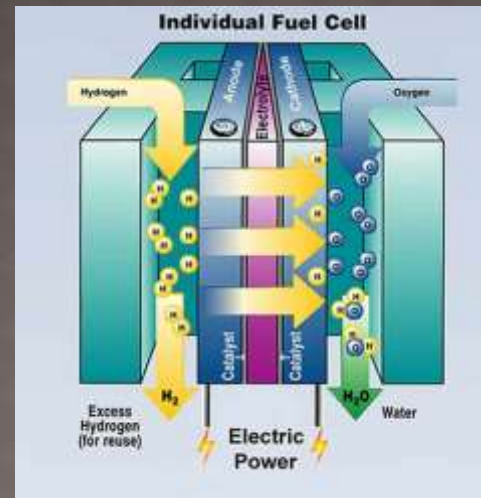


# TRANSPORT LIMITATIONS IN A MICROFLUIDIC FUEL CELL



<http://www.chem.umass.edu/masscrest/fuelingthefuture/images/fuelcell.jpg>

By Jason Tyser  
Professor Debashis Dutta

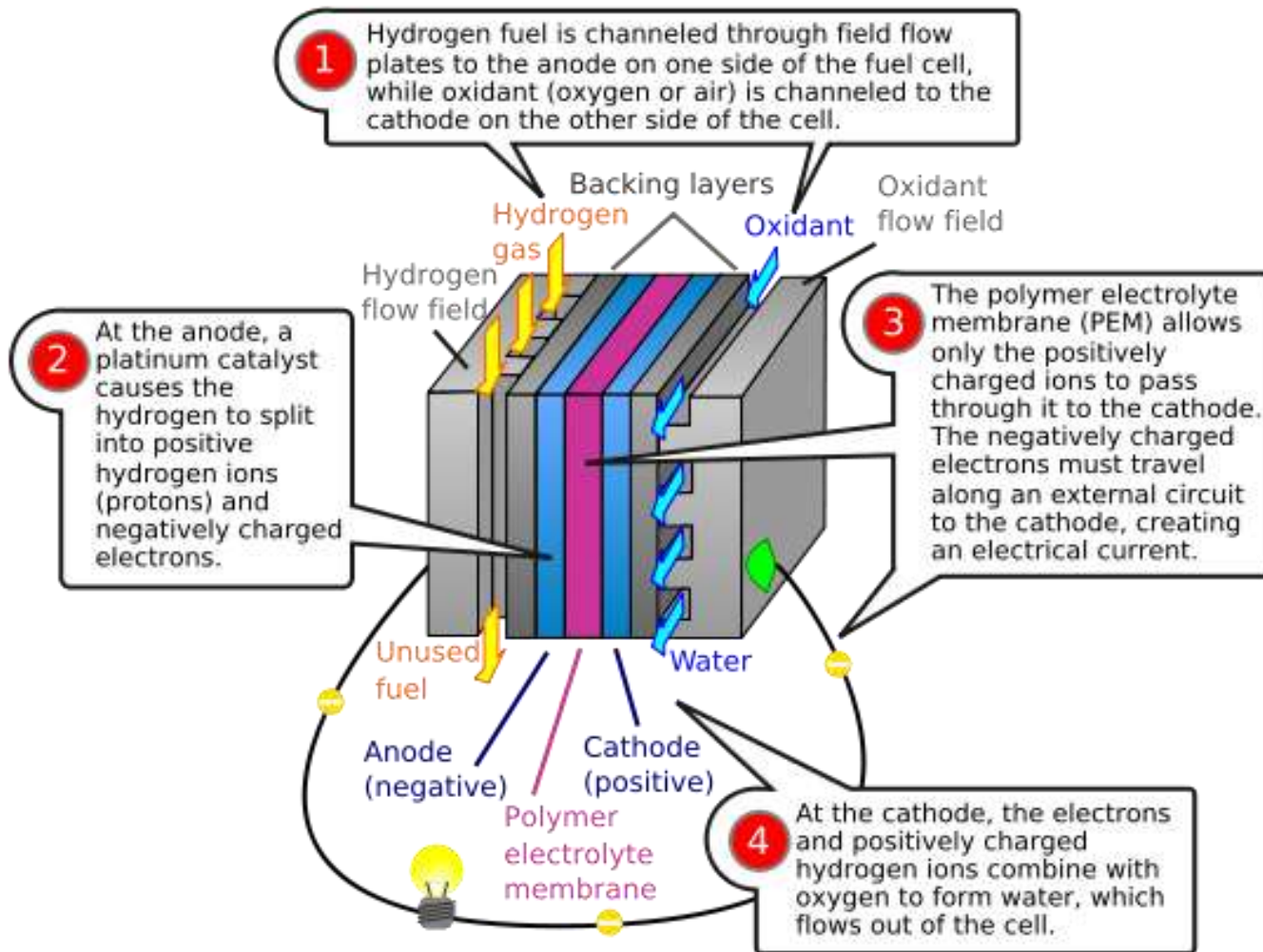
# BACKGROUND

## ○ What is a fuel cell?

- A fuel cell is an electrochemical conversion device.
- A fuel cell is made up of a fuel and an oxidant.
- A fuel cell is not a battery. A fuel cell is an open system. Batteries, in contrast, are considered a closed system.

