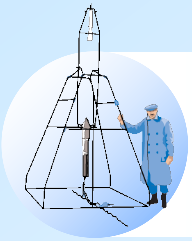
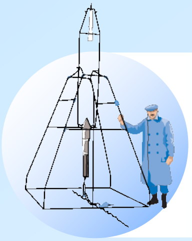


Advances in Electrically Driven Thermal Management

Jeffrey R. Didion
Senior Thermal Engineer
Manager, Nanotechnology Facility

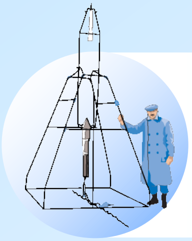


NASA Relevance

- **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)*



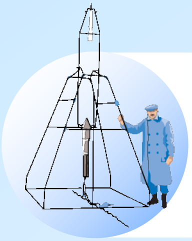
NASA Technology Point of Infusion

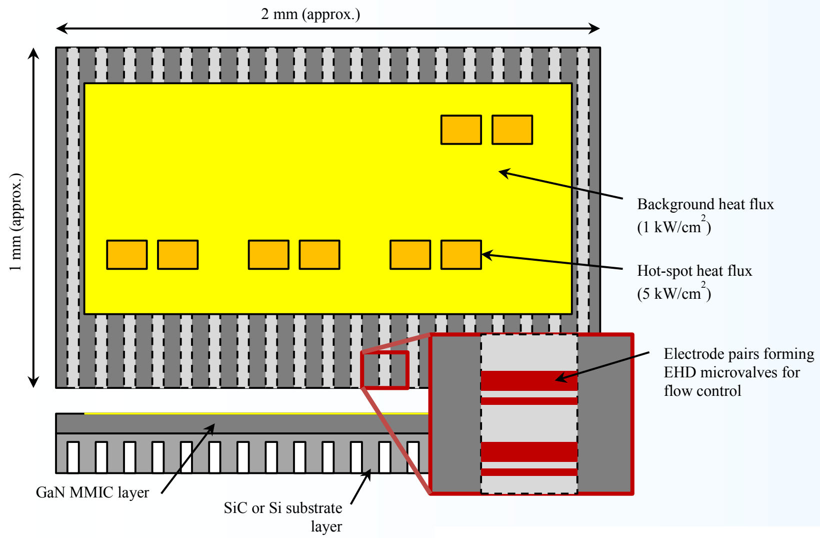
Integrated Radar Subsystem ACE & SCLP

- *High Power Amplifiers (HPA) performance is thermally limited; Improved thermal management for GaN based amplifiers will achieve higher instrument sensitivity via higher duty cycle.*
- *Improved thermal management of high power RF signals alleviates the current frequency limitations (set by International Agreement) and enable the development of Multi-Use Systems*
  - » *Identified Ka Band (35 GHz) transmit/ receive module performance limitations due to thermal management*

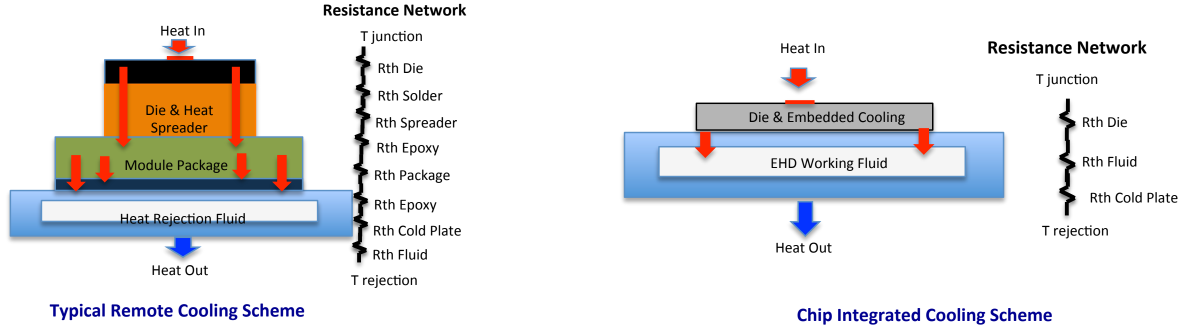
- ***Enabling Technology: Improved transmit/receive module will permit use of synthetic aperture radars***

High Temperature Heat Acquisition: Reduced Thermal Resistance

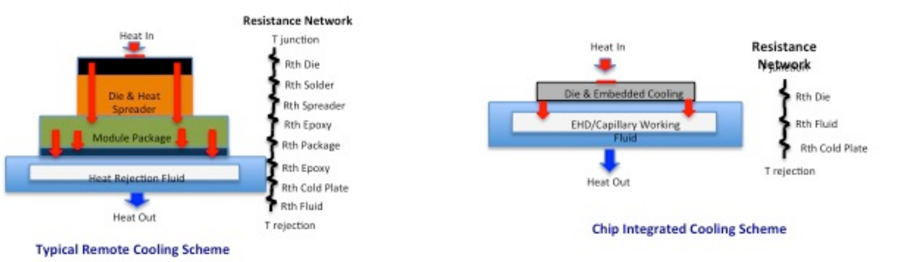




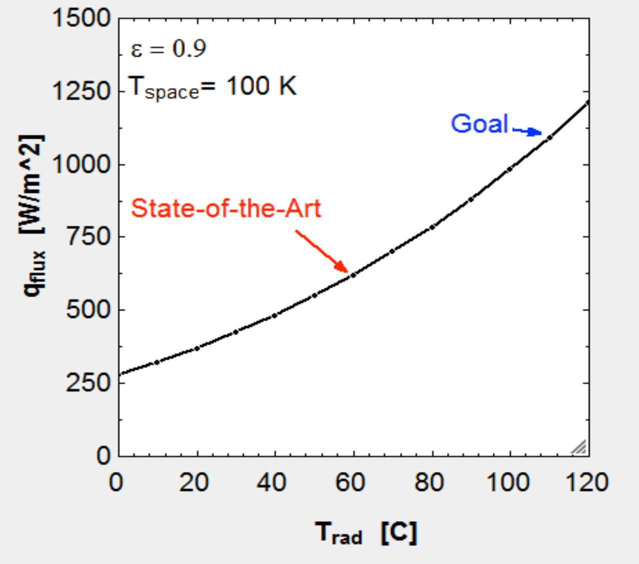
Reduced Mass and Volume of Chip
Reduced Thermal Resistance
High Temperature Heat Acquisition



