October 31, 2021

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Abstract:

Future NASA planetary, Lunar and spacecraft depend upon advanced mission-critical electronics, batteries, high-capability sensors, and crucial infrastructure elements such as power system heat rejection. Increasing use of wide bandgap power devices such as those found on GaN and SiC substrates will significantly improve specific power metrics up to two orders of magnitude, 0.25kW/kg (current) to 25kW/kg (future metric), for all power processing needs. Successful implementation of these technologies requires new power electronic topologies to reliably maintain electronics temperatures at higher heat fluxes and heat generation rates within the architectural limitations of smaller packages. Integrated thermal management technology offer the most promising optimized solutions based upon the size, weight and power consumption and cost (SWaP -C) metrics.

The next generation data centers will be likely located above the earth atmosphere as well. This will require novel, efficient, and compact electronic cooling technologies to allow for successful implementation of such data centers. Basic research in two-phase (liquid/vapor) fluid flows is needed to develop these technologies.

Two Phase Thermal Technology Research and Development:

Development of Integrated Thermal Management for infusion into future NASA planetary, lunar and science mission must address numerous fundamental phenomenological issues specific to both space applications with emphasis towards SWaP-C metrics. Technological thrusts must consider most efficient heat transfer mechanisms infused into smaller, integrated structural/thermal packages which address increasingly constrained mission requirements. Furthermore, NASA Space Technology Roadmaps TX 5: Communications, Navigation and Orbital Debris Tracking and Characterization Systems specifically identifies Power Efficient Technologies (KA Band Amplifiers in Section TX 5.5.2), Antennas (KA Band Phased Arrays in Section TX 5.5.6) and Integrated Technologies – Radio Systems (Section TX 5.5) as technology development priorities. Furthermore, TX 14: Thermal Management Systems calls out High Heat Flux Acquisition at Constant Temperature (Section TX 14.2.1) and Advanced Efficient Pump Technologies (Section TX 14.2.2) as developmental priorities.

<u>Space Applications Research:</u>

1. Heat Transfer Physics
    a. Liquid Film Dynamics
    b. Gravitational Influence on liquid film
    c. Liquid Vapor Phase Management

2. Operational Limits
    a. Minimum Heat Input
    b. Dry-out limit (maximum Heat Input)
3. Practical Models
    a. Performance Model
    b. Optimized Thermal Management subsystem design
4. Advanced Integrated Structural/Thermal Heat Exchangers

<u>A Novel Example:</u> Electrically Driven Liquid Film Flow Boiling

Electrically driven liquid film flow boiling is a complex liquid-vapor phase change phenomenon in the presence of electric field and absence of gravity. This novel concept, illustrated in Figure 1, consists of two mechanisms: 1- The electrical body force pumps (EHD pumping) the dielectric liquid film to electro-wet and to cool the heat source, and 2- The dielectrophoretic (DEP) force extracts the vapor bubbles away from the heat source surface during boiling.

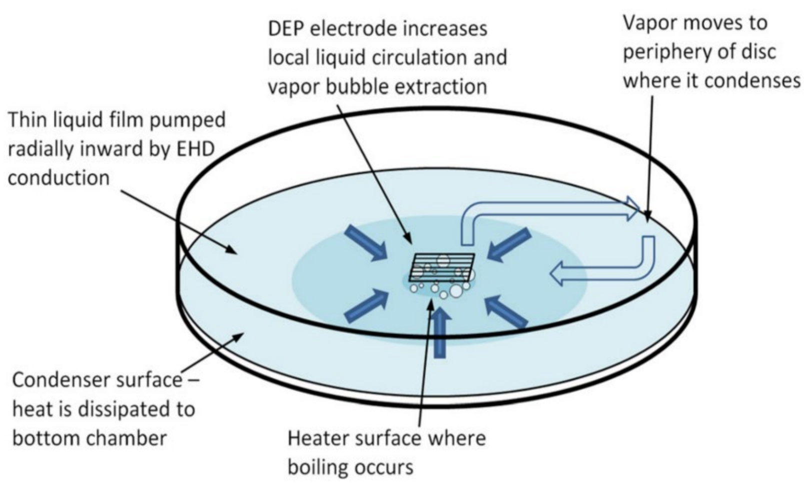

Figure 1. Electrically driven liquid film flow boiling concept

The scientific results from electrically driven liquid film flow boiling in the absence of gravity will provide the scientific foundation for the development of unique, innovative embedded two-phase heat transport devices that may yield significant Size, Weight and Power (SWaP) advancements. Embedded thermal control subsystems are critical to the development of intelligent optimized spacecraft and terrestrial devices.

This study will provide valuable scientific understanding about competing physical phenomena of flow inertia and bubble dynamics in electrically driven liquid film flow boiling in the presence of electric bubble extraction force in microgravity. Specifically,

- Liquid film boiling cannot be sustained in microgravity because vapor bubble departure from the heater does not occur.

- Vapor bubbles cover surface and grow or coalesce; modes of heat transfer will be limited to conduction and possibly radiation.
- To avoid this and to enable boiling to take place, EHD-driven liquid film flow will be fed from the condenser section towards the heater and bubbles will be extracted from the heater surface by DEP force.
- Inertia of EHD driven liquid film flow will electro-wet the boiling surface.
- Bubble repulsion will take place with DEP extraction force.
- Flow inertia is a function of applied EHD potential, electrode design, liquid film thickness, and working fluid properties.
- DEP extraction force is a function of applied potential, electrode design, gap between electrode and heater, and working fluid properties.
- Controlling parameters for this study are, therefore, applied EHD potential, applied DEP potential, heat flux, and liquid film height.
- This project is multi-disciplinary/multi-physics.
- Fluid transport equations are coupled with Poisson equations, in the presence of liquid/vapor phase change, and in the presence and absence of gravity.
- The scientific data gathered aboard ISS will be compared with the numerical predictions.
- The electrically driven liquid film flow boiling data aboard ISS will determine the critical heat flux, onset of boiling, absence of hysteresis, and bubble characteristics in the absence of gravity.