# BACKGROUND

## Proton exchange membrane fuel cell

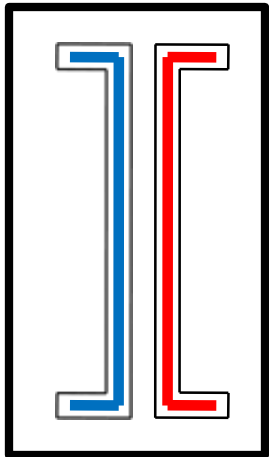


# BACKGROUND

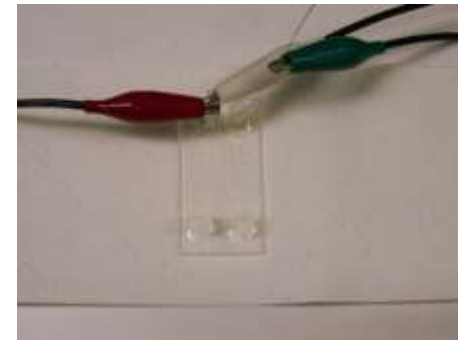
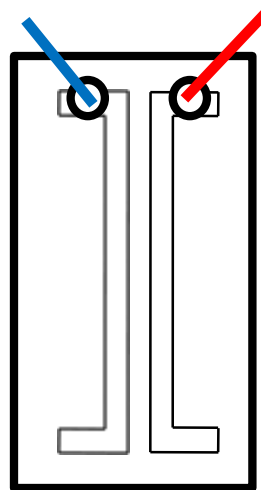
## ◉ Why my research is necessary:

- Deposited electrode vs. external electrode

Deposited electrode



External electrode in circular reservoirs



— = Cathode

— = Anode

# PREVIOUS RESEARCH

# PREVIOUS HYPOTHESES

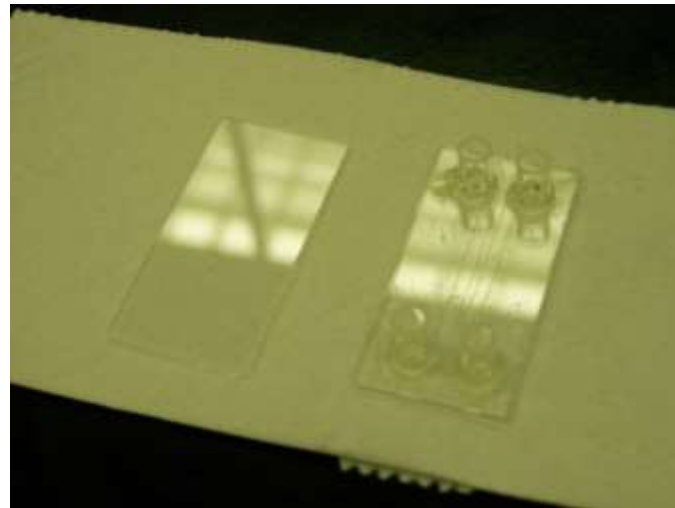
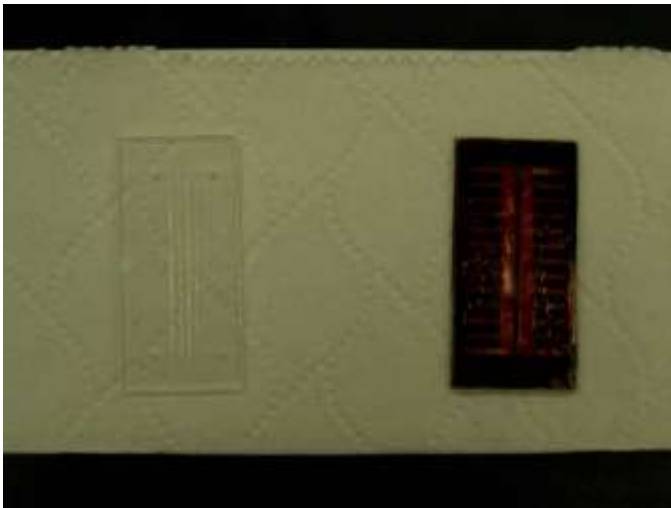
- 1) The current in the fuel cell with the Nafion membrane will be most affected by channel depth
- 2) The larger membrane will yield higher currents
- 3) Higher concentrations of formic acid and  $\text{KMnO}_4$  solutions will yield higher currents

