ABSTRACT

Alternating current electrokinetic (ACEK) technique has received extensive attention as it can enable rapid and efficient operation with high accuracy and within a short time. It also offers the advantages of ease of operation, simplicity in design and manufacturing and high effectiveness. Due to ability to handle high conductive fluids, AC electrothermal (ACET) technique offers significant advantages as compared to the AC electroosmosis (ACEO) technique, so far handling of biological fluids is concerned. Moreover, ACET produces higher fluid velocity than ACEO at the same electrical power consumption. From a fundamental perspective, electrothermally driven fluid flow arises in presence of local variation of electrical conductivity and permittivity caused by temperature gradients in the conducting fluid. ACET mechanisms have been effectively employed for fluid pumping, mixing, and particle manipulation. However, further developments are warranted in this area for widening their possibilities with regard to on-chip applications. Accordingly, in this Thesis, the author has demonstrated some innovative methods of electrothermal mechanism to manipulate colloidal particles, biological cells and to generate strong rotational flow inside surface droplets.

First, a novel method of electrothermal mechanism is developed to generate highly non-uniform electric field and sharp temperature gradients. Internally generated Joule heat varies along radial direction from a concentrated point hotspot. Sharp temperature gradients induce local variation in electric properties which, in turn, generate strong electrothermal vortex. The imposed fluid flow brings the colloidal particles at the centre of the hotspot and enables particle aggregation. Further, by manoeuvering structures of the Joule heating spots, different patterns of particle clustering may be formed in a low power budget. The above method is used for concentratration and patterning biological cells on a chip without exceeding safe temperature limits that do not result in damage of thermally labile biological samples. The efficacy of the cell trapping process is characterized for two different biological entities, namely, *Escherichia coli* bacteria and yeast cell.

Next, a simple yet energy-efficient strategy of generating controlled vortices inside a surface droplet is demonstrated, by deploying interacting electrical and thermal field over inter-digitated electrodes on an electrically-wetted platform. Unlike the traditional electrically-driven mechanisms, this strategy involves significantly low voltage to induce rotational structures inside the droplet. The experiments demonstrate that fluid velocities typically of the order of mm/s can be generated inside the droplet within the standard regimes of operating parameters. Further, a simple strategy of generating strong rotating flow in the surface-droplet is explored. In this method, wire electrodes are employed to generate on-spot heating without necessitating any elaborate micro-fabrication. Applying the same range of operating parameters as that of the former method, induced velocity of the order of mm/s can be achieved. Moreover, altering the diameter of the electrode, vortices can be tuned locally or globally in low power budget, without incurring any droplet oscillations.

The subsequent investigations deal with the transport of two-layer immiscible fluids consisting of one non-conducting fluid and another conducting fluid layer in a micro-grooved channel, employing ACET mechanism. The conducting fluid,

driven by the influence of ACET forces, transfers its induced momentum across the fluid-fluid interface allowing the movement of the non-conducting fluid layer. The efficiency with which the non-conducting layer gets transported is studied with respect to various parameters. It is revealed that the transport mechanism with ACET process has striking advantage over contemporary electrically actuated flow.

The research also reports the study on incompressible flow of a binary system of two immiscible fluids in a parallel plate capillary using ACET as the actuation mechanism. The surfaces of the capillary are wetted with two different alternating wettability patches. The dynamic motion of the interface of the two fluids is tracked using phase-field order parameter-based approach. It is exhibited that motion of the interface can be effectively controlled through effective tuning of the chemical characteristics of the surfaces and forcing parameters.

The methodologies demonstrated in this Thesis can find their use in various applications, such as biomedical diagnostics, biochemical analysis, bioprinting, drug development, biosensors, digital microfluidic technology, thermal management, etc. On the other hand, important findings of the ACET actuated binary fluids have potential to improve fundamental understanding and design optimization of various biomedical and physiological systems that involve flow of two or more immiscible fluids.

Keywords: Alternating current electrokinetic; electrothermal; electroosmosis; biological fluids; pumping; mixing; particle manipulation; colloidal particles; biological cells; surface droplets; energy-efficient; fluid-fluid interface.