Controlling Liquid Metal Droplet Morphology for Thermal Interface Material Optimization

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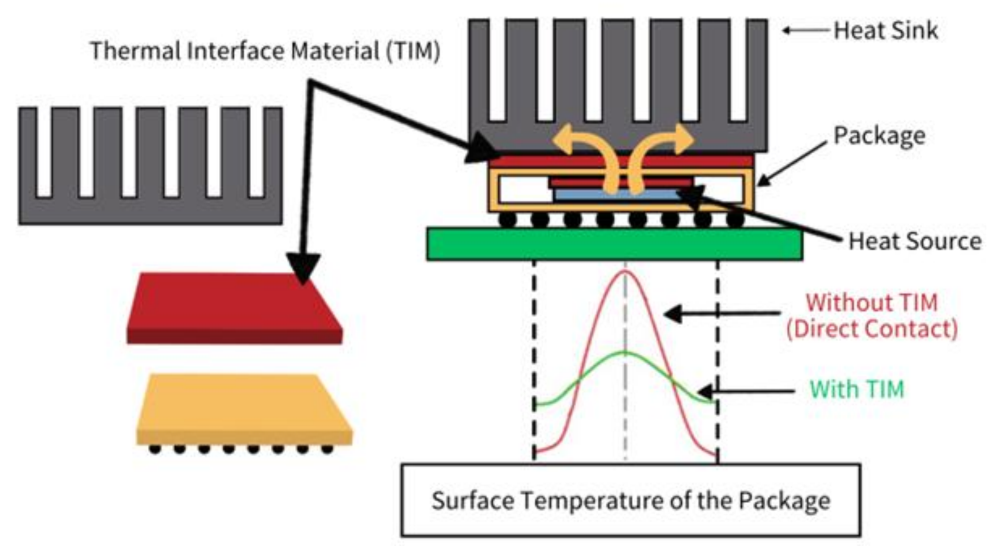
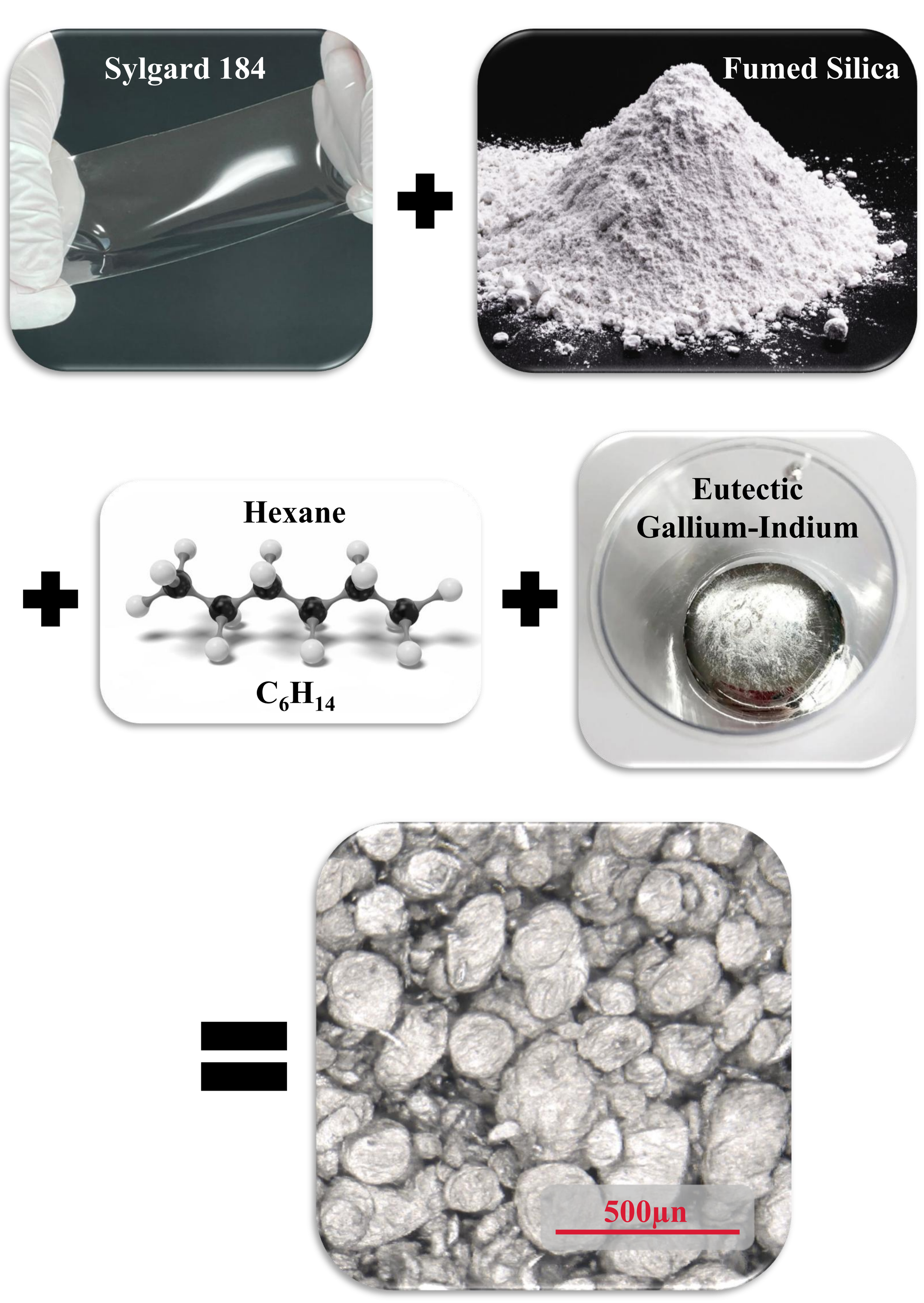
Stretching TIM Potential