# PREVIOUS RESEARCH

## ○ What I did:

- Fabricated fuel cell chip with micro channel depths of 50, 100, 140, 190, 240, 300, and 340 microns.
- Tested chips with a two sizes of a Nafion membrane: 50 and 115 microns.
- Tested chips with two concentrations of potassium permanganate: 0.15 M and 0.30 M  $\text{KMnO}_4$ .
- Tested chips with five concentrations of formic acid: 1.0 M, 2.5 M, 5.0 M, 7.5 M, 10.0 M

# PREVIOUS RESEARCH



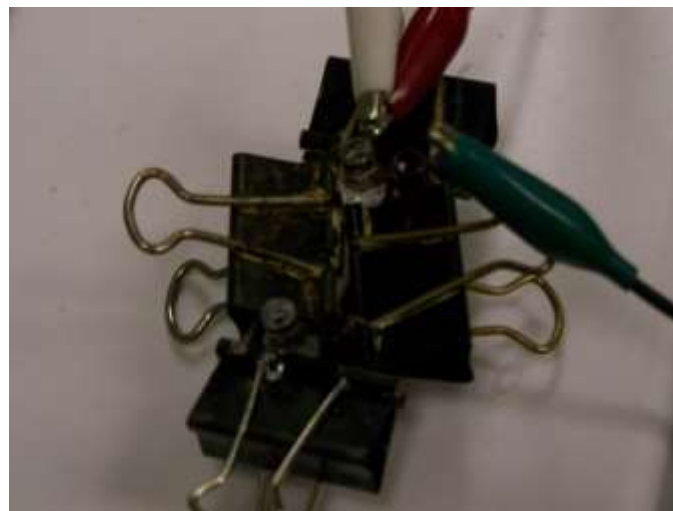
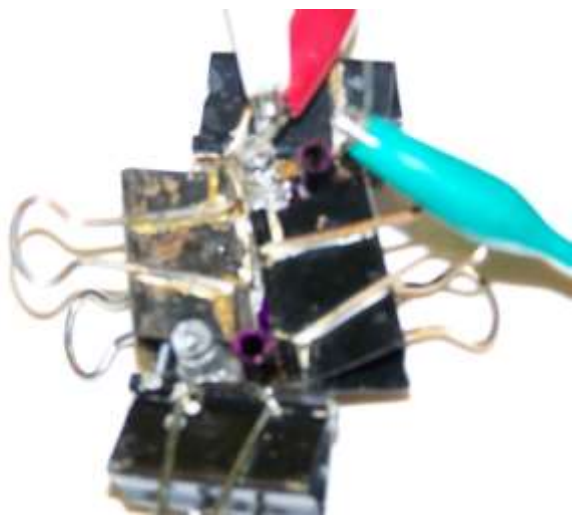
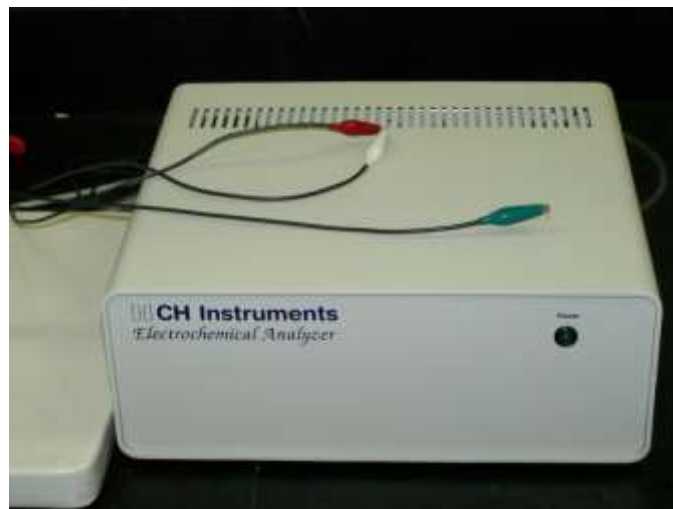


# PREVIOUS RESEARCH

## ○ Experiments

- Adding fuel (formic acid) and oxidant ( $\text{KMnO}_4$ )
- Using the electrochemical analyzer
- Taking an open circuit potential
- Applying voltages: 0.01, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 each for 100 seconds.

