BME Design-Spring 2020 - JONAH MUDGE
Complete Notebook

PDF Version generated by

JONAH MUDGE

on

Apr 29, 2020 @02:58 PM CDT

Table of Contents

- Project Information 2
  - Team contact Information 2
  - Project description 3
- Team activities 4
  - Advisor Meetings 4
    - 1/31/20 Advisor Meeting 4
    - 2/14/20 Advisor Meeting - 5
    - 2/21/20 Advisor Meeting 6
    - 2/28/20 Advisor Meeting 7
    - 3/6/20 Advisor Meeting 8
    - 3/13/20 Advisor Meeting 9
    - 3/27/20 Advisor Meeting 10
    - 4/3/20 Advisor Meeting 11
    - 4/10/20 Advisor Meeting 12
    - 4/17/20 Advisor Meeting 14
  - Design Process 15
    - 2019/12/03- ISFET design with Ag/AgCl reference Electrode 15
    - pH Sensor Design Evaluation 16
    - 2020/04/17 - Design matrix (Delivery method) 19
  - Materials and Expenses 20
    - 2019/12/10-Material Expenses summary 20
    - 2020/4/28-Material Expenses summary 22
  - Fabrication 24
    - Electrodeposition of Ag/AgCl electrode 24
    - Final Design - ISFET and Reference electrode 27
    - 2020/01/27 - Electrodepositing solution 28
    - 2020/02/02 - IrOx Deposition 1 30
    - 2020/02/11 - IrOx Deposition 2 31
  - Testing and Results 32
    - Protocols 32
      - Drift Testing Protocol 32
      - Drift Testing Protocol Updated 33
    - Experimentation 34
      - Calibration of the ISFET and the reference 34
      - Drift Testing Data 36
      - 450 micron data 38
      - electrodeposited electrode data 39
      - kit electrode data 40
      - Cadaver Testing 41
      - IrOx vs Ag/AgCl Drift Testing Data 45
  - Project Files 47
    - PDS 47
    - Amplification and Filtration Ciruit 51
    - Final Report 53
  - Outreach 54
    - 2020/02/18 - Outreach Meeting 54

2020/02/21 - Practice Outreach 56
2020/02/23 - List of Materials 57
Team Meeting 1/28/20 58
Team Meeting 2/10/20 59
Team Meeting 2/18/20 60
Team Meeting 3/2/20 61
Jonah Mudge 62
Research Notes 62
Biology and Physiology 62
Doro's ACS Presentation 62
Fasciotomy Procedure 63
pH Probes 64
Microsens ISFET (combined REF) 64
A pH-ISFET based micro sensor system on chip using standard CMOS technology 65
Micro Dri-Ref Reference Electrode 66
Unisense micro ref electrode 67
Flexible Ag/AgCl micro ref electrode 68
Comparison of Fabrication Methods for Iridium Oxide Reference Electrodes 69
Microfabricated Reference Electrodes 70
Au Reference Electrode Concept 71
Sentron brochure 72
IrOx 73
IrOx electroplating solution 73
IrOx Electrodeposition 74
Governing Equations of Electrodeposition and pH Wire Probes 75
IrOx (on stainless steel) pH sensor 75
CV electrodeposition RSM optimization 76
More EIROF on stainless steel + small wires good 77
heating AIROF electrodes to prevent delamination 78
Design Ideas 79
Solder Reflow solution for ISFET miniaturization 79
Work Records 80
2/1/2020 Ag/AgCl Winsense 48hr drift testing 80
2/11/2020 IrOx + Ag/AgCl layered electrodeposition 81
2/15/2020 Ag/AgCl drift testing 82
2/19/2020 Ag/AgCl Fab 83
2/19/2020 Ag/AgCl drift testing 84
2/26/2020 Ag/AgCl Fab 85
3/3/2020 Ag/AgCl and IrOx electrodeposition 86
3/10/2020 Ag/AgCl and IrOx electrodeposition 87
Lucas Ratajczyk 88
Research Notes 88
Biology and Physiology 88
Acute Compartment Syndrome (ACS) Background 88
ISFET Background 91
Reference Electrodes 92
Electrode Characterization 98
Design Ideas 106
ISFET Idea 10-02-19 106
Training Documentation 107
Biomethodology of Swine 107
48-Hour Drift Test 110
Automation Code 110
02-04-20 Drift Test 112
02-19-20 Drift Test 114
Trying to fix the Sentron ISFET 116
UI Creation 119
ISFET Automation Meeting 121
Syafiqah Saidin 122
Research Notes 122
Biology and Physiology 122

09/27/2019 - Compartment Syndrome 123
03/04/2020 - Toxicity of Ag 125
Competing Designs 126
10/08/2019 - Odin Technology - Valkyrie 126
Microelectronics 127
10/08/2019 - Bare Dies 127
10/08/2019 - Winsense pH Sensor 129
10/17/2019 - Small pH sensor catheter for acidity test in gullet and stomach 131
10/17/2019 - Needle-like IrO/Ag combined pH microelectrode 133
10/18/2019 - pH Sensors Based on Iridium Oxide 135
10/30/2019 - Fabrication of Iridium oxide 137
11/1/2019 - Sol-gel Deposition of Iridium Oxide for Biomedical Micro-Devices 139
04/02/2020 - Fabrication of IrOx film pH microsensor on Pt 141
04/09/2020 - Microelectrode Needle Design 143
Design Ideas 146
12/03/2019 - Final Design - ISFET and Electrodeposited Ag/AgCl reference 146
IrOx Electrode 147
2020/01/27 - IrOx Electrodepositing solution 147
2020/02/02 - Electrodeposition of IrOx 1 149
2020/02/11 - Electrodeposition of IrOx 2 151
2020/04/17 - Delivery design 153
Training Documentation 155
11/25/2019 - Testing Winsense ISFET and its reference electrode 155
12/2/2019 - Fabrication of Ag/AgCl electrode 156
12/3/2019 - Testing 450micron and Electrodeposited reference electrode 158
Testing 160
03/11/2020 - Cadaver Testing 160
Hunter Huth 161
Research Notes 161
Competing Designs 161
10-06-2019 PreSens PH-MP5 161
Technology 162
Commercial Ribbon Cables 10-06-2019 162
9-20-2019 Sentron pH ISFET Bare Die chip 163
2019/17/10 Review article on micro reference Electrodes 164
2019/10/17 Iridium Oxide Reference Electrodes for neurochemical sensing 165
2019/11/12-Electrodeposition of Iridium on platinum 166
2020/21/2 Catheter materials for inner tubing 167
2020/4/09-Template - Micro Electrode Designs 168
Design Ideas 170
10/8/2019 Design for a minimized probe 170
2019/11/20 - IrOx Needle with Ag/AgCl reference 172
2019/11/18-Two Wire design 173
2020/2/2 Obstacles to still overcome 174
2020/25/02-MultiLumen Catheter Design 175
2020/3/05-Lubricious catheter design 176
2020/04/9-Design for placing electrodes on outside of needle 177
2020/4/17- Two-Lumen electrode placement design 179
Training Documentation 181
2020/10/02 Animal Training 181
Minimization meetings 182
9/26/2019 Meeting with Hal Gilles WCNT 182
10/8/2019 Email with Winsense 183
2014/11/03-Entry guidelines 184
2014/11/03-Entry guidelines 185
2014/11/03-Template 186
2014/11/03-Template 187

Team contact Information

JONAH MUDGE - Sep 16, 2019, 11:47 PM CDT

Last Name	**First Name**	**Role**	**E-mail**	**Phone**	**Office Room/Building**
Nimunkar	Amit	Advisor	nimunkar@cae.wisc.edu	(608) 890-1008	2620 Engineering Hall
Doro	Christopher	Client	doro@ortho.wisc.edu	(608) 263-0453	6221, UW Medical Foundation Centennial Building
Mudge	Jonah	Leader	jmudge@wisc.edu	(262) 506-4895	
Huth	Hunter	Communicator			
Saidin	Syafiqah	BSAC	nsaidin@wisc.edu	(608) 698-6616	N/A
Ratajczyk	Lucas	BWIG	LRatajczyk@wisc.edu	(847) 340-8246	N/A
Ratajczyk	Lucas	BPAG	LRatajczyk@wisc.edu	(847) 340-8246	N/A

Project description

JONAH MUDGE - Sep 23, 2019, 9:41 AM CDT

Course Number:

63322

Project Name:

Use of pH or glucose probes to diagnose compartment syndrome

Short Name:

compartment_syndrome

Project description/problem statement:

Compartment syndrome is a difficult-to-diagnose condition that occurs when tissue pressure in a muscle compartment rises enough to cause ischemia and possible muscle death. False-positive diagnoses of compartment syndrome lead to expensive and invasive surgeries, despite being unnecessary. Our goal is to design a device capable of measuring the pH within a muscle compartment, using the pH as a reliable indicator of whether compartment syndrome is actually occurring.

About the client:

Dr. Christopher Doro is an orthopedic surgeon with UW Health Orthopedics and Rehabilitation in Madison, WI. Dr. Doro earned his medical degree from Northwestern University and completed his internship and residency at the University of Michigan in Ann Arbor. Dr. Doro also completed a fellowship at the R. Adams Cowley Shock Trauma Center in Baltimore, Maryland.

1/31/20 Advisor Meeting

LUCAS RATAJCZYK - Feb 10, 2020, 6:52 PM CST

Title: Advisor Meeting

Date: 1/31/20

Content by: Lucas

Present: Team + Dr. Nimunkar - Syafiqah

Goals:

Content:

- Hunter and Syafiqah have access to ECB 2005 and the IrOx solution is curing
- Dr. Doro has (pig) cadaver legs ready for preliminary testing
- Jonah and I are working on automating the ISFET pH reading process so that the 48 hour drift test can be conducted without as much oversight (no all-nighters)
- Preliminary presentation next week
  - Talk about drift test results ans automation of pH recording
  - Talk about IrOx creation so far and plans
- IrOx deposition to occur tomorrow or Sunday (solution finishes curing tonight at midnight)
- Use an instrumentation amplifier for higher input impedance (LT 1167 or 1920)
  - Don't do all amplification in one stage
  - Many stages makes frequency response more robust
  - Even though no frequency component to the signal
  - Check the source papers to see what gain should be needed
- While Dr. Doro specified only a pH range of 7-5 with a resolution of 0.5, we should aim for higher resolution and wider range if possible
- Check the guidelines and recommendations for presentation and report
- Need to choose a journal: Physiological Measurements (looser formatting requirements)

Conclusions/action items:

2/14/20 Advisor Meeting -

JONAH MUDGE - Feb 24, 2020, 11:24 PM CST

Title: Advisor Meeting

Date: 2/14/20

Content by: Jonah

Present: team

Goals:

Content:

- **2/14/20 Advisor Meeting** Amit Nimunkar

  Catheter?

- Less tissue damage
- Make sure that it's innovative, check size of current papers and see if ours is small

  Testing

- 48 hour ISFET/Ag/AgCl test
- 48 hour IrOx/Ag/AgCl test
- Push on toward final prototyping!

  Design, optimize, innovate!!

Conclusions/action items:

Really need to focus on prototyping and testing so we can get our final design done asap

2/21/20 Advisor Meeting

JONAH MUDGE - Feb 24, 2020, 11:26 PM CST

Title: Advisor Meeting

Date: 2/21/20

Content by: Jonah

Present: team

Goals:

Content:

2/21/20 Advisor Meeting Amit Nimunkar

Determine hardness requirement for microtube for electrode separation

-look for comparable products currently on the market

Drift test issues

-research limits of electrodeposited Ag/AgCl efficacy (hours)

-try commercial ref electrode with iridium oxide electrode?

**have a control to compare against

Compare with commercial ph meter?

Journal paper

-physiological measurements

-abstract, intro/background,design, methods, results, discussion, conclusion, acknowledge

Appendix with design process

-fabrication protocol (step 1, 2, 3…)

-design matrix, PDS, design options

KCl gel with Ag/AgCl could not only reduce toxicity but increase electrode survival time?

Conclusions/action items:

Write out journal article draft and preliminary deliverables before Wednesday deadline

2/28/20 Advisor Meeting

LUCAS RATAJCZYK - Feb 28, 2020, 2:40 PM CST

Title: Advisor Meeting

Date: 2/28/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Update Dr. Nimunkar on our progress this week and get feedback for preliminary deliverables.

Content:

- Tech meeting this morning
  - No second doctor to conflict with Dr. Doro
  - No risk of IP claims by the med students
  - Med students used as resources
  - Do we need them to sign the IP form from prelim presentations?
    - Ask Dr. Puccinelli
- Drift Tests
  - 2/19/20 completed
  - 2/26/20 almost done (finishes today in a few hours)
  - Change the Adruino code to automatically remove/reduce pH outside 0-14
  - Clean the ISFET and try again to see whether these results are from the ISFET or some random interference (unauthorized human intervention?)
  - Why is there changes in pH reading prior to AgCl depletion?
    - Code
    - Electrode
    - ISFET
  - Slight offset to the pH even when accurate
- Syafiqah
  - Ag/AgCl is less toxic than Ag+ ions (add references to LabArchives)
- Hunter
  - Electrode sleeves (purchasing them) biluminal to allow both electrodes in without contact.
  - Extrusion companies have large (~$5000) starting cost to make a new model for our specific application
    - They have some premade models that have same shape but are bigger (too big for humans but small enough for dogs)
    - Possible that we just buy a multilumen needle made of PEEK to replace the sleeve and metal needle. Needle still flexible
  - Worried about the ability of compartment fluid to reach the electrodes (compartment contents mostly semisolid)
  - Tri-lumen tube to deliver the electrodes? (third lumen for the needle - catheter-style)
  - Make sleeve/catheter out of ion-permeable membrane to combat the semisolid concern?
    - Solution inside the tubes that accepts the diffusing ions from the compartment
    - If no need for solution surrounding the electrodes, ignore this
    - Syafiqah has a paper which used KCl buffer gel and a tube that was partially ion-permeable (ion-permeable in some parts of the tube) -> See "small pH sensor" entry in her LabArchives notebook under research > microelectronics
  - Buffer solution around the electrode to improve contact surface area
- Jonah
  - IrOx drift testing in progress (finishes up in ~30 minutes)
- Article
  - Formatting less necessary on our end (all one column and they will format it as they want)
  - Don't use figures that we did not make (need to pay source)
  - Replace the Compartment anatomy with a drawing we make ourselves
  - Include protocols in appendix (immediately following the paper - before PDS etc.)
  - Figures in MATLAB instead of Excel (more later)

Conclusions/action items:

- More drift tests and drift test data
- Tubing solutions

3/6/20 Advisor Meeting

LUCAS RATAJCZYK - Apr 28, 2020, 5:27 PM CDT

Title: Advisor Meeting

Date: 3/6/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Update Dr. Nimunkar on our progress this week and get feedback.

Content:

- Jonah:
  - Fabricated some more IrOx electrodes and conducted a fruit test (stuck them in an orange and read the change in voltage after passed through an amplifier)
  - Set up a new drift test with the ISFET and our AgAgCl electrode with the modifications discussed last week (automatically calculate pH and limit when pH goes above 14 or below 0)
- Hunter:
  - Got a sample of multiluminal tubing which can be used in animal testing but not human (only fits in 11 gauge not 16)
  - Will continue contacting companies about getting smaller and alternative tubing methods that would work with 16 gauge needle
- Syafiqah:
  - Created more electrodeposition solution so Jonah could make some IrOx electrodes for the orange test
  - Researched AgCl toxicity and tubes that could even be used on a 13 gauge needle
    - Not very toxic, good enough for spot checking, still looking into 48-hour monitoring period
- Lucas:
  - Made the amplification circuit and low-pass filter we used in the orange test
    - Low pass filter was introduced because we saw a lot of higher-frequency noise in the signal when we first tried it. The corner frequency was set to ~7 Hz so that the ideal pH frequency of 0 Hz was well within the pass band and the primary source of noise (ambient 60 Hz) was well within the stop band.
  - Made the modifications to the drift test code needed to implement the changes Dr. Nimunkar mentioned last week
    - Automatic conversion of voltage to pH: Use the calibration equation, obtained from the voltages of the three test pH solutions prior to drift testing, to calculate the pH directly from the voltage reading in the code and display the pH every 5 minutes
    - Keep track of bad pH readings (>14 or <0): Check the pH once calculated and if it is above 14 or below 0, display the average of the past two pH readings (stored in an array) and increment a "bad_ph" counter to indicate there was a bad pH reading.
    - You can see from the drift data that the bad_pH readings only start occurring once the steep dropoff has occurred. (See the drift test 3/3/20 entry)

Conclusions/action items:

Jonah and Syafiqah are going on their tour of CSC and then will do some cadaver testing

Hunter and Lucas will finish the next step in their necessary training to do the cadaver testing (set up tour of pig facility)

Hunter and Syafiqah will still contact companies about tubing to deliver the electrodes.

3/13/20 Advisor Meeting

LUCAS RATAJCZYK - Apr 28, 2020, 4:52 PM CDT

Title: Advisor Meeting

Date: 3/13/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Present our progress for the past week and get advice on work to do this upcoming week.

Content:

- Still have weekly meetings:
  - BB Collaborate Ultra
- Syafiqah and Jonah
  - Cadaver testing
  - Notes and pictures in LabArchives
- Try Inst Amp with Gain of 1
- Next goal to combine everything (finalize amp circuit and UI)
  - High electrode impedance (because so small) needs high input impedance amplifier
- Solder the wires directly to perf-board ciruit
  - Cut solder to replace wires for testing
  - Final prototype can give the board directly connected to the wires already since these parts of the design are cheap
  - Goal is to remove the extra wires and simplify the design
- Buildings will be closed (students can enter but highly discouraged) so take non-chemical materials to apartment
- More cadaver testing until Dr. Doro says no more for Coronavirus
- Jonah being prevented from going to his lab means electrode fabrication problems (no potentiostat)

Plan for next two weeks:

- Work on the UI and device assembly
- Hold off on testing
- Thermistor to account for temperature variations
  - Assume body temperature except for cadaver testing (use thermometer)

Conclusions/action items:

BB Collaborate Ultra (Access through MyUW)

Work on the UI - fabrication.

Preliminary feedback will given later.

3/27/20 Advisor Meeting

LUCAS RATAJCZYK - Mar 27, 2020, 12:26 PM CDT

Title: Advisor Meeting

Date: 3/27/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Get advice for the rest of the semester with respect to the whole COVID-19 panic/shutdown

Content:

- Since we can't make any more electrodes or do animal testing (facilities shut down),
    - Work on simulations (Jonah - "Comsole"?)
    - Make a paper focusing on the fabrication and theoretical analysis of the electrodes we made (is this a viable suggestion in the long run?)
    - "Comsole" simulations require prior knowledge of the chemical factors which are the confounding variables which may cause issues with our design
        - Use MATLAB?
    - Mathematical framework for the electrode's operation - Characterize the electrodes (blueprint for the electrodes) to make future progress in this work much easier.
        - Literature searches
        - Try to provide physical/chemical explanation for the mathematical behavior
    - Equation for deposit layer thickness dependent on the duration and current of the deposition protocol (fine-tune the deposition protocol) - Comsole
    - UI Work
        - Jonah has soldering kit
        - Syafiqah has Nucleo
- Still trying to publish?
    - YES
    - No hurry because most/all of us will be here next year
    - Would allow more detail in the stuff we need to do still
    - Final product state (packaging etc.) can be worked more on over the summer once quarantine ends
    - **So long as it is helpful for others**
- Maybe no final presentation (wait to hear from Dr. Puccinelli)

Conclusions/action items:

- Simulations (using Comsole or MATLAB or SolidWorks or Autodesk Inventor)
- Equations from literature searches
- User interface and Final Product (packaging etc.)
- Fine-tune the operation code
- Outreach paperwork now due MAY 1st

4/3/20 Advisor Meeting

LUCAS RATAJCZYK - Apr 03, 2020, 12:33 PM CDT

Title: Advisor Meeting

Date: 4/3/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Update Dr. Nimunkar on our progress this past week and get advice for future work.

