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Seungwoo Kim

- Ph.D course
- Department of Mechanical Engineering
- Korea Advanced Institute of Science and Technology (KAIST)
- Office: Mechanical Engineering Building (N7-4) Room #3104
- Email: 73tmddn37@kaist.ac.kr

- Research interest: Electronics thermal management, Jet impingement cooling, Immersion cooling, Thermal test vehicle (TTV), ANN based optimization

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Academic Experiences

Korea Advanced Institute of Science and Technology (KAIST) Sep.2022-Present

Ph.D in Mechanical Engineering (Advisor: Prof. Youngsuk Nam)

Korea Advanced Institute of Science and Technology (KAIST) Jun.2021-Aug.2022

Researcher (Advisor: Prof. Youngsuk Nam)

Kyung Hee University (KHU) Mar.2021-Aug.2022

M.S. in Mechanical Engineering (Co-Advisor: Prof. Youngsuk Nam & Prof. Choongyeop Lee)

- Thesis: Development of energy-efficient Jet impingement cooling for semiconductor thermal management utilizing surrogate model based multi-objective optimization

Kyung Hee University (KHU) Mar.2015-Feb.2021

B.S. in Mechanical Engineering (Advisor: Prof. Youngsuk Nam)

- Thesis: Thermal Optimization of Multi Finger GaN HEMT Considering Circuit Integration

Journal Publications

8) **Seungwoo Kim**, Junsang Kim, Doyeop Kim, Sanghyung Han, So Han Kim, Sejeong Kim, and Youngsuk Nam "Figures of Merit for Dielectric Fluid Selection in Single-Phase Immersion Cooling Classified by Flow Regimes and Operating Constraints" Submitted

7) **Seungwoo Kim**, Han Ku Nam, Sanghyung Han, Dongwook Yang, Jun Soo Kim, Suhyun Maeng, Chulmin Ahn, Younggeun Lee, Byunggi Kim, Young-Jin Kim, and Youngsuk Nam

"Femtosecond Laser Structuring on Direct Bonded Copper (DBC) for Energy-Efficient Thermal Management of Power Electronics", *International Communications in Heat and Mass Transfer,* Vol. 178, pp. 111922 (2026)

6) Insik Lee, Hyunho Cho, **Seungwoo Kim**, Jaechoon Kim, and Youngsuk Nam "High efficiency single and multi-phase direct liquid jet-impingement cooling for heterogeneous packaging" *Energy Conversion & Management,* Vol. 348, pp. 120665 (2026)

5) Hyunho Cho, Insik Lee, **Seungwoo Kim**, Soosik Bang, Jaechoon Kim, and Youngsuk Nam "Optimization Framework for Energy-Efficient and Uniform Jet Impingement Cooling for Heterogeneous Integration Packaging" *Energy and AI*, Vol. 21, pp. 100587 (2025).

4) Soosik Bang, **Seungwoo Kim**, Seokkan Ki, Junyong Seo, Jaechoon Kim, Bong Jae Lee and Youngsuk Nam "Artificial neural network (ANN)-based multi-objective optimization of the vapor chamber with liquid supply layer for high heat flux applications", *International Communications in Heat and Mass Transfer*, Vol. 159 pp.108302 (2024)

3) **Seungwoo Kim**, Seokkan Ki, Soosik Bang, Sanghyung Han, Junyong Seo, Chulmin Ahn, Suhyeon Maeng, Bong Jae Lee, 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)

2) Jaehwan Shim, Seungtae Oh, **Seungwoo Kim**, Donghyun Seo, Subeen Shin, Haeseung Lee, Younghwan Ko, Youngsuk Nam "Long-lasting ceria-based anti-frosting surfaces", *International Communications in Heat and Mass Transfer*, Vol. 140 pp.106550 (2023)

1) Seokkan Ki, Jooyoung Lee, **Seungwoo Kim**, Jeongmo Sung, 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)

Patents

2) Su Hyeon Maeng, Kwang Min Choi, Baek Yu Kim, Chul Min Ahn, Dong Hui Cheon, Sun Sung Kwon, Won Seok Lee, Young Suk Nam, Sang Hyung Han, **Seung Woo Kim** , "Power Module Cooler" , Application No.: 19/388,777 (US) , 202511871320.9 (CN), 102025148620.4 (DE), Date of Application: Nov. 13, 2025 (US), Dec. 12, 2025 (CN), Nov. 24, 2025 (DE).

1) 맹수현, 최광민, 김백유, 안철민, 천동희, 권순성, 이원석, 남영석, 한상형, **김승우**, "파워모듈 냉각 장치", 출원번호 (국내): 10-2025-0047645, 출원일: 2025년 04월 11일

Conferences

22) Chulmin Ahn, Suhyeon Maeng, **Seungwoo Kim**, Sanghyung Han, and Youngsuk Nam, "A Comparative Study on the Inverter Thermal Performance of Micro Pin-Fin Surface Treatment Methods for Heat Transfer Enhancement", *Energy Conversion Congress & Expo (ECCE) Europe 2026*, Valencia, Spain, Sep. 14-18, 2026

