# Soosik Bang

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Research interest: Phase change heat transfer,
Vapor chamber, Electronics thermal management,
ANN based optimization.

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## Academic Experiences

Korea Advanced Institute of Science and Technology (KAIST): Postdoc. (2023.08 – Present)

Korea Advanced Institute of Science and Technology (KAIST): Researcher (2021.06 – 2023.08)

Kyung Hee University: Ph.D (2018.03 – 2023.08)

Kyung Hee University: M.S. (2016.03 – 2018.02)

Kyung Hee University: B.S. (2009.03 – 2016.02)

## Journal Publications:

1) Kyounghwan Song, Inkyu Kim, **Soosik Bang**, Jung-Yeul Jung, Youngsuk Nam, " Corrosion resistance of water repellent aluminum surfaces with various wetting morphologies", *Applied Surface Science*, vol. 467-468, pp. 1046-1052 (2019)

2) **Soosik Bang**, Seunggeol Ryu, Seokkan Ki, Kyounghwan Song, Jinwook Kim, Joongnyon Kim Youngsuk Nam "Superhydrophilic catenoidal aluminum micropost evaporator wicks", *International Journal of Heat and Mass Transfer*, vol. 158, pp. 120011 (2020)

3) Seokkan Ki, Jooyoung Lee, Seunggeol Ryu, **Soosik Bang**, Kichong Kim, Youngsuk Nam "A bio-inspired, low pressure drop liquid cooling system for high-power IGBT modules for EV/HEV applications," *International Journal of Thermal Sciences*, vol. 161, pp. 106708 (2021)

4) Seokkan Ki, Jooyoung Lee, Seungwoo Kim, Jaehwan Shim, Seungtae Oh, Sumin Cho, **Soosik Bang**, Donghyun Seo, Joongnyon Kim, Youngsuk Nam "An energy-efficient battery thermal management system incorporating a porous metal-based multiscale flow manifold", *Energy Conversion & Management*, vol. 269, pp. 116147 (2022).

5) **Soosik Bang**, Jeonghwan Kim, Seunggeol Ryu, Seokkan Ki, Yun Jung Heo, Choongyeop Lee, Youngsuk Nam "Enhanced capillary and heat transfer performance of asymmetric micropost wicks", *International Communications in Heat and Mass Transfer*, vol. 146, pp. 106935 (2023)

6) Seungwoo Kim, Seokkan Ki, **Soosik Bang**, Sanghyung Han, Junyong Seo, Chulmin Ahn, Suhyeon Maeng, Bong Jae Lee and Youngsuk Nam, "Optimizing Energy-Efficient jet impingement cooling using an artificial neural network (ANN) surrogate model for high heat flux Semiconductors", *Applied Thermal Engineering*, vol. 239, pp. 122101 (2023)

7) Jaehwan Shim, Seokkan Ki, Donghyun Seo, Byungyun Moon, **Soosik Bang** and Youngsuk Nam, "Intermittent spray cooling on rationally-designed hierarchical surfaces for enhanced evaporative heat transfer performance", In review

8) **Soosik Bang**, Seungwoo Kim, Seokkan Ki, Junyong Seo, Bong Jae Lee, Youngsuk Nam, "Artificial neural network (ANN)-based multi-objective optimization of the vapor chamber with liquid supply layer for high heat flux applications", In review

9) Seokkan Ki, Seongjong Shin, Sumin Cho, **Soosik Bang**, Dongwhi Choi, and Youngsuk Nam, "Porous liquid metal-based phase change materials with suppressed supercooling for sustainable thermal regulation of electronic devices", In review

10) Jaehwan Shim, Kihwoon Shim, Jun Soo Kim, Seokwan No, **Soosik Bang**, Yongwoo Kim, Bumjun Park, Rishi Raj and Youngsuk Nam, "Cascading Condensation", To be submitted (2024)

## Patent Publications:

1) **Soosik Bang**, Youngsuk Nam, Seunggeol Ryu, Joongnyon Kim and Jinwook Kim, "WICK STRUCTURE AND HEAT PIPE INCLUDING THE SAME AND MANUFACTURING METHOD", Korea patent 10-2017-0100896, 2017.