Content:

- Jonah found some more detailed papers about iridum oxide electrodeposition
  - Researching electrode break-down as next step
  - We can see from experimental data when it is breaking down
  - Temperature can cause some drift (consult the equations to see how much of our drift can be caused by this) but temp is mostly constant so our drift is largely due to the AgCl depletion
  - "Like a battery": don't use the battery until its charge is 0%.
  - Look into BME 462 textbook chapter 5 for AgCl depletion equations
- Hunter working on CAD for simulations
  - Also was working with extrusion companies to buy tri-lumen tubes
    - Start-up costs would be around $4000 - 5000 so make sure it will work out before we begin the purchasing process
    - Contact the company to get suggestions about what they recommend we look at. They would know better what parameters they want us to know a lot about prior to fabrication.
    - No more PEEK needle (better to use catheter method than to use PEEK needle - would be experimental)
  - Difficulties modeling in a semi-solid substrate
- Syafiqah tried to use cellML and Comsole
  - Very difficult, still trying to learn how to use them
  - If learning curve is too steep, try using a simpler software
  - Which fluid-dynamic simulation software can model semi-solid substrates and are easy to learn?
- Lucas looked into electrode impedance characterization (see Lucas Ratajczyk > Research Notes > Electrode Characterization)
  - Also submitted a ticket to BB Collaborate to hopefully fix his mic issue

Conclusions/action items:

- Research electrode breakdown mathematics (BME 462 chapter 5 may help - uploaded to Google Drive)
- Look for fluid-dynamics simulation software that can be used to model semi-solid substrates
  - Maybe just use research if others have already done this
- Continue research into electrode impedance characterization

4/10/20 Advisor Meeting

LUCAS RATAJCZYK - Apr 10, 2020, 12:34 PM CDT

Title: Advisor Meeting

Date: 4/10/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Update Dr. Nimunkar on our progress for the past week and get advice for what we should do next week.

Content:

- Report feedback is on the way
- Last few weeks of the semester
- Jonah has been having issues finding equations to describe IrOx degradation
  - The Ir-O becomes Ir-OH becomes Ir and water breaks off
  - Increased acidity will speed the degradation
  - May be exponential in nature because of the capacitive nature of electrode behavior
    - How to determine the time constant?
    - May require experimentation - Fitting the data to an exponential curve?
- Hunter has been looking into the delivery mechanisms for the microelectrodes
  - Mostly for neural electrodes
  - Small pads with a parylene sleeve but this will probably not be strong enough to withstand our insertion method
    - Would still need the catheter
    - 2 pads (one Ir-Ox and one AgCl)
    - Could be left in for 48 hours
    - Too difficult for us to manufacture
    - In a final product, we would want this method but we may not be able to actually make a prototype.
  - Another method involved in coating the needle in an insulator but leaving portions exposed to act as electrodes
    - Toxicity concerns and probably can't be left in situ for hours on end
    - Clotting factors or leaching toxic ions
    - Easier for us to manufacture
    - The needle would be as small as can penetrate the skin because the electrodes are on the outside of the needle
- Syafiqah found 2 more designs (in her notebook: Research Notes > Microelectronics > Last Note)
  - No needle - borosilicate capillary (inside is electrolyte - saturated KCl - and AgCl electrode)
    - IrOx and AgCl both inside the capillary (multilumenal?)
    - Add an ion-selective membrane to the end
  - Make own needle of silicon with electrodes embedded in the needle
  - Work with Hunter to propose a single design for short-term or long-term
    - Design matrix?
- Lucas found some more equations to calculate the parameters of the equivalent circuit model
  - No real description of how these equations change with respect to electrode size and other physical params
  - Need more about Pt-Ir electrodes (90-10 alloy)
- Next week meeting will focus more on the report and what we need to include in it.
  - Could have a section for UI design
  - Include electrical characterization?
    - More for electrical stimulation and not recording
    - To find the impedance (time constant, etc.) for design constraints for the other circuit components (mainly amplifier input impedance)
  - Proposed delivery method
  - Drift test, cadaver testing (preliminary only prior to COVID-19 but showed delivery method needs improvement)
  - Plans for animal testing
  - Simulation results

Conclusions/action items:

- Continue research
- Choose a delivery method from those found by Hunter and Syafiqah
- Begin working on the report

- Simulations

4/17/20 Advisor Meeting

LUCAS RATAJCZYK - Apr 17, 2020, 12:34 PM CDT

Title: Advisor Meeting

Date: 4/17/20

Content by: Lucas

Present: Team + Dr. Nimunkar

Goals: Get report feedback and advice for the final presentation.

Content:

- Have category assignments in slide 1
    - i.e. Lucas will be talking about __________ and ___________
- Report Feedback
    - Separate report, presentation, and notebook meeting next week
    - Dr. Nimunkar will look over our poster before presentation
    - Wednesday (4/22)
    - Single column format is preferred
    - Make the drift figure using MATLAB instead of Excel
- Try to flush out the future work section with more details
    - What tests do we plan to conduct?
    - What metrics or statistics will we be evaluating from these tests?
- Team Summary:
    - Jonah
        - Unable to find electrode degradation literature
        - Preparing to wrap up the semester (getting report docs ready, etc.)
        - Start fixing up the paper and assigning paper/presentation categories
    - Lucas
        - Use Ch. 5 to get capacitance from the impedance vs time
            - Figure 5.3, 5.4
        - Make an LT Spice model using these values from the most recent paper
        - Have impedance measurement protocols but all need potentiostat
        - Finally got some definitive numerical values for the equivalent circuit model but based on electrode with 10 mm^2 in contact with solution
        - Found impedance vs frequency graph.
    - Hunter and Sayfiqah
        - 4 delivery designs
        - New design matrix is completed as of earlier this morning (it is in LabArchives)

Conclusions/action items:

See highlighted portions of Content above

2019/12/03- ISFET design with Ag/AgCl reference Electrode

HUNTER HUTH - Dec 10, 2019, 9:30 PM CST

Title: ISFET design with Ag/AgCl reference Electrode

Date: 2019-12-03

Content by: Hunter Huth

Present: Entire Team

Goals: Describe the current fabricated design for the current pH electrode

Content:

The current fabricated design uses a PCB mounted ISFET, shown in the materials section, with an Ag/AgCl reference electrode manufactured from electroplating of Chloride ions on silver wire as described in the "Electrodeposition of Ag/AgCl Electrode section. The Reference electrode is mounted to the rear face of the ISFET, and it is placed inside a stainless steel needle. The assembly used heat shrink for water proofing and the attachment of the reference electrode.

Things to improve on design:

1. Size: Measured ~2mm in width, which is too big for a 16-gauge needle. The heat shrink also increased width past usability for an 11-gauge needle
2. Ag/AgCl reference electrode has to be protected from coming in contact with the stainless steel of the needle, which affects its potential.
3. A thicker coating on the Ag/AgCl must be applied to prevent drift for a 48-hour drift test.
4. Design a better method of insulating the drain/source leads of the ISFET to prevent contact with solutions.

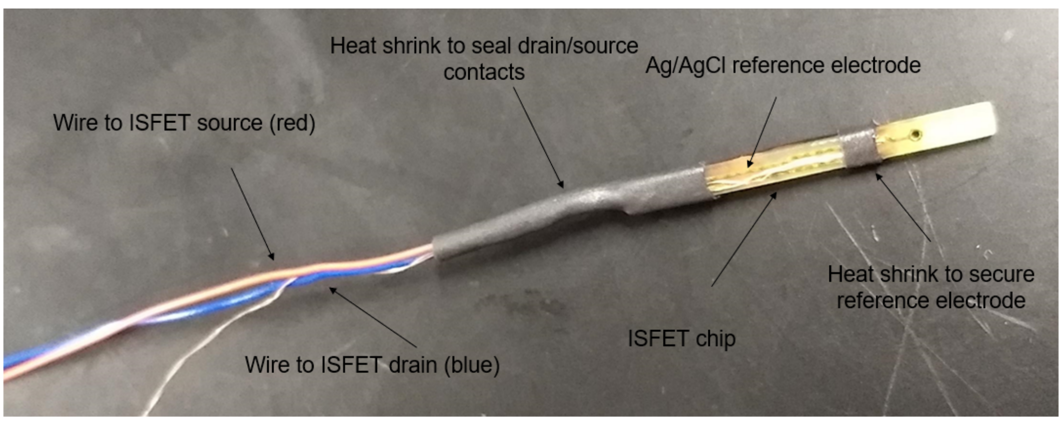


Figure: An Image of the current pH sensing electrode including reference and ISFET. This assembly would be fed inside a stainless steel needle and not visible.

Conclusions/action items:

The next semester must focus on improving this design based on the limitations listed above. Additional testing must be performed including canine testing and a 48-hour drift test.

pH Sensor Design Evaluation

LUCAS RATAJCZYK - Dec 10, 2019, 10:37 PM CST

Title: pH Sensor Design Evaluation

Date: 12/9/19

Content by: Lucas

Present: Team

Goals: To evaluate the preliminary design options for the pH-sensing electrode.

Content:

Designs:

See the Notebook entry for pH sensor design ideas to get more information about these designs.

- ISFET
- Platinum-Iridium Wire
- Iridium-Coated Needle

Criteria (in order of importance):

1. Size
    1. The size of the final design must be able to fir into a 16-gauge needle to be used in humans. The smaller the design can be, the better since this will allow smaller, less-invasive needles to be used, improving patient experience. The maximum size any dimension (in the cross section perpendicular to the needle axis) can be is 1.194 mm, the standard inner diameter of a 16-gauge needle [#]
2. Fabrication Complexity
    1. While fabrication complexity in an ideal world would have no impact on sensor performance, this is not an ideal world. As we are the ones making the sensor, a very difficult-to-fabricate sensor is much more likely to be incorrectly constructed, resulting in worse (if any) function. Thus, the designs with lower fabrication complexity are granted a higher score. Complexity refers to the techniques used in fabrication, especially those requiring special equipment or training.
3. Ease of Use
    1. This criterion evaluates the design's pH sensitivity and ease of integration. The pH sensitivity refers to the sensor's ability to generate a voltage proportional to the pH of the solution. If the sensor can generate a larger voltage for the same change in pH, it has a greater pH sensitivity. The ease of integration refers to our ability to connect the sensor's circuitry to the user interface circuitry.
4. Durability
    1. Some designs are more likely to experience performance issues caused by physical damage to the system. The designs which are more likely to develop these issues (those with circuitry that is more delicately connected/constructed) receive a lower score in this category as this is an undesirable situation for our application.
5. Cost
    1. While cost is always a concern with any design project, it is much less of a factor this semester since the budget is very large compared to the prices of any of these designs. That's why this is the lowest-priority criterion. However, we still care about this and would like the final design to be as inexpensive as possible, all else being equal.

Evaluation:

1. **Size**
    1. ISFET: The width of the ISFET bare die is approximately 1 mm, just barely within the size requirement. Also, this size is very nonnegotiable as the ISFET bare die is purchased commercially and not constructed by us, meaning if the tolerance is insufficient, the bare die may not fit.
    2. Platinum-Iridium Wire: This design requires a small-diameter platinum-iridium wire to be inserted through the needle hole but this wire is much smaller in diameter than even the smallest ISFET bare die. It is also more customizable as the wire is commercially available in a range of small diameters that suit our application.
    3. Iridium-Coated Needle: This design doesn't require anything to be inserted through the needle hole except the reference (which is common to all three designs) and thus, uses the least amount of space.
2. **Fabrication Complexity**

   1. ISFET: The fabrication of this design would require training in and access to a cleanroom which would cost a lot of time and money (and effort) as it requires the micro-scale pads of the ISFET bare die to be soldered to a ribbon cable.
   2. Platinum-Iridium Wire: Fabricating the platinum-iridium wire would not require any additional equipment or training beyond what we have had experience with in various BME and chemistry courses.
   3. Iridium-Coated Needle: The same procedure would be used to coat the needle with iridium as is used to make the platinum-iridium wire, so it was ranked the same.
3. **Ease of Use**
   1. ISFET: The ISFET comes with an analog front-end system that makes this design very easy to integrate into existing UI circuitry.
   2. Platinum-Iridium Wire: This sensor would require noise filtering and signal amplification steps that, while within our skill set - thank you BME 310 and 462, are also more work than is needed for the ISFET design, resulting in a slightly lower ranking.
   3. Iridium-Coated Needle: Once again, the iridium-coated needle is identical to the platinum-iridium wire as it requires the same noise filtering and signal amplification steps. Consequently, it was ranked the same as the platinum-iridium wire.
4. **Durability**
   1. ISFET: The micro-scale connections required in the fabrication of this design would serve as physical weak points for the sensor, meaning this design is more likely to break from application of a physical force.
   2. Platinum-Iridium Wire: (See below)
   3. Iridium-Coated Needle: This design was ranked slightly lower than the similar platinum-iridium wire design because the iridium coating of the needle is also on the needle's exterior. This means that when it is being injected into or removed from the patient, this layer will experience shear forces that would not be felt by the platinum-iridium wire design. However, the fact that the iridium layer is chemically bonded to the needle means that this should not be an issue over the relatively short time spent being inserted/removed. The needle shape is also conducive to reducing shear stresses on the exterior because this improves patient experience, making this concern even less.
5. **Cost**
   1. ISFET: The ISFET bare dies are actually very cheap (around $20 each), granting it the highest score in this category.
   2. Platinum-Iridium Wire: This design is slightly more expensive than the iridium-coated needle since it requires the purchase of a platinum-iridium wire, pushing this design's rank to third behind the iridium-coated needle.
   3. Iridium-Coated Needle: This design doesn't require a platinum-iridium wire and thus, is cheaper than the other iridium-based design.

Summary Table:

Criteria	**ISFET**	**Platinum-Iridium Wire**	**Iridium-Coated Needle**
Size (25)	15	20	**25**
Fabrication Complexity (25)	10	**20**	**20**
Ease of Use (20)	**20**	15	15
Durability (20)	5	**20**	15
Cost (10)	**10**	5	7
Total (100)	60	80	**82**

Conclusions/action items:

While we are out of time to enact this decision this semester, next semester, begin fabrication and testing of the iridium-coated needle design. Also, update the final report to include this evaluation in a paragraph format.

LUCAS RATAJCZYK - Apr 29, 2020, 2:54 PM CDT

Title: pH Sensor Design Evaluation Followup

Date: 4/29/20

Content by: Lucas

Present: Lucas

Goals: Address concerns about this older notebook entry.

Content:

The above entry in this note is actually from the end of the previous semester (Fall 2019) and we have since already made numerous Pt-Ir electrodes as we said would be a good choice (2nd only to the needle) and have been using them all this semester (Spring 2020). The reason we chose to not follow the coated-needle design was because we failed to consider the fact that simply coating the needle, while great for size control, is also very bad for prolonged measurement periods as the rigid needle would provide constant discomfort for the patient. We have since altered the delivery method to involve a catheter system which would use the needle only to insert the electrodes and would then be removed, leaving the tubing with the electrodes behind.

Conclusions/action items:

Pursue this catheter delivery method and continue to try improving the life of the electrodes. They currently only last ~10 hours and could be changed with hospital shifts every 8 hours but it might be better to have one set of electrodes that can last for the full 48 hour period.

2020/04/17 - Design matrix (Delivery method)

JONAH MUDGE - Apr 28, 2020, 8:28 PM CDT

Title: Design matrix for delivery method

Date: 04/17/2020

Content by: Syafiqah

Present: Team

Goals: Design matrix for which delivery method to use

Content:

Criteria	Two-Lumen Catheter w/ micro electrode Array	Electrodes on outside of Catheter	KCl + ion exchange membrane	IrOx electrodeposited on needle
Ease of Calibration (20)	20	20	18	20
Fluid contact (30)	25	30	25	30
Fabrication complexity (10)	3	8	3	5
Ease of insertion (20)	18	20	18	20
Biocompatibility (20)	20	17	20	18
Total (100)	**86**	**95**	**84**	**93**

Figure 1: Design matrix for delivery method

Conclusions/action items:

We decide to choose the design with the electrodes at the outside of the catheter. This is because it offers excellent permeability to fluid while maintaining good ease of insertion, ease of calibration, and minimal fabrication complexity. It scored lowest in biocompatibility due to its use of adhesive to stabilize the electrodes, but this could be remedied by using bioinert adhesive/epoxy.

2019/12/10-Material Expenses summary

HUNTER HUTH - Dec 10, 2019, 2:30 AM CST

Title: Material expenses summary

Date: 2019/12/10

Content by: Hunter Huth

Present: Entire Team

Goals: Discuss the expenses for the semester

Content:

Table: List of cost and quantities of the materials ordered. N/A denotes that a material was not ordered but was already possessed. The total cost was $769.85.

Purpose	Item	Quantity	Cost	Source
ISFET operation	ISFET complete Kit	1	$90.00	Winsense
	PCB mounted Bare die	1	$41.00	Winsense
	Bare die chip	1	$21.00	Winsense
Electrodeposition of IrOx on Pt-Ir wire	127 micron Pt-Ir wire	10 ft	$194.00	A-M Systems
	Iridium Tetrachloride	1g	$103.00	AmBeed
	30% Hydrogen Peroxide	1 L	$27.00	Lab Alley
	Oxalic Acid Dihydrate	100g	$26.50	Sigma-Aldrich
Electrodeposition of AgCl on Ag wire	127 micron Ag wire	10 ft	$48.00	A-M Systems
	Ethanol	N/A	N/A	N/A
	680 Ω resistor	N/A	N/A	N/A
	KCl	N/A	N/A	N/A
Testing of reference electrodes	Dri-Ref 450 Micron Ag/AgCl	1	$206.00	World Precision Instruments (WPI)

	reference electrode			
Fabrication of user interface	LCD Screen	1	$16.95	Sparkfun
	Toggle Switch	1	$1.50	Sparkfun
	Record Button	1	$3.95	Sparkfun
	Arduino Nano	1	$14.95	Sparkfun

Conclusions/action items:

N/A

2020/4/28-Material Expenses summary

HUNTER HUTH - Apr 28, 2020, 8:41 PM CDT

Title: Material expenses summary

Date: 2020/4/28

Content by: Hunter Huth

Present: Entire Team

Goals: Discuss the expenses for the year.

Content:

Table: List of cost and quantities of the materials ordered. N/A denotes that a material was not ordered but was already possessed. The total cost was $941.85.

Purpose	Item	Quantity	Cost	Source
ISFET operation	ISFET complete Kit	1	$90.00	Winsense
	PCB mounted Bare die	1	$41.00	Winsense
	Bare die chip	1	$21.00	Winsense
Electrodepositi on of IrOx on Pt-Ir wire	127 micron Pt-Ir wire	10 ft	$194.00	A-M Systems
	Iridium Tetrachloride	1g	$103.00	AmBeed
	30% Hydrogen Peroxide	1 L	$27.00	Lab Alley
	Oxalic Acid Dihydrate	100g	$26.50	Sigma-Aldrich
	Anhydrous potassium carbonated	500g	$172.00	Fischer Scientific
Electrodepositi on of AgCl on Ag wire	127 micron Ag wire	10 ft	$48.00	A-M Systems
	Ethanol	N/A	N/A	N/A
	680 Ω resistor	N/A	N/A	N/A
	KCl	N/A	N/A	N/A
Testing of	Dri-Ref 450	1	$206.00	World Precision

reference electrodes	Micron Ag/AgCl reference electrode			Instruments (WPI)
Fabrication of user interface	LCD Screen	1	$16.95	Sparkfun
	Toggle Switch	1	$1.50	Sparkfun
	Record Button	1	$3.95	Sparkfun
	Arduino Nano	1	$14.95	Sparkfun

Conclusions/action items:

Not many materials were purchased due to not needing to manufacture more electrodes after COVID-19 cancelled animal testing.

