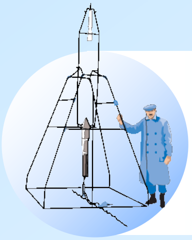

Electrically Driven Liquid Film Boiling Experiment

Jeffrey R. Didion
Senior Thermal Engineer
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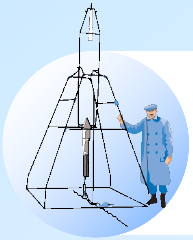
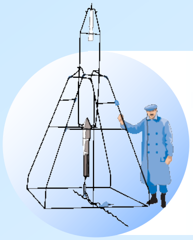


ElectroHydroDynamic (EHD) Physics

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

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



EHD: Advantages & Constraints

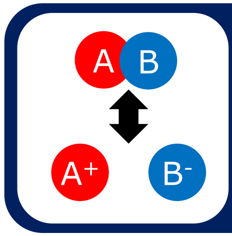
Advantages

- simple design
- light weight
- non-mechanical, no rotating machinery
- rapid and easy control of performance
- low power consumption
- low acoustic noise
- smart system

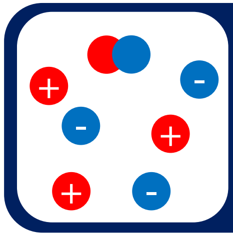
Constraints

- high voltage/electric field
- electric field interference
- electrically conductive fluids
- low pumping efficiency

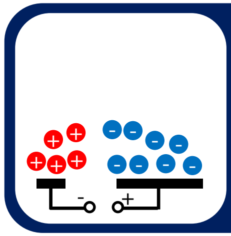
EHD: Conduction Phenomena



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.

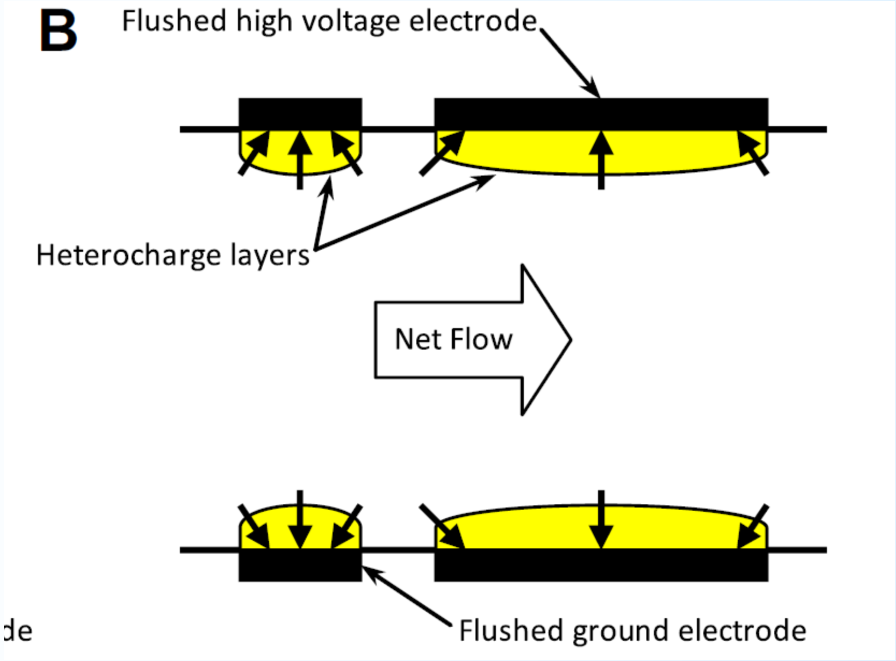


High electric field intensity causes the rate of dissociation to exceed the rate of recombination.



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.