## Conference Presentations:

1) **Soosik Bang**, Seunggeol Ryu and Youngsuk Nam, "Fabrication and Characterization of the Heat Transfer and Capillary Performance of Al based Microposts", *KSME Spring Conference*, Korea, May 24-26, 2017.

2) Seunggeol Ryu, Seungtae Oh, **Soosik Bang** and Youngsuk Nam, "Dynamic behaviors between evaporator and condenser for micro heat spreader", *International Conference Nanochannels, Microchannels and Minichannels Conference, Cambridge*, MA, USA, Aug 27-30, 2017.

3) Seunggeol Ryu, Seungtae Oh, **Soosik Bang** and Youngsuk Nam, "Study of direct liquid supply between evaporator and condenser for micro heat spreaders", *KSME fall Conference*, Korea, Nov 1-3, 2017.

4) **Soosik Bang**, Seunggeol Ryu and Youngsuk Nam, “Aluminum micropost wicks with a circular hyperboloid shape for micro heat spreaders”, *The 16th International Heat Transfer Conference*, Beijing, China, Aug 10-15, 2018.

5) Seokkan Ki, Jooyoung Lee, Seunggeol Ryu, **Soosik Bang** and Youngsuk Nam, "A Bio-Inspired, Low Pressure Drop Liquid Cooling System for High-Power IGBT Modules", *T-SITE at KIST*, Korea, June 27, 2019.

6) Seungwoo Kim, Seokkan Ki, **Soosik Bang**, Chulmin Ahn, Choongyeop Lee and Youngsuk Nam, “Direct cooling system based on multi-objective optimization to improve high heat flux chip cooling efficiency”, KSME Spring Conference, Gyeongju, Korea, April 20-22, 2022

7) **Soosik Bang**, Seungwoo Kim and Youngsuk Nam, “Numerical analysis on heat transfer characteristics of ultra-thin vapor chamber with liquid supply layer based on multi-objective optimization”, KSME Fall Conference, Jeju, Korea, November 9-12, 2022

8) Young Su Ko, Chaeyeong Seo, **Soosik Bang**, Youngsuk Nam, Hyun-Ah Lee, and Choongyeop Lee, "Single-cell level cytoplasmic streaming measurement in plant cell”, KSME Fall Conference, Jeju, Korea, November 9-12, 2022

9) Seungwoo Kim, Seokkan Ki, **Soosik Bang**, Chulmin Ahn and Youngsuk Nam, “The Optimization of a Jet Impingement and Micropost Hybrid Cooling System for High Heat Flux Semiconductors”, 8th Thermal and Fluids Engineering Conference (TFEC), USA, March 26-29, 2023

10) Hyunho Cho, Insik Lee, Seungwoo Kim, **Soosik Bang**, Jaechoon Kim and Youngsuk Nam, “Multi-objective design optimization of direct liquid cooling system for multi-chip semiconductor package using active learning”, KSME Spring, Busan, Korea, Apr 19-22, 2023

11) Jaehwan Shim, Kihwoon Shim, Jun Soo Kim, Seokwan Rho, **Soosik Bang**, Yongwoo Kim, Bumjun Park, Rishi Raj and Youngsuk Nam, “Strategies for Enhanced Dropwise Condensation by Incorporating Interfacial Adsorption of Amphiphilic Molecules”, KSME Spring, Busan, Korea, Apr 19-22, 2023

12) Jaehwan Shim, Seokkan Ki, Donghyun Seo, **Soosik Bang** and Youngsuk Nam, “Strategies for Enhanced Evaporative Heat Transfer Performance by Incorporating Surface Modification with Intermittent Spray”, KIMST, Jeju, Korea, June 15-16, 2023

13) Hyunho Cho, Insik Lee, Seungwoo Kim, **Soosik Bang**, Jaechoon Kim and Youngsuk Nam, "An active learning approach to performance optimization of jet array impingement-based cooling module for chiplet semiconductor package", KSFM Summer Conference, Pyeongchang, Korea, July 5-7, 2023