Electrodeposition of Ag/AgCl electrode

JONAH MUDGE - Apr 27, 2020, 10:02 PM CDT

Title: Electrodeposition of Ag/AgCl electrode

Date: 12/2/2019

Content by: Syafiqah

Present: Jonah, Hunter. Syafiqah

Goals: Fabricating Ag/AgCl electrode

Content:

1. Thin and thick Ag wire are prepared and rinsed with ethanol to remove finger oils.

2. 22.3g of KCl and 100ml of water (3M of KCl) of are added into a beaker.

3. The thicker wire is connected to the negative terminal (cathode) with a 680Ω and thinner wire to the positive terminal (anode). 1.5V is passed through the circuit for few minutes until the thin wire changed to black-purple color.

Electrodeposition equation: Ag + C- = AgCl + e-

4. The thin Ag wire is wiped and stored.

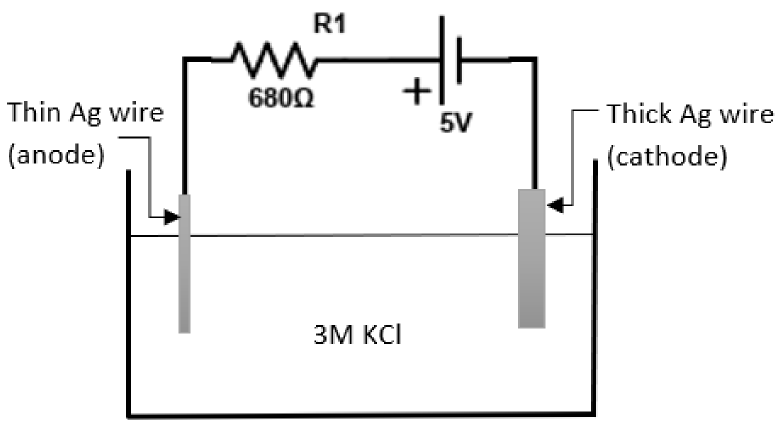


Figure 1: The circuit setup of the electrodeposition of Ag/AgCl reference electrode. The thin and thick wire is connected to the positive and negative terminal, respectively. 680Ω resistor is used to limit the current.

Figure 2: The setup of the electrodeposition of Ag/AgCl electrode

Figure 3: The fabricated Ag/AgCl electrode

Conclusions/action items:

Need to test the electrode as a reference.

Final Design - ISFET and Reference electrode

NUR SAIDIN - Dec 10, 2019, 9:22 PM CST

Title: Final design: ISFET and reference electrode

Date: 12/04/2019

Content by: Syafiqah Saidin

Present: Jonah, Hunter

Goals: Explain the final design

Content:

Two wires were soldered to the circuit board with the ISFET chip. Red wire as the source and blue wire as the drain. The electrodeposited Ag/AgCl reference electrode was attached to the ISFET with a heat shrink. It is used to cover and protect the soldered part and also to secure the reference electrode in place. The diagram of the final prototype is shown below.

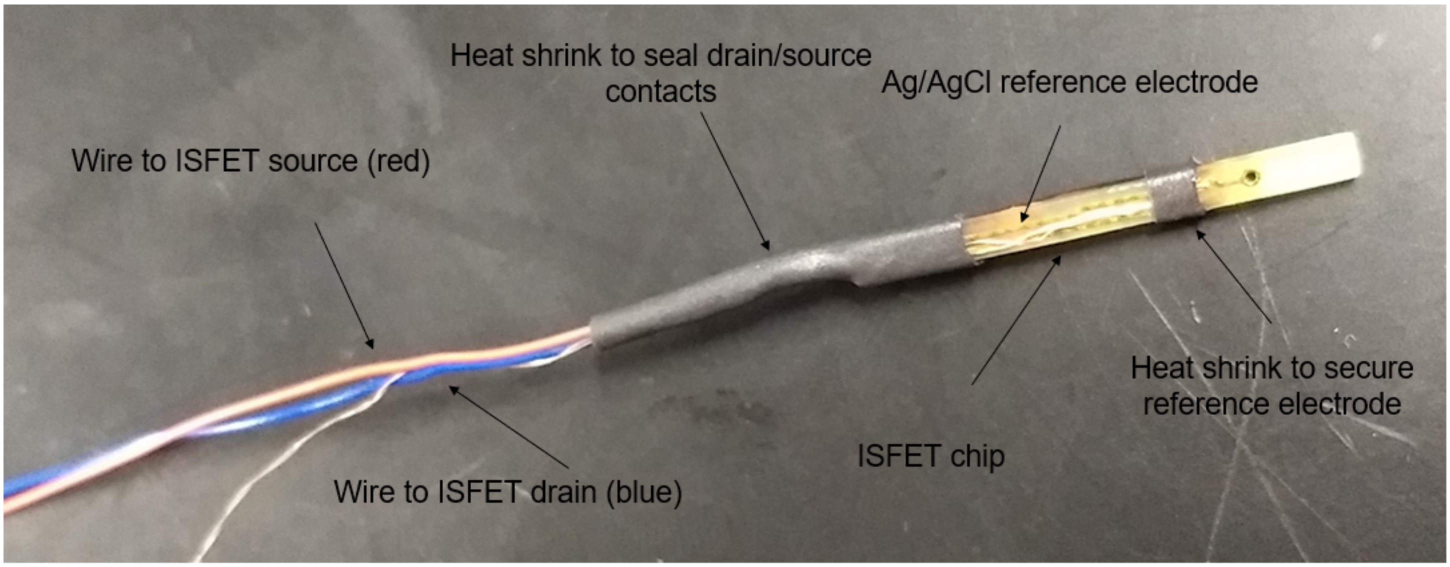


Figure 1: The final prototype which consists of the ISFET and the electrodeposited reference electrode secured with heat shrink.

Conclusions/action items:

Test the final prototype.

2020/01/27 - Electrodepositing solution

NUR SAIDIN - Feb 26, 2020, 8:56 AM CST

Title: Preparation of Electrodepositing Solution

Date: 02/26/2020

Content by: Syafiqah

Present: Hunter

Goals: Prepare the electrodeposition solution to fabricate IrOx solution

Content:

The fabrication protocol that we followed is as follows [1]:

1. Dissolve 75mg iridium tetrachloride in 50mL water
2. Stir 30 min
3. Add 0.5mL 30% hydrogen peroxide (aq) and stir 10 min
4. Add 250mg oxalic acid dihydrate and stir 10 min
5. Adjust pH slowly to 10.5 by adding small portions of anhydrous potassium carbonate
6. Leave at room temperature for 2 days to stabilize

The solution turns from greenish-yellow to blue-black after 48 hours.

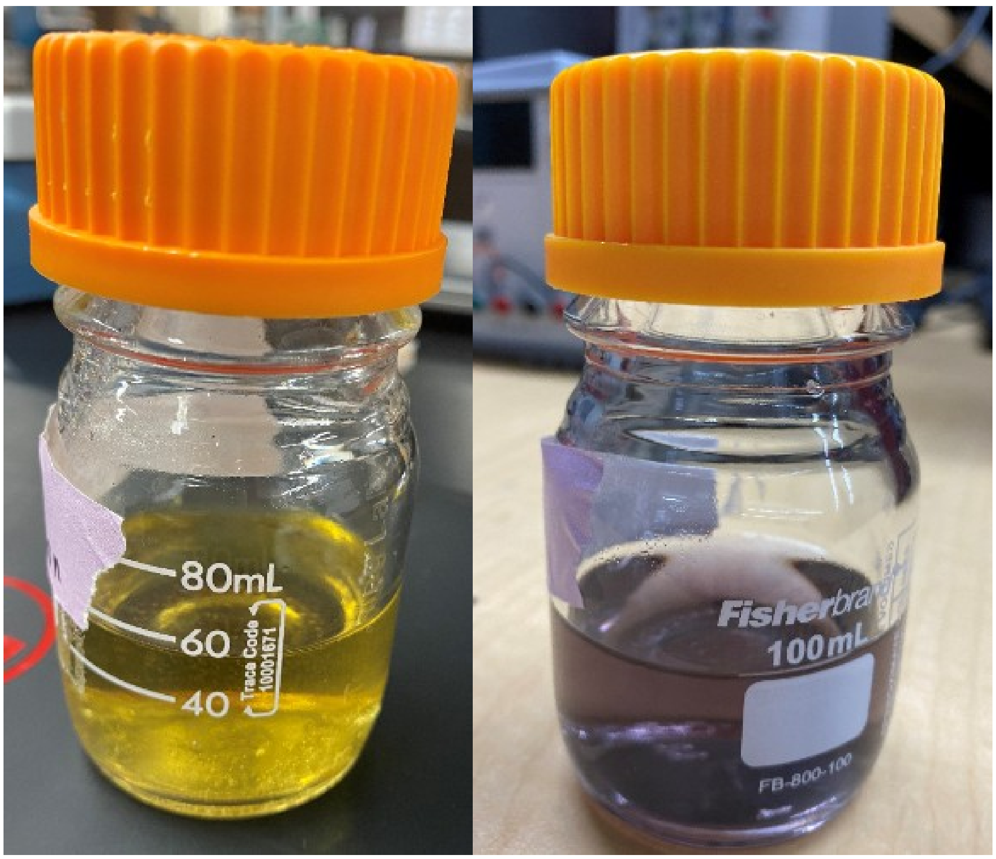


Figure 1: The electrodeposition solution before(left) and after (right) left for two days.

Reference:

[1] S. A. M. Marzouk, S. Ufer, R. P. Buck, T. A. Johnson, L. A. Dunlap, and W. E. Cascio, "Electrodeposited Iridium Oxide pH Electrode for Measurement of Extracellular Myocardial Acidosis during Acute Ischemia," *Anal. Chem.*, vol. 70, no. 23, pp. 5054–5061, Dec. 1998, doi: 10.1021/ac980608e.

Conclusions/action items:

Can proceed with electrdeposition of IrOx with Pt/Ir wire.

2020/02/02 - IrOx Deposition 1

HUNTER HUTH - Feb 02, 2020, 4:20 PM CST

Title: IrOx Deposition

Date: 2020/2/2

Content by: Hunter

Present: Myself and Syfiqah

Goals: Describe the fist try for IrOx depostion

Content:

The oscilloscope was not working properly as a potentiostat, so an adapted procedure was used that more closely matched the Ag/AgCl deposition. A two electrode configuration was used with the working electrode being held at a constant 1.5 V in series with a 470 ohm resistor. This was done for approximately 5 minutes until the working electrode turned into a dark black color. A KEYSIGHT E3631A triple output power supply was used to create the potential between the two electrodes in the IrOx solution.

Conclusions/action items:

We must construct a potentiostat out of an arduino micro controller in order to use the previously outlined procedure. The fabricated electrode must be tested to determine if the alternate procedure was effective.

2020/02/11 - IrOx Deposition 2

JONAH MUDGE - Apr 28, 2020, 8:31 PM CDT

Title: Electrodeposition of IrOx Electrode

Date: 02/11/2020

Content by: Syafiqah

Present: Hunter, Jonah, Lucas, Syafiqah

Goals: Fabricate the IrOx electrode by electrodeposition

Content:

The steps for the electrodeposition of IrOx electrode are as follows [1]:

1. Set up Pt-Ir working electrode with Pt-Ir counter electrode and Ag/AgCl reference electrode in electrodeposition solution
2. Acquire wave generator and oscilloscope
3. Vary triangular waveform from 0 to 0.55V at 50mV/s for 50 cycles
    a. This is to improve EIROF adhesion to substrate
4. Pulse 0 to 0.55V square wave at 0.5s intervals for up to 1600 cycles using Metrohm Autolab potentiostat

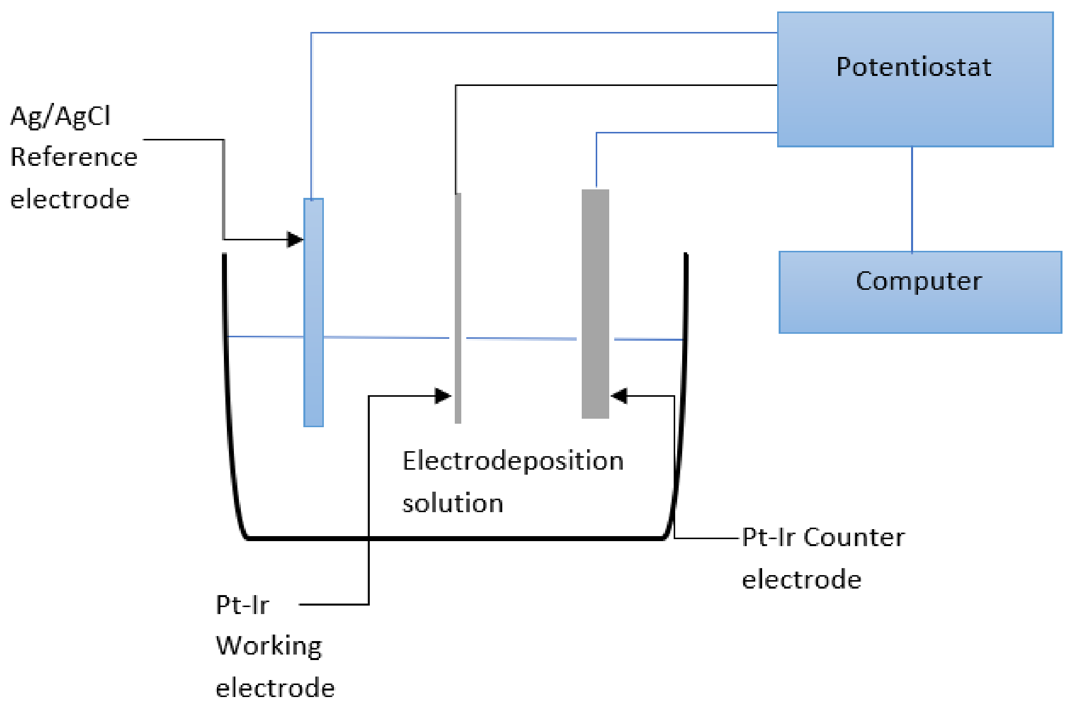


Figure 1: Three-electrodes cell setup of IrOx electrodeposition .

Reference:

[1] R. D. Meyer, S. F. Cogan, T. H. Nguyen, and R. D. Rauh, "Electrodeposited iridium oxide for neural stimulation and recording electrodes," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 9, no. 1, pp. 2–11, Mar. 2001, doi: 10.1109/7333.918271.

Conclusions/action items:

Need to test the electrode for 48 hours

Drift Testing Protocol

JONAH MUDGE - Dec 09, 2019, 10:39 PM CST

Title: Drift Testing Protocol

Date: 12/3/19

Content by: Syafiqah Saidin

Present: Team

Goals: Determine drift testing protocol

Content:

ISFET sensor drift test

The goal of this test to determine which reference electrode provide stable and accurate reading of voltage/pH when immersed in pH 7 buffer solution for 1 hour. The Ag/AgCl reference electrodes used include the ones obtained from Winsense kit, the 450µm-diameter, and the electrodeposited electrode. Each reference electrode is first cleaned with deionized water and calibrated as described in the *Final Prototype* section. The reference electrode was then left in the pH 7 buffer solution and recorded the voltage reading using the multimeter for every 10 minutes (1 hour duration). Based on the voltage measured, the drift from the neutral pH reading was observed.

Conclusions/action items:

Use these data to determine best reference electrode option moving forward with the project

Drift Testing Protocol Updated

JONAH MUDGE - Apr 29, 2020, 11:13 AM CDT

Title: Drift Testing Protocol

Date: 2/10/20

Content by: Jonah Mudge

Present: Team

Goals: Determine drift testing protocol

Content:

Drift test to determine the operating time of IrOx and Ag/AgCl electrodes

We took voltage measurements from the IrOx + Ag/AgCl electrode pair at pH = 4, and from the ISFET + Ag/AgCl pair at pH = 4. Because the ISFET shouldn't degrade, it provides a benchmark for the longevity of the Ag/AgCl electrode alone.We can then determine which electrode, IrOx or Ag/AgCl, is the limiting factor in the device's operational time. We took voltage measurements at 5 minute intervals over the course of 48 hours.

Conclusions/action items:

Use these data to determine whether the electrodes are up to Dr. Doro's specifications.

Calibration of the ISFET and the reference

NUR SAIDIN - Dec 11, 2019, 3:00 PM CST

Title: Calibration of the ISFET and the reference electrode

Date: 12/11/2019

Content by: Syafiqah

Present: Team

Goals: Explain the calibration process of the reference electrode.

Content:

Before we begin the drift test for each combination of the ISFET sensor with three differenct Ag/AgCl reference electrodes, the sensor needs to be calibrated first. The reference electrodes include the one from Winsense kit, the 450micron from World Precision Instrument, and the electrdeposited Ag/AgCl. Both the ISFET and the reference need to be cleaned with deionized water and wiped gently. The sensor is the put into the buffer solution with pH of 4,7, and 10. The voltage reading from each solution is recorded. Note that the sensor is cleaned before and after it is put inside the solution to ensure that the there is no residue from the other solution, which may provide wrong values. From the voltage values recorded, the voltage vs. pH graph is plotted and a linear regression line is obtained. From the linear regression equation we can get the pH equation. The graphs for each combination of ISFET and the reference electrodes are as follows:

pH	Voltage
4	1.229
7	1.387
10	1.538

pH = (voltage - 1.0242) / 0.515

Winsense electrode 1 hr drift test (pH = 7)

Time (min)	Voltage	Variance:
0	1.383	0.000004
10	1.38	
20	1.378	
30	1.378	
40	1.382	
50	1.382	
60	1.382	

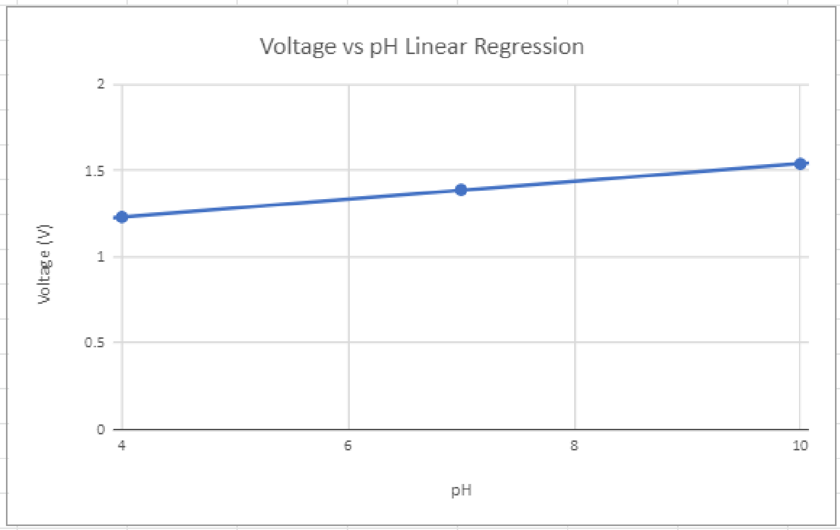


Figure 1: The linear regression plot for the ISFET and the Winsense reference electrode.

pH	Voltage			Input	Output
4	0.943				
7	1.081	No rinsing between measurements to avoid additional loss of AgCl	pH -> Voltagе	10	1.234
10	1.237		Voltage -> pH	1.238	10.0816326

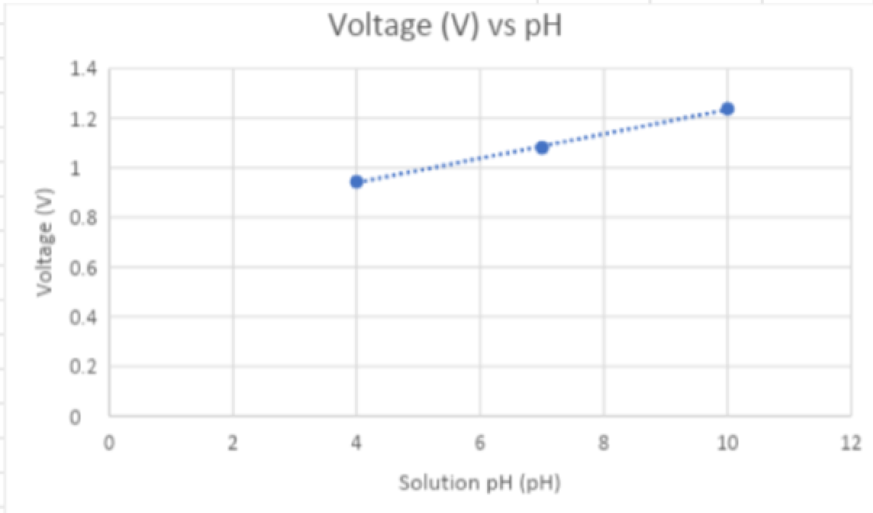


Figure 2: The linear regression plot for the ISFET and the 450micron reference electrode.

