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Modern Materials for a Connected Society

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Liquid Metal Embedded Elastomers (LMEE) as Low-BLT Thermal Interface Materials

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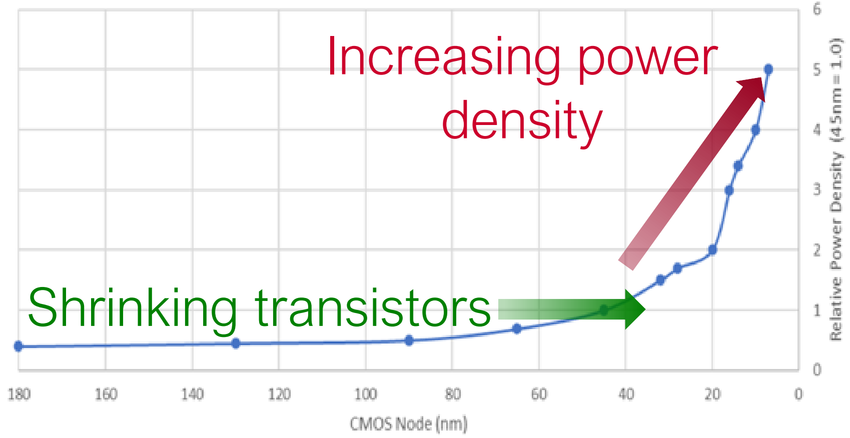
Thermal Challenges Constrain Technology

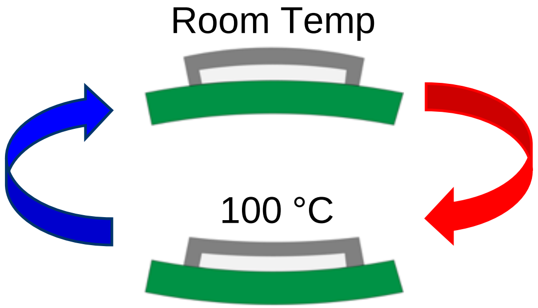
Modern semiconductors have exponentially growing power densities



Stillmaker, Integration, 2017

…leading to thermal stresses

…and failed package interfaces.



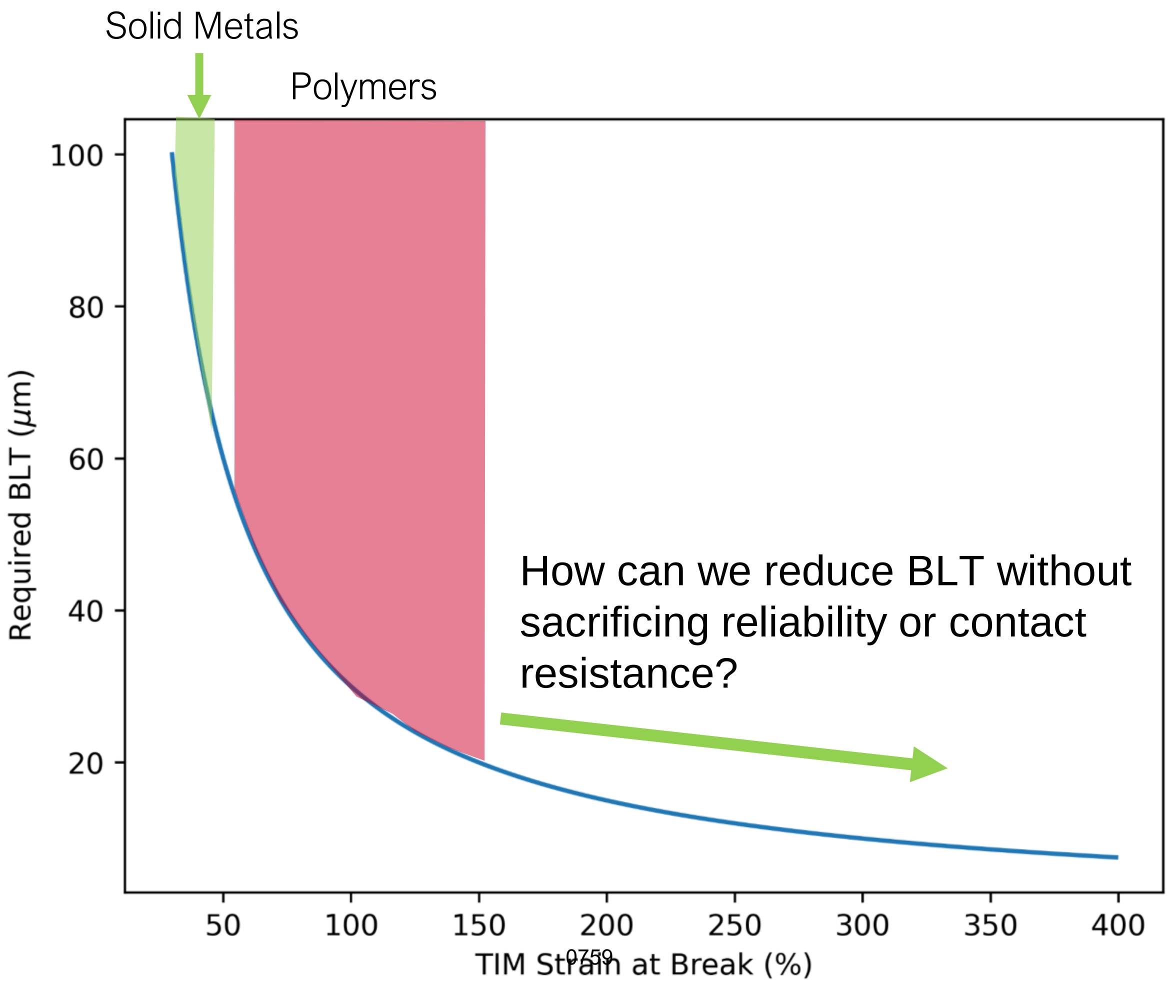
Progress requires new TIMs that maintain low thermal resistance $R_{th} = \frac{BLT}{\kappa} + R_{contact}$ throughout device lifetime

Subramanian, J. Elec. Packaging, 2019

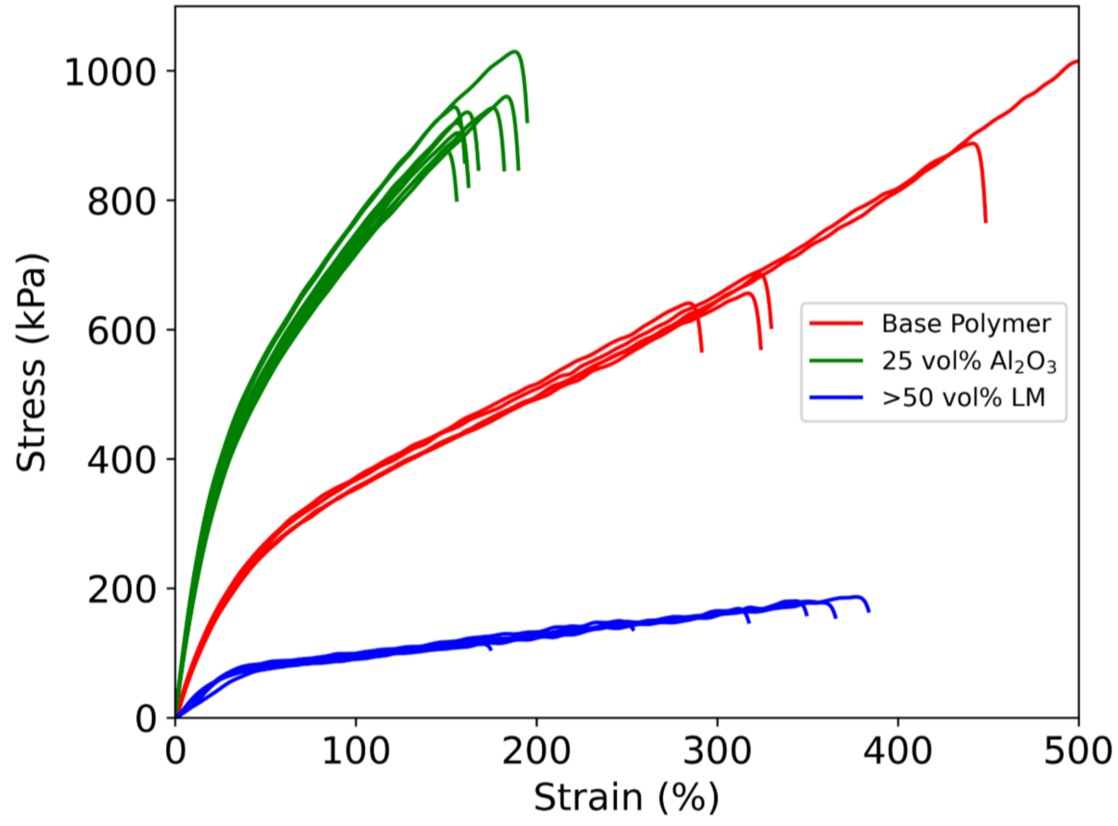
Achievable BLTs are Limited by TIM Elongation

