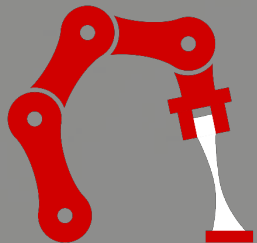


Lightweight Liquid Metal Elastomer Composites for Passive Thermal Management



Eric Markvicka, PhD
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eric.markvicka@unl.edu

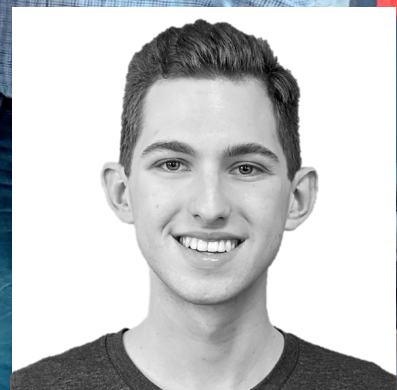


Smart Materials and Robotics Laboratory

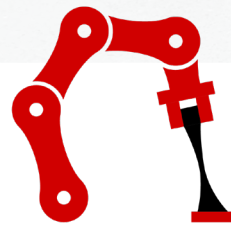
<http://smr.unl.edu>



Ethan Krings



Aaron Haake



Smart Materials and Robotics Laboratory

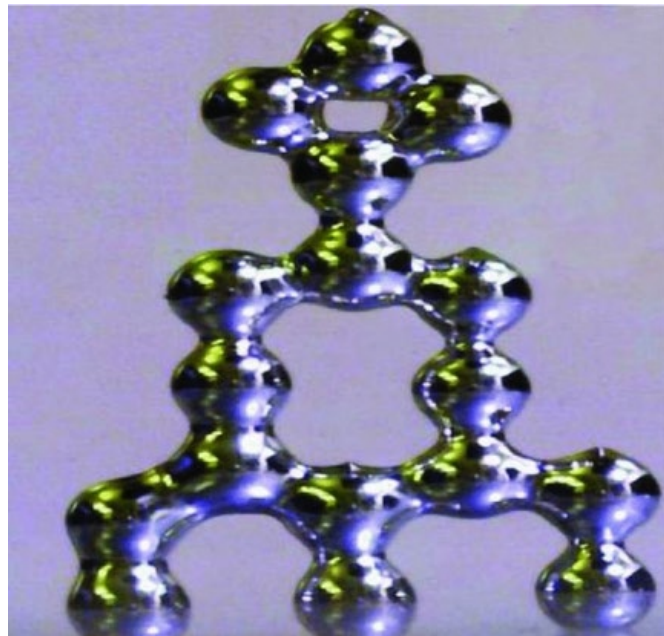


College of Engineering

MECHANICAL & MATERIALS ENGINEERING

Liquid Metal- Eutectic Gallium Indium (EGaIn)

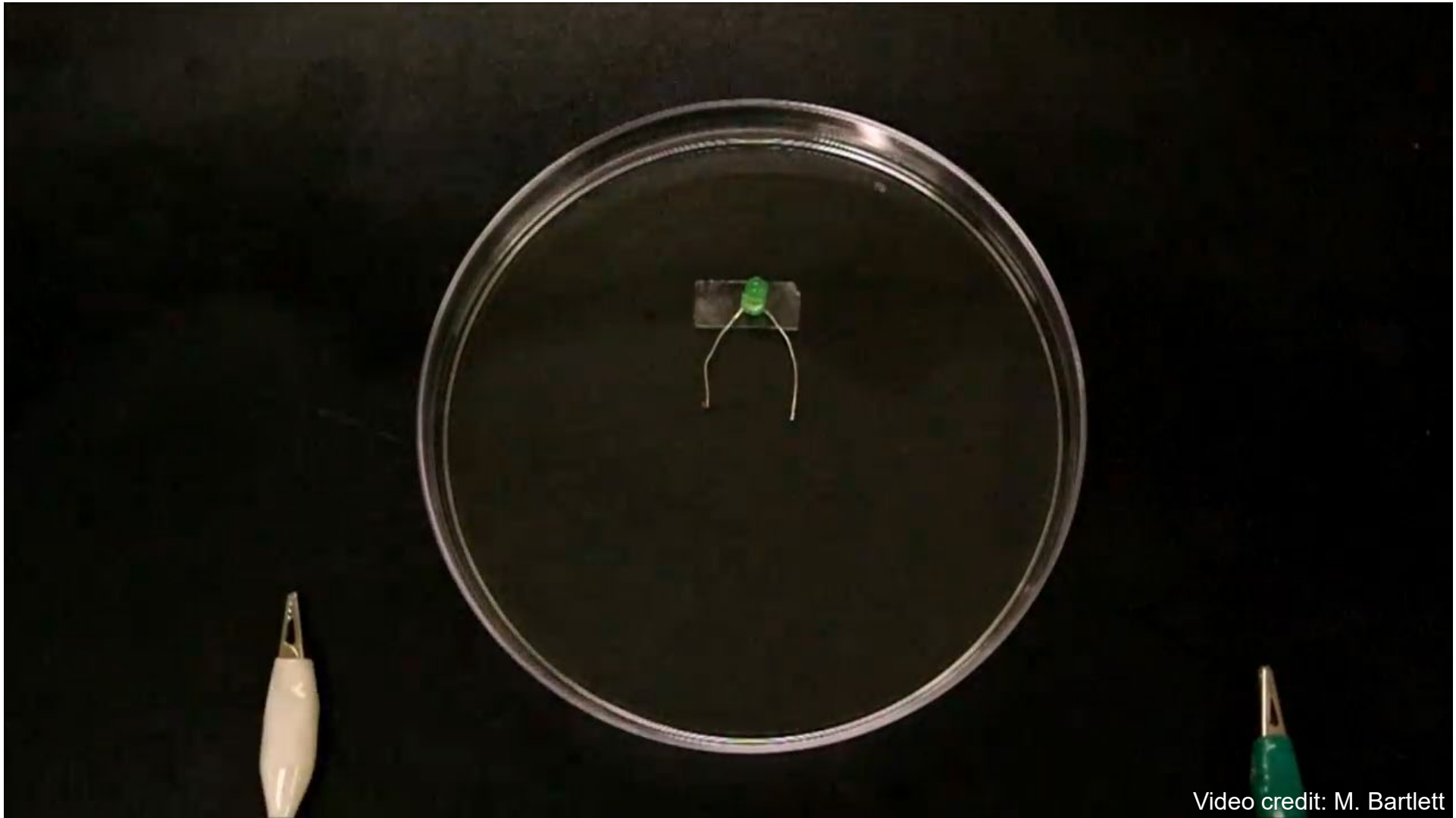
- Liquid metal with $T_{m,bulk} \approx 15^\circ\text{C}$ $T_{m,particles} \approx -85^\circ\text{C}$
- Low viscosity and negligible toxicity
- Forms 3-5 nm oxide skin in presence of oxygen, allowing the metal to be shaped and molded



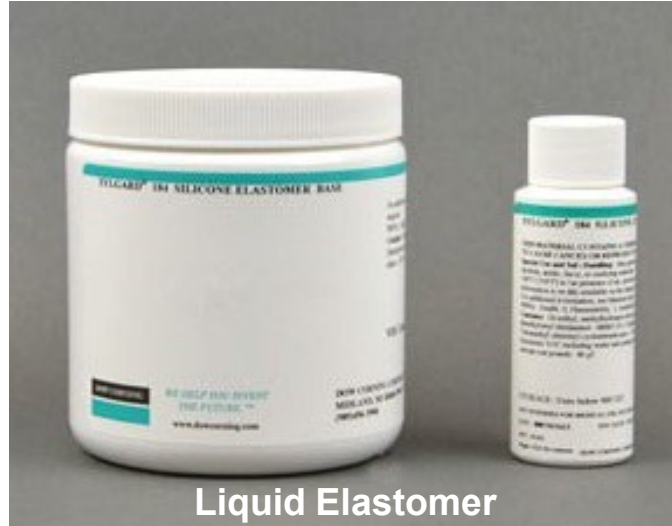
Ladd, C., et al. Adv. Mater. (2013)



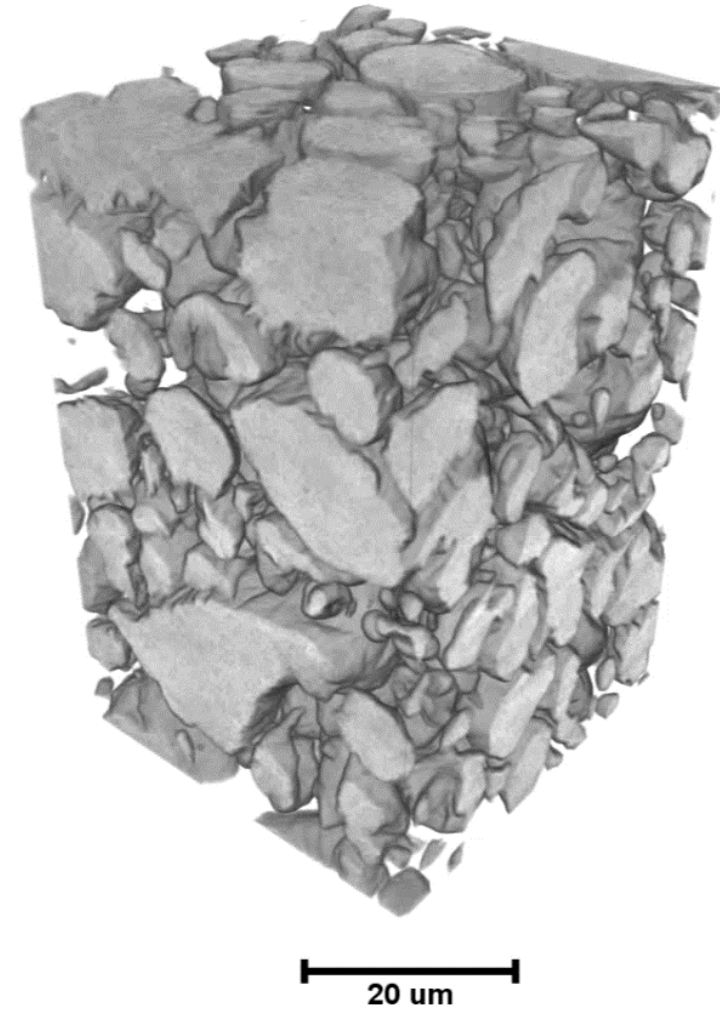
Video credit: M. Ford



Video credit: M. Bartlett

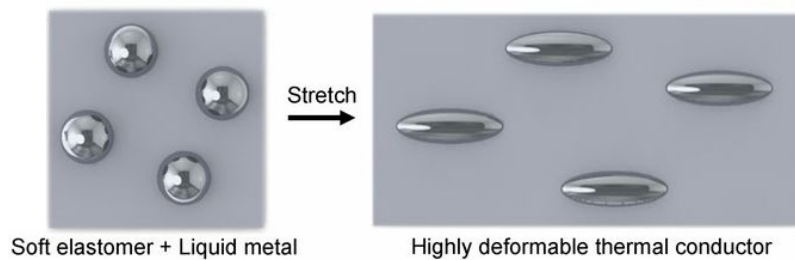
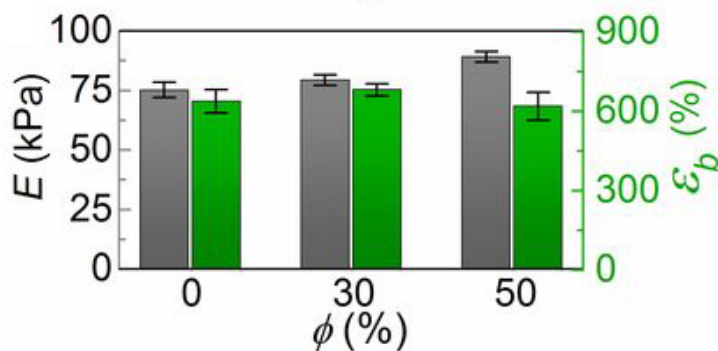
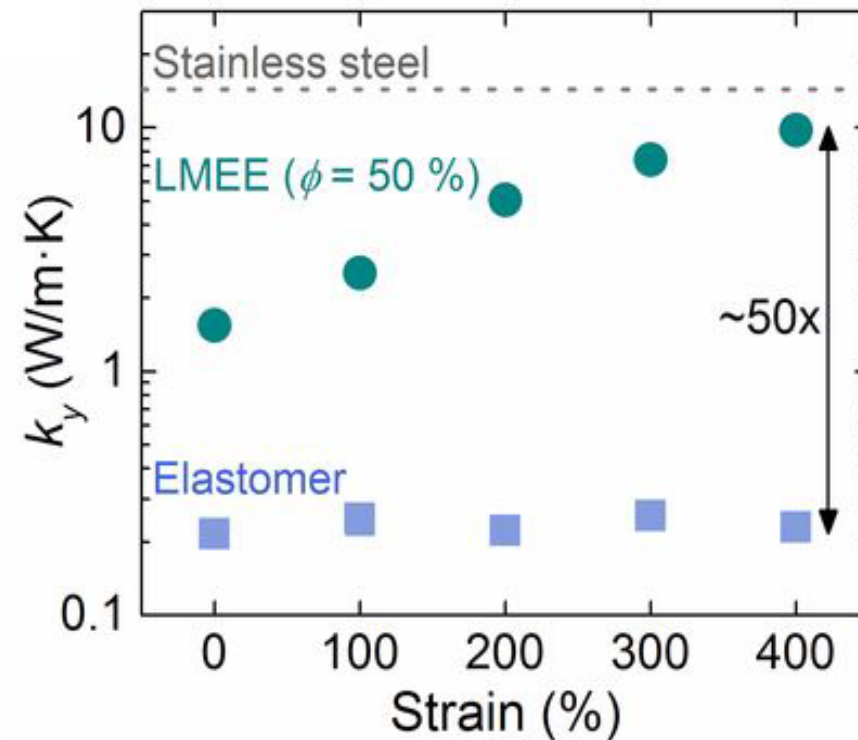
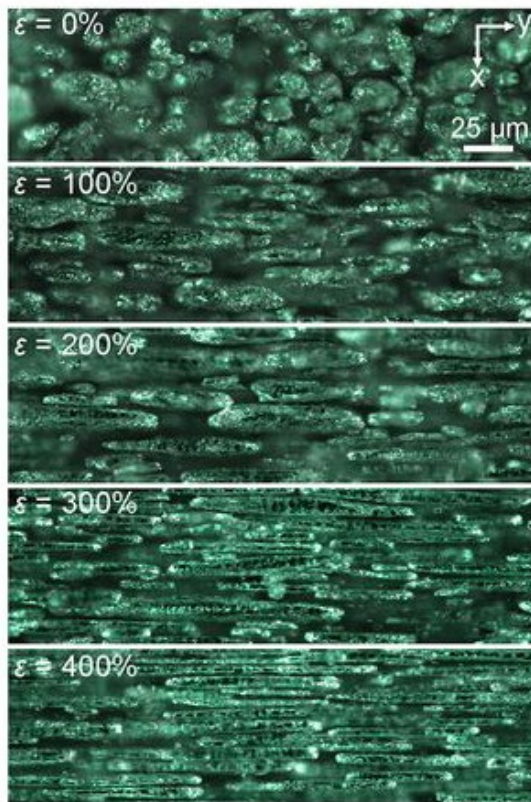
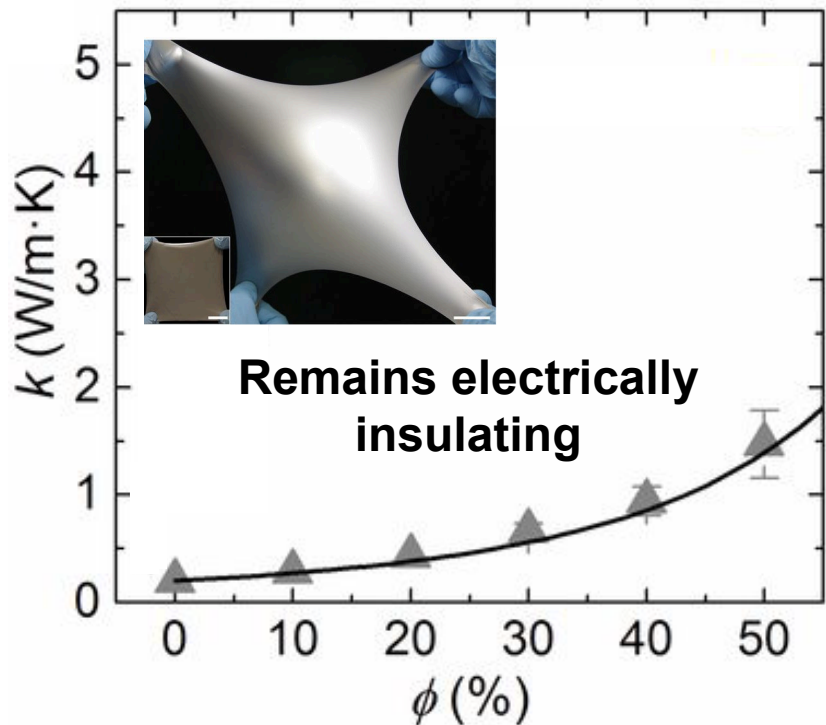