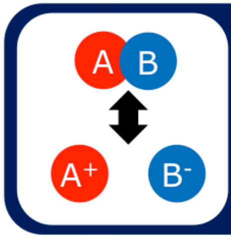
High Temperature Heat Rejection



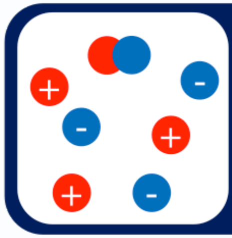
Higher Heat Rejection Temperature
Lower System Thermal Resistance



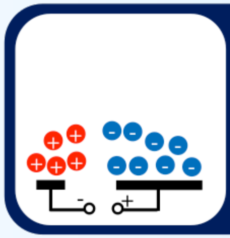
EHD Conduction Phenomenon



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.

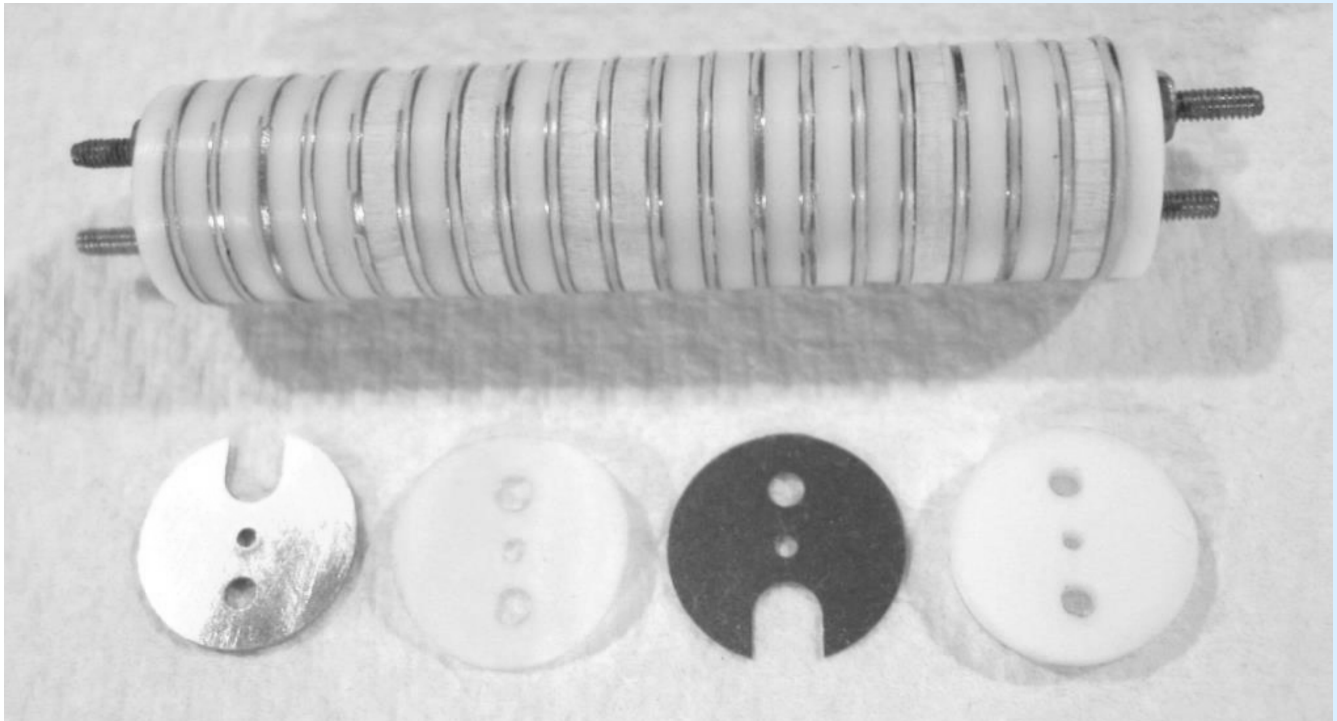


High electric field intensity causes the rate of dissociation to exceed the rate of recombination.