Electrophoretic Pumping: Channel



Di-electrophoretic Phase Management

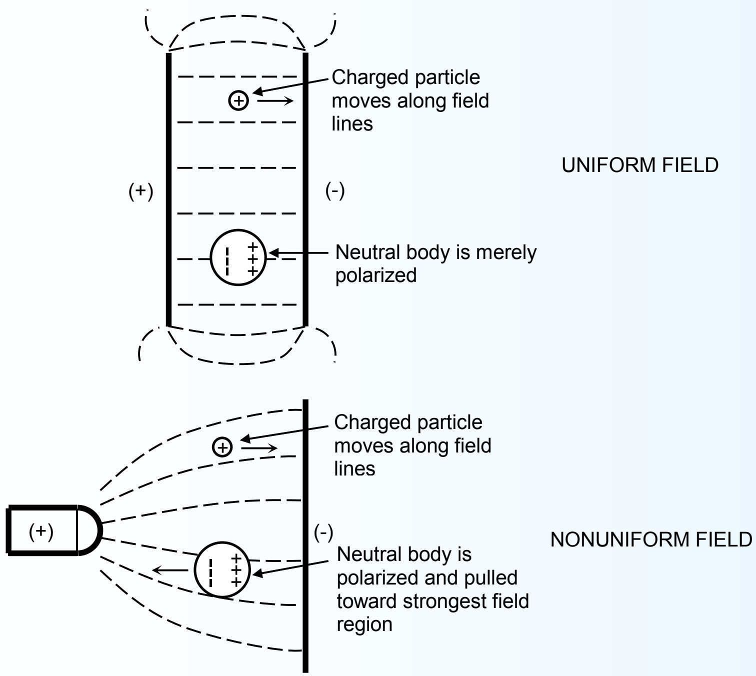


Figure 3. Dielectrophoretic Force in Uniform and Non-Uniform Field

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

EHD Thin Film Boiling Experiment: Electrophoretic Pumping (EP)

Objective:

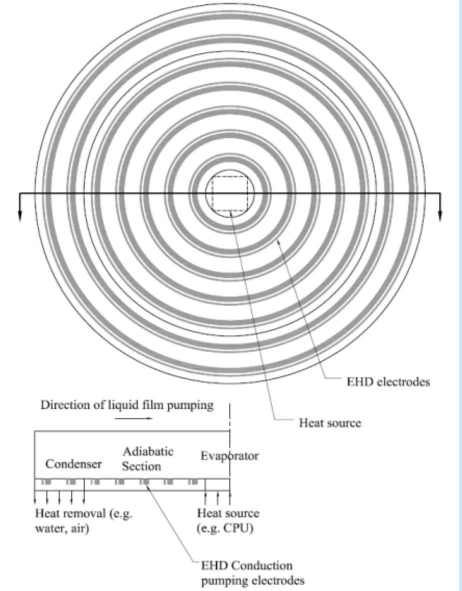
- Characterize the effects of gravity on the interaction of electric and flow fields in the presence of phase change specifically pertaining to:
  - The effects of microgravity on the electrically generated two-phase flow.
  - The effects of microgravity on electrically driven liquid film boiling (includes extreme heat fluxes).
- Electro-wetting of the boiling section will repel the bubbles away from the heated surface in microgravity environment.

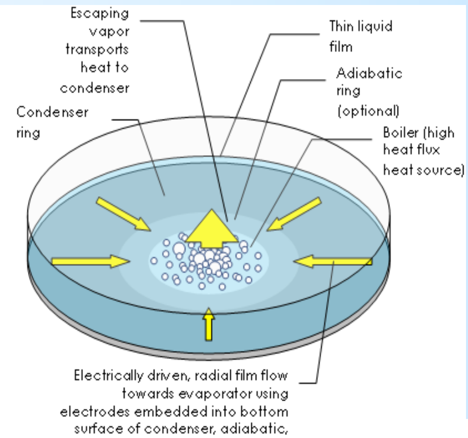
Relevance/Impact:

- Provides phenomenological foundation for the development of electric field based two-phase thermal management systems leveraging EHD, permitting optimization of heat transfer surface area to volume ratios as well as achievement of high heat transfer coefficients thus resulting in system mass and volume savings.
- EHD replaces buoyancy or flow driven bubble removal from heated surface.