Nano-CT Scan



Centrifugal Mixing

Unique Combination of Properties- Thermal Conductivity



Lightweight Liquid Metal Elastomer Composites

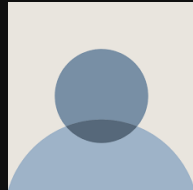
Soft, stretchable thermally conductive
elastomer composite



Ethan Krings



Haipeng Zhang



Suchit Sarin



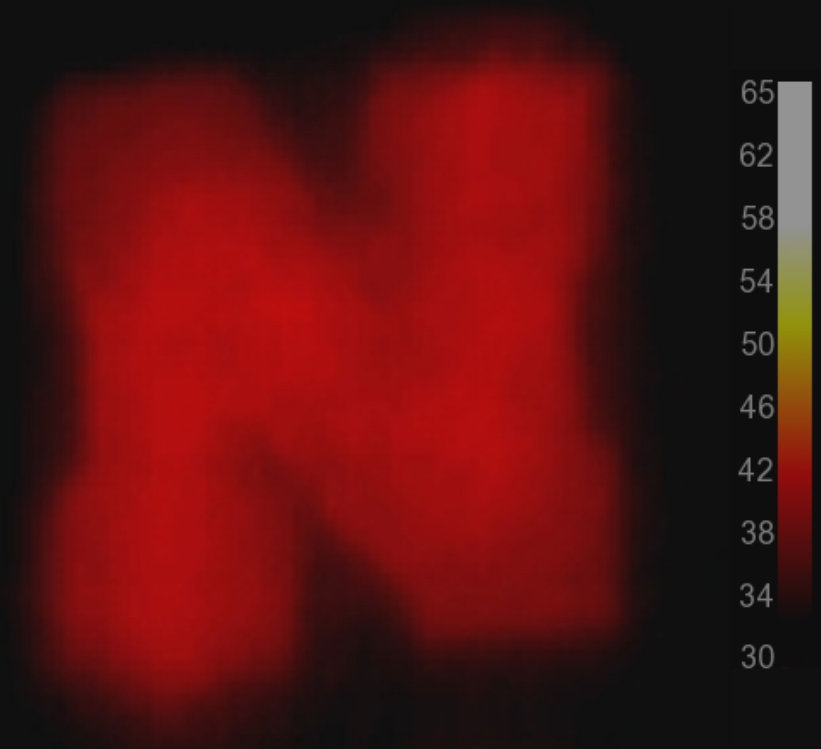
Jeffery Shield

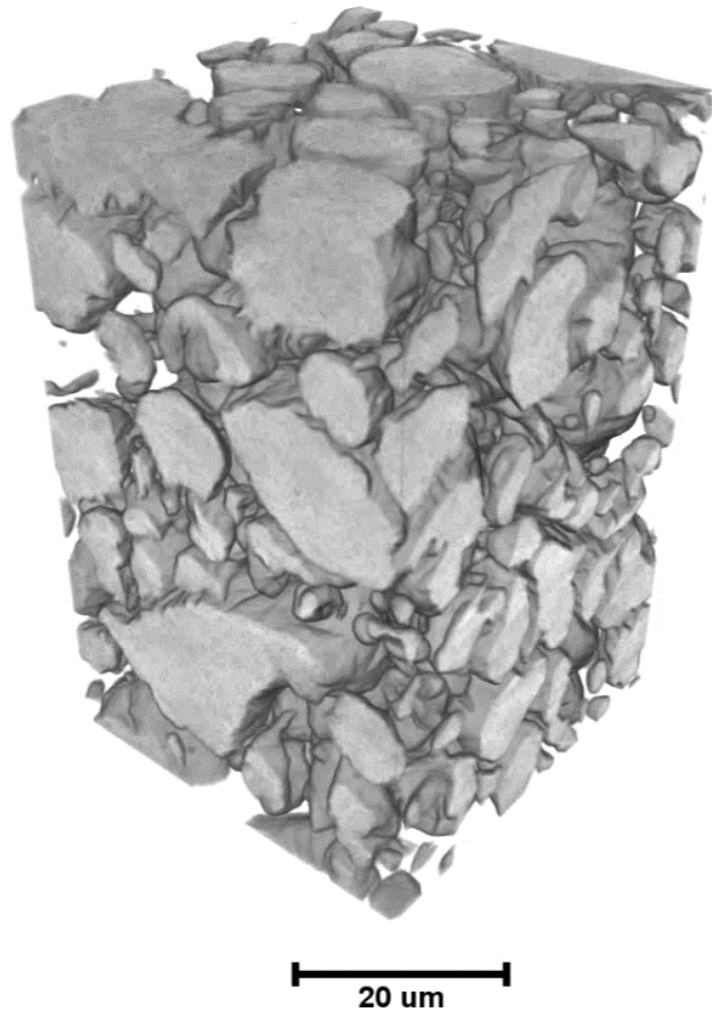


Sangjin Ryu



Eric Markvicka





Mixing ratio:

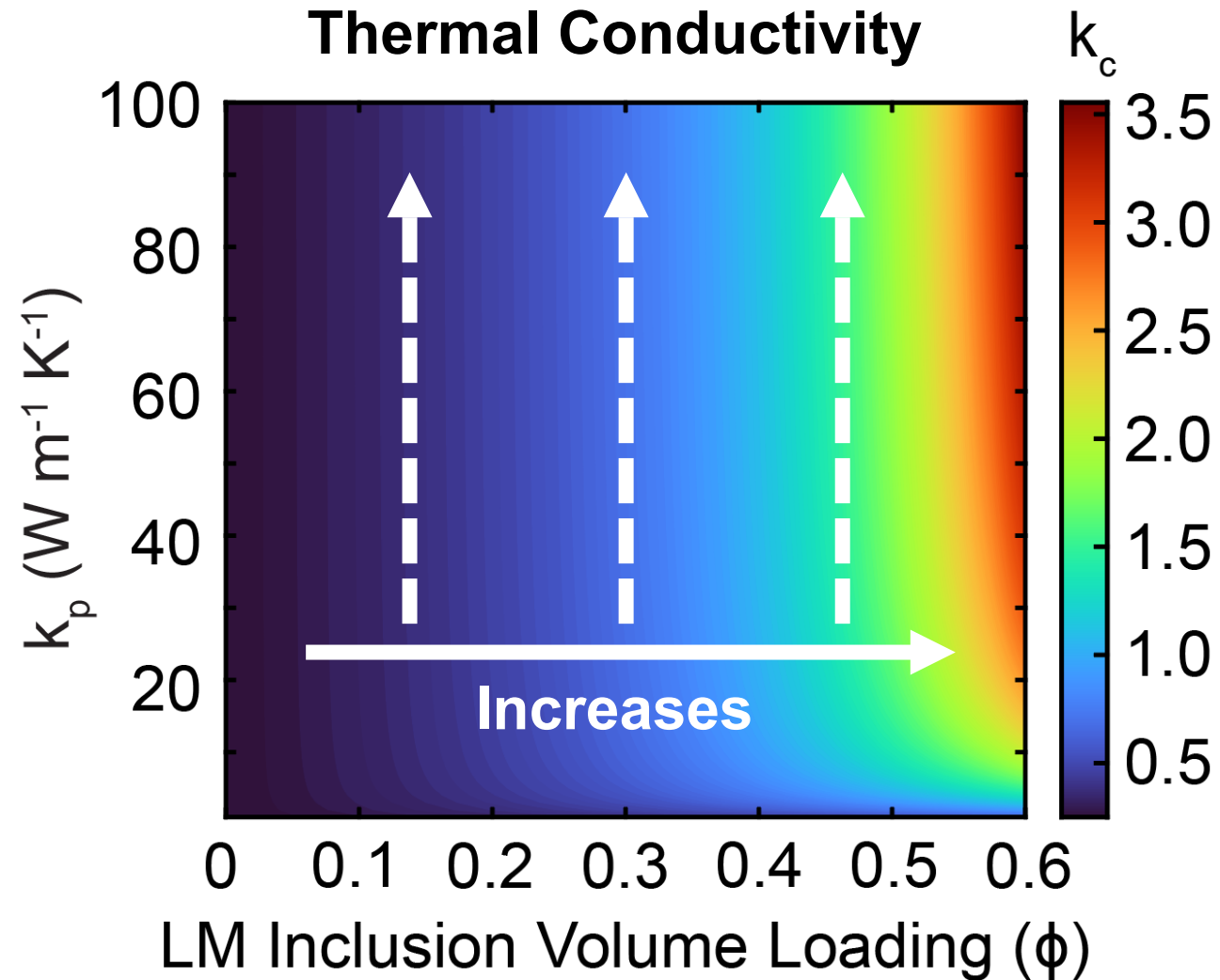
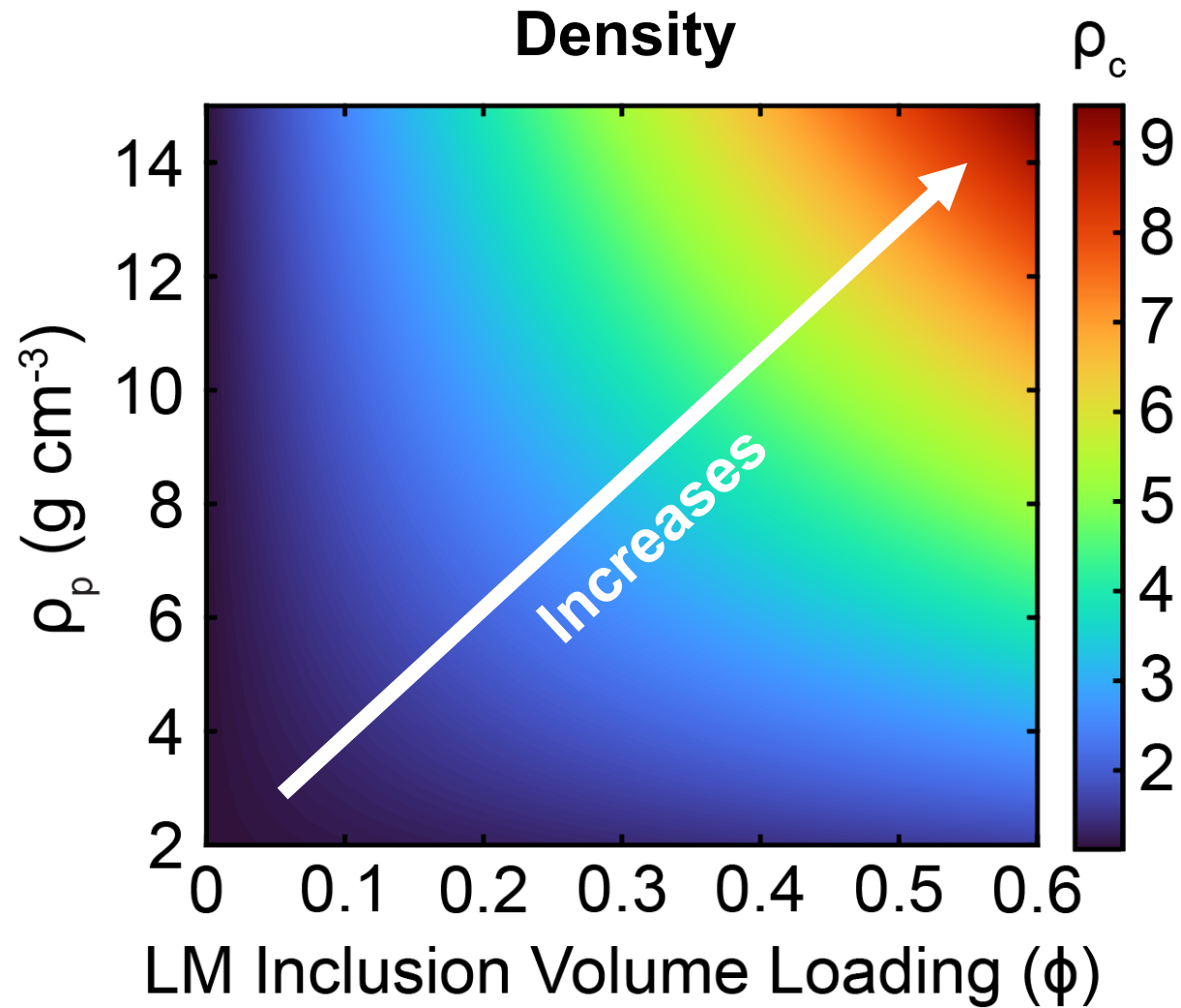
- >50 vol% or >85 wt% EGaIn