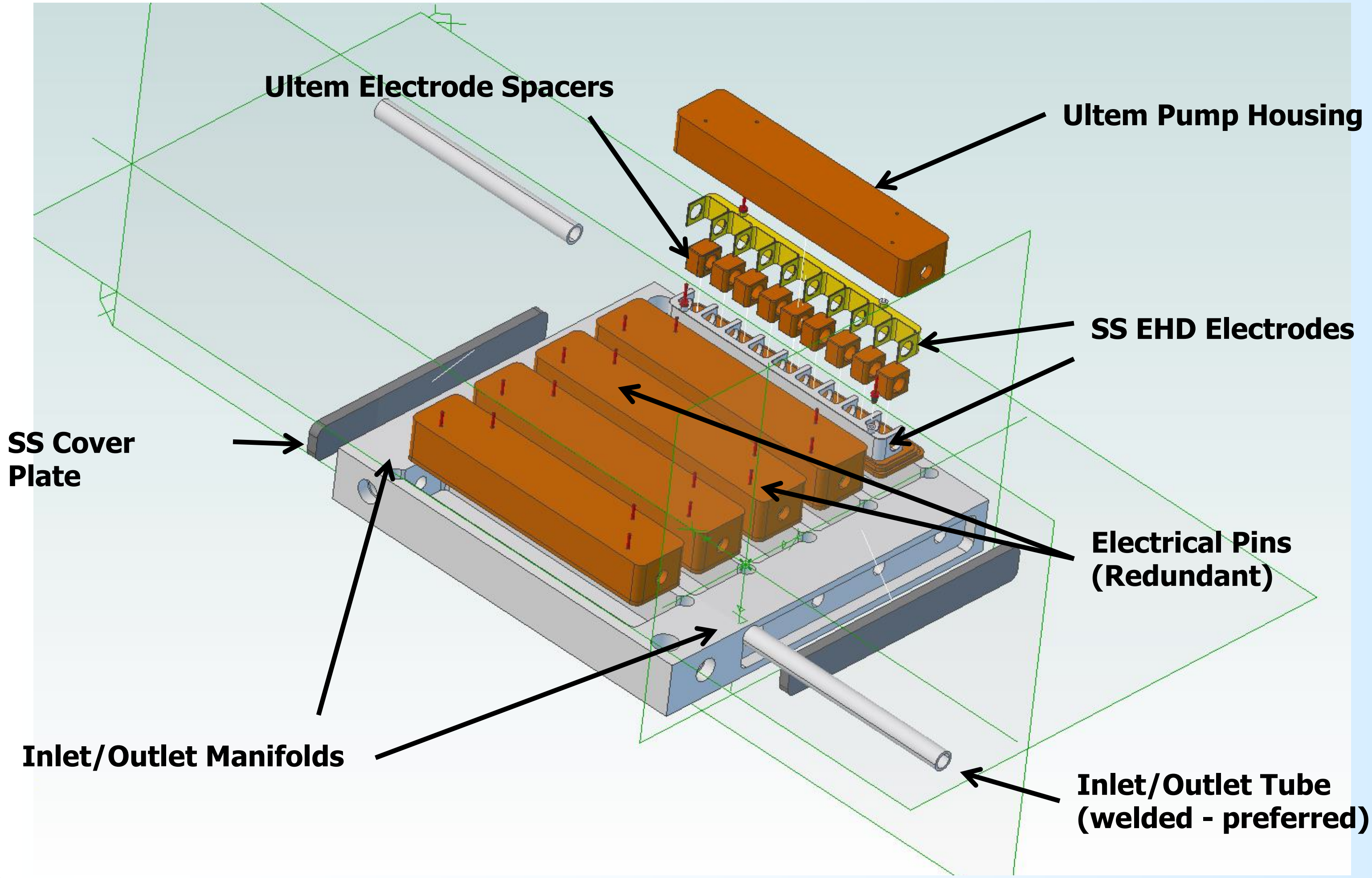


These charges redistribute due to the electric field, forming heterocharge layers. The attraction of charges to the nearby electrode causes fluid motion. By designing electrodes to produce asymmetry of electric field, net flow results.