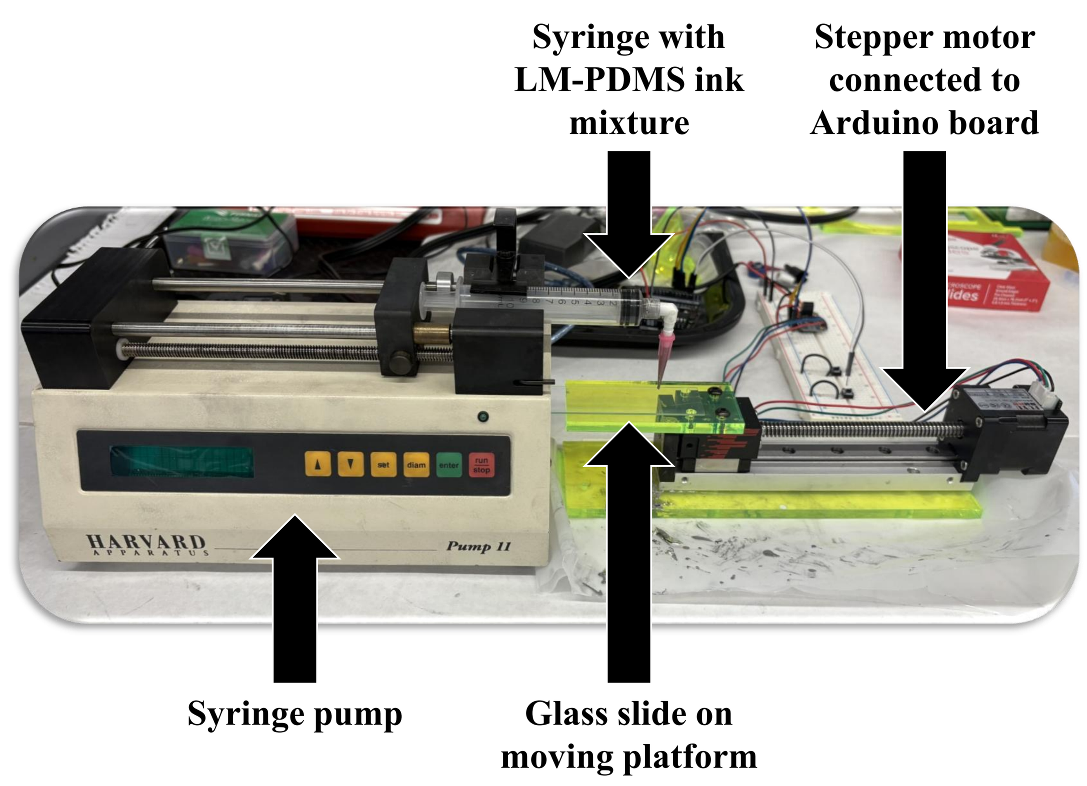
- Thermal interface materials (TIMs) regulate operating temperatures in electronics.
- Previous research has proven that elongated liquid metal (LM) droplets in a polydimethylsiloxane (PDMS) matrix allow TIMs to have higher thermal conductivity. [1]
- Droplets have been elongated before with shear forces by movement across a platform while 3-D printing the LM-PDMS ink. This method requires control of too many parameters for it to be scalable. [2]
- Elongation by shear forces from the nozzle and flow rate would make a simpler method.
- Creating design maps of how various parameters affect elongation would allow for ease of manufacturing.

