Electrochemical Analysis of Silver-CNT Electrode Based Biosensors

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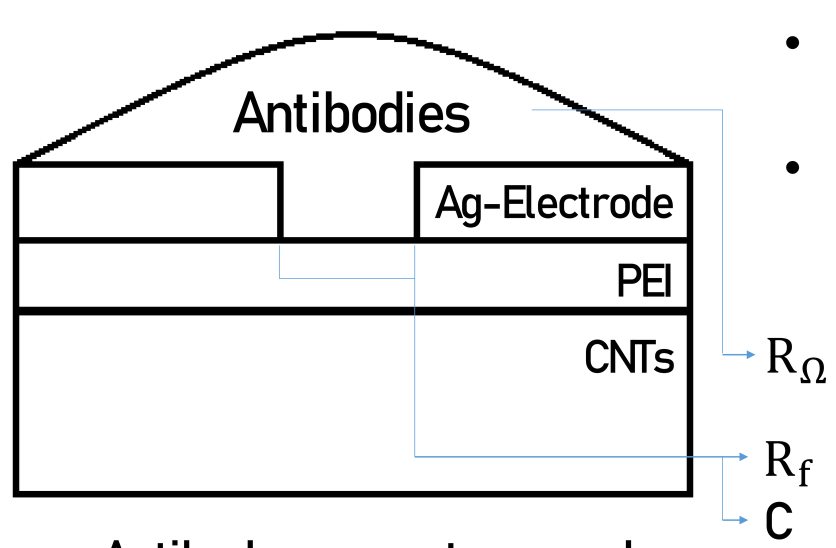
Abstract

There have been continuous demands to develop better biosensors, which identify the presence of a particular biological strain within a fluid sample, in an inexpensive, readily available and reliable manner. Our research aims to analyze the degradation mechanism in silver-CNT electrode-based biosensors, using electrochemical analysis methods. These sensors were developed with and without a conducting polymer layer, polyethyleneimine (PEI), across the CNT surface, as the PEI can improve the precision of such devices. However, the sensors are suffering from continuous change in resistance, therefore, we executed an electrochemical analysis using electrochemical impedance spectroscopy (EIS). The resistance and capacitance of a fluid bio-sample was measured and compared to resistance and capacitance of the fluid solvent. By repeated EIS experiments on the same sensors over time, we observed that the sensors experience their most dramatic decay within the first 8 hours of production and completely settled after 2 weeks. This might be explained by the fact that CNTs are known to experience oxidation, which can change their material properties. To identify if this is the cause of the decay, we took sensors immediately after manufacturing, both with and without a PEI layer and placed them inside a vacuum chamber for a 7-hour period. We observed an initial increase in resistance from both sensors immediately after removing them, after which they resumed their previously observed rate of decay; indicating that oxygen does contribute to the degradation.

Sensors

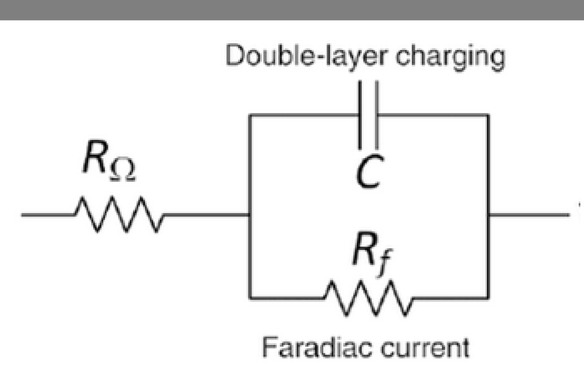


- Current is applied to the Ag-electrode
- Resistance and capacitance is generated in the antibodies and antibody interface

- Antibody parameters can be compared to reference sensor
- Antigen concentration can be identified