# PREVIOUS RESEARCH

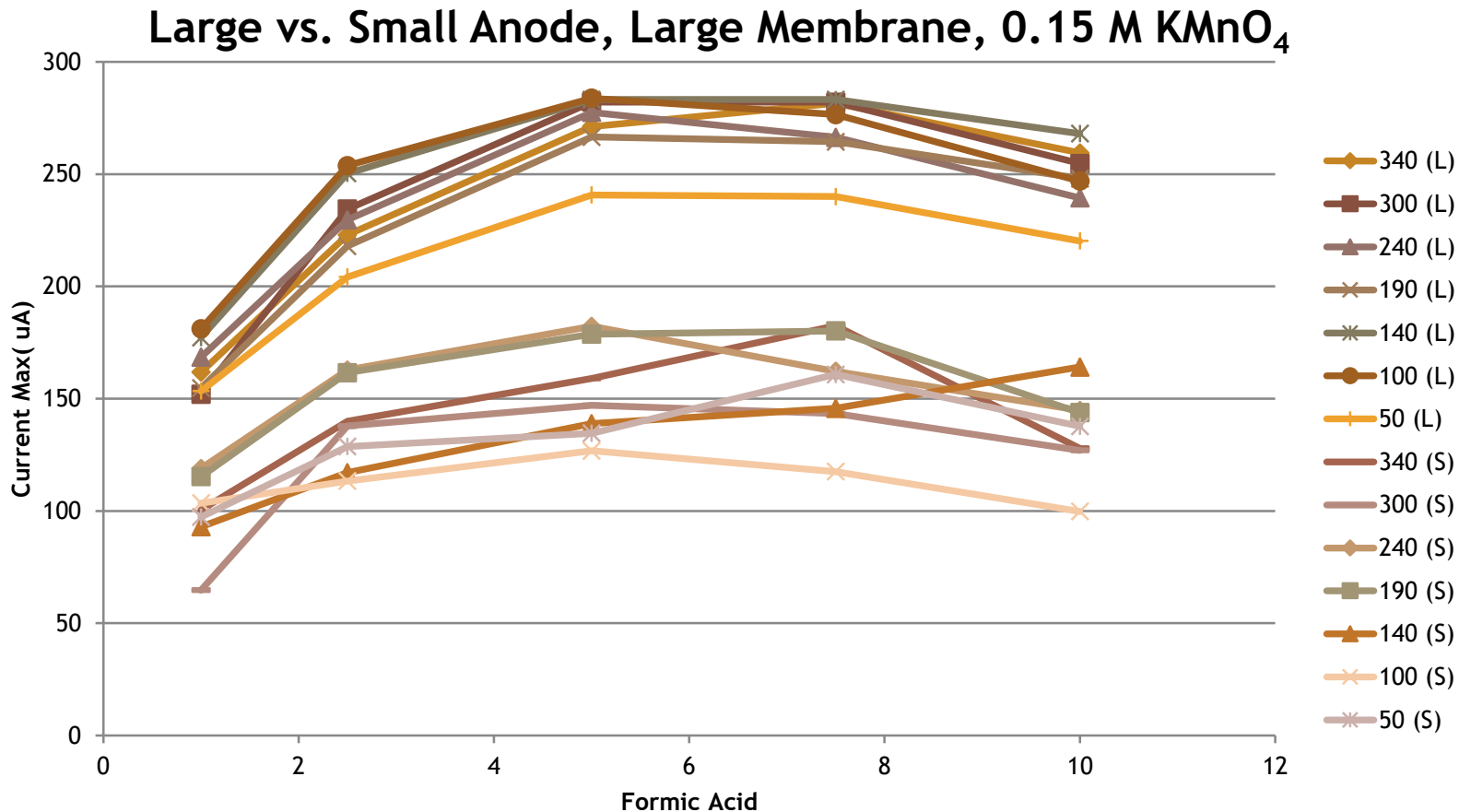


# PREVIOUS RESULTS

- ⦿ The 0.3 M  $\text{KMnO}_4$  did not produce higher currents than the 0.15.
- ⦿ The large membrane did produce higher currents than the small membrane.
- ⦿ Increasing the formic acid concentration did increase the current- although there was a consistent peak around 5 to 7.5 M
- ⦿ Usually the deeper the chip, the higher the current (but not always)
- ⦿ The size of the anode was determined to be the rate determining step.

# PREVIOUS RESULTS

- By making loops in the anode, the surface area increased from 30.883 mm<sup>2</sup> to 59.447 mm<sup>2</sup>



# PREVIOUS CONCLUSION

- ⦿ The area of the anode does affect the current and it was maximized in these last experiments.
- ⦿ The micro channel depth is not the limiting factor once the anode surface area is maximized.
- ⦿ We hypothesize that the membrane is the limiting factor.

