Characterization of Thermal Properties and Interface Development in Cu-In Liquid Phase Sintered Composite Solders

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Objectives

- Measure the effective thermal resistance of next generation Copper-Indium composite thermal interface materials
- Adapt the ASTM D5470-06 standard method for measuring thermal transmission properties for sample geometry and under vacuum
- Determine effects of aging on the growth of inter-layers, such as $Cu_{11}In_9$.
- Determine the benefits of an $AuIn_2$ inter-layer as a wetting agent and diffusion barrier

Introduction

Performance and functionality increases in today's microelectronic devices often result in higher power consumption in increasingly smaller chip surface areas. These ever increasing power demands must be matched by more effective thermal solutions. Thermal interface materials (TIM) play an integral role in facilitating heat transfer from silicon microelectronic devices to metallic heat sinks by minimizing thermal contact resistance. These solders must have high thermal and electrical conductivity as well as sufficient mechanical compliance in shear to compensate for differing amounts of thermal expansion. The next generation solder of interest is a composite alloy of highly conductive copper particles embedded in a compliant indium matrix prepared using liquid phase sintering. Factors influencing the thermal resistance of the solder may include composition, solder bond line thickness (BLT), operating temperature, presence and thickness of inter-layers, aging time, and applied pressure.

Figure 1: Microstructure of a liquid phase sintered solder containing Cu particles in an In matrix.* The thin layer of intermetallic at the interface indicates good bonding with the substrate. (photo below)

