

Next Gen Thermal Design and Technologies

Industry Co-Development Center (ICC) with Industry Consortium for
Next Gen Research and Workforce

Faculty Leads:

Anandaroop Bhattacharya, *IIT Kharagpur*
Amrit Ambirajan, *IISc Bangalore*



Industry Leads:

Hari Shanker Thakur, *Intel India*
Shailesh Joshi, *Toyota USA*



Global Collaborators:

Justin A. Weibel, *Purdue Univ.*
Satish Kumar, *Georgia Tech.*

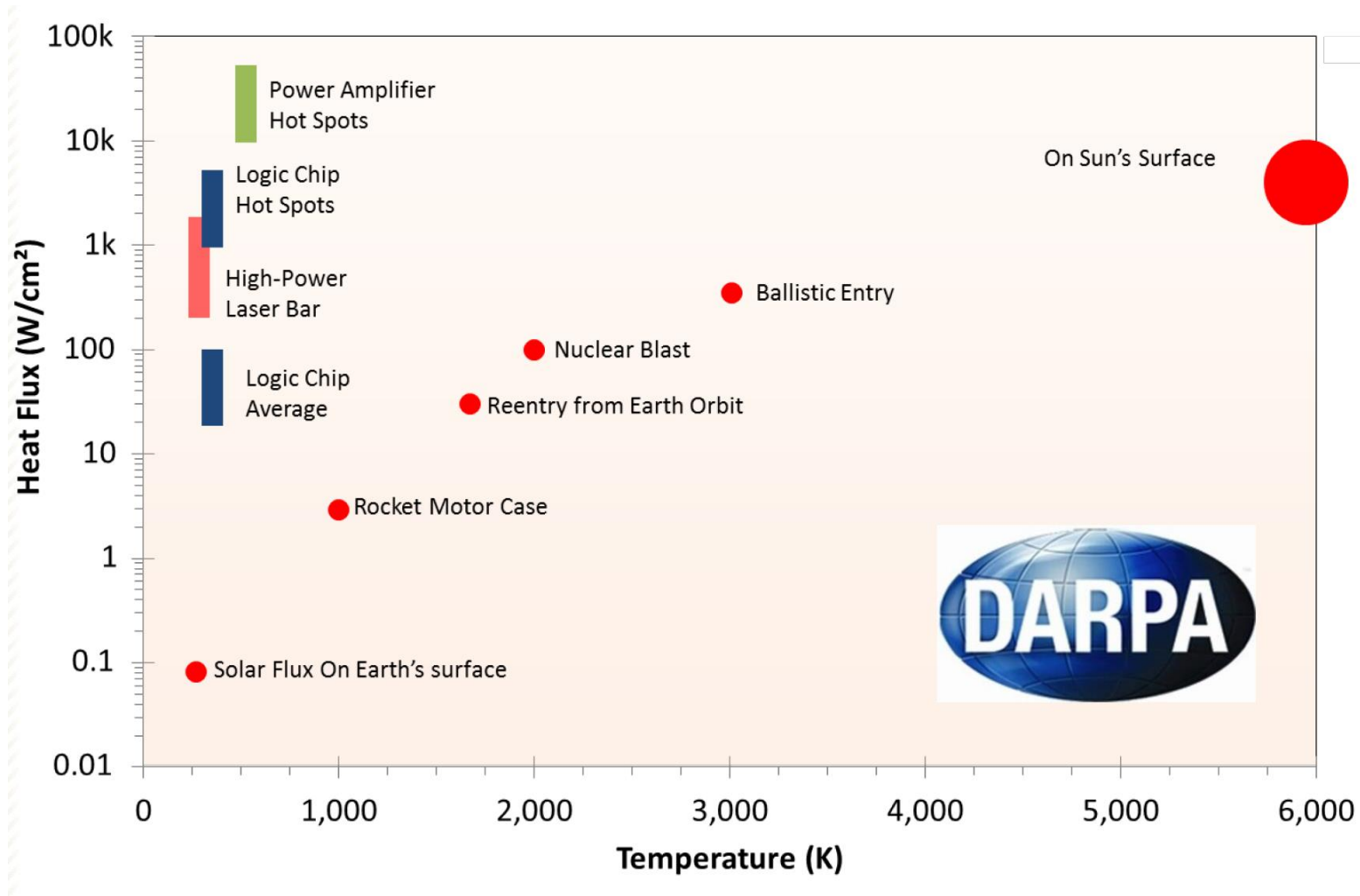


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Heat Flux Challenge



Problem of "astronomical" magnitude

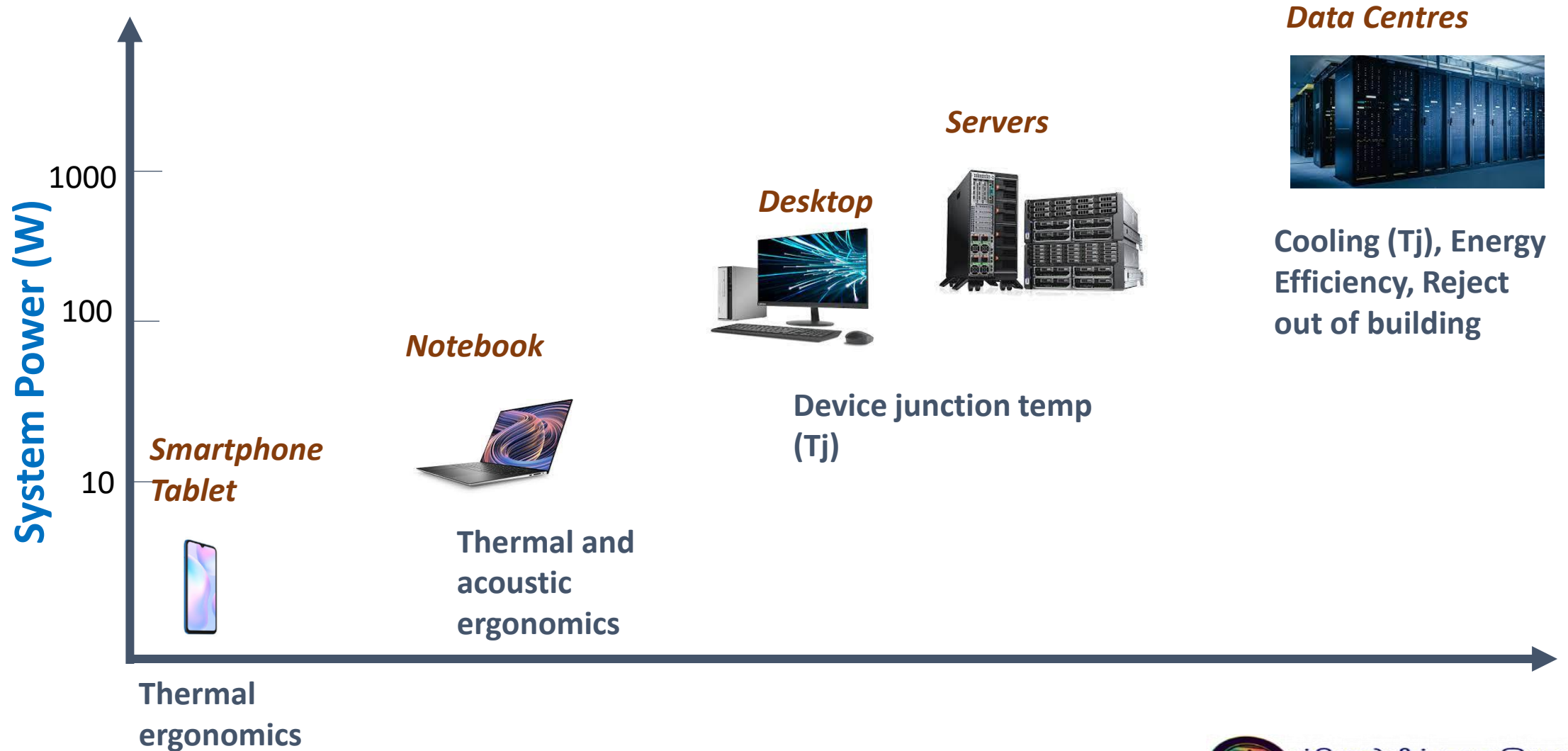
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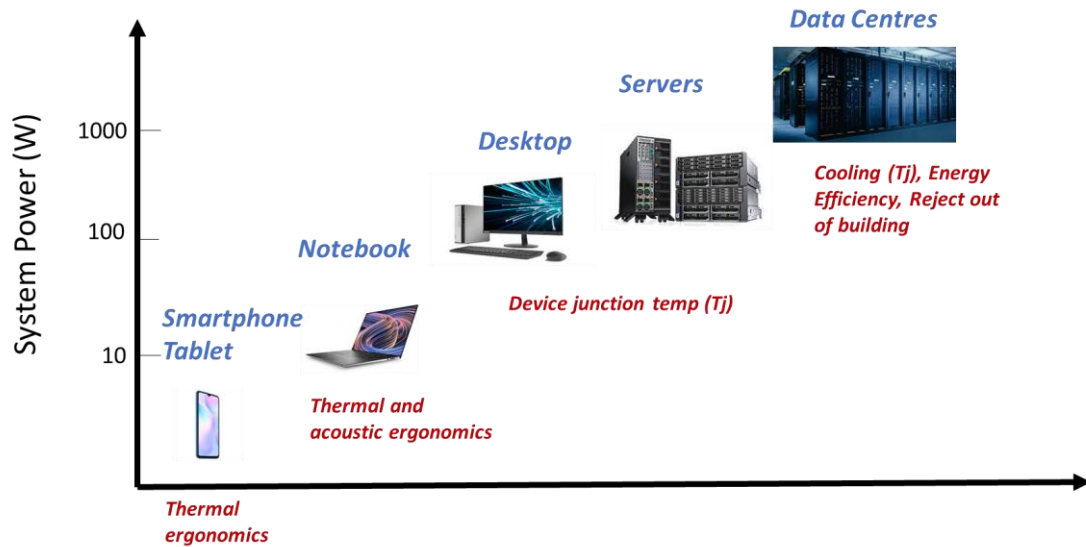
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Thermal Challenge Spectrum