21) **Seungwoo Kim**, Han Ku Nam, Sanghyung Han, Jun Soo Kim, Suhyun Maeng, Chulmin Ahn, Young-Jin Kim, and Youngsuk Nam, "Femtosecond Laser Structuring of Direct Bonded Copper (DBC) for Enhanced Jet Impingement Cooling in Power Electronics", *18th International Heat Transfer Conference (IHTC)*, Rio De Janeriro, Brazil, Aug. 2-7, 2026

20) Insik Lee, Sangha Baek, **Seungwoo Kim**, Jaechoon Kim, and Youngsuk Nam, "Enhancing Two-Phase Direct Liquid Jet-Impingement Cooling With Etched and Laser-Ablated Pin-Fins for 2.5D Semiconductor Packages", The 25th Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Orlando, FL, USA, May 26-29, 2026

19) **Seungwoo Kim**, Han Ku Nam, Sanghyung Han, Jun Soo Kim, Suhyun Maeng, Chulmin Ahn, Young-Jin Kim, and Youngsuk Nam, "Femtosecond Laser Structuring of Direct Bonded Copper (DBC) Substrates for Enhanced Cooling Performance of Power Electronics", *KSME Spring Conference*, Jeju, Korea, Apr. 22-25, 2026

18) Sang Hyung Han, **Seungwoo Kim**, Chul Min Ahn and Youngsuk Nam, "Energy Efficiency Analysis of a Double-Sided Jet Impingement Cooled EV Inverter Assembly", *KSME Spring Conference*, Jeju, Korea, Apr. 23-26, 2025

17) **Seungwoo Kim**, Sungwook Yoon and Youngsuk Nam, "TTV-Based Two-Phase Immersion Cooling for Thermal Performance Evaluation of 2.5D Semiconductor Packaging", *KMEPS 2025*, Incheon, Korea, Apr. 1-3, 2025

16) Insik Lee, Hyunho Cho, **Seungwoo Kim**, Jaechoon Kim and Youngsuk Nam, "Single and Two-Phase Jet Impingement Cooling for Thermal Management of 2.5D Semiconductor Packages", *KMEPS 2025*, Incheon, Korea, Apr. 1-3, 2025

15) Hyunho Cho, Insik Lee, **Seungwoo Kim**, Soosik Bang, Jaechoon Kim and Youngsuk Nam, "Active learning-based design optimization of direct liquid cooling modules for heterogeneously integrated semiconductor packages", *The 3rd Pacific Rim Thermal Engineering Conference (PRTEC 2024)*, Hawaii, USA, Dec 15-19, 2024

14) Hyunho Cho, Insik Lee, **Seungwoo Kim**, Soosik Bang, Jaechoon Kim and Youngsuk Nam, "Jet nozzle array optimization for enhancing temperature uniformity in direct liquid cooling of semiconductor packages with non-uniform heat fluxes", *The 22th International Symposium on Microelectronics and Packaging (ISMP 2024)*, Korea, Nov. 5-8, 2024

13) **Seungwoo Kim**, Seokkan Ki, Soosik Bang, Sanghyung Han, Junyong Seo, Chulmin Ahn, Suhyeon Maeng, Youngsuk Nam, "Efficient Cooling Solutions for High Heat Flux Electronics: ANN Optimization of Jet Impingement and Micropost Systems", *InterPACK 2024*, San Jose, CA, October, 8-10, 2024

12) **Seungwoo Kim**, Seokkan Ki, Soosik Bang, Sanghyung Han, Junyong Seo, Chulmin Ahn, Suhyeon Maeng, Youngsuk Nam, "Enhancing Thermal Management with Jet Impingement and Microposts: Inducing Vortices and Reducing Boundary Layer Thickness", *ICTAM 2024*, Daegu, Korea, August, 25-30, 2024

11) Soosik Bang, **Seungwoo Kim**, Seokkan Ki, Junyong Seo, Jaechoon Kim, Bong Jae Lee and Youngsuk Nam, "Optimizing the vapor chamber with liquid supply layers for high heat flux applications using an ANN-based multi-objective genetic algorithm", *The 23rd Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, Denver, CO, USA, May 28-31, 2024

10) Sanghyung Han, **Seungwoo Kim**, Su Hyeon Maeng and Youngsuk Nam, "Design of jet impingement cooling system for multi-device power module with double-sided cooling", *KSME Spring Conference*, Jeju, Korea, Apr. 24-26, 2024

9) Hyunho Cho, Insik Lee, **Seungwoo Kim**, Soosik Bang, Jaechoon Kim and Youngsuk Nam, "Design optimization of single-phase jet impingement cooling module for efficient thermal management of heterogeneous integration semiconductor package using CNN-based surrogate model", *KSME Spring Conference*, Jeju, Korea, Apr. 24-26, 2024

8) 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*, Jeju, Korea, Nov. 29-Dec. 1, 2023

7) **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

6) 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

5) 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

4) **Seungwoo Kim**, Seokkan Ki, Soosik Bang, Chulmin Ahn, Choongyeop Lee 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.

3) 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

2) Seokkan Ki, Jooyoung Lee, **Seungwoo Kim**, Joongnyon Kim and Youngsuk Nam, "Battery thermal management system using manifold flow channels combined to porous metal layer", *KSME Spring Conference*, Korea, April 20-22, 2022.

