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HIGH-PERFORMANCE, NANOENGINEERED TWO-PHASE COOLING SYSTEM FOR HIGH POWERED ELECTRONICS

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T-018032

Technology Description

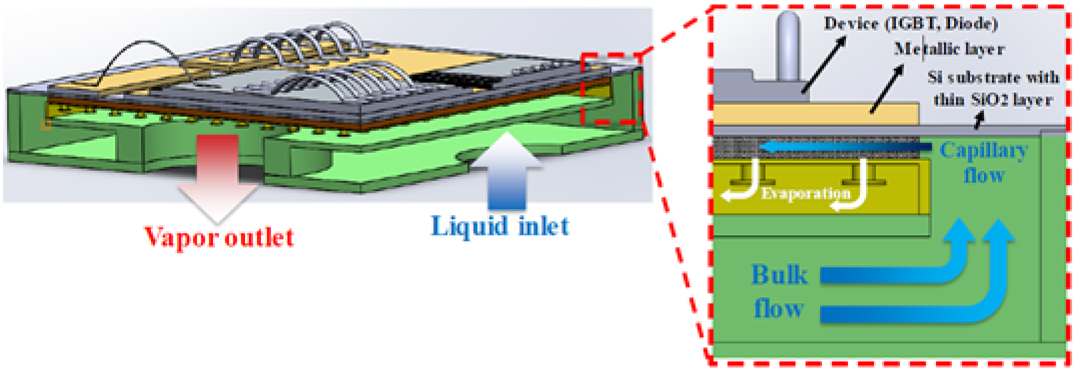
Engineers in Prof. Damena Agonafer's laboratory have developed a highly-efficient, compact, modular evaporative cooling platform with materials and nanostructured geometries designed to greatly enhance thermal management of 3D integrated circuits, power converters and a wide range of high-powered electronics.

State-of-the-art electronic devices must be kept at a reasonable temperature to optimize their performance. However, traditional cooling methods are incapable of dissipating the high heat flux these devices generate, making thermal management a critical bottleneck that hinders continued advancement. This technology provides an aggressive droplet evaporation cooling strategy rationally designed to provide a large amount of phase change heat transfer to ensure reliable performance.

This bioinspired microheat exchanger cooling platform features several techniques to efficiently deliver liquids and enhance evaporation to remove heat from the electronic device. The cooling platform includes:

- **Porous micropillar evaporating layer** – An array of porous micropillars creates a structure to efficiently wick the cooling liquid to the surface. This surface is uniquely shaped to promote ultrafast evaporation for effective cooling. In addition, the micropillars have functional nanocoatings to enable higher effective contact area and enhanced heat transfer compared to a plain surface. (WUSTL Technology T-018032)
- **Metal foam delivery layer** – This porous, high thermal conducting material delivers liquid to the evaporating layer. The hierarchically structured metal foam has high heat conduction and high permeability to enhance liquid delivery and heat transport. (WUSTL Technology T-018575)
- **Integrated cooling modules** – Systems for liquid delivery and phase routing thermal modules for 2D and 3D power electronics and 2D and 3D microelectronics. (WUSTL Technology T-018574)

This technology is projected to have a heat transfer coefficient >10^6 W/m^2-K and would be capable of dissipating extreme heat flux (~500 – 1000 W/cm^2 with a thermal resistance ~0.01 C/W) for a 1cm^2 x 1 cm^2 heat source . Overall, this system has great potential for thermal management in a variety of high powered micro-and power-electronics, particularly with **gallium nitride (GaN) chips used in electric and hybrid vehicles and with 2.5D and 3D stacked integrated circuits (3D ICs) in data centers**.



Schematic of high-performance micropillar two-phase cooling system for power electronics: *The liquid enters the delivery layer where it collects heat from the adjacent device. Then the liquid wicks through nanoengineered micropillars where it forms thin film droplets that quickly evaporate. The vapor escapes to an ambient environment where it is condensed and recycled in a closed loop system. The integrated thermal management system is shown here as part of a traditional planar power module. The technology could also be stacked in 3D semiconductor devices.* ***The micropillar system can be adapted with vapor chamber technology for microelectronics/portable electronics.***

Stage of Research

The inventors have designed, fabricated and evaluated a phase routing evaporative micro-heat exchanger.

Simulations: The proposed micropillar structure can dissipate a heat flux of 1 $KWcm^{-2}$ with a thermal resistance less 0.1 Kcm^2W^{-1}.

Experiments: The inventors identified an optimized micropillar cross-sectional shape with a heat transfer coefficient ~25% greater than circular micropillars.

Future work: The inventors plan to optimize fabrication and test evaporation from the micropillars.

Applications

- **Electronics cooling** – two-phase evaporative cooling for thermal management for a variety of semiconductor devices and power electronics, including:
  - 2D/2.5D/3D semiconductor devices
  - 3D integrated circuits (3D IC) used in data centers
  - gallium nitride (GaN) High Electron Mobility Transistors (HEMT), such as those used in electric and hybrid vehicles, radar amplifiers, and LED arrays
  - traditional transistors (IGBT, MOSFET)
- **Additional applications for porous material –** the structured porous material could potentially be adapted for supercapacitor electrodes, reaction beds for thermochemical energy storage or gas sensors

Key Advantages

- **High performance**:
  - system designed to dissipate extreme heat flux range of 500 – 1000 W/cm^2
  - heat transfer coefficient is projected exceed 100 W/cm^2-K
  - asymmetric micropillar geometry yields higher evaporation rate with higher heat transfer

  coefficients than circular structures
  - metal foam material simultaneously provides high heat conduction and effective wicking performance
  - functionalized nanocoatings create high specific surface area with enhanced heat transfer
- **Scalable** – design is easily scalable in size based on end-user application
- **Compatible with phase change material –** heat exchanger platform could potentially be integrated with phase change material for transient thermal buffering
- **Adaptive cooling –** self-adapts to variable heat load using a pressure balance technology

Publications

- Shan, L.,…Agonafer, D. (2019). Investigation of the Evaporation Heat Transfer Mechanism of a Non-Axisymmetric Droplet Confined on a Heated Micropillar Structure. *International Journal of Heat and Mass Transfer,* 141, 191-203.
- Shuai, S., Du, Z., Ma, B., Shan, L., Dogruoz, B., & Agonafer, D. (2018, August). Numerical Investigation of Shape Effect on Microdroplet Evaporation. In *ASME 2018 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems* (pp. V001T04A010-V001T04A010). American Society of Mechanical Engineers.
- Agonafer, D. D., Lee, H., Vasquez, P. A., Won, Y., Jung, K. W., Lingamneni, S., ... & Maitra, T. (2018). Porous micropillar structures for retaining low surface tension liquids. *Journal of colloid and interface science*, 514, 316-327.

Patents

- Provisional US Patent Application Filed

Website

- Nanoscale Energy and Interfacial Transport Lab