14) Seungwoo Kim, Seokkan Ki, **Soosik Bang**, Sanghyung Han, Junyong Seo, Chulmin Ahn, Suhyeon Maeng, Youngsuk Nam, "Thermal Management in EV Inverters: Optimizing Jet Impingement Cooling with Micropost Integration", The 21th International Symposium on Microelectronics and Packaging (ISMP 2023), Korea, October 25-27, 2023

15) Seokkan Ki, Seongjong Shin, Sumin Cho, **Soosik Bang**, Dongwhi Choi, Youngsuk Nam, "Porous Liquid Metal-based Phase Change Materials with Suppressed Supercooling for Sustainable Thermal Regulation of Electronic Devices", The 21th International Symposium on Microelectronics and Packaging (ISMP 2023), Korea, October 25-27, 2023

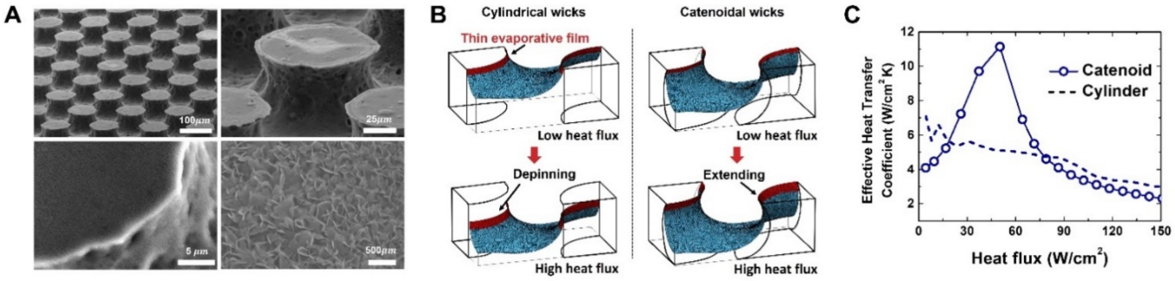
16) Kihwoon Shim, Jaehwan Shim, Jun Soo Kim, Seokwan Rho, **Soosik Bang**, Rishi Raj and Youngsuk Nam, "Transition of Condensation Mode via Adsorption of Volatile Amphiphilic Molecules", KSME Fall, Incheon, Korea, Nov. 1-4, 2023

17) Young-Su Ko, Chaeyeong Seo, **Soosik Bang**, Keunhwan Park, Youngsuk Nam, Hyun-Ah Lee and Choongyeop Lee, "Experiment Measurement of Cytoplasmic Streaming Velocity within a Single Plant Cell", Bulletin of the American Physical Society, Washington, DC, USA, Nov 19-21, 2023

18) Hyunho Cho, Insik Lee, Seungwoo Kim, **Soosik Bang**, Jaechoon Kim and Youngsuk Nam, Optimization of thermal management performance of direct liquid cooling module for chiplet packages using active learning and hierarchical exploration, *KSFM Winter Conference*, Korea, Nov 29 - Dec 1, 2023

