Supporting Information:

Modeling Electrohydrodynamic Flows. The completely rigorous treatment of electrohydrodynamics in the IDS device requires the simultaneous solution of the Poisson, Nernst-Planck, Navier-Stokes, and (thermal) energy conservation equations. To mitigate the computational constraints imposed by the full model, we pursue a simplified version predicated on two primary assumptions. The first assumption is that the frequency is sufficiently high that we may use time-averaged quantities for the polarization force and Joule heating, both of which depend on the square of the electric field, and that polarization at the electrode interface is negligible. Electrode polarization relaxation occurs on a time scale that depends upon both the solvent and the geometry of the electrodes. For electrodes with characteristic dimensions on the order of 10 µm in a typical electrolyte with a conductivity of ~0.1 S/m, frequencies greater than a few 10's of kilohertz are sufficiently high that the screening of the electric field and induced charge electroosmosis associated with electrode polarization may be safely neglected.

The second assumption is that the conductivity varies over distances considerably larger than the applied electric field. This motivates us to formulate the problem using regular perturbation, in which the small parameter is taken as the fractional change in conductivity over the region of large electric field. For the case of the imposed conductivity gradient, this parameter is of order $h/w \sim 10^{-2}$ (h = channel height, w = channel width), and is thus universally valid. For thermally induced gradients in conductivity and permittivity, validity of the perturbation analysis is contingent on the temperature rise being reasonably modest ($\Delta T < 10$ K, typically).

The 0^{th} order term in the perturbation series corresponds to the behavior of the different physical domains in the absence of any coupling. The fluid velocity, $\mathbf{u}_0$, is Poiseuille, the electric field, $\mathbf{E}_0$, is solenoidal, and the conductivity and permittivity are, to 0^{th} order, uniform. After scaling the governing system of equations (Table SI 1) and eliminating inessential terms, the first correction for the fluid velocity, $\mathbf{u}_1$, is governed by:

$$0 = -\tilde{\nabla}\tilde{P}_1 + \tilde{\nabla}^2\tilde{\mathbf{u}}_1 + \frac{1}{2}\left[\frac{\varepsilon E_0^2 h}{\mu U}\right]\left[\left(\frac{\tilde{\nabla}\tilde{\varepsilon}_1 - \tilde{\nabla}\tilde{\sigma}_1}{1+\omega^2\tau_e^2}\cdot\tilde{\mathbf{E}}_\mathbf{0}\right)\tilde{\mathbf{E}}_\mathbf{0} - \frac{1}{2}\left(\tilde{\mathbf{E}}_\mathbf{0}\cdot\tilde{\mathbf{E}}_\mathbf{0}\right)\tilde{\nabla}\tilde{\varepsilon}_1\right] \qquad \mathbf{(1)}$$

in addition to continuity ($\tilde{\nabla}\cdot\tilde{\mathbf{u}}_1 = 0$). The 1^{st} order conductivity and permittivity are assumed to be known from imposed conditions and from the 0^{th} order temperature (i.e. $\tilde{\nabla}\tilde{\sigma}_1 \propto \tilde{\nabla}\tilde{\varepsilon}_1 \propto \tilde{\nabla}\tilde{T}_0$, where the constants of proportionality are taken from the linearized temperature coefficients of conductivity and permittivity), so that $\mathbf{u}_1$ is fully determined.

To analyze induced flows in the IDS device, we consider the case of imposed and thermally induced conductivity gradients separately. Figure SI 1 depicts the flow fields and scaling typical for the two different cases. For conductivities of ~0.1 S/m and voltages of 20 V_{pp}, we predict intrinsic and thermal EHD to be comparable in magnitude (~10^{-4} m/s), or about one tenth the velocity of the imposed flow.

Variable	**Scale Description**
$\mathbf{E} = \tilde{\mathbf{E}} E_0 = \tilde{\mathbf{E}} \left[V_0 / d \right]$	Applied field
$\nabla = \tilde{\nabla} / h$	Chamber height
$\mathbf{u} = \tilde{\mathbf{u}} U = \tilde{\mathbf{u}} \left[Q / (wh) \right]$	Imposed velocity
$\rho_e = \tilde{\rho}_e \left[\varepsilon E_0 / h \right]$	Charge scale from Gauss's Law
$T = \tilde{T} \left[\sigma_0 E_0^2 h^2 / \kappa \right]$	Joule heating balanced with thermal conduction
$P = \tilde{P} \left[\mu U / h \right]$	Viscous pressure scale

Table SI 1: Parameter scales used in the electrohydrodynamic model.

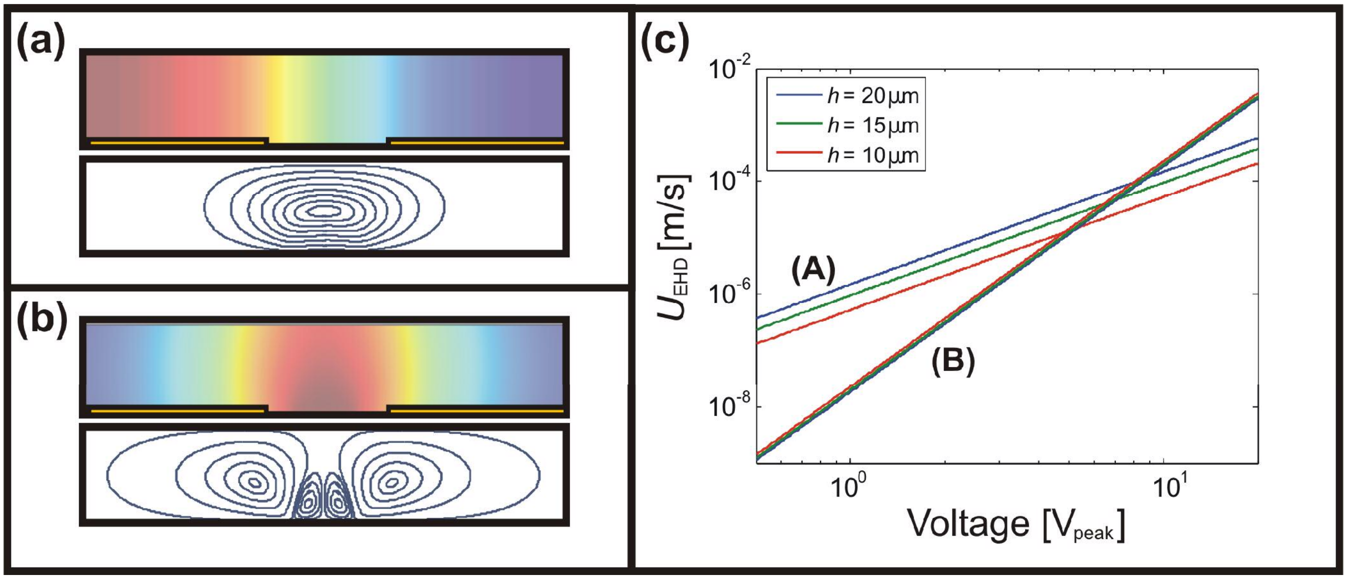

Figure SI 1: Streamlines and scaling for EHD flows due to the two dominant mechanisms. (A) Coupling to the imposed conductivity gradient (color plot), creating a single counter-clockwise vortex. (B) Coupling to conductivity and permittivity gradients induced by localized heating, creating two primary and two secondary flow vortices. (C) Plot showing the predicted scaling and magnitude of EHD velocities with the applied (zero-to-peak) voltage.