1) **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*, Korea, April 20-22, 2022.

Project

14) **차세대 반도체 테스트 핸들러 냉각기 및 테스트 칩 개발**

JT CORP, 2026.05 ~ 2027.02.

13) **30W/mK 이상 열전도도를 갖는 PIM 패키지용 방열 소재 및 void 5% 이하 트렌치 충진 공정 개발**

Korea Planning & Evaluation Institute of Industrial Technology (KEIT), 2026.01 ~ 2027.12.

12) **고발열 1U 서버용 DTC-액침 하이브리드 냉각 기술 성능 검증**

LG Electronics, 2025.08 ~ 2026.12.

11) **파우치형 배터리의 열 균일성을 위한 열교환기-액침 냉각 시스템**

KAIST Undergraduate Research Participation (URP) Program, 2025.06 ~ 2025.12

10) **임베디드 근접 냉각 방식을 적용한 고효율 3D 칩렛 패키징 열관리**

Samsung Electronics, 2025.02 ~ 2027.02.

9) **인버터 냉각 성능 향상을 위한 2-phase 냉각 기법 연구**

HYUNDAI Motor Group, 2024.09 ~ 2026.02.

8) **열관리 고도화 응용을 위한 반도체 박막-공동 3 차원 구조 글로벌 기초연구실**

National Research Foundation of Korea (NRF), 2024.08 ~ 2027.04.

7) **고밀도 데이터센터 Direct-to-Chip 열관리 기술 및 Server-Rack 운영기술 개발**

Korea Energy Technology Evaluation and Planning (KETEP), 2024.07 ~ 2027.06

6) **냉각 실험을 위한 TTV(Thermal Test Vehicle) 제작**

Furiosa AI, 2024.05 ~ 2025.07.

5) **액침냉각용 열전달 유체 성능비교평가**

DL Chemical, 2024.05 ~ 2025.05.

4) **인버터 냉각 성능 향상을 위한 제트 충돌 냉각기 Micropost 최적화**

HYUNDAI Motor Group, 2023.03 ~ 2026.06.

3) **2.5D/3D 고전력 반도체 패키지 일체형 액체 냉각시스템 개발**

Samsung Electronics, 2021.09 ~ 2024.08.

2) **고출력인버터 냉각효율 향상을 위한 직접 냉각시스템 개발**

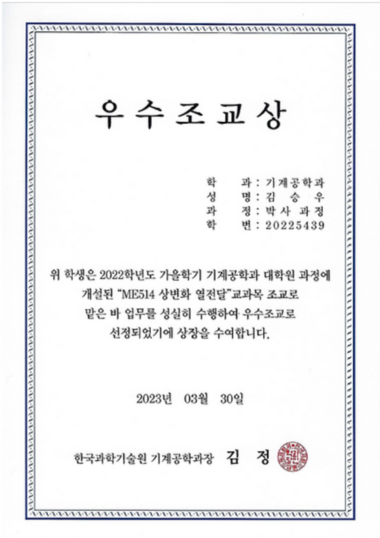
HYUNDAI Motor Group, 2021.03 ~ 2022.08.

1) **메탈폼 이용 액체냉각 최적화 설계**

LG Electronics, 2019.08 ~ 2020.08.

Awards

1) **Outstanding TA award**, *KAIST*, Korea, March 30, 2023.



우 수 조 교 상

학　　과 : 기계공학과
성　　명 : 김 승 우
과　　정 : 박사 과정
학　　번 : 20225439

위 학생은 2022학년도 가을학기 기계공학과 대학원 과정에 개설된 "ME514 상변화 열전달"교과목 조교로 맡은 바 업무를 성실히 수행하여 우수조교로 선정되었기에 상장을 수여합니다.

2023년 03월 30일

한국과학기술원 기계공학과장 김 정

2) **Young Scientist Award**, *The 21th International Symposium on Microelectronics and Packaging (ISMP 2023)*, Korea, October 27, 2023.

kmeps

No. 23-39

YOUNG SCIENTIST AWARD

is presented to

Seungwoo Kim[1], Seokkan Ki[1], Soosik Bang[1], Sanghyung Han[1], Junyong Seo[2], Chulmin Ahn[3], Suhyeon Maeng[3], Youngsuk Nam[1,†]

[1]Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Republic of Korea
[2]Energy Efficiency Research Division, Korea Institute of Energy Research (KIER), Daejeon 34129, Republic of Korea
[3]Research & Development Division, Hyundai Motor Group, Hwaseong, 18280, Republic of Korea

Title: Thermal Management in EV Inverters: Optimizing Jet Impingement Cooling with Micropost Integration

