NAVDEEP SINGH DHILLON

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PARTICULARS

EDUCATION

University of California, Berkeley — Berkeley, CA
Ph. D. in Mechanical Engineering, GPA: 3.88 — *December 2011*
M. S. in Electrical Engineering and Computer Sciences — *December 2011*

Purdue University — West Lafayette, IN
M. S. in Mechanical Engineering, GPA: 3.71 — *August 2006*

Indian Institute of Technology (IIT), Kharagpur — Kharagpur, India
B. Tech. in Ocean Engineering and Naval Architecture — *May 2004*
University Silver Medalist, GPA: 9.12 / 10

CURRENT STATUS

U.S. F1 VISA, Citizen of India.

RESEARCH INTERESTS

My research interests span the areas of Micro-Electro-Mechanical Systems (MEMS), Fluid Mechanics, Computational Fluid Dynamics (CFD), Heat Transfer, Classical Thermodynamics, and Statistical Thermodynamics (Thermal Physics). I have a specific interest in the design, modeling and fabrication of MEMS-based liquid-phase-change microfluidic devices for high-heat-flux electronics cooling applications. I am also involved in the theoretical and experimental study of phase change phenomena in micro/nano structures, and applying finite volume and finite element based CFD approaches to numerically simulate evaporation and heat transfer in phase change devices.

Ph. D. DISSERTATION

Title: “Micro-Columnated Loop Heat Pipe: The Future of Electronic Substrates"
Advisor: Prof. Albert P. Pisano

My thesis deals with the design, fabrication, thermodynamic modeling and experimental testing of a planar Micro-Columnated Loop Heat Pipe (μCLHP) for localized phase-change cooling of planar high-heat-flux electronics substrates. The μCLHP is designed for fabrication on silicon and Pyrex wafers using standard MEMS microfabrication techniques and incorporates novel design features such as a coherent porous silicon (CPS)-based dual scale vertical wicking structure to enhance thin-film evaporation and avoid catastrophic wick dry-out. Theoretical/numerical modeling of the two-phase flow loop, coupled with experimental data from thermal testing of fabricated Micro Loop Heat Pipe (μLHP) prototypes, is used to identify and optimize device components and topologies critical to enabling a single-substrate two-phase flow loop for maximum latent heat transport.

M. S. THESIS

Title: “Coupled Electro-Thermal-Phase Change Modeling of a Chalcogenide Switch"
Advisor: Prof. Jayathi Y. Murthy

Chalcogenide switches are the central components of the chalcogenide alloy based Phase Change Memory (PCM) technology, one of the primary candidates for dynamic semiconductor memories. In order to determine the switching parameters, I implemented a comprehensive and fully coupled electro-thermal-phase change numerical model using C++ that was solved in discrete space and time domains using a Finite Volume discretization approach. Charge transport was implemented using carrier continuity equations, heat transfer using a Fourier model, and phase change was modeled using the Johnson-Mehl equations. Simulation of SET and RESET electrical pulses was used to demonstrate the physics of the switching process and characterize switching parameters for a nanoscale chalcogenide switch.

ACADEMIC HONORS

- Best Presentation Award in the Fluids Engineering in Micro- and Nanosystems Symposium at the ASME-IMECE 2011.
- Fellow at the ninth annual *Summer Institute for Preparing Future Faculty*, UC Berkeley, May 25 – June 29, 2011
- Ross Fellowship for academic excellence, Purdue University, Aug 2004
- Institute Silver Medal, IIT Kharagpur, 2004
- J.C. Ghosh Memorial Award for excellent academic performance, IIT Kharagpur, 2003
- Hemchandra Rout Scholarship, IIT Kharagpur, 2003–2004
- Jagadis Bose National Science Talent Search Award, 2000–2001
- National Talent Search Exam (NTSE) scholarship, Govt. of India, 1998

ACADEMIC RESEARCH EXPERIENCE

- **Research Assistant, University of California, Berkeley**, Aug 2006–Present.

– *Design, thermodynamic analysis, and fluid flow modeling of a planar Micro-Columnated Loop Heat Pipe (μCLHP) for high heat flux cooling of electronic substrates.* Device design parameters are optimized using monotonicity analysis and numerical optimization. Finite element method (FEM) modeling is used to predict and minimize parasitic heat flow from the device evaporator.

– *Three dimensional numerical modeling of thin-film evaporation from the steady state meniscus in a coherent porous silicon-based micro-columnated wicking structure.* Finite volume method (FVM)-based open source numerical libraries from OpenFOAM are used for the numerical solution. The effect of wick geometry and working fluid properties on the rate of evaporation is characterized.

