A Dopamine Sensor on Paper with Printed Carbon Nanotube Electrodes

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This work presents an electrochemical sensor on a paper substrate, which is composed of printed carbon nanotube electrodes, for dopamine sensing. Carbon nanotubes are inkjet-printed to form a conductive path on paper, which works as electrodes of an electrochemical cell. The fabrication process is remarkably simple, requiring just an inkjet printer to pattern carbon nanotube electrodes and a hydrophobic layer to confine liquid. As a demonstration of the capabilities of the sensor, we measured dopamine concentrations in the range of 20 \(\mu\text{M}-200\ \mu\text{M} \).

Dopamine is one of the key neurotransmitters of the brain which is known to be associated with Parkinson’s disease [1]. As such, dopamine concentration has been investigated to better understand the dynamics of its neurostimulation properties. Dopamine undergoes a two-electron oxidation process where, by application of an electrical potential, it is possible to oxidize dopamine to dopamine-o-quinone. Thus, electrochemical methods of dopamine determination are ideal for measuring its concentration in solution. Various electrochemical detection methods have been developed for dopamine determination. Potential step voltammetry requires the application of a potential step between the working and reference electrodes, while reading the current generated between the counter and working electrodes. It is a simple electroanalytical method which effectively gives the electric current of the redox reactions occurring inside solution. We use this concept to develop an electrochemical sensor composed of only carbon nanotube electrodes. Moreover, the paper substrate provides a low cost platform for fabricating the sensor.

An office inkjet printer was employed in order to print carbon nanotube electrodes on paper. First, a multi-walled carbon nanotube (MWCNT) ink was prepared, according to a previous report [2]. MWCNT and sodium dodecyl sulfate (SDS) are mixed with ratio of 1 wt% and 0.7 wt% in deionized water solution. SDS is necessary to disperse the CNTs and prevent the occurrence of aggregates. It is then sonicated for 30 min and centrifuged for 5 min, allowing the supernatant to be recovered and injected into a cartridge for later use. Figure 1 illustrates the electrochemical sensor, with all electrodes inkjet-printed on paper as well as the hydrophobic barrier. Figure 2 shows an actual sensor and a sensor while dipped into solution with dye to demonstrate confinement of the liquid.

Conventionally, printed electrodes are composed of carbon paste electrodes as substrate and carbon nanotubes modifying the surface to achieve better selectivity and/or sensitivity [3]. Usually the working electrode is modified with CNTs/nanoparticles and the reference electrode is composed of Ag/AgCl paste. Our approach combines the ability of carbon nanotubes to be inkjet-printed in an ink form while being able to form a conductive path on a paper substrate.

As a demonstration of the sensor, the concentration of dopamine was measured. Figure 3 shows the step voltammogram for different concentrations of dopamine. The concentration could be determined within a range from 20 \(\mu\text{M}\) to 200 \(\mu\text{M}\). Figure 4 shows a parametric study of the area of the working electrode. The settling current increased with the area of the working electrode. Therefore, it is anticipated to achieve a better sensitivity and a lower limit of detection with further optimization of the sensor design.

References:

![Figure 1. Illustration of the designed electrochemical sensor on paper. Electrodes are inkjet-printed using carbon nanotube ink and a hydrophobic barrier is patterned on top to confine liquid to the sensing electrodes.](image1.png)

![Figure 2. Fabricated sensor on paper: (a) a photograph of the electrochemical sensor on paper and (b) sensors dipped into a dye solution showing confinement (left) by a hydrophobic barrier and absorption of liquid (right) without hydrophobic barrier after 3 min.](image2.png)

![Figure 3. The measured dopamine concentration using potential step voltammetry.](image3.png)

![Figure 4. Influence of the working electrode area. By increasing the area of the working electrode, it would be possible to achieve better sensitivity and lower limit of detection.](image4.png)