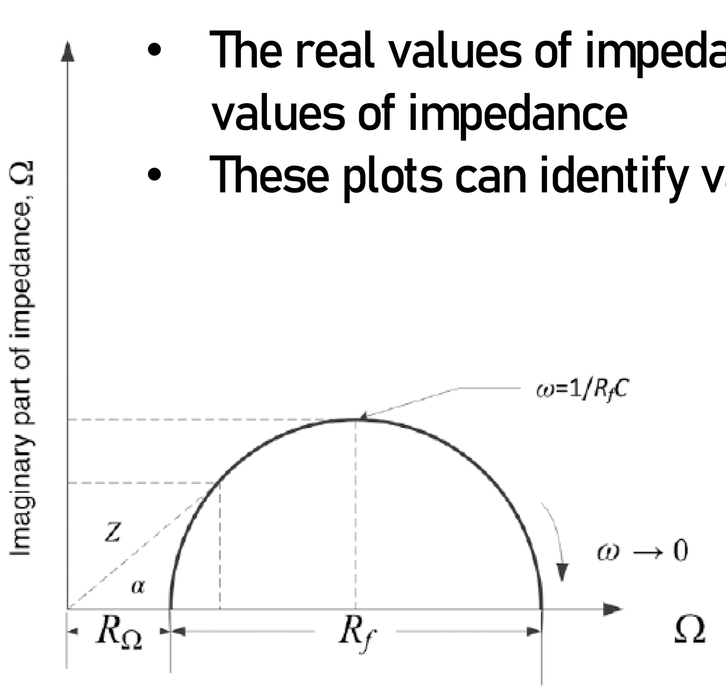
Electrochemical Impedance Spectroscopy (EIS)

$$Z(\omega) = R_\Omega + \frac{1}{\frac{1}{R_f} + j\omega C}$$



Nyquist Plots

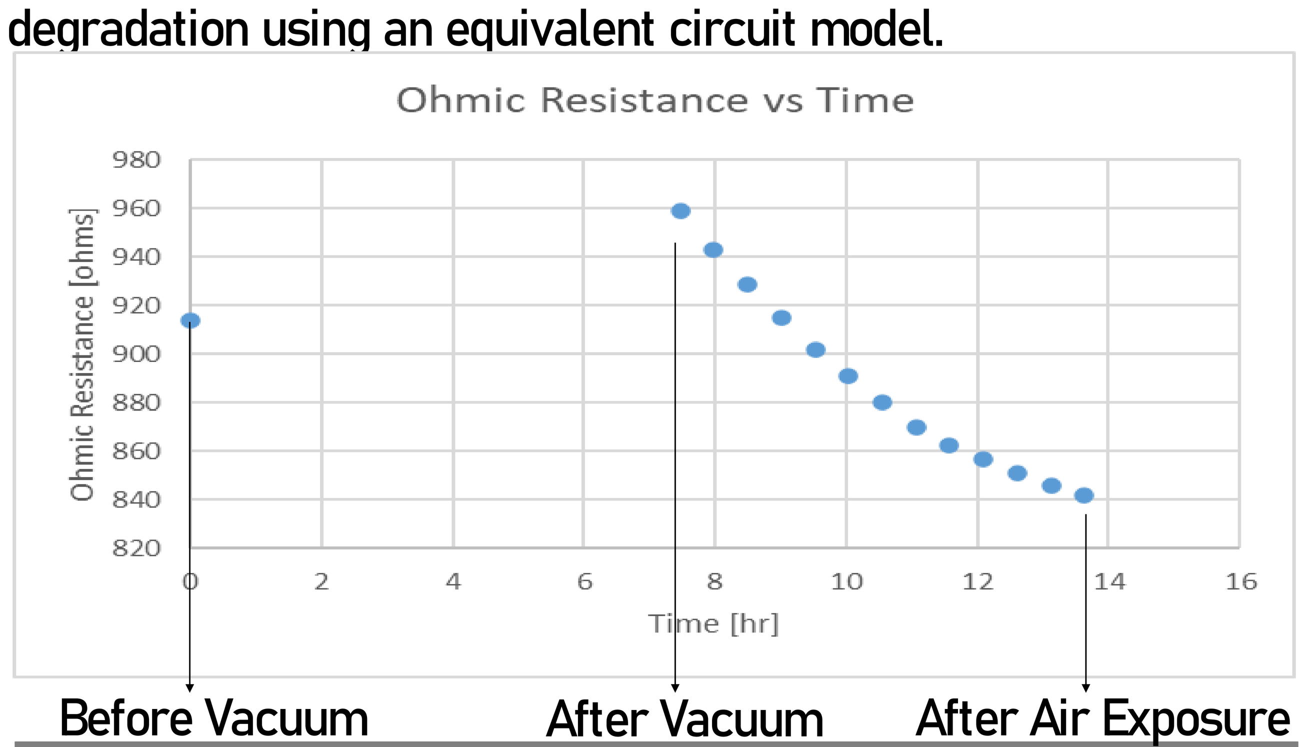
- The real values of impedance are plotted across the imaginary values of impedance
- These plots can identify values of resistance and capacitance