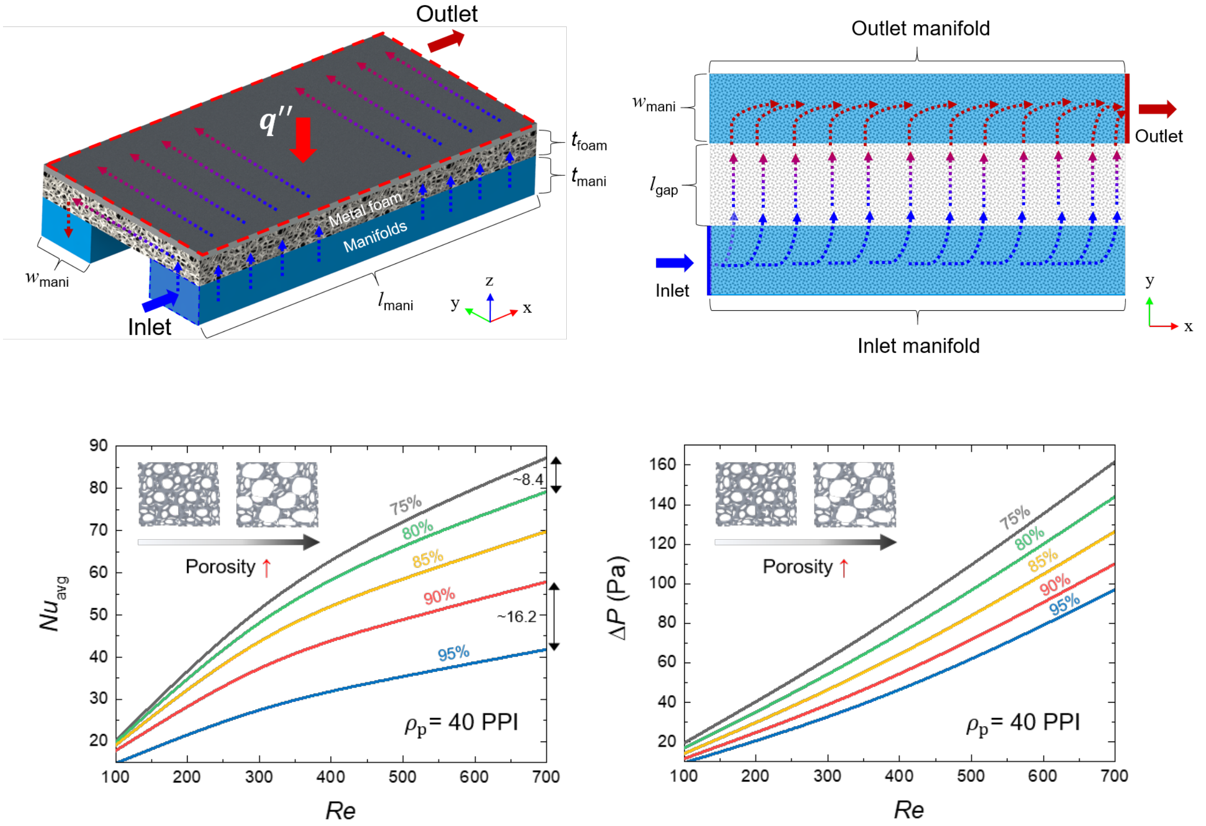
at The 21st International Symposium on Microelectronics and Packaging

27th October, 2023

Sayoon Kang
General President of ISMP 2023

Major Research Topics

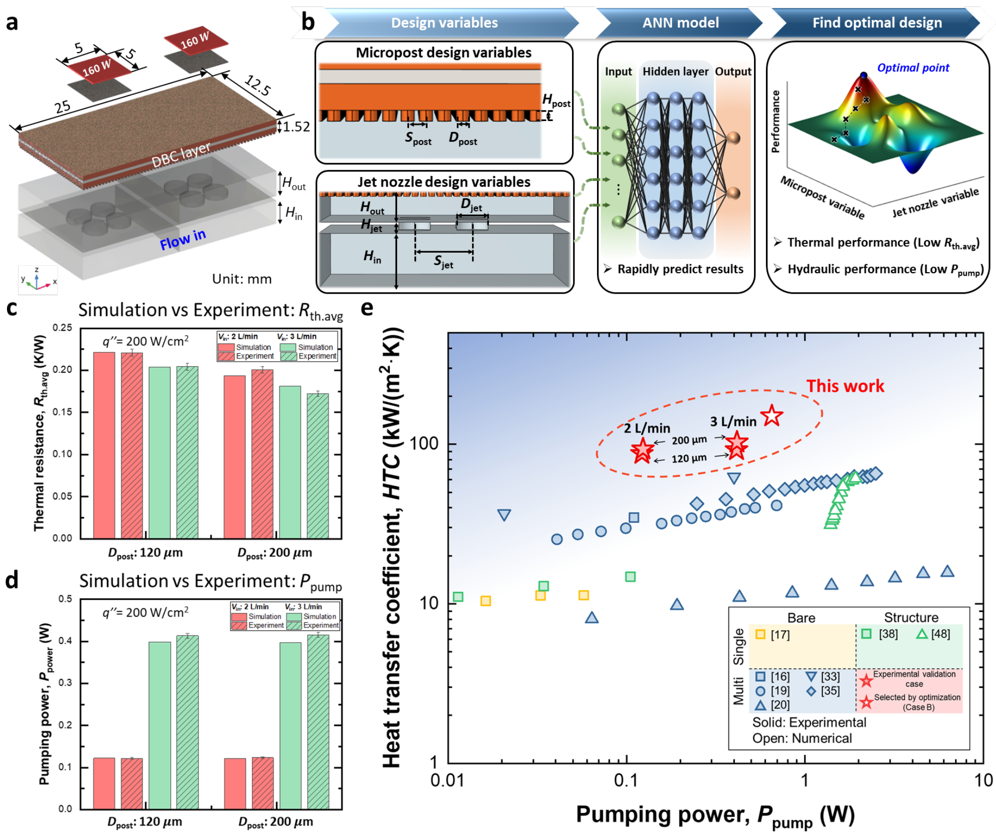
1) Development of a compact manifold–metal foam (MMF) cooling module for battery thermal management: a unit-cell-based design approach



S. Ki, ..., S. Kim, et al., "An energy-efficient battery thermal management system incorporating a porous metal-based multiscale flow manifold," *Energy Convers. Manage.*, 269, 116147 (2022).