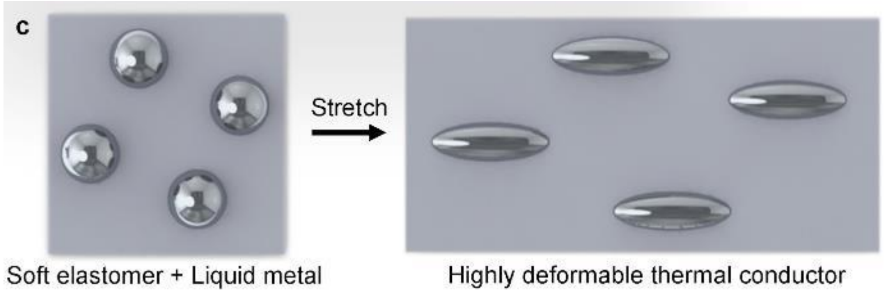
Given a package warpage (Δ_{BLT}) requirement (e.g. 30 μm), TIM strain at break ϵ_b dictates a required minimum bondline thickness (BLT)

$$BLT_{min} = \frac{\Delta_{BLT}}{\epsilon_b}$$

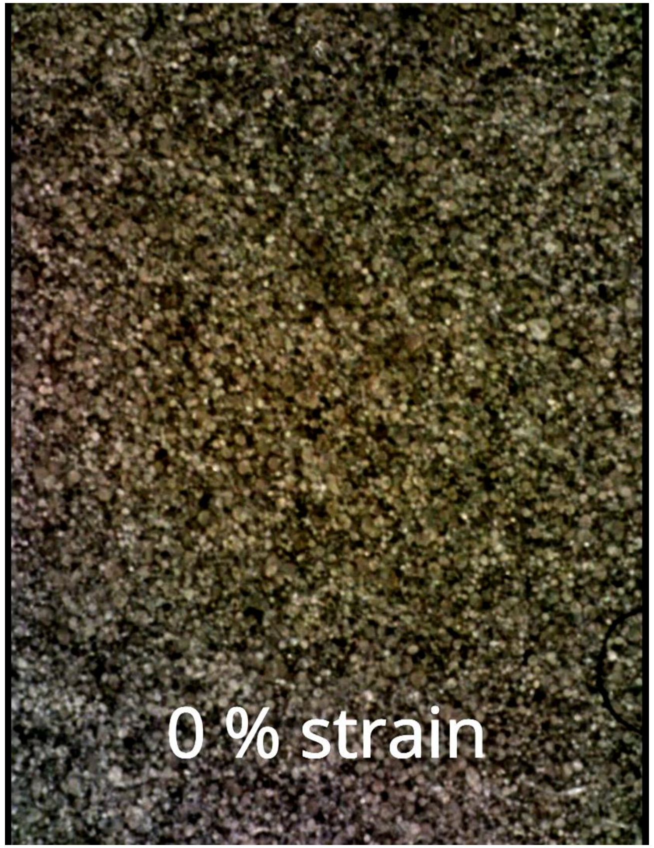


Strain at Break is Driven by Filler Type





Bartlett, PNAS, 2017



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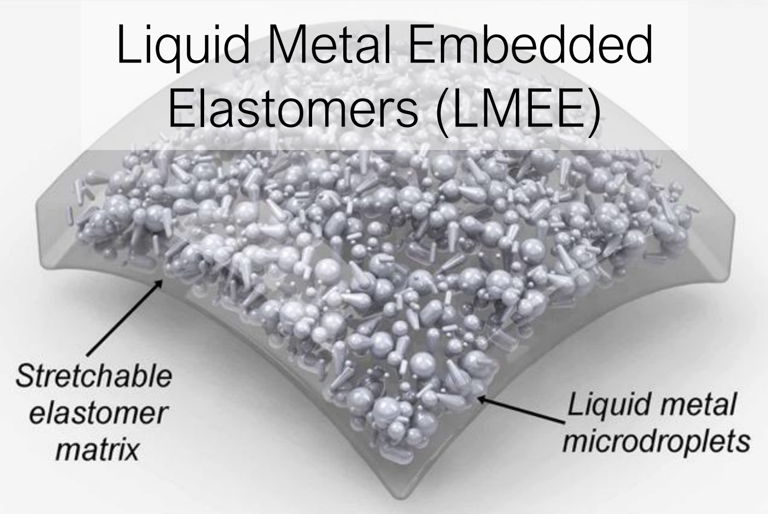
Properties of Gallium-alloy Liquid Metals

Chiechi, Angew. Chem. Int. Ed., 2008

Joshipura, J. Mater. Chem. C., 2015

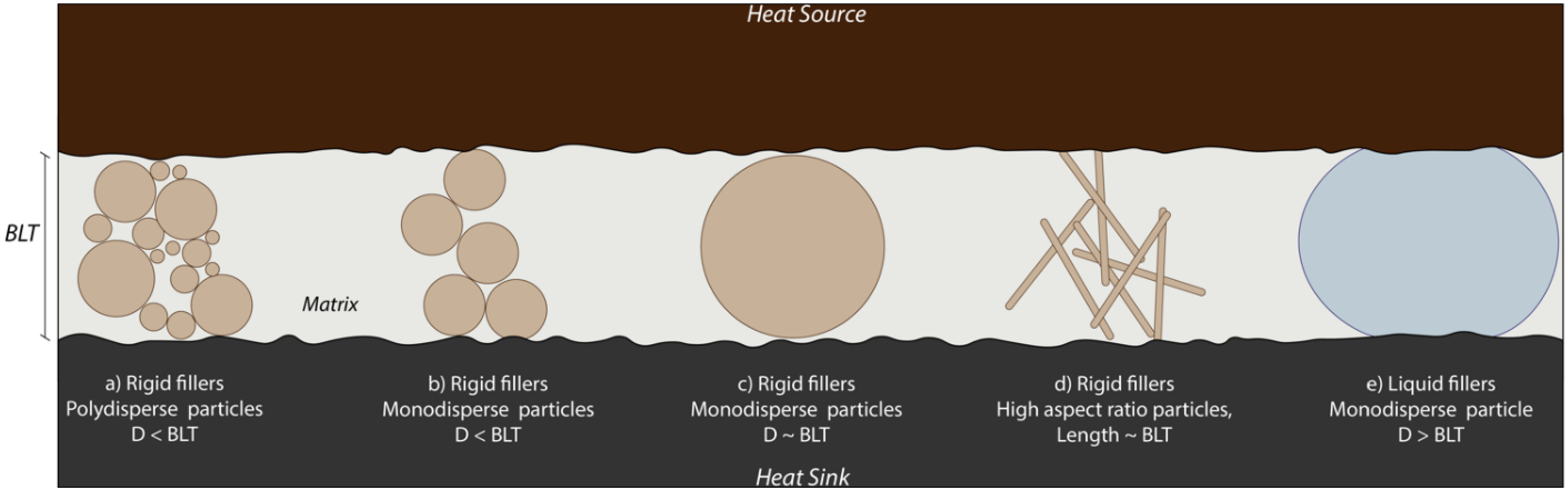
- Low melting point ~15.5 °C
- Low viscosity ~2 cP
- High thermal conductivity ~26 $\frac{W}{m \cdot K}$ at 30 °C
- Forms passivated oxide layer
- Enables fabrication of stabilized droplets in polymers