Development Approach:

- Conduct preliminary experiments in low gravity and ground-based facilities to refine technique and obtain preliminary data for model development.
- ISS environment required to characterize electro-wetting effect on nucleate boiling and CHF in the absence of gravity.
- Will operate in the FIR – designed for autonomous operation.



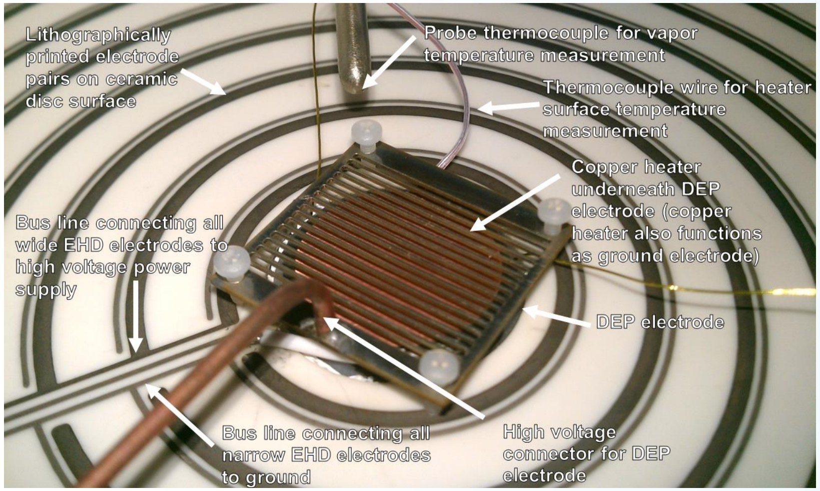


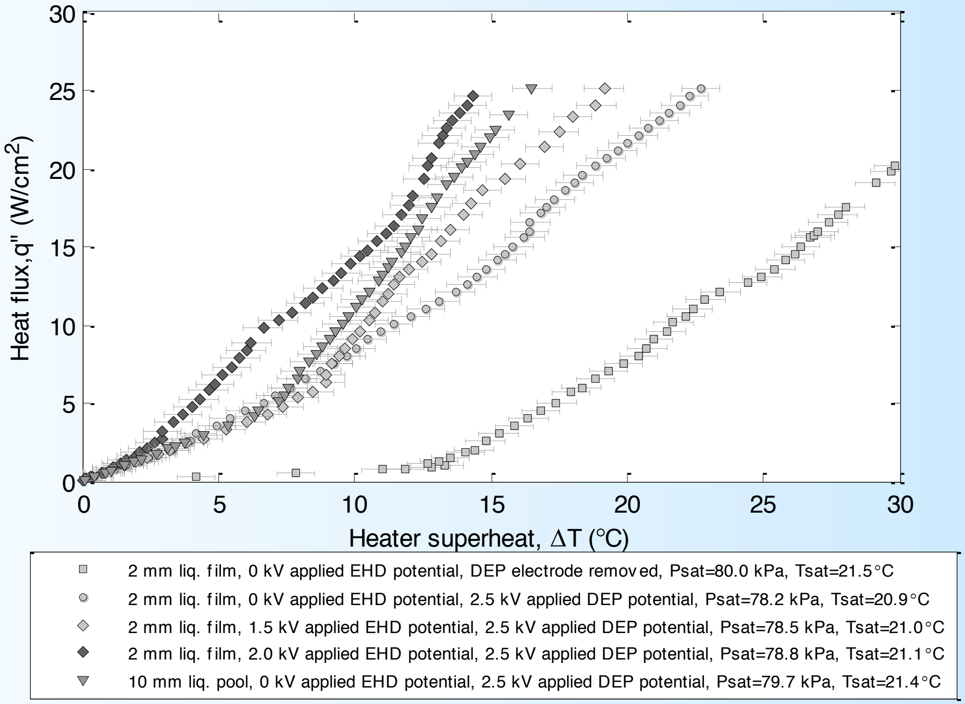
EHD Thin Film Boiling Experiment: Combined DEP & EP