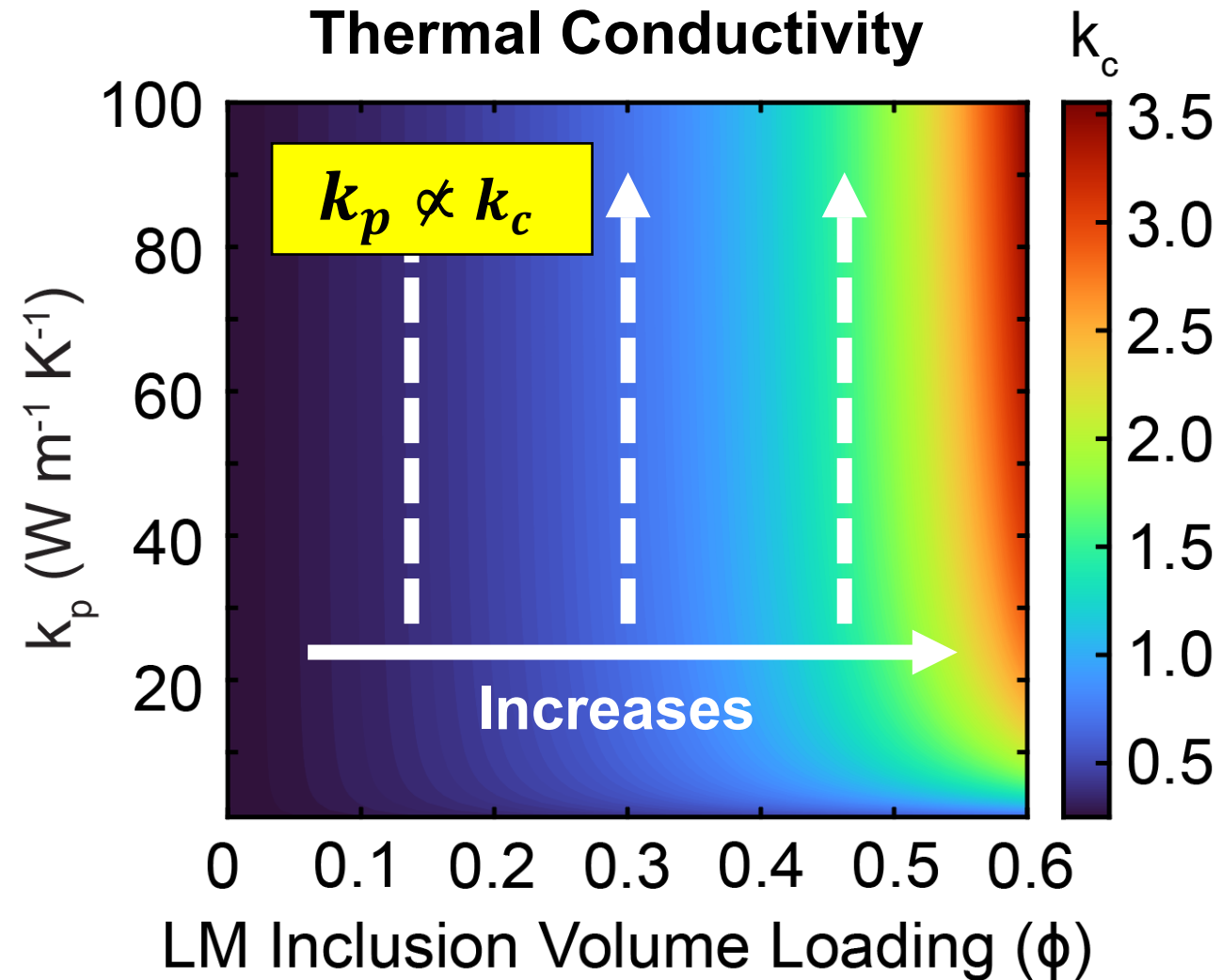
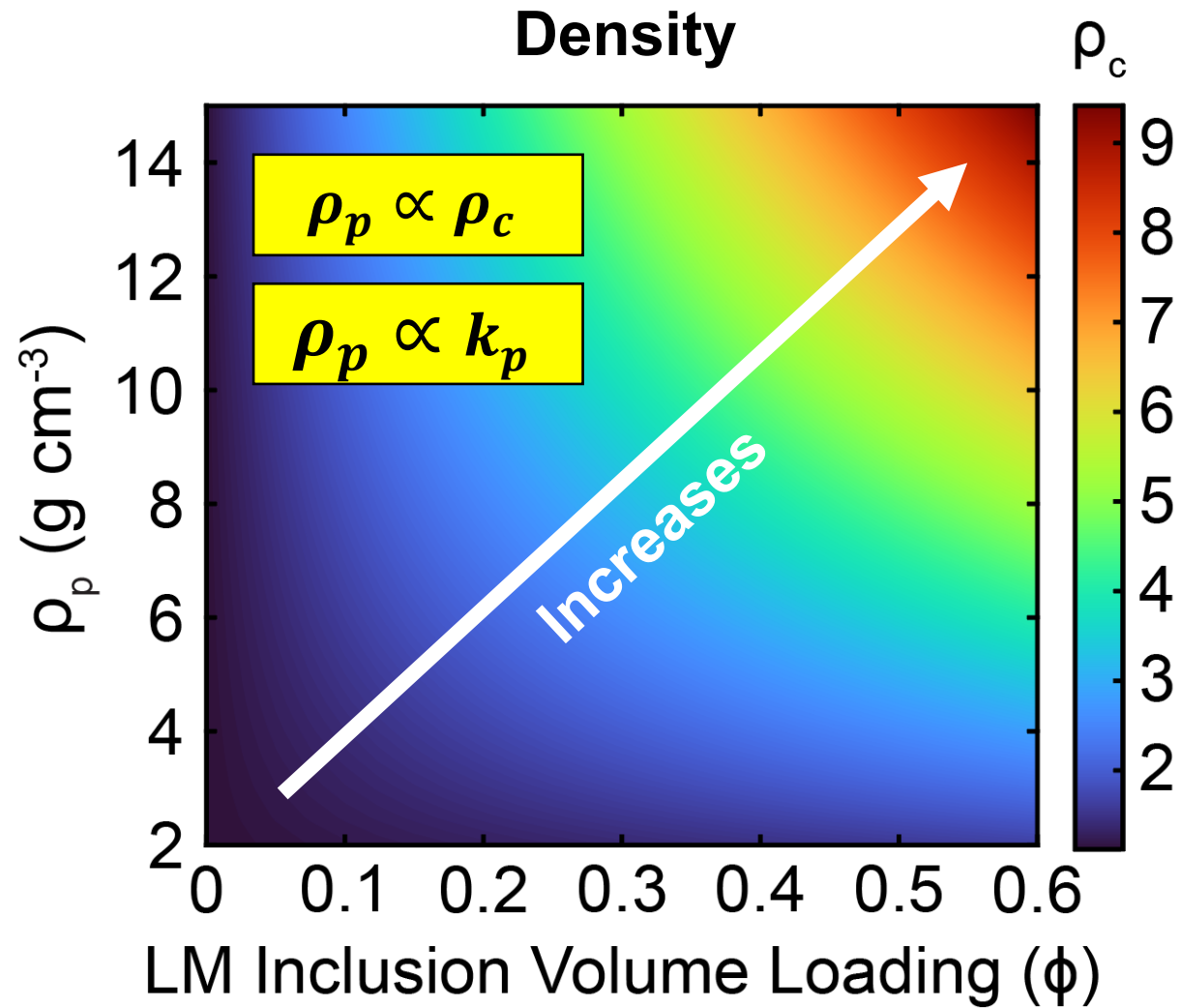
Density:

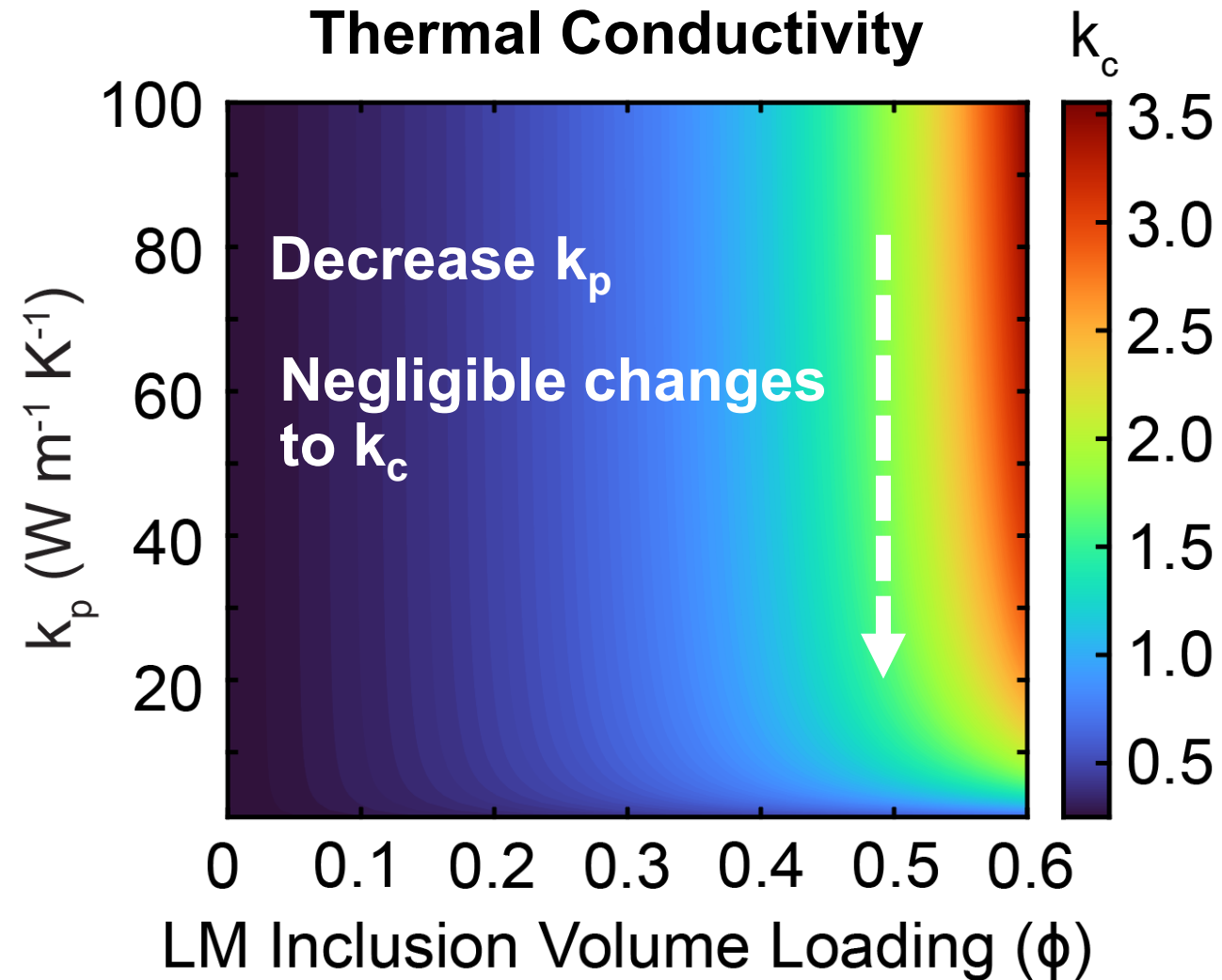
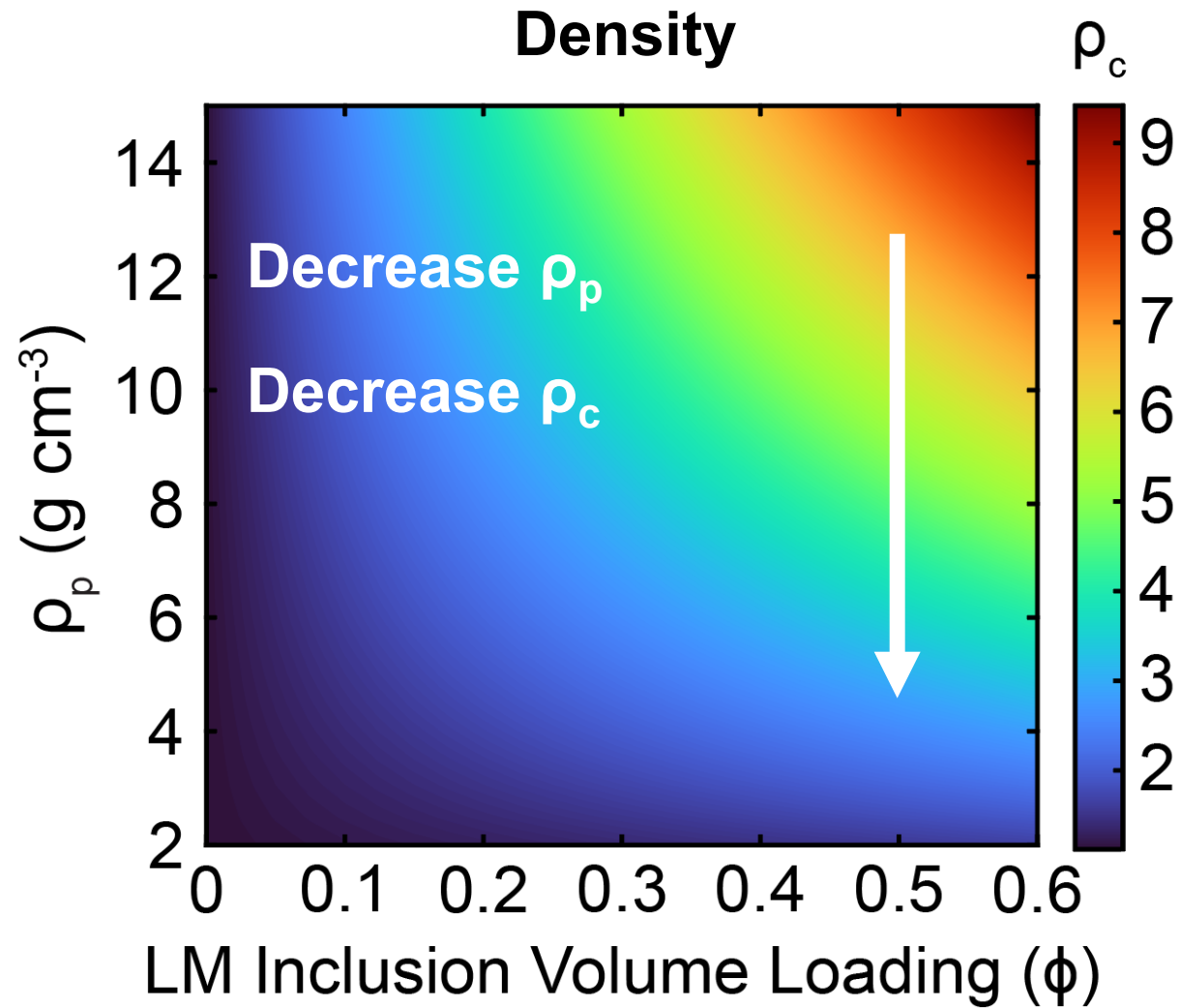
- Elastomer- 1.0 g/cm³
- Ga-based liquid metal- 6.3 g/cm³

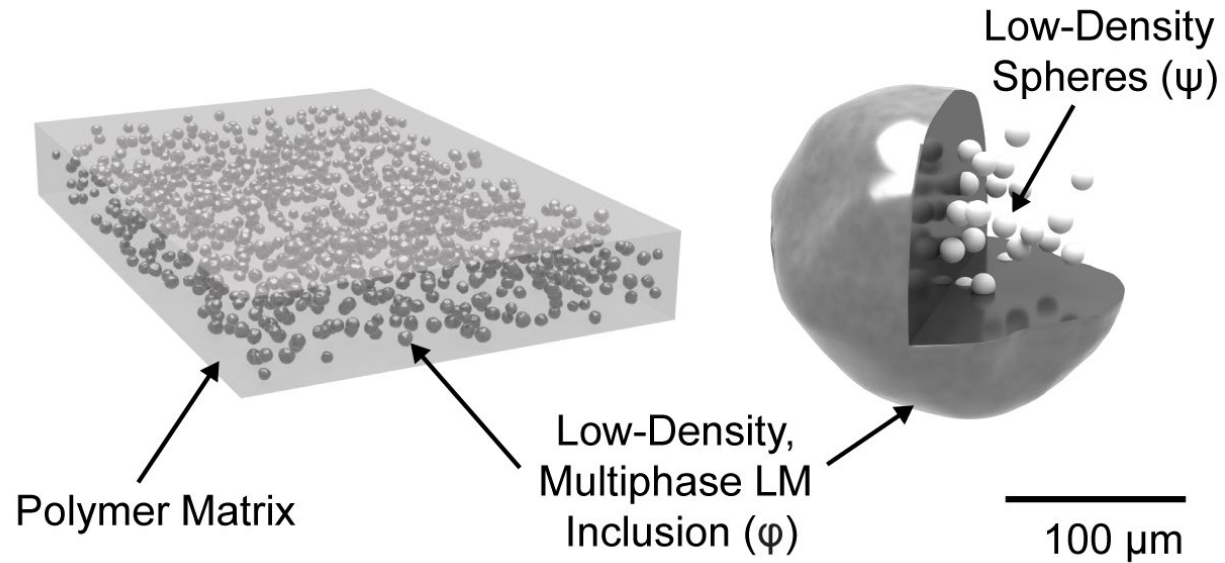
Problematic:

