The Miniaturization of an Oscillating Heat Pipe

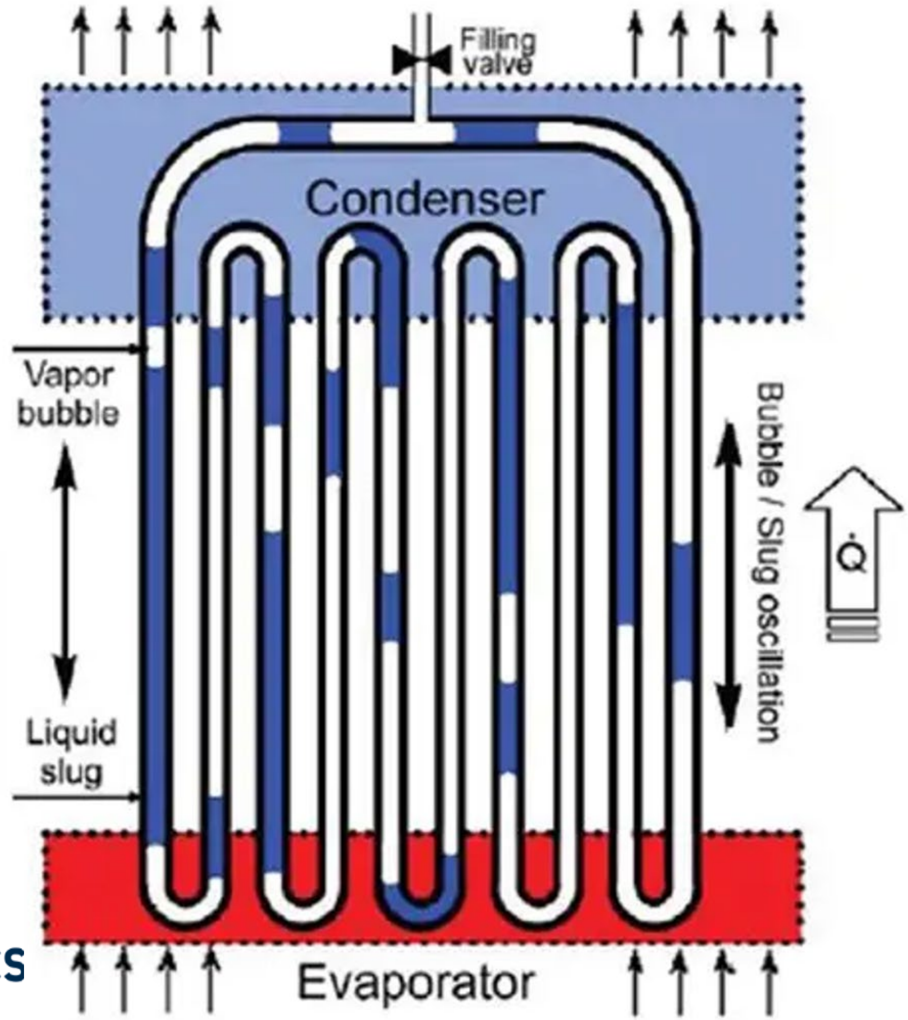
PI: Satish Kumar

Mentor: Max Pawlick

SUIN REU: Jalen White

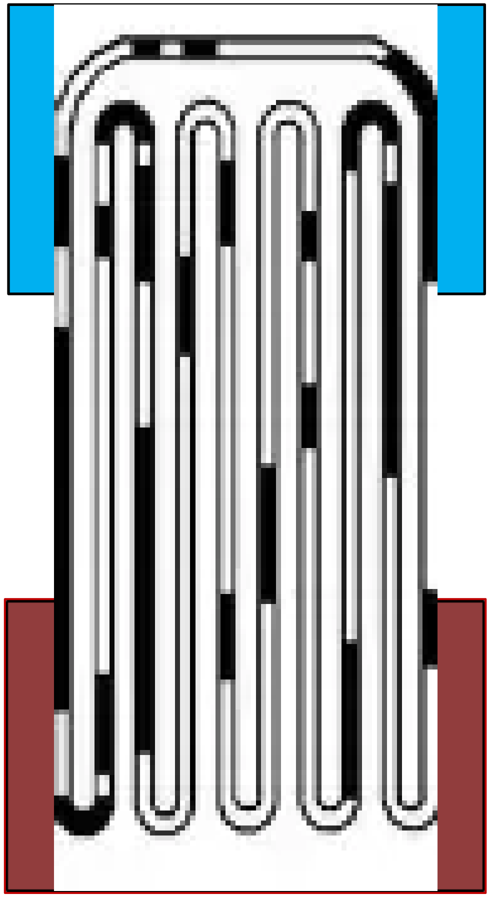
National Nanotechnology Coordinated Infrastructure

