TFAWS Passive Thermal Paper Session

Experimental Characterization of Cryogenic Heat Pipe Evaporator for Lunar Ice Collection

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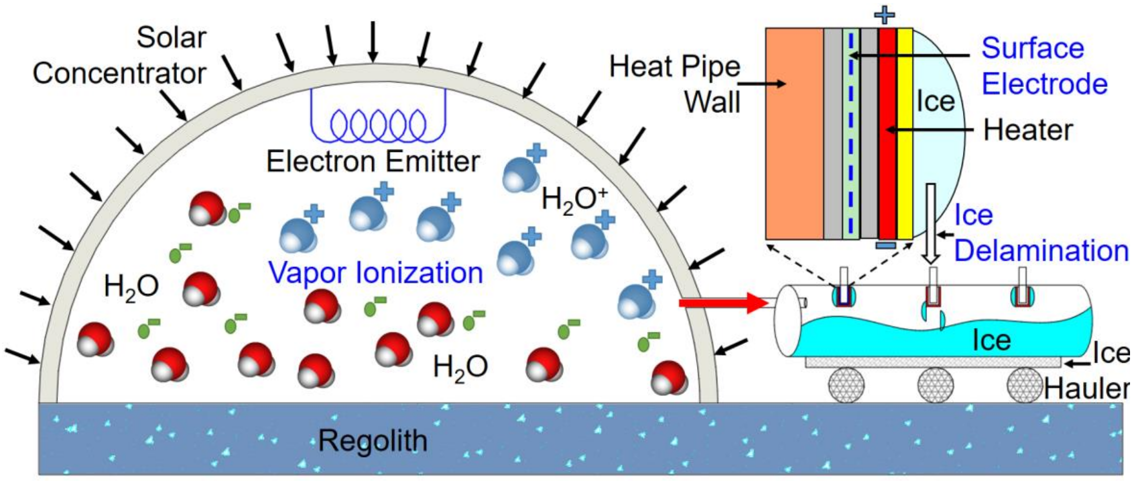
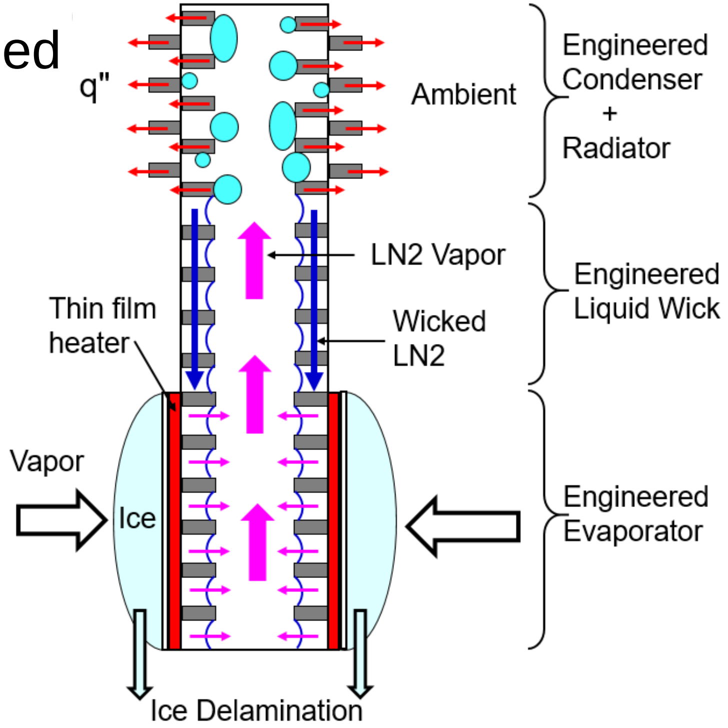
Research Goal: To develop and demonstrate an advanced thermal mining technology of 1 kg ice collection prototype in approximately 11 hours from icy lunar regolith that integrates engineered