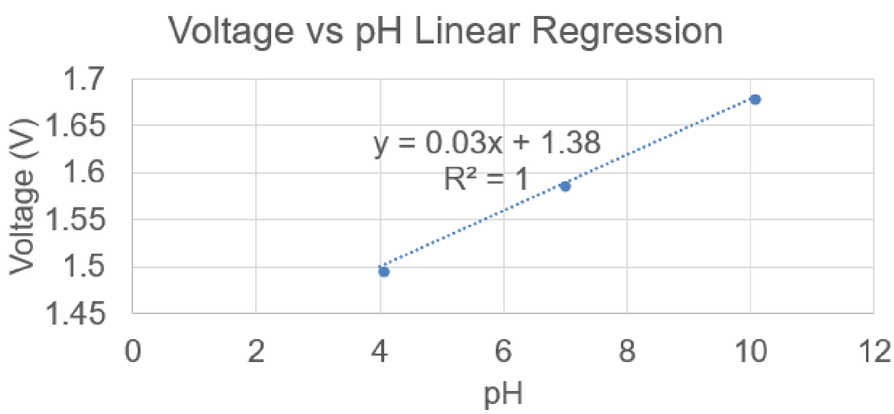


Figure 3: The linear regression plot for the ISFET and the eletcrodeposited Ag/AgCl reference electrode

Conclusions/action items:

The voltage increase with increasing pH. More acidic, less voltage

Drift Testing Data

JONAH MUDGE - Apr 28, 2020, 8:43 PM CDT

Title: Drift Testing Data

Date: 12/9/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: show and analyze data

Content:

See attached excel file. From the standard deviations reported, it is clear that the winsense kit electrode and electrodeposited electrode have the lowest standard deviation, so are the most stable when reading pH for a 1 hour time period.

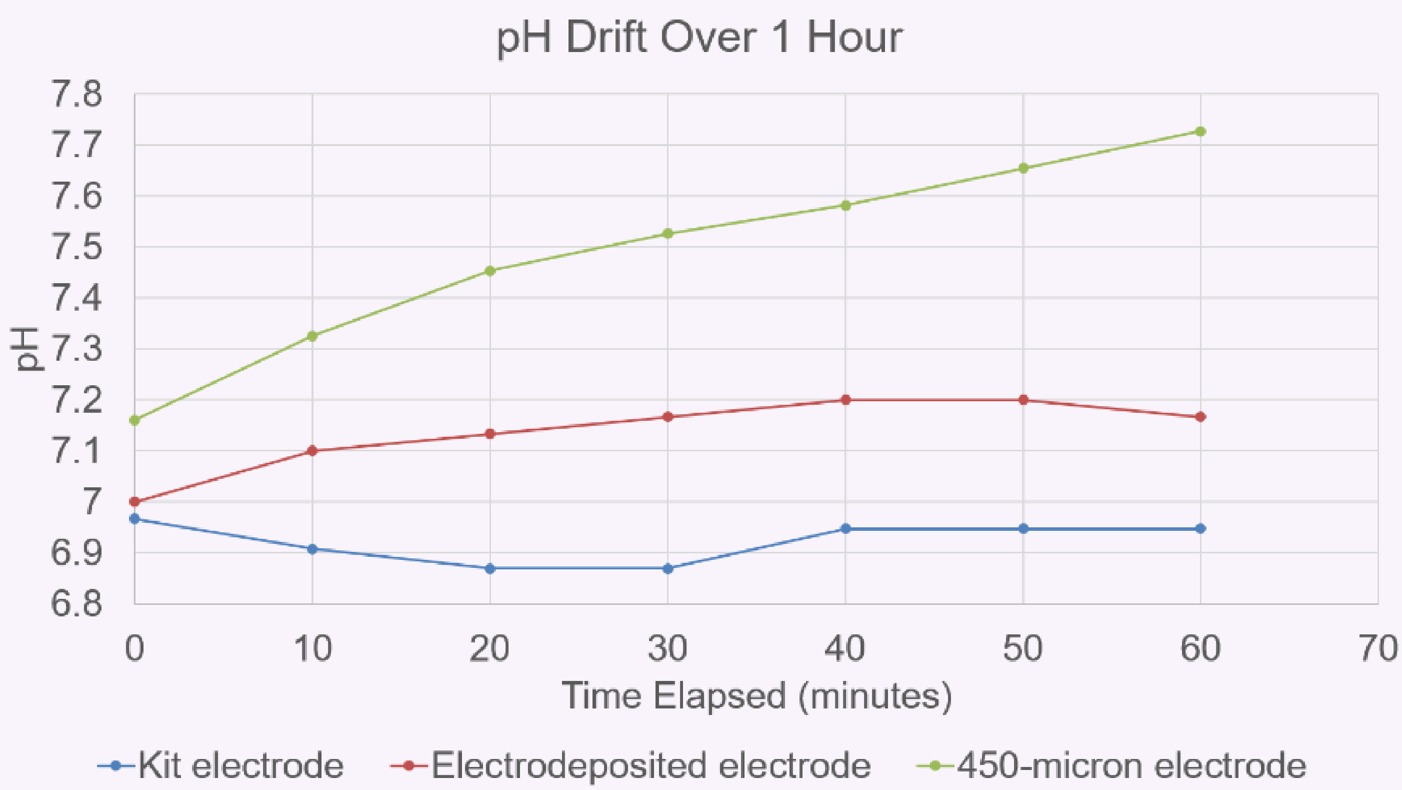
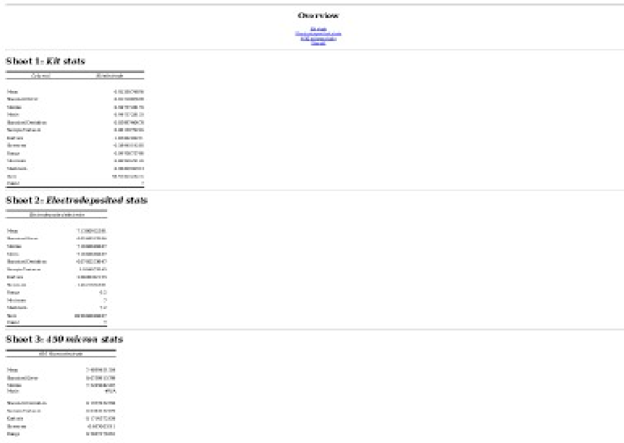


Figure 1: The comparison of three different Ag/AgCl reference electrode over one hour of pH recording. The readings were taken every 10 minutes.

Conclusions/action items:

Use these data to determine best reference electrode option moving forward with the project; it is clear from the standard deviations that the electrodeposited reference electrode provides the greatest stability, with the kit electrode coming second. The 450-micron electrode, however, should not be used.

JONAH MUDGE - Dec 09, 2019, 10:40 PM CST



Drift_Data.xlsx(19.5 KB) - download

450 micron data

JONAH MUDGE - Apr 28, 2020, 8:44 PM CDT

Title: 450 micron data

Date: 12/9/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: show and analyze data

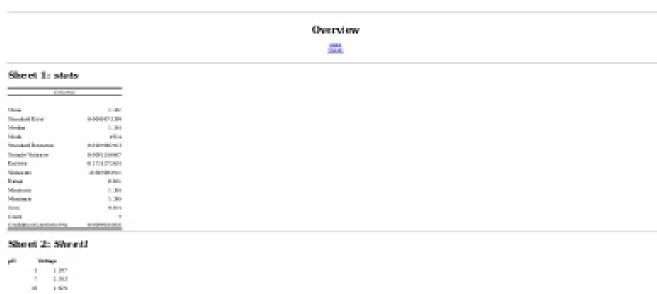
Content:

See attached excel file. Includes linear regression used to calibrate 450 micron Ag/AgCl reference electrode

Conclusions/action items:

Use these data to help determine best reference electrode option moving forward with the project. The linear regression shows that the 450 micron electrode (does not have a very high R value) is not a good candidate for reference electrode use.

JONAH MUDGE - Dec 11, 2019, 8:58 AM CST



AgAgCl_450_micron_ref_electrode_drift_testing_12-3.xlsx(23.4 KB) - download

electrodeposited electrode data

JONAH MUDGE - Apr 28, 2020, 8:45 PM CDT

Title: Electrodeposited electrode data

Date: 12/9/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: show and analyze data

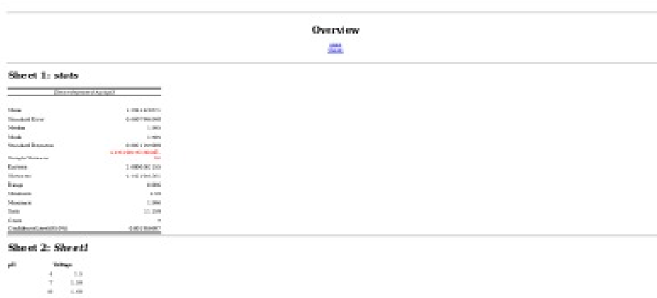
Content:

See attached excel file. Includes linear regression used to calibrate electrodeposited reference electrode

Conclusions/action items:

Use these data to help determine best reference electrode option moving forward with the project. Used with drift testing data to demonstrate that the electrodeposited reference electrode possesses the best characteristics to be used in future testing.

JONAH MUDGE - Dec 11, 2019, 8:59 AM CST


Overview

Sheet 1: stats

Sheet 2: Sheet1

AgAgCl_electrodeposited_ref_electrode_drift_testing_12-3.xlsx(23.4 KB) - download

kit electrode data

JONAH MUDGE - Apr 28, 2020, 8:46 PM CDT

Title: Kit electrode data

Date: 12/9/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: show and analyze data

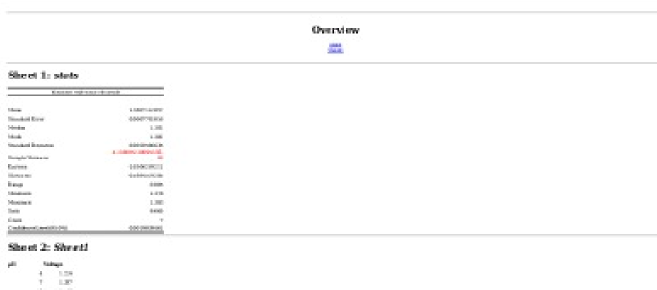
Content:

See attached excel file. Includes linear regression used to calibrate the Winsense kit reference electrode

Conclusions/action items:

Use these data to help determine best reference electrode option moving forward with the project. Use in conjunction with drift testing to demonstrate the optimal reference electrode to be used in future testing/design

JONAH MUDGE - Dec 11, 2019, 9:01 AM CST



Overview

Sheet 1: stats

[illegible]

Sheet 2: Sheet1

pH	Voltage
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

Winsense_ref_electrode_drift_testing_12-3.xlsx(23.5 KB) - download

Cadaver Testing

NUR SAIDIN - Mar 13, 2020, 11:01 AM CDT

Title: Cadaver Testing

Date: 03/11/2020

Content by: Syafiqah

Present: Jonah and me

Goals: Compare our electrodes and commercial one in detecting pH in semi-solid substrate

Content:

1. We first palpate the limb of the cadaver and find the appropriate spot to puncture. Then, we puncture the 11-gauge needle into the muscle compartment.

Figure 1: An 11-gauge needle punctured into the cadaver's limb

2. We insert the double lumen tube with the IrOx electrode and Ag/AgCl reference into the needle. Both electrodes have been calibrated before used.

The calibration equation obtained is y = -0.0192x + 0.3658, with R^2 = 0.9292

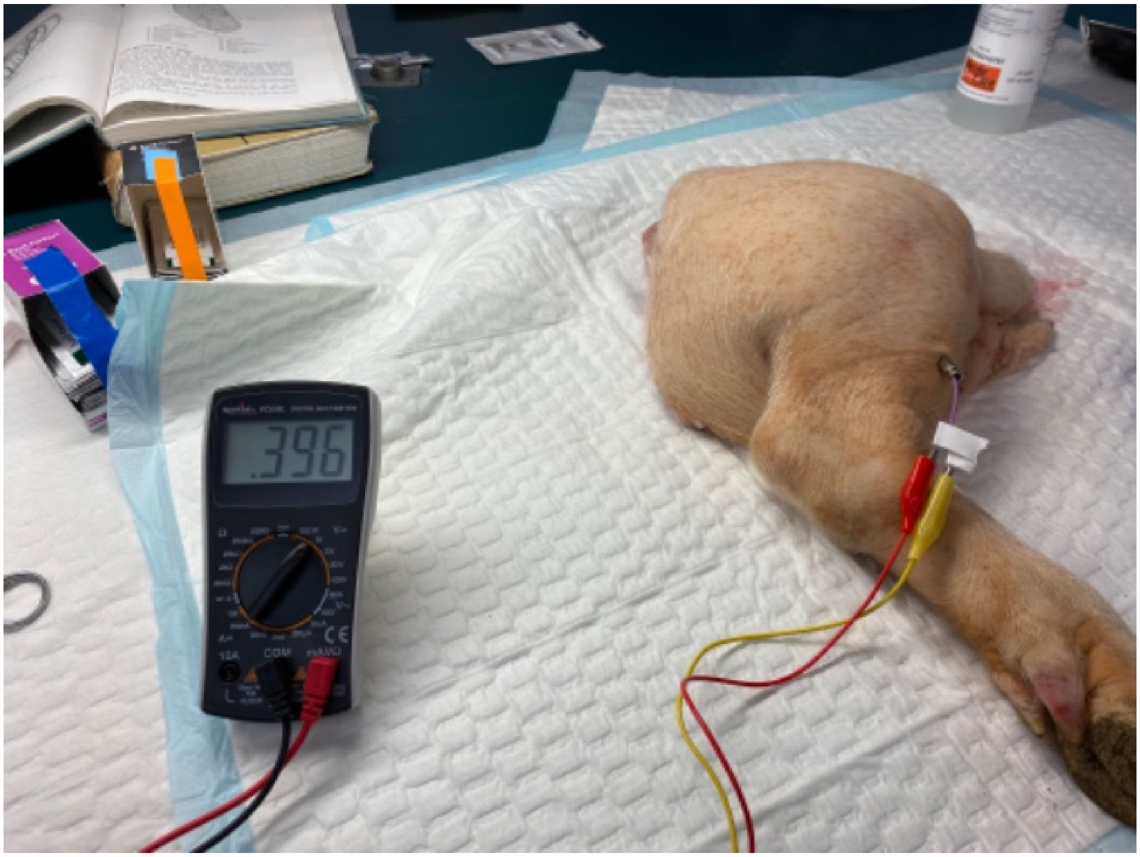


Figure 2: Double lumen tube with IrOx electrode and Ag/AgCl electrode inserted into the needle.

The reading shows 0.396V which is around pH 2.

3. We then used the commercial pH electrode from Sentron. We made an incision so that we can insert the probe.

Figure 3: Measure the pH of the compartment using Sentron’s probe.

The Sentron’s probe measured pH of 5.66. The pH obtained from the IrOx electrode is far off from the commercial probe. We hypothesized that the stainless steel needle might have thrown off our reading somehow. This has happened before when we used the ISFET probe.

4. We then tested the electrodes without the needle and obtained the result below.

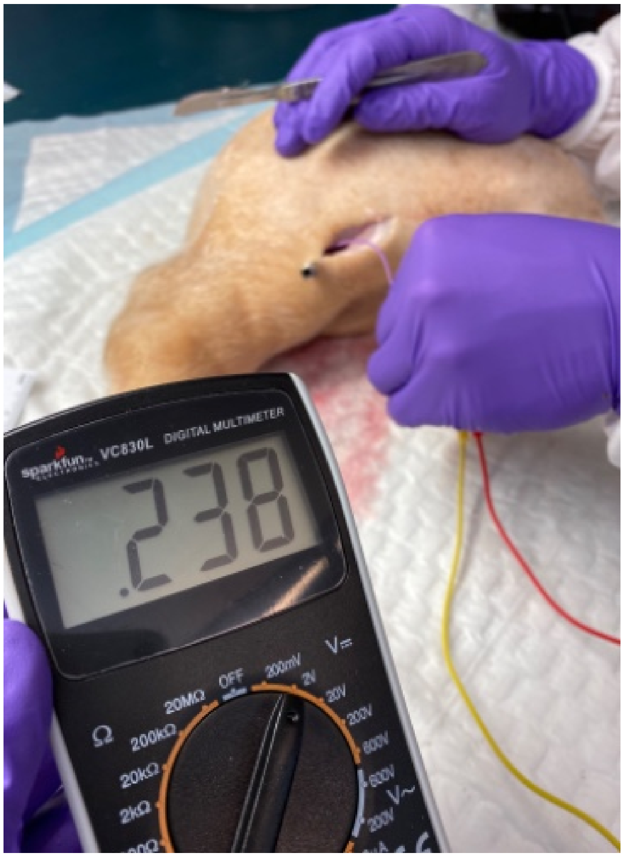


Figure 4: Double-lumen tube with IrOx electrode and Ag/AgCl reference inserted into the cadaver’s muscle

The reading shows the voltage of 0.238V which around pH 6. The reading is slight off from the commercial one’s but closer to the right value.

We observed that the electrodes were flaking a bit at the end of the electrode. This might be due to the friction when we inserted the electrodes into the needle. The electrodes also have been exposed to radiation, before the testing, that might have caused our reading to be off.

Conclusions/action items:

Need to improve our the assembly of our probe. Maybe add more layers of IrOx to avoid flaking. Must make better electrodes before test in live animals.

IrOx vs Ag/AgCl Drift Testing Data

JONAH MUDGE - Apr 29, 2020, 11:19 AM CDT

Title: Drift Testing Data IrOx vs Ag/AgCl

Date: 3/10/20

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: show and analyze data

Content:

See attached excel file. From the standard deviations reported, it is clear that the IrOx electrode is more accurate (remains closer to the actual pH value) compared to the Ag/AgCl + ISFET combination. However, the Ag/AgCl reference has a longer operating time. In this regard, the IrOx electrode is the limiting factor. See attached data.