Bartlett, Adv. Mat., 2016

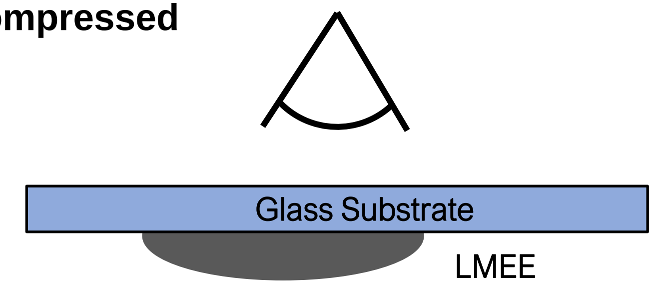
Rigid vs. Liquid Fillers

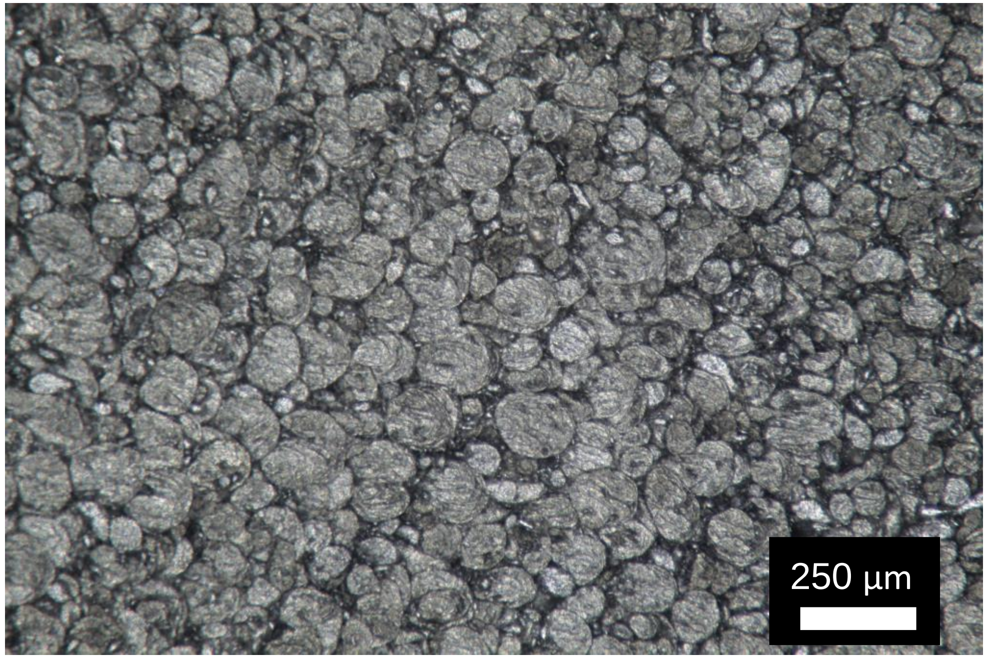
LM droplet compression tends to reduce contact resistance