High energy density battery packs consist of numerous closely spaced heat sources, which makes uniform temperature control difficult while keeping the cooling module compact and the pumping penalty low. This study proposes an alternative cooling module that combines the advantages of a manifold structure, which secures a high mass flow rate at a low initial pressure drop by dividing the flow into short parallel paths, with the advantages of porous media, which provide a large effective heat transfer area and uniform coolant distribution. To avoid the prohibitive computational cost of simulating a full-scale pack, a repeating unit geometry of the manifold–metal foam (MMF) configuration was defined and used as the design domain. Within this unit cell, the physical properties of the metal foam (porosity, pore density, and the resulting permeability and effective thermal conductivity) and the geometrical parameters of the flow channels were systematically investigated with respect to thermal resistance and pressure drop. This approach enabled identification of the optimal channel geometry and metal foam porosity at a fraction of the computational cost, and the resulting unit-cell design was subsequently scaled up into a full-scale battery thermal management system (BTMS), demonstrating that the unit-cell strategy is an efficient route for designing cooling modules with multiple distributed heat sources.

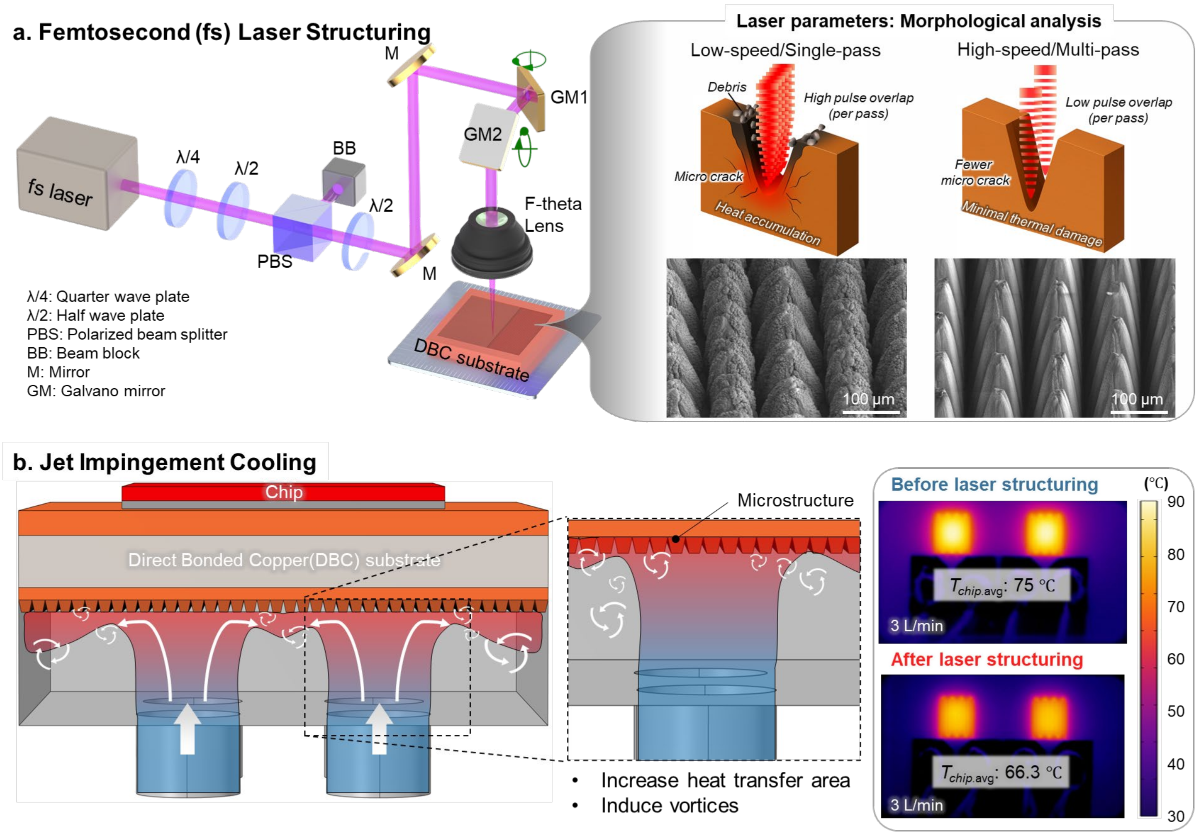
2) Development of energy-efficient jet impingement cooling for semiconductor thermal management using surrogate-model-based multi-objective optimization



S. Kim, et al., "Optimizing energy-efficient jet impingement cooling using an artificial neural network (ANN) surrogate model for high heat flux semiconductors," *Appl. Therm. Eng.*, 239, 122101 (2023).