1st Generation EHD Conduction Pump



Manifold 2nd Generation EHD Conduction Pumps



STP-H5 EHD Conduction Pump Life Test Loop

5 parallel EHD Pumps operating at 1000 Vdc

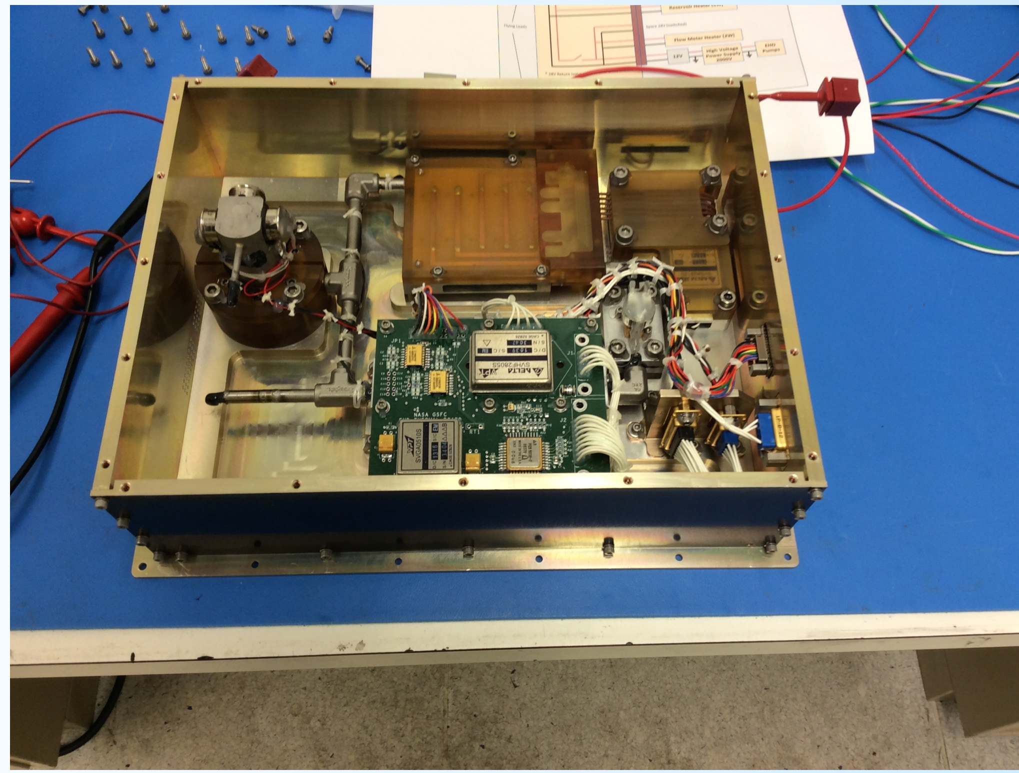
- ~ 0.43 g/s HFE 7100
- ~1000 Pa

Instrumentation

- Thermal Mass Flow
- 7 TCs

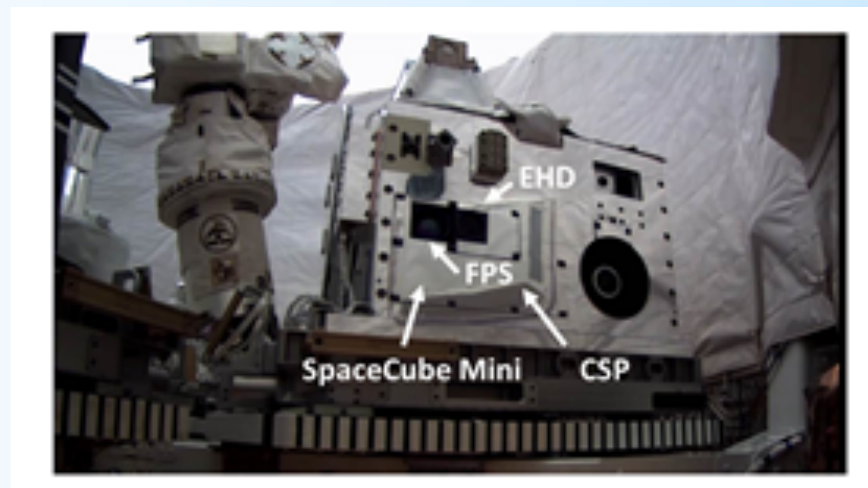
Status: ON ORBIT

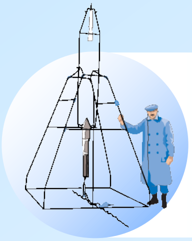
- Delivery: February 2015
- Launch: February 2017



STP-H5 EHD Conduction Pump Life Test Loop

GSFC ISEM Experiment (Thomas Flatley PI)





Electrically Driven Liquid Film Boiling Experiment: ISS MSG 2021

Objective:

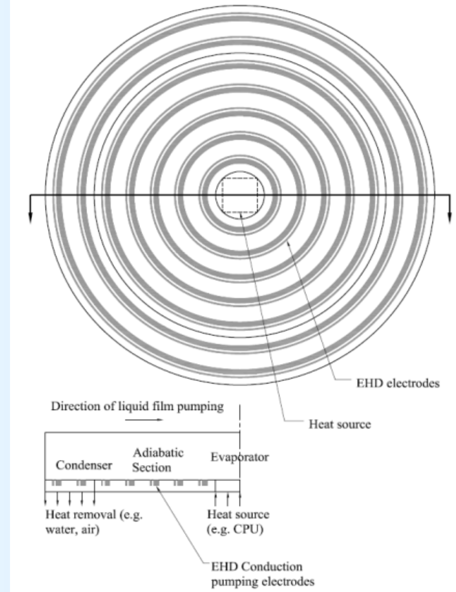
- Characterize the effects of gravity on the interaction of electric and flow fields in the presence of phase change specifically pertaining to:
  - The effects of microgravity on the electrically generated two-phase flow.
  - The effects of microgravity on electrically driven liquid film boiling (includes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

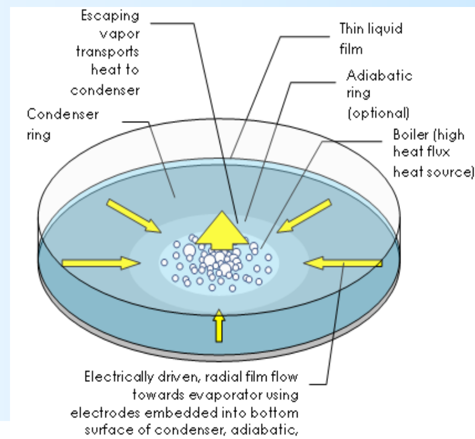
Relevance/Impact:

- 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.





Electrohydrodynamic (EHD) Phenomenon

Interaction between electric field and flow field

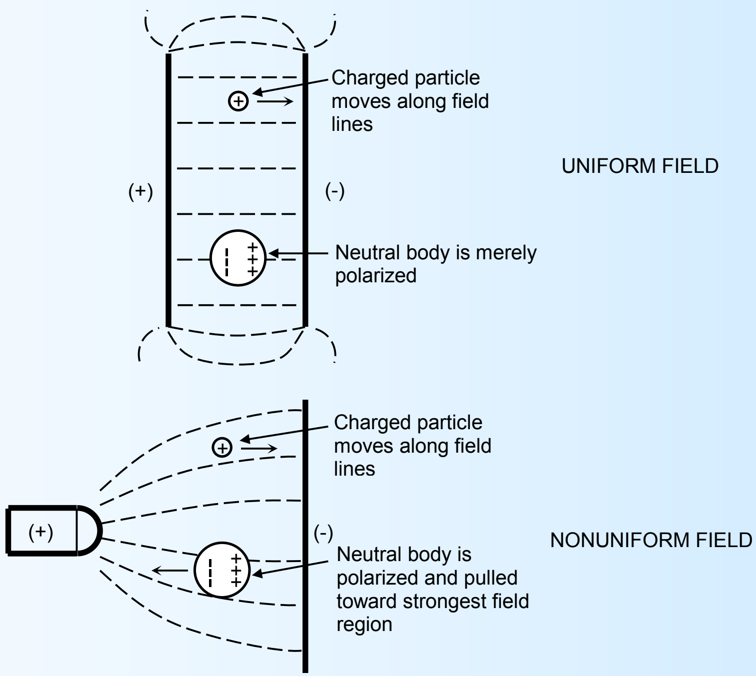
$$\boldsymbol{f}_e = \rho_e \boldsymbol{E} - \underbrace{\frac{1}{2} E^2 \nabla \varepsilon + \frac{1}{2} \nabla \left[E^2 \left(\frac{\partial \varepsilon}{\partial \rho} \right)_T \rho \right]}$$