- Weight sensitive applications
- Large area electronics or thermal management

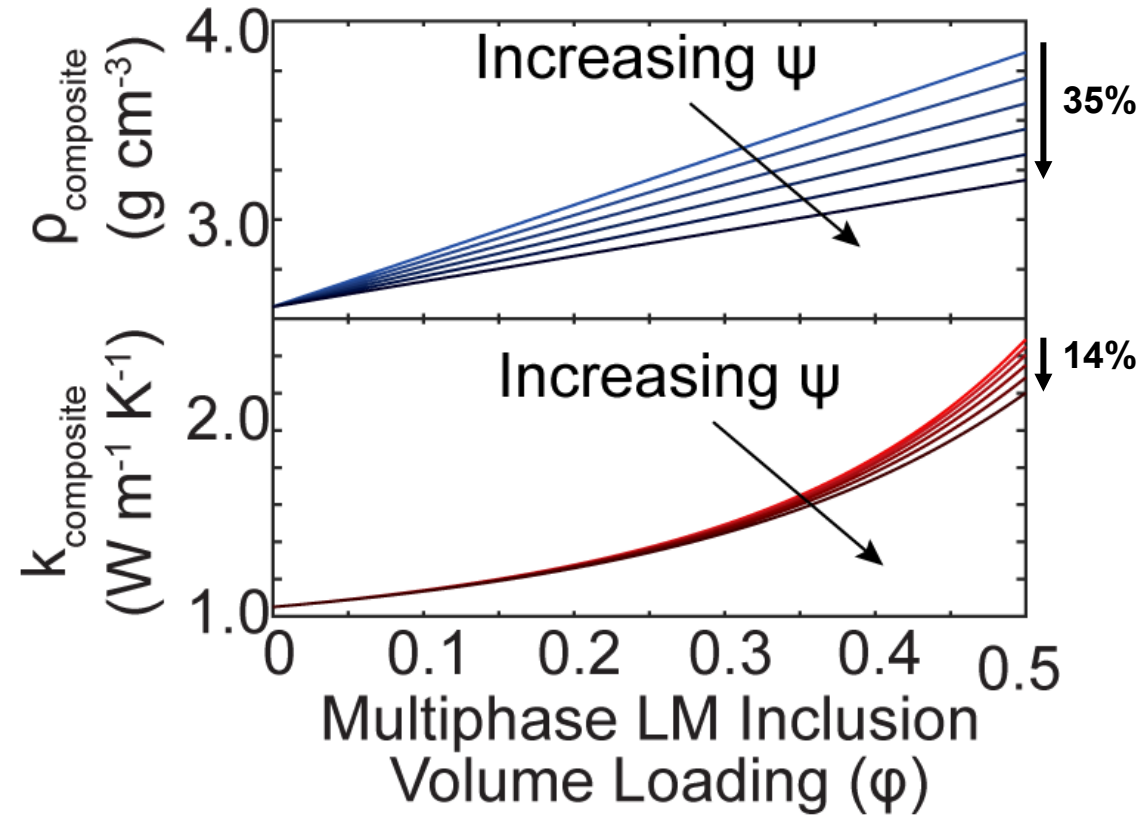




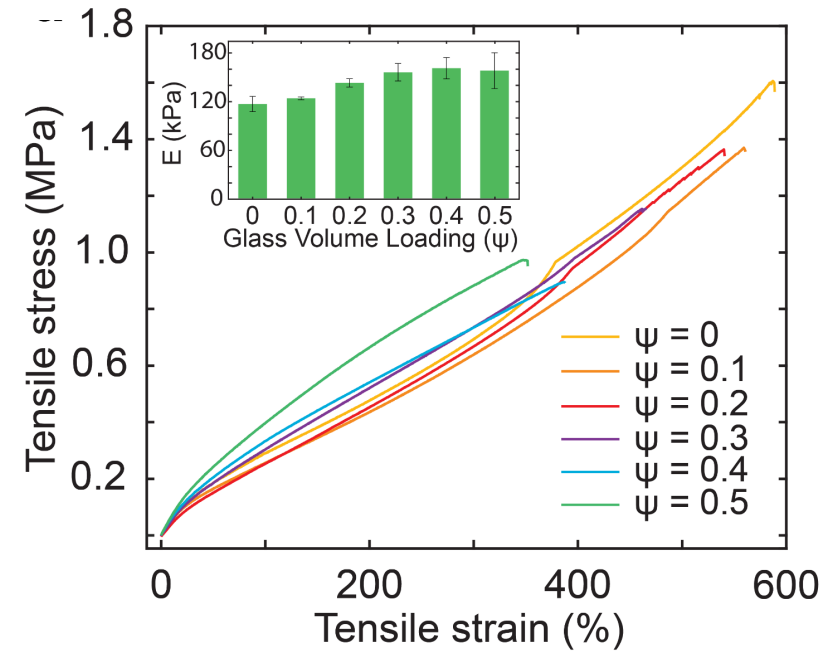
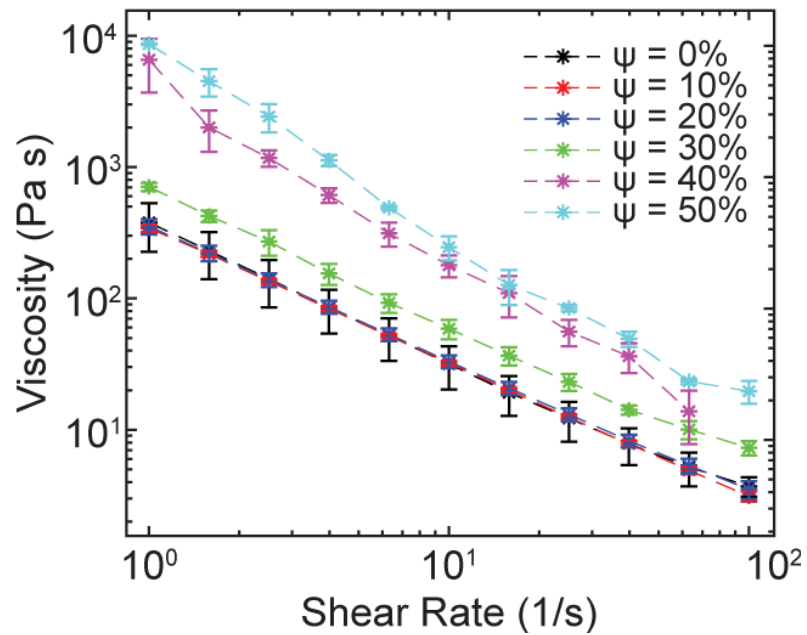
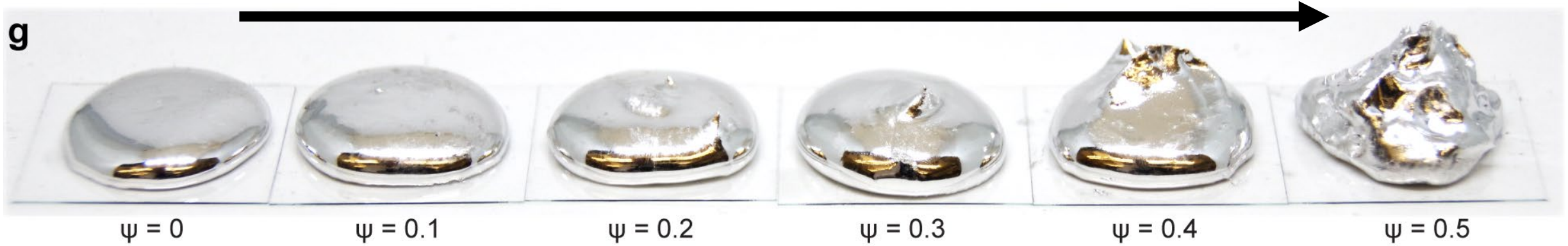


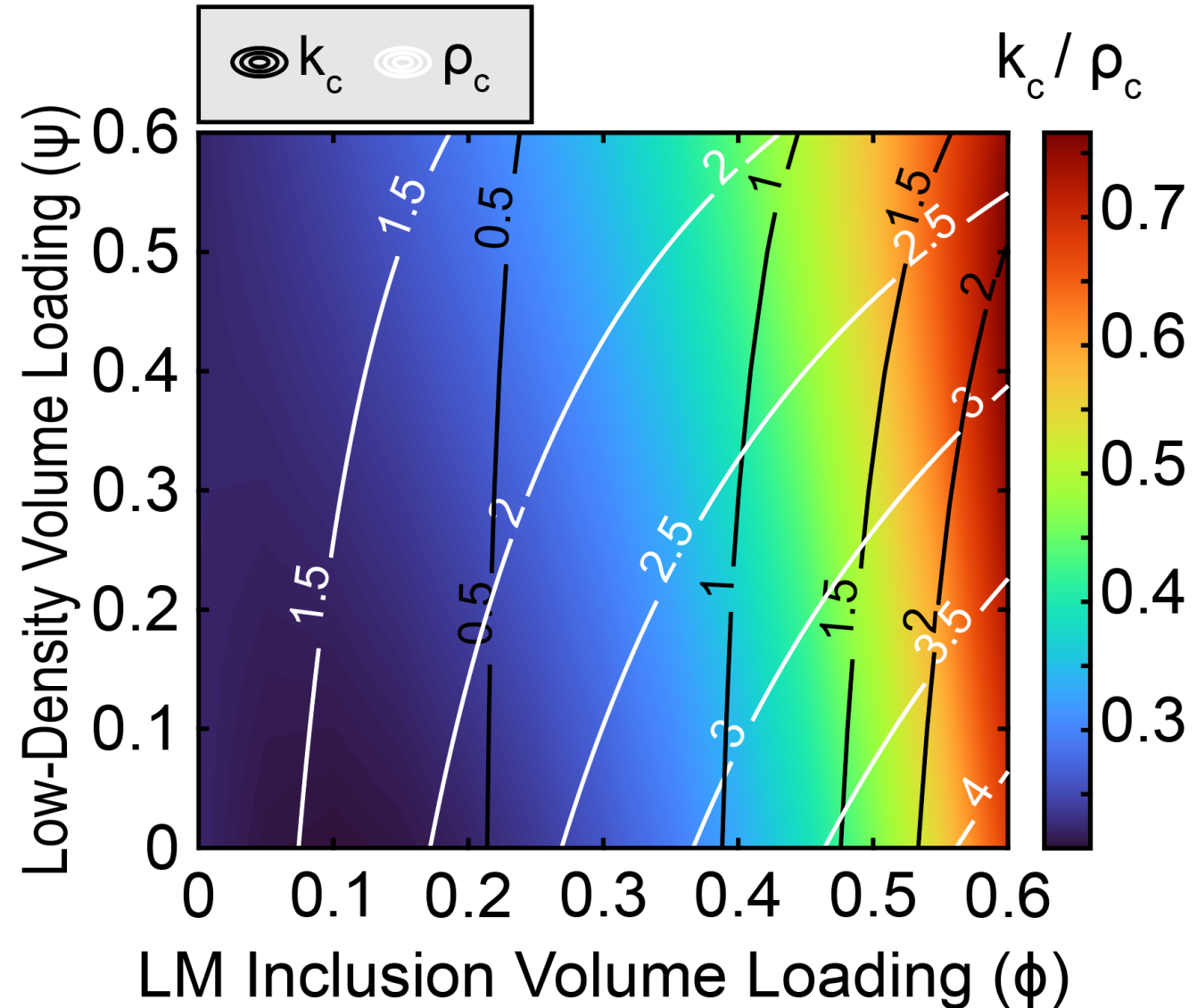
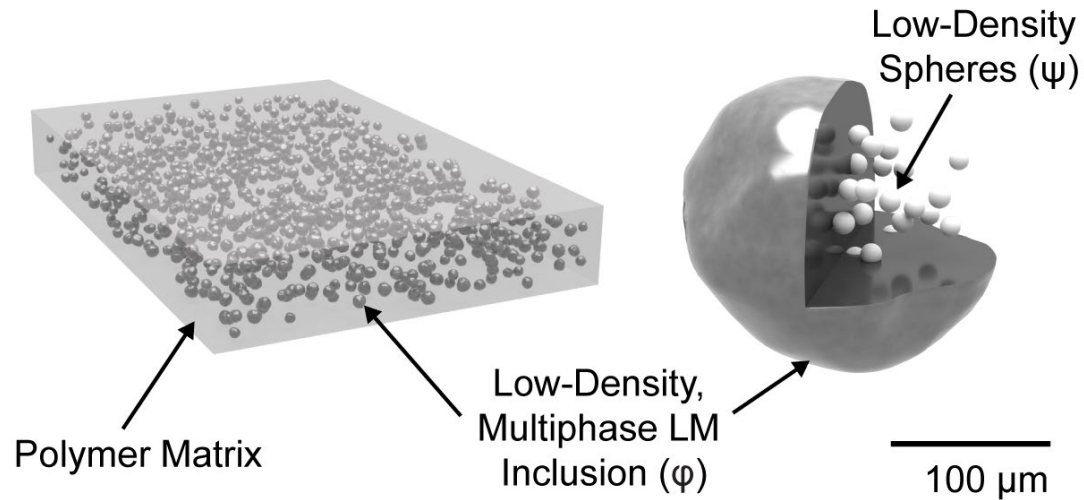