# CURRENT RESEARCH

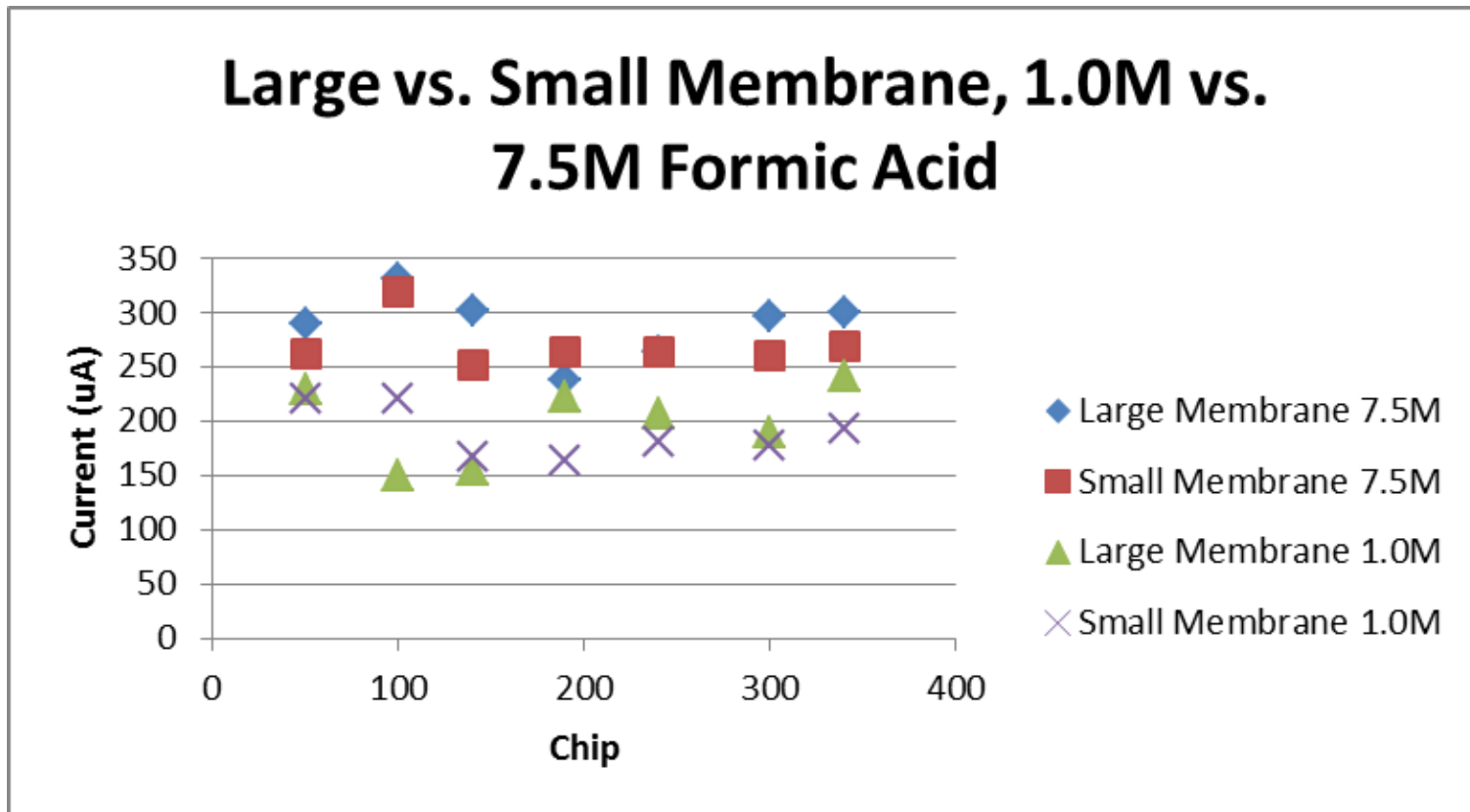
3 OBJECTIVES

# RESEARCH, 1<sup>ST</sup> OBJECTIVE

- ⦿ Used new membrane preparation technique outlined by Motokawa et. al. (2004)
- ⦿ Boiled Nafion membrane in 1 M  $\text{H}_2\text{O}_2$  solution for 1 hour
- ⦿ Rinsed it in boiling ultra-pure water for 1 hour
- ⦿ Treated it with boiling 1 M  $\text{H}_2\text{SO}_4$  for 1 hour
- ⦿ Ran same tests as before (using only 1.0 M and 7.5 M formic acid and 0.15 M  $\text{KMnO}_4$ )