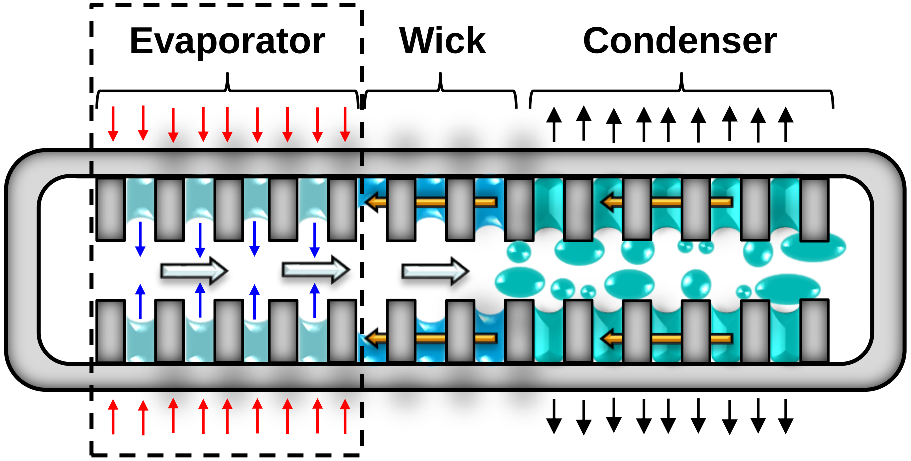
i. Extraction (thermal drill and capture tent)
ii. Vapor ionization and transportation
iii. Re-collection of water vapor using pulsed delamination of ice on an engineered cryogenic heat pipe
iv. System-level scale-up analysis of the proposed thermal mining technology