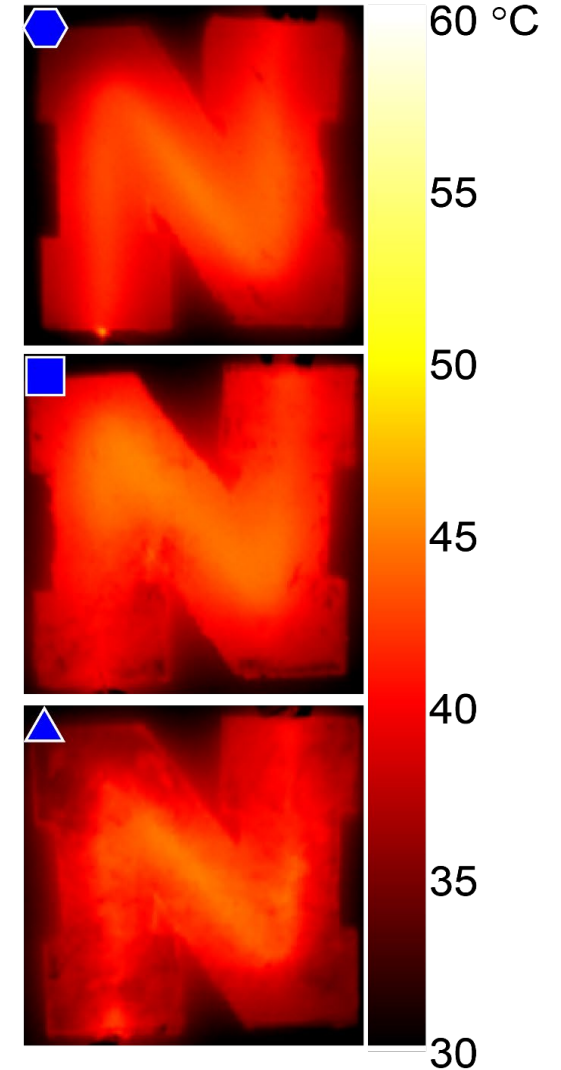
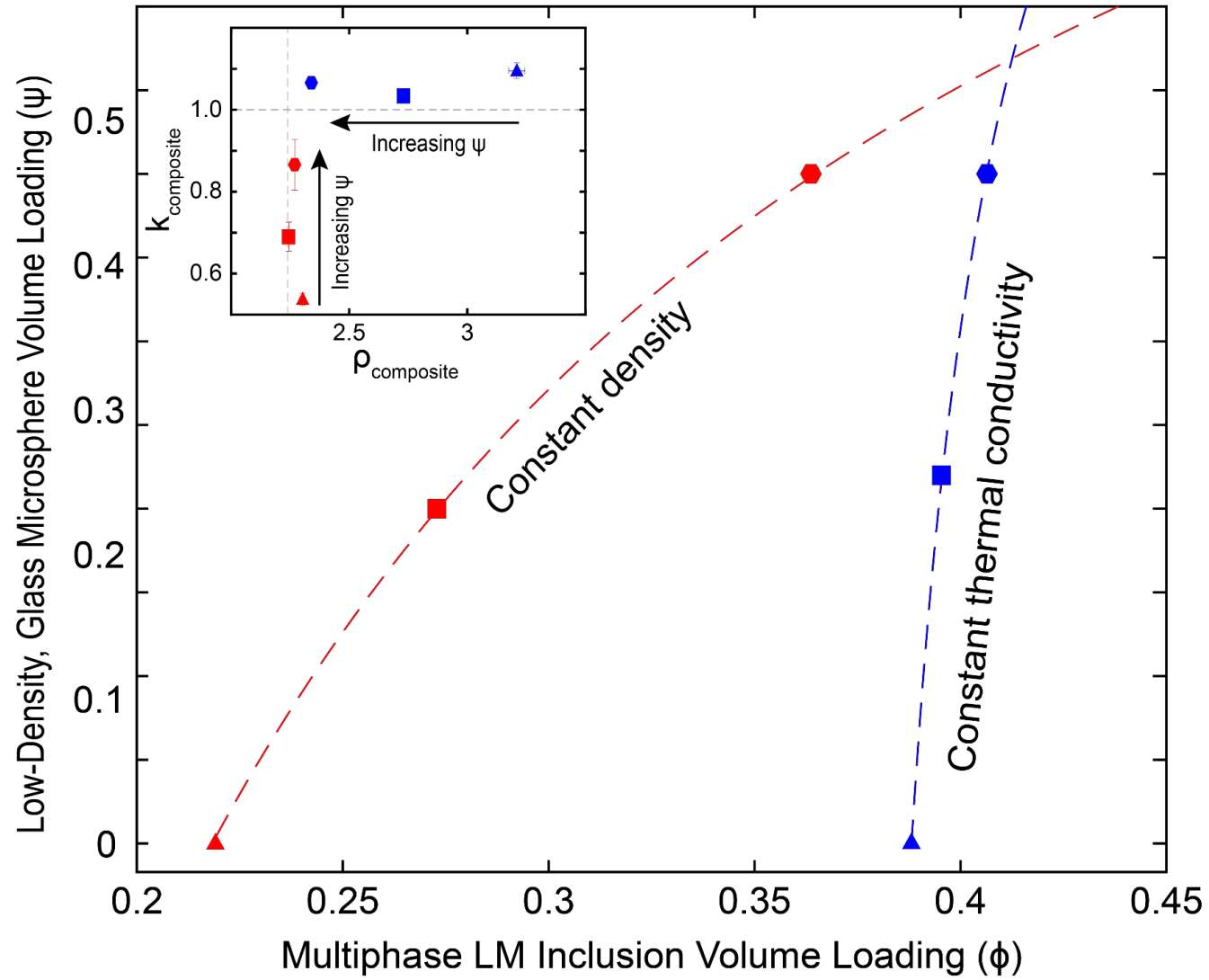
Independently tune density or thermal conductivity (functional properties)



Increased loading of hollow glass spheres







Lightweight Liquid Metal Elastomer Composites

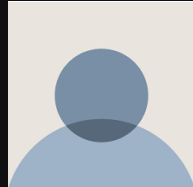
Acknowledgements:



Ethan Krings



Haipeng Zhang



Suchit Sarin



Jeffery Shield

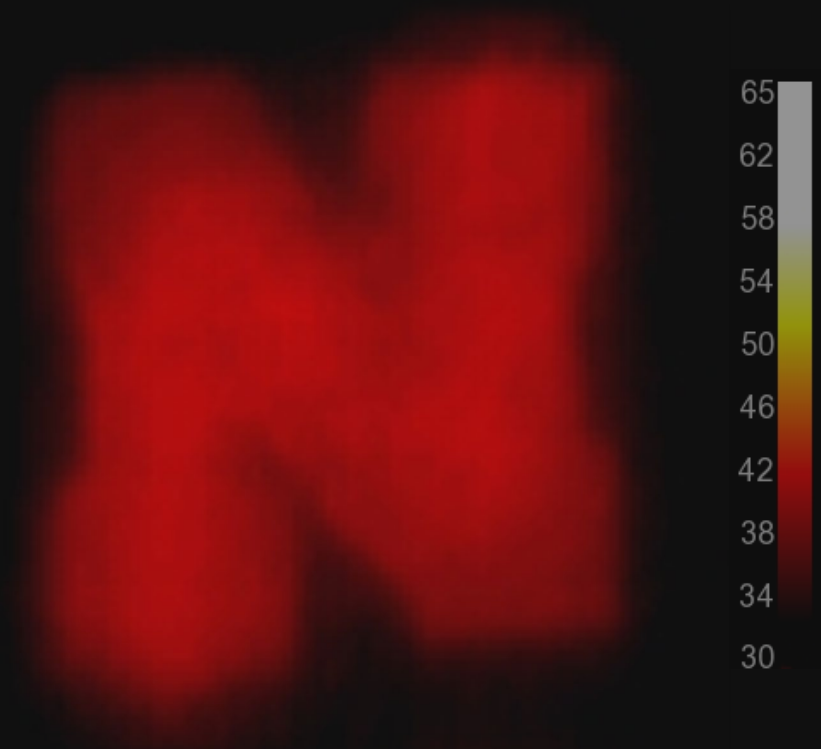


Sangjin Ryu



Eric Markvicka

Funding Support: NASA NE Space Grant, Nebraska Tobacco Settlement Biomedical Research Development



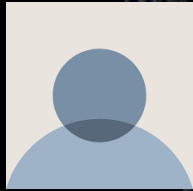
Additive manufacturing for spatial control of liquid metal microstructure



Aaron Haake*



Ravi Tutika*



Gwyn Schloer

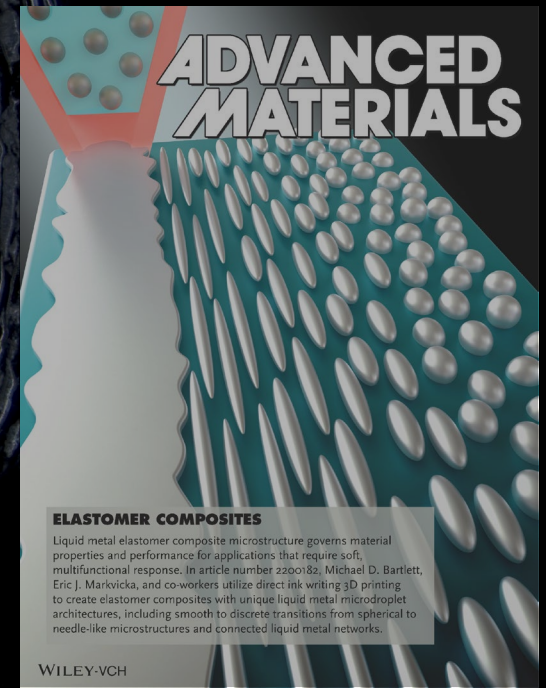


Mike Bartlett



Eric Markvicka

(*Contributed equally)

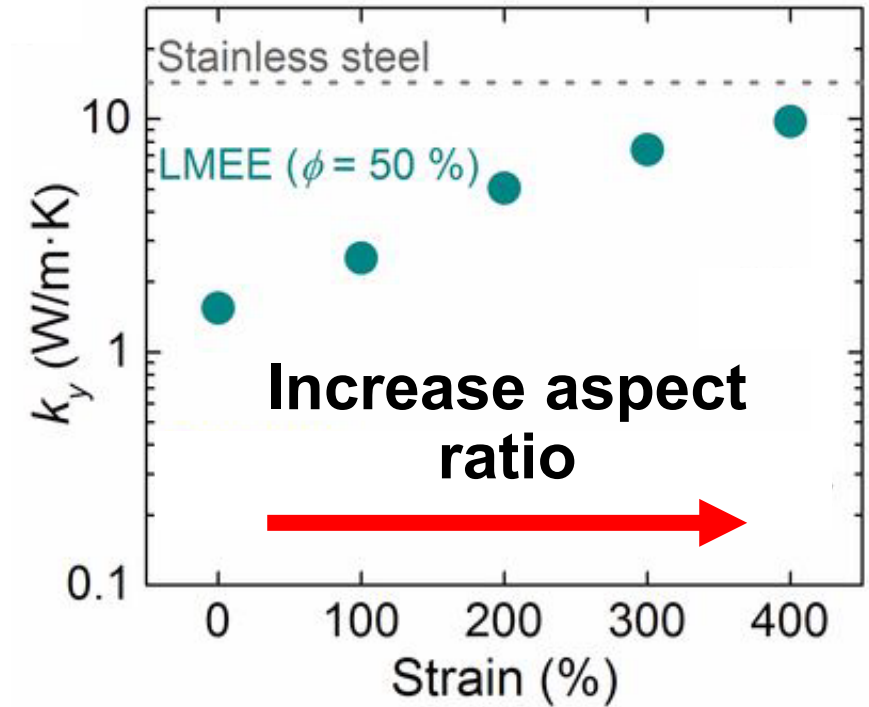
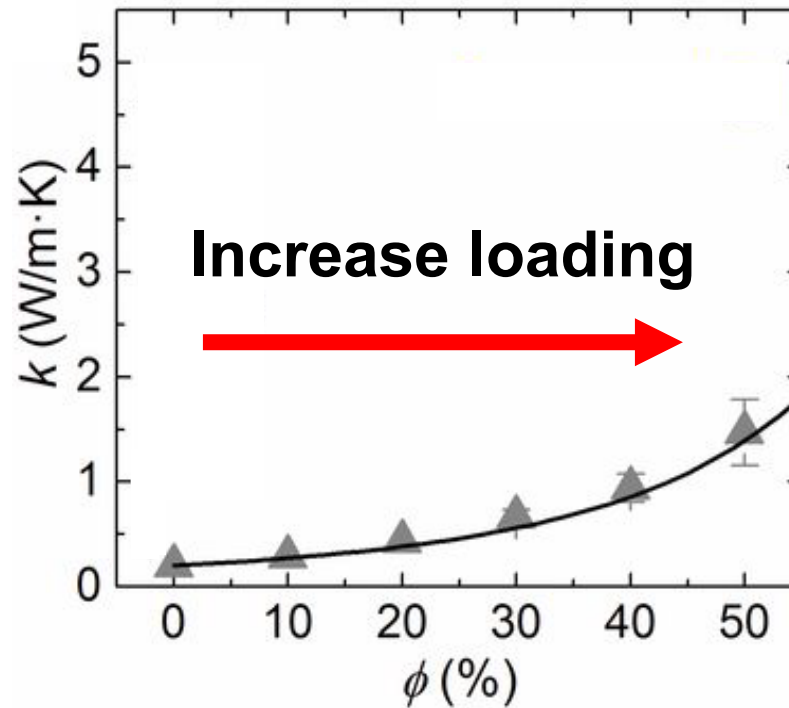


ELASTOMER COMPOSITES

Liquid metal elastomer composite microstructure governs material properties and performance for applications that require soft, multifunctional response. In article number 2200182, Michael D. Bartlett, Eric J. Markvicka, and co-workers utilize direct ink writing 3D printing to create elastomer composites with unique liquid metal microdroplet architectures, including smooth to discrete transitions from spherical to needle-like microstructures and connected liquid metal networks.