# RESULTS 1<sup>ST</sup> OBJECTIVE

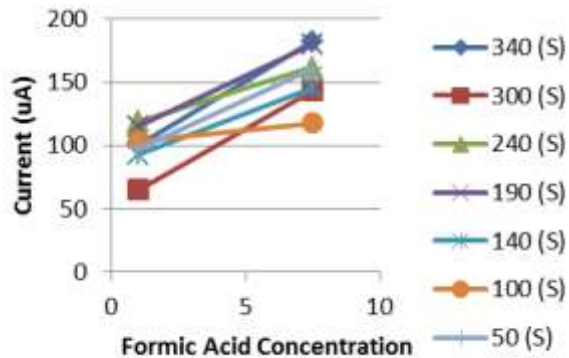
- There was still scatter in the data



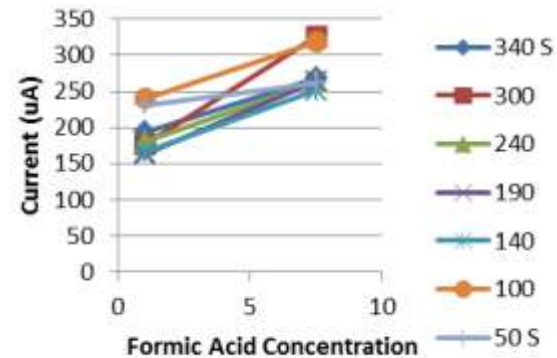


# RESULTS 1<sup>ST</sup> OBJECTIVE

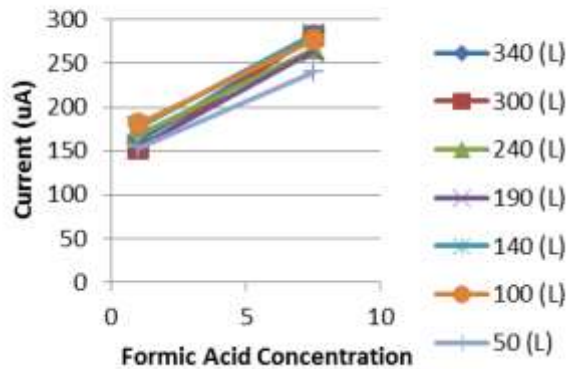
Last Year, Small Membrane, 1.0M vs. 7.5 M Formic Acid, 0.15M KMnO<sub>4</sub>



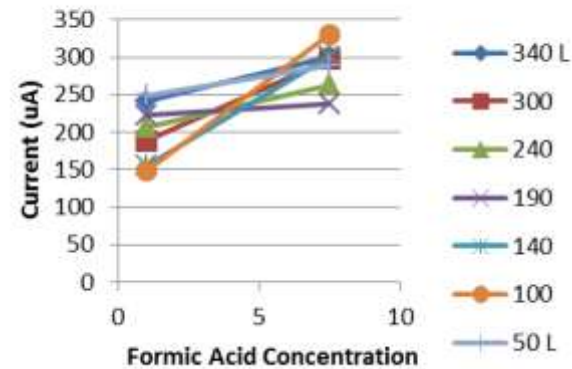
This Year, Small Membrane, 1.0M vs. 7.5M Formic Acid, 0.15M KMnO<sub>4</sub>