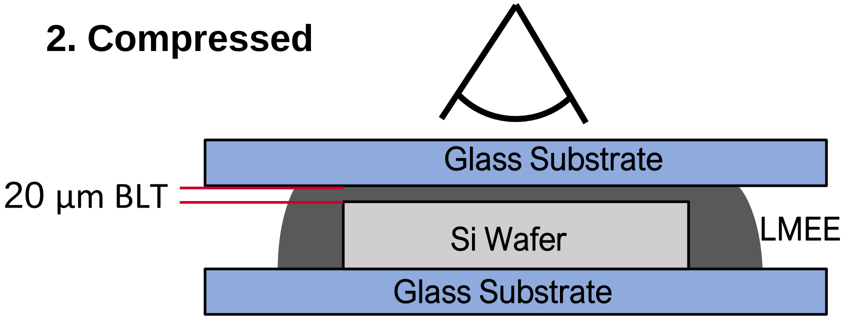
Compression → Increased Contact Area

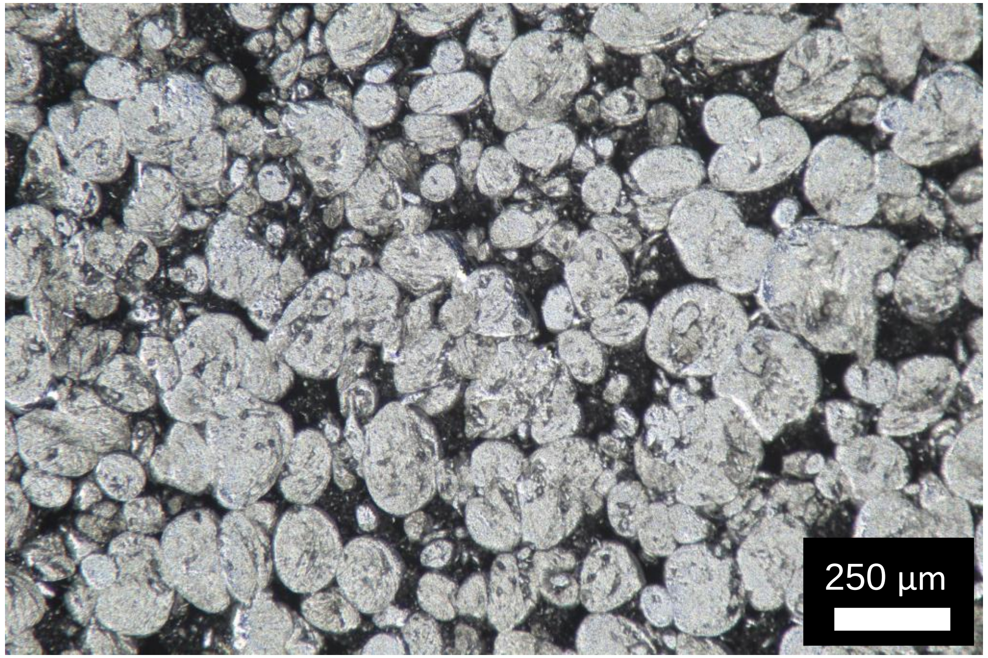
1. Uncompressed





2. Compressed

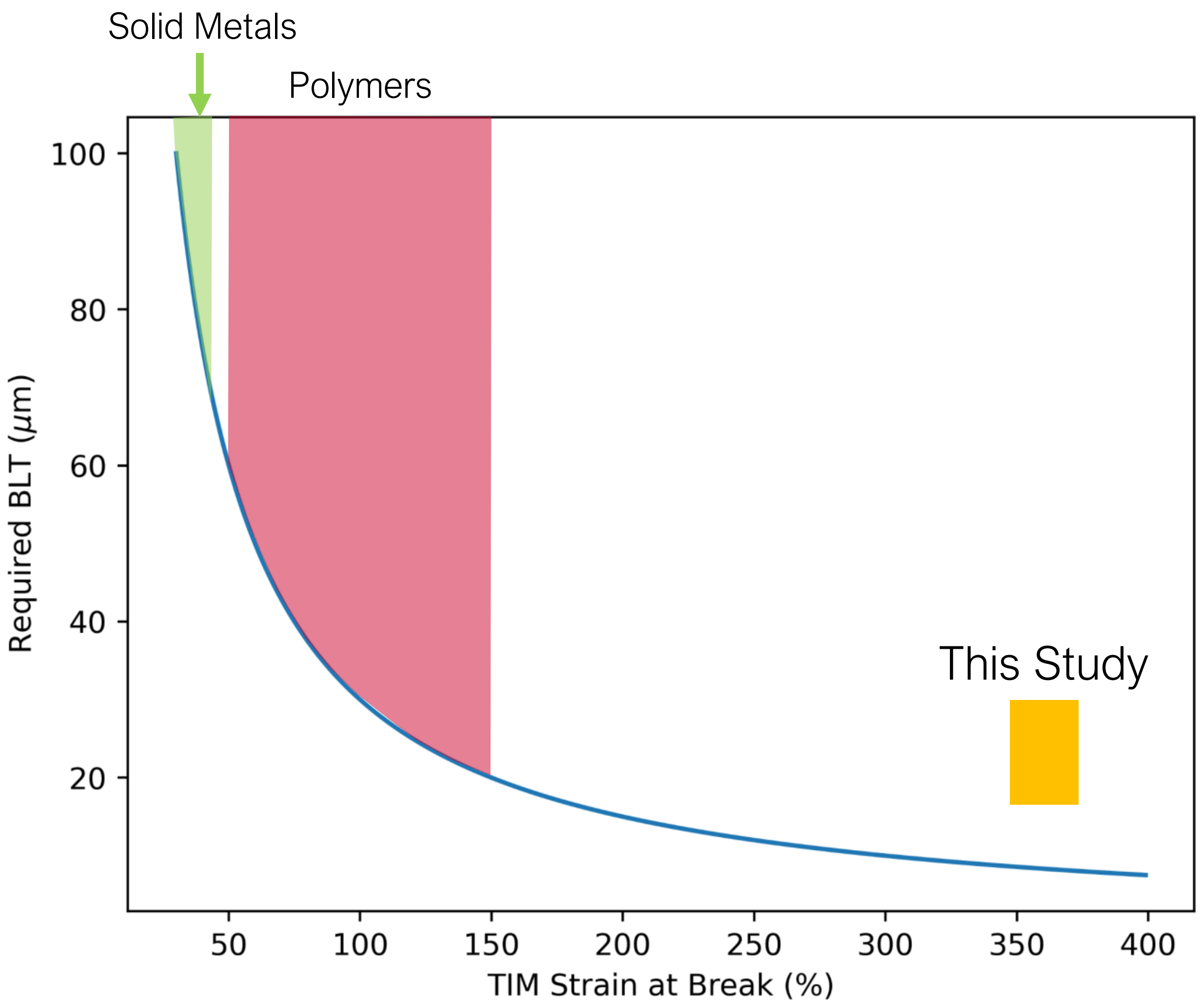




LMEE TIMs Enable Low BLT

- For warpage of 30 μm, 350% strain at break allows for $BLT_{min} = \frac{\Delta_{BLT}}{\epsilon_b} = 8.6\mu m$

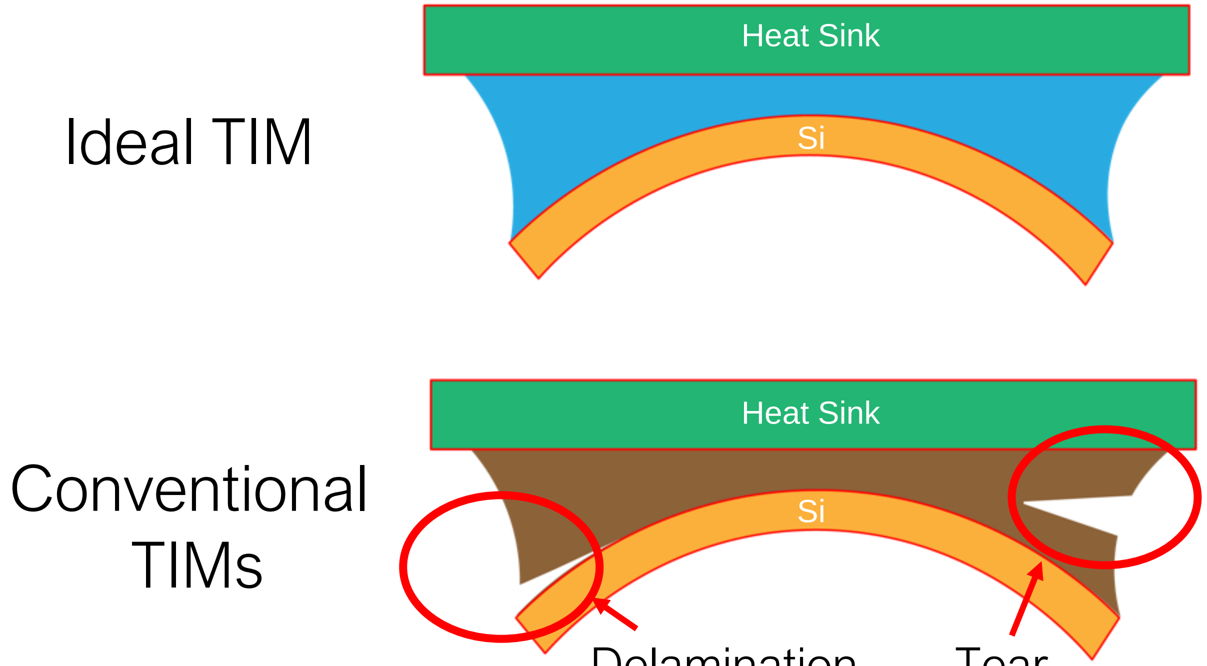
- In this study, we targeted BLT of 20 μm



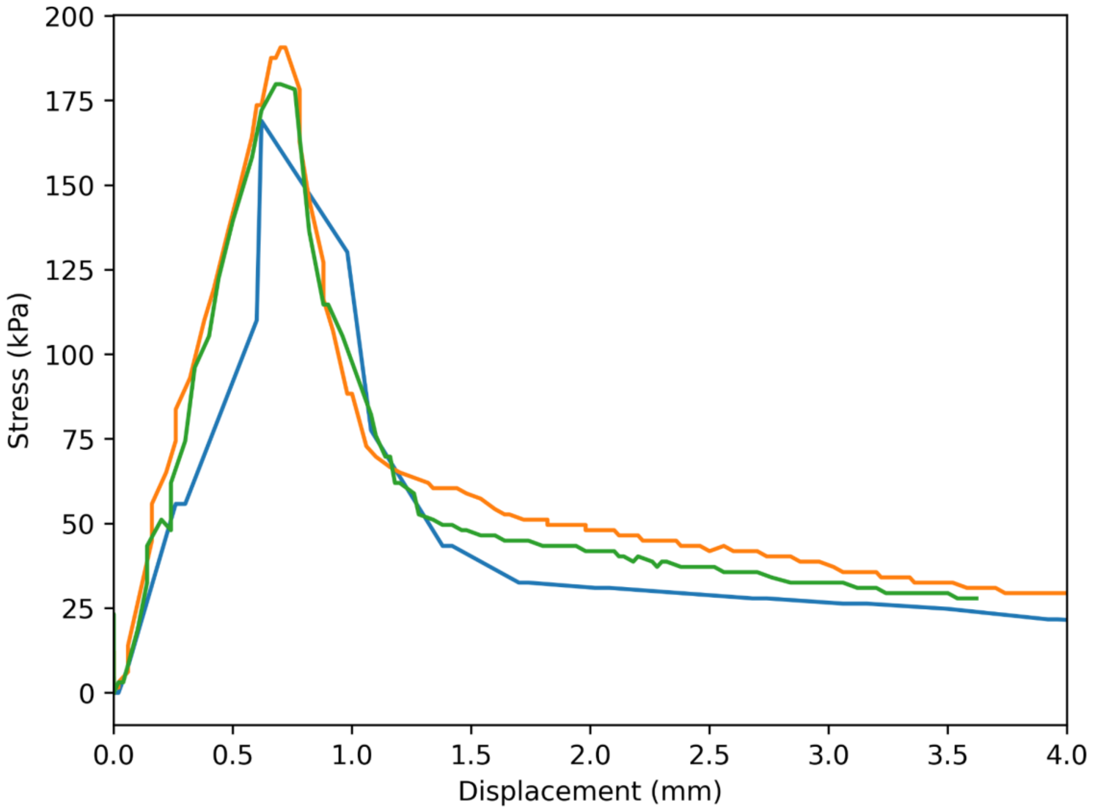
Adhesion: The Achilles' Heel of Interfaces