– *Experimental investigation of thin-film evaporation and characterization of the design parameters of a 3-D micro-columnated wicking structure.* An open loop evaporator is employed and using a novel approach evaporative heat fluxes are characterized by measuring the evaporator in-plane apparent thermal conductivity with an IR camera.

– *Fabrication of in-plane-wicking micro loop heat pipe (μLHP) prototypes using MEMS microfabrication techniques.* The devices are fabricated on silicon and Pyrex wafers using dry and wet etching techniques, respectively. Anodic bonding is used to assemble the final devices.

– *Packaging, degassing, and fluid filling of the μLHP prototypes with a working fluid (water).* A novel thermal flux method is used for filling the devices and non-invasive hermetic device sealing approaches are developed using induction heating.

– *Experimental study of evaporation and two-phase flow dynamics in the μLHP prototypes.* An experimental setup is implemented to supply and remove heat from the evaporator and condenser sections of the μLHP, respectively. A high speed camera is used to observe and characterize evaporation in the wicking structure and track the liquid-vapor phases in the device to understand the thermodynamic behavior of the flow loop.

- **Research Assistant, Purdue University, West Lafayette**, Aug 2004–Jul 2006.

– *Numerical Modeling of Chalcogenide Alloy based Phase Change Memory Technology*. I developed a C++ code for modeling heat transfer, charge transport, and material structure phase change inside a nanometer scale chalcogenide memory switch. Device physics inside the solution domain was discretized in space and time using the finite volume method (FVM). Time varying voltage and current boundary conditions to the solution domain were used to simulate the application of SET and RESET pulses to the switch. The numerical results were used to demonstrate the physics inside the switch and characterize the key parameters of the electrical pulses controlling the ON/OFF state of the switch.

INDUSTRY EXPERIENCE

- **Research Intern, Star RF Inc., Boston MA,** Jun 2009–Sep 2009. Star RF Inc. is a small entrepreneurial company, which creates state of the art RF and high performance analog components for wireless applications. In my role as a thermal scientist, I set up and evaluated thermal models for the integrated circuit package and printed circuit board system of a high power RF Chip. Over a course of three months, using both a simplified theoretical heat conduction model and more detailed finite volume method-based numerical simulations, I predicted the individual thermal resistance contributions of the IMD (inter metal dielectric), Polysilicon and metal-interconnect layers on a RF Power Amplifier chip. The results, detailing the non-uniform heat flux distribution over the chip surface, helped design engineers in identifying appropriate locations for the thermally conducting metal bumps in a flip-chip packaging assembly.

- **Research Intern, IRS R&D center, Mumbai, India,** May 2003–Aug 2003. The Indian Register of Shipping (IRS) is an internationally recognized independent ship classification society. While working as an intern at their research and development center, I developed a numerical code to model the flow of water around a ship propeller, in order to identify aerofoil designs which yield the least flow resistance.

TEACHING EXPERIENCE

- **Graduate Student Instructor, University of California, Berkeley**

– *Electronic Techniques for Engineering (EE 42/100), Howard Lei, Summer 2010.* I gave lectures and discussed problems in the discussion sections. I also supervised weekly lab sessions and graded lab reports.

– *Electronic Techniques for Engineering (EE 42/100), Prof. Ali M. Niknejad, Spring 2010.* I gave lectures and discussed problems in the discussion sections. I also supervised weekly lab sessions and graded lab reports.

– *Parametric and Optimal Design of MEMS (ME 219/EE C246), Prof. Liwei Lin, Spring 2010.* I have lectures in the discussion sections and discussed homework problems and project assignments with the students. I also gave several class lectures when Prof. Lin was out of town.

– *Introductory Physics (PHYS 8A), Dr. William Golightly, Summer 2010.* I supervised weekly lab sessions in which the students performed experiments and solved problems on alternate weeks.

– *Experimentation and Measurement (ME 107A), Prof. Lydia Sohn, Fall 2007.* I supervised lab sessions in which the students performed a variety of engineering experiments using LabView for data acquisition.

- **Teaching Assistant, Purdue University, West Lafayette**

– *Fluid Mechanics (ME 309), Prof. Steven T. Wereley, Fall 2004.* I gave lectures and solved fluids problems in weekly discussion sections. I also supervised students in the fluid mechanics lab and graded their lab reports and homeworks.

– *Heat and Mass Transfer (ME 315), Prof. Jayathi Y. Murthy, Spring 2005.* I supervised student lab sessions and graded lab reports. I also helped students in identifying and working on their final class project.

