Electrokinetic flow modelling at channel entrance

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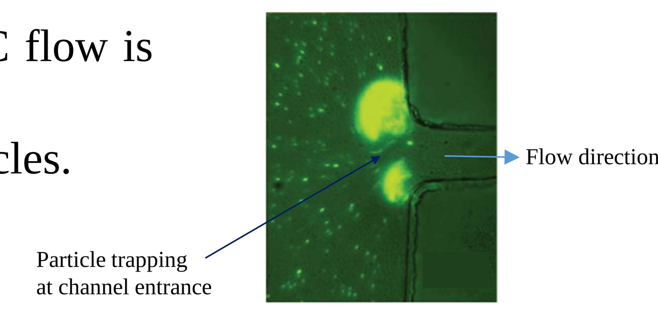
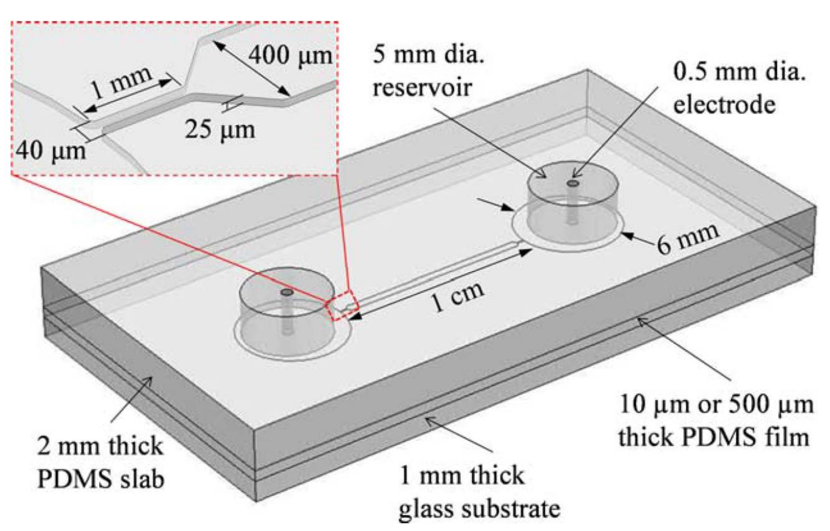
Motivation

- In classical pressure driven flow the velocity profile is constant throughout the entire channel cross section at channel entrance.
- Electrokinetic flow is flow driven by electrical potential difference.
- Due to Electrothermal and Induced Charge (I.C) effects in electrokinetic flow at channel entrance, vortices are formed.
- Electrothermal flow is due to joule heating and IC flow is due to leakage of electric field into PDMS.
- The vortices can be used to mix fluids or trap particles.

