Optimal design of insulator-based dielectrophoretic (iDEP) traps

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**Motivation and background**

**Lab on a chip (LoC)**
- Laboratory on a micro-scale chip
- Cheap, efficient and portable
- Instant analysis with high throughput
- Often used to trap/concentrate biological species for sensing / analysis

**Insulator-based dielectrophoretic traps**
- $Q_{TH} = \sigma |E|^2$
- Electrothermal force $f_{ET} = \nabla \cdot (\sigma E \nabla T + \sigma E^2)$
- $U_{DEP} = U + U_{EP}$
- $U_p = U_{EK} + U_{EP}$
- Trapping number $\tau = \frac{U_{DEP}}{U_{EK}}$
- $0 < \tau < 1$ : Focusing
- $\tau \geq 1$ : Trapping $\tau = f(r) = \frac{E_{AC}}{E_{DC}} \sigma, t_{Ch}, d$

**Governing Equations**
- $\nabla \cdot (\sigma E) = 0$
- $\rho C_p (U \cdot \nabla T) = k \nabla^2 T + \sigma |E|^2 (1 + r^2)$
- $\rho (U \cdot \nabla U) = -\nabla p + \nabla \cdot (\eta \nabla U) + (1 + r^2) f_{ETDC}$
- $U_p = U + \frac{\epsilon_p E}{\eta} + \frac{d^2 \epsilon_{Real(cm)}}{12 \eta}(1 + r^2)(\nabla E_{DC}^2)$

**Analytical model**
- $E_{DC} = \frac{W_{Ch} \sigma_{ref}}{W_{Ch}} E_{DC,Bulk} \frac{E_{DC,Bulk} + \Delta T}{1 + \Delta T}$
- $\nabla \cdot E_{DC}^2 = \frac{\nabla \cdot E_{DC,Bulk}}{2} \frac{E_{DC,Bulk}^2}{W_{Ch}(1 + \Delta T)^2}$
- $k \Delta T = \frac{\sigma E_{DC}^2 (1 + r^2)}{U_{ET}}$ [Pe DC $< 1$]

**Conclusions**
- IDEP devices, although efficient in trapping biological species, suffer from Joule heating. It induces electrothermal flow at the constrictions, which provides an additional velocity to the fluid close to the channel center-line. It scales as the fourth power of the electric field and thus helps the species to overcome the DEP velocity that scales as the square of the electric field when heating is strong.
- The ratio of DEP velocity to EK velocity is defined as a trapping number, which is a strong function of the AC DC ratio, channel depth, solution conductivity and particle size. For given input parameters and channel geometry, trapping will only occur if the trapping number exceeds unity. Experimental, numerical and analytical investigations prove this hypothesis and establish the trapping number as a good criterion to design iDEP traps.