Next Generation Industry Needs and Technical Challenges

Computing Needs



Servers with >2000W per xPU

Low acoustic air movers

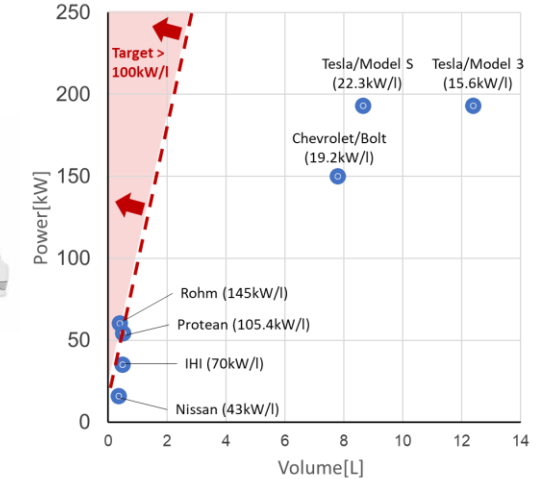
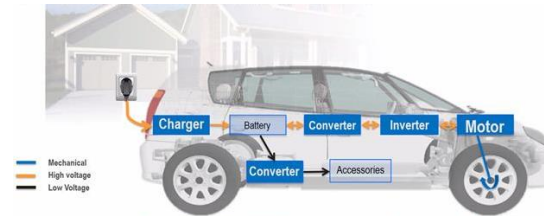
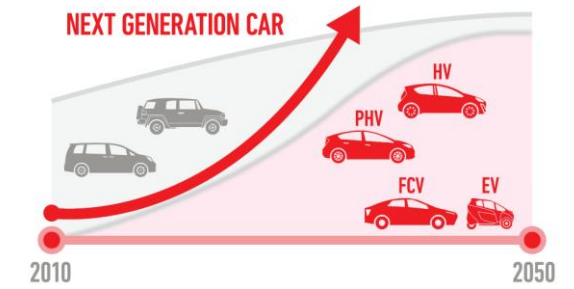
Passive Cooling techniques

High performance TIMs

Data Center EUF < 1.05

Multi-scale modelling of HI packages

Automotive Needs



High power inverter, converter, charger

Maximize volumetric power density

Cooling of WBG devices

Objectives

- Set up the research and education infrastructure for one or more India-wide Industry- centric COEs for **Industry Driven Research, Education and Workforce Development**
- **Research**
 - Define multi-disciplinary research Program consistent with industry needs involving industry engineers
 - Set up mini industry consortium in this ICC for industry collaboration and technology transfer
- **Education**
 - Train UG & PG students on topics related to next-gen Thermal Design and technologies
 - Develop hands-on educational labs in 10 or more institutions in the country
 - Incorporate this domain in regular curriculum through regular courses, electives and hands-on instructional laboratories
 - Short Term certificate and diploma courses for technical workforce development
- **Industry Partnership in Research and Education**
 - Research goals aligned with industry needs Industry Consortium driven research
 - Engineers on campus Co development of technologies
 - Working Professional Ph.D.s



Industry engagement and team work – 2 pillars of success

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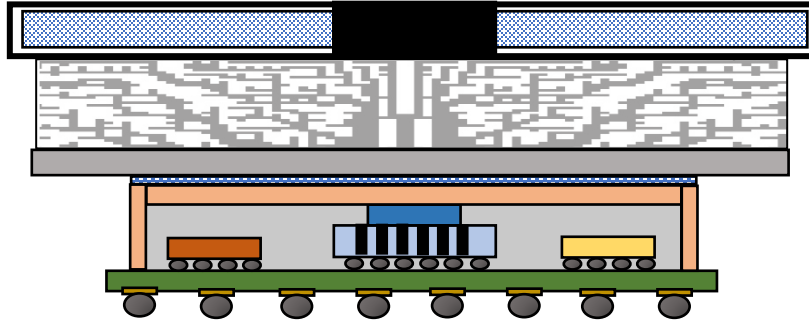


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Research Vision: Strategic Research Focus Areas

Cooling of Servers and Data Centres
- A. Bhattacharya



Low acoustic air movers
- A. Bhattacharya

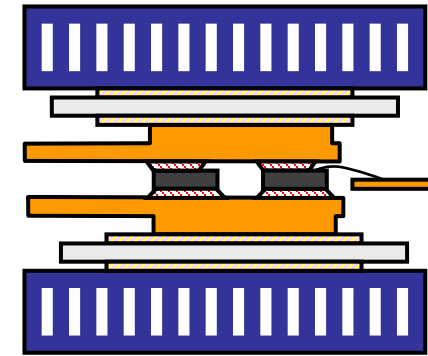
Passive Cooling
- A. Ambirajan

Multiphysics Modeling
- Somnath Roy

Thermal Interface Materials
- P. Dixit

Liquid cold plates
- S. Saha

2-phase flows
- R. Ganguly, S. Sett



LED cooling
- A. Ambirajan, S Dash

Boiling Heat Transfer
- A. Bhattacharya

This list is always evolving based on industry inputs
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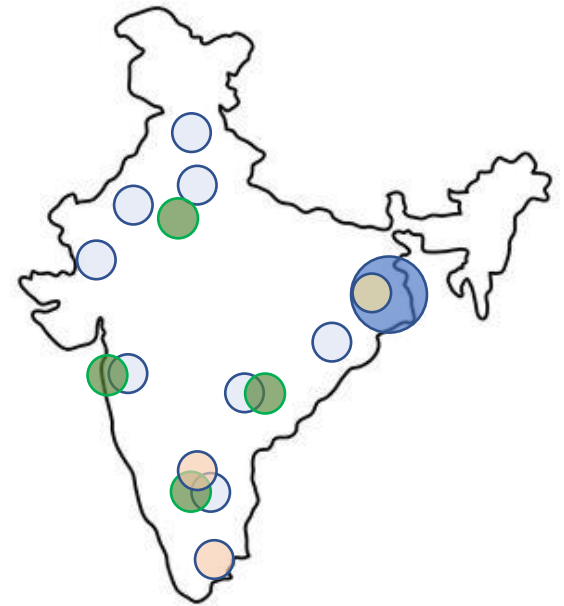
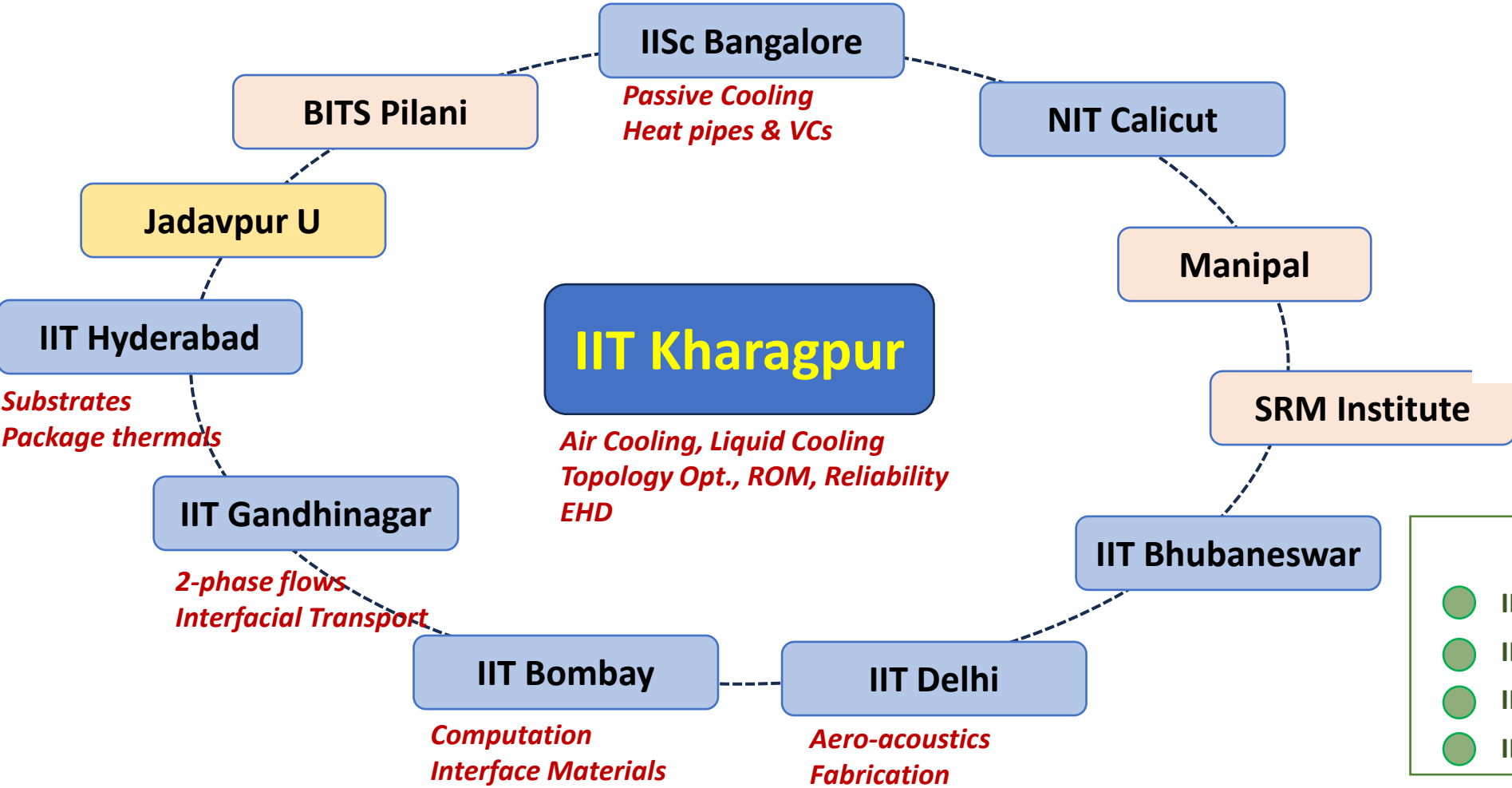
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ICC Team: India-wide, multidisciplinary Faculty, Global Collaborators and Industry Partners