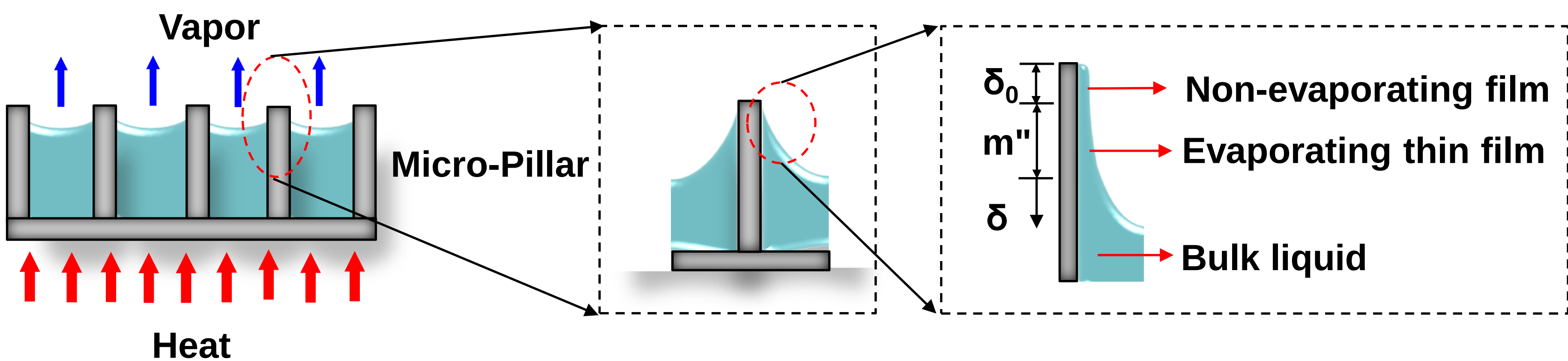




Thin Film Evaporation

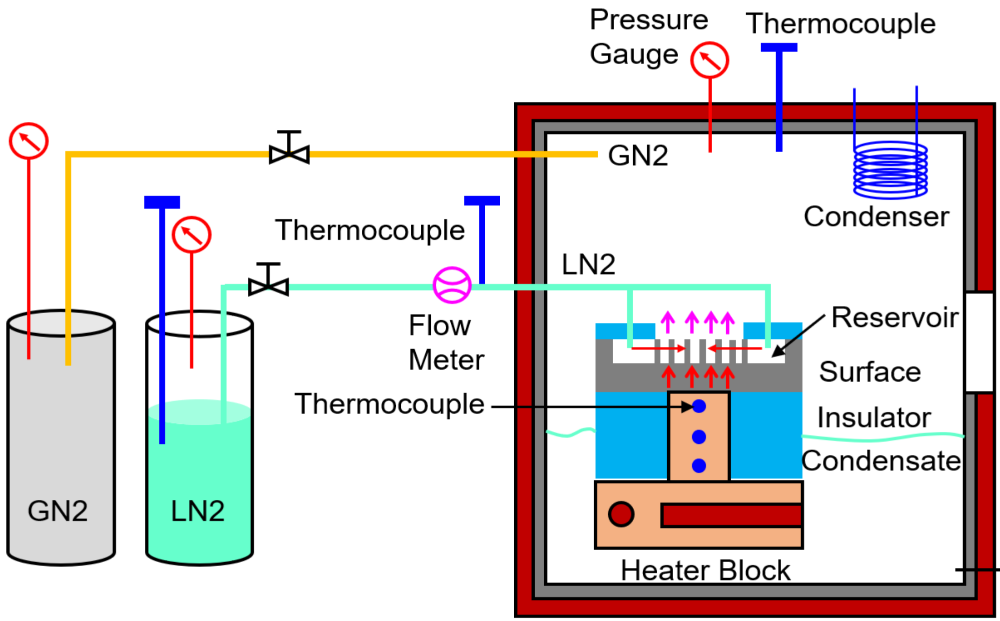
- New technique to enhance the heat pipe evaporator performance.
- During capillary rise, the extended meniscus forms non-evaporating, transition and intrinsic meniscus.
- Phase change occurs through transition region of extended meniscus of micro-pillar walls.
- Improves heat transfer by increasing evaporation area and decreasing conduction resistance.

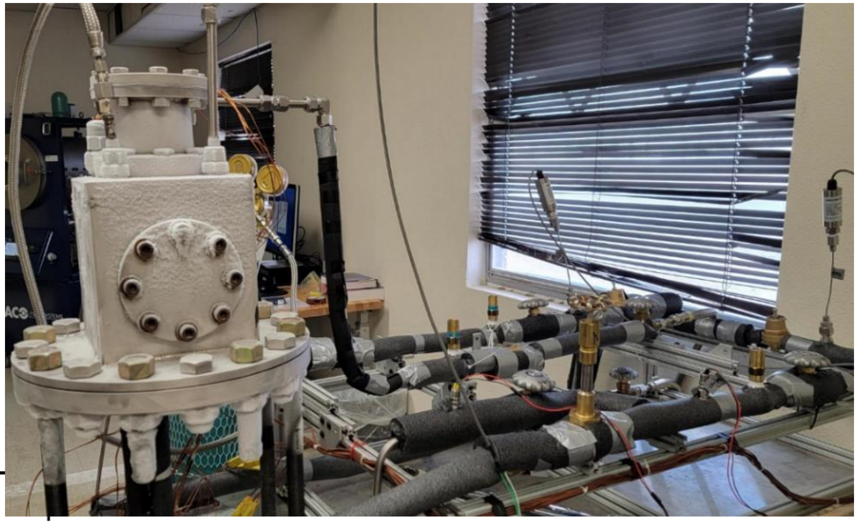




Test Facility

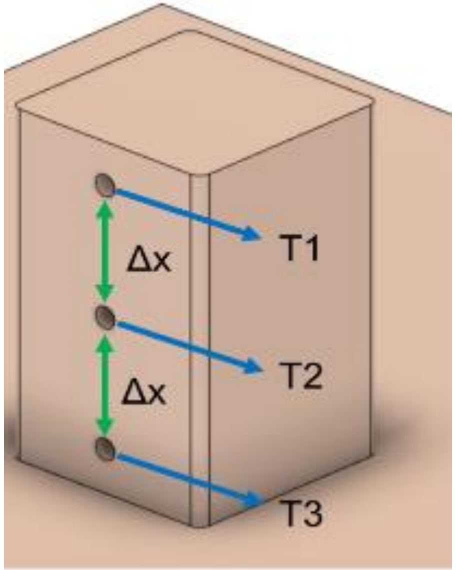
- Nitrogen gas (GN2) is used to pressurize the test chamber (14 bar).
- Liquid Nitrogen (LN2) is used to cool the chamber (110 K).
- LN2 is the working fluid for thin film evaporation.
- A copper condenser coil is used to achieve the operating cryogenic condition.
- One-dimensional heat conduction through copper heater block.
- All surfaces tested up to **dry-out** critical heat flux.