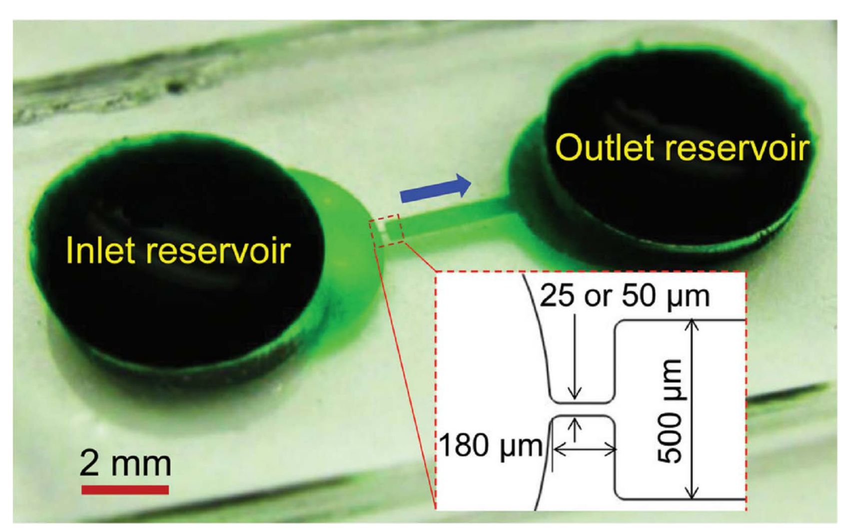


Experimental setup

Electrothermal Vortices



Induced charge vortices



Numerical Modelling

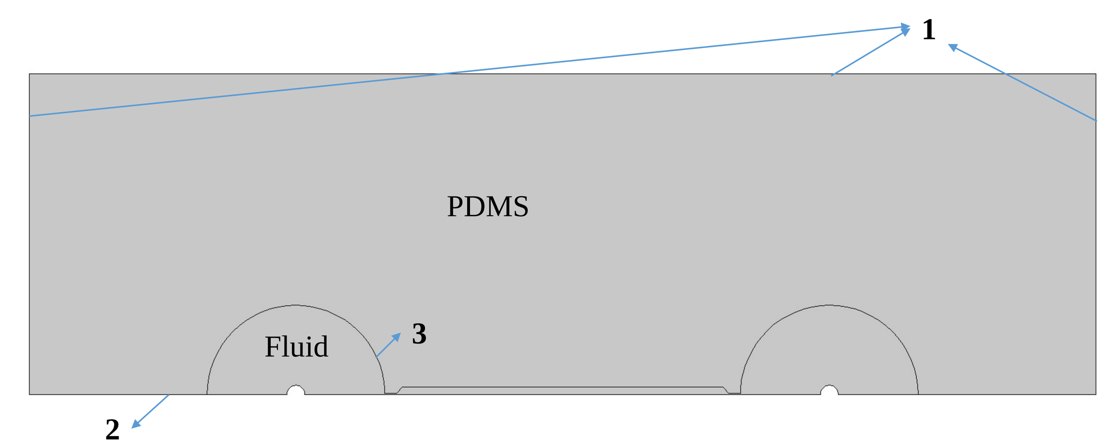
- The 2D Numerical modelling of the electrothermal and induced charge vortices solves the following differential equations, given in the table.

Equation solved	Electrothermal	Induced charge
$\nabla . (\sigma E) = 0$	Domain 1	-
$\nabla . (\varepsilon E) = 0$	-	Domain 1 and 2
$\nabla . u = 0$ $\rho\, u.\nabla u = -\nabla p + \eta \nabla^2 u + F$	Domain 1 $F = (F_c - F_d)$	Domain 1 $F = 0$
$\rho c_p u . \nabla T = k \nabla^2 T + \sigma E^2 - Q_{dissipated}$	Domain 1 and 2 $Q_{dissipated} = (T-T_i)^* (1/Rus + 1/Rbs) / t_{ch}$	-

Here
Domain 1 - Fluid domain
Domain 2 - PDMS

Where
σE^2 - Heat generation in fluid (due to electrical conductivity)
Rus, Rbs - Thermal resistance at top and bottom substrate
F_c - Coloumb force = $\nabla . (\sigma E) E$
F_d - Dielectric force = $0.5 E^2 \nabla \varepsilon$

BOUNDARY CONDITIONS:

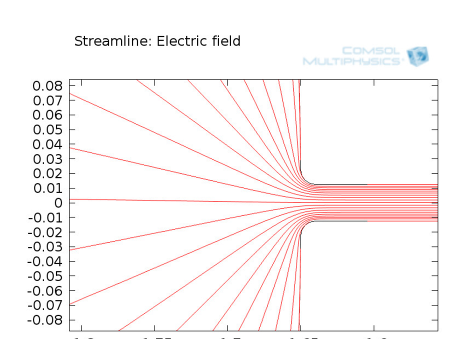


BOUNDARIES	ELECTROTHERMAL	INDUCED CHARGE
1	Natural Convection	Electrical insulation
2	Symmetry in temperature Electric potential and velocity	Symmetry in Electric potential and velocity
3	Electrical Insulation Electroosmotic slip velocity Continuity in heat transfer	Electric field leakage Induced charge slip velocity