Name	Institution
Anandaroop Bhattacharya	IIT Kharagpur (ME)
Amrit Ambirajan	IISc Bangalore (ME)
Somnath Roy	IIT Kharagpur (ME)
Monojit Chakraborty	IIT Kharagpur (Chem. E)
Pradeep Dixit	IIT Bombay (ME)
Sandip K. Saha	IIT Bombay (ME)
Susmita Dash	IISc Bangalore (ME)
Soumyadip Sett	IIT Gandhinagar (ME)
Krishnakant Agrawal	IIT Delhi (ME)
Soumya Subhra Nag	IIT Delhi (EE)
Shiv Govind Singh	IIT Hyderabad (EE)
Sumit Pramanick	IIT Delhi (EE)
Ranjan Ganguly	Jadavpur University
S. Manikandan	SRM IST
K. Anusuya	SRM IST
Nidhul K	MIT Maipal
Anoop Kanjirakat	MIT Manipal
Umesh Madanan	IIT Kanpur
Gangadhara Kiran Kumar L	NIT Calicut
Rohini Kumar Bandaru	NIT Calicut



Primary and Satellite ICC centres for TTD



- Cross ICC spokes**
- IIT Bombay (Power Electronics)
 - IIT Kanpur / Hyd (Substrates)
 - IISc Bangalore (Materials)
 - IIT Hyderabad (Photonics)

Each site will eventually have their differentiating expertise

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Global Academic and Industry Collaborators



Prof. Justin Weibel
Purdue University

- *Advanced electronics cooling*
- *Phase-change transport*
- *Additive manufacturing*
- *Topological optimization and ML-based design*
- *Microscale and nanoscale surface engineering*



Prof. Satish Kumar
Georgia Tech.

- *Electronics Cooling*
- *Micro-nano heat transfer*
- *Electro-thermal transport*
- *Nanoscale materials and devices*
- *CFD*



Dr. Hari Shanker Thakur
Intel India



Dr. Shailesh Joshi
Toyota Research Inst. NA

List of Interested Companies

Intel	IBM	AMD
Western Digital	Applied Materials	Indium
Ansys	IME Singapore	Qualcomm
CISCO	AT & S	Kaynes
Micron	Renesas	L&T Semiconductor
Toyota	NXP	Henkel

Industry Advisors

Dr. Ravi Mahajan – *Intel* Dr. Mark Macdonald – *former Intel*
Dr. Ravi Bhatkal – *McDermid Alpha* Dr. Madhu Iyengar - *Google*
Dr. Sreekant Narumanchi – *NREL* Dr. Vara Calmidi – *Microsoft*
Dr. Gaurang Choksi – *former Intel*

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Education Plan for Workforce Development

Development of hands-on instructional laboratories

- Formed across 10-12 institutions across the country
- Each labs equipped with 4-5 critical experiments involving air cooling, liquid cooling, passive thermal management, refrigeration systems and system teardown.
- Used for instructional purposes for regular students and outreach

Incorporation into regular curriculum:

- Senior UG and Masters level elective courses with both classroom and hands-on components
 - “Fundamentals of Electronic Packaging” course at IIT Kharagpur
 - Similar courses at IIT Kanpur, IIT Bombay, IISc, IIT Hyderabad
- Introduce electronic thermal management as part of fundamental courses

Aggressive Outreach

- Short term outreach courses (both online and offline) to create trained manpower for the industry
- NPTEL courses – *one course existing from IIT Kharagpur*

Expected Workforce Development

Year	5 Years	10 Years
B Techs	30	75
M Techs	30	75
PhDs	10	50
Courses and Outreach	1000	3000



Initial Research Project Proposals

- ❑ **Design and Development of Liquid Cooling and Immersion Cooling Technologies for Servers**
Anandaroop Bhattacharya (IIT Kharagpur), Soumyadip Sett (IITGGN), Ranjan Ganguly (Jadavpur U), Shiv Govind Singh (IITH)
- ❑ **Low Acoustic Fans and Air Movers for Laptop/ Server Cooling Design**
Anandaroop Bhattacharya (IIT Kharagpur), Somnath Roy (IIT Kharagpur), Krishnakant Agarwal (IIT Delhi)
- ❑ **Vapour Chamber- based Heat Spreader for High Heat Flux Electronics**
Susmita Dash, Amrit Ambirajan (IISc, Bangalore)
- ❑ **Liquid and Air Cooling of Automotive Power Modules using Innovative Heat Sink Designs**
Sandip Saha (IIT Bombay), Soumya Shubhra Nag (IITD), Sumit K. Pramanick (IITD)
- ❑ **Development of 2D Materials-based Thermal Interface Materials for Enhanced Cooling**
Pradeep Dixit (IIT Bombay)
- ❑ **Dust Mitigation Technologies for Higher Reliability of Thermal Solutions in Air Cooled Systems**
Anandaroop Bhattacharya (IIT Kharagpur)
- ❑ **Integrating porous metal foams with phase-change materials in a cold plate for thermal management of electronics**
S. Manikandan, K. Anasuya (SRM Institute of Science and Technology)
- ❑ **Embedded Cooling of Packages**
S. Manikandan, K. Anasuya (SRM Institute of Science and Technology)
- ❑ **Thermal management of PCBs utilizing pulsating air jet impingement cooling**
Anoop Kanjirakat, Nidhul K (Manipal Institute of Technology), Pawan K Singh (IIT Dhanbad)
- ❑ **Design and development of Loop Heat Pipe (LHP) for CPU cooling applications**
Anoop Kanjirakat, Nidhul K (Manipal Institute of Technology), Pawan K Singh (IIT Dhanbad)
- ❑ **Development of single-phase Immersion Cooling for Data Servers with nanoparticles**
Nidhul K, Anoop Kanjirakat, (Manipal Institute of Technology), Pawan K Singh (IIT Dhanbad)



Thermal Research Projects, Faculty Leads and Institutions

- ❑ **Integrated Vapor Chamber with MOHP/MHP Fins for High Performance CPU Processors**
 - PI: Gangadhara Kiran Kumar L (NIT Calicut), Co-PI : Rohinikumar Bandaru (NIT Calicut)
- ❑ **Lid Integrated Flat Heat Pipe with Extended HP/OHP Fins for 2.5D Semiconductor Packaging**
 - PI: Gangadhara Kiran Kumar L (NIT Calicut), Co-PI : Rohinikumar Bandaru (NIT Calicut)
- ❑ **Micro Pin-Fin Channel Cooling with Through-Silicon Vias (TSV) for Three-dimensional Integrated Chips**
 - PI: Gangadhara Kiran Kumar L (NIT Calicut), Co-PI : Rohinikumar Bandaru (NIT Calicut)
- ❑ **Development of a Peltier-Based Thermal Management System for High Heat Flux GPUs**
 - PI: Rohinikumar Bandaru (NIT Calicut), Co-PI : Gangadhara Kiran Kumar L (NIT Calicut)
- ❑ **Superfluid Helium Based Thermal Management System for Quantum Chips**
 - PI: Rohinikumar Bandaru (NIT Calicut), Co-PI : Gangadhara Kiran Kumar L (NIT Calicut)

Project 1: Design and Development of Liquid Cooling and Immersion Cooling Technologies for Servers

PI: Anandaroop Bhattacharya (IITKGP)

Co-PIs: Soumyadip Sett (IITGGN), Ranjan Ganguly (Jadavpur U), Shiv Govind Singh (IITH)

Objective - Investigate thermal technologies for cooling of high end servers and push the cooling envelope to 2.5 - 3kW per xPU

	Current state*	Proposed
Power level in server CPU/GPU	1500 W	2500 W for same T_j
Junction temperatures	100 - 105 °C	90 – 95 °C at same power and ambient
Energy Utilization Factor (EUF)	1.2	1.10- 1.05
Immersion Fluid	PFAS fluids	Enchantment techniques in non-PFAS fluids

References*

- Ahmed A. Alkrush, Mohamed S. Salem, Osama. Abdelrehim, A.A. Hegazi, Data Centers Cooling: A Critical Review of Techniques, Challenges, and Energy Saving Solutions., International Journal of Refrigeration (2024), <https://doi.org/10.1016/j.ijrefrig.2024.02.007>.
- COOLERCHIPS: Cooling Operations Optimized for Leaps in Energy, Reliability, and Carbon Hyperefficiency for Information Processing Systems, Advanced Research Projects Agency – Energy, U.S. Department of Energy (2023), <https://arpa-e.energy.gov/technologies/programs/coolerchips>

Cold plate design

Topology optimized 3D printed Cold plates



<http://temisth.com/the-cold-plate-for-gpu-card-is-printed/>

<https://www.ntop.com/resources/case-studies/cold-plate-automotive-power-electronics/>