Coulomb Force: $\rho_e \boldsymbol{E}$

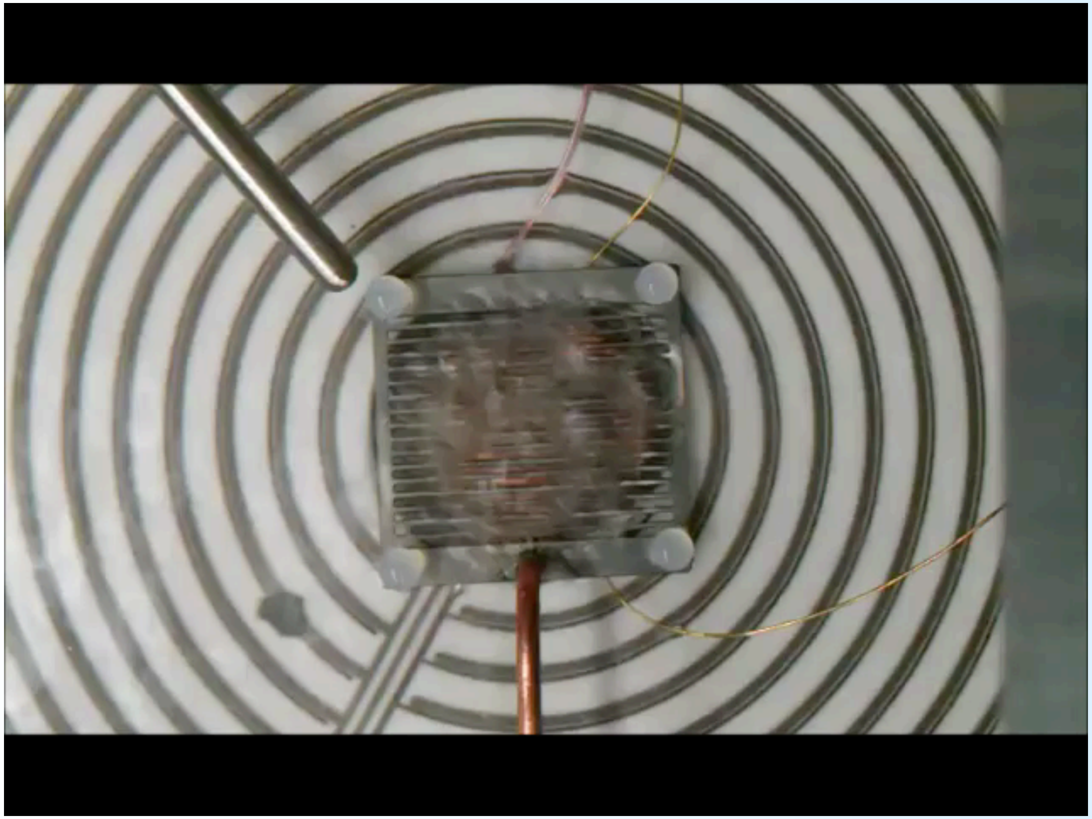
Polarization Forces: $- \frac{1}{2} E^2 \nabla \varepsilon + \frac{1}{2} \nabla \left[E^2 \left(\frac{\partial \varepsilon}{\partial \rho} \right)_T \rho \right]$

EHD Di-electrophoretic Force

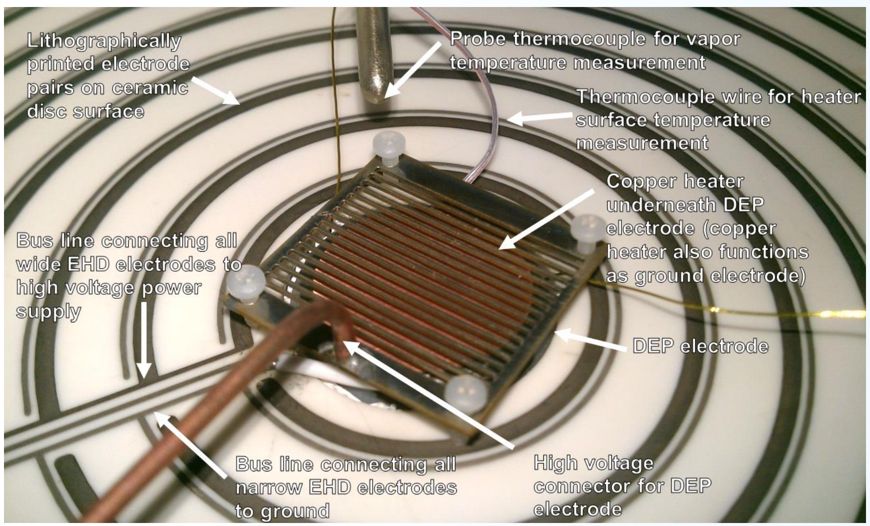
$$\boldsymbol{F}_{\boldsymbol{DEP}} = 2\pi a^3 \varepsilon_1 \left(\frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + 2\varepsilon_1} \right) \boldsymbol{\nabla} |\boldsymbol{E}_e|^2$$