Last Year, Large Membrane, 1.0M vs. 7.5M Formic Acid, 0.15M KMnO<sub>4</sub>

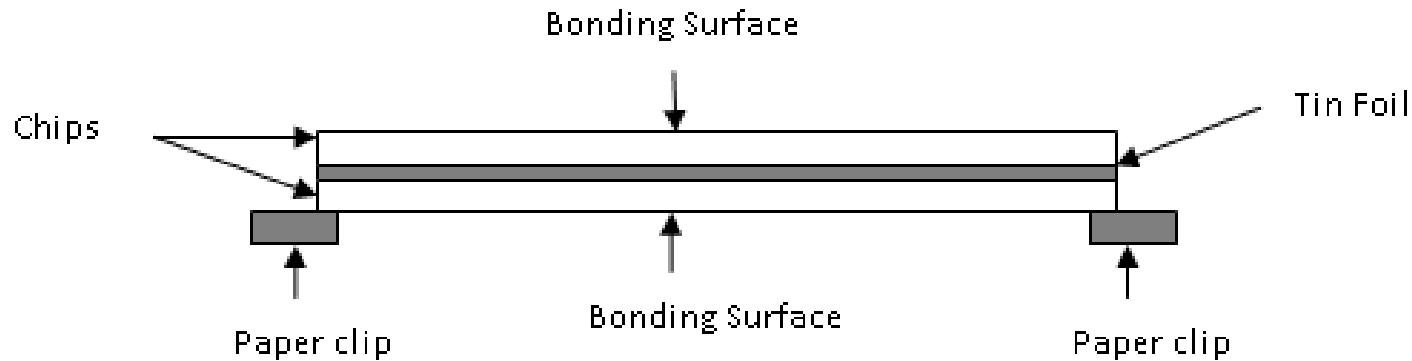


This Year, Large Membrane, 1.0M vs. 7.5M Formic Acid, 0.15M KMnO<sub>4</sub>



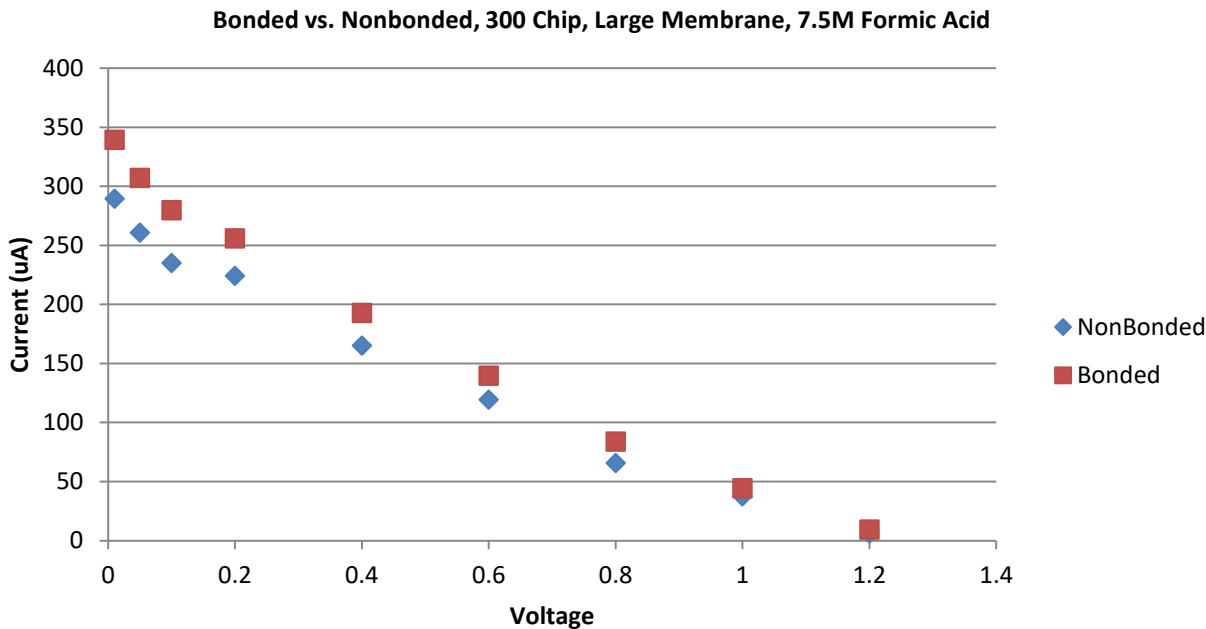
# RESEARCH, 2<sup>ND</sup> OBJECTIVE

- Bond the Nafion membrane to glass chips.
- Collaborated with Dr. Robert Corcoran, an organic chemist, to develop the process.
- Bonding solution was: 20% v/v solution of 3-aminopropyl-triethoxysilane in  $\text{CH}_2\text{Cl}_2$ .
- This would give + charge to glass surface to bond with  $\text{SO}_3^-$  groups on the Nafion.



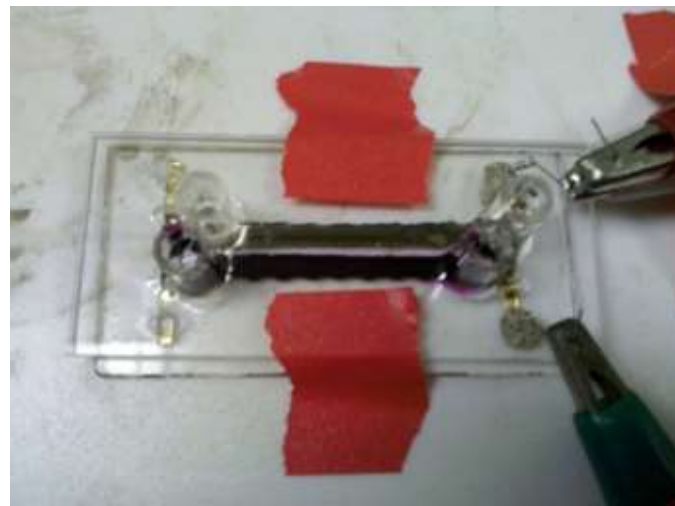
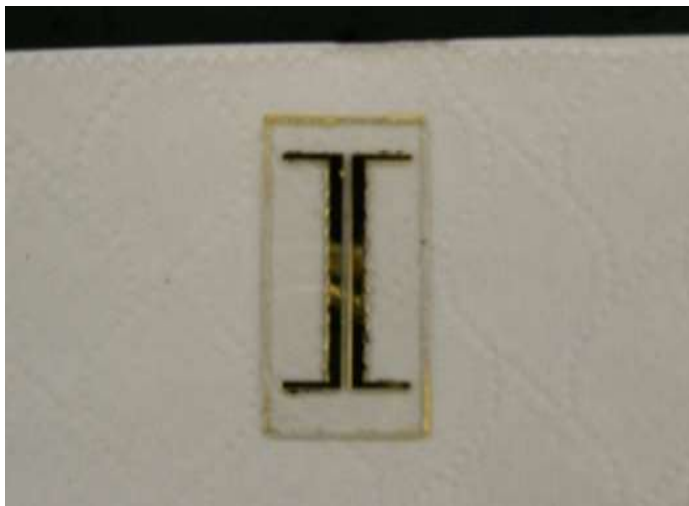
# RESULTS 2<sup>ND</sup> OBJECTIVE