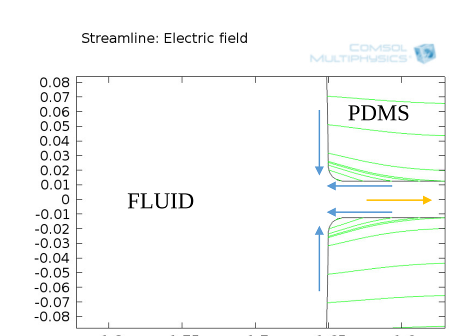
Electroosmotic slip velocity = $-\varepsilon \zeta^e E / \eta$
IC slip velocity $u_s = -\varepsilon (\zeta^i + \zeta^e) E / \eta$
Electric field leakage: $\phi_w + \frac{\delta \phi_w}{\delta n} = \phi_f + \zeta^e$

RESULTS

Electric field – Induced charge



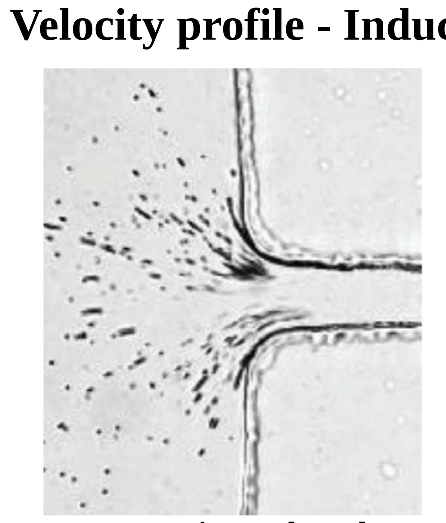
Electric field in fluid



Electric field in PDMS

Due to the leakage, velocity in micro-channel walls entrance (←) gets reversed as opposed to bulk fluid motion (→) resulting in a vortex.

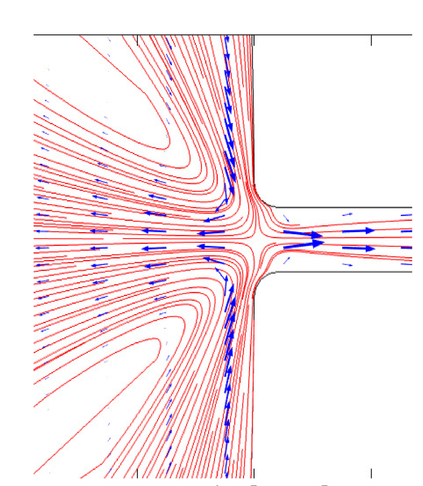
Velocity profile - Induced charge :



Experimental result

- Image of particles trapped in the vortices at 10V DC and 200V AC.

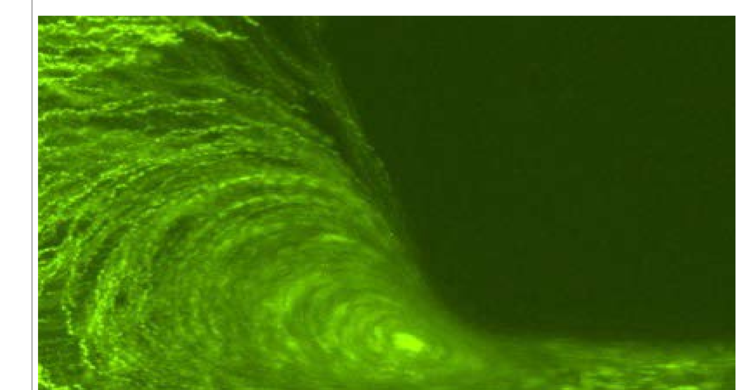
- Picture taken at 20s where the particle trapping is beginning to be visible.
- It shows the stream lines and direction arrow for fluid velocity