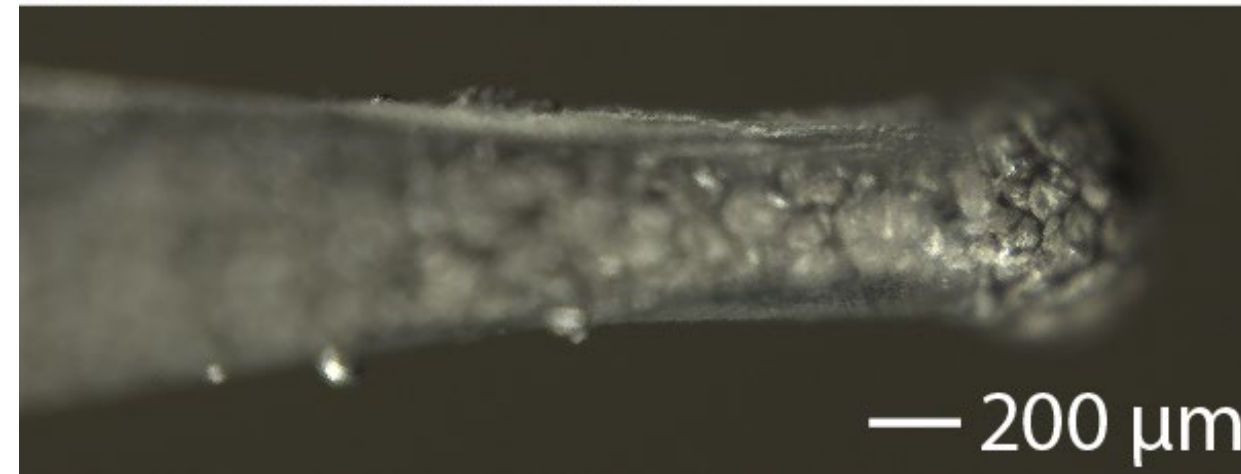
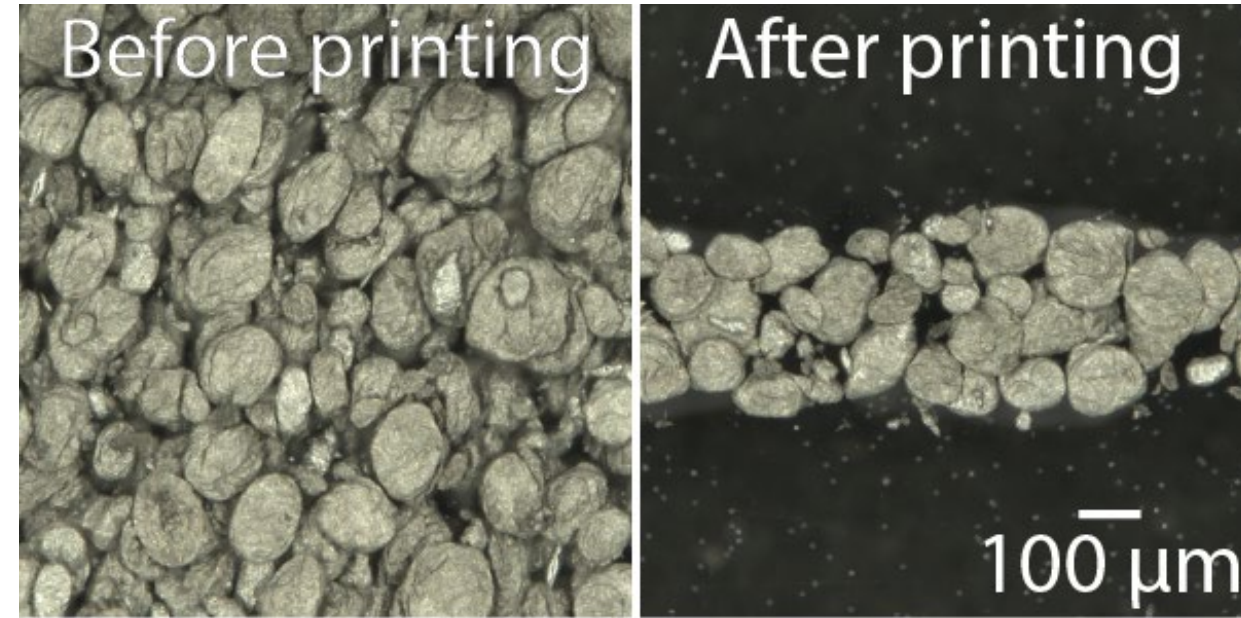
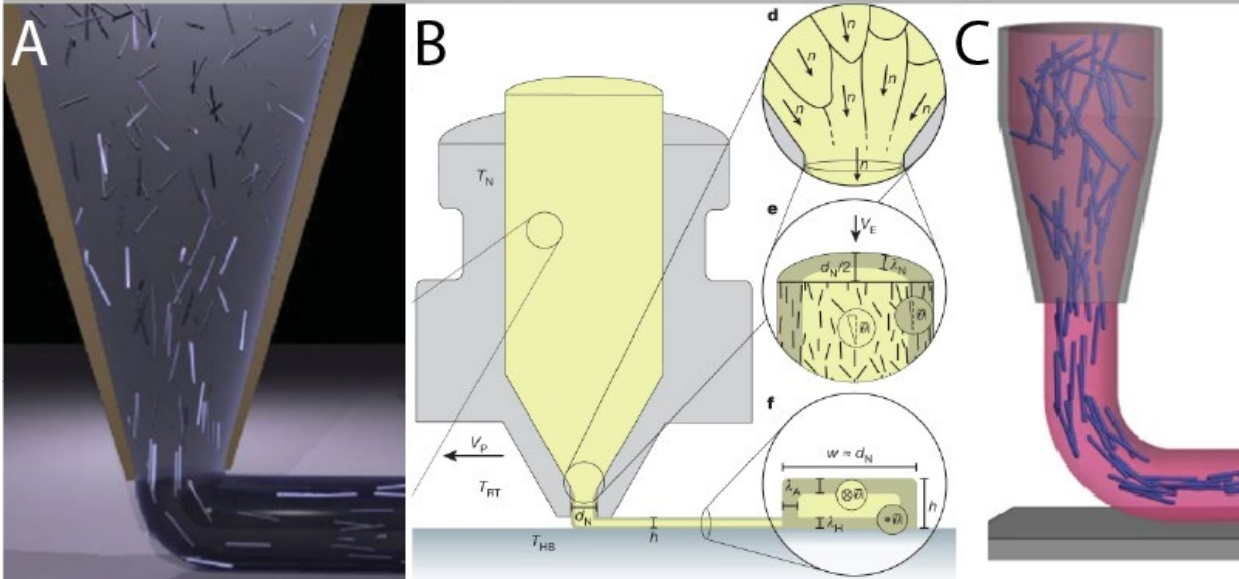
WILEY-VCH

Eric Markvicka, PhD | Smart Materials and Robotics Laboratory | University of Nebraska-Lincoln



Controlling droplet microstructure would enable highly tunable functional response and enhanced material properties

Alignment caused by shear forces during extrusion



Compton, B. G. *et al.*, *Adv. Mater.* (2014)
Gantenbein, S. *et al.*, *Nature* (2018)
Gladman, A. S. *et al.*, *Nat. Mater.* (2016)

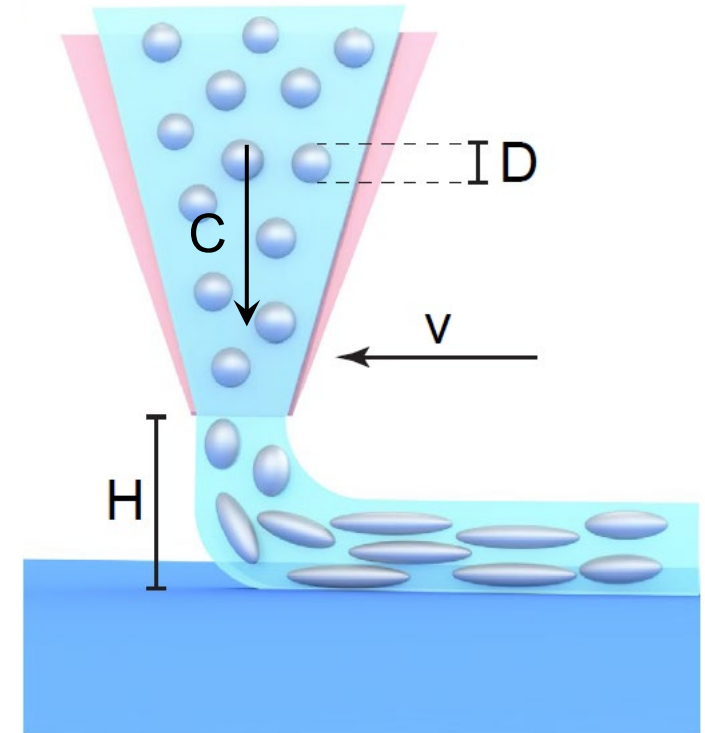
Solid-liquid emulsions offer new opportunities to not only control the orientation but also the shape of the liquid inclusions during direct ink writing

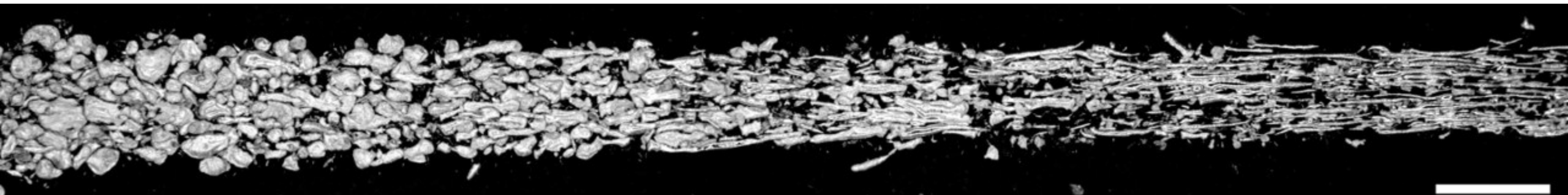
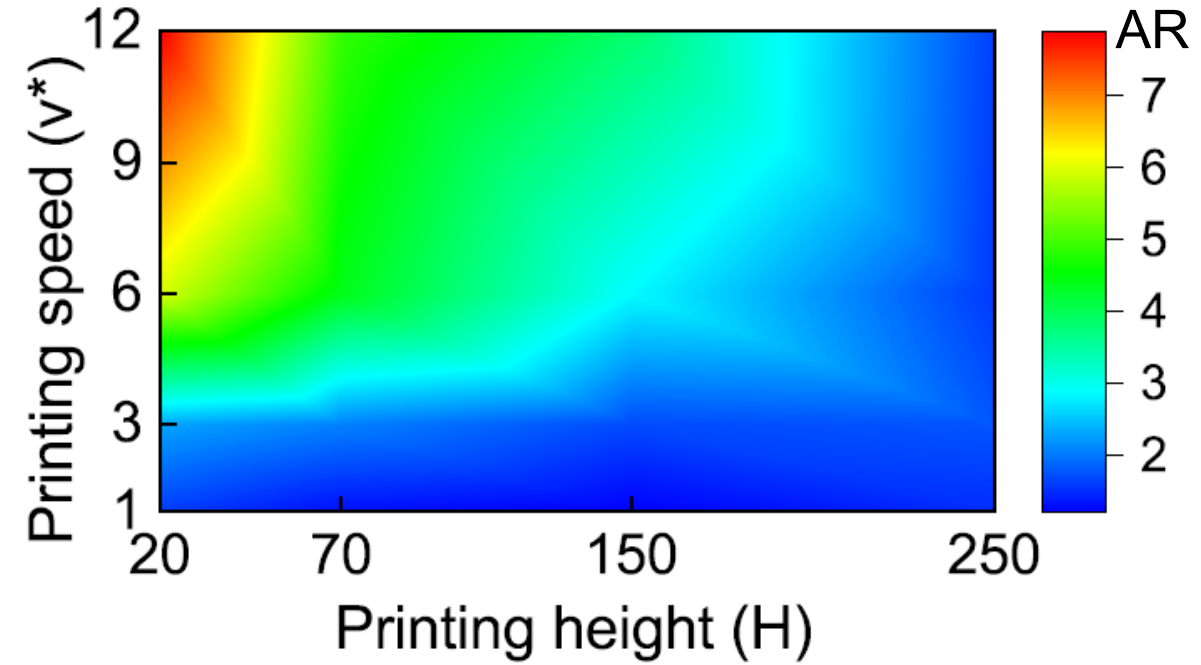
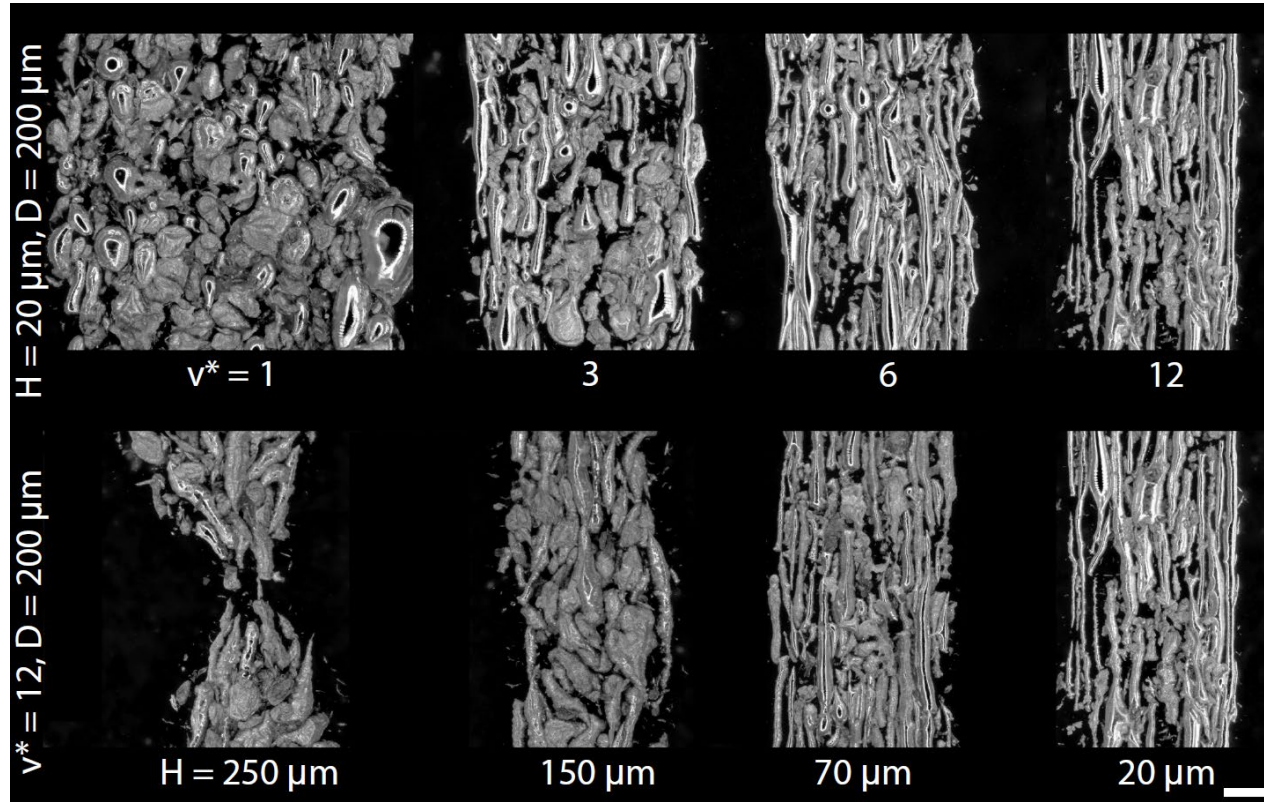
Parameter Sweep:

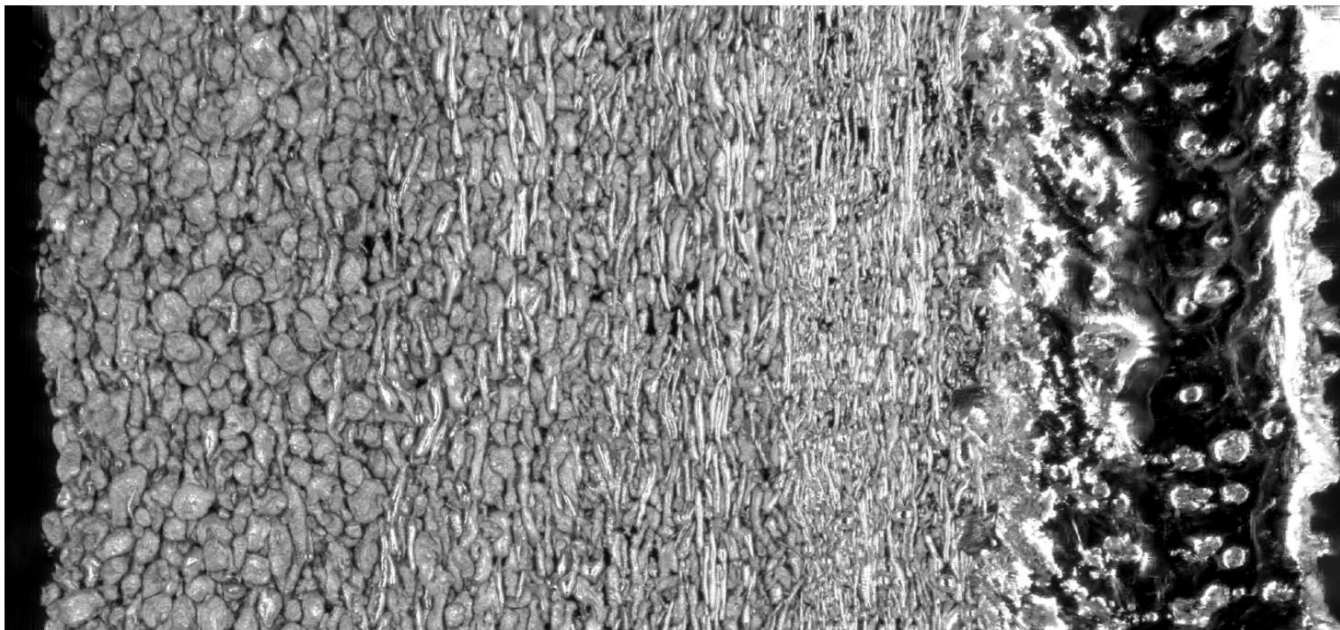
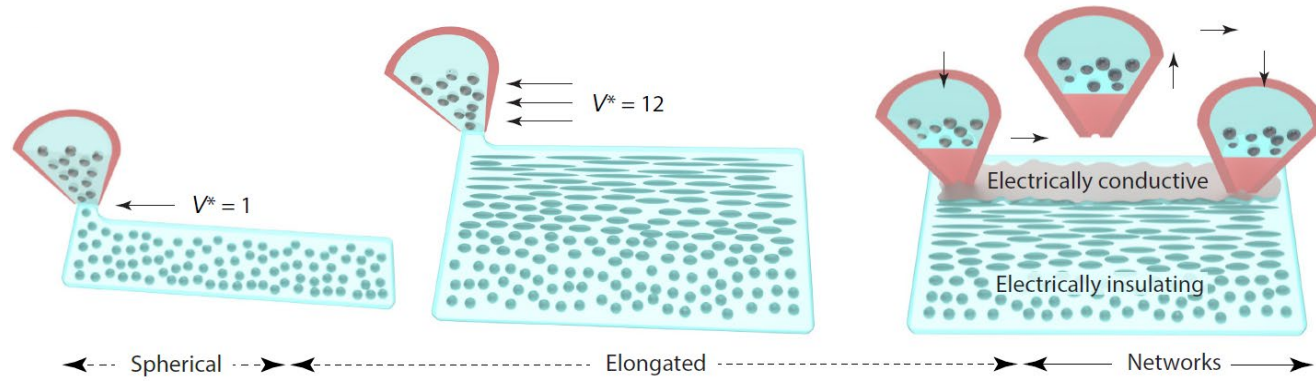
- Nondimensionalized print head velocity

$$V^* \equiv v/c = \frac{\text{print head speed}}{\text{extrusion speed}}$$

- Nozzle height H



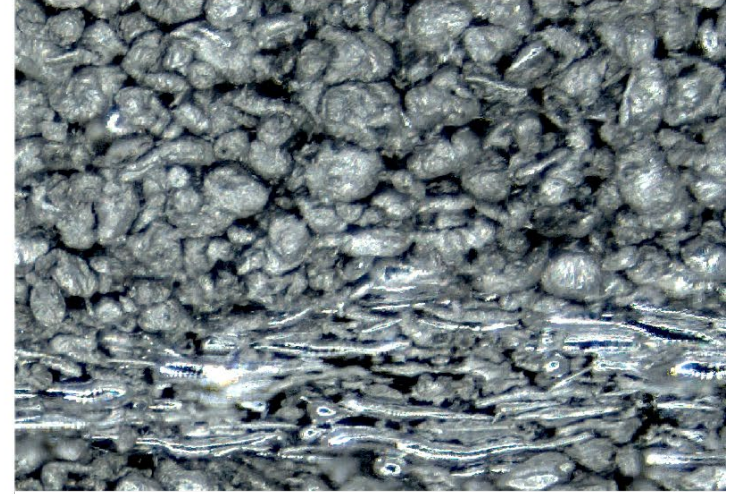
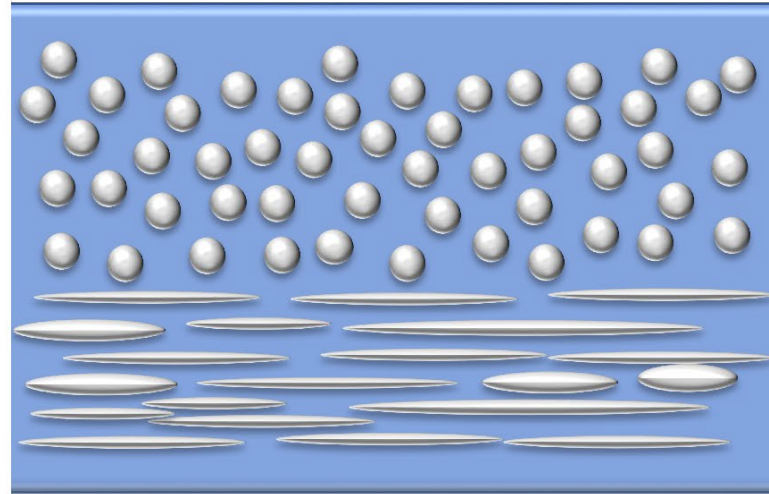
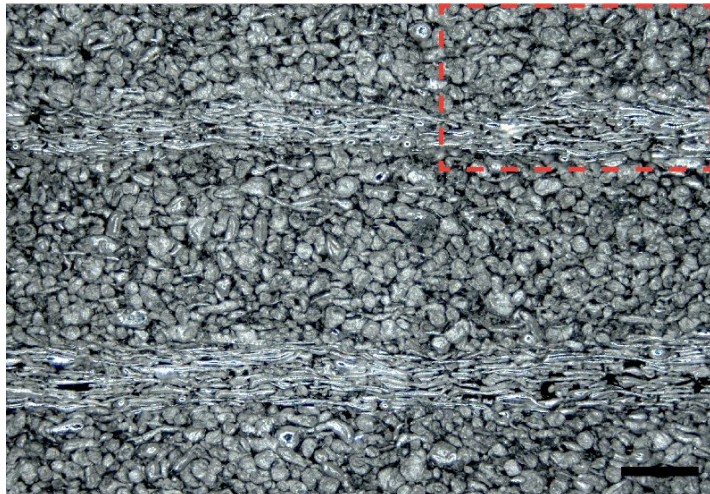
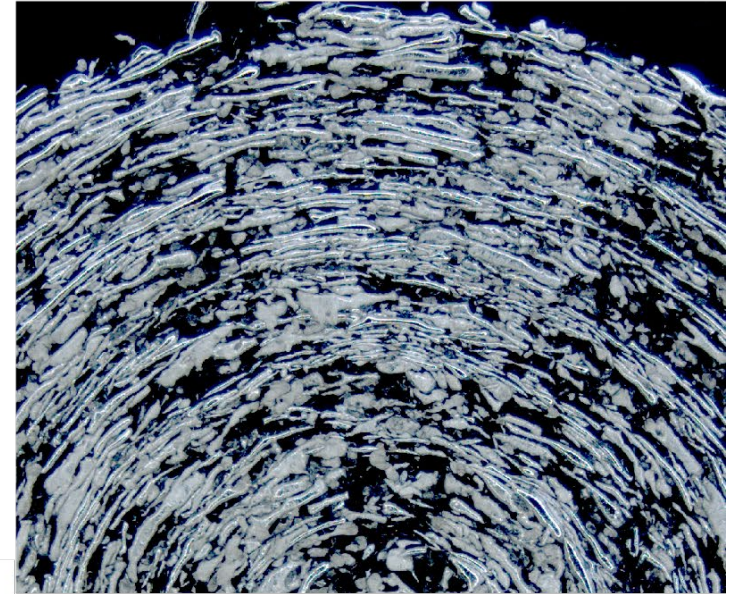
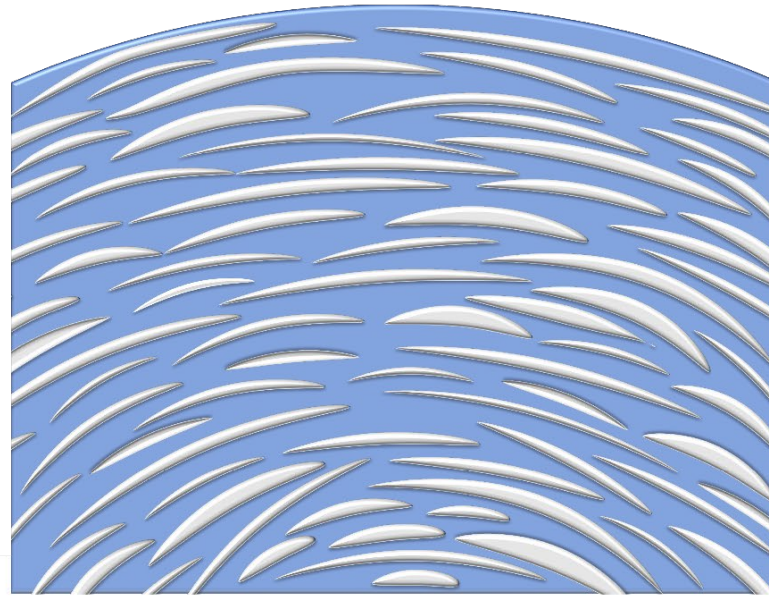
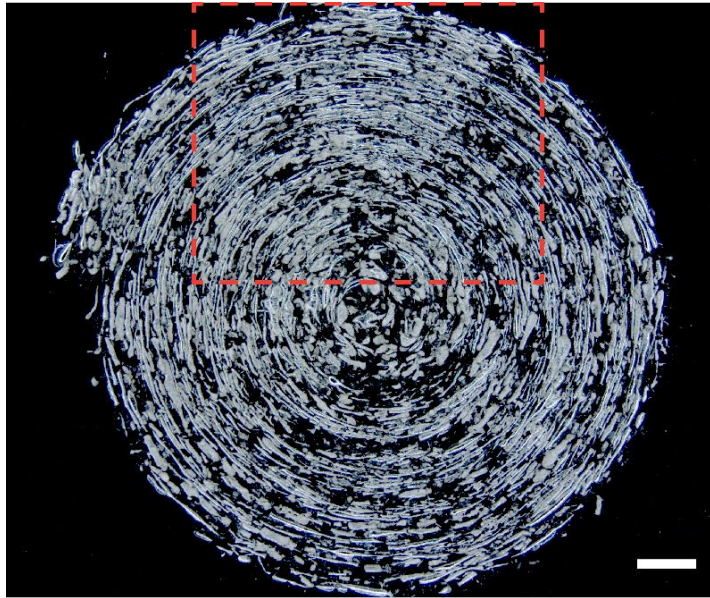


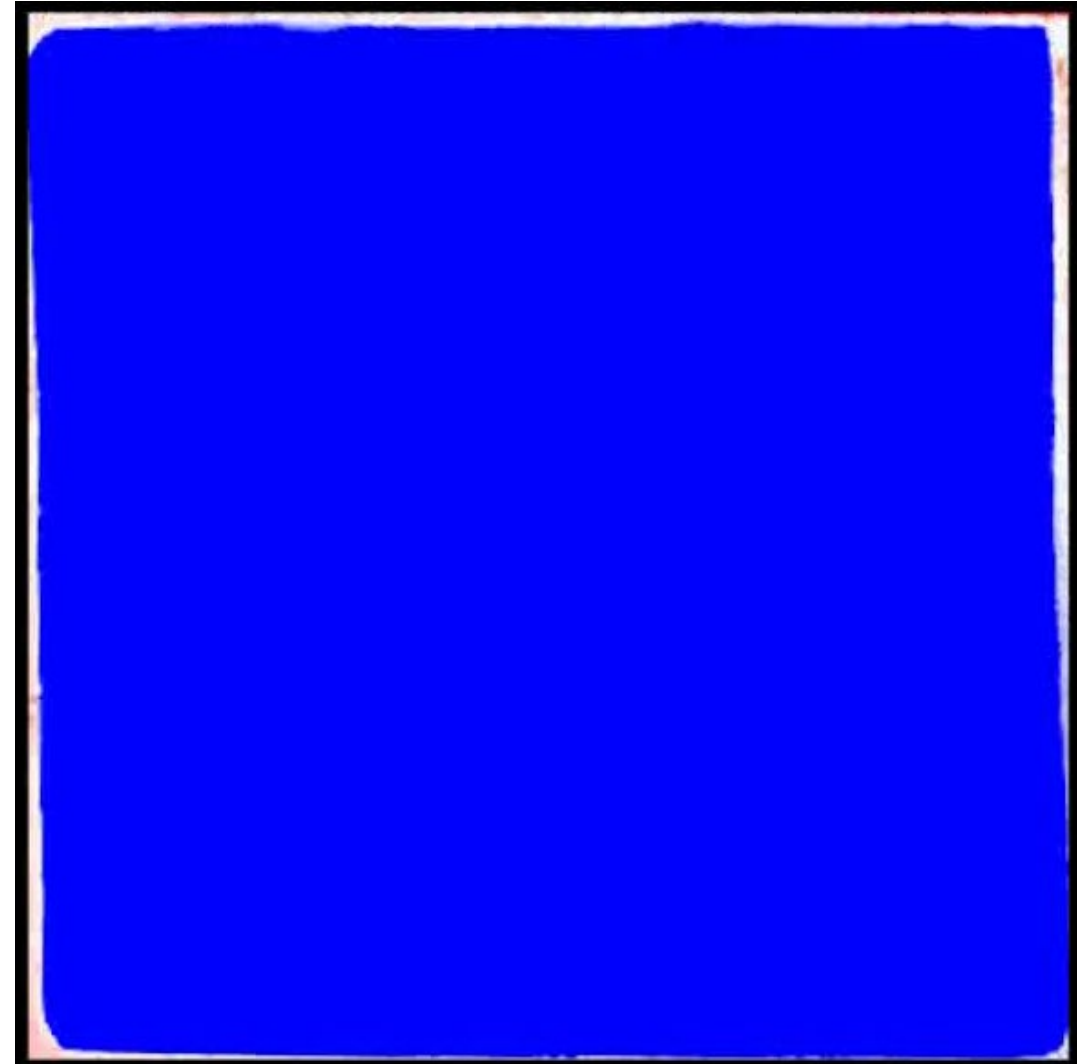
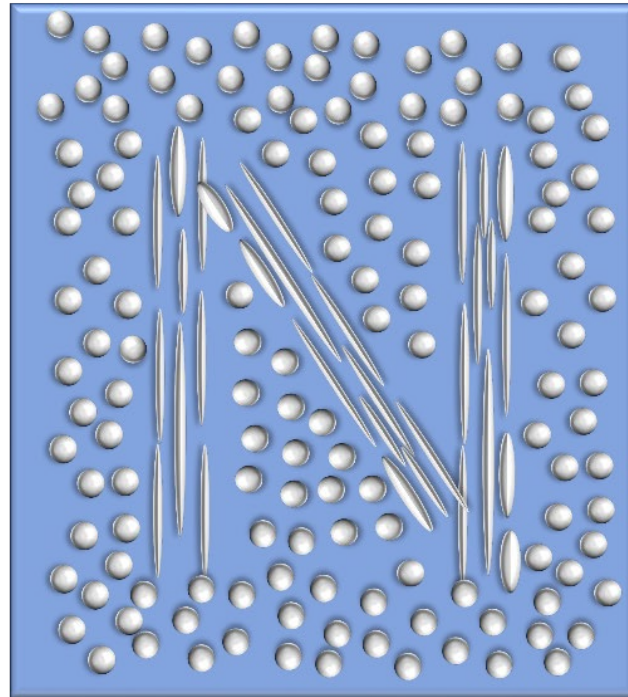