- Only the 300 $\mu$ m chip was tested, but all of the tests (7.5M, 1M, small and large membrane) with the bonded fuel cell gave higher currents than the nonbonded fuel cell



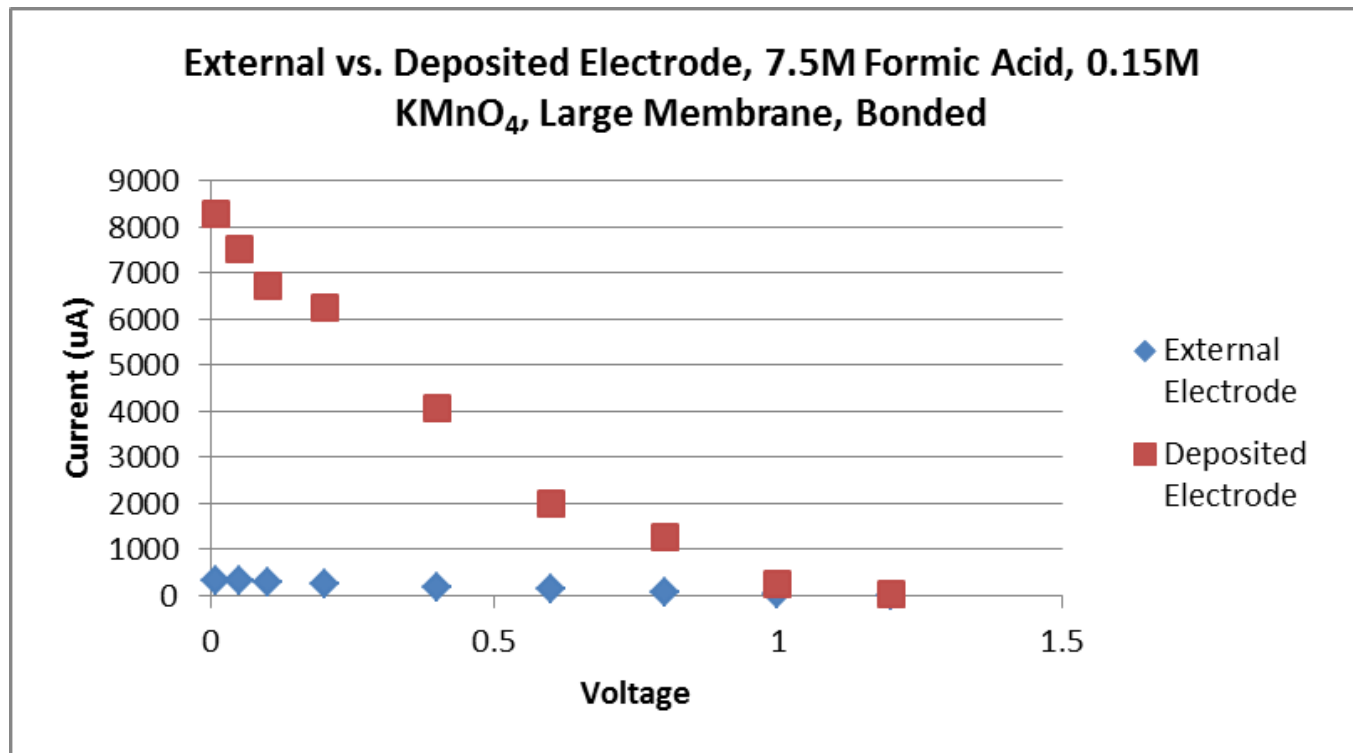
# RESEARCH, 3<sup>RD</sup> OBJECTIVE

- ◉ Deposited electrodes in the channels of the glass chips.
- ◉ This involved many steps:
  - ◉ Prepare chip and apply photo-resist
  - ◉ Use a metal evaporator to apply chromium and gold.
  - ◉ Deposit platinum through electrodeposition in a chemical bath containing 1mM  $K_2PtCl_6$  in 0.1M HCl



# RESULTS 3<sup>RD</sup> OBJECTIVE

- Using a 300  $\mu\text{m}$  chip, the deposited electrode fuel cell produced much higher currents than the external electrode fuel cell



# CONCLUSIONS & FUTURE RESEARCH

- ◉ Using the Motokawa et. al. (2004) technique, better results were produced for the small Nafion membrane, but more research needs to be done to alleviate scatter.
- ◉ Bonding microfluidic fuel cells produces better results than unbonded fuel cells.
- ◉ Deposited electrode fuel cells greatly outperform external electrode fuel cells; however, more research should be done to simplify deposition process.

# ACKNOWLEDGEMENTS

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