PUBLICATIONS

REFEREED PAPERS

1. Navdeep S. Dhillon, Matthew W. Chan, Jim C. Cheng, Albert P. Pisano, “Noninvasive Hermetic Sealing of Degassed Liquid Inside a Microfluidic Device Based on Induction Heating", In *Proceedings of PowerMEMS*, Seoul, South Korea, Nov 2011.

2. Navdeep S. Dhillon, Christopher Hogue, Jim C. Cheng, Albert P. Pisano, “Experimental Investigation of Thin-Film Evaporation in an Open-Loop Columnated Micro-Evaporator", In *Proceedings of PowerMEMS*, Seoul, South Korea, Nov 2011.

3. Navdeep S. Dhillon, Chris Hogue, Matthew W. Chan, Jim C. Cheng, Albert P. Pisano, “Integrating Coherent Porous Silicon as a Wicking Structure in the MEMS Based Fabrication of a Vertically Wicking Micro-Columnated Loop Heat Pipe", In *Proceedings of ASME IMECE*, Denver, CO, United States, Nov 2011.

4. Navdeep S. Dhillon, Jim C. Cheng, Albert P. Pisano, “Minimizing the Wick Thickness in a Planar Microscale Loop Heat Pipe Using Efficient Thermodynamic Design", In *Proceedings of ASME IMECE*, Denver, CO, United States, Nov 2011.

5. Navdeep S. Dhillon, Jim C. Cheng, Albert P. Pisano, “Device Packaging Techniques for Implementing a Novel Thermal Flux Method for Fluid Degassing and Charging of a Planar Microscale Loop Heat Pipe", In *Proceedings of ASME IMECE*, Denver, CO, United States, Nov 2011.

6. Navdeep S. Dhillon, Jim C. Cheng, Albert P. Pisano, “Heat Transfer Due to Microscale Thin Film Evaporation From the Steady State Meniscus in a Coherent Porous Silicon Based Micro-Columnated Wicking Structure", In *Proceedings of ASME IMECE*, Denver, CO, United States, Nov 2011.

7. Navdeep S. Dhillon, Christopher Hogue, Matthew A. Hopcroft, Albert P. Pisano, “Geometric Control of the Fluid-Transport Meniscus in a Passive Phase-Change Microfluidic Electronics Cooling Device", In *Proceedings of PowerMEMS*, pages 15-18, Leuven, Belgium, Dec 2010.

8. Navdeep S. Dhillon, Christopher Hogue, Matthew A. Hopcroft, Albert P. Pisano, “MLHP - A High Heat Flux Localized Cooling Technology for Electronic Substrates", In *Proceedings of ASME IMECE*, pages 621–630, Boston, MA, United States, Nov 2008.

9. Navdeep S. Dhillon, Jayathi Y. Murthy, “Coupled Electro-Thermal-Phase Change Modeling of a Chalcogenide Switch", In *Proceedings of ASME IMECE*, Chicago, IL, United States, 2006.

JOURNAL ARTICLES IN PREPARATION

10. Navdeep S. Dhillon, Albert P. Pisano, “Design Optimization of a Vertically Wicking Passive Phase-Change Microfluidic Electronics Cooling Device"

11. Navdeep S. Dhillon, Jim C. Cheng, Albert P. Pisano, “Microfluidic Components and Topologies Critical to Enabling Two-Phase Flow Loop in a MEMS Loop Heat Pipe"

12. Navdeep S. Dhillon, Albert P. Pisano, “Thermodynamic Analysis of an Extremely Thin Microscale Loop Heat Pipe Fabricated on a Single Planar Substrate"

13. Navdeep S. Dhillon, Albert P. Pisano, “Design Approaches for Parasitic Heat Flow Management in a Planar MEMS Loop Heat Pipe"

14. Navdeep S. Dhillon, Matthew W. Chan, Albert P. Pisano, “A Noninvasive Hermetic Sealing Approach For Purging Non-Condensible Gases from High Temperature Microfluidic Devices"

15. Navdeep S. Dhillon, Albert P. Pisano, “Numerical Modeling of Thin-Film Evaporation in a Coherent Porous Silicon Based Micro-Columnated Wicking Structure"

16. Navdeep S. Dhillon, Norvan Sahiner, Jim C. Cheng, Albert P. Pisano, “Novel 3D MEMS Evaporator for a Micro Loop Heat Pipe Through Experimental Optimization of Coolant Conduits and Surface Topology"

OTHER REPORTS

17. Navdeep S. Dhillon “Coupled Electro-Thermal-Phase Change Modeling of a Chalcogenide Switch", *Masters Thesis Report*, Jul 2006, Purdue University, West Lafayette.