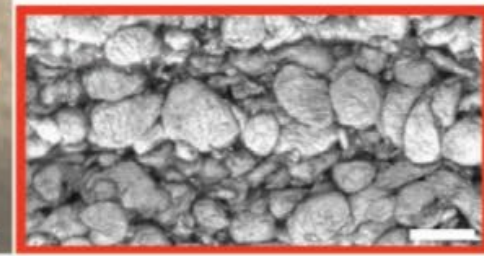
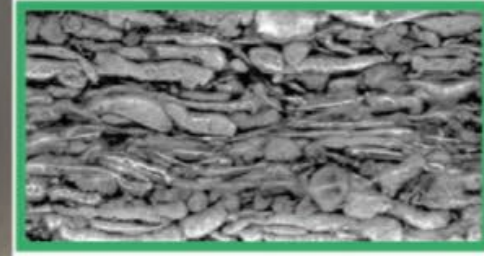
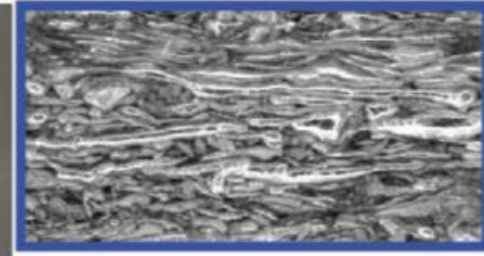
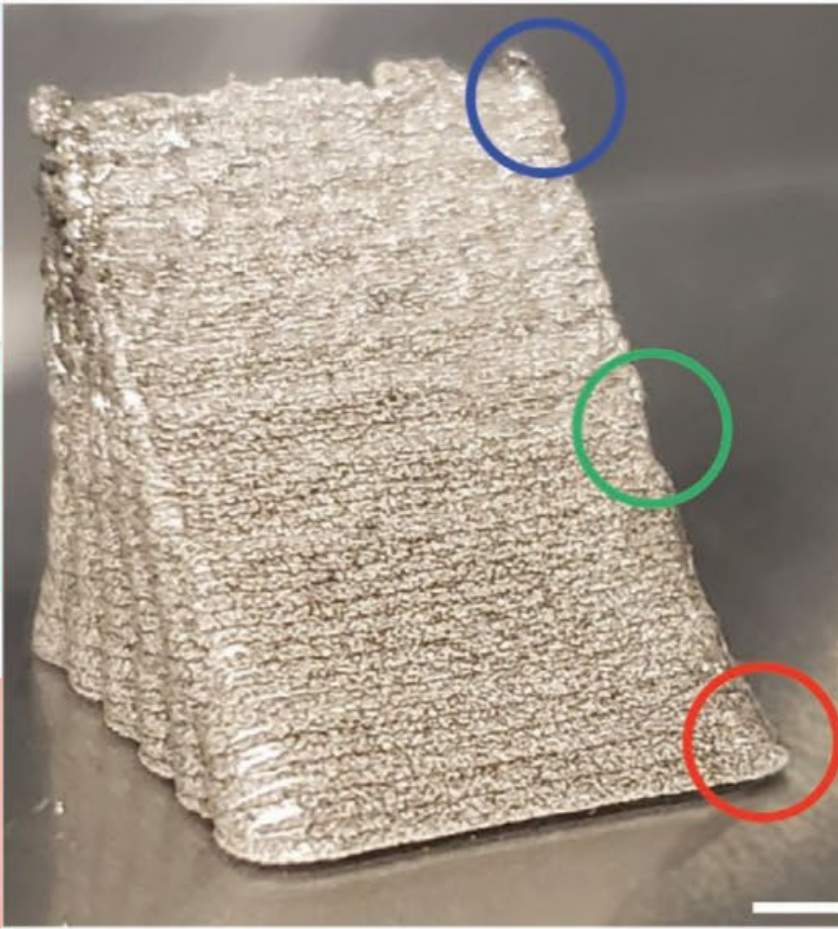
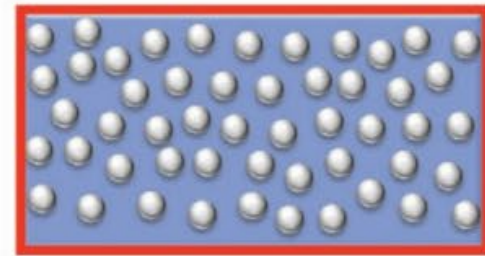
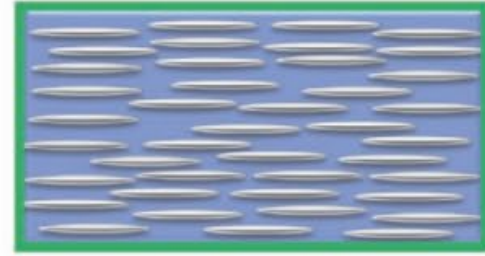
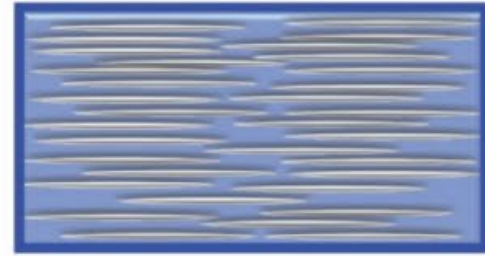
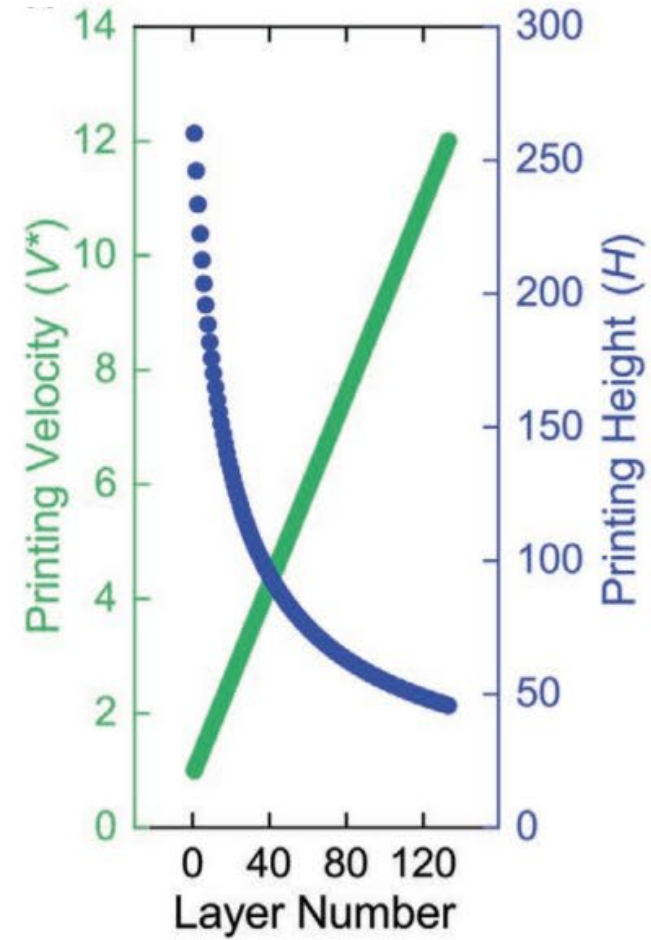
Isolated electrically non-conductive

Connected electrically conductive

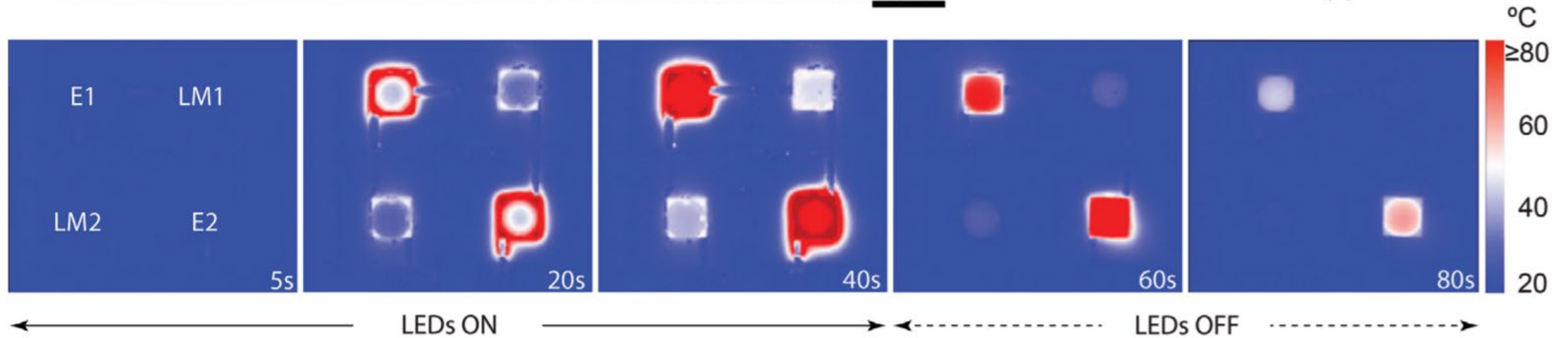
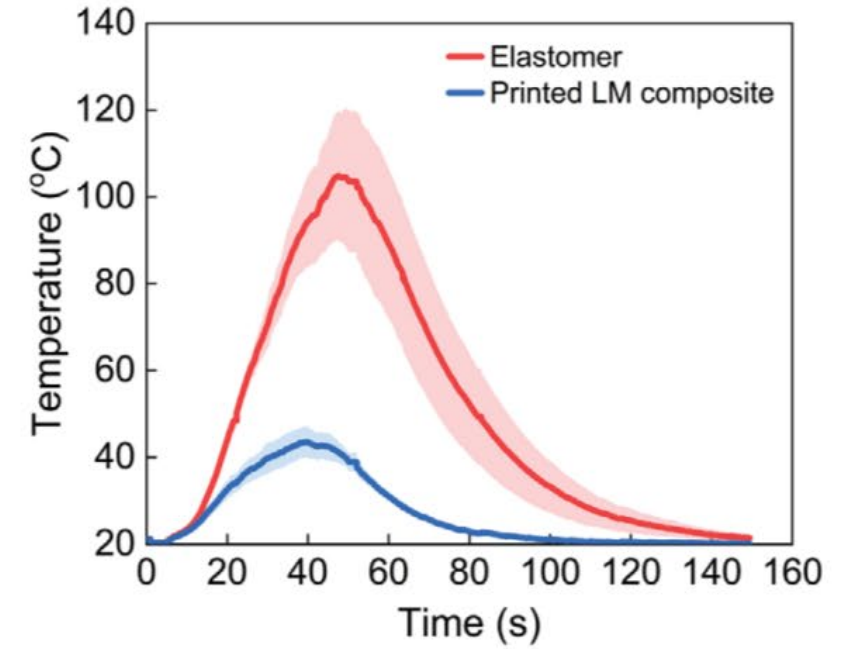
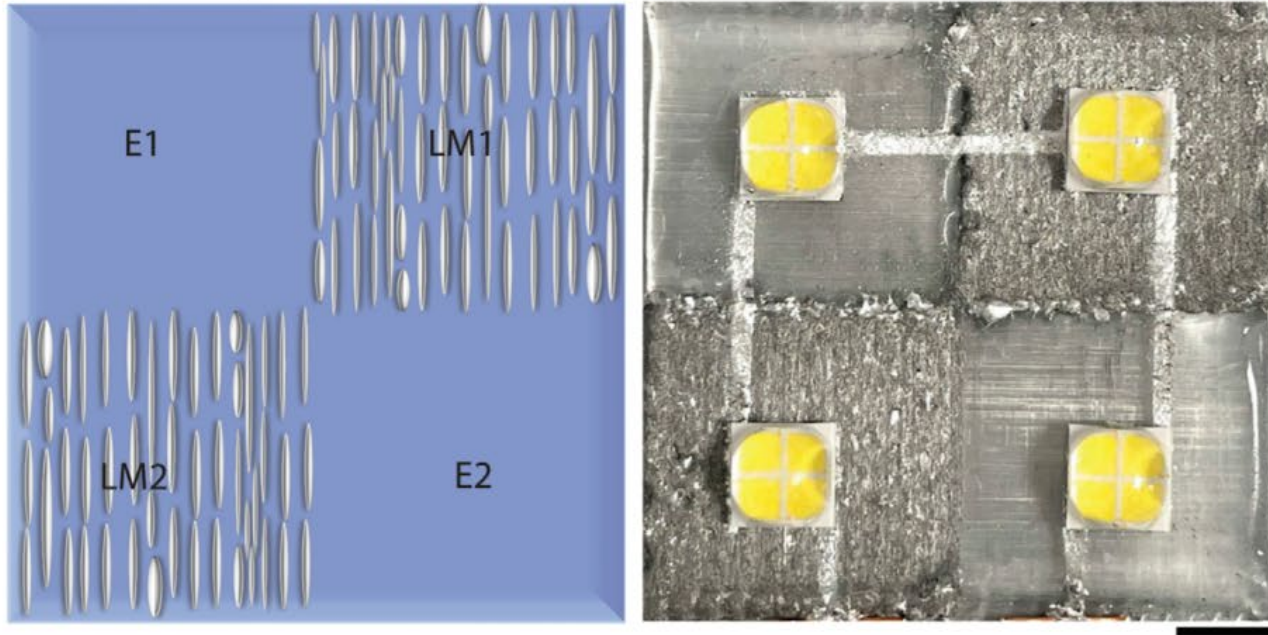
- One ink
- One nozzle
- Multiple properties with spatial control







E - ExSil, LM - Liquid Metal



Additive manufacturing for spatial control of liquid metal microstructure



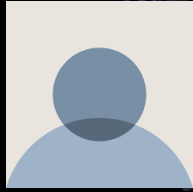
Acknowledgements:



Aaron Haake*



Ravi Tutika*



Gwyn Schloer

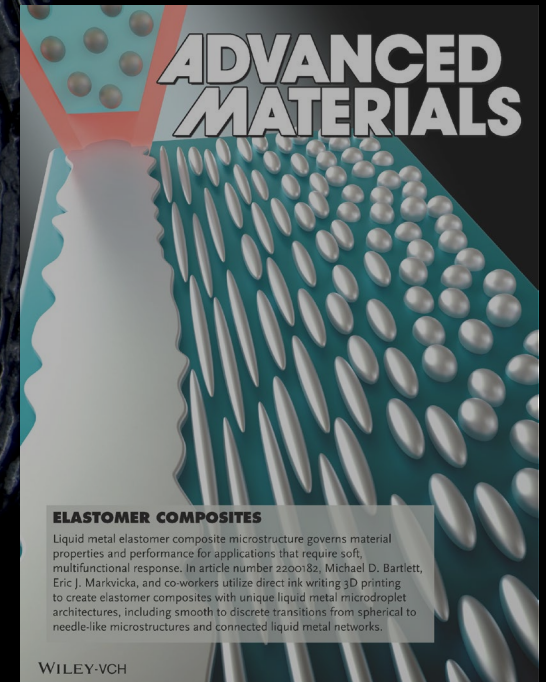


Mike Bartlett



Eric Markvicka

(*Contributed equally)



Funding Support: NSF, DARPA, NASA NE Space Grant, Nebraska Tobacco Settlement Biomedical Research Development

Questions