Cold plates mounted server rack



<https://www.servethehome.com/wiwynn-liquid-cooling-for-8kw-of-ai-accelerators-shown-oam-oai-ocp-ubb/>

Immersion cooling

Tank with submerged servers



<https://www.grcooling.com/>

1- Φ immersion cooling



<https://www.akcp.com/blog/liquid-cooling-data-centers/>

2- Φ immersion cooling



<https://www.techspot.com/news/95323-intel-designing-new-hardware-immersion-cooling-mind.html>



Project 2: Low Acoustic Fans and Air Movers for Laptop/Server Design

PI: Anandaroop Bhattacharya (IITKGP)

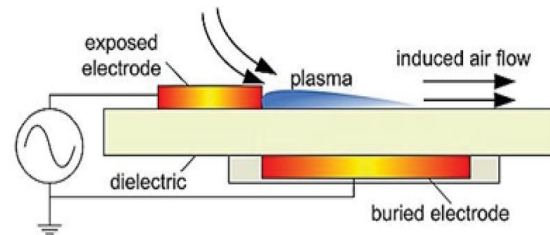
Co-PIs: Somnath Roy (IIT Kharagpur), Krishnakant Agarwal (IIT Delhi)

Objective – a. Reduce acoustic noise of fans/blowers
b. Alternate air-movers for local enhancement

- Noise absorbing materials for workstations and servers
- Dielectric barrier discharge (DBD) based localized air movers under AC electric field
- Active and passive noise cancellation techniques for mobile systems



Volumetric Resistance Blower (VRB)¹
Girhe et al. (2021)



Dielectric Barrier Discharge (DBD)
<https://knepublishing.com>

	Current state*	Proposed
Sound Pressure Level (SPL) Laptop	35 dBA	32dBA @same flow rate
Sound Pressure Level (SPL) Server	70 dBA	60 dBA
Sharpness	Baseline	20% Lower
Airflow (CFM) - Laptop	2-3 CFM	2.25 – 3.3 CFM (iso acoustic)

Non-Conventional Blower/ Mover	Proposed
DBD Air mover Airflow (CFM)	3 CFM @ 0 static pressure
DBD Air mover power consumption	<2W
Synthetic jet air mover air flow (CFM)	3 CFM @ 0 static pressure
Synthetic Air mover SPL	<17 dBA

References*

- Girhe, S., Cardenas, R., MacDonald, M., and Bhattacharya, A. "Numerical Modeling and Simulation of a Volumetric Resistance Blower Using Porous Rotor," ASME. J. Electron. Packag., 143(2) (2021), <https://doi.org/10.1115/1.4048036>
- Alastair Hales, Xi Jiang, "A review of piezoelectric fans for low energy cooling of power electronics," Applied Energy, 215, (2018), <https://doi.org/10.1016/j.apenergy.2018.07.044>



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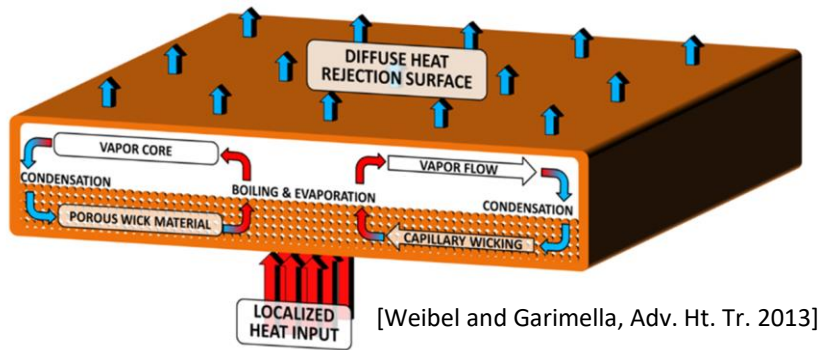
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Project 3 - Vapour Chamber- based Heat Spreader for High Heat Flux Electronics

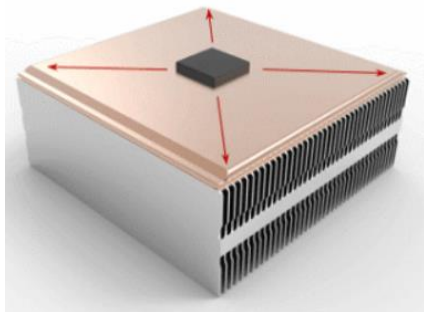
PI: Susmita Dash (IISc, Bangalore)

Co-PIs: Amrit Ambirajan (IISc, Bangalore)

Objective: Develop a vapour chamber as an advanced passive two-phase heat spreader for high heat flux electronics ($>300\text{W}/\text{cm}^2$, over approximately 1cm^2).



[Weibel and Garimella, Adv. Ht. Tr. 2013]



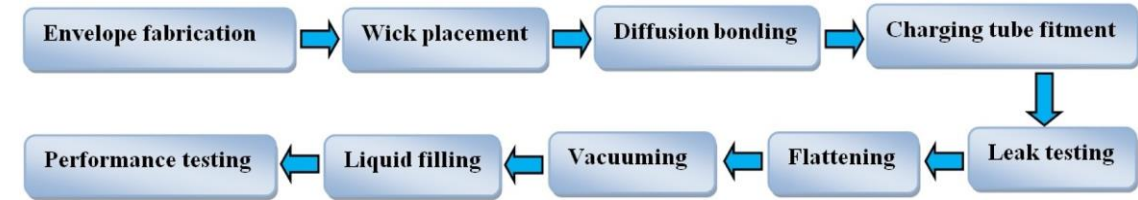
[<https://celsiainc.com/technology/vapor-chamber/>]

Proposed vs. Prior Art

	Current state*	Proposed
Heat flux capacity (W/cm^2)	100-200	> 300
Effective thermal conductivity ($\text{W}/\text{m}^2\text{K}$)	5000-20000	> 10000
Overall thermal resistance (K/W)	~ 0.3	< 0.2
Thickness (mm)	2.5 to 4	< 2

Approach

- Development of high heat flux structured surfaces
- Advanced assembly and fabrication methods



[Chitnis, et.al., JMES. 2022]

Example of a possible fabrication approach

Outcome and Impact

- Demonstration of advanced *vapour chamber* heat spreader technology at TRL 6
- Design, fabrication, testing and mounting methodology

References*

- Bar-Cohen, A., et.al., "Two-Phase Thermal Ground Planes: Technology Development and Parametric Results," ASME Journal of Electronic Packaging, Vol. 137, pp. 010801, 2015.
- Cheng, X., et.al., "Recent advances in the optimization of evaporator wicks of vapor chambers: From mechanism to fabrication technologies," Applied Thermal Engineering, Vol. 188, pp. 116611, 2021.



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Project 4: Liquid and Air Cooling Automotive Power Modules using Innovative Heat Sink Designs

PI: Sandip Kumar Saha (IITB)

Co-PIs: Soumya Shubhra Nag (IITD), Sumit K. Parmanick (IITD)

Objective - Investigate, design and demonstrate cooling technologies for high power PCB-embedded SiC MOSFET Half-Bridge Module for Electric Vehicles to dissipate 0.15 W/mm^2 heat flux with a temperature limit of $150\text{-}175 \text{ }^\circ\text{C}$.

- Standalone heat sink design for air cooled system.
- Standalone and integrated heat sink design for liquid cooling system.
- System level modelling and simulation platforms.

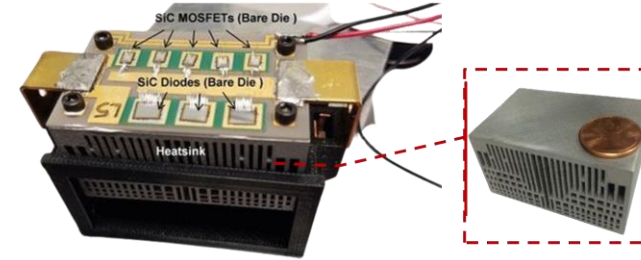
	Current state*	Proposed
Air Cooling for MOSFET	1 W/cm ²	2.5 W/cm ²
Liquid Cooling	200 – 900 W/cm ²	1 kW/cm ²

References*

1. Y. Wang, S. Jones, A. Dai, G. Liu, Reliability enhancement by integrated liquid cooling in power IGBT modules for hybrid and electric vehicles, *Microelectronics Reliability* (2014) 54(9–10), pp. 1911-1915
2. Y. Chen, B. Li, X. Wang, Y. Yan, Y. Wang, F. Qi, Investigation of heat transfer and thermal stresses of novel thermal management system integrated with vapour chamber for IGBT power module, *Therm. Sci. Eng. Prog.*, 10 (2019), pp. 73-81

Air cooling system

Power module with GA optimized heatsink



<https://ieeexplore.ieee.org/document/8821419>

SiC inverter with air cooled heat sink



<https://www.osti.gov/servlets/purl/1474508>

Liquid cooling system

Cold plate mounted IGBT module



<https://www.qats.com/cms/tag/power-brick/>

Direct liquid cooled XM3 module



https://www.how2power.com/newsletters/2010/articles/H2PToday2010_design_Wolfspeed.pdf?NOR_EDIR=1

Outcome and Impact - Recommending heat sinks for PCB-embedded SiC MOSFET Half-Bridge Module and commercialized T-type and B6 module-based traction inverters.