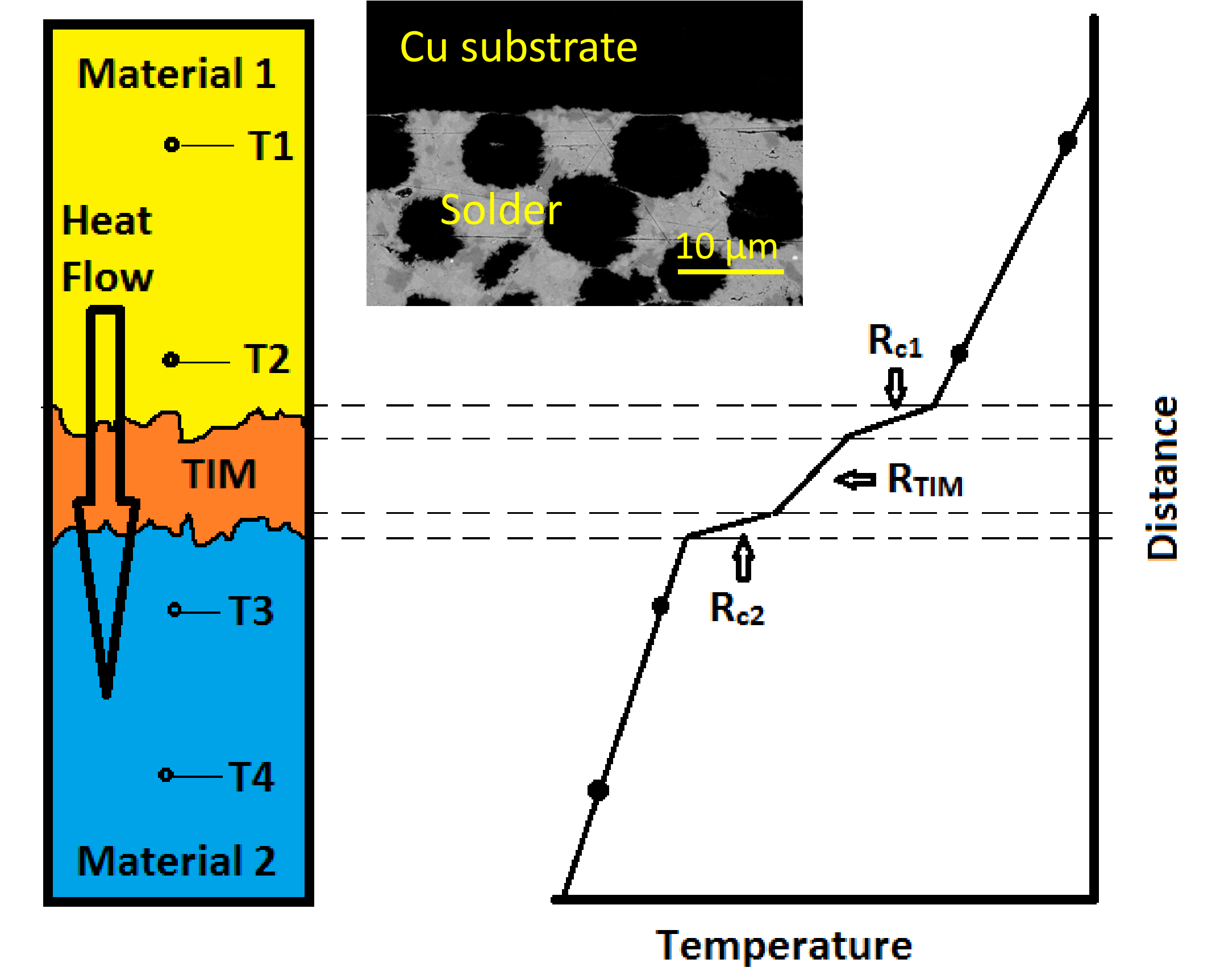

Figure 2: Schematic of two materials bridged with a Thermal Interface Material. The effective thermal resistance of the joint is a sum of the TIM resistance as well as interfacial contact resistance (above)