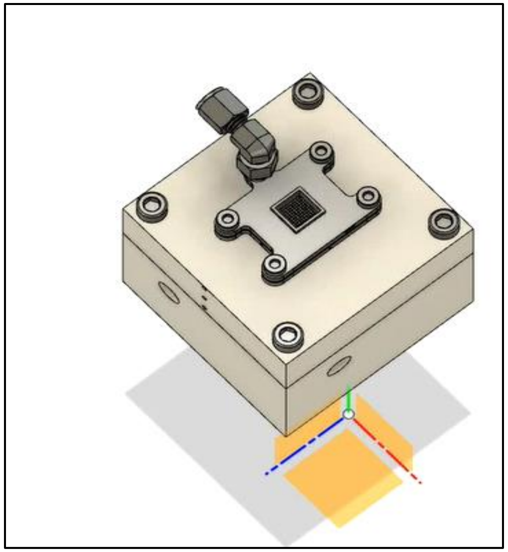


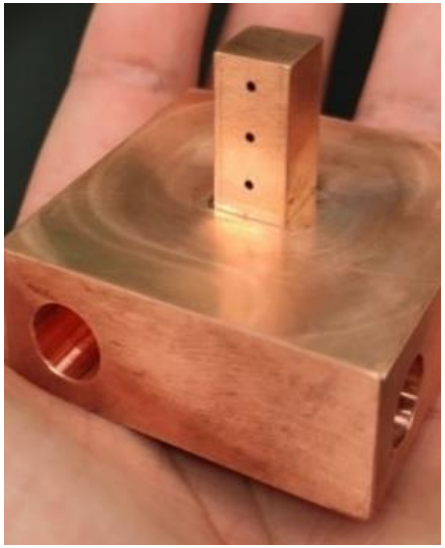


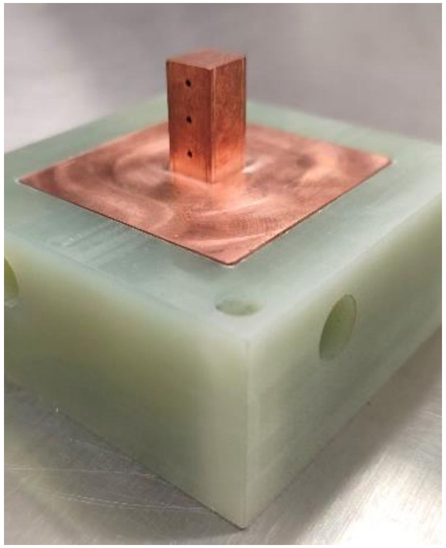
Heater Block Assembly

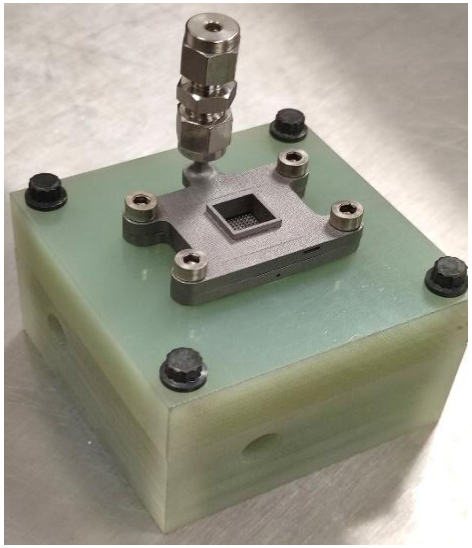
- A 50.8 mm x 50.8 mm x 38.1 mm copper heater block.
- The heater block has a 2.5 cm long neck and 1×1 cm^2 area to heat the test surfaces.
- Four cartridge heaters are used which can generate 1600 W.
- Three 1 mm holes for thermocouples to calculate the given heat flux.
- G10 insulation to ensure 1-D heat conduction.