- R_Ω: Ohmic resistance in the electrolyte [ohms]
- R_f: Faradic resistance in the electrode/electrolyte film [ohms]
- C: Double layer capacitance between the electrode and the electrolyte [Farads]

Problem

The electrical resistance and capacitance of the biosensors is known to decay with time. Our goal is to identify the cause of degradation using an equivalent circuit model.



Experiment

- To identify if oxidation was a cause of decay, an EIS experiment was preformed on a freshly fabricated sensor.
- The sensor was then placed in a vacuum chamber for 7 hours.
- Once removed, the sensor was tested with EIS every half hour for 6.5 hours

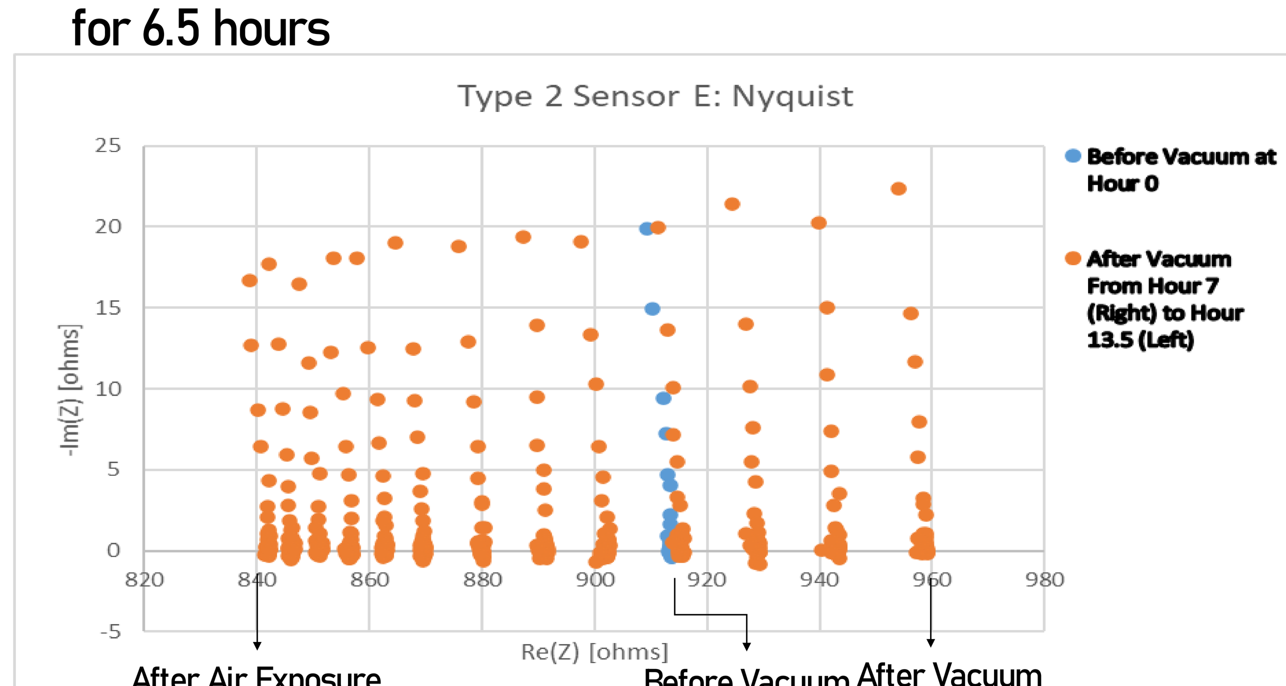


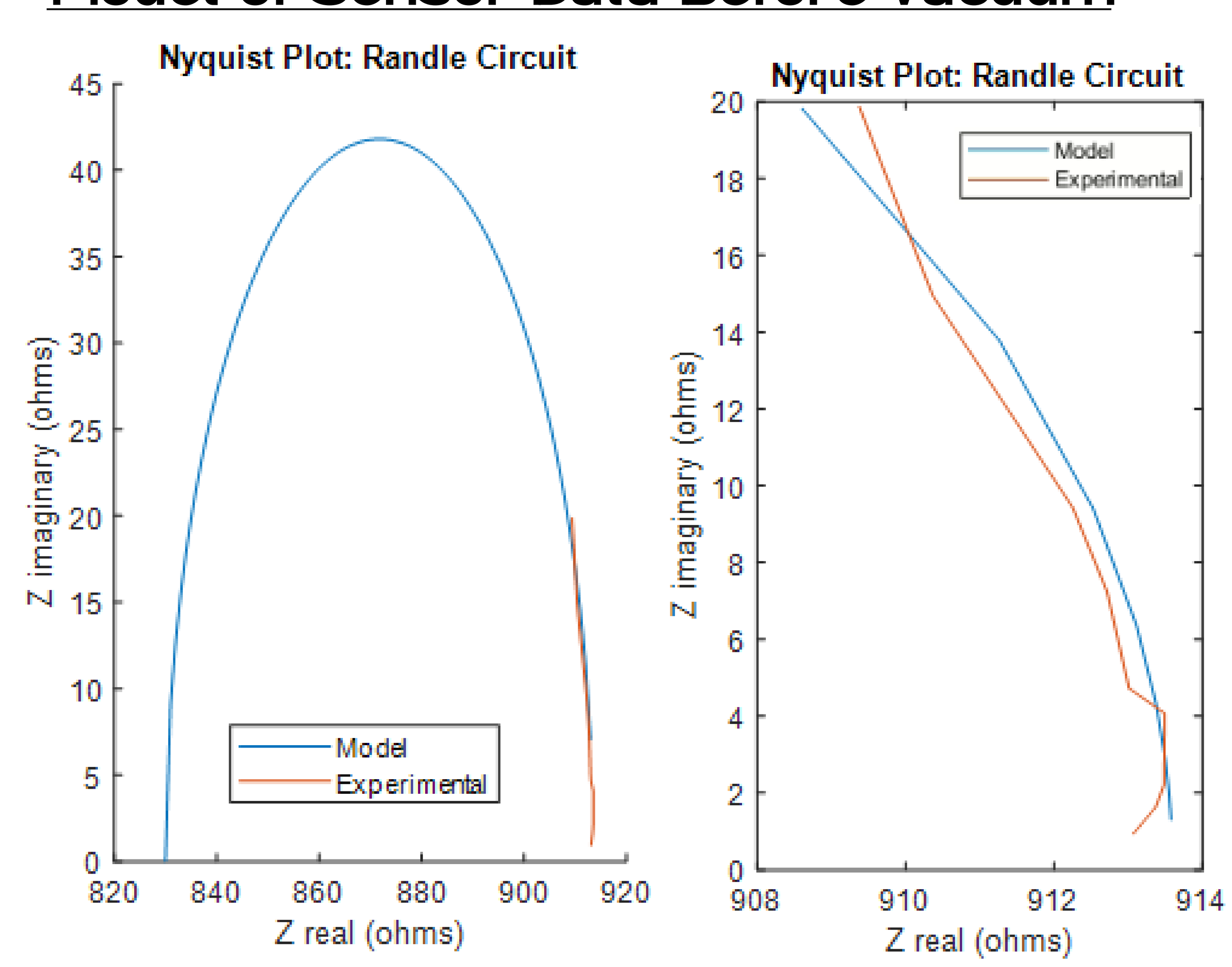
Figure shows EIS experiments taken before going into a vacuum chamber (blue) and after coming outer of the chamber (orange) then experiencing decay from the right to left

- The EIS data follows a semicircular pattern, but only a section of the circle is visible, thus it appears as a line

Model

- Nyquist plots of the sensor resistance, behave as incomplete semicircles
- The model can generate these both full and incomplete circles to identify R_Ω, R_f and C