- TIMs must pass TST, uHAST, HTS, and Reflow to be viable in package

- Passing TST requires both elongation **and adhesion**

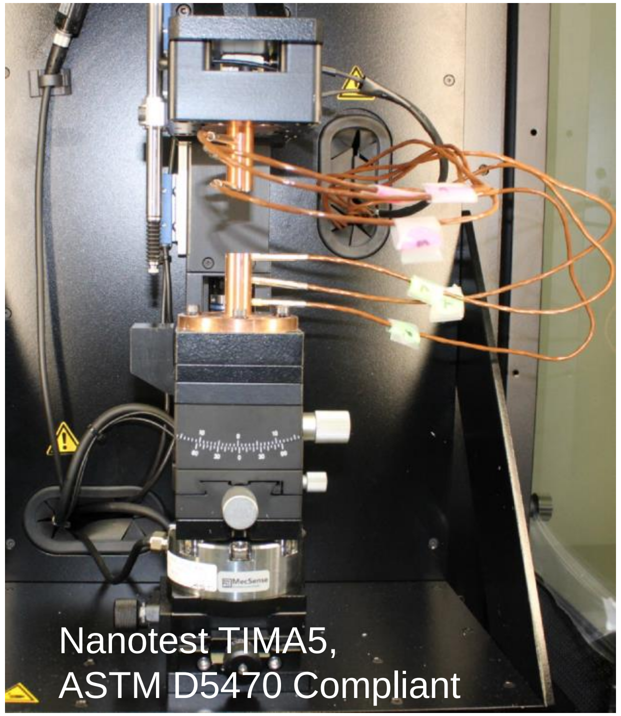


Adhesive Properties of LMEE

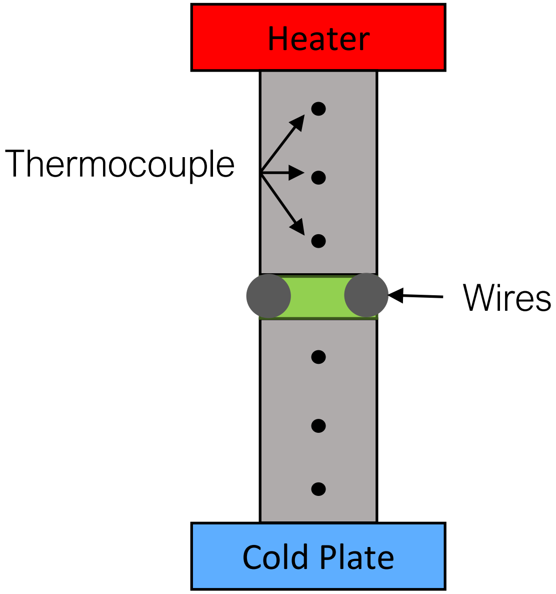


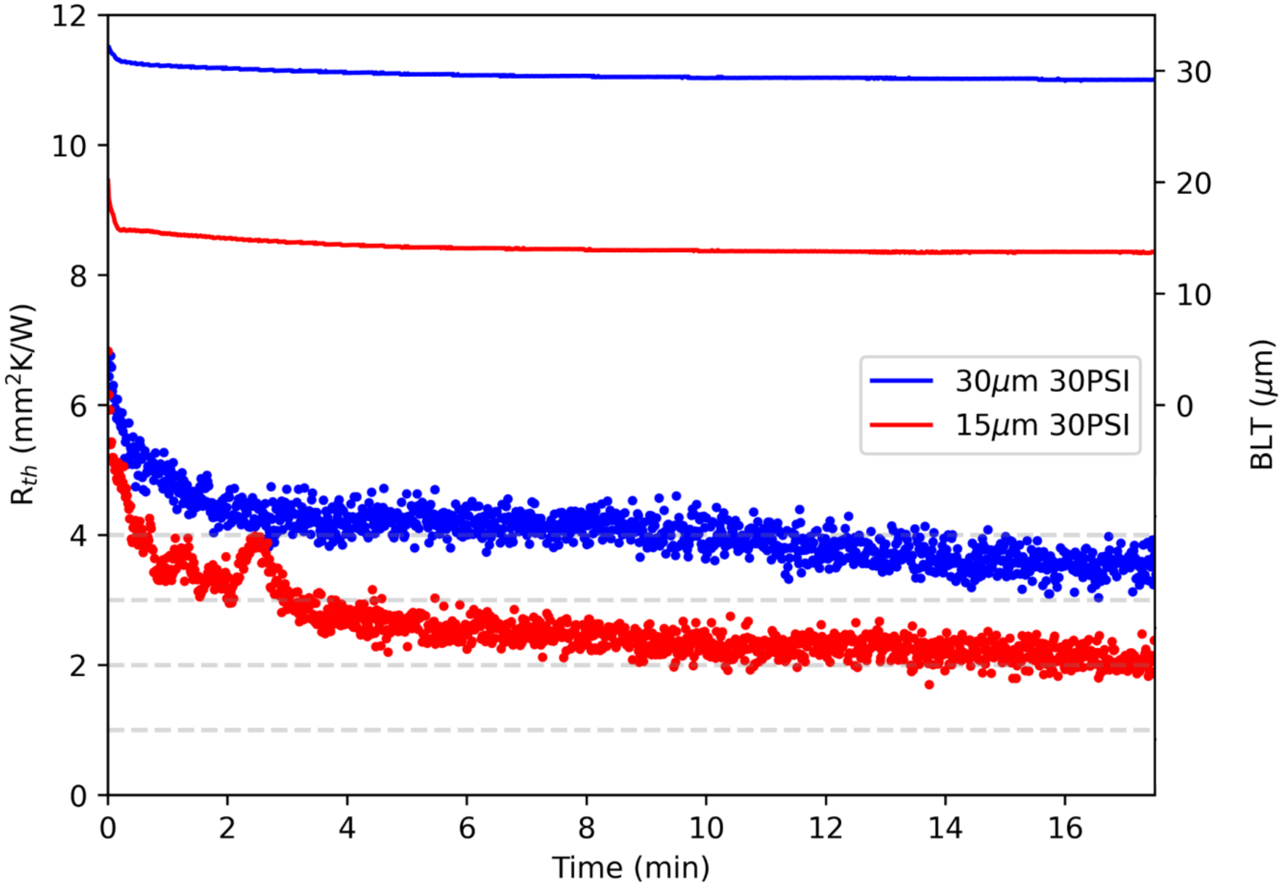
LMEE exhibits high adhesion to nickel substrates and cohesive failure