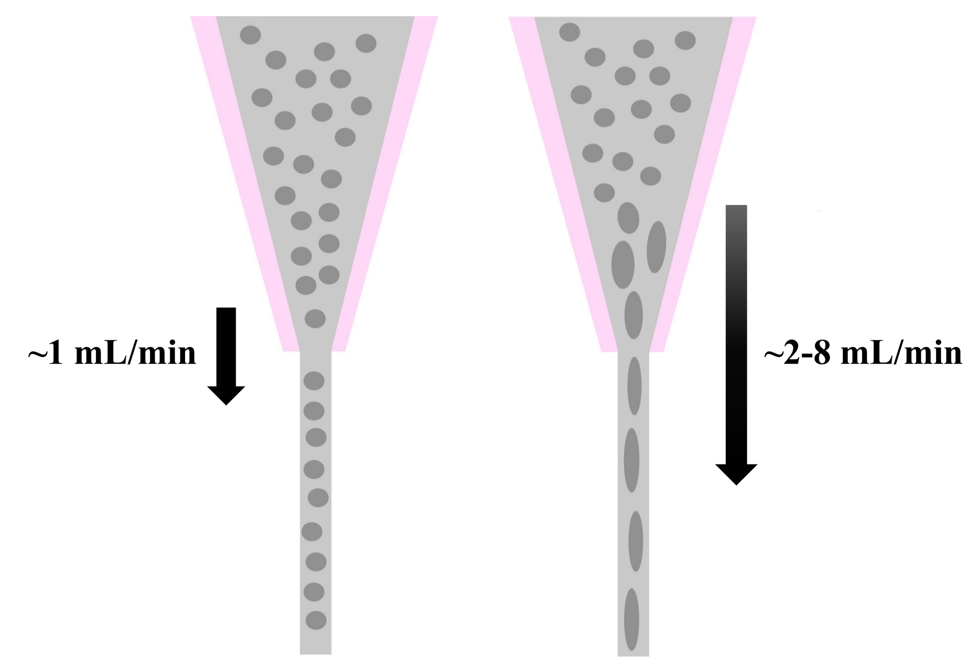
Making LM-PDMS Ink



1. PDMS (Sylgard 184) and crosslinker are mixed. This allows the composite to cure.
2. Fumed silica is added to increase viscosity.
3. Hexane is added to increase LM droplet size.
4. LM (eutectic gallium-indium) is added.
5. The mixture sits in a desiccator for 2 hours to evaporate the hexane.