18. Navdeep S. Dhillon “Study of Bow Vortices Formation and Finding the SSP and FSSP for a Free Surface Viscous Incompressible Flow Past a Semi-submerged 2-D Cylinder Using the SMMC Method", *Bachelors Thesis Report*, May 2004, IIT Kharagpur, India.

PATENTS & APPLICATIONS

The following patents are under review

1. Navdeep S. Dhillon, Jim C. Cheng, Albert P. Pisano, “Passive, flexible device for multi-dimensional spreading and removal of heat", Invention disclosure submitted June 2011.

2. Navdeep S. Dhillon, Jim C. Cheng, Albert P. Pisano, “Interline-Optimized Evaporator for Heat Spreading", Invention disclosure submitted June 2011.

TALKS

CONFERENCE TALKS

1. “Noninvasive Hermetic Sealing of Degassed Liquid Inside a Microfluidic Device Based on Induction Heating", PowerMEMS 2011, 11th International Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, Seoul, South Korea, Nov 2011.

2. “Experimental Investigation of Thin-Film Evaporation in an Open-Loop Columnated Micro-Evaporator", PowerMEMS 2011, 11th International Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, Seoul, South Korea, Nov 2011.

3. “Minimizing the Wick Thickness in a Planar Microscale Loop Heat Pipe Using Efficient Thermodynamic Design", ASME 2011 International Mechanical Engineering Congress & Exposition, Denver, CO, United States, Nov 2011.

4. “Device Packaging Techniques for Implementing a Novel Thermal Flux Method for Fluid Degassing and Charging of a Planar Microscale Loop Heat Pipe", ASME 2011 International Mechanical Engineering Congress & Exposition, Denver, CO, United States, Nov 2011.

5. “Heat Transfer Due to Microscale Thin Film Evaporation From the Steady State Meniscus in a Coherent Porous Silicon Based Micro-Columnated Wicking Structure", ASME 2011 International Mechanical Engineering Congress & Exposition, Denver, CO, United States, Nov 2011.

6. “Geometric Control of the Fluid-Transport Meniscus in a Passive Phase-Change Microfluidic Electronics Cooling Device", PowerMEMS 2010, 10th International Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, Leuven, Belgium, Dec 2010.

7. “MLHP - A High Heat Flux Localized Cooling Technology for Electronic Substrates", ASME 2008 International Mechanical Engineering Congress & Exposition, Boston, MA, United States, Nov 2008.

INDUSTRY/OTHER TALKS

8. “Flip Chip Thermal Modeling of a RF Power Amplifier", StarRF Inc., Boston, United States, Jul 2009

9. “Micro Loop Heat Pipe Chip Cooling System—Columnated Wick and Device Design", Berkely Sensor & Actuator Center Symposium, Berkeley, United States, Mar 2009.

TECHNICAL SKILLS

COMPUTING SKILLS

I have theoretical and practical experience in the use of *Finite Difference* (FD), *Finite Volume* (FV), and *Finite Element* (FE) methods for the numerical solution of physics and engineering problems. Specifically, I have worked with the following programming tools and software packages:

- **C, C++, and Python**: Open source programming languages.
- **FLUENT and COMSOL**: Commercial packages for discrete numerical solution of partial differential equations, which use the finite volume and finite element formulations respectively.
- **OpenFOAM**: An open source Computational Fluid Dynamics (CFD) toolbox based on C++ libraries, which uses the finite volume formulation.

I have also extensively used the following generalized numerical mathematical packages:

- **MATLAB, MATHEMATICA**: General purpose programming languages for numerical computing.
- **GNU Scientific Library (GSL)**: An open source numerical library for C and C++ programmers. The library provides a wide variety of mathematical routines in a range of subject areas.

I am proficient in the use of several CAD and publishing tools:

- **SOLIDWORKS, TURBOCAD, AUTOCAD, GOOGLE SKETCHUP, XFIG, and ADOBE ILLUSTRATOR**: 2-D and 3-D CAD design and graphics tools.
- **TeX, LaTeX, BibTeX, Microsoft Office**: Publishing and Presentation tools.