Georgia Tech
Institute for Electronics and Nanotechnology



What is an Oscillating Heat Pipe

- An Oscillating heat pipe is a heat transfer system that spreads heat
- Uses a flowing two-phase fluid (Liquid and vapor) in one continuous loop.
- It’s a passive system (No Pumps)
- Uses expansion and contraction (evaporation and condensation) to move liquid throughout the system.



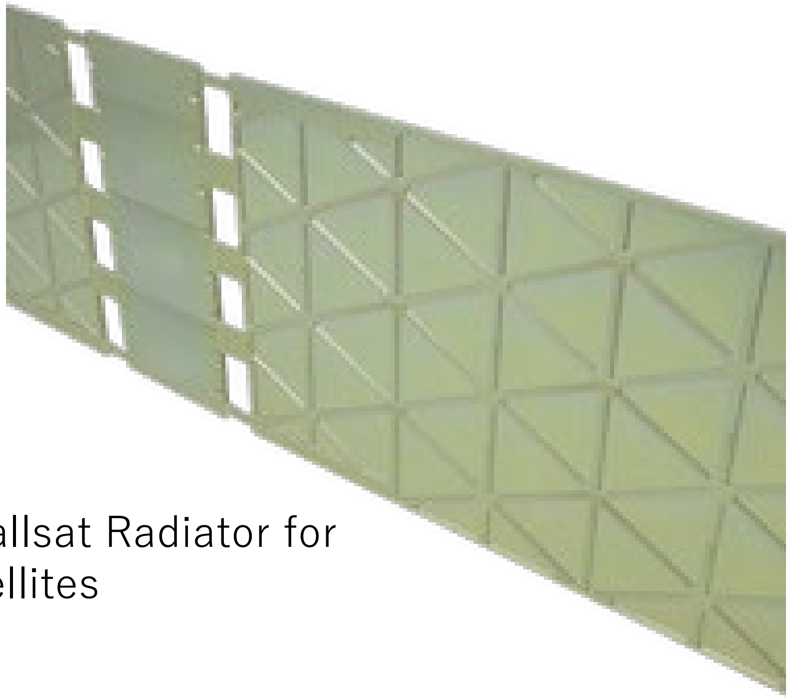
Closed-loop OHP

Example Video of Oscillating Heat Pipe Operation

Purpose of an Oscillating heat pipe

- This is used for cooling electrical systems such as data servers and computer systems.
- Aerospace and defense mechanisms, such as satellites, radiators, commercial airplanes, and more.
- Smaller versions must be made to apply to computer systems and processors.

- Biggest advantage: No pump is required for oscillating heat pipes
- Performance is difficult to predict without experimentation



Smallsat Radiator for satellites

My Project: Microchannel Oscillating Heat Pipe

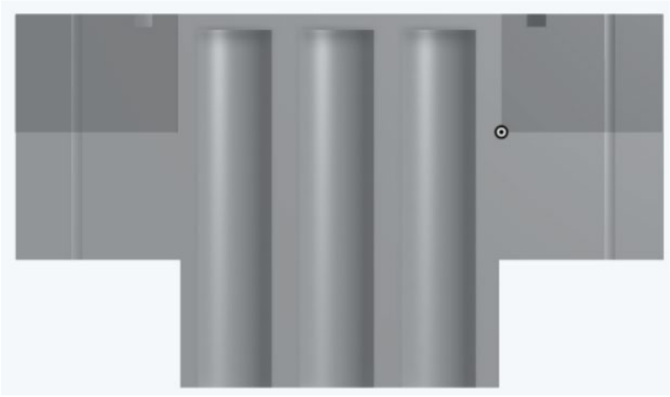
- This Oscillating heat pipe is considerably smaller than our current models
- We have a channel length of 96 mm and a heat transfer system width of 26 mm with 38 channels.
- We are doing this because we need to make smaller channels to fit more of them within that 26 mm of space
- Oscillating heat pipes don't work as well without a large number of channels.

