Development of Paper-based Screen-printed Carbon-paste Electrode for Sensing Glucose for Diabetics

Yechan Hwang
Hope College

Development of Paper-based Screen-printed Carbon-paste Electrode for Sensing Glucose for Diabetics

Yechan Hwang, Dr. Kenneth L. Brown
Hope College, Department of Chemistry, Holland, MI 49423

Abstract

In recent years there have been many interests in developing paper-based electrodes.[1] The purpose of this project is to develop a working paper-based electrode that can detect glucose via an enzyme and redox mediator (Tris(5-amino-1,10-phenanthroline) Iron(II)). In the process of developing a paper-based electrode, cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) were used as primary methods. The redox mediator was electropolymerized onto glassy carbon (GC) and carbon-paste electrodes (CPE) and their subsequent charge-transfer properties were characterized using CV and EIS. Cyclic voltammetry characterization studies of the electropolymerized films revealed excellent charge transfer properties with ΔEp ~0 mV. Electrochemical impedance spectroscopy showed that the charge transfer properties of the carbon paste vary with carbon:binder mass ratio (1:1, 1:2, 1:3). Carbon paste formulation was successfully placed onto a wax-coated Whatman filter paper. Initial attempts to prepare films on carbon-paste based-paper electrodes have been successful.

[1] *ACS Appl. Mater. Interfaces* 2016, 8, 32, 20501-20515
Publication Date: July 27, 2016
https://doi.org/10.1021/acsami.6b04854

Introduction

Many people with diabetes have to use a glucometer and test strips in order to monitor their blood sugar levels. However, to this day, the test strips are made out of plastic, which can be a little expensive at times. Therefore, the Brown's Lab is focusing on developing a working paper-based electrode that can detect glucose via an enzyme and redox mediator. There are many advantages in using paper over plastic, because paper is cheap, biodegradable, and renewable.

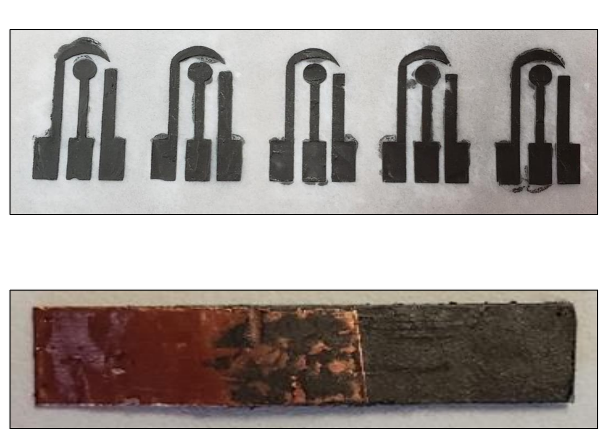


Figure 1. (Top) Conceptual three electrode paper-based electrode. Ideally, would like to have all electrodes into one paper, just like glucometer test strips. (Bottom) The process of developing a paper-based electrode has been a step-by-step process. A Whatman filter paper was coated with wax, copper tape was taped onto the paper, then carbon paste was painted on top of the copper tape and paper. The electrode was used for both working and counter electrode ***[figure 2]***.

Method

Cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) were used as primary methods for the development of the paper-based electrodes. CV was used to polymerize the electrode with the redox mediator and look at its redox potentials while EIS was used to determine the resistivity of charge transfer of electrodes. GC electrode were used to understand what to expect from the redox mediator. A Whatman filter paper was coated with candle wax, which then copper tape was taped to the wax-coated paper. Then carbon paste (carbon:binder mass ratio of 1:1) was painted on top of the copper tape and the wax-coated paper.