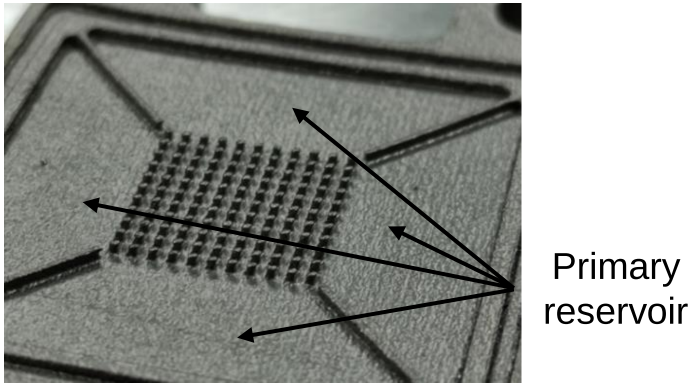


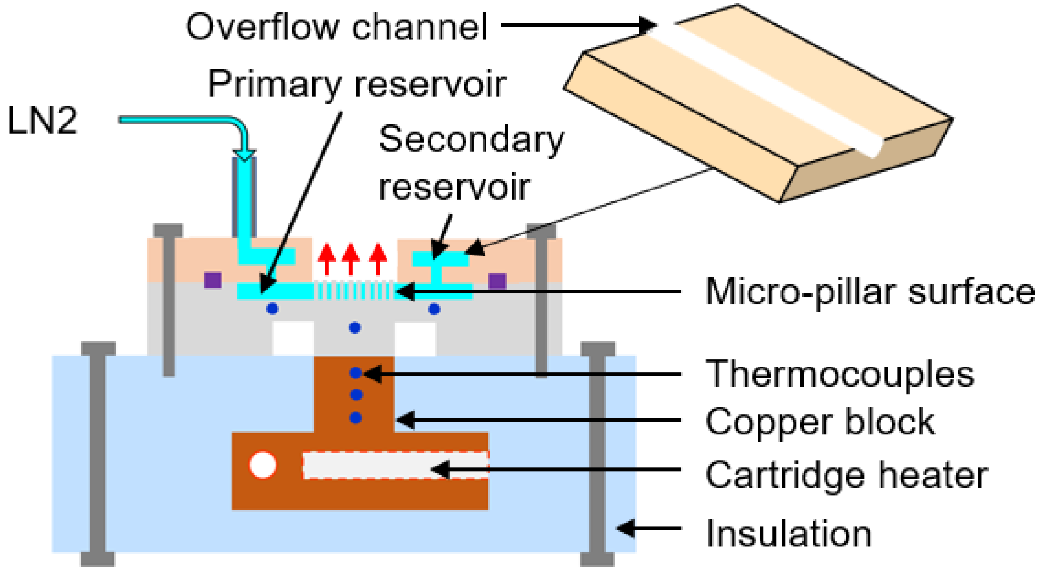


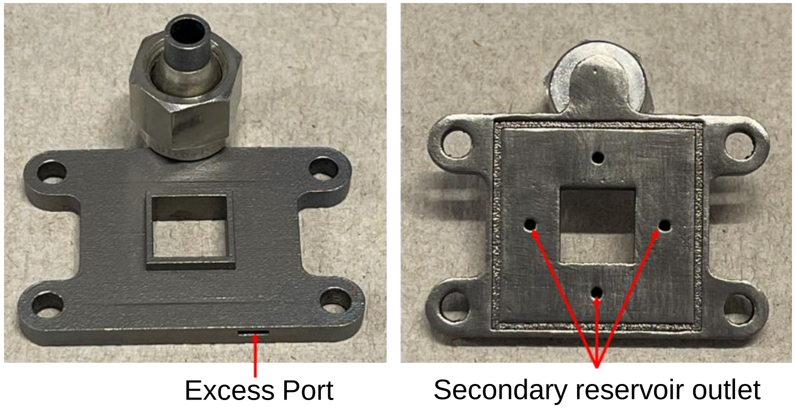


Test Surface Assembly

- Secondary reservoir is continuously filled with LN2 supply.
- Primary reservoir supplies LN2 to micro-pillars through capillary action.
- The drip holes in the secondary reservoir fills the primary reservoir through gravity.
- The excess LN2 flow is drained through an excess port in secondary reservoir ensuring the test procedure is not forced convection driven.