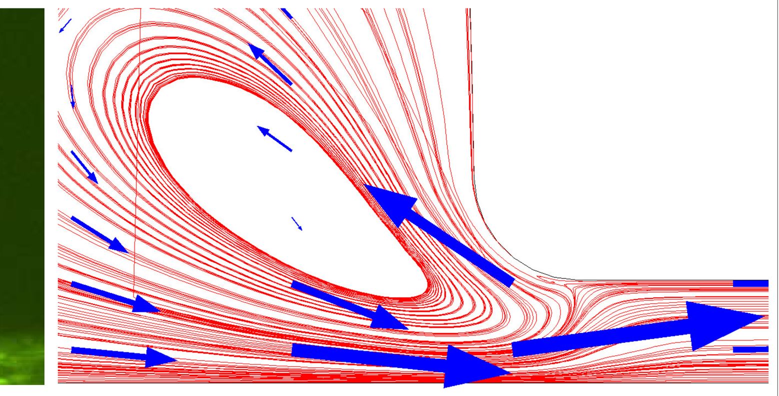
Numerical result

- The equilibrium potential and DC voltage applied are altered to match 10V DC and 200V AC.

Velocity profile - Electrothermal:



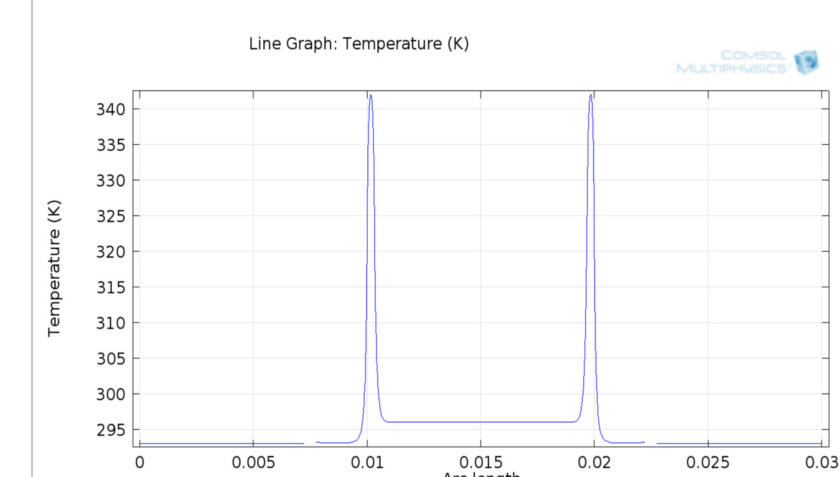
Experimental result: This picture is taken be superimposing images. Thus the streamline of flow is seen at channel entrance.



2D Modelling : The picture is taken at the entrance of microchannel at 20V DC and 400V AC current. It shows the streamlines and arrows of the velocity field.

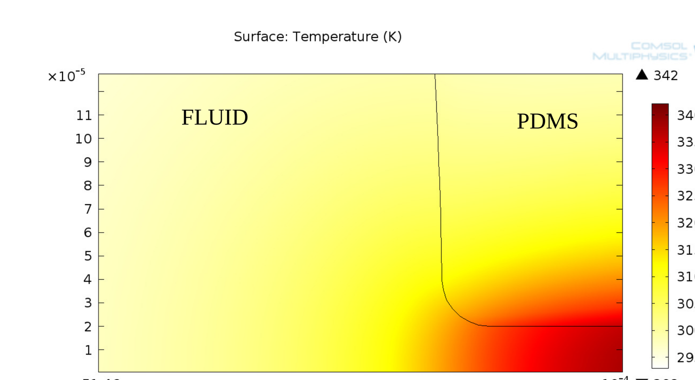
It is clearly visible from IC and electrothermal velocity profiles that the vortex generated by the two are exactly opposite in nature.

Temperature profile – electrothermal flow:



- Numerically predicted temperature profile along the center line of the channel.
- The center line is chosen because the temperature is maximum.

The two peaks in temperature are at the constriction region because of the amplification of electric field in that region.



- This picture depicts the temperature distribution in fluid and PDMS domains.
- It can be understood that the heat generated is maximum in constriction

Most of the heat generated in constriction is dissipated in Z direction. This explains why the temperature drops rapidly to room temperature as we move away from constriction in X-Y plane

CONCLUSION

- Since the IC vortex and electrothermal vortex are opposite in direction, they can be used in the same model where the vortex cancel each other.
- This can be applied in cases where the vortex generation is undesirable.
- The conditions when the vortex can cancel each other can be determined which would be very useful.

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