Electrically Driven Liquid Film Flow Boiling in the Absence of Gravity

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Co-Investigator

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Experiment Development Team

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Experiment Integration & Testing: Mario Martins LenTech
Disk and Heater Design & Fabrication: Timothy Miller NASA GSFC

Experiment Overview

PI Team: PI Prof. Jamal Yagoobi, Worcester Polytechnic Institute
Co-I: Jeffrey Didion, NASA GSFC
GRC Project Manager: MSI/Bob Hawersaat
GRC Project Scientist: LTZ/Dr. Mojib Hasan

Objective:

- Characterize the effects of gravity on the interaction of electric and flow fields in the presence of phase change specifically pertaining to:
  - The effects of microgravity on the EHD generated two-phase flow.
  - The effects of microgravity on the EHD driven liquid film flow boiling and di-electrophoretically extracting bubbles from heating surface.

Experimental Approach:

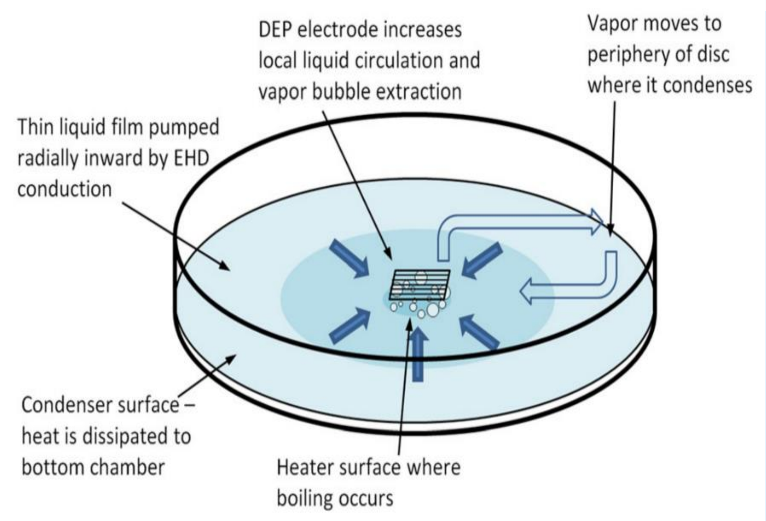
- The EHD experiment will use two test chambers, one with 2mm and one with 3 mm film thickness.
- Test chamber ground testing will be performed at GSFC.

Relevance/Impact:

- Provides phenomenological foundation for the development of EHD based two phase thermal management systems.
- Development of intelligent two-phase heat transport device with no moving parts, light weight, and easy to control.
- Concurrent development of prototype EHD based two-phase thermal management devices for customer/adopter infusion.
- Potential applications range from micro-g to high-g and from micro-scale to macro-scale.

Project Development Approach:

- The development approach is drop tower rig, variable gravity flight (March 2019) breadboard, engineering unit and flight unit. The flight unit test chamber will be developed by GSFC.
- The EHD experiment will be operated in the MSG facility.



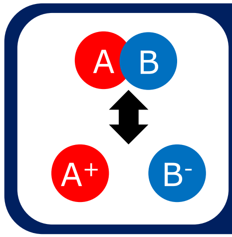
Accommodation (carrier)	Microgravity Science Glovebox (MSG)
Upmass (kg) (w/o packing factor)	50 (estimate)
Volume (m^3) (w/o packing factor)	0.10 (estimate)
Power (kw) (peak)	0.50 (estimate)
Crew Time (hrs) (installation/operations)	11 hours to install/change out test chambers/stow
Autonomous Operation	80 days
Launch/Increment	June 2021 / Inc 66

ElectroHydroDynamic (EHD) Physics

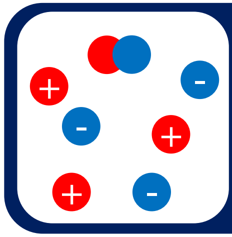
$$\boldsymbol{f}_e = \underbrace{\rho_e \boldsymbol{E}}_{\text{Coulomb Force}} \underbrace{- \frac{1}{2} E^2 \nabla \varepsilon + \frac{1}{2} \nabla \left[E^2 \left(\frac{\partial \varepsilon}{\partial \rho} \right)_T \rho \right]}_{\text{Polarization Forces}}$$