Thermal Performance of LMEE



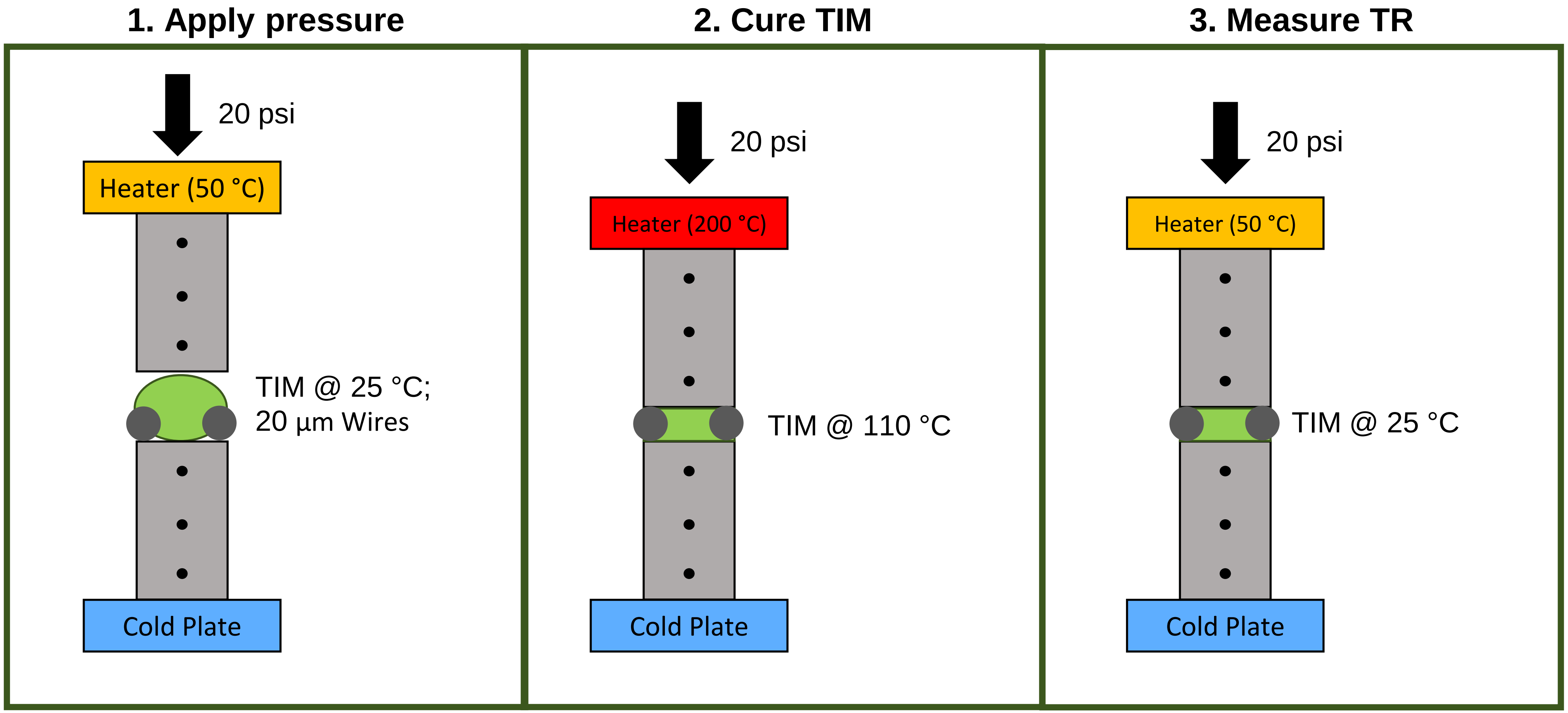
Stabilizing BLT under constant pressure





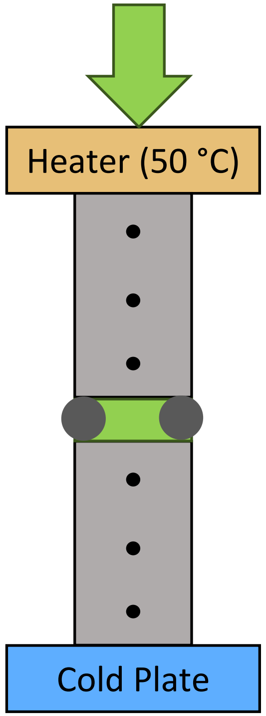
LMEE reaches low BLT and demonstrates comparable thermal performance to S-TIM