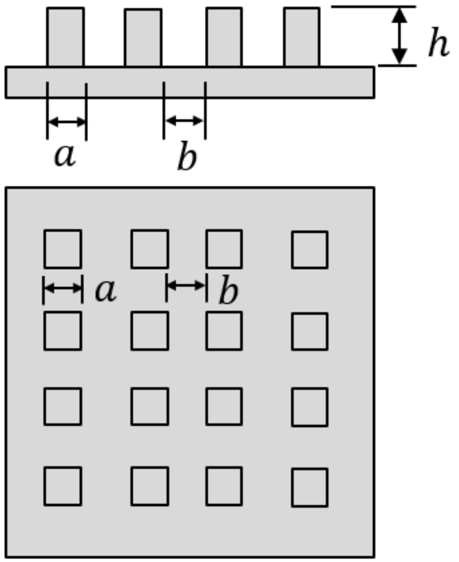


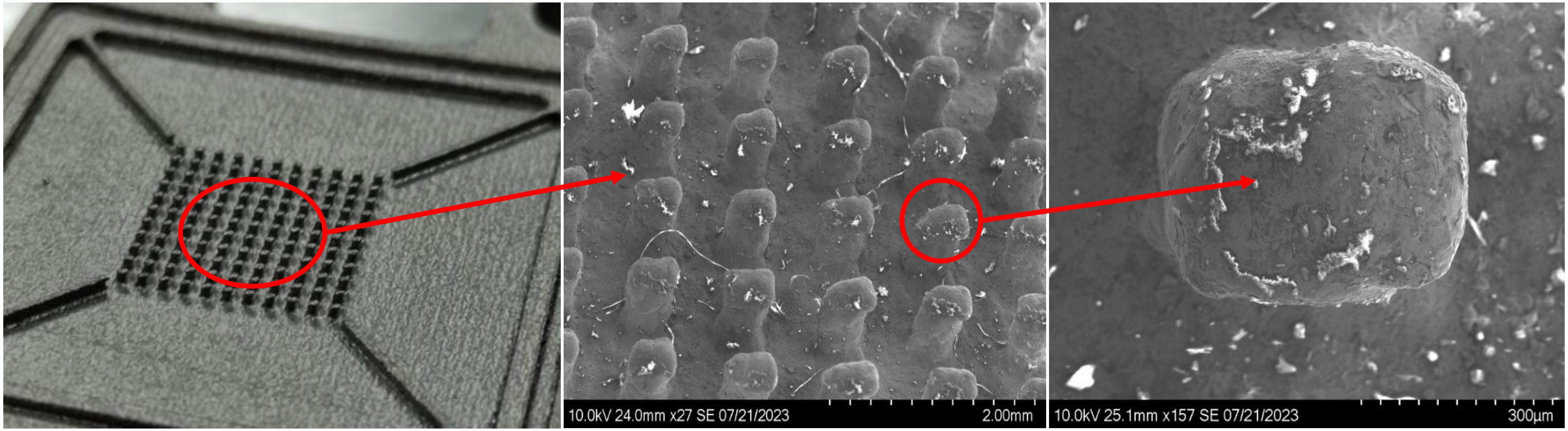


Additively Manufactured Top Cover

Engineered Micro-Structured Surface

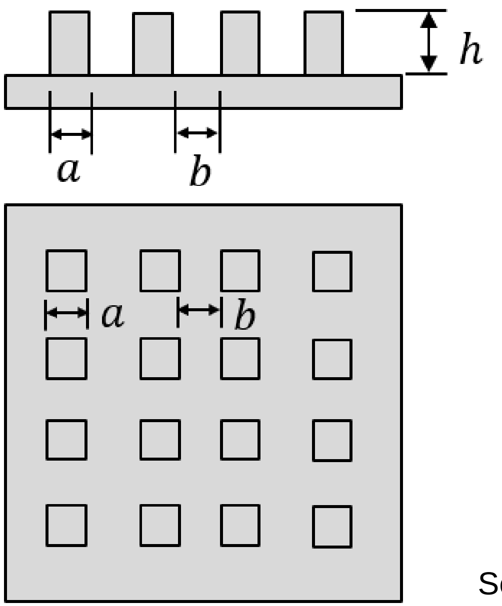
Material	Manufacturing Process	Width, a [μm]	Spacing, b [μm]	Height, h [μm]
Titanium Ti-64	Additive	400	400 500 600	600
Stainless Steel	CNC	400	500	600
Titanium Ti-64	Additive	400	500	800