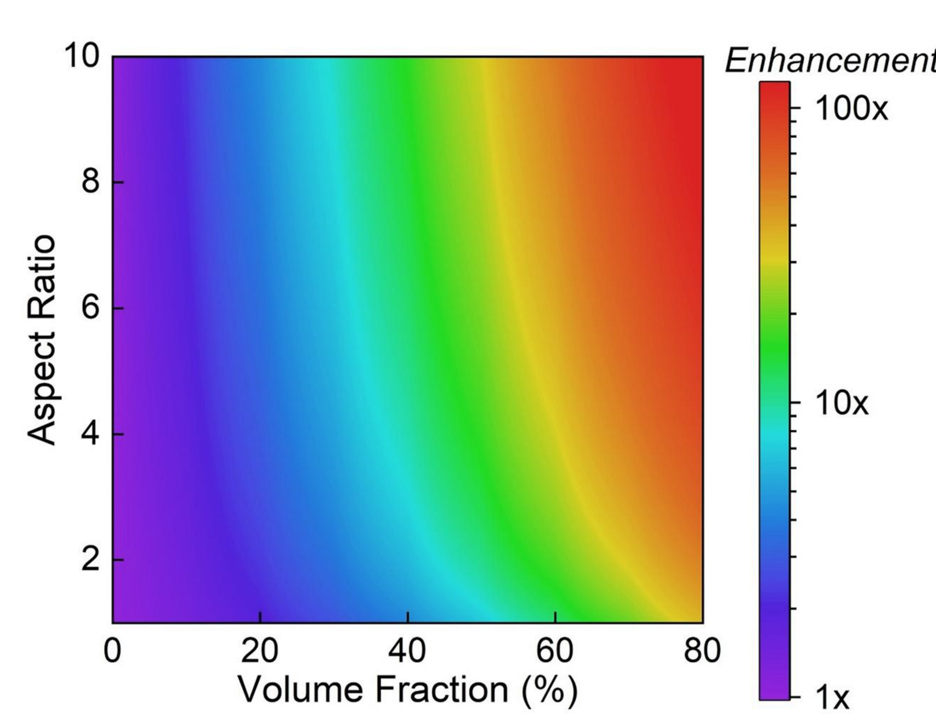
Extrusion Setup

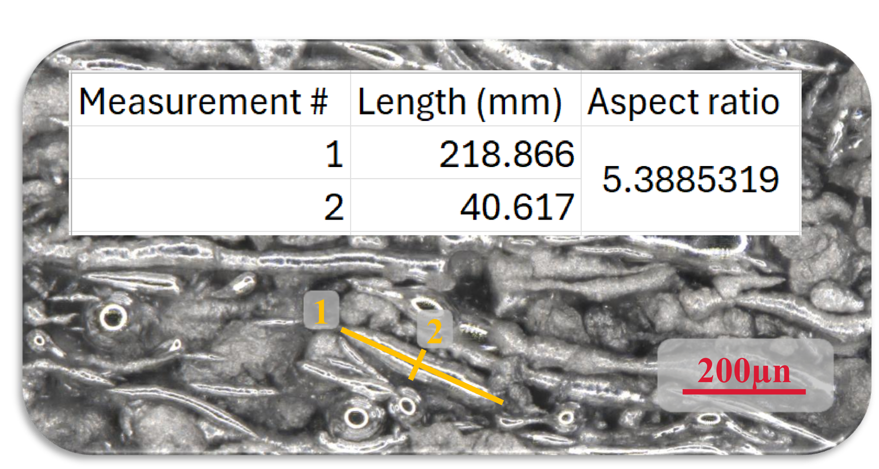




- The platform always moves at 10 mm/s, which is the maximum speed of the motor.
- So far, only the flow rate of extrusion and the nozzle size have been adjusted.
- Flow rates of 1 to 8 mL/min at 0.5 mL/min increments and nozzle diameters of 0.25 mm, 0.58 mm, and 1.19 mm were measured.

Measuring Aspect Ratio



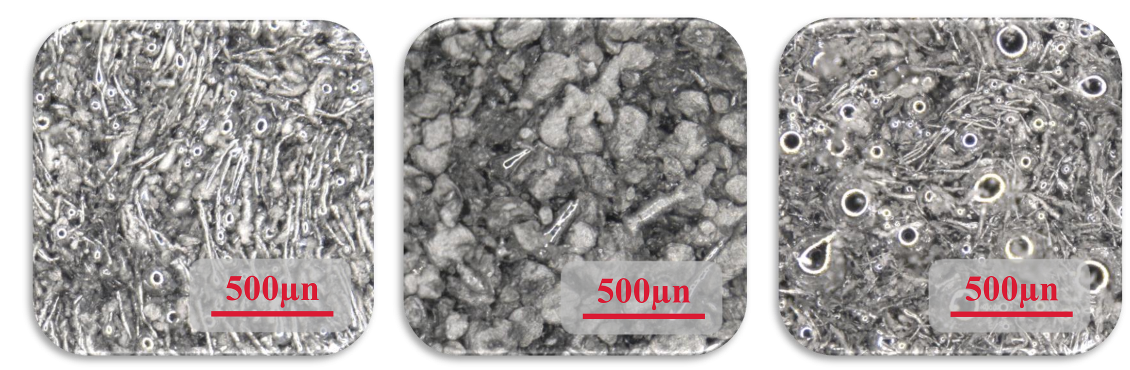


Measurement #	Length (mm)	Aspect ratio
1	218.866	5.3885319
2	40.617	

- Take microscope pictures and measure using ImageJ.
- Aspect ratio (AR) is measured by dividing the long axis of a droplet by its short axis.
- Measure at least 20 droplets for each extrusion rate to get an estimate of the average AR and standard deviation.