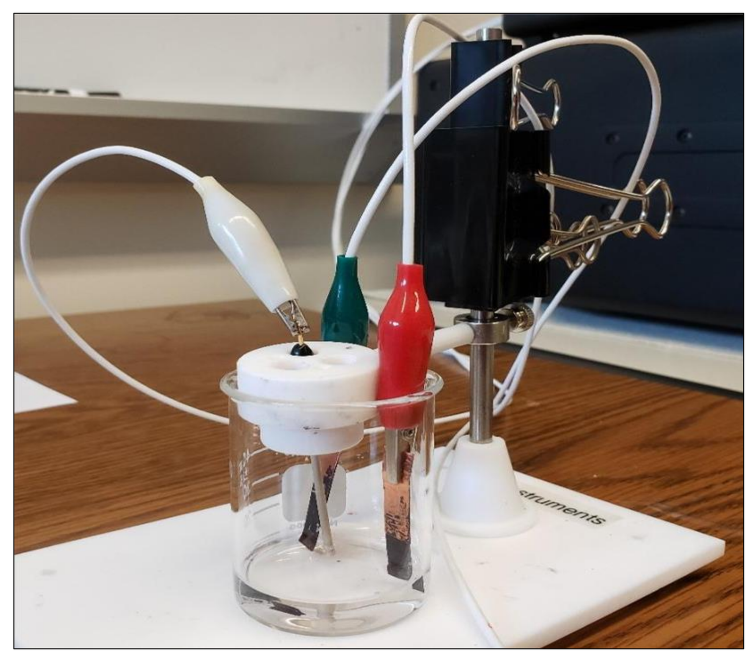


Figure 2. The setup for the cyclic voltammetry and electrochemical impedance spectroscopy. The setup demonstrates the usage of the carbon-paste paper-based electrode for both working and counter electrode. Green is the working electrode (WE), White is the reference electrode (RE), and Red is the counter electrode (CE). The figure is showing the process of characterization and EIS specifically.

Results & Discussion

There were many challenges in developing a paper-based electrode, thus the process was taken step-by-step. Cyclic voltammetry characterization studies of the electropolymerized films and the electrochemical impedance spectroscopy studies revealed that the carbon paste formulation of carbon:binder mass ratio of 1:1 was the best due to the lowest resistance in charge transfer and small peak separation in the CV characterization. The wax-coated Whatman filter paper turned out to withstand the solution very well. First, the paper-based electrode were only used as a working electrode (WE), and after many successful attempts, both WE and counter electrode (CE) were paper-based electrodes. The carbon-paste paper-based electrode was found to work very well with both WE and CE. For future work, WE and CE will have to be in one paper-based electrode, and later figure a way to make the reference electrode (RE) also paper-based.

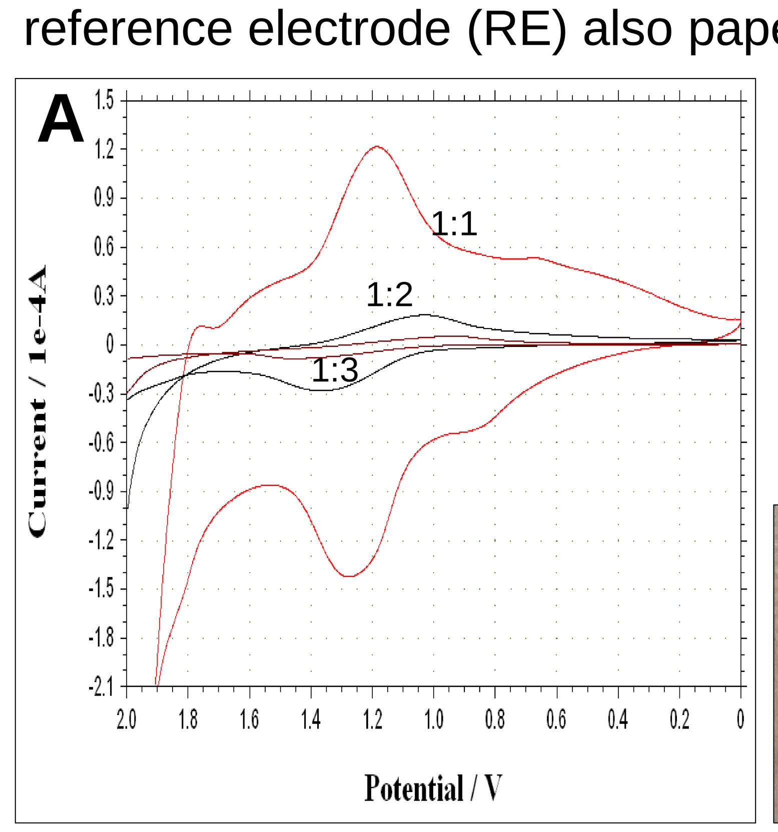
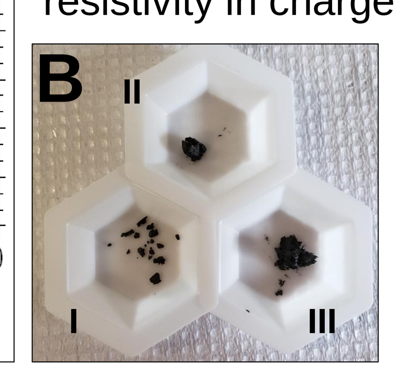


Figure 3. (A) An overlay of cyclic voltammetry characterizations of 3 carbon-paste electrodes with different carbon:binder mass ratio (1:1, 1:2, 1:3). The figure shows highest peak with smallest peak separation with the mass ratio of 1:1, which is due to its low resistivity in charge transfer ***[figure 4]***.