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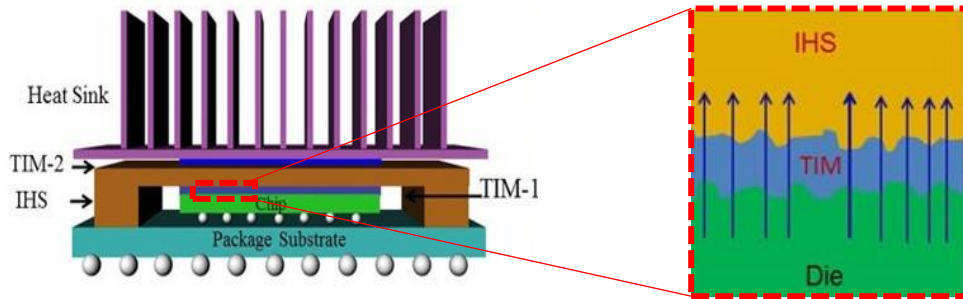
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Project 5: Development of 2D Materials-based Thermal Interface Materials (TIM) for Enhanced Cooling

PI: Pradeep Dixit (IIT Bombay)

Objective: Develop a Carbon-based materials (Graphene/CNT/MoS2) based Thermal interface Materials (TIM) to achieve a 10x higher heat dissipation in high-density electronic packaging applications.

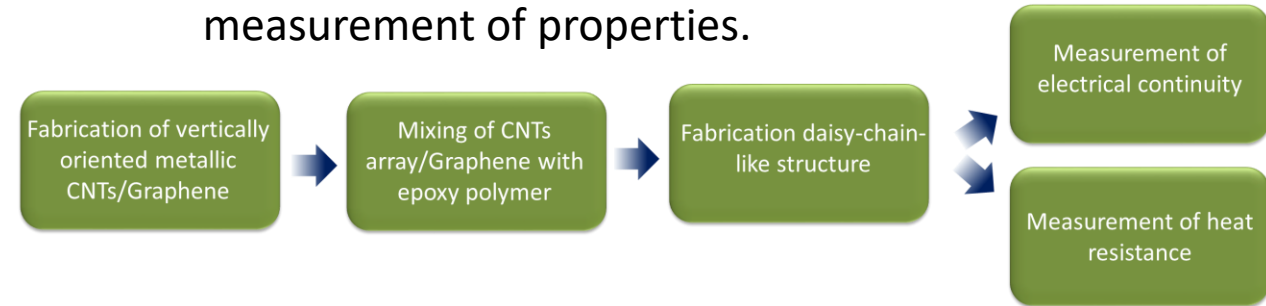


Proposed vs. Prior Art

	Current state	Proposed
TIM	Ceramic particles in epoxy	Graphene/CNTs
Effective thermal conductivity	1.5 – 10 W/m-K	>20 W/m-K

Approach

- Growing vertically oriented array of metallic CNTs
- Transferring the CNTs array and mixing with epoxy polymer
- Fabrication of a daisy-chain-like test structures for measurement of properties.



Outcome and Impact

- Demonstration of advanced Carbon-materials based thermal interface material (TIM)
- Design, synthesis, and characterization methodology

References*

1. Zhang et al, "Recent progress in the development of thermal interface materials: a review", Phys. Chem. Chem. Phys., 23, 753-776 (2021).
2. Dai et al, "Ultralow Interfacial Thermal Resistance of Graphene Thermal Interface Materials with Surface Metal Liquefaction", Nano-Micro letters, 15, pp. 8 (2022).



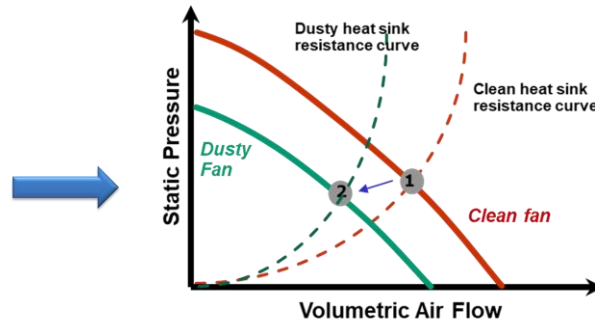
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Project 6: Dust Mitigation Technologies for Higher Reliability of Thermal Solutions in Air Cooled Systems

PI: Anandaroop Bhattacharya (IITKGP)

Objective - Investigate technologies/techniques to arrest degradation in thermal performance of air cooled solutions due to accumulation of dust



Proposed Approach

Anti-static coating paint on heat sinks & fan blades

Periodic reverse rotation of fan blades

Rapping mechanism via periodic vibrations in heat sink base

Technology demonstration through testing on test vehicles.

Outcome and Impact

- Development and demonstration of anti dust technologies
- Design, testing and periodic maintenance methodology

References*

1. Ashley Matuska and Rain Kengly, 3 Helpful Ways to Keep Dust Out of Your Computer (2023), <https://www.wikihow.com/Keep-Dust-Out-of-The-Computer>
2. How to Prevent Dust Build-Up Inside Electrical Cabinets, Parker (2018), <https://blog.parker.com/site/usa/details-home-page/how-to-prevent-dust-build-up-inside-electrical-cabinets-us>



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	Current state	Proposed
Sink to Ambient thermal resistance degradation (per yr)	> 20% (if not cleaned)	< 10%
Sound Pressure Level (SPL)	Not quantified but substantial and unergonomic	Increase limited to 1-3 dBA without cleaning

9/11/2025

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Project 7: Embedded cooling of 3D stacked dies (Package level cooling)

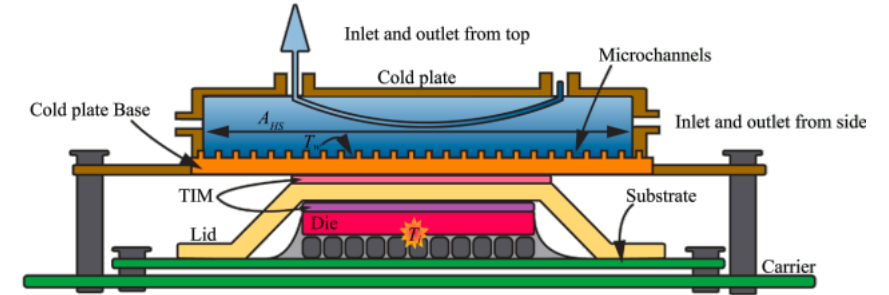
PI: Dr. K. Anusuya (SRM IST)

Co-PIs: Dr. S. Manikandan (SRM IST), Dr. P. Balakrishnan (SRM IST)

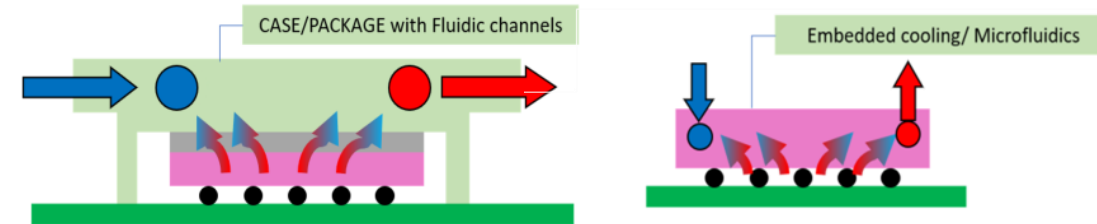
Objective – Analyze the thermal performance of package-level embedded cooling system using
 (a) microchannel integrated heat spreader
 (b) embedded cooling within the silicon die

- Reduce the dependence of the second thermal interface material (TIM-2)
- This technique can be employed in cooling of 3-D stacked dies.
- Single phase and two-phase cooling can be studied

	Current state*	Proposed
Usage of TIM-1 and TIM-2	Yes (single and two-phase cold plates)	Only TIM-1
Junction temperature (T_j)	90 °C	< 80 °C (for similar operating conditions)
Fluid	Water	Dielectric fluid (single phase)



Present status of cold plate [3]



Package level cooling [2]

References*

- Rangarajan et al. "A Review of Recent Developments in "On-Chip" Embedded Cooling Technologies for Heterogeneous Integrated Applications." Engineering (2023). <https://doi.org/10.1016/j.eng.2022.10.019>
- Ramakrishnan, Bharath, et al. "CPU overclocking: A performance assessment of air, cold plates, and two-phase immersion cooling." IEEE Transactions on Components, Packaging and Manufacturing Technology 11.10 (2021): 1703-1715. [10.1109/TCPMT.2021.3106026](https://doi.org/10.1109/TCPMT.2021.3106026)
- Azarifar et al. "Liquid cooling of data centers: A necessity facing challenges." Applied Thermal Engineering (2024): 123112. <https://doi.org/10.1016/j.applthermaleng.2024.123112>



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Project 8: Integrating porous metal foams with phase-change materials in a cold plate for thermal management of electronics