Electrophoretic Force (Coulomb): Liquid Pumping
Dielectrophoretic (Polarization): Two Phase Management

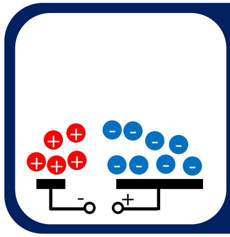
EHD: Conduction Phenomena



Molecules dissociate into positive and negative ions, while ions recombine into neutral molecules. When electrical field intensity is low, dissociation & recombination rates are in dynamic equilibrium.



High electric field intensity causes the rate of dissociation to exceed the rate of recombination.



These charges redistribute due to the electric field, forming heterocharge layers. The attraction of charges to the nearby electrode causes fluid motion. By designing electrodes to produce asymmetry of electric field, net flow results.

Di-electrophoretic Phase Management

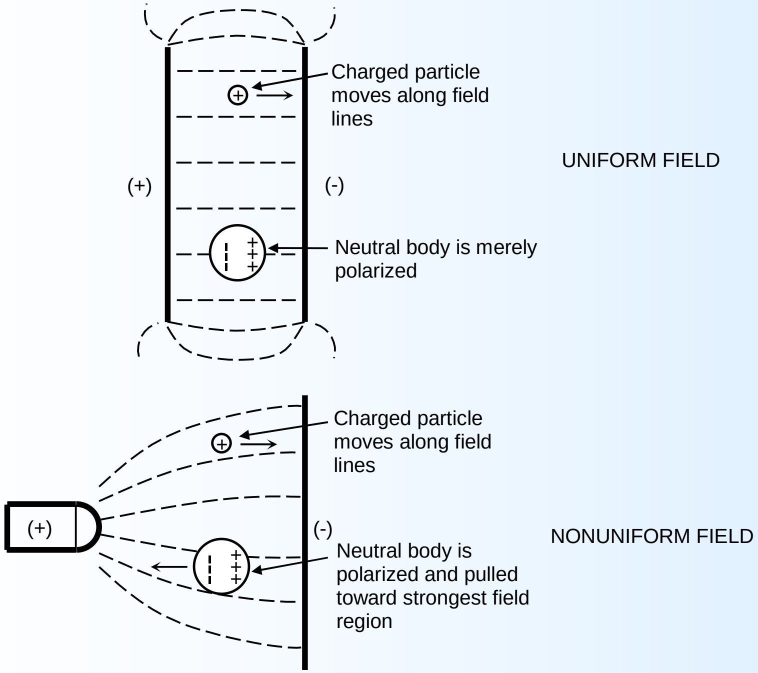
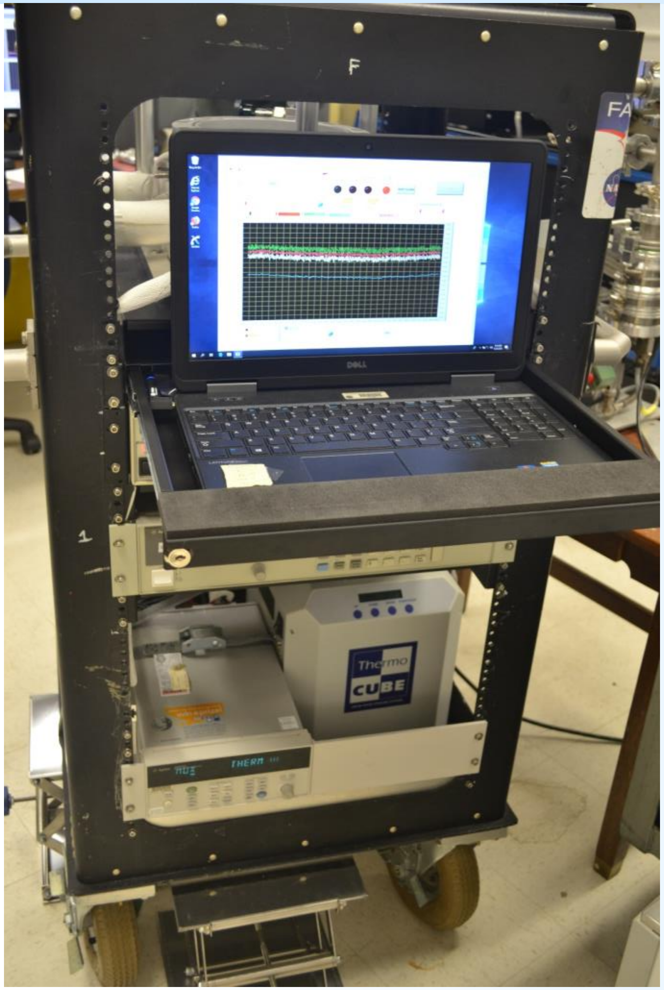
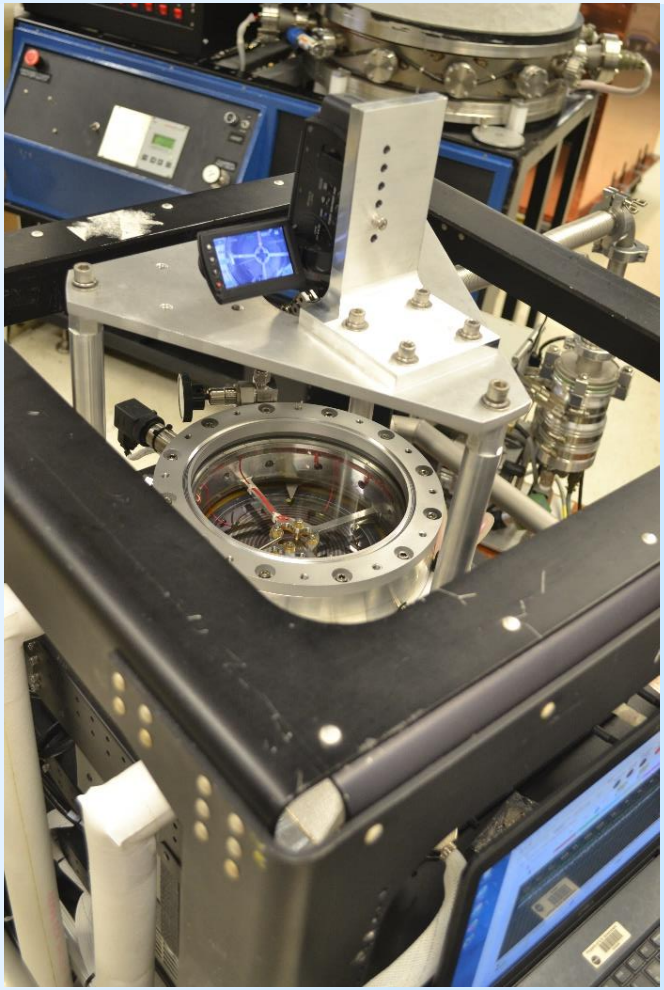