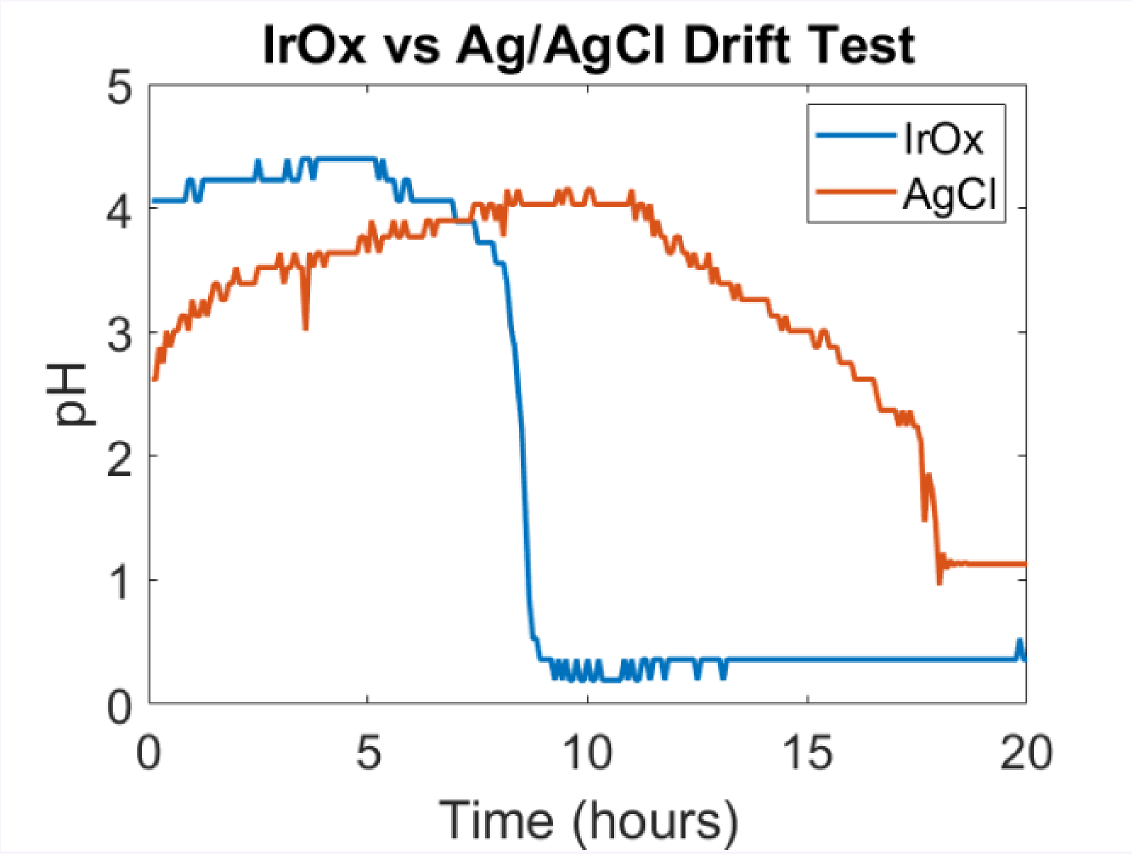
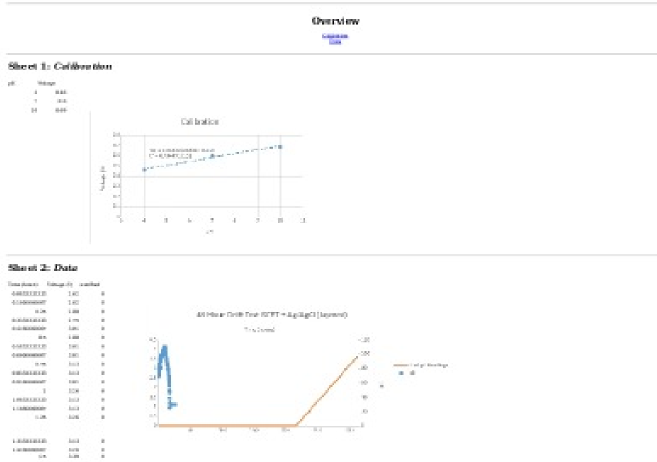


Figure 1: The comparison of IrOx + Ag/AgCl and ISFET + Ag/AgCl over hours with readings taken every 5 minutes.

Conclusions/action items:

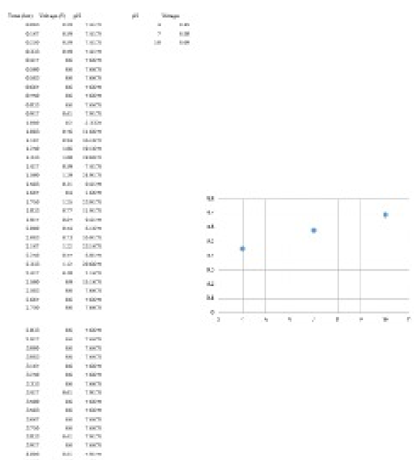
We have some work to do before the electrodeposited electrodes are up to specs. Need to research new electrodeposition methods to determine where improvements can be made.

JONAH MUDGE - Apr 29, 2020, 11:20 AM CDT



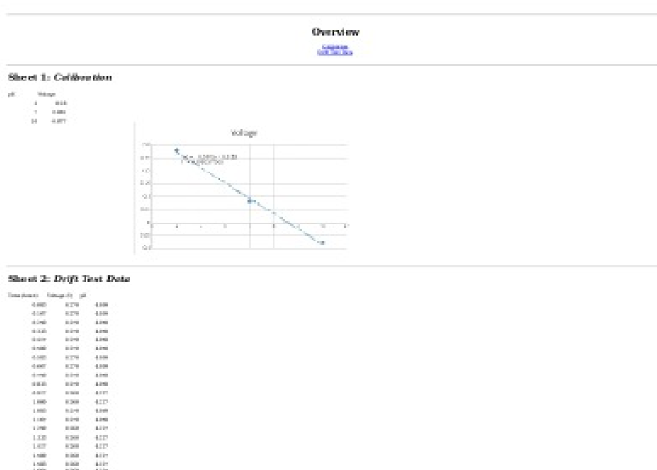
3-3-20_Drift_Data.xlsx(33.9 KB) - download

JONAH MUDGE - Apr 29, 2020, 11:21 AM CDT



48-hr_Drift_Test_2-19-20.xlsx(21 KB) - download

JONAH MUDGE - Apr 29, 2020, 11:21 AM CDT



Drift_Test_02-26-20_Data.xlsx(47.9 KB) - download

PDS

JONAH MUDGE - Apr 28, 2020, 8:50 PM CDT

Title: PDS

Date: 10/8/19

Content by: Team

Present: Team

Goals: Determine constrains for design and record them

Content:

pH Probes to Diagnose Compartment Syndrome

Date: 26 September 2019

Team Members: Jonah Mudge, Lucas Ratajczyk, Hunter Huth, Nur Saidin

Advisor: Dr. Amit Nimunkar

Client: Dr. Christopher Doro

Function:

The pH probe interface must reliably display the pH level read by an ISFET sensor, and record it on a screen that is easily usable by a surgeon. It must be capable of recording pH data for a clinically relevant time period, while ensuring that no data or timestamps are lost. The device must also feature buttons (on a touch screen or otherwise) that are simple and reliable for a surgeon to interact with quickly, especially in high-stress situations in an OR. Along with probe interface is the ISFET probe casing, which must be able to fit into a 16 gauge needle while allowing accurate pH readings.

Problem Statement:

Compartment syndrome is a difficult-to-diagnose condition that occurs when tissue pressure in a muscle compartment rises enough to cause ischemia and possible muscle death. False-positive diagnosis of compartment syndrome can lead to expensive, invasive surgeries, and unnecessary surgeries. Our goal is to design and test a device for clinical use capable interfacing with an ISFET probe and measuring the pH within a muscle compartment, and using the pH as a reliable indicator of whether compartment syndrome is actually occurring.

Client requirements:

- Create a device capable of measuring intramuscular pH *in vivo*
- The device must be able to record at least 48 hours of pH measurements
- The device should be minimally invasive

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements:

- The probe should accurately measure the pH that relates to compartment syndrome that is within the range of 5 to 7.
- The probe must continuously record the pH inside the compartment up to 48 hours.

b. Safety:

- The electronics should not cause electrical shock to the user or patient.
- The device should not cause any infection to the muscle compartment.
- The device should not dissociate or fragment during compartmental insertion.
- The device must not release toxic materials into the patient.
- The device must be sanitizable to prevent transfer of infectious material.

c. Accuracy and Reliability:

- The device must be able to acquire the signal from the ISFET probe without noise
- pH read from the probe must be accurate within a range of 5 - 7
- Accuracy must be within 0.1 to ensure accurate readings and diagnosis

d. Life in Service:

- The probe must maintain its structure and function over many daily uses.
- The probe is disposable for a single use but the electronics of the pH sensor should last at least 5 years.
- The electronic systems must be resilient for repeated use without breakdown.

e. Operating Environment:

- The probe must survive insertion into a muscle compartment without shattering
- The probe casing must not degrade or otherwise allow any leakage into the muscle compartment during insertion and monitoring
- The main analyzer/probe interface must be able to survive falls in the case of an accidental drop
- The main analyzer/probe interface must be able to weather small spills of bodily fluids or chemicals that might occur during an OR situation

f. Ergonomics:

- The handheld probe interface should be shaped in a form that is easy to hold and does not pose any risks of injury from dropping

g. Size:

- The probe must fit through the hole of a 16 gauge needle
- The handheld portion of the device must not exceed a prism of the size 8”x8”x3”

h. Weight:

- The probe must not exceed 2 ounces in weight
- The handheld portion of the device must not weigh more than 16 ounces

i. Materials:

- Semiconductor for the probe
- Metal for the wiring to and within the handheld device
- Hard plastic for the housing of the handheld portion of the device

j. Aesthetics, Appearance, and Finish:

- Skin safe coating and material for use inside the body (muscle compartment)
- The device should be intuitive and simple to understand and operate
- The coating of the handheld portion of the device should have a rough texture to allow for better grip in time-sensitive situations

2. Production Characteristics

a. Quantity: 1 (prototype)

b. The budget is dependent upon grants received by the client with minimum immediately available funds exceeding $1,000

3. Miscellaneous

a. Standards and Specifications:

- The size of the needle is limited to a 16-Gauge needle to align with standards for use in trauma patients.

b. Customer:

- Customers (practicing trauma doctors) would desire a pH sensor that is placed inside a 16-gauge needle, which can read the real-time pH inside the muscle compartment of a patient who is at risk for compartment syndrome.

c. Patient-related concerns:

- The device must have a detachable and replaceable needle/sensor. The display and electronics casing should be sterilizable with an alcohol.

- Material of the device doesn’t cause an inflammatory response, which could further increase pressure in the limb.

d. Competition:

- The Valkyrie by Odin Technologies uses Near-infrared spectroscopy to estimate the blood oxygenation. This device has a benefit of being completely non-invasive, but this technology has been around for decades without success in accurately diagnosing compartment syndrome.
- Patent (US7381186B2) by NASA is a system which uses the reflections of ultrasonic waves emitted into the compartment to estimate compartmental pressure.

e. FDA classification:

*Based on a s*imilar device which involves intramuscular electrical stimulation using a needle, we believe that the device be classified as a Class II device *(see reference)*

Conclusions/action items:

Finalize constraints with Dr. Doro

References:

FDA, "Intramuscular dry-needling stimulator product classification," FDA, [Online]. Available: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpcd/classification.cfm?id=2730. [Accessed 29 April 2020].

Amplification and Filtration Ciruit

LUCAS RATAJCZYK - Apr 29, 2020, 2:45 PM CDT

Title: Amplification and Filtration Circuit

Date: 4/29/20

Content by: Lucas

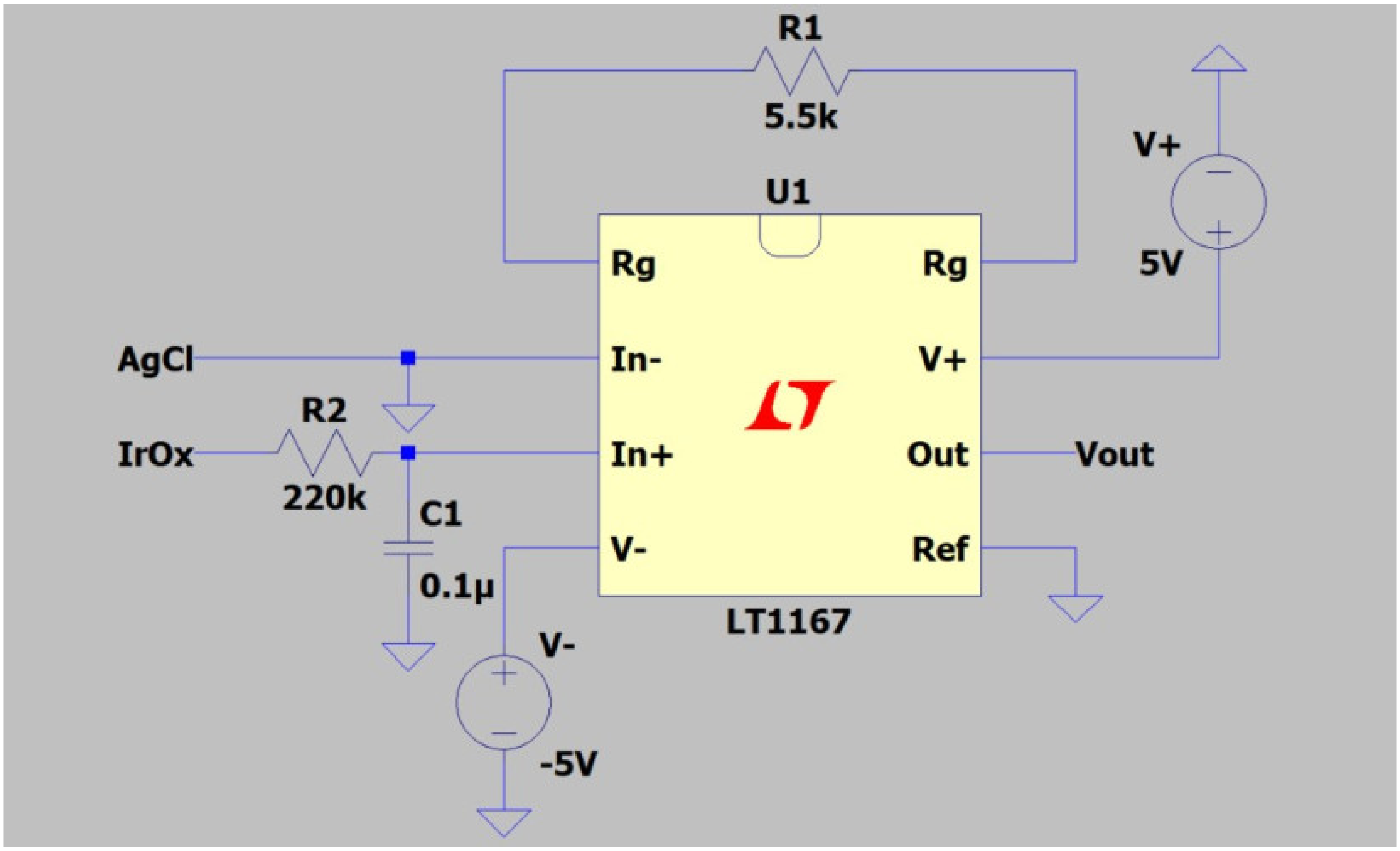
Present: Lucas

Goals: Compile the details of the amplification and filtration circuit we assembled to use with our IrOx electrodes.

Content:

Based on our tests using the IrOx-AgCl electrode pair without an amplifier, we determined that the voltage generated by the pair had an approximately 300 mV difference in the readings at 4 pH and 10 pH. We therefore chose our instrumentation amplifier to have a gain that would raise this range to approximately 3 V. While the Arduino can handle 0-5 V, the voltage range from the electrodes wasn't centered at 0 V and we therefore couldn't expand it to fill the whole 5 V range without implementing a level shifter prior to the amplification stage. To achieve a gain of 10 V/V (= 3 V / 0.3 V), we used an LT1167 with Rg = 5.5 kΩ = 2.2 kΩ + 3.3 kΩ which was obtained using the LT1167's gain equation obtained from its datasheet: Gain = (49.4 kΩ / Rg) + 1.

Once we constructed this and connected the electrode, we saw there was an abundance of ambient 60 Hz noise in the signal and decided to include a low-pass filter prior to the amplification stage with a corner frequency around 7 Hz (so 0 Hz pH measurements are well within the pass band and 60 Hz noise measurements are well within the stop band). We constructed this using a 220 kΩ resistor and a 0.1 μF capacitor as you can see in the LT Spice schematic included below.



The instrumentation amplifier is supply with +/- 5 V. The amplified and filtered signal can be measured at Vout. IrOx is the point of connection for the IrOx electrode and AgCl is the point of connection for the AgCl electrode (NOTE that this electrode is grounded as it is the reference electrode).

Conclusions/action items:

Perhaps add a level shifter or some variation of a circuit that will automatically center the signal at 2.5 V so that the gain can be steadier (currently relies on the actual voltage values and not just their range).

Use this circuit whenever we want to measure the voltage of the IrOx-AgCl electrode pair.

Final Report

JONAH MUDGE - Apr 29, 2020, 2:43 PM CDT

Title: Amplification and Filtration Circuit

Date: 4/29/20

Content by: Jonah

Present: Jonah

Goals: Final report for reference of future groups

Content:

See attached

JONAH MUDGE - Apr 29, 2020, 2:43 PM CDT

compartment_syndrome_final_report.docx(932 KB) - download

2020/02/18 - Outreach Meeting

NUR SAIDIN - Feb 26, 2020, 8:22 AM CST

Title: Outreach meeting

Date: 18/02/2020

Content by: Syafiqah

Present: Jonah, Lucas, Hunter, Anna Keller, Syafiqah

Goals: Prepare the slides for outreach

Content:

We will conduct our outreach activiity this upcoming Monday (February 24th) at Homestead High School. We aim to teach the students the basic electronics skill with respect to basic electrochemistry in foods. Some of the learning goals includes:

1. Understand the basics of current flow in solution
2. Differentiate between parallel and series electrical sources
3. Implement an LED in designs
4. Understand the electrochemistry behind food battery.

During the activity, the students will be divided into groups and create a circuit using lemons, potatoes, and oranges to light up the LED. They can try different combination of series and parallel to see which gives the brightest LED. We also prepared a presentation slide that introduce us, the BME department, and a brief explanation how electrochemistry relates to our project.

Conclusions/action items:

Need to practice the presentation, list down the materials that we need to bring, and try build the circuit ourselves.

NUR SAIDIN - Feb 26, 2020, 8:23 AM CST

Electrochemical_Fruit_BME.pptx(10.4 MB) - download

2020/02/21 - Practice Outreach

NUR SAIDIN - Feb 26, 2020, 8:47 AM CST

Title: Practice Outreach

Date: 21/02/2020

Content by: Syafiqah

Present: Jonah, Lucas, Hunter, Anna Keller, Syafiqah

Goals: Practice outreach

Content:

During this activity, we will be using potatoes, oranges, and lemons. Each fruits has different voltages as they have different composition of ions and acidity. We figured that, to light up an LED, we need to use three potatoes or three lemons, or four oranges. We tried different combination of fruits, connected them in series and parallel, and even added more fruits to see the difference in the LED brightness.