This study presents the design optimization of a high-heat-flux (865.8 W/cm²) semiconductor thermal management system targeting an EV inverter. The cooling system employs jet impingement integrated with microposts. Thermal resistance ($R_{th,avg}$) and pumping power (P_{pump}) were evaluated through computational fluid dynamics (CFD) simulations by varying the jet nozzle parameters, micropost variables, and volume flow rate, and the CFD model was experimentally validated with less than 5% error. A surrogate model predicting $R_{th,avg}$ and P_{pump} was then developed using an artificial neural network (ANN). Sensitivity analysis identified the dominant design factors, and the Pareto optimal fronts were determined via the elitist non-dominated sorting genetic algorithm (NSGA-II). The approach provided multiple optimal designs across a broad spectrum of P_{pump} values within a short computation time (less than 200 seconds), owing to the rapid estimations of the ANN-based surrogate model. The experimentally validated design achieved a 65% improvement in heat transfer coefficient (~102.96 kW/(m²·K)) at a comparable pumping power level (~0.42 W) relative to previously reported jet impingement studies, while the optimization-selected design (Case B) projected a 140% enhancement (~150.2 kW/(m²·K)) for only a 63% rise in P_{pump} (~0.65 W). By exploring a wider range of multi-jet and micropost configurations than conventional parametric studies allow, higher performance was attained at equivalent energy cost. This work highlights the combination of jet impingement and microposts as a highly attractive strategy for high-heat-flux, multi-hot-spot applications.

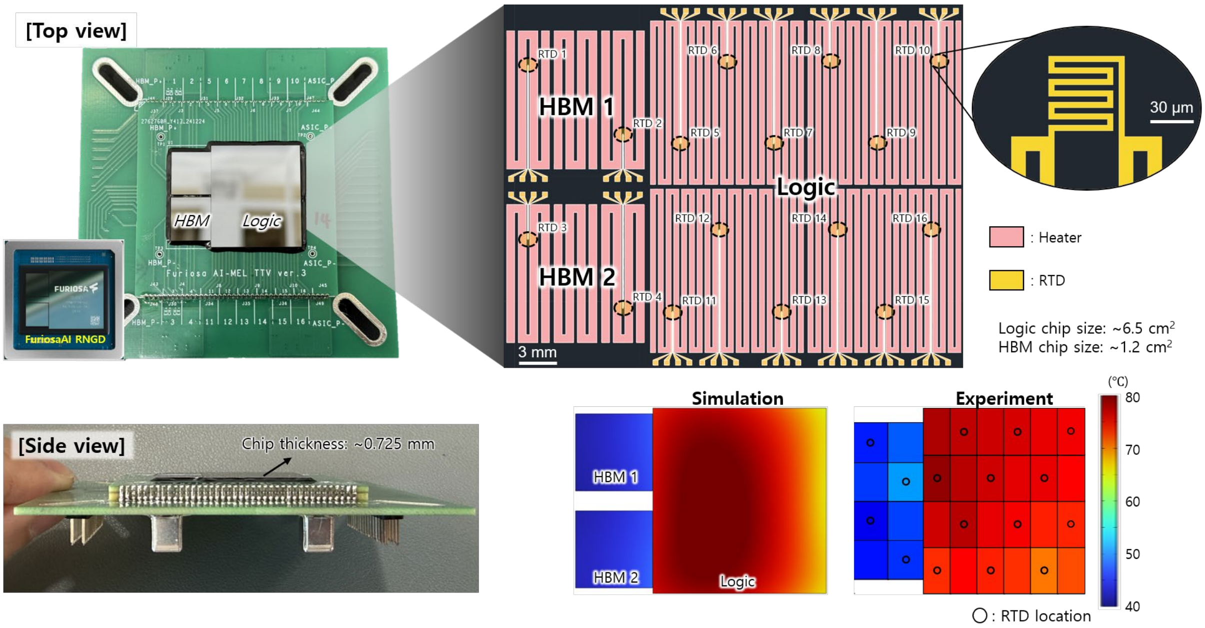
3) Femtosecond laser surface structuring for enhanced jet impingement cooling



S. Kim, et al., "Femtosecond laser structuring on direct bonded copper (DBC) for energy-efficient thermal management of power electronics," *Int. Commun. Heat Mass Transfer*, 178, 111922 (2026).

The increasing power density of electric vehicle (EV) inverters has amplified the importance of thermal management. Among available cooling methods, jet impingement provides a high heat transfer coefficient at local hot spots, and its performance can be further enhanced when combined with surface structures such as micro pin-fins. In this study, jet impingement cooling performance was improved by fabricating high-density microstructures directly on a direct bonded copper (DBC) substrate using a femtosecond laser. The structure depth was measured as a function of laser scan speed and the number of scanning passes, confirming that a "high-speed multi-pass" strategy (100 mm/s, 100 passes) is significantly more effective than a "low-speed single-pass" approach: for the same total processing time, it generated structures three times deeper (~210 μm) while minimizing debris generation. In-situ temperature measurements further showed an average process temperature 10 °C lower than the low-speed single-pass case, confirming a substantially reduced thermal load on the substrate during fabrication. Jet impingement experiments demonstrated that the microstructured surface fabricated under the optimal condition reduced thermal resistance by up to 19% compared with a bare surface. This work shows that femtosecond laser structuring is an effective and damage-free route for enhancing the thermal performance of power module substrates.