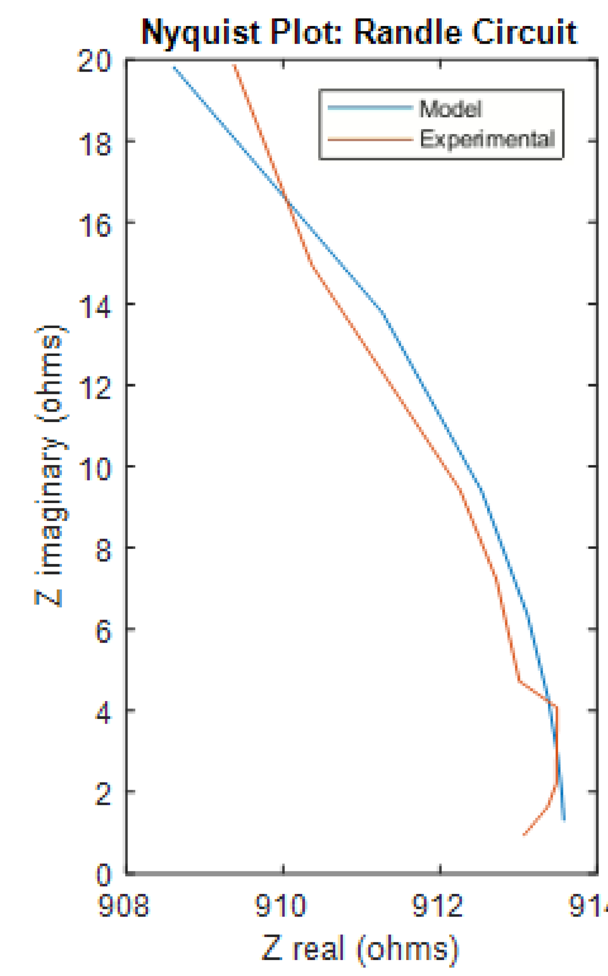
Model of Sensor Data Before Vacuum



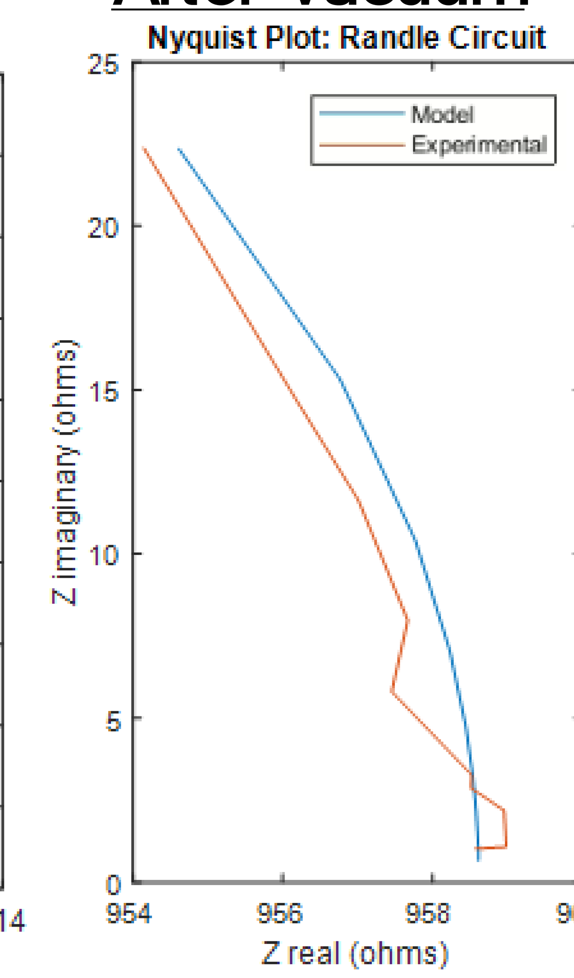
- Above left shows semicircle model over experimental data
- Above right shows semicircle model over experimental data