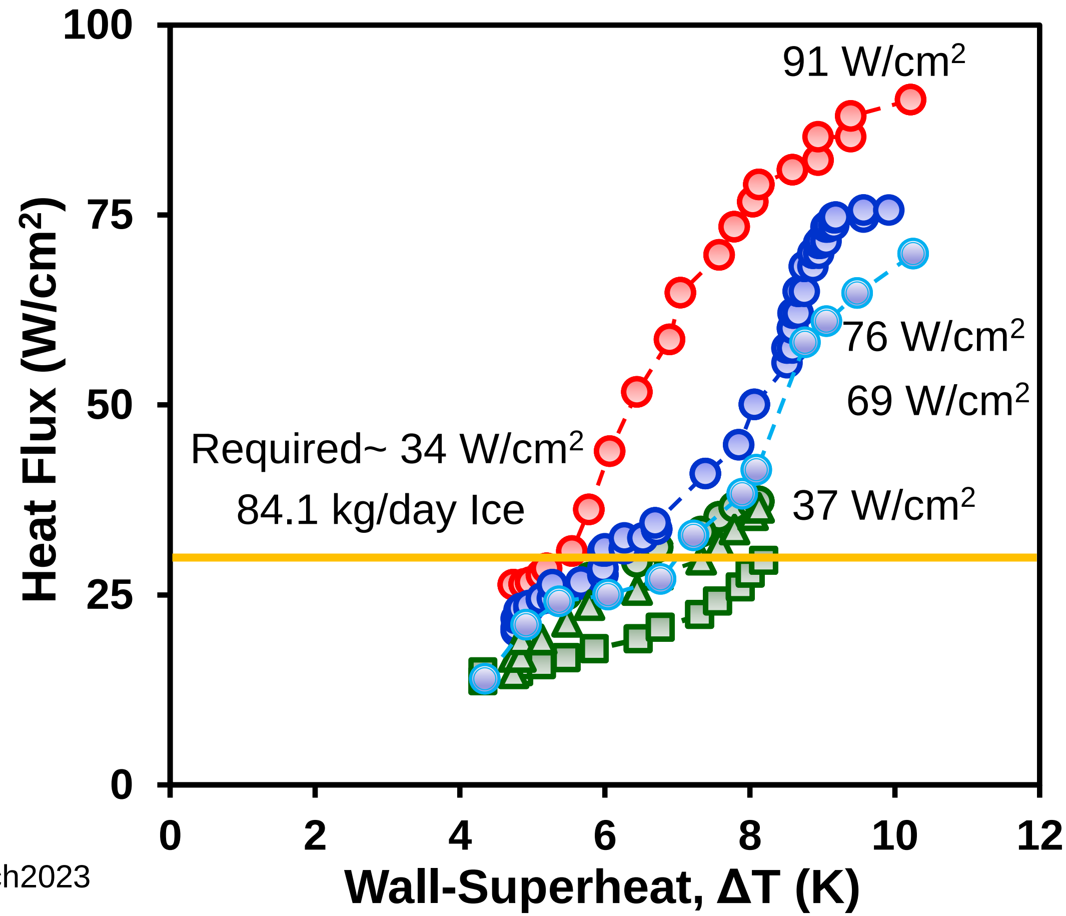




Effect of Spacing

- More than 140% increase in dry-out for additively manufactured surfaces.
- Maximum dry-out heat flux ~ 91 W/cm^2
- More than 167% higher capacity as compared to mission requirement.