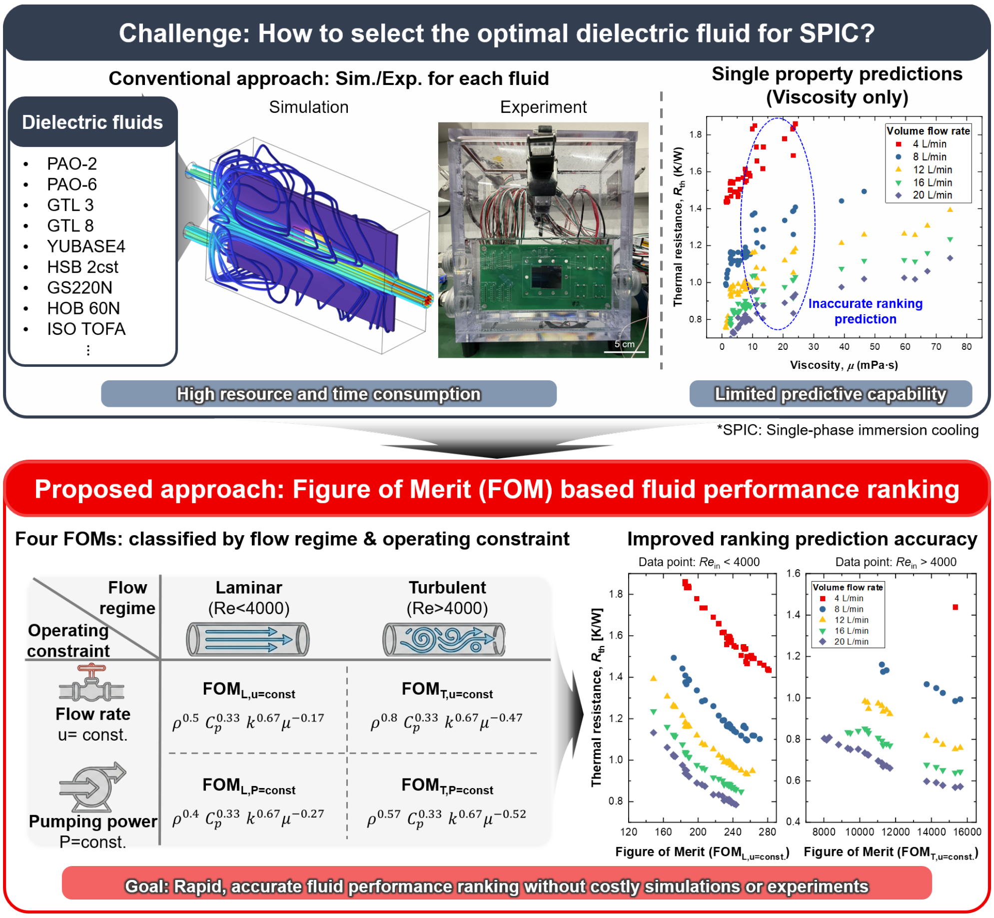
4) Development of a silicon-based thermal test vehicle (TTV) for chip-level thermal characterization



S. Kim, et al., "Figures of merit for dielectric fluid selection in single-phase immersion cooling classified by flow regimes and operating constraints," submitted.

As data center demand grows, accurate thermal evaluation at the chip and package level has become essential in the early stage of cooling-solution development. However, testing with actual commercial chips is prohibitively expensive and often impractical for repeated thermal experiments. Conventional alternatives (e.g. copper cartridge heaters, film heaters, and ceramic heaters) have been widely used and each offers distinct advantages, but they fundamentally fail to reproduce the material properties, thickness, and non-uniform heat generation of real silicon dies, limiting the fidelity of thermal test results. To address this limitation, a silicon-based TTV fabrication methodology was established in this study. The TTV integrates patterned thin-film heaters that emulate the power map of an actual chip, together with resistance temperature detectors (RTDs) distributed across the die to capture the full temperature distribution rather than a single average value. A 2.5D-type package configuration was implemented, consisting of a logic die (~6.5 cm²) and two HBM dies (~1.2 cm² each) with a chip thickness of ~0.725 mm, mounted on a dedicated PCB with individually controllable heating zones. Sixteen RTDs were calibrated and used to resolve hot-spot locations and in-plane gradients, and the measured temperature maps showed good agreement with the corresponding numerical simulation, validating the TTV as a reliable and cost-effective platform for evaluating advanced cooling solutions.