Apparatus

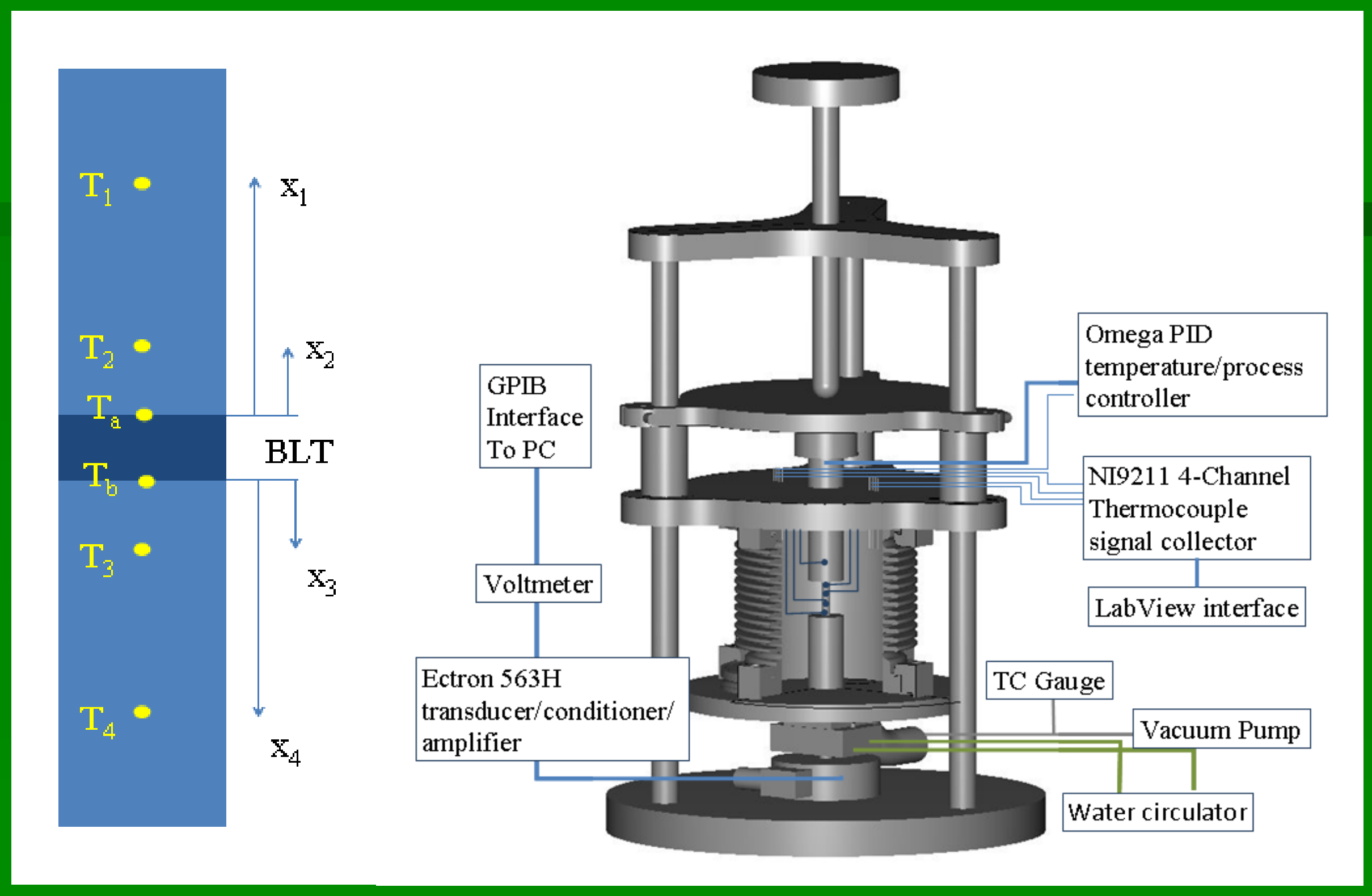

Figure 3: Schematic of the test apparatus and specimen dimensions

Measurement

- The composite solder specimens are prepared between two copper bars of well known thermal conductivity as shown in figure 3.
- Steady state heat flow is achieved when temperature readings remain constant to within ±0.1°C for 5 minutes.
- The effective thermal resistance is given by the equations below, where T_a and T_b are extrapolated temperatures at top and bottom interfaces:

$$R_{eff}^{joint} = \frac{T_a - T_b}{Q} A = \frac{L}{k_{eff}}$$

$$Q = \frac{k_{copper} A \Delta T_{12}}{\Delta x_{12}} = \frac{k_{copper} A \Delta T_{34}}{\Delta x_{34}}$$

Results

- Device was able to measure the thermal conductivity of standard copper to with in 3%
- The thermal resistance of a joint sample with copper particles coated with 50 nm of gold was measured under constant temperature varying applied pressure, and constant pressure varying average joint temperature.