Figure 3. Dielectrophoretic Force in Uniform and Non-Uniform Field

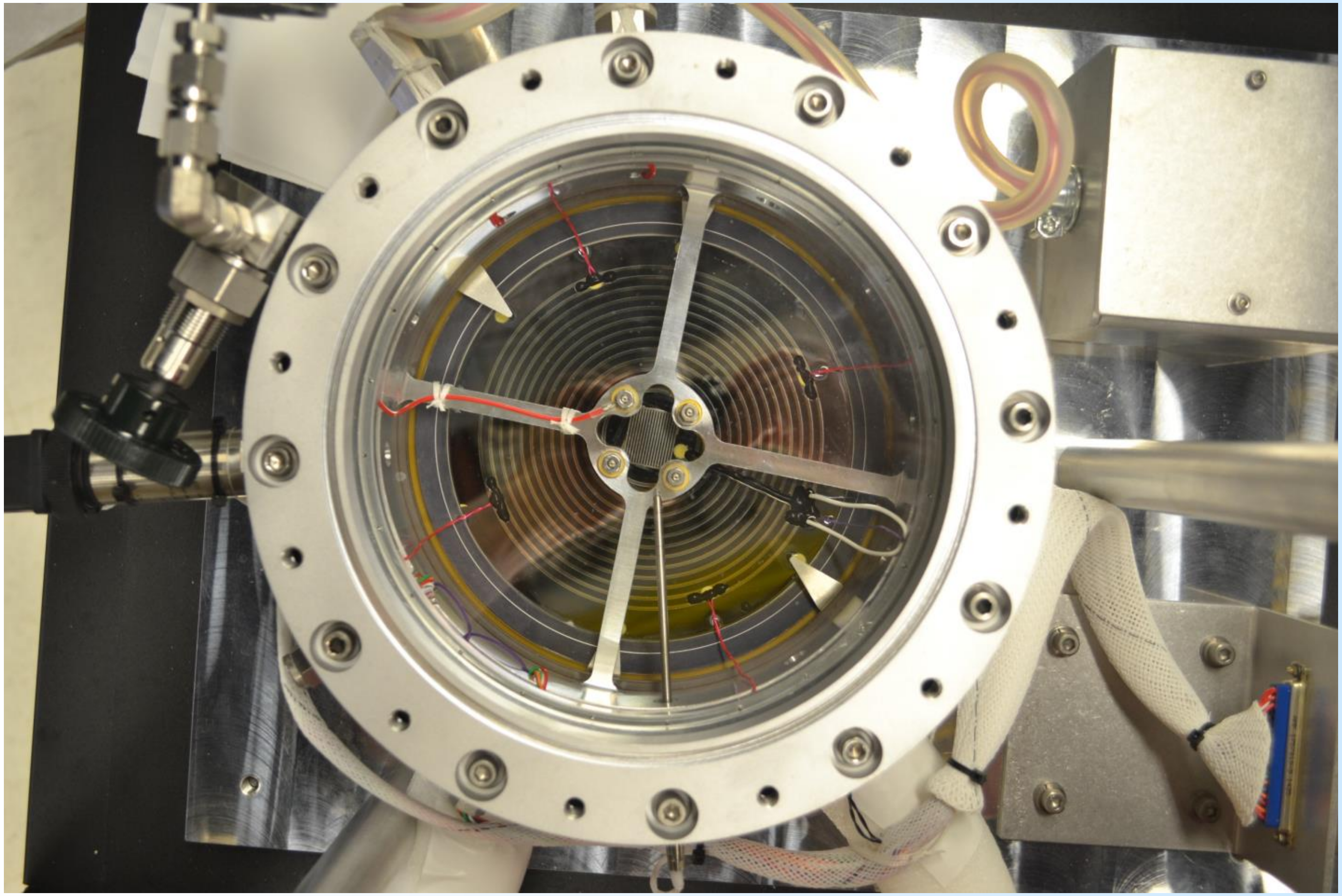
$$F_{DEP} = 2\pi a^3 \varepsilon_1 \left(\frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + 2\varepsilon_1} \right) \nabla |E_e|^2$$