(b)

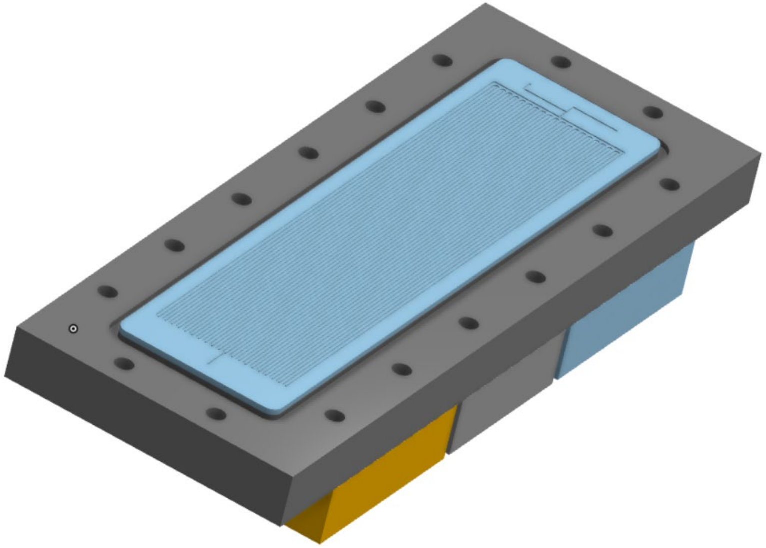
(b) SEM image showing a cross-sectional view of different micro-O s cillating heat pipe channels that use silicon as their base （Qian et al.）.

Oscillating Heat Pipe Configuration

- For our configuration, the Channel plate is placed on a frame with an open section for the heating and cooling blocks to be placed underneath.
- The center block will be heated with cartridge heaters
- The outside cooling blocks will be cooled with chilled water to drive heat transfer across the device.
- This is used to evaluate performance for computer chip applications.



Side view of the heating block

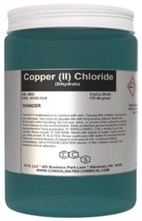


The Chemical Etch process

- Using Cleanroom equipment, our first possible manufacturing process used a step-by-step operation of different machines to etch the channels in our copper.

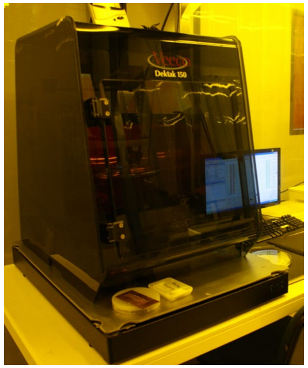
Suss Microtec
Spin Coater

MA/BA8 Mask
Aligner Gen 4 series



Cupric Chloride

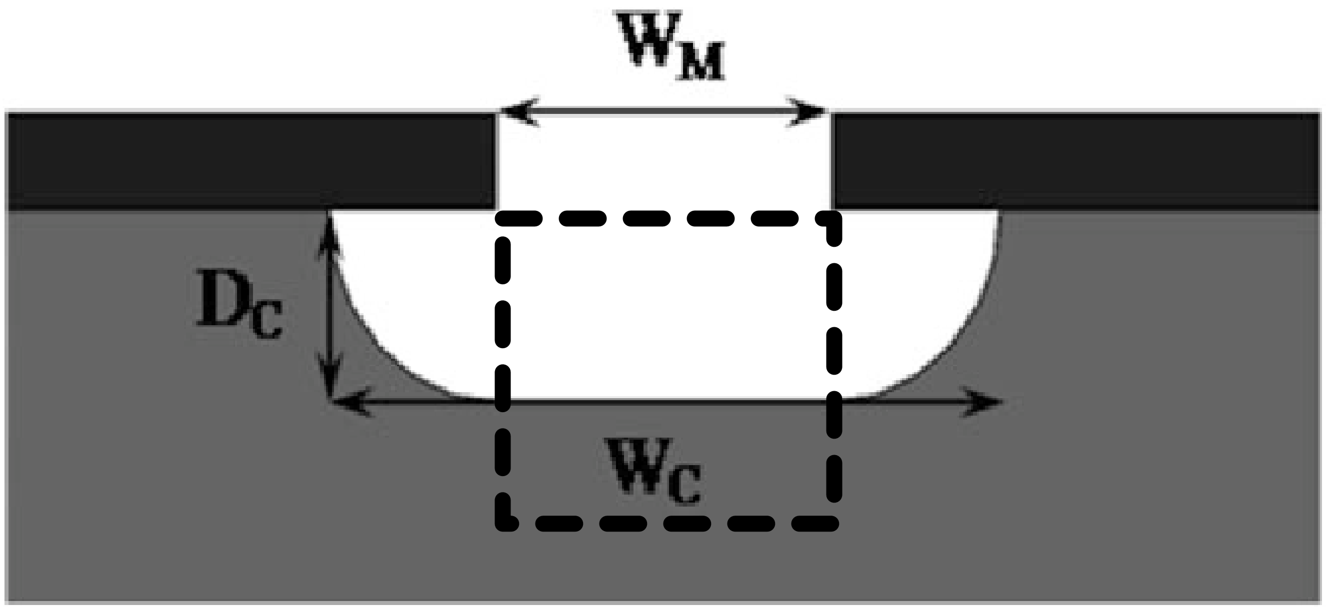
Chemcut 2315E
Differential copper etch
system