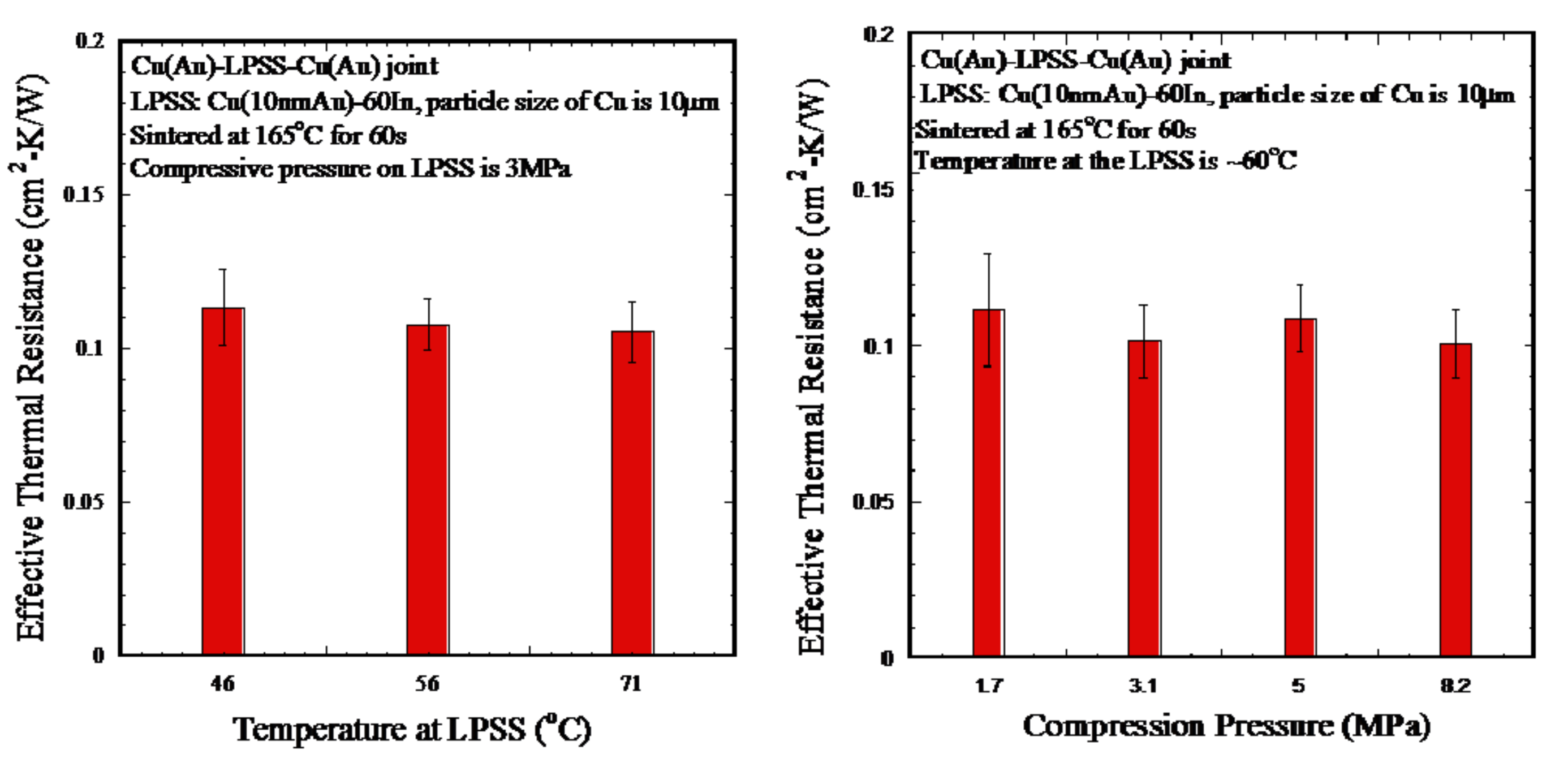

Figure 4: Thermal resistance plotted with varying joint temperature (left) and varying compression pressure (right). Over these ranges neither variance in temperature or pressure significantly affect the thermal resistance. This is a result of the solder being bonded to the copper heat transfer bars.