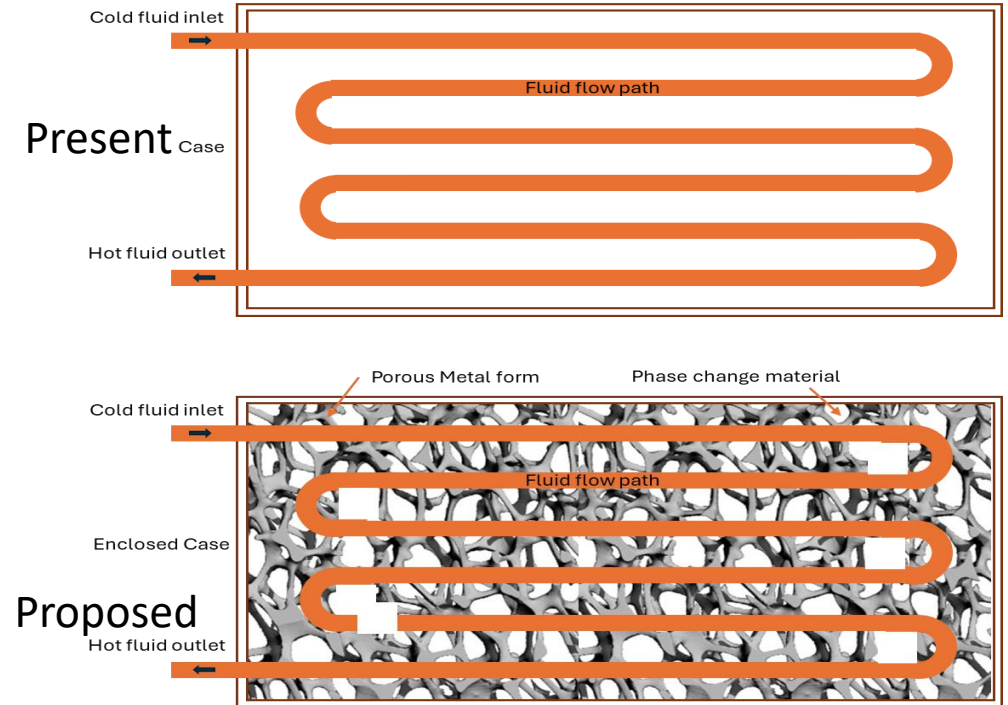
PI: Dr. S. Manikandan (SRM IST)

Co-PI: Ms. K. Anusuya (SRM IST)

Objective – Analyze the thermal performance of a cold plate with phase-change materials encapsulated in porous metal foams

- ❑ Porous metal foams have a high surface area due to their porous structure, which enhances heat transfer.
- ❑ PCMs absorb and store large amounts of heat as they change phase from solid to liquid. The high surface area helps distribute heat effectively to the PCM, ensuring a uniform phase change and efficient thermal management.

	Current state*	Proposed
TDP	1500 W	2000 W
Junction temperature (T_j)	98 - 103 °C	< 95 °C (for similar operating conditions)
Thermal Resistance (°C/W) $(T_{case} - T_{in})/Q$	0.1 to 0.04 (3.5 to 5.5 LPM)	0.06 to 0.02 (3.5 to 5.5 LPM)
Fluid	EG / PG	PG+ GnP for single phase & refrigerants for two phase



References*

1. Haghshenas, Kawsar, et al. "Enough hot air: the role of immersion cooling." Energy Informatics 6.1 (2023): 14. <https://doi.org/10.1186/s42162-023-00269-0>
2. Zheng, Jinquan, et al. "A novel thermal management system combining phase change material with wavy cold plate for lithium-ion battery pack under high ambient temperature and rapid discharging." Applied Thermal Engineering 245 (2024): 122803. <https://doi.org/10.1016/j.applthermaleng.2024.122803>



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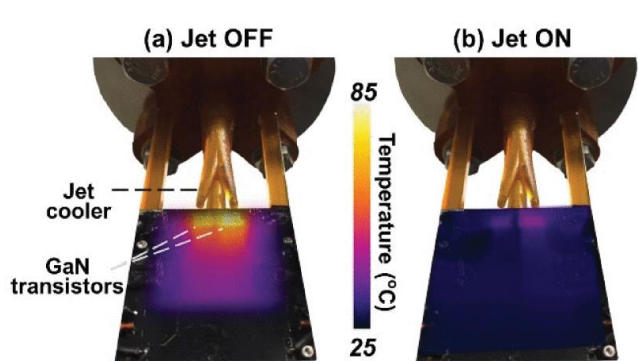
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Project 9: Thermal management of PCBs utilizing pulsating air jet impingement cooling

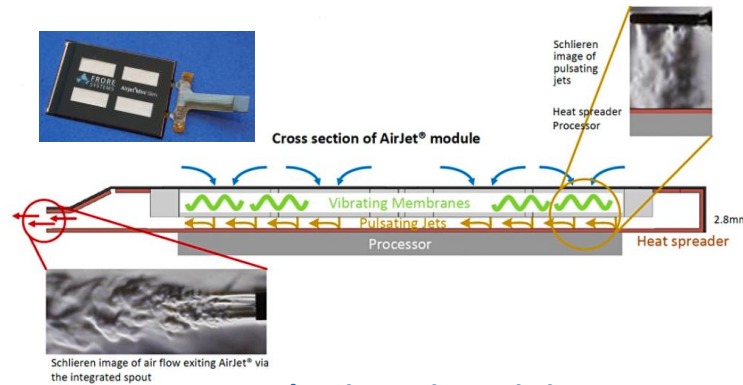
Investigators: Anoop Kanjirakat, Nidhul K (MIT, Manipal),
Pawan K Singh (IIT Dhanbad)

Objectives – a. Develop array of miniaturized nozzles air jets
b. Pulsating air jets for enhanced heat transfer

- ❑ Thermal management of GaN transistors on PCBs using single and array of miniaturized air jet impingement
- ❑ Localized hotspot targeted impingement on PCB for improved efficacy
- ❑ Multiple-pulsating air jets that enhance mixing in the boundary layer



Air jet cooling of GaN transistors²
Kwon et al. (2019)



**Pulsating micro air jets:
AirJet® by Frore Systems**
<https://www.froresystems.com/>

	Current state*	Proposed
Cooling technique widely used	Heat sinks Fans	Single and multiple array of air jet impingement
Maximum Allowable temperature	150°C	Maintain 20-30% lower
Nozzle diameter	2-5mm	~ 1mm
Cooling rate	5 °C/sec	8-10 °C/sec
Configuration	1-2 jets non-pulsating	Flexible design for top/bottom impingement with array of miniaturized pulsating jets

References*

- Sarkar, S., Gupta, R., Roy, T., Ganguly, R., & Megaridis, C. M. (2023). Review of jet impingement cooling of electronic devices: Emerging role of surface engineering. *International Journal of Heat and Mass Transfer*, 206, 123888. <https://doi.org/10.1016/j.ijheatmasstransfer.2023.123888>
- Kwon, B., Foulkes, T., Yang, T., Miljkovic, N., & King, W. P. (2019). Air jet impingement cooling of electronic devices using additively manufactured nozzles. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, 10(2), 220-229. <https://doi.org/10.1109/TCPMT.2019.2936852>



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Project 10: Design and development of Loop Heat Pipe (LHP) for CPU cooling applications

Investigators: Anoop Kanjirakat, Nidhul K (MIT, Manipal), Pawan K Singh (IIT Dhanbad)

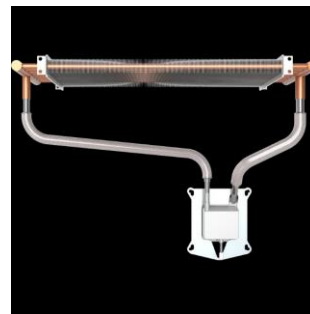
Objective – Thermal management solution for chip level cooling using Loop Heat Pipe (LHP) with heat dissipation in the range of 150 W per CPU

- ❑ Usage of LHP for higher heat dissipation
- ❑ Loop heat pipe design without a compensation chamber
- ❑ Flexible design that be mounted directly on CPU

	Current state*	Proposed
Power level in Intel Xeon processor	120 W	150 W (with air cooled condenser)
Junction temperature	100 - 105 °C	85-90 °C
Wick design	Uniform wick	Variable wick structure
Max chip temperature	85°C	<70°C
Working fluid	water	with fluid additives



Loop Heat Pipe¹
Li et al. (2021)



Cooling a processor dissipating 300W
[https://www.calyos-
tm.com/applications/personal-computers](https://www.calyos-tm.com/applications/personal-computers)

References*

1. Li, J., Zhou, G., Tian, T., & Li, X. (2021). A new cooling strategy for edge computing servers using compact looped heat pipe. Applied Thermal Engineering, 187, 116599. <https://doi.org/10.1016/j.applthermaleng.2021.116599>
2. Ahmed, S., Pandey, M., & Kawaji, M. (2022). Loop heat pipe design: an evaluation of recent research on the selection of evaporator, wick, and working fluid. Journal of Thermal Science and Engineering Applications, 14(7), 070801. <https://doi.org/10.1115/1.4052593>



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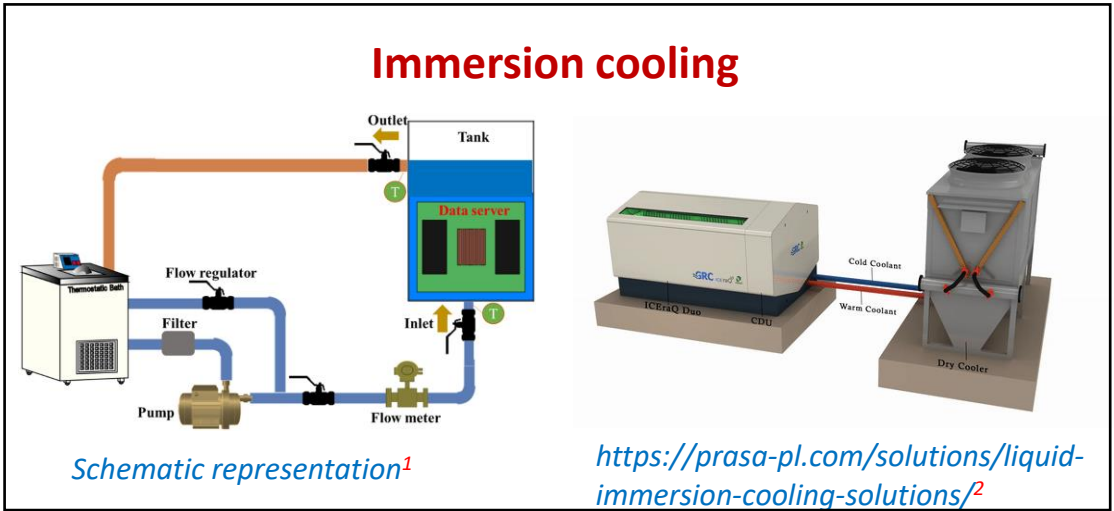
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Project 11: Development of single-phase Immersion Cooling for Data Servers with nanoparticles

Investigators: Nidhul K. (MIT Manipal), Anoop Kanjirakat (MIT Manipal)

Objective - Investigate the thermo-hydraulic performance of high-end servers and increase the heat dissipation capacity for dynamic environments

	Current state*	Proposed
Power	1000 W	1.5 to 2 kW
Junction temperatures	100 - 105 °C	90 – 95 °C
Energy Utilization Factor (EUF)	1.20 (for air)/1.05 (for liquids)	1 to 1.02
Coolants	Air/PFAS coolant	Hydrocarbon-based coolant with nanoparticles



Advantage: Scalability and lower EUF

Allows data center operators to expand their infrastructure unlike indirect cooling, an advantage in dynamic environments where rapid expansion may be required.

