Abstract

The thesis presents a comprehensive investigation into the application of two-dimensional (2D) materials—cobalt telluride (2D-$CoTe_2$) and multicomponent aluminium quasicrystals (2D-Al QC)—for next-generation sensing platforms and healthcare applications. A 2D-$CoTe_2$-based electrode was developed for dopamine monitoring, achieving an ultralow detection limit of 0.21 pM with selectivity, reproducibility, and one-month stability. A flexible paper-based sensor was further fabricated, enabling real-time dopamine quantification from artificial sweat. Beyond neurotransmitter sensing, the molecular interactions of 2D-$CoTe_2$ with single-stranded DNA (ssDNA) nucleobases were investigated through Raman and FTIR spectroscopy, complemented by atomic force microscopy, revealing a preferential binding trend of poly-G ≈ poly-A > poly-T > poly-C. Such capability enabled differentiation of guanine- and adenine-rich regions in hybrid sequences, highlighting the potential of 2D-$CoTe_2$ for label-free nucleotide identification. The adsorption mechanism of γ-aminobutyric acid (GABA) on 2D-CoTe2 was elucidated using vibrational spectroscopy, spectral mapping and real-time *in-situ* liquid cell transmission electron microscopy (LCTEM) at the atomic scale, revealing edge-driven surface adsorption. These insights facilitated the development of a GABA sensor with a detection limit of 0.61 pM and excellent operational stability. Expanding this approach, norepinephrine (NE) interactions with 2D-Al QC were resolved by spectroscopy and atomic-scale LCTEM, leading to an electrochemical NE sensor with dual linear ranges and a minimum detection limit of 0.17 pM, demonstrating exceptional reproducibility and ninety-day stability. Finally, a scalable sensing platform based on 2D-Al QC was developed for the detection of perfluorooctanoic acid (PFOA), a prevalent member of the Per- and polyfluoroalkyl substances (PFAS) family, achieving an ultralow detection limit of 0.63 pM. FTIR and Raman spectroscopic evidence validated the strong adsorption of PFOA molecules onto the quasicrystal surface, governed by Al–F interactions. Collectively, this work establishes 2D-$CoTe_2$ and 2D-Al QC as highly tunable and robust materials for ultrasensitive, selective, and durable sensing, offering broad implications for neurotransmitter monitoring, nucleic acid identification, and PFAS remediation, while paving the way for their future integration into wearable and IoT-enabled real-time monitoring systems.