(B) Figure of the carbon paste at different mass ratio. (I) 1:1, (II) 1:2, (III) 1:3

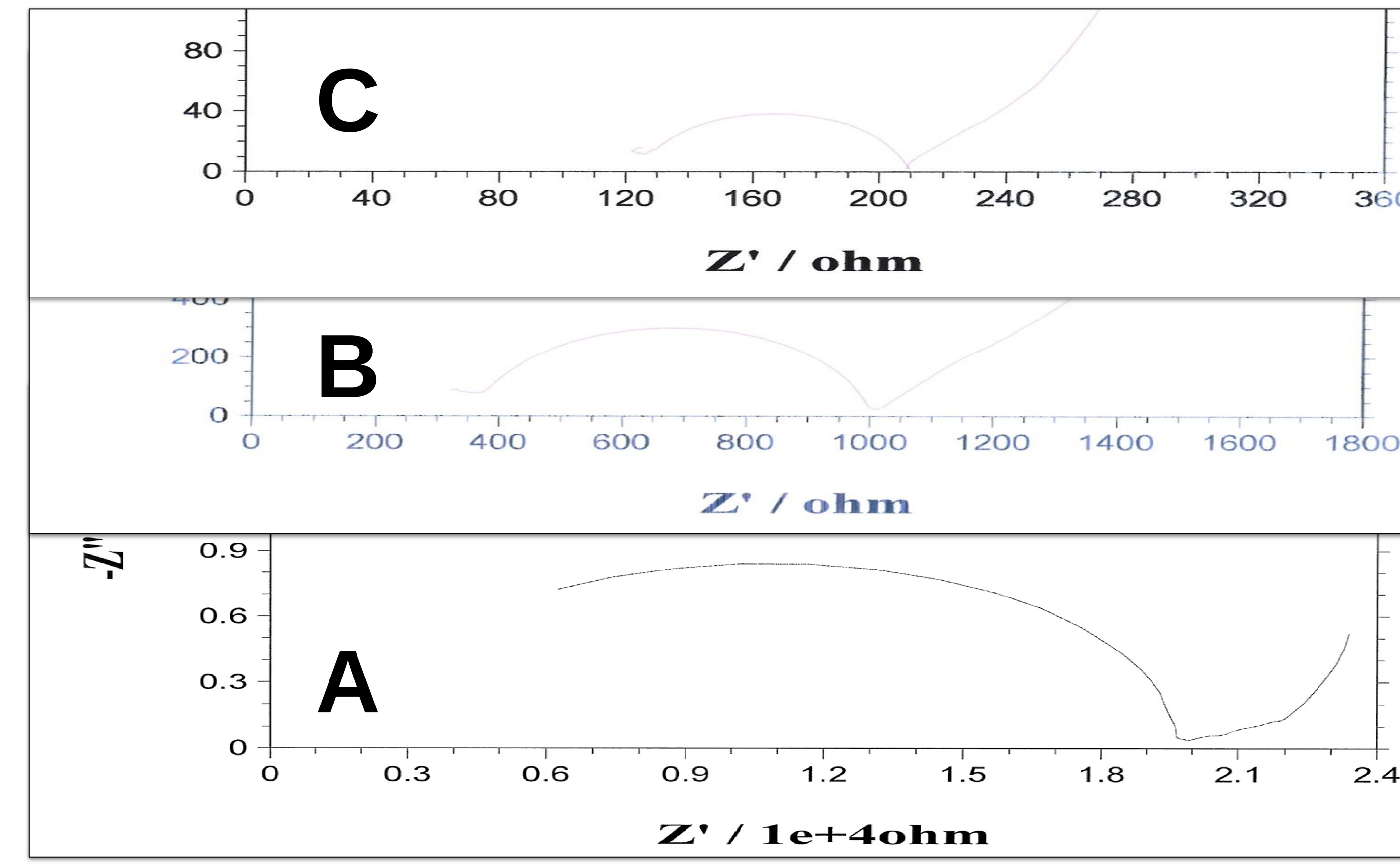


Figure 4. Nyquist plots of electrochemical impedance spectroscopy with different carbon:binder mass ratio (1:1, 1:2, 1:3). EIS is used to determine the resistivity of charge transfer of electrodes (semi-circle of the plot). The smaller semi-circle (charge transfer), the lower the resistivity. (A) 1:3, (B) 1:2, (C) 1:1. The figure shows the smallest charge transfer with the carbon-paste mass ratio of 1:1, which is due to low resistivity in charge transfer, which can be seen in the characterization plot ***[figure 3]***. It was determined from the EIS plot that the mass ratio of 1:1 was the best carbon-paste formulation and therefore carbon-paste mass ratio of 1:1 was used for the development of the paper-based electrode.

