ABSTRACT

Transport through ion channels has garnered significant attention from the scientific community in recent years due to its ubiquitous presence and pivotal role in regulating several biological processes essential for the sustenance of life. This wide gamut of important roles across various biological systems and processes has inspired the emergence of several biomimetic electrokinetic applications at micro and nanoscales, with the aim of leveraging the benefits of such bio-inspired transports in engineered systems. However, associated fabrication complexities and maintenance of functionality at small scales often pose as biggest challenges towards the sustainable development of such applications, affecting their scalability and commercial viability. This necessitates further investigations towards the formation of a better understanding of these nature-inspired flows, which may facilitate their subsequent practical adaptations towards the development of several biomimetic electrokinetic systems. Motivated by this, the present thesis focuses on studying the transport through physiological and bio-inspired synthetic ion channels, with the aim of understanding the driving/resulting electrokinetic phenomena for their subsequent adaptation in plant-based energy harvesting and the development of nanopore-based artificial synapses.

The first part of this thesis investigates the potential for extracting energy from a living plant. It presents quantitative evidence on how circadian rhythms influence ion transport in living plants and discusses the limitations of using streaming potential as a mechanism for harnessing energy from live plants. Moving forward, an alternate mechanism employing the plant's self-defence on invasive injury has been tested and validated for extracting usable power from live vegetative sources.

The subsequent part of this thesis focuses on enhancing solid-state nanopore-based biomolecular analysis systems, through the voltage-dependent dynamic variations in the effective aperture of nanopores fabricated in thin film dielectric membranes. The results from this study also provide quantifications of the blockade current at high electric fields as DNA translocates through the pores.

The final part of this thesis presents the description of a novel fluidic memristor developed using solid-state nanopores through a comprehensive investigation of the movement of ions within the nanopore-based fluidic confinements. The developed biomimetic memristive device could also mimic synaptic features like long-term potentiation and depression, demonstrated through alterations in pore conductance levels analogous to the modulation of synaptic weight.

By combining elements from biology, electrokinetics, nanotechnology, and materials science, this doctoral thesis aims to contribute to the advancements in sustainable energy harvesting, nanopore-based biomolecular analysis, and nanofluidic memristors through extensive experimental studies and analysis of ionic transport in narrow physiological and bio-inspired pathways. The fundamental insights derived from the studies of this thesis are expected to further encourage adaptations of nature-inspired ionic flows in current engineering systems.

Keywords: Ionic flows, Streaming Potential, Energy Harvesting, Nanopore Sequencing, Fluidic Memristor, Artificial Synapses.