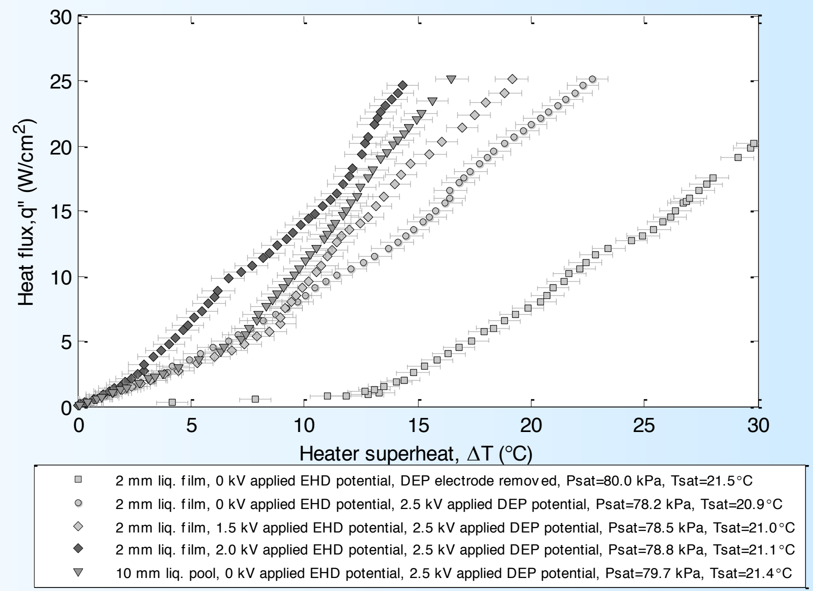


Dielectrophoretic (DEP) Phase Management & Conduction Pump

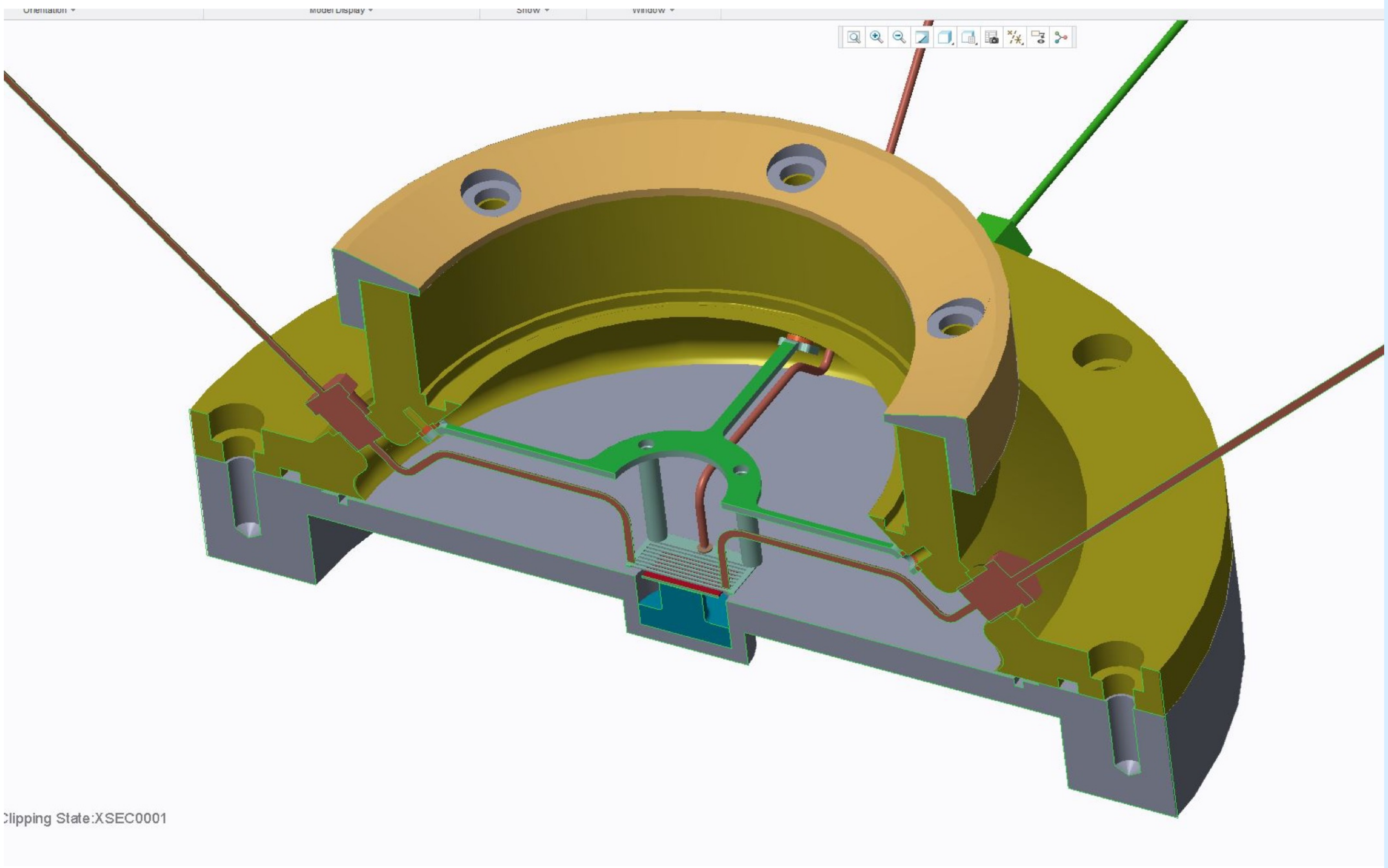


Dielectrophoretic (DEP) Phase Management & Conduction Pump





Experiment Breadboard Design

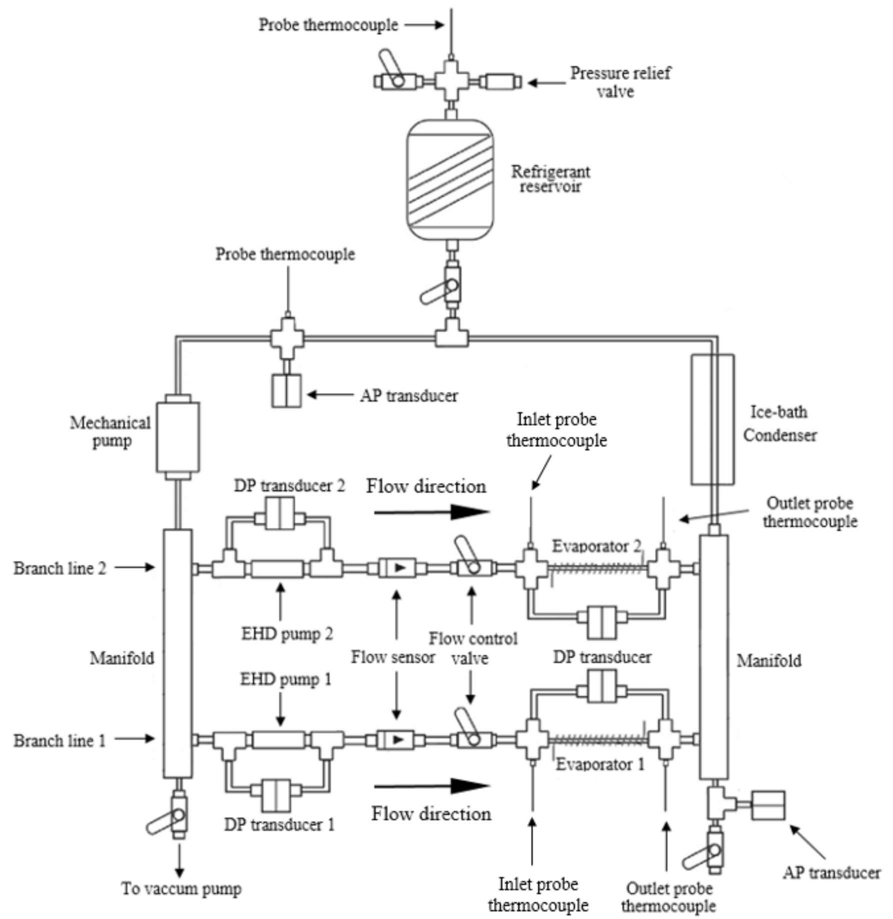


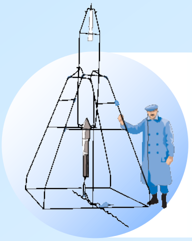
EHD Flow Distribution Control

- **Investigate the flow distribution control in meso-scale with same and reverse EHD conduction pumping direction**

- **Experimentally investigate the effect of upstream flow velocity on the formation of heterocharge layer in the vicinity of electrodes**

