid Metal Challenge #1:[2] Avoid Aluminum

The reaction process of gallium and aluminum is not actually a corrosion process per se. The Ga dissolves the grain boundaries, causing the Al structure to crumble.



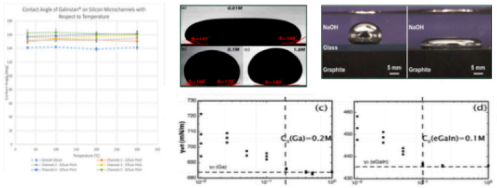
Alternative Metals to Aluminum[3]



Nickel (Ni) is widely used as it has limited solubility in Ga

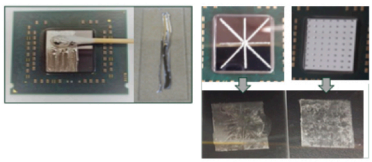
Temperature dependence of complete corrosion time (tgr) of hard metal specimens in gallium: left – metals of the first long period; right – other metals.

Liquid Metal Challenge #2:[4,5,6] Ga Surface Tension



Surface Tension vs. Wetting

- Ga will wet to most any surface but requires some agitation
- Application method and pattern will need optimization to ensure complete coverage



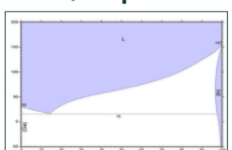
Liquid Metal Challenge #3: Automation

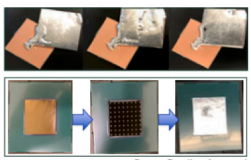
- Standard dispensing is a challenge due to high-density, low viscosity
- Jetting more easily implemented
- Alloy purity and compositional accuracy is critical

Solid/Liquid Hybrid (SLH) Metal TIM Innovation

- Technology Basics
  - Combine metal that is liquid at room temperature with one that is solid at room temperature
  - Liquid material provides wetting and low interfacial resistance
  - Solid material creates structure, minimizing the risk of pump-out
  - Solid material must have limited solubility in the liquid alloy
- Methods of Application
  - Premix solid and liquid to create a slurry
  - Combine solid and liquid material at the time of use

SLH: Ga/In Liquid with In Preform



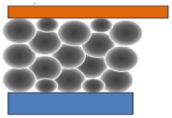


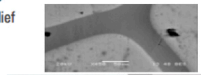
Patent-Pending Approach

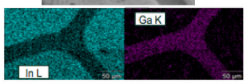
Gallium Grain Boundary Flow

The Result: A Metallic Sponge

Liquid alloy is contained but provides shear relief

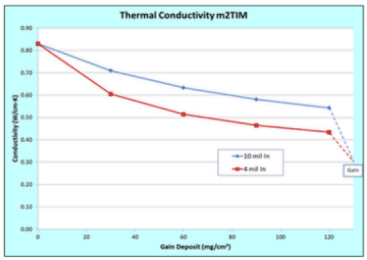




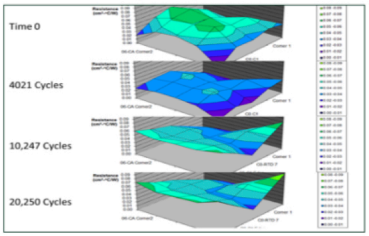


Indium cores dissolve and reform during heat cycle

SLH Improves Thermals



SLH Won't Pump-Out (0-80W Power Cycling)



Summary

- With increasing thermal demands on devices today, liquid metals are re-emerging as viable thermal materials for TIM1, TIM1.5, and TIM2 applications
- There are viable options that address many of the processing challenges of using a liquid metal
- Solid/Liquid Hybrid solutions could emerge as a significant improvement in both thermal performance and lifespan

Sources

1. IBM Research Division, Yves St. Martin and Theodore van Kessel, "High Performance Liquid Metal Thermal Interface for Large Volume Production," IMAPS Symposium 2007, San Jose, CA USA November 2007.
2. http://www.xtremesystems.org/forums/showthread.php?72814-Liquid-Metal-Thermal-Paste; August 29,2005, 7:33am.
3. Cui, Yuntao & Ding, Yujie & Xu, Shuo & Zhenze, Yang & Zhang, Pengju & Rao, Wei & Liu, Jing. (2018). Liquid Metal Corrosion Effects on Conventional Metallic Alloys Exposed to Eutectic Gallium–Indium Alloy Under Various Temperature States. International Journal of Thermophysics. 39. 1-14. 10.1007/s10765-018-2440-x.
4. Davis, Ethan Allan, "On The Wetting States of Low Melting Point Metal Galinstan and Wetting Characteristics of 3-Dimensional Nanostructured Fractal Surfaces" (2017). Mechanical (and Materials) Engineering -- Dissertations, Theses, and Student Research. 118. http://digitalcommons.unl.edu/mechengdiss/118.
5. Xu, Q., Oudalov N, et al; Effect of Oxidation on the Mechanical Properties of Liquid Gallium and Eutectic Gallium-Indium; Physics of Fluids 24, 063101 (2012); https://doi.org/10.1063/1.4724313.
6. TY - JOURAU - Hu, LiangAU - Yuan, BinAU -Liu, JingPY - 2017DA - 2017/08/03TI - Liquid metal amoeba with spontaneous pseudopodia formation and motion capabilityJO - Scientific ReportsSP - 7256VL - 7IS - 1AB.

About the Author

- **Tim Jensen**
  Senior Product Manager, Engineered Solder Materials
  Indium Corporation
  tjensen@indium.com