LABORATORY SKILLS

In the course of my research work, involving design, fabrication, and testing of MEMS devices, I have acquired the following experimental skills:

- **Semiconductor Device Fabrication**: I have worked extensively in the cleanroom environment at the Berkeley Microfabrication and the Marvell Nanofabrication Labs, in order to fabricate MEMS/microfluidic devices using silicon and Pyrex wafers. I am proficient in the usage of following processing techniques:
  - *Mask Making*: A *mask* is a stencil that is used to repeatedly generate a desired pattern on resist-coated wafers. I have used a number of CAD and IC layout packages, such as Autocad, L-Edit, and Layout Editor, to generate masks for a number of microfabrication process flows.
  - *Photolithography*: This is the most widely used technique in the IC industry for pattern transfer from masks onto thin films. The wafers are cleaned, coated with a UV-sensitive photoresist, exposed to a UV light-source, treated with a developer solution, and hard-baked. The resulting photoresist mask is then used to pattern the underlying substrate layers.
  - *Thin-Film Deposition*: I have experience in the use of thermal furnaces, Chemical Vapor Deposition systems (silicon oxide film deposition), plasma sputtering systems (metal and dielectric film deposition), and e-beam evaporation systems (metal deposition).
  - *Dry Etching*: I have used both Reactive Ion Etching (RIE) and Deep Reactive Ion Etching (DRIE) techniques to etch thin films and thicker substrates, respectively, using various plasma based dry etching systems.
  - *Wet Etching*: I have experience in the wet etching of both silicon (using KOH or TMAH etchant) and Pyrex (using hydrofluoric acid) substrates. This includes the deposition and patterning of a suitable etch mask.
  - *Testing and Inspection*: I have experience in the usage of stylus-based surface profilometers, optical film thickness-measurement systems, and scanning electron microscopes for the testing and inspection of samples.
  - *Device Packaging*: I have extensively used a Thermo-Compression & Anodic bonder for bonding silicon and Pyrex substrates, and a Dicing Saw for the precision cutting of fabricated devices.

- **Experimentation & Data Acquisition**: For testing the microscale loop heat pipe (μLHP) prototpes I had to put together an elaborate experimental setup for device packaging, degassing, fluid filling and data acquisition, which helped me to acquire the following skills:

  – *Machining of components*: I gained considerable expertise in using conventional machining tools such as saws, lathes, and milling machines, while fabricating packaging assemblies for the μLHP prototypes.

  – *Heat Flux and Temperature measurements*: I know how to use thermocouples, thermistors, and infrared cameras for taking temperature and heat flux measurements.

  – *High Speed Imaging of two-phase flow dynamics*: I can work with high-speed optical cameras for studying microscale flow phenomena.

SERVICE TO THE PROFESSION

- Reviewed conference papers for the *ASME 2011 International Mechanical Engineering Congress & Exposition*.
- Organized the Fall 2009 Faculty Seminar Series in the department of Mechanical Engineering at UC Berkeley.

LANGUAGES

Proficient in English, Hindi and Punjabi. Elementary knowledge of French and German.

GRADUATE ACADEMIC COURSEWORK

MEMS / Nano
Introduction to MEMS (ME 119, UCB)
Microfabrication Technology (EE 143, UCB)
Introduction to MEMS Design (EE C245, UCB)
Micro-Electro-Mechanical systems (ME C219, UCB)
Introduction to Nano Science and Engg. (NSE C201, UCB)
Nano Fabrication (NSE C203, UCB)

Fluid Mechanics
Introduction to Continuum Mechanics (ME 185, UCB)
Intermediate Fluid Mechanics (ME 509, Purdue)
Advanced Fluid Mechanics (ME 260B, UCB)
Microscale Fluid Mechanics (ME 167, UCB)
Numerical Methods in Heat, Mass and Momentum Transfer (ME 608, Purdue)
Electrodynamics in Continuous Media (ME 285C, UCB)

Heat Transfer and Thermal Engineering
Advanced Thermodynamics (ME 500, Purdue)
Intermediate Heat Transfer (ME 505, Purdue)
Convection of Heat and Mass (ME 605, Purdue)
Micro-Nano Scale Energy Transfer Processes (ME 597F, Purdue)
Nano scale Thermal Transport (ME 595, Purdue)
Heat Transfer in Electronic Systems (ME 597G, Purdue)
Laser Processing and Diagnostics (ME 290G, UCB)

Physics
Advanced Maths for Engineers and Physicists (ME 527, Purdue)
Electromagnetism and Optics (PHYS 110A, UCB)
Statistical Thermal Physics (PHYS 112, UCB)
Solid State Physics (PHYS 141A, UCB)
Quantum Mechanics (PHYS 660, Purdue)

Electrical Engineering
Microelectronic Devices and Circuits (EE 105, UCB)
Solid State Devices (EE 606, Purdue)
Charge Transport in Semiconductors (EE 656, Purdue)

REFERENCES

1. **Prof. Albert P. Pisano**
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   FANUC Professor of Mechanical Systems
   Director, Berkeley Sensor & Actuator Center
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   Professor of Electrical Engg. and Computer Sc.
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2. **Prof. Liwei Lin**
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