Liquid-Metal-Based Thermal Interface Materials Keep Microelectronics Cool

As engineers continue to pack more performance into smaller electronics, Moore's law and its corollaries have led to a massive increase in the power density of modern devices. However, with great power comes great heat.

Electronics use thermal interface materials (TIMs) to overcome thermal issues. These materials — including polymers, thermal greases, and solid-metal soldering materials — represent a $3 billion global TIM market. Each material has strengths and weaknesses, limited by how low of a thermal resistance it can achieve or how long it can survive extended use.

As semiconductor companies chase the ideal TIM, they have a long list of requirements and often face trade-offs. Low thermal resistance of solid-metal TIMs is desired, but these materials have a high total manufacturing cost. Easy dispensing is also desirable, but many dispensable materials suffer from "pump-out," where the material squeezes out of the interface as the device flexes under temperature changes during operation. To solve the pump-out problem, many manufacturers turn to stretchable polymeric TIMs.

Arieca, Inc., a Pittsburgh-based start-up funded by the U.S. National Science Foundation (NSF) and spun out of Carnegie Mellon Univ., is commercializing a new class of TIMs that combines the best properties of each TIM category to create a unique TIM for the modern era. Their goal is to create the ideal TIM that simultaneously exhibits the low thermal resistance of metals, reliability of polymeric binders, and ease of dispense of thermal greases.

Arieca's soft, highly stretchable, and thermally conductive TIMs comprise custom-formulated elastomers embedded with microscale droplets of liquid metal (LM) alloy (Figure 1). These LMs are alloys of gallium that are liquid at room temperature, have negligible toxicity, and have high electrical and thermal conductivity. Arieca's polymer science team optimizes the polymer and LM microstructure to engineer LM-embedded elastomer (LMEE) composites that balance the requirements of customer applications and maintain compatibility with commercial dispensers that are designed for low- to medium-viscosity fluids.

Arieca currently has several TIMs that are available to customers in computing and power electronics. In their work aimed at advanced semiconductor packaging, partially supported by the NSF Small Business Innovation Research program, Arieca is targeting a low thermal resistance that rivals a solder TIM (<5 mm^2K/W) while maintaining stretchability greater than 250% (allowing the TIM to stretch to 3.5x its original length). In contrast, soft metals like indium undergo inelastic deformation when stretched to 30% strain, while typical metals like silver may break at 5–10% strain.

Arieca's products are under evaluation at many of the world's largest semiconductor manufacturers and outsourced assembly and testing (OSAT) companies. "We need an innovative thermal interface material between the power module and heat sink," said Ken Nakahara, Fellow and Head of ROHM Semiconductor's R&D Center. "The most important requirement is compatibility with sufficient thermal conductivity and reliability, which are usually in a trade-off relationship. Arieca's LMEE has the possibility to satisfy this prerequisite, allowing us to innovate in the EV market."

Additionally, Arieca is working to scale up the manufacturing process and develop procedures for charging, storage, and stable cold-temperature transport of syringes compatible with the high-volume production tools used by customers. Meeting these thermal demands for advanced semiconductor packaging helps to sustain the trajectory of Moore's law and amplify the computational power needed for our interconnected society. CEP

▲ **Figure 1.** Arieca's liquid metal embedded elastomer (LMEE) combines liquid metals with proprietary elastomer blends to create stable and robust thermal interface materials for the semiconductor industries. The left image shows liquid metal droplets compressed between glass slides, highlighting their high-volume loading and ability to conform to their environment, and the right image shows LMEE being dispensed onto a silicon die.

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