A printable Organic Electrochemical Transistor on paper for biochemical sensing

Abstract

Cellulose-based materials hold significant promise as substrates for point-of-care diagnostic devices. Among them, lateral flow assays (LFAs) owe their widespread success to their ease of use, portability, and affordability. However, their limited sensitivity and qualitative output still represent important drawbacks for broader analytical applications.

In response to the growing need for rapid and reliable diagnostic and monitoring tools, Organic Electrochemical Transistors (OECTs) have gained attention as powerful devices for biosensing applications because of their high sensitivity, low operating voltage, and compatibility with biological environments.

PEDOT:PSS is one of the most widely employed organic mixed ionic-electronic conductors in OECTs. Its broad use originates from its solution processability, biocompatibility, and high tunability, which make it compatible with a wide range of deposition techniques and device architectures. Continuous advances in additive manufacturing are making the fabrication of high-performance organic electronic devices increasingly accessible by reducing processing steps, lowering production costs, and enabling deposition on unconventional substrates such as paper, plastics, and flexible supports. These aspects are particularly relevant for diagnostic and point-of-care (POC) applications, where low fabrication cost must be combined with high sensitivity, reliability, and scalable production.

This thesis investigates how different printing techniques influence the morphology, structural organization, and electrical performance of PEDOT:PSS films. *In situ* Raman spectroscopy was employed to monitor the evolution of PEDOT structure during OECT depending on different gating condition. Atomic force microscopy was used to compare films deposited by inkjet printing and aerosol jet printing, highlighting how differences in roughness, phase segregation, and nanoscale organization strongly affect the electrochemical performance of the devices.

With the aim of developing a printable, low cost OECT on paper for biochemical sensing, a commercial PCB printer was employed for the non-contact dispense printing of silver tracks and PEDOT:PSS channel, gate, and extended gate onto a nitrocellulose strip, a material commonly used in immunochromatographic lateral flow assays. Acting as a self-standing passive microfluidic platform, the cellulose substrate was designed to transport and interact with liquid samples while preserving a contamination-free region for the active electronic components. Within a dry area defined by a hydrophobic barrier, a solid-state electrolyte (SSE)

layer enables ionic communication between channel and gate. Outside this region, a PEDOT:PSS extended gate selectively interacts with the analyte carried by the liquid sample, preventing direct contamination of the channel and improving operational stability.

With a maximum transconductance of approximately 4 mS, the proposed system demonstrates the feasibility of integrating an easily manufacturable transistor into an affordable biochemical assay, providing quantitative information at the point-of-care site to complement and strengthen the conventional colorimetric response of LFAs. The sensing platform was validated through dopamine detection, achieving a limit of detection of 0.01 mM.

Overall, the results presented in this thesis highlight the potential of combining printed PEDOT:PSS electronics, scalable additive manufacturing, and paper-based microfluidics for the development of next-generation low-cost diagnostic technologies.