Abstract

Organic electrochemical transistors have emerged as versatile devices for bioelectronic applications due to their ability to operate at low voltages, interface efficiently with aqueous and soft environments, and be fabricated using flexible processing techniques. Despite their growing adoption, a comprehensive understanding of how fabrication strategies, device geometry, and layout influence their electrical behavior remains essential for the development of reliable and application-specific organic electrochemical transistor-based platforms.

This thesis investigates the role of material deposition, device architecture, and geometry in governing organic electrochemical transistor performance, following a bottom-up approach that progresses from fabrication-oriented studies to device design and, finally, to application-driven use.

First, different deposition techniques for PEDOT:PSS are systematically compared as channel fabrication methods for organic electrochemical transistors. Among them, aerosol jet printing is identified as the most promising technique, yielding devices with enhanced amplification and switching characteristics. Electrical performance improvements are partially correlated with film morphology, highlighting the importance of processing-induced material properties.

A floating gate organic electrochemical transistor architecture is introduced to explore more complex device functionalities, including memory-related behavior and sensing concepts. A modified double parylene peel-off fabrication process enabling the independent patterning of gold and poly(3,4-ethylenedioxythiophene) (PEDOT):polystyrene sulfonate (PSS) is developed, alongside a compact circuit-level model calibrated on experimental organic electrochemical transistor data. While discrepancies between simulations and experiments are observed for floating gate devices, a systematic investigation reveals electrolyte-mediated electrode crosstalk and global gating effects as the dominant mechanisms underlying the observed behavior.

These results emphasize the critical role of device layout, capacitance engineering, and collective electrochemical effects in multi-electrode organic electrochemical transistor systems.

Finally, organic electrochemical transistors are employed as experimental platforms to probe the dynamic behavior of supported lipid bilayers. By analyzing transistor response under voltage pulse stimulation, this work demonstrates the capability of organic electrochemical transistors to sensitively detect membrane disruption and recovery processes. The results elucidate membrane damage and recovery processes, showing that lipid bilayers can readily recover under specific conditions and they highlight the potential of organic electrochemical transistors as tools for investigating time-dependent biointerface phenomena.

Overall, this thesis demonstrates that fabrication strategies and device geometry are active design parameters that critically determine organic electrochemical transistor performance and functionality. The insights gained provide a foundation for the rational design of organic electrochemical transistor-based platforms integrating sensing, memory, and biointerface probing within a unified device framework.