Dielectrophoresis of Liquid Deuterium for IFE Target Filling

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Summary

Foam shells have been filled using dielectrophoresis

• There is a need to fill IFE targets more quickly than by permeation
• Basic predictions of dielectrophoresis are confirmed for liquid D$_2$ using parallel vertical electrodes
• Two methods of dispensing a small volume of liquid D$_2$ from a larger reservoir are demonstrated
• A volume of liquid has been wicked into a foam shell

This is a first demonstration of dielectrophoretic behavior in a cryogenic liquid.
Acknowledgement

- Kyle Kentsch
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Surface Evolver* software accurately predicts the shape of the liquid surface between electrodes by minimizing surface energy.

18.8 K, 0 V radius of curvature = 7.3 mm

26.9 K, 0 V radius of curvature = 11.0 mm

Matches height and curvature of upper left image.

A prediction of dielectrophoresis is verified: the height of a liquid column between parallel vertical electrodes

- A dielectric liquid in an electric field $E$ is governed by
  \[ \nabla p_\ell = -\frac{1}{2} E^2 \nabla \varepsilon - \rho_\ell g \hat{z} \]

  where $p_\ell$ is hydrostatic pressure in the liquid, $\varepsilon$ is permittivity, $\rho_\ell$ is the density of liquid, and $\hat{z}$ is the vertical unit vector.

- For the hydrogens, $\theta = 0$ for contact with nearly all materials.
The height of rise of a column of liquid D$_2$ between parallel plates is accurately predicted.

Electrodes: glass coated with indium tin oxide
Width = 7.6 mm
Gap = 0.86 mm
Converging electrodes are used to dispense a volume of liquid from the larger bath by “bifurcation”.

Experimental view direction through transparent electrodes.

Liquid height as a function of voltage has a double-valued solution.

- Pinch-in
  - 1500 V_{rms}
  - 1590 V_{rms}
- Narrow neck
  - 1300 V_{rms}
  - 1289 V_{rms}
- Liquid trapped
  - 1400 V_{rms}
  - 1254 V_{rms}
Vertical electrodes lift the liquid $D_2$ column to horizontal electrodes, allowing for a volume of liquid to be dispensed.
Liquid D$_2$ is lifted and moved horizontally, then a separate volume is dispensed by de-powering the lifting electrodes.

Volume is approximately 28 $\mu$L as required by an IFE target.
The volume of liquid D$_2$ that is dispensed depends on the initial voltage.

- Initial voltage $\approx 1.6$ kV, approximately $23 \, \mu$L
- Initial voltage $\approx 1.5$ kV, approximately $12 \, \mu$L
A foam shell is placed into the region between the electrodes.
Liquid $D_2$ (14 $\mu$L) is rapidly absorbed (<10 s) into a foam shell at 25 K

(i) 3.2-mm-diam 0.1-gm/cc rf foam shell (160-$\mu$m wall)

(ii) Liquid moving to the electrode containing foam shell

(iii) Liquid encapsulating and infiltrating the foam shell

(iv) Encapsulation and infiltration continues...

(v) Liquid infiltrating the foam wall

(vi) Liquid fully absorbed in the foam wall, shell void is not filled
Further work is needed

- A filled foam shell needs to be coated while cold with a barrier against leakage
- Greater precision is needed in generating the desired volume
- The desired amount of liquid needs to be obtained inside the cavity of the shell
- Dielectrophoresis needs to be tried with DT
The ability to dispense and move droplets of liquid cryogen provides another way for loading DT into shells.

1. Form liquid DT into discrete droplets
2. Wick liquid into the foam shell
3. Condense Ne (Ar,Kr,Xe) as a barrier coating onto the foam
4. Form ice layer – move through a thermal gradient (20 K → 19.5 K) at 0.001 K/5 min
5. Inject target – Ne overcoat ablated during transit. Tailor Ne thickness to insulate the target

An electromechanical microfluidic scheme is proposed for the cryogenic aspects of forming targets.
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