Curing LMEE in Modified ASTM D5470 Setup

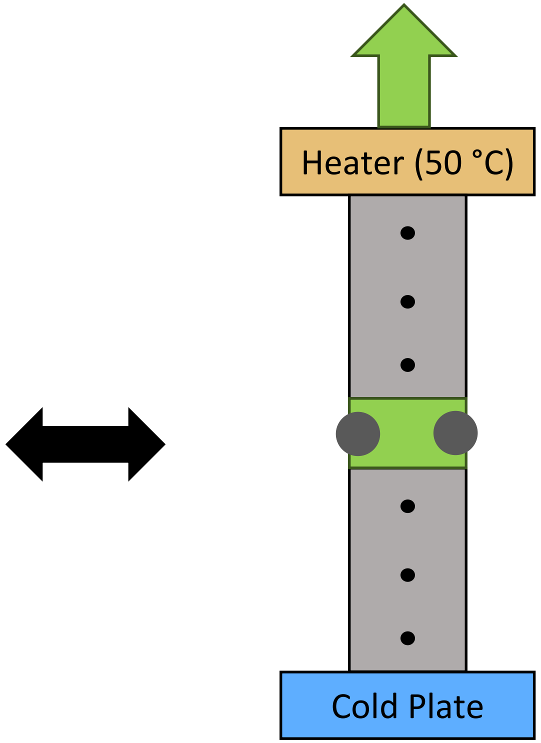


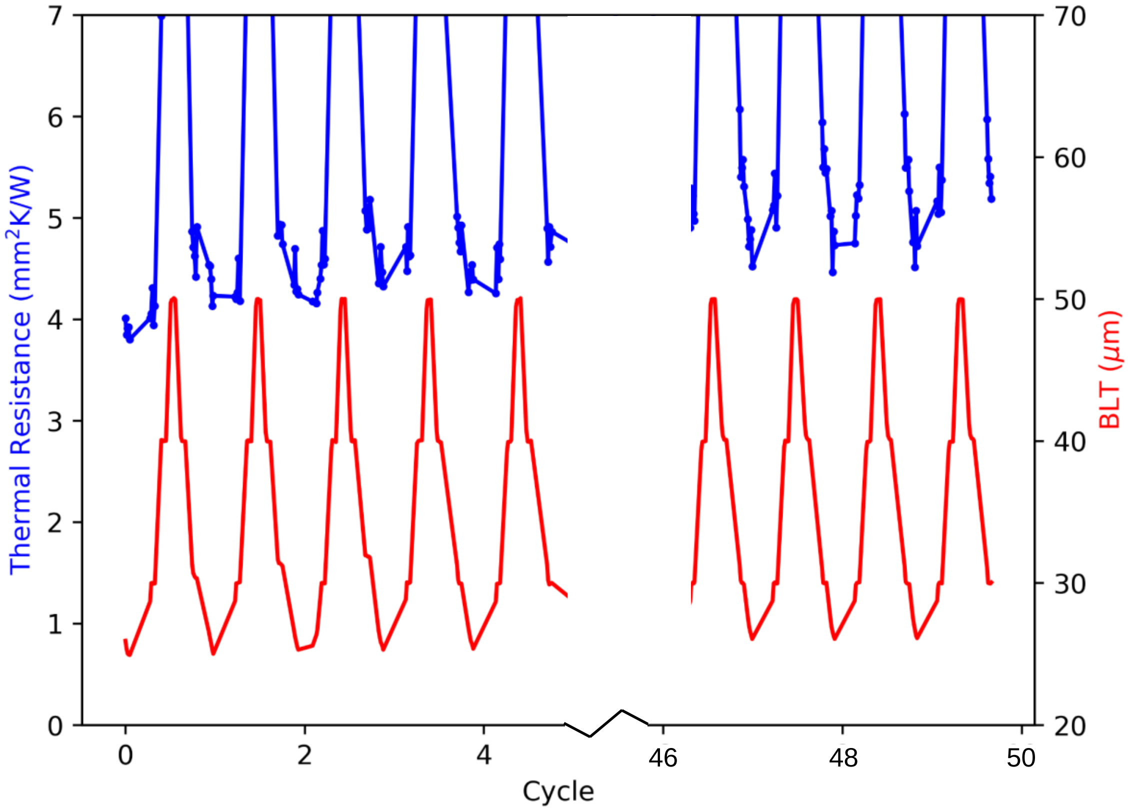
Strain Cycling

4. Compress at 20 psi



5. Stretch to 50 µm

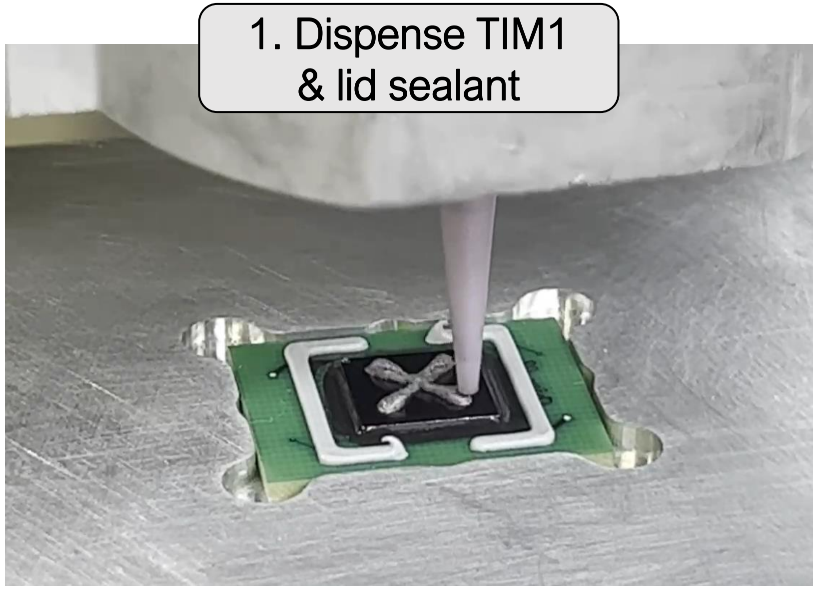


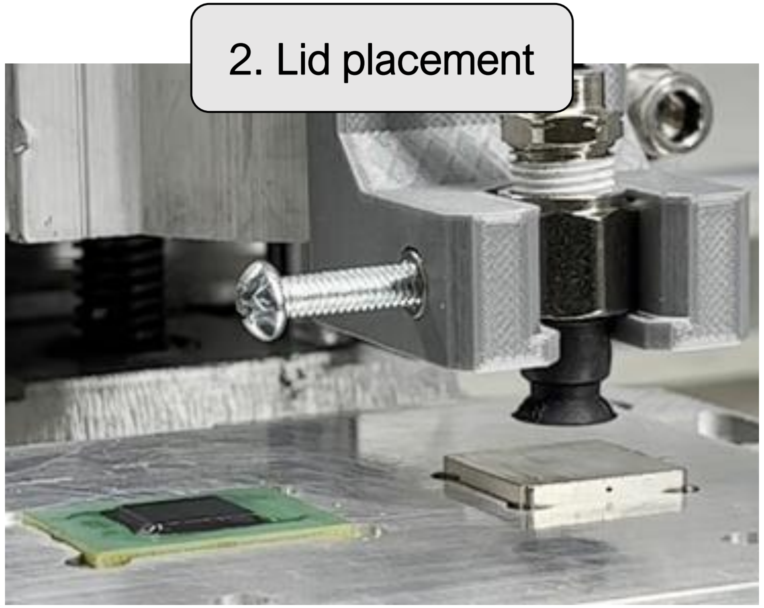


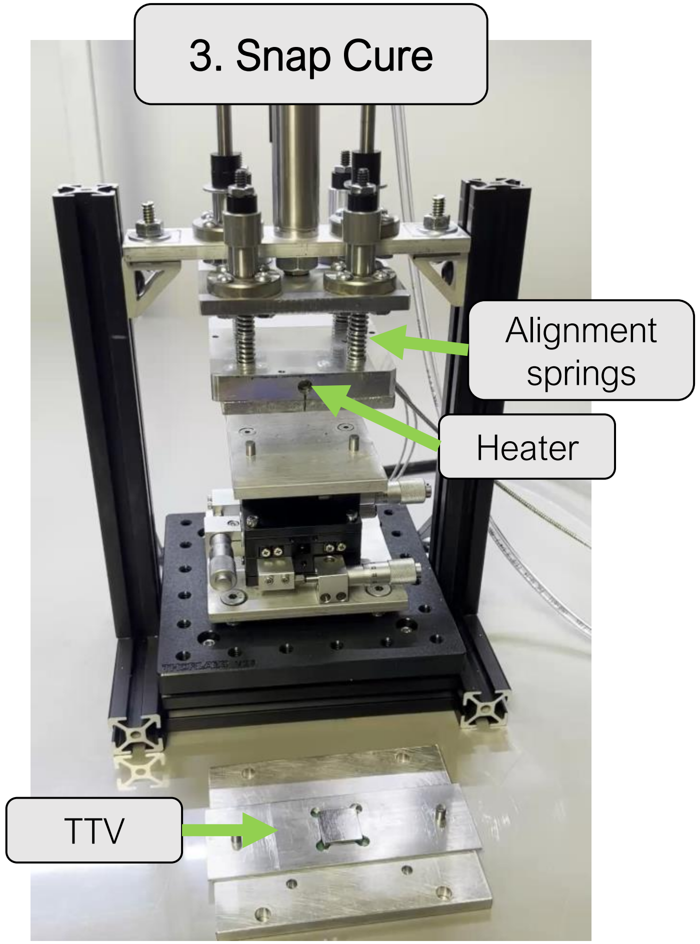
LMEE TIM exhibits $R_{th} < 5\,\frac{mm^2K}{W}$ after 50 strain cycles