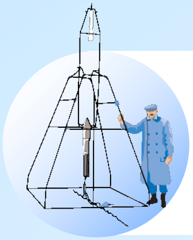
Objective:

- Investigate combined effect of Dielectrophoretic Force and Electrophoretic Force (Conduction Mechanism) on heat transfer enhancement

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







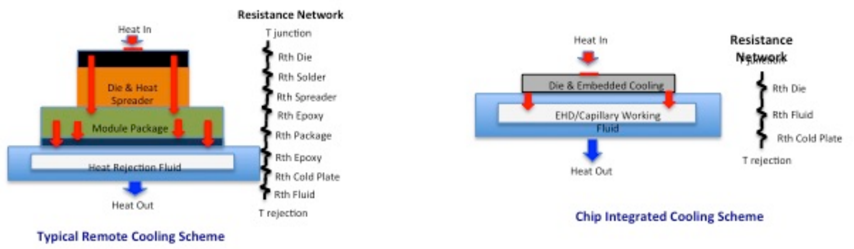
Application: High Heat Flux High Temperature Heat Acquisition

- **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*

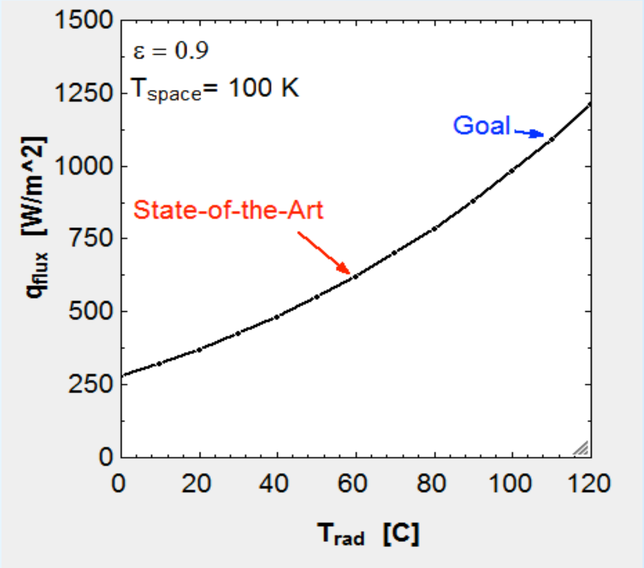
- **Decadal Survey Missions**

  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)*

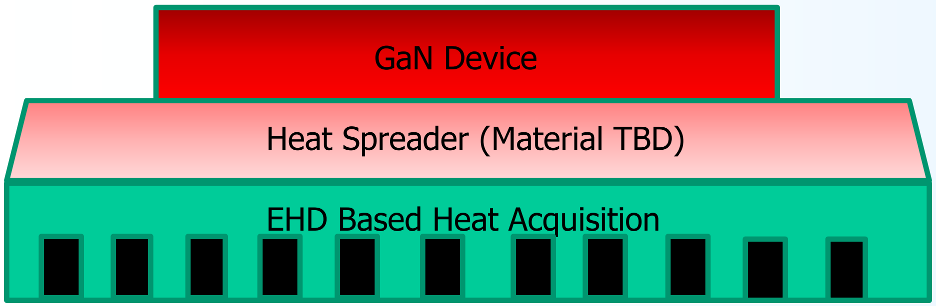
High Temperature Heat Acquisition Advantages



Higher Heat Rejection Temperature
Lower System Thermal Resistance



GaN Heat Acquisition Concept



GaN Substrate Electric Field (EHD) Driven High Heat Flux High Temperature Heat Acquisition Device