Abstract

Electrochemical sensors have attracted a considerable amount of attention in recent years because they provide an appealing platform for detecting a vast plethora of target analytes. In general, they are known as devices with high selectivity and sensitivity, low limits of detection, cost-effective fabrication, ease of customization, possibility for sensing target analytes in complex sample matrices, and facile operation. They have acquired an important position in the broader fields of analytical chemistry, medicine, pharmaceutical analysis, food analysis, environmental science, chemical industry, and others. Since some of these sensors have become commercially available, they have also gained an important role in everyday life. With the development of various nanomaterials, the limits of detection and sensitivity of electrochemical sensors have been pushed further than ever before.

In the scope of this work, graphene-based nanomaterials were synthesized according to an improved Hummer method, characterized, and used in the development of electrochemical sensors for H_2O_2, glucose, and human folate receptor alpha (FOLR-1). It was shown that the use of such materials to modify the electrode surface positively influenced the electrochemical properties of the electrode surface while also improving the sensitivity of the developed sensors by increasing the surface area of the electrode and enhancing the charge transfer.

The developed non-enzymatic amperometric H_2O_2 sensor was based on a carbon paste electrode (CPE), modified with 1:1 MnO_2 and nitrogen doped heat treated graphene oxide nanoribbons (N-htGONR). The sensor exhibited a wide linear range (1 – 300 µM), low LOD (0.08 µM), excellent reproducibility, high sensitivity, and satisfactory lifetime. An interference study was also performed, which showed that the sensor is suitable for use in real samples. The sensor was also successfully applied to detect the target analyte in pharmaceutical and biological real samples. Finally, the sensing platform was successfully transferred from the bulky classical three-electrode system to a miniaturized screen-printed three-electrode system, which will be used for further applications.

An amperometric glucose sensor was also developed by utilizing the enzymatic oxidation of glucose by glucose oxidase (GOX) and a subsequent reaction of the by-product H_2O_2 at the electrode surface. Screen-printed carbon electrodes were modified with N-htGONR, MnO_2, and GOX in order to obtain such a sensor. The device exhibited a wide linear range (0.05 – 5.0 mM), low LOD (0.008 mM), and favourable lifetime and reproducibility. Interference studies showed that the sensor is selective and can thus be used to detect glucose in a real matrix. Glucose was detected

in spiked beer samples with accuracy of 93.5 – 103.5%, confirming the suitability of the sensor for real applications.

The FOLR-1 sensor was developed by immobilizing a folic acid derivative on the electrode surface of an htGONR-modified gold screen-printed electrode. Three folic acid derivatives were synthesized and then used to modify the electrode surface. The electrodes modified with a folic acid derivative (FAd3) exhibited the highest sensitivity towards the target analyte. The operation of the sensor is based on the adsorption of FOLR-1 onto the electrode surface (binding of the substrate), blocking reaction sites for an electrochemical reaction of an electrochemical probe ($[Fe(CN)_6]^{3-/4-}$). The developed sensor exhibited a low LOD (53 pM) and an appropriate linear range (up to 1 nM) for potential final applications in human blood or serum.

In the scope of the research work for this dissertation, graphene-based nanomaterials were shown to improve the electrochemical properties of bare electrodes, which is crucially important in the development of an electrochemical sensor. The sensors for H_2O_2 and glucose were developed using specific and novel material combinations (N-htGONR with MnO_2), and their properties were significantly improved compared to similar sensors from previously published works. The FOLR-1 sensor was developed using a new approach in which folic acid derivatives with desired structural segments were first synthesized and used to modify the electrode surfaces.