EHD Flow Distribution Control

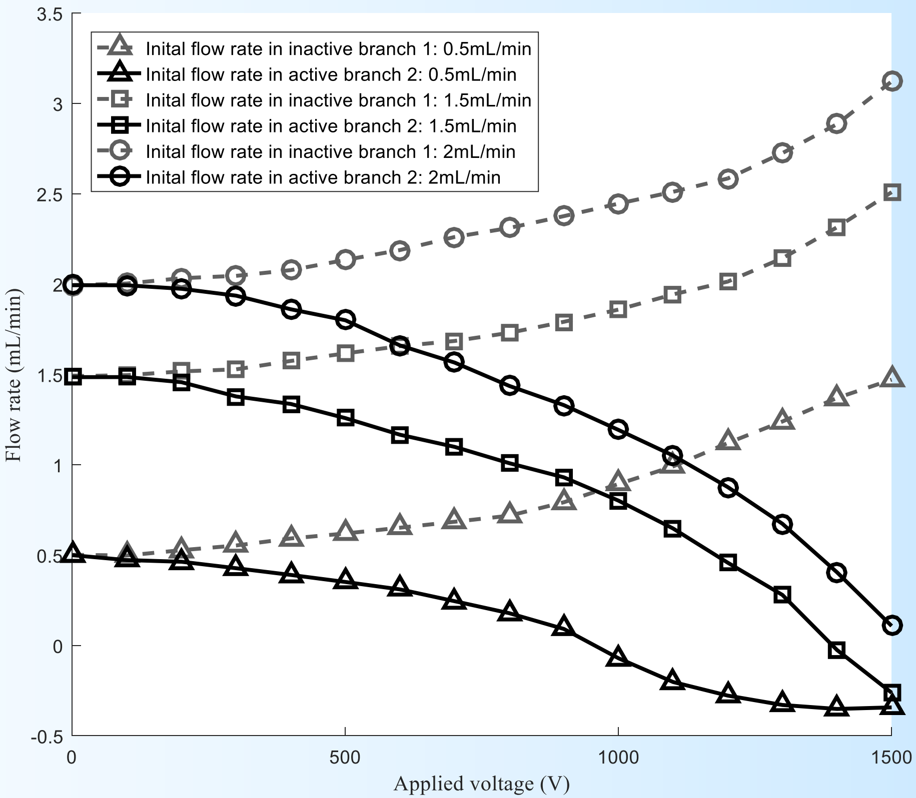




EHD Flow Distribution Control: Single Phase Liquid Flow

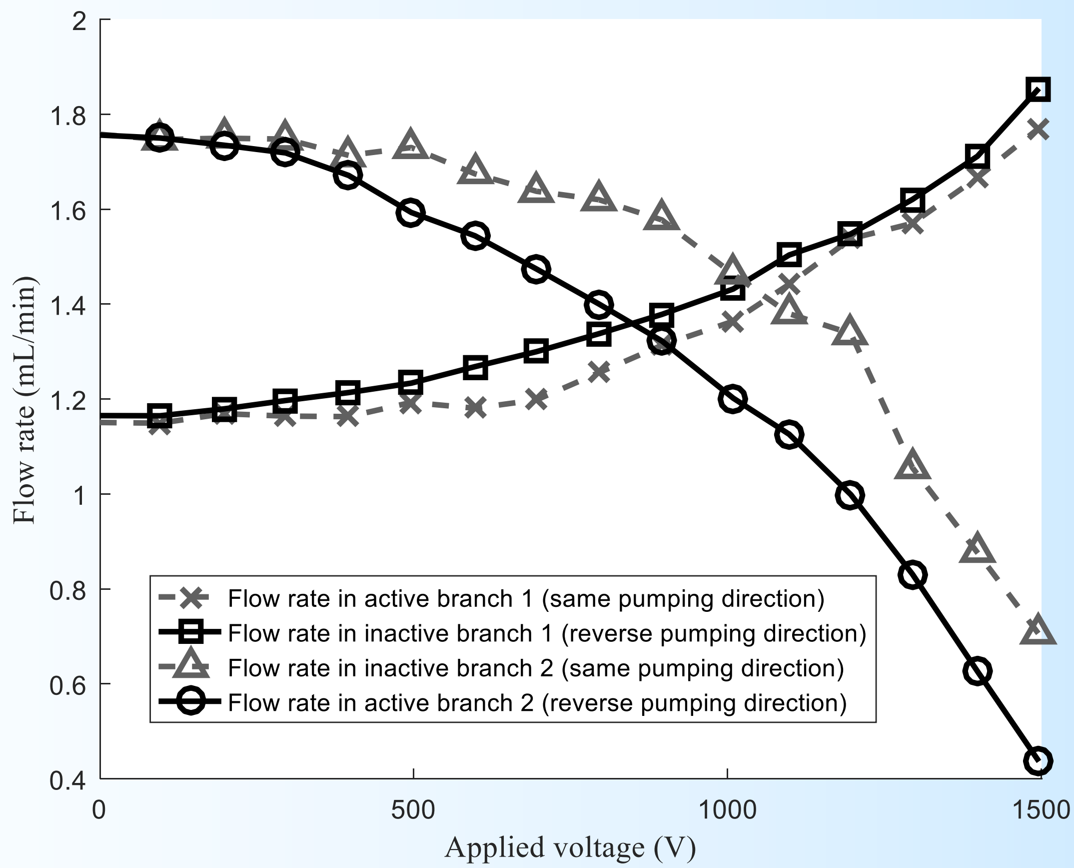
- Flow redistribution with reverse EHD pumping configuration and comparison with the same EHD pumping configuration

- Flow maldistribution correction with reverse EHD pumping configuration and comparison with the same EHD pumping configuration



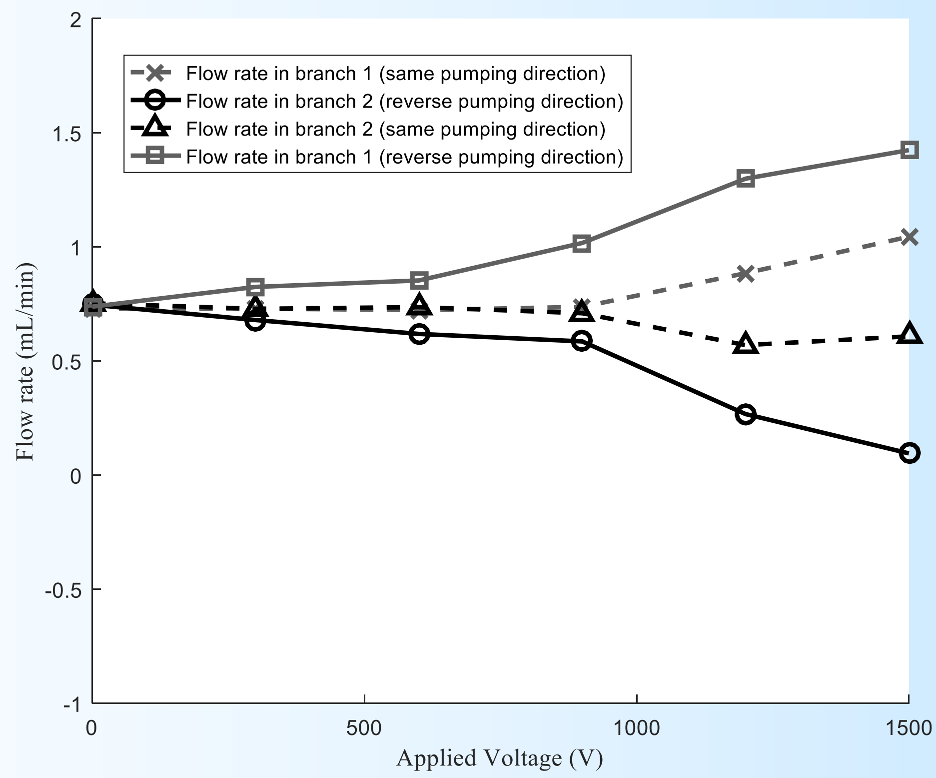
EHD Flow Distribution Control: Mal-distributed Initial Flow

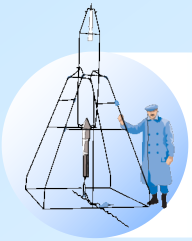
Measured flow rates w. initially mal-distributed flow: 1.15 mL/min & 1.75 mL/min



EHD Flow Distribution Control: Two-Phase Flow

Measured flow rates (averaged over 1min): initial two-phase flow distribution @ 0.75 mL/min





EHD Flow Distribution Control: Conclusions

The reverse pumping direction configuration was more effective than the same pumping direction configuration:

1. More immediate influence on the flow distribution with lower applied EHD conduction pump voltage.
2. Advanced the flow equalization for the maldistribution correction cases.
3. Greater flow separation between the active and inactive branches.