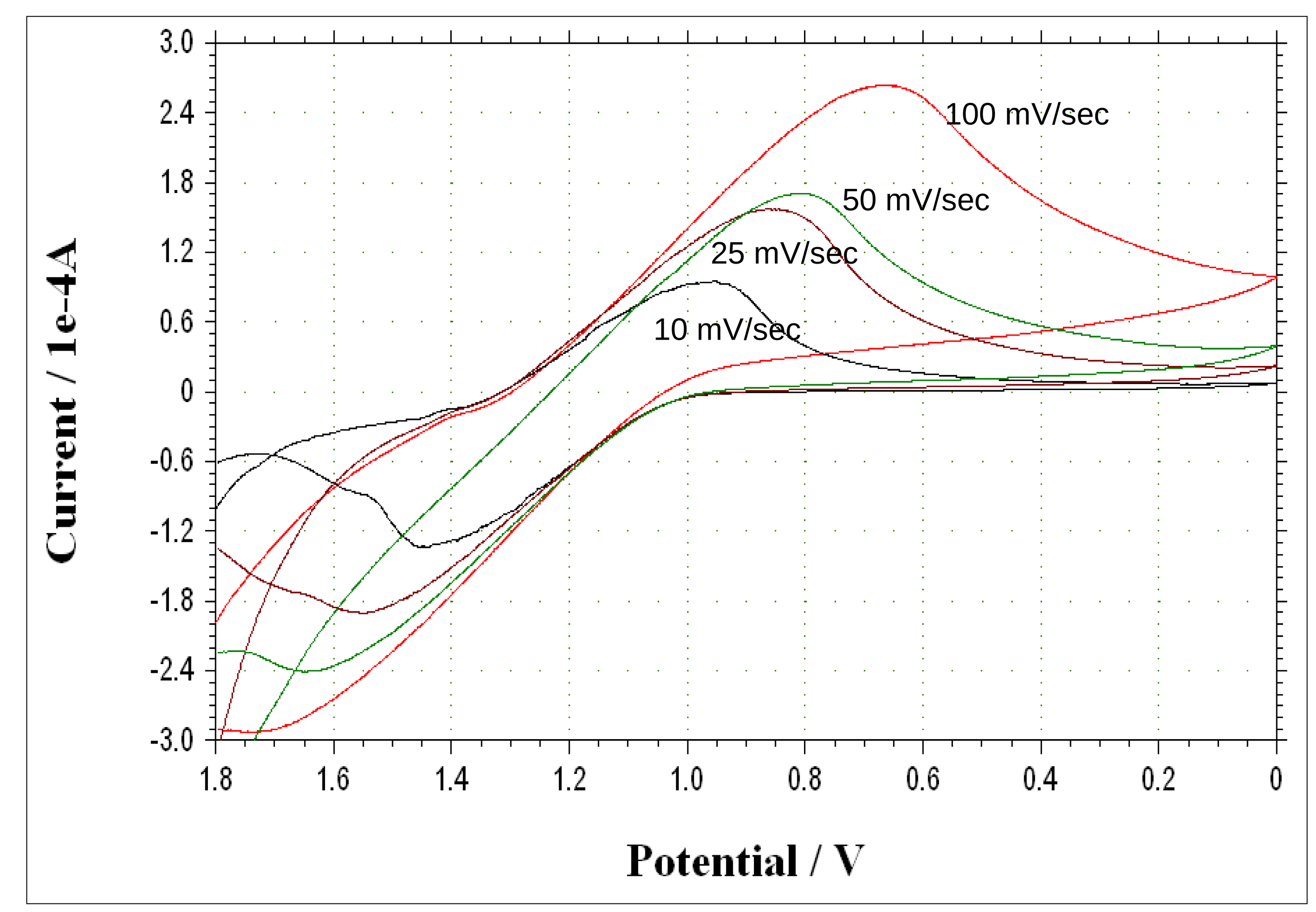


Figure 5. Overlay of characterization at different scan rates of WE and CE being carbon-paste paper-based electrodes. The figure shows an excellent characterization plot, and it was expected to see the peaks increasing in height as the scan rates were increased. Furthermore, the expected linear relationship of scan rate vs peak height were seen when scan rate and peak height were plotted. The carbon-paste formulation mass ratio of 1:1 was used for the paper-based electrode. The image of the paper-based electrode can be found in ***[figure 1]***.

Acknowledgements

•Kenneth L. Brown
•Hope College Department of Chemistry