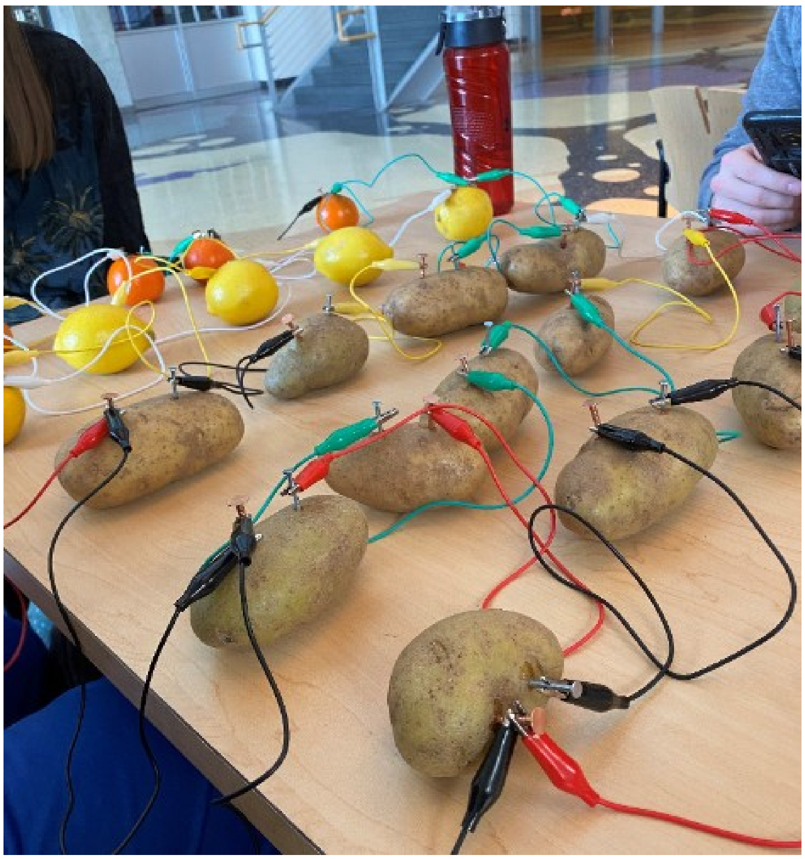


Figure 1: Fruits (or foods since potatoes aren't fruits) connected in parallel.

Conclusions/action items:

Need to print the photo release form and buy all the stuffs we need.

2020/02/23 - List of Materials

NUR SAIDIN - Feb 26, 2020, 8:49 AM CST

Title: List of materials for outreach

Date: 02/23/2020

Content by: Syafiqah

Present: Jonah, Lucas, Hunter, Anna Keller, Syafiqah

Goals: List down the materials we need

Content:

1. 10 lemons ph 2-3
2. 10 oranges ph 3-4
3. 10 potatoes ph ~6
4. Galvanized Nails
5. Copper wiring
6. 60 Alligator clips
7. Assorted LEDs
8. Paper plates/paper towel
9. Candy

Conclusions/action items:

Print photo release form

Team Meeting 1/28/20

LUCAS RATAJCZYK - Feb 10, 2020, 6:54 PM CST

Title: Team Meeting

Date: 1/28/20

Content by: Lucas

Present: Team

Goals: Get organized for the semester and upcoming weeks

Content:

- Discussed the 48 hour drift test
  - None of us have access to 2005 yet so until we get that, we can't implement any plans
  - Instead of having Jonah and I split the 48 hours into 6 hour shifts, we may split it into smaller shifts and have Hunter and Syafiqah take some
  - Can we automate the pH-reading process so that we can leave it alone for the 48 hours (Hunter)
    - Good for long term since that would make it easier to use in the clinical setting
    - Difficult to implement in one week -> Should we get started on it now or wait until we decide whether to use the ISFET (the ISFET analog front-end would be the troublesome part so if we decide later to use the IrOx, then the difficult work will have been for nothing)

- Outreach
  - Anna's high school said Tuesday Feb. 11th and Wednesday Feb. 12th work best for them
  - They said "afternoon" on a weekday - Most likely around 3 - 4 PM (leave here around 1 get back around 6)
  - Fridays seem to work better for everyone so we can try that
  - If not, we can do Tuesday and I will ask Ben (the other BME 310 SA) to trade that week's Tuesday lab section so that I can be free from 12:30 PM to 6:00 PM
  - Jonah's school would not get us any funding but it would be slightly earlier (~1:45 PM) and no days of the week specified

- Animal testing
  - We will be working with pigs now
  - I need to get trained to work with them (the others are already trained - surprisingly more prevalent than expected)
  - Training through RARC (https://www.rarc.wisc.edu/training/course/swine) but it is a closed access class so I would need to be on a protocol

- Hunter mentioned that although only the tip of the IrOx needle is coated but we would need to insulate the rest of the needle so that the non-compartment tissue is not contributing to the potential
- Jonah made an outline (copy attached below)

Conclusions/action items:

- Order the AC->9V(DC) adapter
- Make Arduino program to store the voltage values to computer or micro SD
  - Ask if we can get one from the BME department (they don't use them for BME 201 anymore)
  - Hunter may have one, so the above would be unnecessary
- Get access to 2005
- Organize the outreach scheduling with Anna's and Jonah's high schools

Team Meeting 2/10/20

LUCAS RATAJCZYK - Feb 10, 2020, 7:32 PM CST

Title: Team Meeting

Date: 2/10/20

Content by: Lucas

Present: Team

Goals: IrOx Electrodeposition plans, preliminary deliverables, and outreach materials.

Content:

- IrOx Electrodeposition:
    - Material transport to WIMR 3rd floor (Ludwig lab?)
    - Will be done tomorrow (meeting at ECB @ 8pm and driving to WIMR)
    - Hunter's source for carbon microtubes have ones that are small enough to fit our application and have multiluminal versions (biluminal version to have one electrode in each lumen -> both in solution but separated by microtube material)
        - He will call them tomorrow (they haven't responded to his emails)
- Outreach materials
    - Waiting to hear back from Anna's contact about February 24th
    - Send photo consent form
    - Other paperwork?

Conclusions/action items:

- Send the outreach photo consent form once confirmation received
- Meet tomorrow in ECB at 8pm to move the electrodeposition materials (bring the LT1920 from my BME 463 circuit)
- Ask Dr. Nimunkar for more details about what all we need to do for preliminary deliverables (due 2/26)

Team Meeting 2/18/20

LUCAS RATAJCZYK - Apr 28, 2020, 4:50 PM CDT

Title: Team Meeting

Date: 2/18/20

Content by: Lucas

Present: Outreach Team (Normal Team + Anna Keller)

Goals: Discuss what we need for Outreach next Monday (2/24)

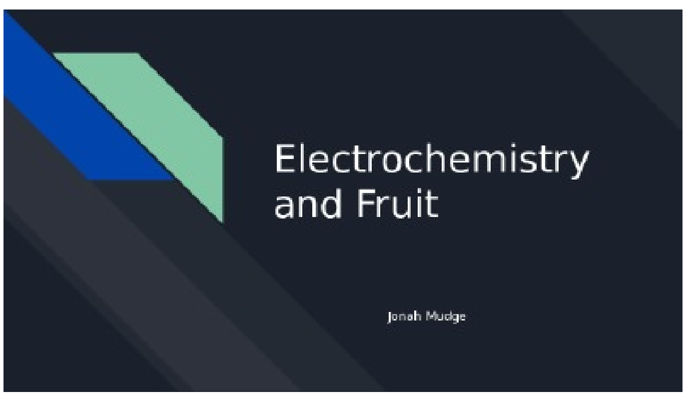
Content:

- Jonah did an informal presentation of the same activity over winter break to a church group so we are not starting from nothing. I attached a copy of that presentation below.
    - When he did this, he spent not enough time on the explanation and went too high-level and he could tell that the participants didn't get it.
- How to make it more competitive:
    - Different fruits to choose: Who lights up the most LEDs
    - Morse message?
    - Color paper that shows hidden message when lit up with the right color LED -> piece total message together in groups -> race to unscramble the message
        - The special paper is difficult to find
- Solve a riddle
- All hints in rhyme?
- Bring paper plates and paper towels to clean up the lemon juice
- Practice on Saturday (2/22)

Conclusions/action items:

Refine the presentation, purchase materials, and practice on Saturday. Once done, Monday we will be doing the final version of the presentation and activity.

LUCAS RATAJCZYK - Feb 18, 2020, 8:08 PM CST



Jonah_s_Winter_Break_Activity_Presentation.pptx(4.2 MB) - download

Team Meeting 3/2/20

LUCAS RATAJCZYK - Mar 02, 2020, 7:36 PM CST

Title: Team Meeting

Date: 03/02/20

Content by: Lucas

Present: Team

Goals: Make a plan of things to do this week.

Content:

- Hunter got some multi-lumenal tubing samples that are small enough to fit the 11-gauge needle (pigs) but not small enough for 16-gauge (human).
  - The electrodes can be threaded through it very easily (Jonah did it in less than a minute
- The ion-selective membrane idea put forth by Dr. Nimunkar is a good idea but we don't know how to make it and don't have time to figure it out this semester.
- IrOx electrode only lasted for ~10 hours
  - Ask Dr. Doro if this will be OK
  - Josh (Med student from TECH) says the nurse can switch out the electrodes so have them do this every 5-10 hours
- Lucas:
  - Make an amplifier circuit with LT1920 (or LT1167) to amplify electrode voltage from ~300mV range to full 5V range of Arduino
    - Use multiple amplification stages - per Dr. Nimunkar's request
    - TL072 stage after Instrumentation Amp (1167 or 1920)
  - 3D print the UI box
  - Design/order a PCB for the amplifier circuit?
    - If I were to do this, I would also incorporate the LCD and Arduino Nano Every connections
- Hunter:
  - Keep working on finding multi-lumenal tubes or an alternative to fit our solution
- Syafiqah:
  - Make IrOx electrodeposition solution for Jonah's fruit testing
- Jonah:
  - Electrodeposit new electrode pair and test in lemon (or other fruit)

Conclusions/action items:

See the lists of stuff to do in the main body of the entry

Doro's ACS Presentation

JONAH MUDGE - Sep 24, 2019, 8:39 AM CDT

Title: Dr. Doro's ACS Presentation

Date: 9/24/19

Content by: Jonah Mudge -- PowerPoint by Dr. Doro

Present: Jonah Mudge

Goals: Clinical background behind ACS

Content:

see attached PDF

Conclusions/action items:

Use this knowledge about ACS to ensure our design appropriately meets clinical constraints

JONAH MUDGE - Sep 24, 2019, 8:35 AM CDT

Compartment_BME.ppt(6.9 MB) - download

Fasciotomy Procedure

JONAH MUDGE - Sep 24, 2019, 8:41 AM CDT

Title: Dr. Doro's fasciotomy procedure presentation

Date: 9/24/19

Content by: Jonah Mudge -- PowerPoint by Dr. Doro

Present: Jonah Mudge

Goals: Details behind invasiveness of fasciotomy procedure

Content:

see attached PDF

Conclusions/action items:

Fasciotomies should be avoided if at all possible, as misdiagnosis of ACS leads to these very invasive and expensive surgeries. Our device aims to limit these unnecessary surgeries.

JONAH MUDGE - Sep 24, 2019, 8:46 AM CDT

CD_Vegas19_ACS.pptx(84.7 MB) - download

Microsens ISFET (combined REF)

JONAH MUDGE - Oct 02, 2019, 10:10 PM CDT

Title: Microsens

Date: 10/2/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design

Content:

Includes combined sensor and reference electrode in one package!

MSFET 3330 pH-ISFET sensor

The ISFET sensing element is packaged onto a miniature PCB for easy handling. Different shapes and sizes of the packaging are available on demand.

Characteristics

- small size
- wide range of applications
- requires interface electronics and a reference electrode

Key Specifications

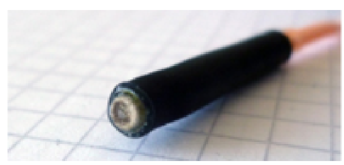
- Typical pH range: pH1 - pH12
- Typical sensitivity: 55mV/pH
- Response time: 90% signal level: < 1 sec

Datasheets

- MSFET 3330 Flyer
- MSFET 3330 Datasheet
- Si_3N_4 ISFET line (on demand): Flyer, Datasheet

MSREF Miniature reference electrode

Microsens has developped a miniature reference electrode to work with the MSFET3330. More information can be found in the MSREF Datasheet.



Combined sensor head

MICROSENS also offers solutions combining the MSFET3330 and the MSREF into one sensor head. The standard solution has the same dimensions as the MSFET3330, but different shapes and sizes are available on demand.

Conclusions/action items:

Find smallest, most effective probe for our applications

References:

http://microsens.ch/products/ISFET.htm

A pH-ISFET based micro sensor system on chip using standard CMOS technology

JONAH MUDGE - Oct 02, 2019, 10:12 PM CDT

Title: A pH-ISFET based micro sensor system on chip using standard CMOS technology

Date: 10/2/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design

Content:

Includes combined sensor and reference electrode in one package, on same FET chip!

Abstract:

A monolithic pH sensor system has been studied and developed, based on standard CMOS technology. The micro system includes an on-chip integration of differential ISFET/REFET sensing devices, metal constructed pseudo reference electrode (PRE) and front-end measurement electronics. A post CMOS process flow is devised in our laboratory to allow the ISFET to be fabricated in a standard CMOS foundry with minimal modifications. The chip has been realized with Chartered Semiconductor's 0.35/spl mu/m, 4-metal and 2-poly layer CMOS process and operates at 3.3 V. The total die area is 5mm/sup 2/. Thanks to the on-chip signal conditioning; the micro sensor system achieves a superior sensitivity of 53.67mV/pH as well as an enhanced linearity. Hence, it demonstrates the possibility of embedding ISFET based micro sensor arrays in advanced digital, analog and mixed signal VLSI for the intelligent measurement required in various chemical, biochemical and biomedical applications.

Conclusions/action items:

Find smallest, most effective probe for our applications

References:

H. Yang, H. Sun, J. Han, J. Wei, Z. Lin, S. Xia, and H. Zhong, “A pH-ISFET based micro sensor system on chip using standard CMOS technology,” *Fifth International Workshop on System-on-Chip for Real-Time Applications (IWSOC05)*, 2005.

Micro Dri-Ref Reference Electrode

JONAH MUDGE - Oct 03, 2019, 12:55 PM CDT

Title: Micro Dri-Ref reference electrode

Date: 10/2/19

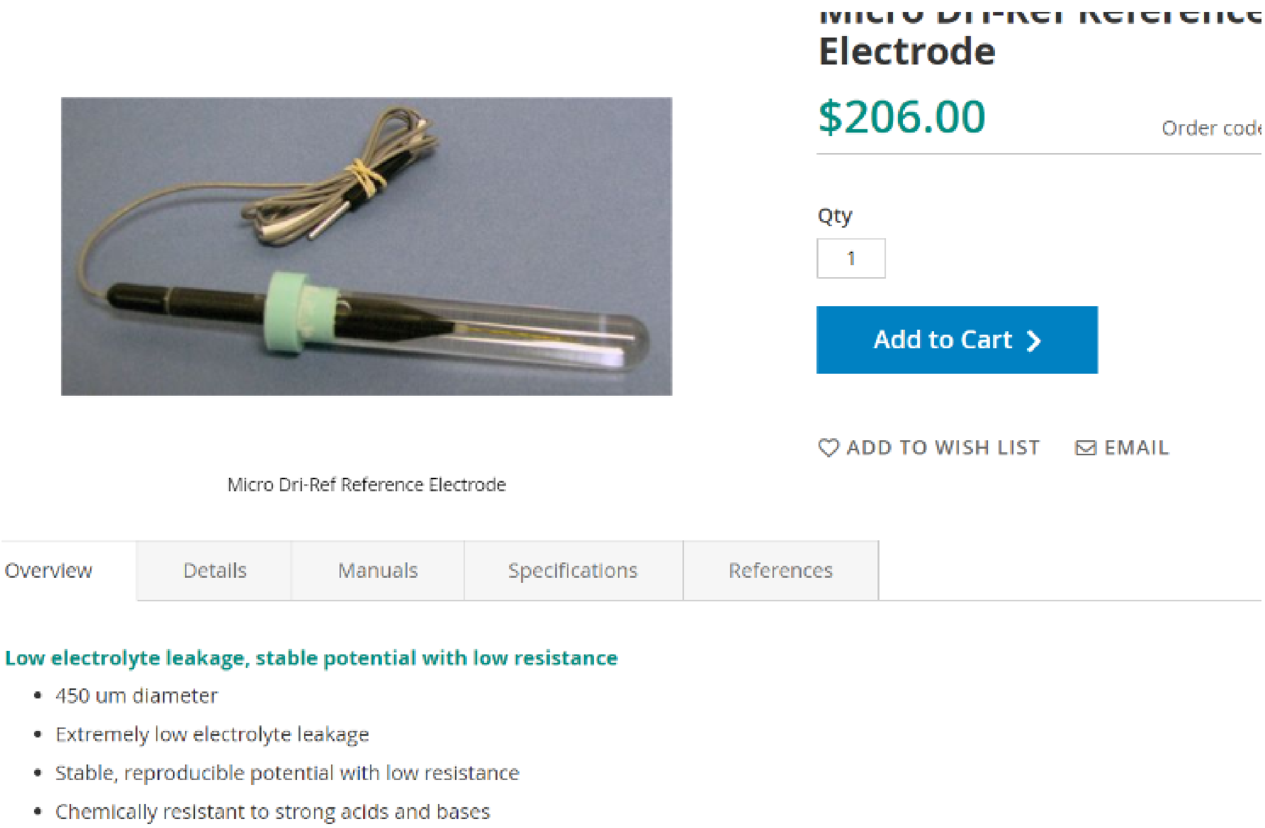
Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design

Content:

450 um diameter, could be co-inserted with Sentron ISFET die into needle tip



Conclusions/action items:

Find smallest, most effective probe for our applications

References:

https://www.wpiinc.com/driref-450-micro-dri-ref-reference-electrode

Unisense micro ref electrode

JONAH MUDGE - Oct 21, 2019, 9:23 PM CDT

Title: Unisense micro ref electrode

Date: 10/21/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:

Reference electrode for pH or Redox microelectrodes

Reference electrodes from Unisense are simple silver/silver-chloride open-ended electrodes designed to work with potentiometric microelectrodes (e.g. Unisense pH and Redox microelectrodes). For measurements with these sensors, it is important that the measuring sensor is in fluid contact with the reference. For most purposes this can be achieved with a large macro-reference. For some applications the sample is so small (e.g. a droplet) that the reference must be as small as the measuring microelectrode.

For laboratory use, Unisense provides a macro reference electrode from Radiometer Analytical. Our micro-sized reference electrodes are glass electrodes manufactured at Unisense. For in situ use, Unisense manufactures a pressure-compensated macro electrode.

Ordering Information

Standard Glass Sensor	Outside tip diameter
REF-10	8-12 µm
REF-100	90-110 µm
REF-N	1,1 x 40 mm - needle sensor
REF-NP	1,6 x 40 mm - needle sensor for piercing
REF-RM	5 mm
REF-Insitu	5 mm

Conclusions/action items:

Find smallest, most effective probe for our applications

References:

https://www.unisense.com/reference#spec_3961

Flexible Ag/AgCl micro ref electrode

JONAH MUDGE - Oct 21, 2019, 9:26 PM CDT

Title: Flexible Ag/AgCl micro ref electrode

Date: 10/21/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:

Sens Actuators B Chem. 2017 Aug;247:92-97. doi: 10.1016/j.snb.2017.02.135. Epub 2017 Mar 2.