Interfacial Characterization

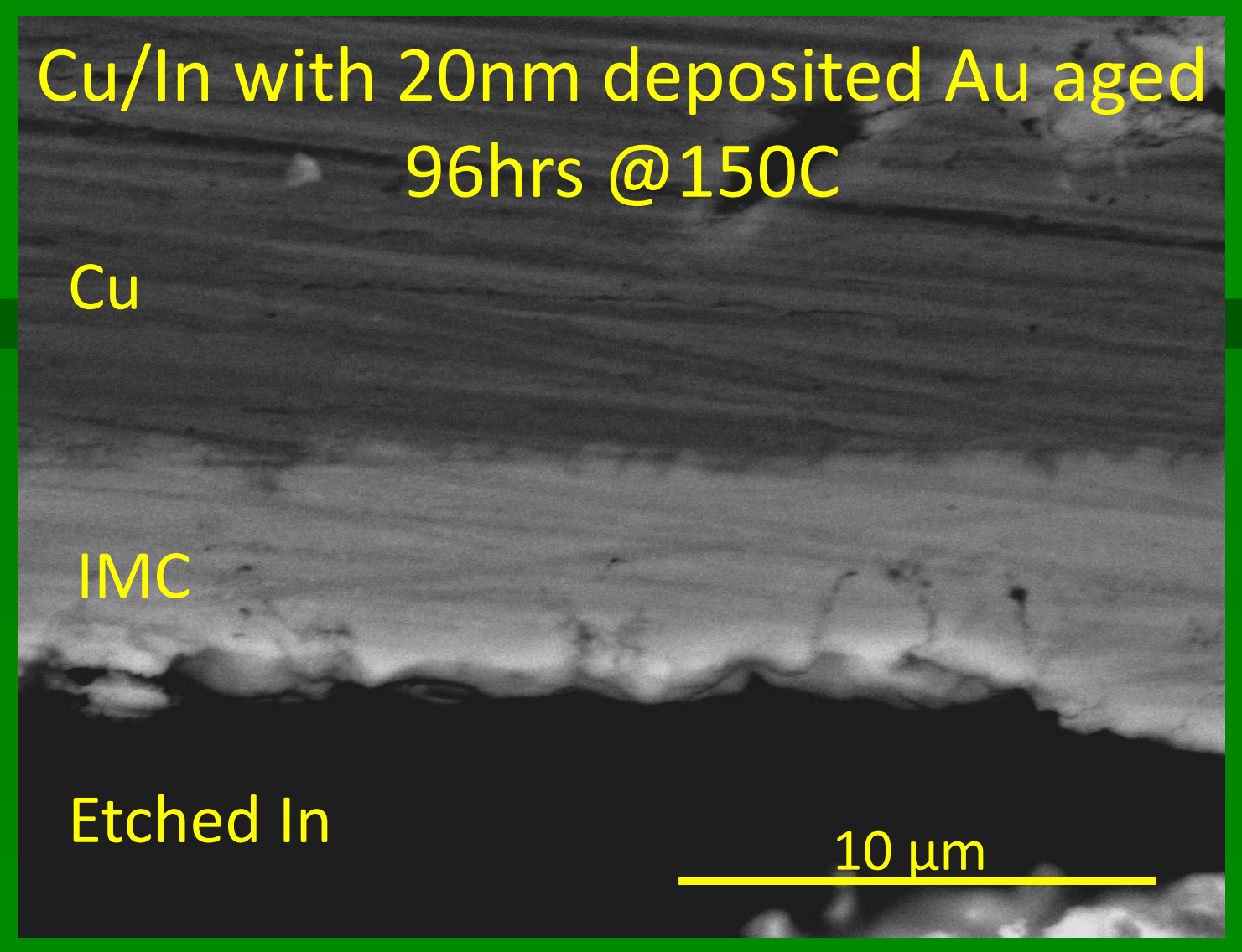

Figure 5: Interface Sample with 20 nm Au*

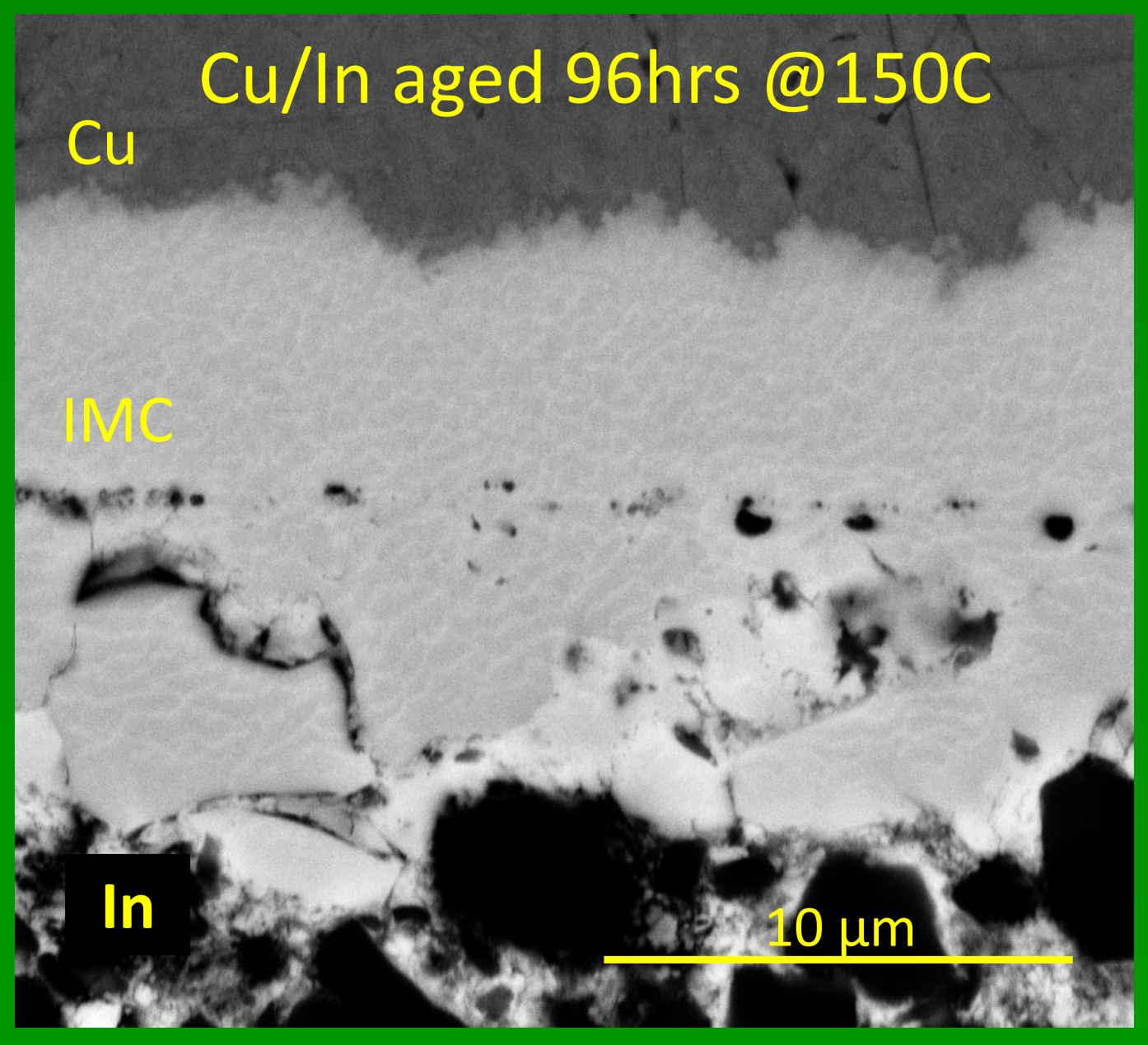

Figure 6: Interface Sample with no Au inter-layer*

- A very thin inter-layer of $AuIn_2$ is of interest as a wetting agent and diffusion barrier.
- 20 nm of Au was electrolessly deposited on the polished copper substrate prior to In bonding (fig. 5). Effectively, all Au reacts immediately to form $AuIn_2$.
- The intermetallic compound $Cu_{11}In_9$ is observed both with and without a $AuIn_2$ inter-layer
- The thickness of the intermetallic layer is 5.7 µm with an $AuIn_2$ inter-layer (fig. 5) and 13.5 µm without any inter-layer (fig. 6).
- $AuIn_2$ appears to slow the growth of $Cu_{11}In_9$ by inhibiting In diffusion.

Future Work

- Determine the relationship between solder thickness and thermal resistance in order to determine the relative importance of interfacial resistance and material thermal resistance.
- Determine optimum solder thickness and develop processing techniques to further reduce contact resistance
- Further improve on interface polishing techniques in order to reveal inter-layers and produce high quality images.
- Determine the rate controlling step and diffusion constant of interfacial reactions by measuring intermetallic thickness as a function of aging time.
- Measure the activation energy of the interfacial reaction by measuring the diffusion constant as a function of aging temperature.

$$\Delta x \propto (Dt)^n$$

$$D = D_0 \exp\left(-\frac{Q}{DT}\right)$$

*SEM photos provided by J. Liu

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