Coolant: Polyalphaolefin³

- Lower viscosity at higher temperature (> 50°C)
- With nanoparticle addition, thermal conductivity can be enhanced

References*

1. Shrigondekar, H., Lin, Y.C. and Wang, C.C., 2023. Investigations on performance of single-phase immersion cooling system. International Journal of Heat and Mass Transfer, 206, p.123961., <https://doi.org/10.1016/j.ijheatmasstransfer.2023.123961>.
2. <https://prasa-pl.com/solutions/liquid-immersion-cooling-solutions/>
3. <http://www.bemcoinc.com/PAO1/Index2.htm>

Project 12: Integrated Vapor Chamber with MOHP/MHP Fins for High Performance CPU Processors

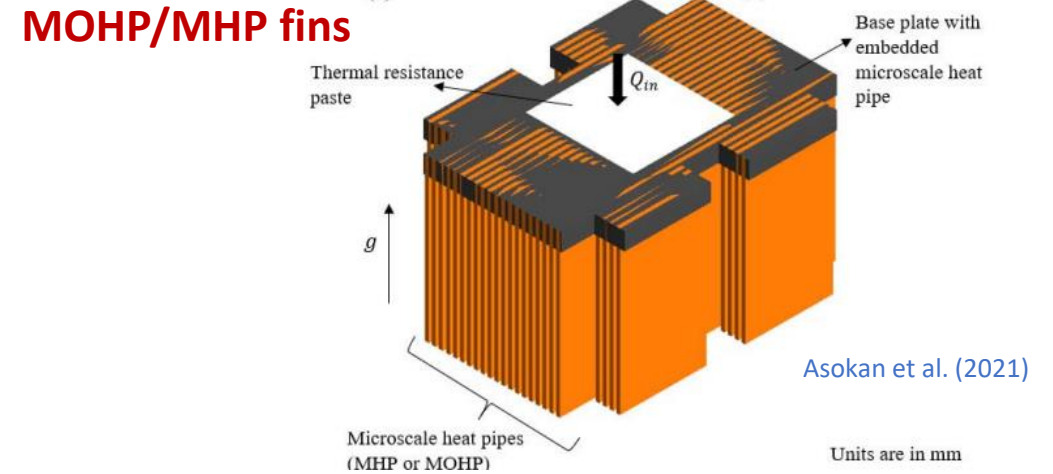
PI: Gangadhara Kiran Kumar L (NIT Calicut)

Co-PIs: Rohinikumar Bandaru (NIT Calicut)

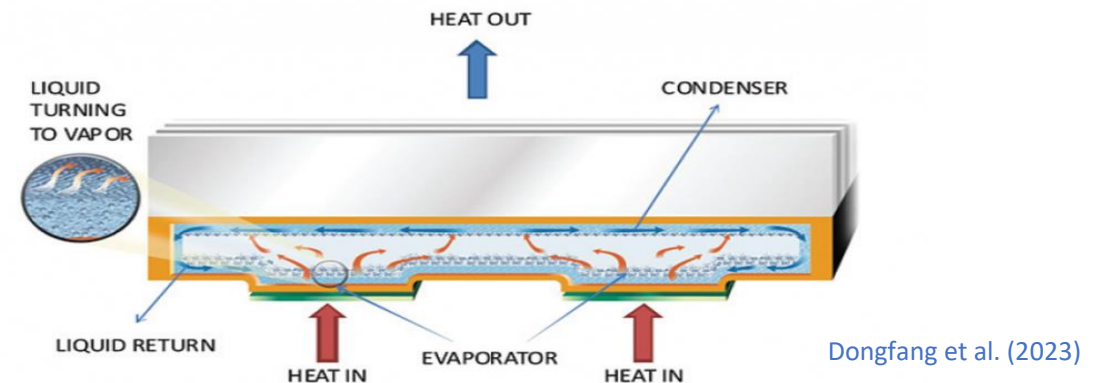
Objective - To Integrate Vapor chamber with MOHP/MHP fins at condenser section for effective removal of high heat flux.

- ❑ Standalone design of MOHP/MHP fins for high performance CPU processors.
- ❑ Integrating vapor chamber with MOHP/MHP fins for better thermal performance.

	Current state	Proposed
TDP	120W	250W
Thermal resistance	0.224K/W	<0.2 K/W
Junction temperature	100-105 °C	85-95 °C
Working fluid	Water	Alternate fluids



Vapor chamber



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Project 13: Lid Integrated Flat Heat Pipe with Extended HP/OHP Fins for 2.5D Semiconductor Packaging

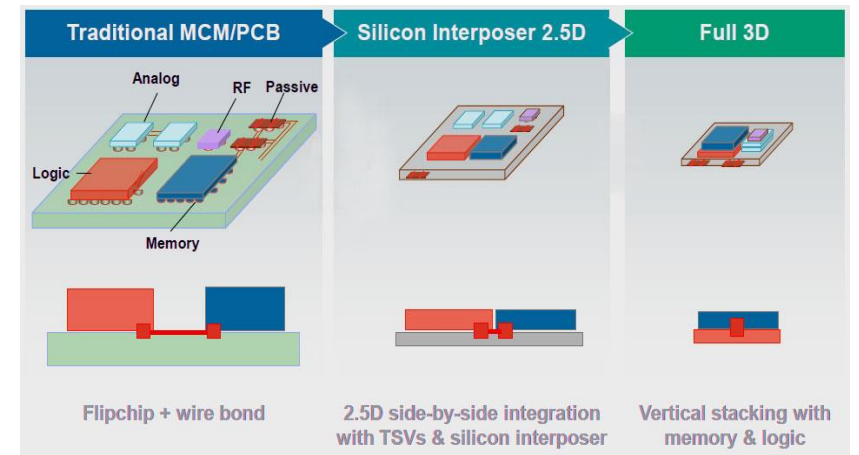
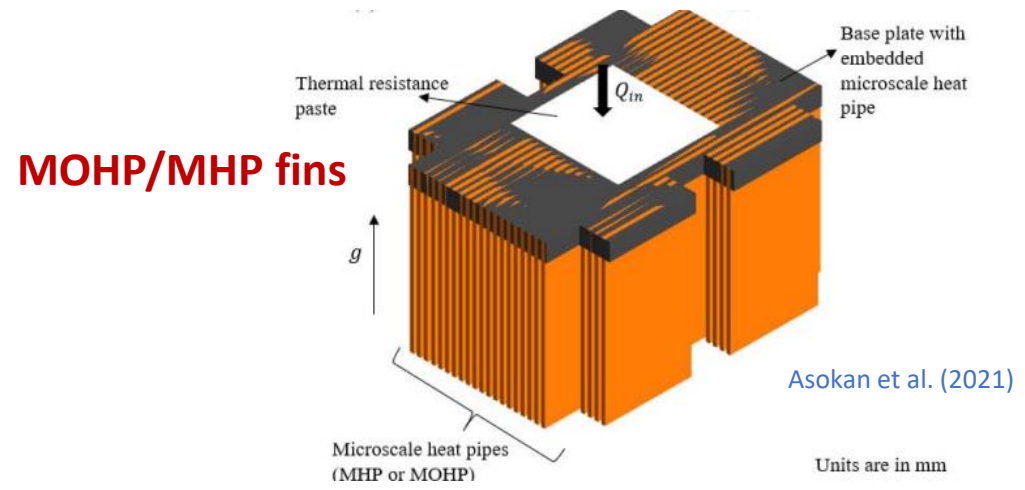
PI: Gangadhara Kiran Kumar L (NIT Calicut)

Co-PIs: Rohinikumar Bandaru (NIT Calicut)

Objective - To develop lid integrated flat heat pipe with extended HP/OHP fins for 2.5D semiconductor packaging

- Develop lid integrated flat heat pipe with extended HP/OHP fins for 2.5D semiconductor packaging
- Extended HP/OHP fins are placed at suitable locations as per the design.