A flexible Ag/AgCl micro reference electrode based on a parylene tube structure.

Zhao Z[1], Tu H[1], Kim EG[1,2], Sloane BF[3], Xu Y[1].

Author information

1 Department of Electrical & Computer Engineering, Wayne State University, Detroit, Michigan, USA.
2 Department of Biomedical Engineering, Wayne State University, Detroit, Michigan, USA.
3 Department of Pharmacology, Wayne State University, Detroit, Michigan, USA.

Abstract

In the effort of developing micro-electrochemical sensors, the miniaturization of reference electrodes has been a challenging task. In this paper, a flexible micro reference electrode with an internal electrolyte reservoir is reported. This new device is based on a unique microfabricated parylene tube structure, which is filled with Cl^- rich electrolyte, into which a 50 μm diameter silver (Ag) wire covered with a 7.4 μm thick silver chloride (AgCl) layer is inserted. The distal end of the tube is filled with potassium chloride (KCl) saturated agarose gel. The Ag wire, thick AgCl layer, and internal electrolyte reservoir lead to a long operation time and a stable reference voltage. The drift over a 10-hour period has been found to be less than 2 mV. The total operation time of the device has exceeded 100 hours. Furthermore, the compatibility with microfabrication allows the integration of other components, leading to truly miniaturized electrochemical sensors or sensing systems. To prove this, we demonstrated a pH sensor by combining the reference electrode and an iridium oxide electrode monolithically integrated on the surface of the parylene tube.

KEYWORDS: Iridium Oxide; MEMS; Parylene tube; Reference electrode; pH sensor

Conclusions/action items:

Find smallest, most effective probe for our applications

References:

https://www.ncbi.nlm.nih.gov/pubmed/28970651

Comparison of Fabrication Methods for Iridium Oxide Reference Electrodes

JONAH MUDGE - Apr 27, 2020, 9:25 PM CDT

Title: Comparison of Fabrication Methods for Iridium Oxide Reference Electrodes

Date: 10/22/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:

A Comparison of Fabrication Methods for Iridium Oxide Reference Electrodes

Robert K. Franklin
Dept. of Electrical Engineering and Computer Science
The University of Michigan
Ann Arbor, MI, USA
rkfrankl@umich.edu

Segyeong Joo
Medical Research Center
Seoul National University
Seoul, Korea

Sandeep Negi, Florian Solzbacher, and Richard B. Brown
Dept. of Electrical and Computer Engineering
The University of Utah
Salt Lake City, UT, USA

Abstract—**Several methods for the manufacturing of Iridium Oxide (IrOx) electrodes have been discussed in the literature. Two commonly used fabrication methods are Sputtered Iridium Oxide Films (SIROF) and Activated Iridium Oxide Films (AIROF). Most of the studies for *in vivo* electrodes have reported optimizations to these methods in the context of stimulation of and recording from neural tissue. In this work we characterize three fabrication methods of IrOx films for use as reference electrodes during *in vivo* neurochemical recordings, and we conclude that AIROF electrodes are preferable as reference electrodes due to their superior open circuit potential (OCP) stability.**

I. Introduction

In order to probe the delicate chemical interactions involved in intracellular communication[1], various methods have been explored including adaptations of traditional methods such as microdialysis[2] as well as newly developed methods such as hybrid hydrogel-optical detection systems[3,4]. Neurochemical sensors based on electrochemical detection methods such as cyclic voltammetry

reaction that allows current to pass through the electrode without affecting its potential.

Ag/AgCl is the most popular reference electrode used in electrochemical detection. Its Nernst reaction depends on the chloride concentration in the surrounding media which in biological media is normally well controlled. As a result, many of the neurochemical sensors reported to date have used Ag/AgCl as the reference electrode. Unfortunately, Ag/AgCl, is unsuitable for chronic implantation due to its toxicity. This has led to the reference electrode being placed in a remote location to minimize its effect of the tissue of interest, or to its being replaced by a pseudo-reference electrode such as stainless steel which lacks the long-term potential stability of a real reference electrode. We previously suggested IrOx as a suitable replacement for Ag/AgCl in the brain and presented results of an initial study that showed IrOx to be suitable for this application [10]. Here, we expand upon that work by comparing multiple fabrication methods and examining the electrochemical stability of IrOx films.

Conclusions/action items:

Find smallest, most effective probe for our applications

Ag/AgCl not suitable for chronic implantation due to toxicity. But can our application be considered chronic?

References:

https://warwick.ac.uk/fac/sci/eng/research/grouplist/sensorsanddevices/mbl/database/ieeesensors09/PDFs/Papers/248_5549.pdf

Franklin, R. K., Joo, S., Negi, S., Solzbacher, F., & Brown, R. B. (2009, October). A comparison of fabrication methods for Iridium Oxide reference electrodes. In *SENSORS, 2009 IEEE* (pp. 1086-1089). IEEE.

Microfabricated Reference Electrodes

JONAH MUDGE - Apr 27, 2020, 9:27 PM CDT

Title: Microfabricated Reference Electrodes

Date: 10/22/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:

4.2. Microfabricated Solid-State Ag/AgCl

As previously discussed, the Ag/AgCl is notably the most practical and effective electrode to use in research as its macroscopic version is simplest and safest to manufacture. Also, the kinetics of cholride ion adsorption and the mechanism of silver chloride layer formation have been studied and electrochemically optimized in great detail [45,46]. Due to its popularity in the macroscale, Ag/AgCl reference electrode is most often targeted for miniaturization and implementation in various bio-sensors. Particular attention has been given to solid-state reference electrodes in favour of eliminating the liquid junction and associated potential present in reference electrodes employing the filling solution. Details of such electrode operation and associated chemistry have been documented [47]. Typically, the filling solution is replaced with a solid-state exchange membrane doped with the ions required for the electrode equilibrium. Having solid-state support limits or eliminates convective mixing-induced drifts. One way to accomplish a solid-state support is using electrolyte-infused gels. For example, agar gel saturated with KCl has been spin coated [48] and screen printed [49] on microfabricated Ag/AgCl thin films (Figure 6). This modification has a significant effect in making the solid state reference electrode insensitive to pH in the range of 4–10 [44] and Cl- ion concentration in the range of 10^{-6} M to 0.3 M [45].

Conclusions/action items:

Find smallest, most effective probe for our applications

Solid-state Ag/AgCl electrodes are an option. Additional advice on reference electrode fabrication.

References:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3264446/

Shinwari, M. W., Zhitomirsky, D., Deen, I. A., Selvaganapathy, P. R., Deen, M. J., & Landheer, D. (2010). Microfabricated reference electrodes and their biosensing applications. *Sensors (Basel, Switzerland)*, *10*(3), 1679–1715. https://doi.org/10.3390/s100301679

Au Reference Electrode Concept

JONAH MUDGE - Apr 27, 2020, 9:28 PM CDT

Title: Au Reference Electrode Concept

Date: 10/30/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:

that the experiment is done with an integrated Au electrode on the wafer, shows that ISFETs can be fully integrated with signal conditioning circuits since there is no need of a bulky reference electrode. In a multisensory system, the ISFET provides full and

51

compact integration. Third, the threshold voltage sensitivity to pH is the same as in the case of Figure 4.5 since the work function is a constant parameter and therefore cancels out during sensitivity calculation.

Conclusions/action items:

Find smallest, most effective probe for our applications

Specifically states that single integrated gold wire is enough to get accurate pH values without a bulky Ag/AgCl reference electrode.

References:

https://pdfs.semanticscholar.org/46c0/de9d0a12488f1ab8d246cf822c842388f9f4.pdf

Baylav, Murat, "Ion-sensitive field effect transistor (ISFET) for MEMS multisensory chips at RIT" (2010). Thesis. Rochester Institute of Technology.

Sentron brochure

JONAH MUDGE - Sep 23, 2019, 9:53 AM CDT

Title: Sentron pH probe brochure

Date: 9/23/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design

Content:

see attached PDF

Conclusions/action items:

Find smallest, most effective probe for our applications

JONAH MUDGE - Sep 23, 2019, 9:54 AM CDT

Brochure_Sentron_MiniFET_pH_probe.pdf(359.9 KB) - download

IrOx electroplating solution

JONAH MUDGE - Dec 09, 2019, 9:41 PM CST

Title: IrOx electroplating solution

Date: 11/14/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:

Anodic Electrodeposition of Iridium Oxide Film. Anodic electrodeposition of iridium oxide film was performed according to the method described by Yamanaka.[25] The deposition solution was prepared as follows. A 75-mg portion of iridium tetrachloride was dissolved in 50 mL of water. The solution was magnetically stirred for 30 min. A 0.5-mL aliquot of aqueous 30% hydrogen peroxide solution was added, and the resulting solution was stirred for 10 min. A 250-mg portion of oxalic acid dihydrate was added, and the solution was stirred again for 10 min. The pH of the solution was adjusted slowly to 10.5 by addition of small portions of anhydrous potassium carbonate. The resulting yellow solution was covered and left at room temperature for 2 days for stabilization. The anodic deposition was performed on the sputtered Pt disk electrodes and platinum wire electrodes. A 5-cm-diameter Pt mesh was used as cathode. The recommended current density (0.16 mA/cm^2) for electrodeposition on indium–tin oxide electrodes[25] proved to be inadequate for platinum. No deposits were observed after at least 20 min. However, a current density of 0.5–1 mA/cm^2 gave a blue deposit on sputtered platinum within 3 min. Deposits obtained by 6 min of deposition at 1 mA/cm^2 proved to be adequate. To complete the construction of the pH electrode, a 0.25-μL aliquot of 5% Nafion solution was deposited onto the electrode surface and air-dried for 10 min. The electrodes were individually cut and connected to electrical wire using conductive silver epoxy (Epoxy Technology) and heated at 100 °C for 1 h. The electrical connection was then insulated with silicone rubber (Dow Corning 3140 RTV). The electrodes were conditioned in tris buffer, pH 7.0, for 2 days to stabilize the potential readings. The construction of the planar electrode is shown in Figure 1. When Pt wire was used as electrode support,

The buffers were prepared by dropwise addition of 1 M solutions of HCl and NaOH to universal stock buffer solution having the following composition: 5 mM potassium hydrogen phthalate, 5 mM potassium dihydrogen phosphate, 5 mM tris(hydroxymethyl)-aminomethane, 2.5 mM Borax, and 100 mM NaCl. Calibration curves covering only the physiological pH range were constructed by titrating 0.1 M phosphate buffer with 1 M HCl and 1 M NaOH between pH 6 and 8. The reproducibility of the pH responses in the pH range 2–9 was evaluated by changing the pH, randomly, by addition of 1 M HCl and 1 M NaOH to a tris buffer with 100 mM NaCl ion background [15 mM tris(hydroxymethyl)amino-methane–140 mM NaCl]. The pH values of all buffer solutions were determined with a calibrated Orion pH Ross electrode (model 81-02).

Electrode Selectivity. The selectivity of the AEIROF pH electrode was assessed under conditions relevant to the physiological applications. The iridium electrode, along with the Ag/AgCl double-junction reference electrode, was immersed in well-stirred 45-mL volume of 0.1 M tris buffer adjusted to pH 7.0 with HCl. After potential stabilization, a 5-mL aliquot of 1 M solution of NaCl, KCl, LiCl, NH_4Cl, or $CaCl_2$ prepared in 0.1 M tris buffer, pH 7.0, was added. The changes in millivolt reading were recorded. The effects of ascorbic, uric, and lactic acids were evaluated similarly using 0.1 M stock solution of ascorbic acid and lithium lactate prepared in 0.1 M Tris buffer and adjusted to pH 7.0. Milky suspension of 0.1 M sodium urate was obtained by brief sonication. The effect of dissolved oxygen was evaluated by allowing potential stabilization in tris buffer containing 100 mM NaCl as background. Nitrogen gas was bubbled for 15 min and then stopped for another 15 min. The potential readings were observed during changes of the oxygen tension.

Conclusions/action items:

Use protocol in this paper to mix the electroplating solution

References:

https://pubs-acs-org.ezproxy.library.wisc.edu/doi/pdf/10.1021/ac980608e

S. A. M. Marzouk, S. Ufer, R. P. Buck, T. A. Johnson, L. A. Dunlap, and W. E. Cascio, "Electrodeposited Iridium Oxide pH Electrode for Measurement of Extracellular Myocardial Acidosis during Acute Ischemia," *Analytical Chemistry*, vol. 70, no. 23, pp. 5054–5061, Dec. 1998.

IrOx Electrodeposition

JONAH MUDGE - Dec 09, 2019, 9:58 PM CST

Title: IrOx electrodeposition

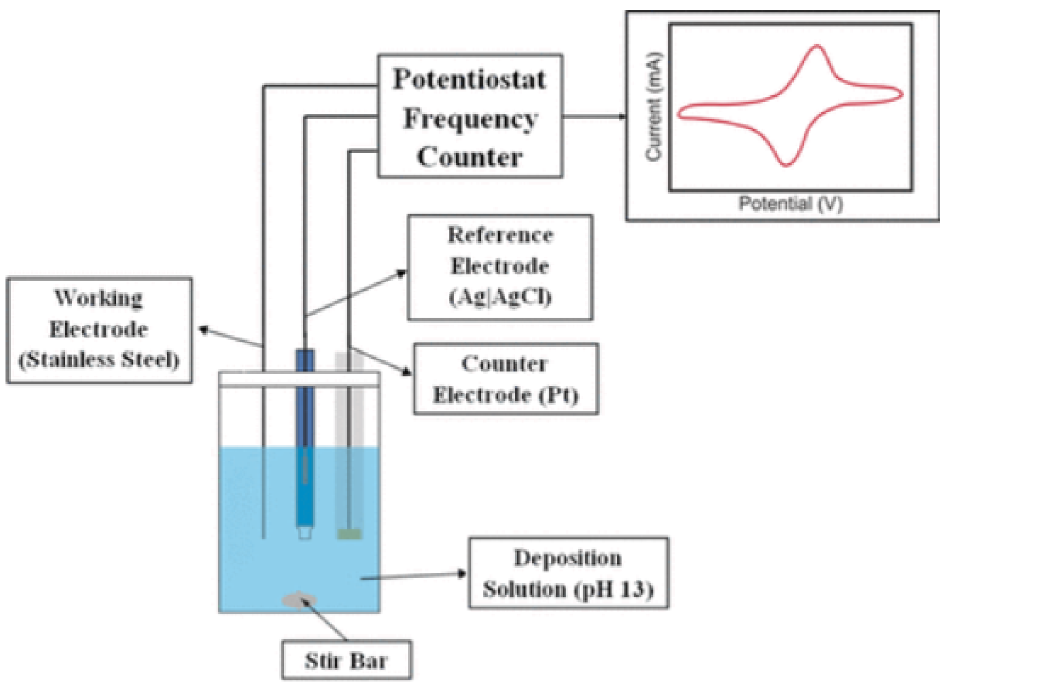
Date: 11/14/19

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine best pH probe for our design, reference electrode in particular

Content:



Conclusions/action items:

Use protocol in this paper to complete electrodeposition of iridium oxide onto platinum-iridium wire. Plan to use Pt-Ir for working and counter electrode, with Ag/AgCl ref

References:

http://jes.ecsdl.org.ezproxy.library.wisc.edu/content/163/9/B485.full

M. Khalil, S. Wang, J. Yu, R. L. Lee, and N. Liu, "Electrodeposition of Iridium Oxide Nanoparticles for pH Sensing Electrodes," *Journal of The Electrochemical Society*, vol. 163, no. 9, Jun. 2016.

IrOx (on stainless steel) pH sensor

JONAH MUDGE - Apr 03, 2020, 12:34 AM CDT

Title: IrOx (on stainless steel) pH sensor

Date: 4/3/20

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine governing equations of pH wire probes and electrodeposition

Content:

tential of the IrO_2 electrode is measured in 200 ml of titration buffer until a variation of < 0.05 V over 30 s occurs. Known volumes of 1 N NaOH are added according to Table II, and the corresponding potentials are registered. Fig. 5 shows the dynamic response of the pH sensor.

IV. Discussion

When a pH sensor is evaluated, a conventional glass electrode is used, which is normally acquired commercially rather than fabricated by the students. The exercises presented here offer the possibility of making the same evaluation by means of a novel, robust and precise pH sensor, easily fabricated by students in the laboratory.

$$2IrO(OH) + 2H^+ + 2e^- \longleftrightarrow Ir_2O(OH)_2 + H_2O.$$

The half-cell potential is obtained by applying Nernst equation, as follows:

$$E = E^\circ + \frac{2.303RT}{nF}\log\frac{[IrOOH]^2[H^+]^2}{[IrO(OH)_2]}. \qquad (2)$$

Where
E° = standard redox potential at pH = 7.0
E = measured potential
R = gas constant: 8.31 J/° mol
T = absolute temperature in ° K (298° K)

F = Faraday constant: 23 062 cal/V or 96 406 J/V.
Rearranging (2)

$$E = E^\circ + \frac{2.303RT}{nF}\log\frac{[IrOOH]^2}{[IrO(OH)_2]} + \frac{2.303RT}{nF}\log[H^+]^2 \qquad (3)$$

$$E = E^{0\prime} - \frac{2.303RT}{F}\mathrm{pH} \qquad (4)$$

where $E^{0\prime}$ is

$$E^{0\prime} = E^\circ + \frac{2.303RT}{nF}\log\frac{[IrOOH]^2}{[IrO(OH)_2]}. \qquad (5)$$

Replacing the constant values in (4) the equation can be written as

$$E = E^{0\prime} - 0.059\mathrm{pH}.$$

A slope of −0.059 implies a Nernstian behaviour. This sensor

[2] T. Togawa, T. Tamura, and P. Åke Öberg, *Biomedical Transducers and Instruments.*. Boca Raton, FL: CRC Press, 1997.
[3] S. Yao, M. Wang, and M. Madou, "A pH electrode based on melt-oxidized iridium oxide," *J. Electrochem. Soc.*, vol. 148, no. 4, pp. H29–H36, 2001.
[4] R. D. Meyer, S. F. Cogan, T. H. Nguyen, and R. D. Rauh, "Electrodeposited iridium oxide for neural stimulation and recording electrodes," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 9, no. 1, pp. 2–10, Mar. 2001.
[5] C. C. Mayorga, R. E. Madrid, and C. J. Felice, "Caracterización por impedancia de la electrodeposición de oxido de Iridio en electrodos de acero inoxidable," in *Proc. 5th Int. Ibero-Amer. Congress Sensors* , Montevideo, Uruguay, Sep. 2006, CD-ROM.
[6] A. N. Bezbaruah and T. C. Zhang, "Fabrication of anodically electrodeposited iridium oxide film pH microelectrodes for microenvironmental studies," *Anal. Chem.*, vol. 74, pp. 5726–5733, 2002.
[7] I. A. Ges, B. L. Ivanov, D. K. Schaffer, E. A. Lima, A. A. Werdich, and F. J. Baudenbacher, "Thin-film IrO_x pH microelectrode for microfluidic-based microsystems," *Biosen. Bioelectr.*, vol. 21, pp. 248–256, 2004.
[8] S. A. Marzouk, S. Ufer, and R. P. Buck, "Electrodeposited iridium oxide pH electrode for measurement of extracellular myocardial acidosis during acute ischemia," *Anal. Chem.*, vol. 70, no. 23, pp. 5054–5061, 1998.
[9] M. J. Johnson, O. E. Kao, and D. R. Kipke, "Spatiotemporal pH dynamics following insertion of neural microelectrode arrays," *J. Neurosci. Methods*, vol. 160, pp. 276–287, 2007.
[10] I. A. Ges, B. L. Ivanov, A. A. Werdich, and F. J. Baudenbacher, "Dif-

Conclusions/action items:

These equations lend more insight on the operation of wire-based pH probes. Need more info on electrodeposition governing equations however.