Results

Before Vacuum



After Vacuum



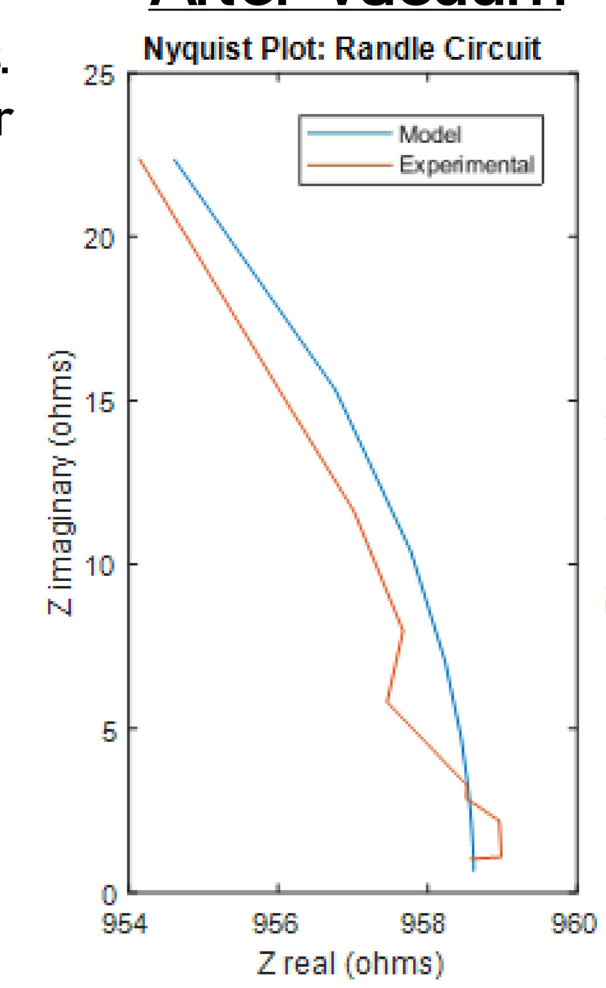
Before Vacuum

- R_Ω =830 Ω
- R_f =83.6 Ω
- C =4.8*10^{-8} F

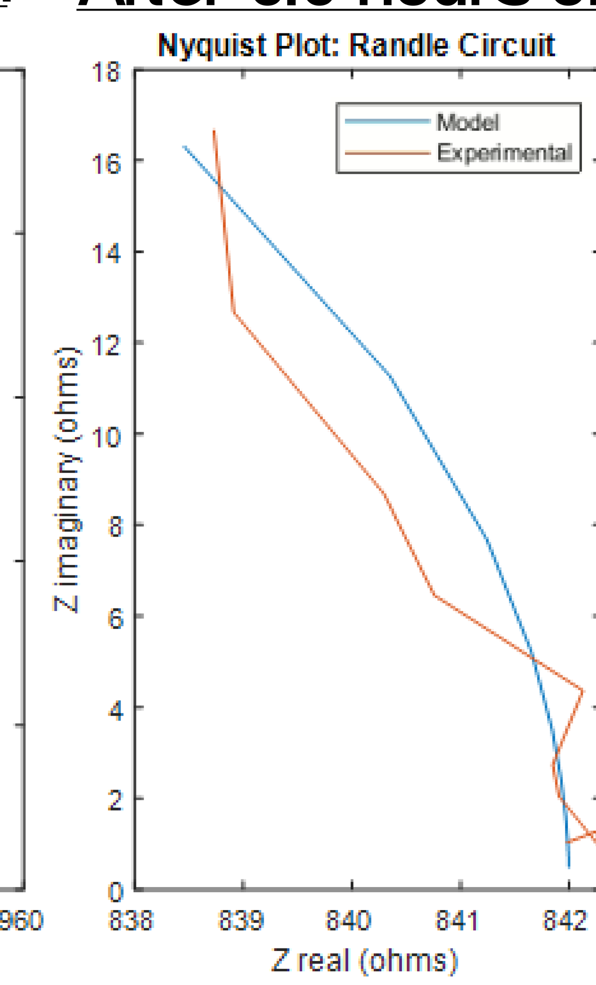
After Vacuum

- R_Ω =830 Ω
- R_f =128.62 Ω
- C =2.22*10^{-8} F

After Vacuum



After 6.5 hours of Air Exposure



After Vacuum

- R_Ω =830 Ω
- R_f =128.62 Ω
- C =2.22*10^{-8} F

After Air Exposure

- R_Ω =763.4 Ω
- R_f =78.6 Ω
- C =4.4*10^{-8} F

- While in the vacuum chamber: no observable changes in the ohmic resistance while the Faradic resistance and the capacitance increase.
- While exposed to air: ohmic and Faradic resistance decay while the capacitance increases

Conclusions

- An Electrode based biosensors is loosing its electrical resistance with time.
- While in a vacuum chamber, sensors with and without PEI layers did underwent changes in Faradic resistance
- While in a vacuum chamber, sensors with and without PEI layers did underwent decay in both Ohmic and Faradic resistance
- **Future Work:** Use a higher capacitance electrolyte to extend the length of the semicircle arc

References

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