	Current state	Proposed
Heat load	140 W	200W
Thermal conductivity	14000 W/mK	20000 W/mK
Working fluid	Water	Alternate fluids
Thermal resistance	0.312 °C/W	<0.2 °C/W



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Project 14: Micro Pin-Fin Channel Cooling with Through-Silicon Vias (TSV) for Three-dimensional Integrated Chips

PI: Gangadhara Kiran Kumar L (NIT Calicut)

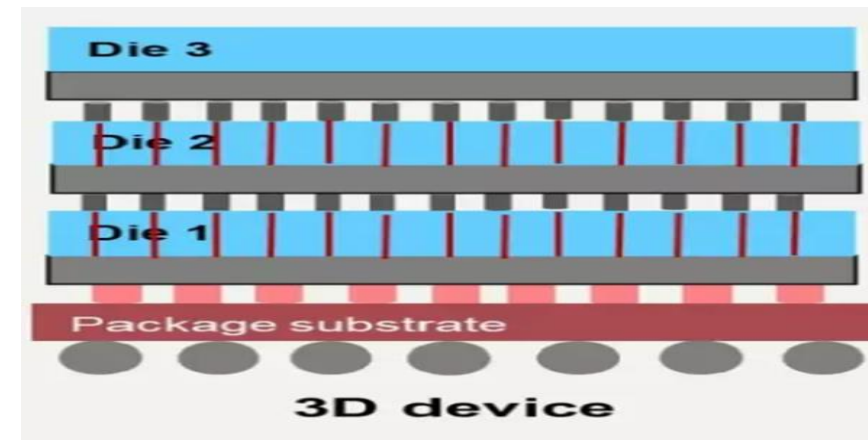
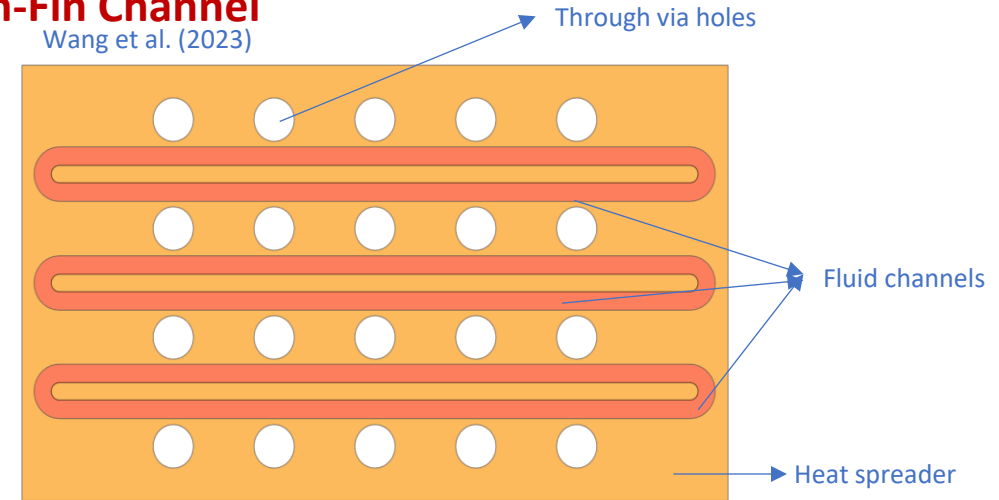
Co-PIs: Rohinikumar Bandaru (NIT Calicut)

- Objective** - To develop micro pin-fin channel cooling with embedded MHP/MOHP for 3D packaging
- ❑ Design and develop micro pin-fin channel cooling with embedded MHP/MOHP for 3D packaging.
 - ❑ MHP/MOHP are placed at suitable locations as per the design of 3D packaging.

	Current state	Proposed
Type of cooling	Air cooling	Air cooling with Heat pipes
Thermal resistance (K/W)	13.9	10
Cooling Technique	Micro fins	Micro fins with embedded MHP/MOHP

Micro Pin-Fin Channel

Wang et al. (2023)



<https://semiwiki.com/eda/319014-dft-moves-up-to-2-5d-and-3d-ic/>



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Project 15: Development of a Peltier-Based Thermal Management System for High Heat Flux GPUs

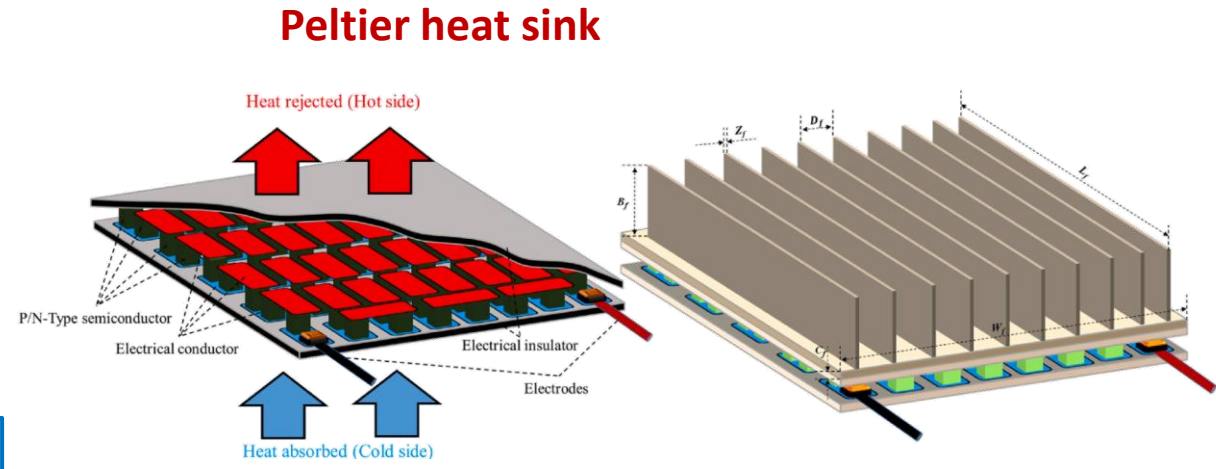
PI: Rohinikumar Bandaru (NIT Calicut)

Co-PIs: Gangadhara Kiran Kumar L (NIT Calicut)

Objective - To develop Peltier based cooling system for high end GPUs

- Standalone heat sink design with Peltier module for GPU with higher capacity.
- Integrating Peltier module on the metal fin for better thermal performance.

	Current state	Proposed
Tooling technology	Air, water	Peltier module
Power level in high end GPU	630 W	1000 W
Maximum temperatures	95 - 105 °C	80 – 90 °C



He et al. (2024)

Conventional GPU



https://en.wikipedia.org/wiki/Graphics_card

Project 16: Superfluid Helium Based Thermal Management System for Quantum Chips

PI: Rohinikumar Bandaru (NIT Calicut)

Co-PIs: Gangadhara Kiran Kumar L (NIT Calicut)

Objective: Develop a cooling system for quantum computer for 2000 qubits machine

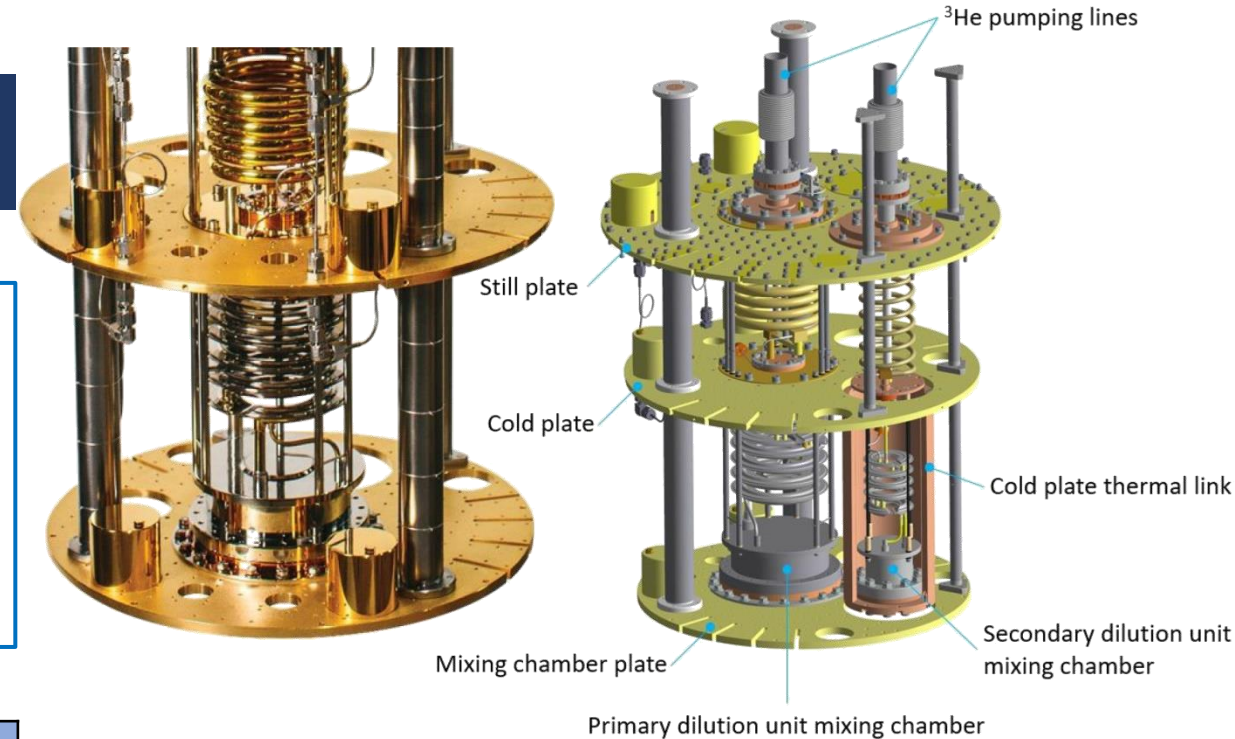
- ❑ Quantum chips have to operate at very low temperatures in order to maintain the quantum information.
- ❑ Down to temperatures just a fraction of a degree above absolute zero.
- ❑ Qubit activity produces a small but critical heat load.

Proposed vs. Prior Art

	Current state	Proposed
Qubits	<1120	> 2000
Refrigerant	^3He and ^4He	Superfluid helium

Approach

- ❑ Dilution refrigerator systems with auxiliary cry-cooler



Poole et al. (2022)



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Thank You

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