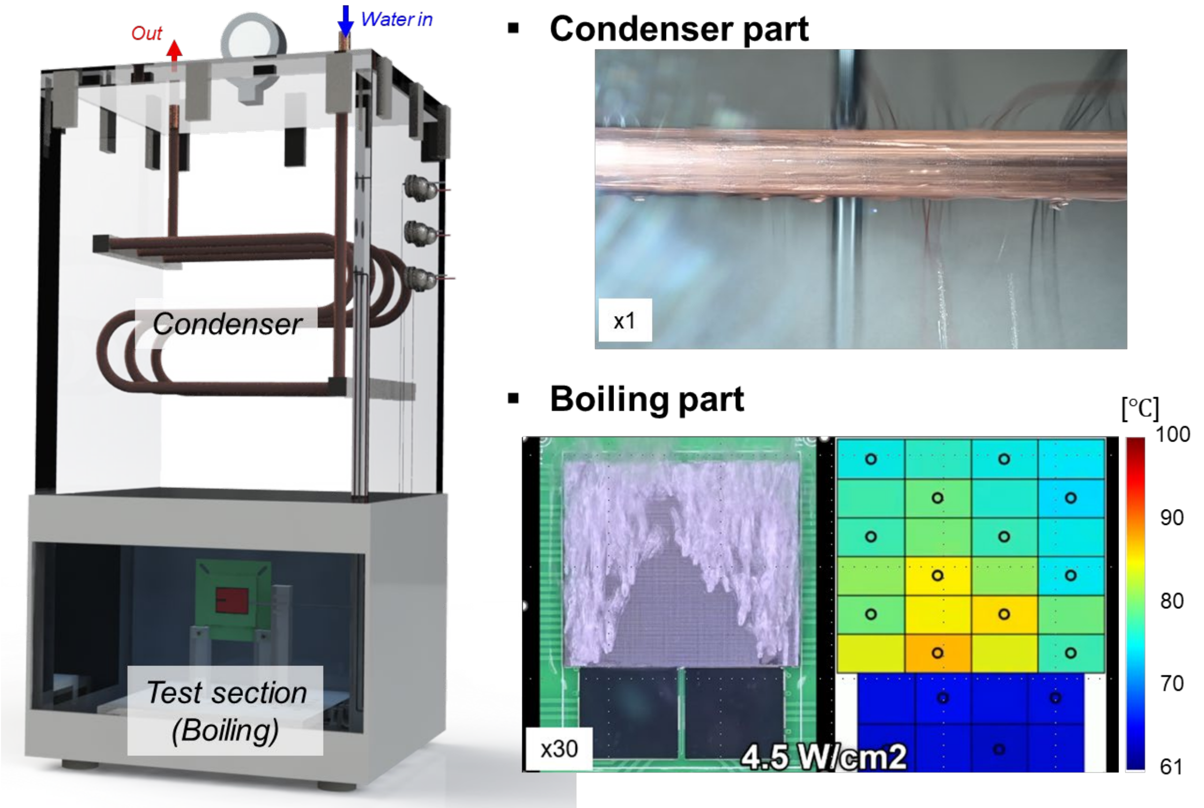
5) Figure of merit (FOM)-based dielectric fluid selection for single-phase immersion cooling (SPIC)



S. Kim, et al., "Figures of merit for dielectric fluid selection in single-phase immersion cooling classified by flow regimes and operating constraints," submitted.

Single-phase immersion cooling is a promising thermal management solution for high-power data center hardware, but selecting the optimal dielectric fluid among numerous commercially available candidates has conventionally required dedicated simulations or experiments for each fluid, consuming significant time and resources. Moreover, ranking fluids based on a single property such as viscosity provides limited predictive capability and frequently yields incorrect performance ordering. To overcome this, a figure of merit (FOM)-based fluid ranking framework was developed. Starting from the governing convective heat transfer correlations, four FOMs were derived and classified according to flow regime (laminar, Re < 4000 and turbulent, Re > 4000) and system operating constraint (constant flow rate and constant pumping power), each expressed as a power-law combination of density, specific heat, thermal conductivity, and viscosity. The proposed FOMs were validated against CFD results and immersion cooling experiments over a volume flow rate range of 4–20 L/min, showing a clear monotonic correlation with thermal resistance and substantially improved ranking accuracy compared with single-property predictions. This framework enables rapid and accurate screening of dielectric fluid candidates without costly case-by-case simulations or experiments.

6) Two-phase immersion cooling for 3D chiplet packages: system-level boiling and condensation performance



Manuscript in preparation.

The semiconductor industry has continuously improved chip performance through miniaturization, but as circuit line widths approach a few nanometers, further scaling becomes increasingly difficult. The path forward lies less in increasing transistor count on a single die and more in 3D chiplet packaging technologies, where multiple dies are vertically and laterally integrated. In such architectures, heat is generated in a highly concentrated and stacked manner, making thermal dissipation one of the most critical bottlenecks. Among the available solutions, two-phase immersion cooling is one of the most promising technologies, since it exploits the latent heat of vaporization of a dielectric fluid to remove high heat fluxes at a nearly uniform saturation temperature without requiring a dedicated coolant path for each die. This work aims to predict and optimize two-phase immersion cooling performance as a function of packaging design, including die arrangement, surface condition, and package orientation, which govern bubble departure and rewetting behavior. In addition, rather than evaluating the boiling side alone, the study takes a holistic system-level perspective in which boiling at the package surface and condensation at the heat exchanger are assessed together, since the condenser capacity ultimately determines the sustainable operating pressure and the overall cooling limit of the system.