TTV Evaluation - Assembly

LMEE was pneumatically dispensed and cured onto NanoTest NT16-TTV5 TTV



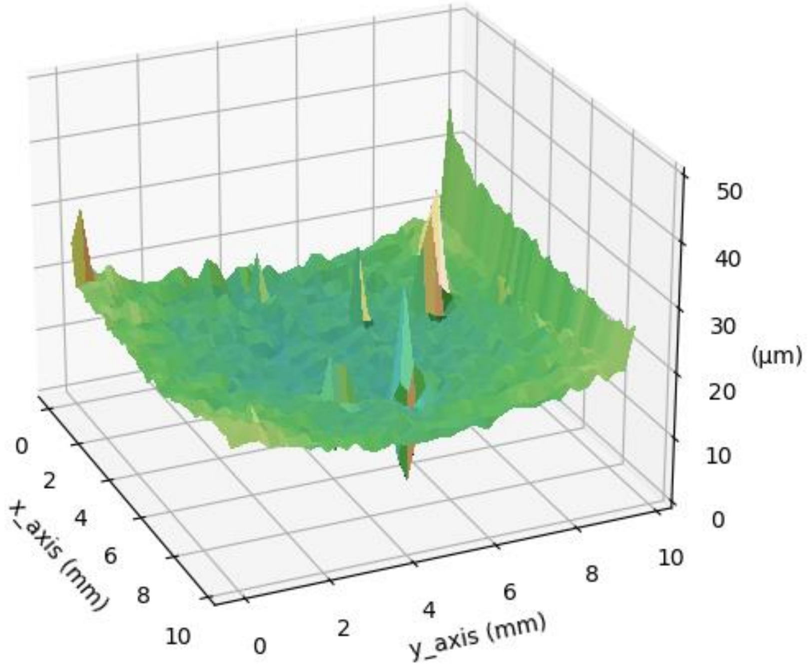


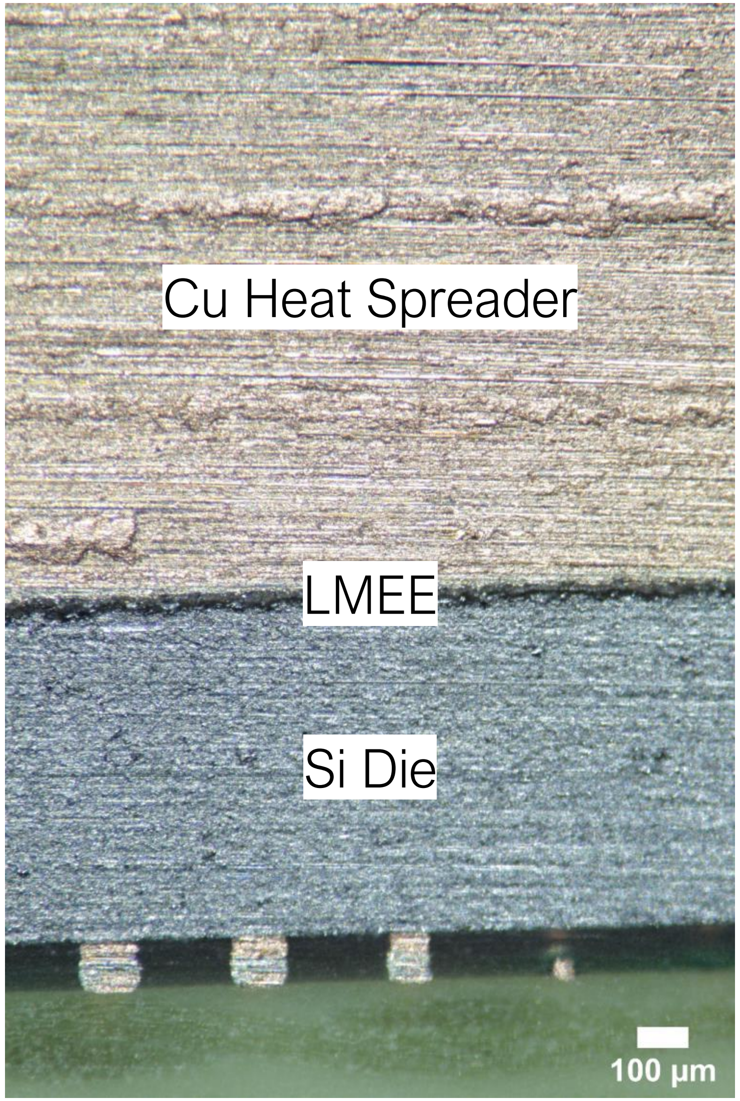


TTV Evaluation – BLT Estimation

LMEE was pneumatically dispensed and cured onto NanoTest NT16-TTV5 TTV, achieving BLT ~20 µm

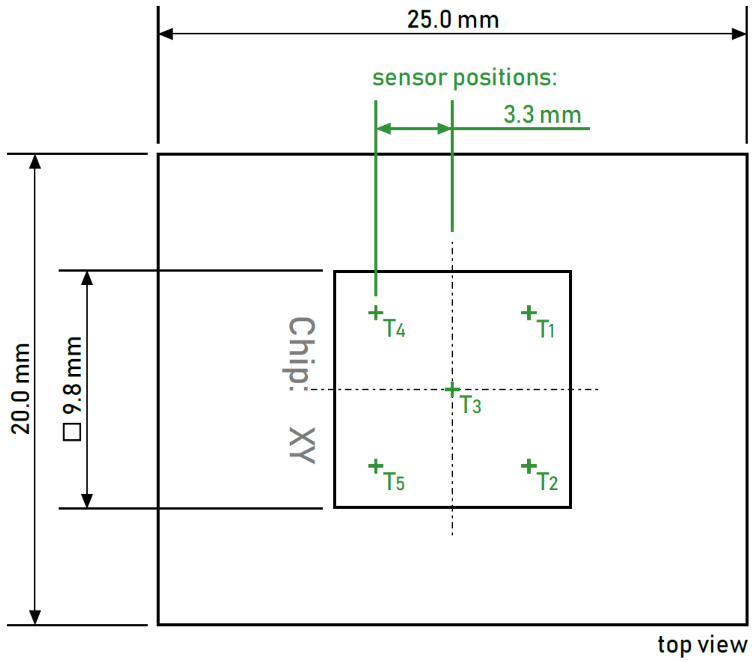
Profilometer estimated a lower BLT at the center, possibly due to package warpage.



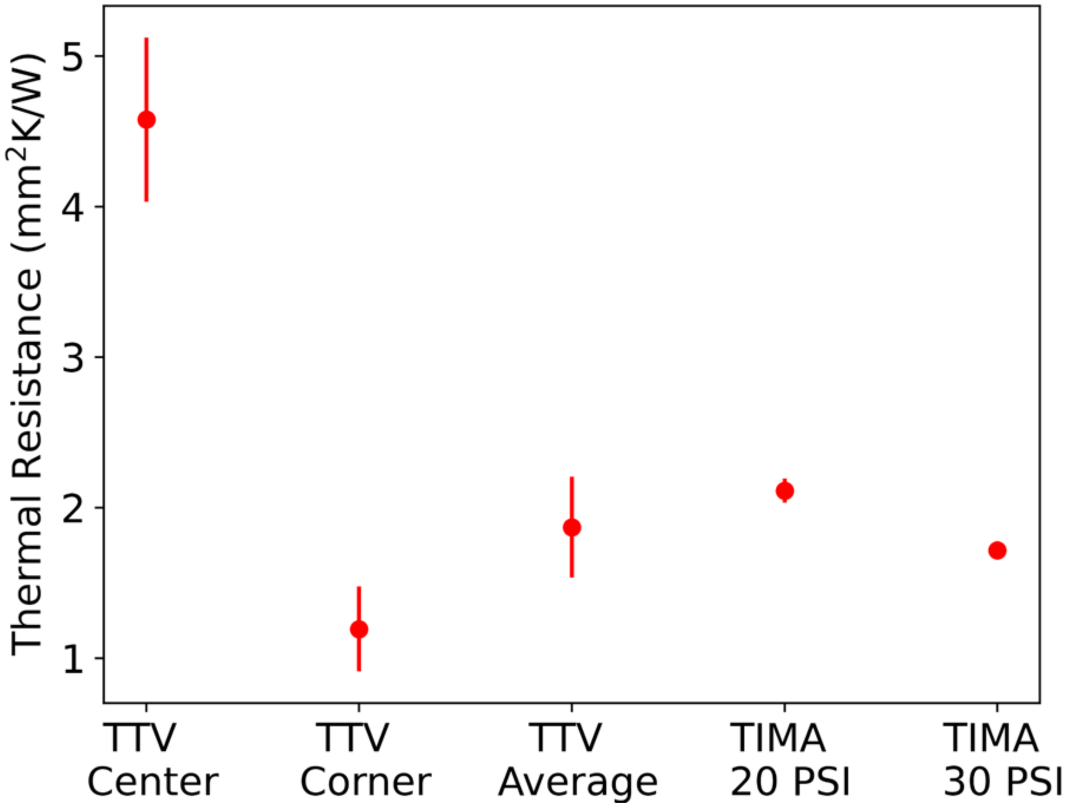


TTV Evaluation - Rth

Average R_{th} matches TIMA measurement, but R_{th} seems higher at center



Nanotest GmbH., NT16-TTV5 Datasheet, 2018



Summary

1. Strain at break places a constraint on the minimum achievable BLT

2. Liquid metal fillers enable high strain w/o reducing thermal performance

Observed LMEE with

- 350% max. strain → $BLT_{min} = 8.6\ \mu m$ for package $\Delta_{BLT} = 30\ \mu m$
- $R_{th} < 4\frac{mm^2K}{W}$ @ 30 µm
- Survived >50 cycles to 150% strain with $R_{th} < 5\frac{mm^2K}{W}$

Acknowledgements

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