Experiment Hardware: Lab Set Up

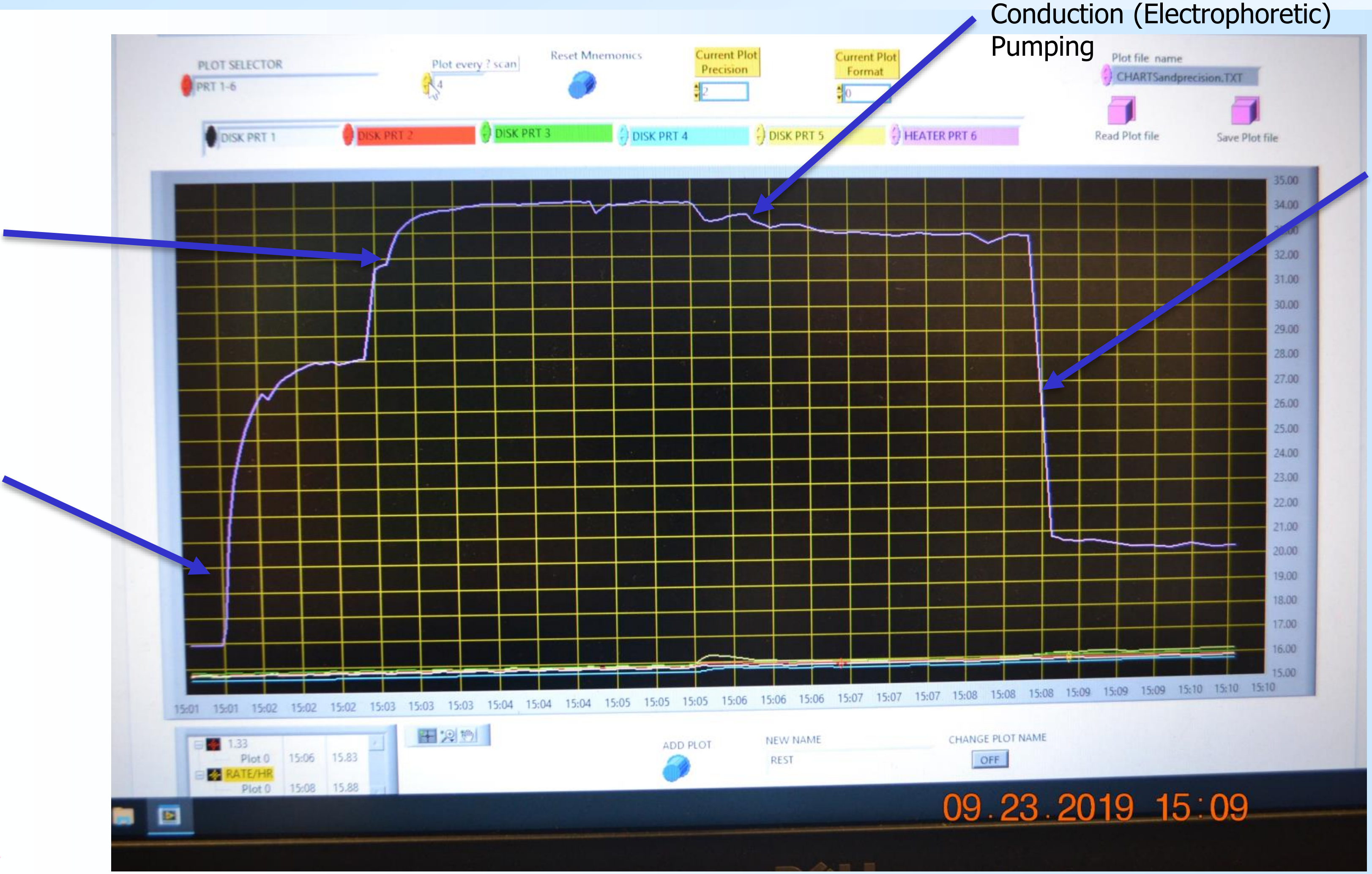




Experiment Hardware: Top View



Electrically Driven Liquid Thin Film Boiling



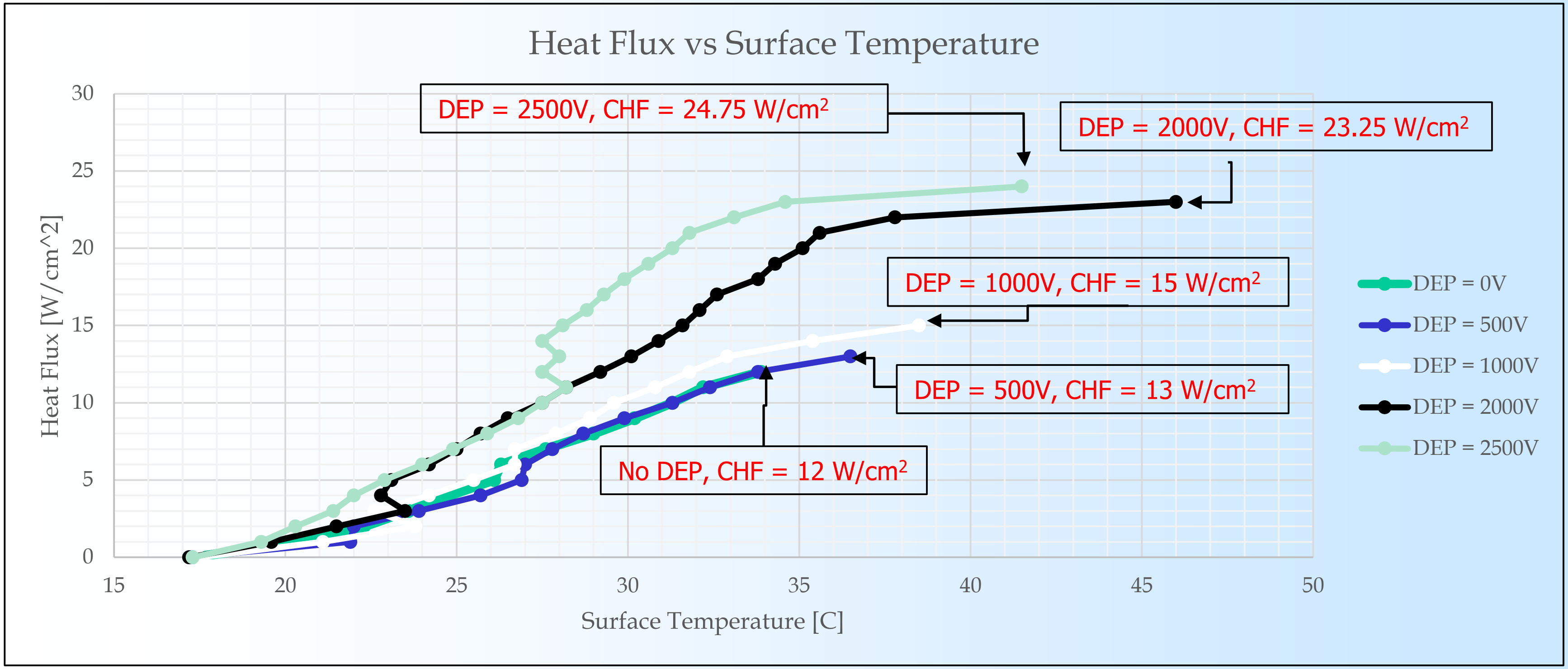
Conduction (Electrophoretic) Pumping

Apply 2000V DEP

Pool Boiling

Single Phase Heating

Pool Boiling: Heat Flux v Temperature DEP Effect



DEP = 2500V, CHF = 24.75 W/cm^2

DEP = 2000V, CHF = 23.25 W/cm^2

DEP = 1000V, CHF = 15 W/cm^2

DEP = 500V, CHF = 13 W/cm^2

No DEP, CHF = 12 W/cm^2

Application: High Heat Flux High Temperature Heat Acquisition

- **NASA Space Technology Roadmaps:**
  - *TA 5: Communications, Navigation, and Orbital Debris Tracking and Characterization Systems*
    - *TA 5.5.2 Power Efficient Technologies (Ka Band amplifiers)*
    - *TA 5.2.6: Antennas (Ka Band Phased Arrays)*
    - *TA 5.5: Integrated Technologies – Radio Systems (reduced SWaP)*
  - *TA 14: Thermal Management Systems*
    - *TA 14.2.1: High Heat Flux Acquisition @ constant Temperature*
    - *TA14.2.2: Advanced Efficient Pump Techniques; specifically calls out EHD pumping*

- **Decadal Survey Missions**

  High Power RF Amplifiers (HPA) have thermal challenges that limit microwave (communication and radar) performance
  - *Aerosol, Cloud and Ecosystem (ACE)*
  - *Snow and Cold Land Processes (SCLP)*