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Staying Cool – Liquid Metal Embedded Elastomers (LMEEs) at Low Temperature

Liquid metal (LM) droplets embedded in elastomers exhibit an enhancement in thermal and electrical properties of soft elastomers without degrading their mechanical properties. These unique combinations of properties arise from the combined metallic conductivity and low viscosity of the LM droplets inside the elastomer. The liquid inclusions can deform and adapt to large background strain field without inducing much resistance against deformation. In this whitepaper, we show the extent of temperatures where the liquid metal droplets remain in liquid phase.

In their bulk state, the melting and freezing points of gallium-based LM alloys that we use are between -20ºC to 30ºC. By creating LM droplets in the micro/nanometer range, freezing and melting temperatures have shown a significant reduction to below -60ºC and -25ºC, respectively. This reduction in the freezing and melting temperatures enables the use of LMEEs for applications in semiconductors, wearable electronics, biocompatible machines and soft robotics that are exposed to extreme environmental constraints. This supercooling effect is independent of polymer choice and a function of droplet size (**Figure 1**).

Stability of the composite across the temperature of certain applications plays a crucial role in performance reliability. Differential Scanning Calorimetry (DSC) measurements can identify phase change temperatures of materials. **Figure 2** shows a comparison of thermal properties for an unfilled base elastomer and its corresponding LMEE. As shown here in the temperature range of -50ºC to 30ºC we see no different phase change behavior between the base polymer and the LMEE.

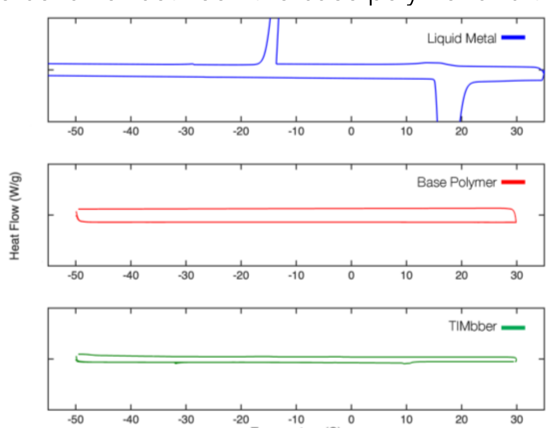

Figure 2. Comparison of DSC plots of LM and unfilled base polymer along with LMEE (TIMbber). Clearly the TIMbber shows unique combination of properties with no phase change.

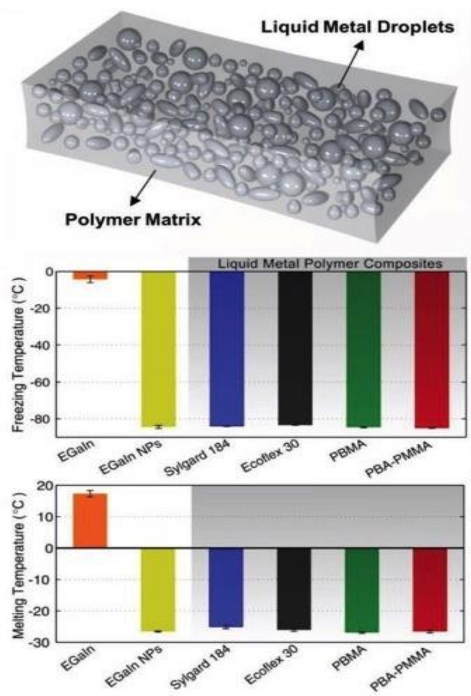

Figure 1 (a) Schematic of LMEEs, (b) Comparison of freezing/melting temperature of bulk LM with micro/nano droplet of LMs embedded in different polymers.

Semiconductor Industry TIM1 Application

The ability of this material to withstand thermal cycling as observed through the DSC analysis makes LMEEs a potential candidate for their application in the semiconductor industry. This significantly broad range in temperature from -50ºC to 30ºC provides the flexibility for the devices to function at low temperature (>-50ºC) to high temperature (<30ºC) without undergoing degradation.

Wearable Application

The combination of high thermal conductivity and rubbery compliance at low temperatures provides an opportunity to utilize this stretchable elastomer for wearable electronics. To demonstrate its use for emerging wearable technologies, the LMEE is incorporated into a thermoelectric generator (TEG) shown in Figure 3. Because of its mechanical deformability and compliance, the TEG can be used as a wearable energy harvester. The hybrid combination of the TEG with one side being the unfilled elastomer while the other side as the LMEE layers works as a heat shield preventing unwanted energy dissipation. The wearable device absorbs body heat on the unfilled elastomer interface as the LMEE interface serves as a heat release.

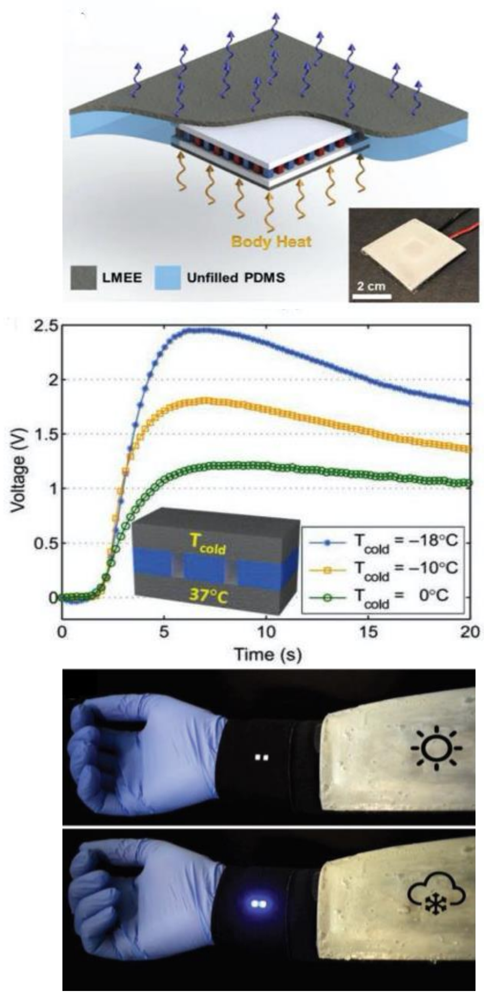

Figure 3. Thermoelectric generator designed using combination of unfilled/ LMEE interface, with open circuit voltage and a device worn on the body.

Summary

- LMEEs have a unique combination of thermal, electrical, and mechanical properties that arise from the use of liquid metal inclusions.
- Micro/nano LM droplets show no freezing above -50ºC due to the supercooling effects of micro/nano size droplets, which provides a pathway to design devices that can operate at low temperatures.
- This wide range of temperature stability can be utilized in the semiconductor industry, wearable electronics, and soft robotics.

Reference: Mohammad H. Malakooti, Navid Kazem, Jiajun Yan, Chengfeng Pan, Eric J. Markvicka, Krzysztof Matyjaszewski, and Carmel Majidi, Adv. Funct. Mater. 2019,1906098.