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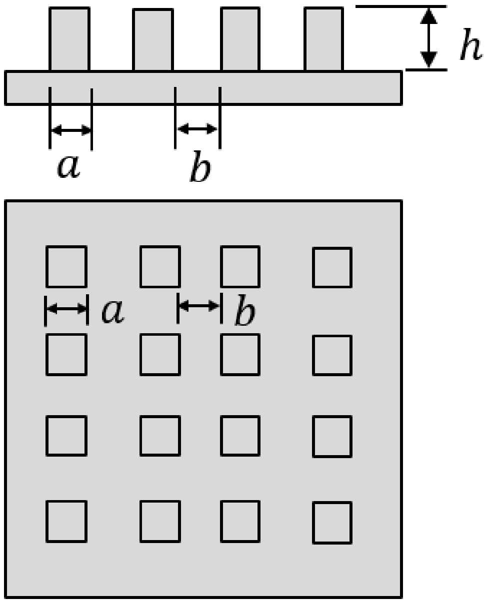
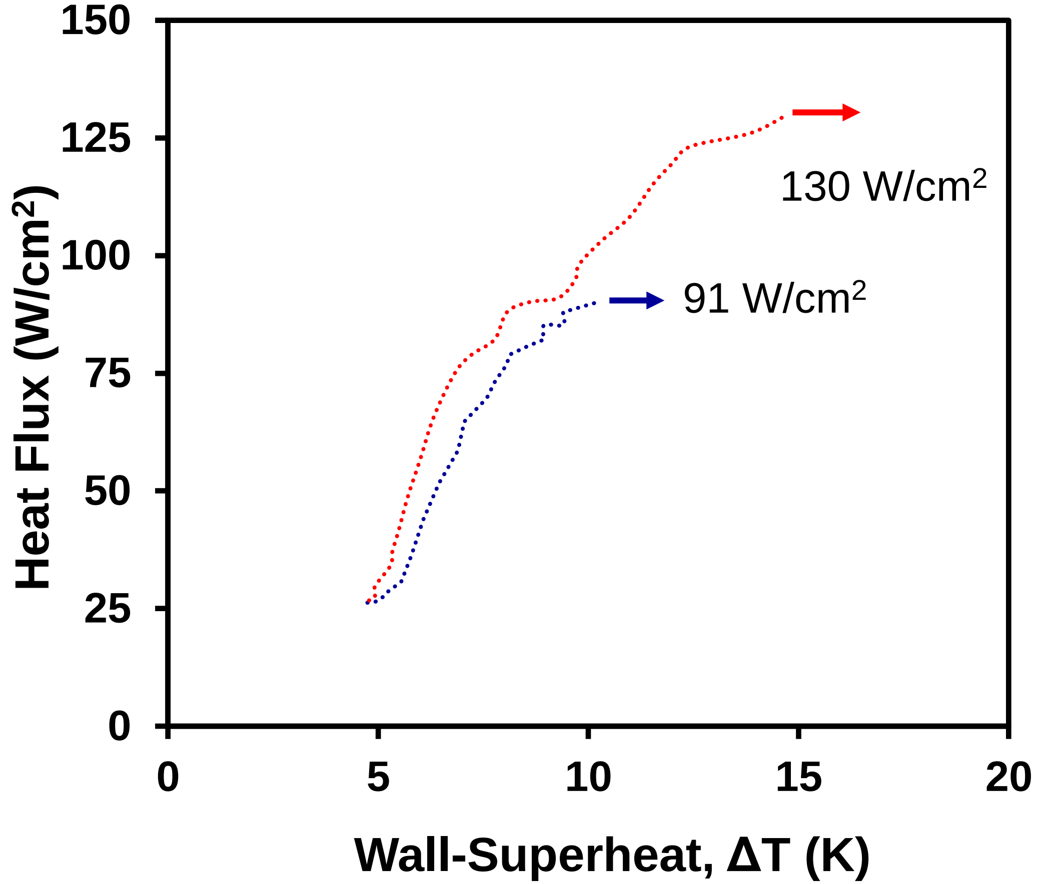
Effect of Height

- Additively manufactured Ti-64 micro-structured evaporator.
- More than 40% increase in dry-out heat flux with increasing the height of the micro-pillars.
- Maximum dry-out heat flux ~ 130 W/cm²





Conclusions

- Additively manufactured cryogenic heat pipe evaporators with micro-structured surfaces have been fabricated for enhanced heat collection from the water vapor re-capture process.
- From four different additively manufactured micro-structure samples, maximum dry-out heat flux was achieved as ~ 130 W/cm^2 for 800 µm micro-pillar with wall-to-wall spacing of 500 µm and square pillar width of 400 µm.
- For the same spacing, whenever the micro-pillar height was increased, the maximum dry-out heat flux was also increased by ~ 50%.
- More than 200% increased heat flux has been achieved as compared to the lunar ice mining requirements.

Acknowledgement

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