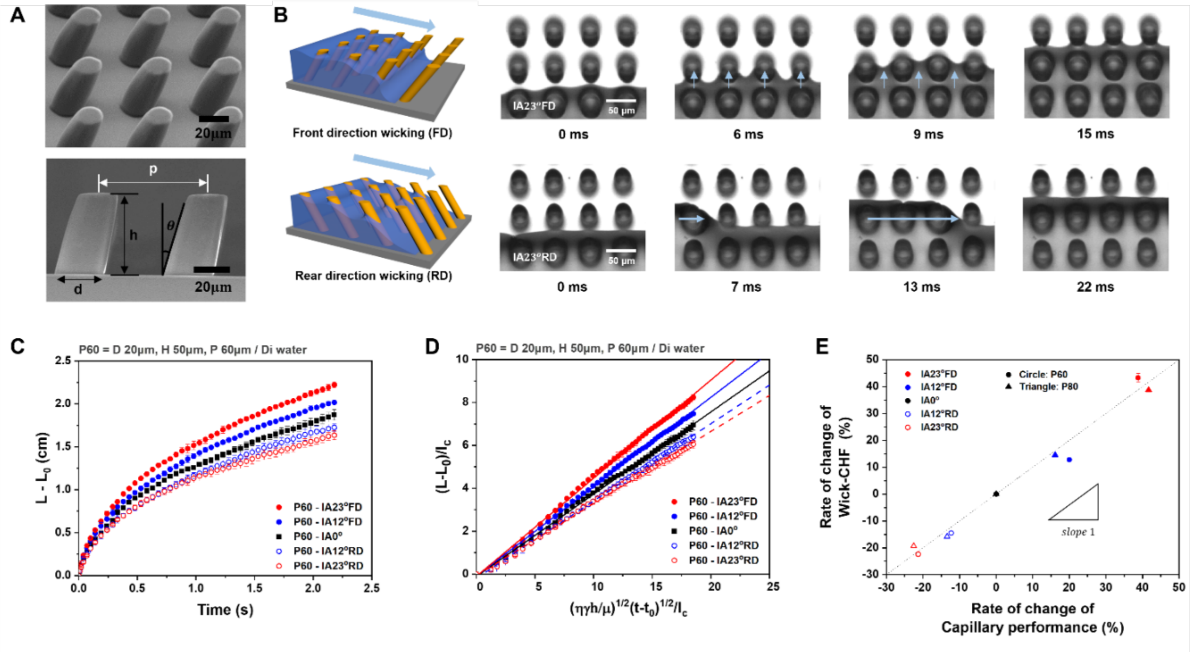
## **Research Topics**:

1) Superhydrophilic catenoidal aluminum micropost evaporator wicks:



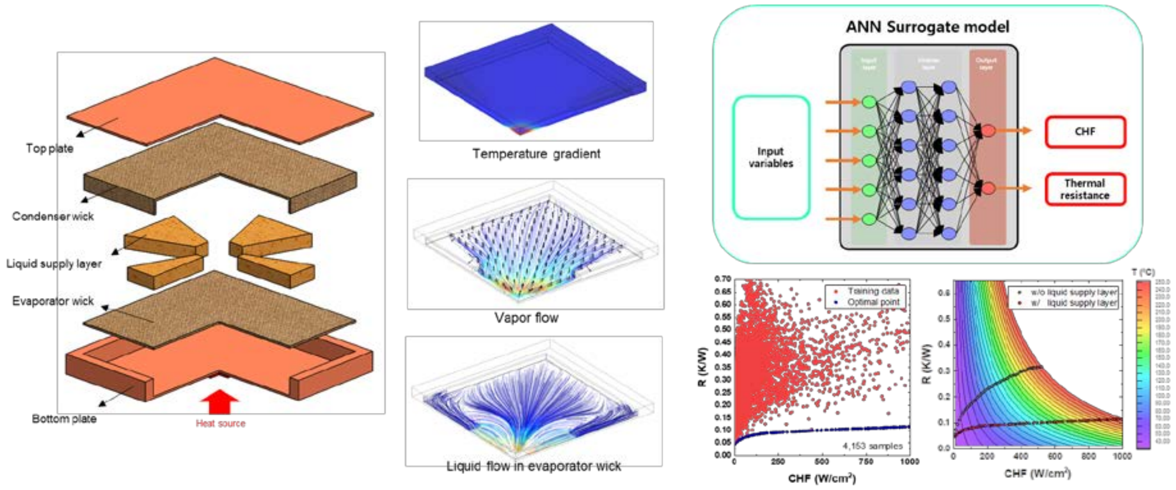

The thermal management problem of power electronic devices has been the challenge over the past decades. Heat pipes and vapor chambers are widely employed in electronics cooling. In the past decade, various types of vapor chamber with capillary wick structures have been developed due to the evaporator wicks are core elements that determine the heat transfer performance. Unfortunately, the traditional porous structures are not applicable for the Al vapor chamber because of the technical difficulty. For this reason, the most of Al heat spreader generally uses simple linear groove wicks using the extrusion process. It leads to a limitation in the performance of vapor chamber. Here, we introduce the superhydrophilic catenoidal aluminum (Al) wicks fabricated by a multi-step wet etching process followed by wet chemical oxidation. The unique three-dimensional sidewall morphology of the developed wick provides the re-pinning of the liquid meniscus during the receding, which substantially increases the thin evaporative film area and the resulting heat transfer performance. The nanostructured aluminum oxide layer (AlO(OH)) was incorporated to enhance both the corrosion resistance as well as the wettability of the wick with water. The experiment shows that the heat transfer coefficient of the developed wick rapidly increases as the heat flux increases up to ~60 W/cm2. The maximum heat transfer coefficient of the catenoidal wick is measured to be ~117% higher than that of the previously-reported cylindrical ones. The numerical simulation clarifies that the increase in the heat transfer coefficient was due to the ~75% increase in the thin evaporative film area. The polarization scanning test shows that the corrosion resistance of the superhydrophilic catenoidal wicks was increased by ~82% compared to the unstructured ones, which clarifies the incorporated aluminum oxide layer acts as an effective corrosion barrier.

2) Enhanced capillary and heat transfer performance of asymmetric micropost wicks:




An evaporator wick is one of the crucial elements determining the performance of micro heat pipes since the heat transfer coefficient and the critical heat flux are determined by the capillary performance and the thin evaporative film area of the evaporator wicks, respectively. Previous studies have put great effort into developing a variety of evaporator wicks to increase thin film area and/or capillary performance. However, it is still challenging to create a surface that can improve both the heat transfer coefficient and liquid supply capacity. Dense wicks can achieve high heat transfer coefficients due to their large thin-film area, but they also induce large liquid pressure drops, which reduce capillary performance and consequently critical heat flux. Here, we developed asymmetric capillary wicks composed of slanted microposts using inclined photolithography. Then we investigated the effects of inclination angle and wicking direction on the capillary and the heat transfer performances. The working fluid accelerates when it flows in the slope direction of the structure (forward direction, FD) and decelerates when it flows in the opposite slope direction (rear direction, RD). We applied the scaling law to the capillary rise experiment data to verify that the inclination angle and the wicking direction affect the capillary performance. The capillary performance parameter was improved by up to ~39% with FD case and decreased by 21.3% with RD. The heat transfer performance test showed that the wick-CHF (the enhanced critical heat flux due to the formation of the wick) of the asymmetric FD case was increased by 43.3% compared to symmetric ones while maintaining the heat transfer coefficient.

3) Artificial neural network-based multi-objective optimization of the vapor chamber with liquid supply layer for high heat flux applications:




A vapor chamber (VC) is a highly efficient heat spreading device that is widely used in electronic devices, especially in high-power applications. The porous wick structure is an important element of VC that plays a role in evaporating and transporting the working fluid. The wick structure is designed to enhance liquid spreading and evaporation by providing high capillary pressure and large thin film area. Hybrid wicks or multi-artery wicks have the advantage of significantly improving the critical heat flux compared to a single layer wick by separating the working fluid transport section from the evaporation section. Here, we developed ANN-based multi-objective optimization process to predict the performance of the vapor chamber (VC) with liquid supply layer, designed for high heat flux applications. We used a numerical model to study the thermal performance of the VC and its structural components. An artificial neural network (ANN) surrogate model was developed that can predict thermal resistance ($R_{VC}$) and critical heat flux (CHF) through given input variables by bypassing the process of comparing capillary pressure (calculated using the Young-Laplace equation) and pressure drop (computed via a numerical analysis model). We were able to obtain optimal design variables that minimize thermal resistance for various CHFs using the ANN-based Multi-Objective Genetic Algorithm (MOGA) method. At a heat flux of 500 W/cm$^2$, the $R_{vc}$ of the VC with liquid supply layer is 1/3 of that of the VC without liquid supply layer. Additionally, the junction temperature in the VC with liquid supply layer is approximately 100 ℃ lower compared to the VC without liquid supply layer. Our approach resulted in a VC with significantly reduced thermal resistance and enhanced critical heat flux (CHF), primarily due to a well-delineated role division between the evaporator wick and the liquid supply layer.