Dektak 150
Profilometer

Complications with the Copper spray etch

- We could not use our cupric chloride solution in the copper spray etch machine.
- The machine was needed to combat the side wall etching that would cause our channels to grow their Wc width much more than the DC depth.
- The Performance of the oscillating heat pipe degrades with wide aspect ratios, as it affects the number of turns.



The Femtosecond laser process

- Using the Femtosecond Laser, we uploaded a dxf drawing file of our channels to the machine.
- This process isn't nearly as cost-efficient as the chemical etching process but is more precise in creating the channel shape.
- The laser, through cold ablation, removes the highlighted channels in the copper.
- A process that we found would take 10 to 20 hours to complete on the highest settings. Which is not cost-effective for our lab.

OPTEC#1 Femtosecond Laser Micro-machining System

The PCB Mill process

- Using the LPKF S103 ProtoMat PCB plotter. The end mill bit that the machine uses causes high surface roughness and dimensional inaccuracies.
- It's difficult to create channels this small without breaking the end mill bits
- However, the machine has been more time-effective than previous processes.
- Commercially, the chemical etching process is more cost-efficient on a greater scale.

LPKF S103 ProtoMat PCB (Printable Circuit Board) plotter, router, and drill press

PCB Mill Results

Trial 1#:

Trial 2# and 3#:

Trial 4#:

Width: 26mm Length: 96mm

- In a few trials, the best I could output in the 4th trial was a shallow, rough rubout of the channels before an end mill bit broke.

- This proves that the channels can be made using this process, but the PCB mill creates poor-quality channels that would not be ideal for this project.

Future work

- We would run experiments and tests with the micro-oscillating heat pipe to gather data points that show us the performance of the system.
- Our lab is now better equipped to select proper micromanufacturing processes for heat transfer applications.

Picture of a larger-scale oscillating heat pipe currently under experimentation.

Future work continued

- In the distant future, we would experiment with gallium as the metal can carry more heat throughout the system.

Example of a gallium flow experiment
(Max Pawlick)

Acknowledgments

PI: Dr. Satish Kumar

Mentor: Max Pawlick

Leslie O’Neil

Dr. Mikkel Thomas

References

- Oscillating Heat Pipes. (n.d.). In *ThermAvant Technologies*. Retrieved July 22, 2026, from https://www.thermavant.com/oscillating-heat-pipes
- Heat Pipe Principle and Applications. (n.d.). In *www.heatpipe.com*. Retrieved July 22, 2026, from https://www.heatpipe.com/engineering-manual/heat-pipe-principle-and-applications/
- Qian Qian, Xin Zhang, Shurong Tian, Bojing Yao , Justin A. Weibel, & Liang Pan. (2024). *Silicon-based microscale-oscillating heat pipes for high power and high heat flux operation*. https://pubs.aip.org/aip/apl/article-abstract/125/2/024103/3302933/Silicon-based-microscale-oscillating-heat-pipes?redirectedFrom=fulltext

Questions?