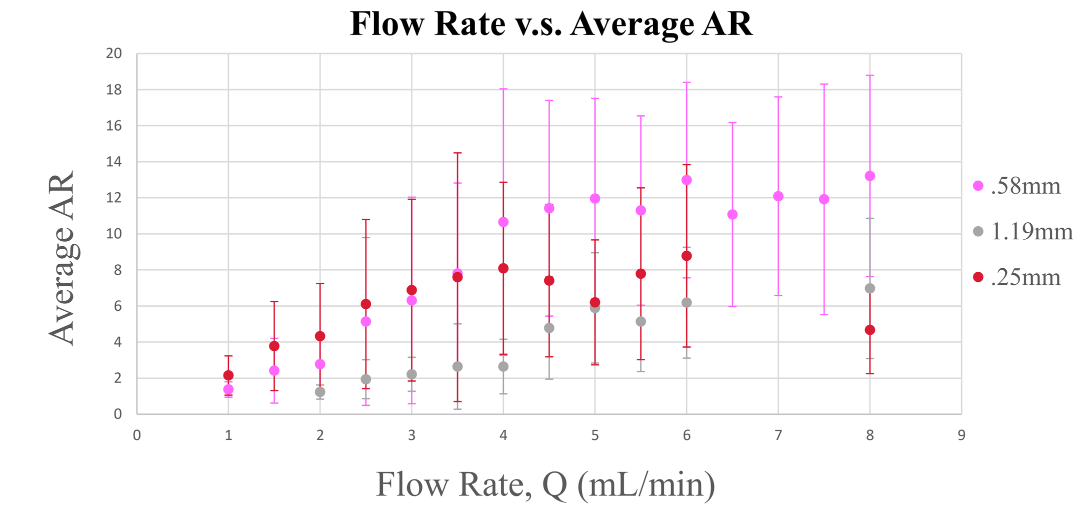
Results

Extrusions at 4 mL/min with the three nozzles

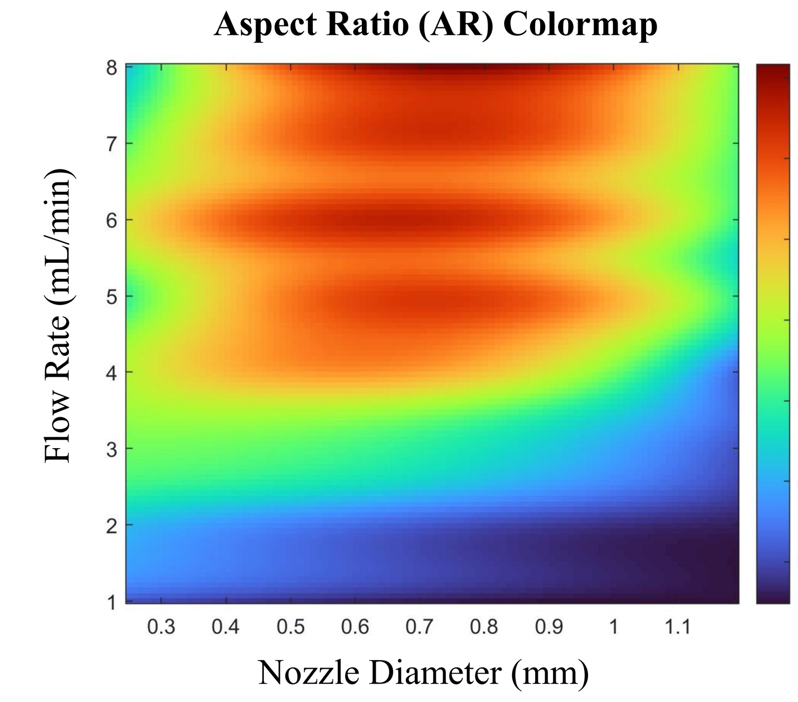


0.58mm (pink) — 1.19mm (grey) — 0.25mm (red)

Flow Rate v.s. Average AR



Aspect Ratio (AR) Colormap



- In general, the data follows expected trends.
- Inconsistency of droplet elongation makes the standard deviation heavily increase.
- Data after 4 mL/min with the red nozzle and 6 mL/min with the pink nozzle may not be fully accurate due to pump overloading issues.

Future Work

- Find a pump system that can undergo higher stress and potentially achieve greater elongation than the current syringe pump. Check the accuracy of current data.
- Fix the rope coiling issue by utilizing a faster motor for the platform or 3-D printing.
- Adjust fumed silica and hexane content and make design/color maps with collected data.
- Integrate phase change materials (PCMs) and 3-D print molds to make sample TIMs.

Acknowledgements

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[1] Hur, O., Markvicka, E. J., & Bartlett, M. D. (2024). Anisotropic and Heterogeneous Thermal Conductivity in Programmed Liquid Metal Composites Through Direct Ink Writing. *Advanced Functional Materials*. https://doi.org/10.1002/adfm.202417375

[2] Hur, O., Tutika, R., Klemba, N., Markvicka, E. J., & Bartlett, M. D. (2024). Designing liquid metal microstructures through directed material extrusion additive manufacturing. *Additive Manufacturing*, *79*, 103925. https://doi.org/10.1016/j.addma.2023.103925