References:

https://ieeexplore-ieee-org.ezproxy.library.wisc.edu/abstract/document/4674521

C. C. Mayorga Martinez, R. E. Madrid and C. J. Felice, "A pH Sensor Based on a Stainless Steel Electrode Electrodeposited With Iridium Oxide," in *IEEE Transactions on Education*, vol. 52, no. 1, pp. 133-136, Feb. 2009.

CV electrodeposition RSM optimization

JONAH MUDGE - Apr 03, 2020, 12:46 AM CDT

Title: CV electrodeposition RSM optimization

Date: 4/3/20

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine governing equations of pH wire probes and electrodeposition

Content:

4.2.1 Coded experimental model equations for oxide thickness

The DOE software suggested a 2FI model considering the adjusted R-squared and the predicted R-squared rather than other models. The regression model for IrO_x thickness, in coded factors, is shown by the following *2FI* model equation:

$$H=931.20-(511.59A)+(386.71B)+(403.76C)-(98.63AB)-(433.63AC)+(35.37BC) \qquad (2)$$

where H is the IrO_X thickness (nm). A, B, and C represent the scan rate, temperature, and number of cycles, respectively. According to equation 5, the predicted R^2 of 0.2651 is not as close to the adjusted R^2 of 0.8911 as normally expected. This discrepancy suggests a large block effect or a problem with this model.

To address this problem, insignificant terms (AB and BC) should be removed from the proposed model to obtain an improved equation. The improved equation in terms of coded factors after removing the insignificant terms is shown as follows:

$$H=+931.20-(511.59A)+(386.71B)+(403.76C)-(433.62AC) \qquad (3)$$

According to equation 3, the predicted R^2 of 0.7444 is in agreement with the adjusted R^2 of 0.8897. Adequate precision measures the signal-to-noise ratio. A ratio greater than 4 is acceptable. The adequate precision ratio of 26.438 indicates an adequate signal. Therefore, this model can be used to navigate the design space. As indicated in Eq. (3), the main effects of temperature and number of cycles correlate positively with the IrO_X thickness. The coefficients for scan rate (A) and number of cycles (C) are larger than the coefficients for temperature, indicating that parameters (A) and (B) have a more significant effect on the IrO_X thickness than parameter (B).

Figure 2 shows the predicted result obtained from Eq. (3), which is in agreement with the experimental data, thereby indicating the reliability of the improved model for predicting IrO_X coating thicknesses under various electrodeposition conditions. An acceptable correlation-to- linear regression fit was also obtained, with an R^2 of 0.9255 for IrO_X thickness.

04024-p.3

Conclusions/action items:

Response surface methodology used to optimize several CV configurations: scan rate, temperature, and # of cycles. Allowed for approximate calculation of IrOx coating thickness.

**** pH sensitivity is NOT dependent upon IrOx thickness. CSC(c) does change, however**

References:

https://www.matec-conferences.org/articles/matecconf/pdf/2014/04/matecconf_icper2014_04024.pdf

Kakooei, Saeid, et al. "Electrodeposition of Iridium Oxide by Cyclic Voltammetry: Application of Response Surface Methodology." *MATEC Web of Conferences*, vol. 13, 2014, p. 04024., doi:10.1051/matecconf/20141304024.

More EIROF on stainless steel + small wires good

JONAH MUDGE - Apr 03, 2020, 12:52 AM CDT

Title: More EIROF on stainless steel + small wires good

Date: 4/3/20

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine governing equations of pH wire probes and electrodeposition

Content:

Detailed EIROF fabrication for electrodeposition on stainless steel

showed that thinner pH sensors have a **faster response

Conclusions/action items:

still need more equations

References:

http://www.electrochemsci.org/papers/vol8/80303290.pdf

Kakooei, S., Ismail, M. C., & Wahjoedi, B. A. (2013). Electrochemical study of iridium oxide coating on stainless steel substrate. *Int. J. Electrochem. Sci*, *8*(3), 3290-3301.

heating AIROF electrodes to prevent delamination

JONAH MUDGE - Apr 27, 2020, 6:44 PM CDT

Title: Heating AIROF electrodes helps prevent delaminatioin

Date: 4/9/20

Content by: Jonah Mudge

Present: Jonah Mudge

Goals: Determine governing equations of pH wire probe degredation

Content:

§3. Electrochemical Behavior of AEIROFs

3.1 *Effect of heat treatment on the coloration-bleaching reaction reactivity of AEIROFs*

Anodically electrodeposited iridium oxide As-grown films contain a large amount of water. They are blue-black in color and so soft that they are easily scratched. X-ray diffraction patterns of anodically electrodeposited films showed that they were amorphous in the As-grown state and became crystalline IrO_2 through heat treatment above 500°C for 1 h. Transmission electron microscope (TEM) images of cross sections of As-grown films showed that the deposited films are composed of very small crystals (diameter: about 15A).[8] These results show that As-grown films are composed of crystals which are too small to be detected by X-ray measurements. Water is evaporated from the films with heat treatment at about 100°C. Consequently, the films become hard and difficult to scratch.

Conclusions/action items:

This article includes an option for heat treatment of AIROF electrodes to prevent delamination of the electrodeposited layers. By heating the electrodes to about 100 degrees Celsius, excess water is evaporated and the AIROF films become hard and difficult to remove.

References:

https://iopscience-iop-org.ezproxy.library.wisc.edu/article/10.1143/JJAP.30.1285/pdf

Yamanaka, K. (1991). The electrochemical behavior of anodically electrodeposited iridium oxide films and the reliability of transmittance variable cells. *Japanese journal of applied physics*, *30*(6R), 1285.

Solder Reflow solution for ISFET miniaturization

JONAH MUDGE - Oct 08, 2019, 10:50 PM CDT

Title: Solder reflow solution for ISFET miniaturization

Date: 10/5/19

Content by: Jonah Mudge

Present: Team

Goals: Determine how to connect ribbon cable to miniaturized ISFET bare die

Content:

Spoke with several of the members of the lab that I work at concerning electrode nanofabrication. They proposed using a solder reflow oven to solder the ISFET bare die to the ribbon cable pads. This could work! Just need to verify that the ISFET can withstand that kind of heat (~250 C).

Conclusions/Action Items:

Determine ISFET max temp

2/1/2020 Ag/AgCl Winsense 48hr drift testing

JONAH MUDGE - Feb 10, 2020, 6:56 PM CST

Title: Winsense Ag/AgCl 48hr drift test

Date: 2/10/2020

Content by: Jonah Mudge

Present: Jonah, Lucas

Goals: Test Winsense probe with longer 48hr drift test

Content:

Met in 1036 to run 48hr drift test. Data failed to save for the first 5 hours, and our graphs showed a marked decline in output voltage.

Conclusions/Action Items:

Attempt layered electrodeposition to combat probe degredation over recording period.

2/11/2020 IrOx + Ag/AgCl layered electrodeposition

JONAH MUDGE - Apr 27, 2020, 9:32 PM CDT

Title: IrOx + Ag/AgCl layered electrodeposition

Date: 2/11/2020

Content by: Jonah Mudge

Present: Team

Goals: Use Ludwig Lab potentiostat (Metrohm Autolab) for layered electrodeposition on Pt-Ir and Ag wires

Content:

Met at ECB to gather equipment and head over to WIMR

Conclusions/Action Items:

Attempt layered electrodeposition to combat probe degredation over recording period.

2/15/2020 Ag/AgCl drift testing

JONAH MUDGE - Feb 19, 2020, 11:38 AM CST

Title: 48 hr Ag/AgCl drift testing with Winsense isfet

Date: 2/15/2020

Content by: Jonah Mudge

Present: Jonah, Lucas

Goals: Test drift with new layered Ag/AgCl reference electrode over the course of 48 hours

Content:

Met at ECB 2005, started testing at around 8pm. Unfortunately, the computer we were using to record data automatically restarted shorty into the test. Need to retest with fresh electrode.

Conclusions/Action Items:

Verify Ag/AgCl layered resilience to breakdown over time

2/19/2020 Ag/AgCl Fab

JONAH MUDGE - Apr 27, 2020, 9:53 PM CDT

Title: Ag/AgCl Fab

Date: 2/19/2020

Content by: Jonah Mudge

Present: Jonah

Goals: fab new ref electrode

Content:

Fabricated layered Ag/AgCl reference electrode using WIMR potentiostat. Injected 1.5 V amplitude square wave (2s period, 50% duty time) through 680 ohm resistor to working electrode in 3 M KCl solution. See Fabrication/Electrodeposition of Ag/AgCl for images of setup and equation.

Conclusions/Action Items:

Verify Ag/AgCl layered resilience to breakdown over time

2/19/2020 Ag/AgCl drift testing

JONAH MUDGE - Apr 27, 2020, 10:04 PM CDT

Title: Ag/AgCl 48hr drift test

Date: 2/19/2020

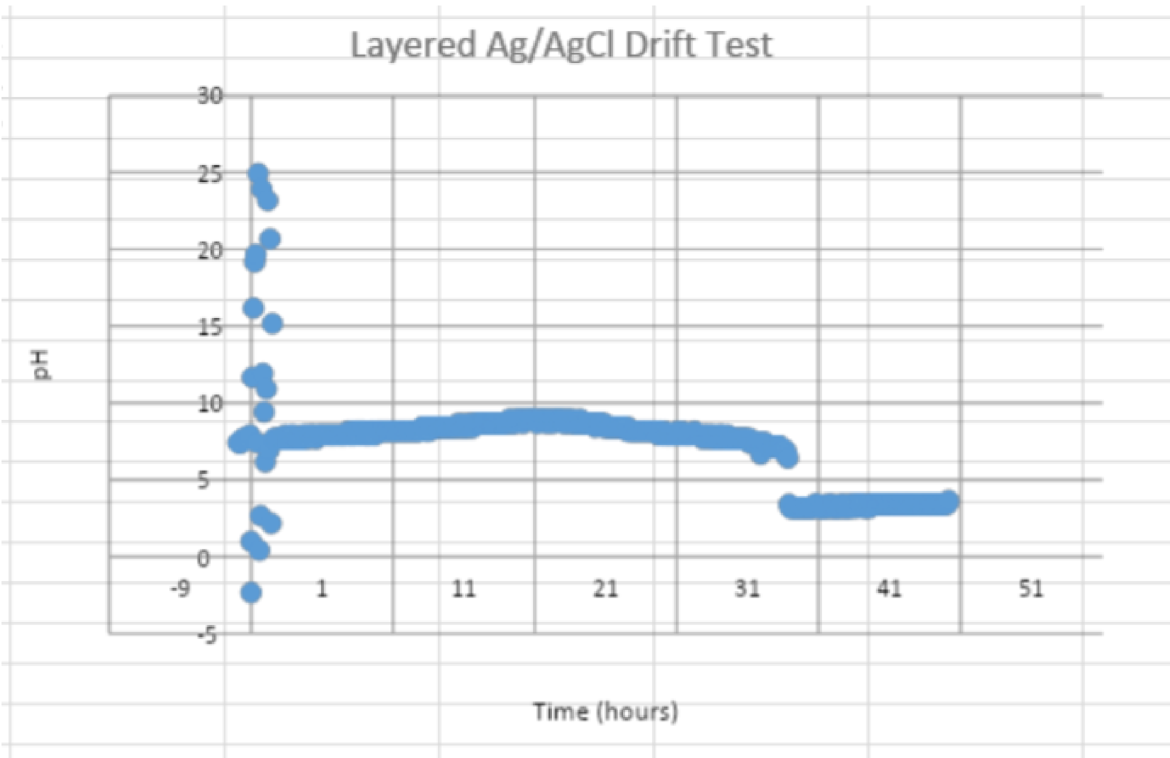
Content by: Jonah Mudge

Present: Jonah and Lucas

Goals: perform 48hr drift test on layered Ag/AgCl with Winsense ISFET to confirm reference electrode stability

Content:

Tested layered Ag/AgCl reference electrode to determine deterioration over time, determined that it can last ~30 hours before deteriorating.



Some "noise" visible at beginning of trial.

Conclusions/Action Items:

Verify Ag/AgCl layered resilience to breakdown over time

2/26/2020 Ag/AgCl Fab

JONAH MUDGE - Apr 27, 2020, 10:05 PM CDT

Title: Ag/AgCl Fab

Date: 2/26/2020

Content by: Jonah Mudge

Present: Jonah

Goals: fab new ref electrode

Content:

Fabricated layered Ag/AgCl reference electrode using WIMR potentiostat. Injected 1.5 V amplitude square wave through 680 ohm resistor to working electrode in 3 M KCl solution for 1000 cycles. See Fabrication/Electrodeposition of Ag/AgCl for images of setup and equation.

Conclusions/Action Items:

Verify Ag/AgCl layered resilience to breakdown over time, test IrOx with confirmed functional Ag/AgCl electrode to assess breakdown.

3/3/2020 Ag/AgCl and IrOx electrodeposition

JONAH MUDGE - Apr 27, 2020, 10:07 PM CDT

Title: Ag/AgCl and IrOx electrodeposition

Date: 3/3/2020

Content by: Jonah Mudge

Present: Jonah

Goals: fab new ref electrode and sensing electrode

Content:

Fabricated two layered Ag/AgCl electrodes and one layered IrOx sensing electrode for testing purposes. See Fabrication/Electrodeposition of Ag/AgCl and Fabrication/IrOx Deposition 2 for images of setup and equation.

Conclusions/Action Items:

Verify Ag/AgCl layered resilience to breakdown over time, test IrOx with confirmed functional Ag/AgCl electrode to assess breakdown.

3/10/2020 Ag/AgCl and IrOx electrodeposition

JONAH MUDGE - Mar 10, 2020, 7:17 PM CDT

Title: Ag/AgCl and IrOx electrodeposition

Date: 3/10/2020

Content by: Jonah Mudge

Present: Jonah

Goals: fab new ref electrode and sensing electrode

Content:

Fabricated two layered Ag/AgCl electrodes and one layered IrOx sensing electrode for testing purposes; these will be used in cadaver testing tomorrow.

Conclusions/Action Items:

Verify Ag/AgCl layered resilience to breakdown over time, test IrOx with confirmed functional Ag/AgCl electrode to assess breakdown.

Acute Compartment Syndrome (ACS) Background

LUCAS RATAJCZYK - Oct 08, 2019, 11:46 PM CDT

Title: ACS Background

Date: 9/30/19

Content by: Lucas

Present: Team

Goals: Gather some background information on Acute Compartment Syndrome (ACS)

Content:

Source 1: D. Purcell, B. A. Terry, and B. R. Sharp, “Acute Compartment Syndrome,” in *Emergency Orthopedics Handbook*, D. Purcell, S. A. Chinai, B. R. Allen, and M. Davenport, Eds. Cham: Springer International Publishing, 2019, pp. 79–85.

- A very useful handbook that seem geared towards professionals as a quick reference (organization is heavily focused on skimmability)
- Provides a lot of methods for identifying ACS and a quick description of what ACS is
- Also has some information about the history of ACS and some recommendations for process to follow when a doctor thinks a patient might have ACS.

Source 2: A. D. Duckworth, S. E. Mitchell, S. G. Molyneux, T. O. White, C. M. Court-Brown, and M. M. McQueen, “Acute Compartment Syndrome of the Forearm:,” *The Journal of Bone and Joint Surgery-American Volume*, vol. 94, no. 10, pp. e63-1–6, May 2012.

- This source was essentially a survey of people who had a fasciotomy in their forearm to see the demographics of who was most at risk of developing ACS.
- Findings:
    - Predominantly males
    - Longer time between injury and fasciotomy correlated with more complications in the procedure and skin-grafting
    - Age was related to split-thickness and skin-grafting for wound closure

Conclusions/action items:

Use this information in the preliminary presentation on Friday (10/04/19) and in subsequent design decisions

LUCAS RATAJCZYK - Oct 08, 2019, 11:33 PM CDT

Title: ACS Background

Date:10/08/19

Content by: Lucas

Present: Team

Goals: Gather some background information on Acute Compartment Syndrome (ACS)

Content:

Source 3: S. T. B. 1 Challa, A. R. Hargens, A. 1 Uzosike, and B. R. Macias, "Muscle Microvascular Blood Flow, Oxygenation, pH, and Perfusion Pressure Decrease in Simulated Acute Compartment Syndrome," *Journal of Bone*, vol. 99, no. 17, pp. 1453–1459, Sep. 2017.

- A simple paper that essentially proves that pH, ppO_2, perfusion pressure, and blood flow all decrease in a simulated model of ACS.

Source 4: A. Whitney *et al.*, "Do one-time intracompartmental pressure measurements have a high false-positive rate in diagnosing compartment syndrome?:," *Journal of Trauma and Acute Care Surgery*, vol. 76, no. 2, pp. 479–483, Feb. 2014.

- A study was conducted where some people (n = 46) were given fasciotomies based on a single intracompartmental pressure check if the pressure value was in the range established by previous research.
- The error rate was 35% (that's HUGE) meaning that 35% of the patients had a fasciotomy when they did not need one.

Source 5: J. W. Weick *et al.*, "Direct Measurement of Tissue Oxygenation as a Method of Diagnosis of Acute Compartment Syndrome," Nov-2016. [Online]. Available: https://www.ingentaconnect.com/content/wk/jot/2016/00000030/00000011/art00008. [Accessed: 08-Oct-2019].

- A test of diagnosing ACS by measuring partial pressure of Oxygen in the blood (ppO_2)
- It was very accurate and shows promise
- However, in our conversation with Dr. Doro a few weeks ago, he said that the probes needed for this are very expensive (thousands of dollars per probe) and the paper doesn't mention anything about probe pricing (perhaps this is a limiting factor to its application which they sought to downplay?)

Source 6: Attached unpublished paper by Dr. Doro

- It is a small 1-page abstract that shows how he induced ACS in canines (beagles :( ) and saw that the intracompartmental pH was significantly lower in the minutes and hours after ACS was induced when compared with intracompartmental pH in canines without ACS inducement

Conclusions/action items:

Use this information to inform further design decisions and as sources in the background of the preliminary report.

LUCAS RATAJCZYK - Oct 08, 2019, 11:36 PM CDT

Wed., 10/11/17 Basic Science: General Trauma, PAPER #12

PAPER ABSTRACTS

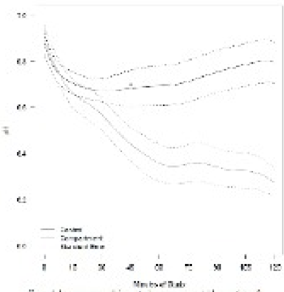
Can Intramuscular pH Levels Diagnose Acute Compartment Syndrome?

Christopher Doro, MD[1]; David Hennessy, MD; Robert V. O'Toole, MD; Thomas F. Higgins, MD
[1]University of Wisconsin, Madison, Wisconsin, USA

Purpose: Acute compartment syndrome (ACS) impacts many trauma patients. Intracompartmental pressure measurements are the current standard of care but have been shown to have important limitations. We hypothesized that pH would be sensitive and specific for determining muscle hypoxia and therefore for diagnosing ACS.

Methods: Compartment syndrome was created in 11 anesthetized adult mixed-sex beagles. ACS was created in the craniolateral compartment of a lower leg by infusion of lactated Ringer's solution. Compartment pressure and pH were recorded with commercially available probes. Our primary outcome measures were intramuscular pH.

Results: Mean arterial pressure averaged 67 mm Hg during the experiment. The compartment pressures were maintained at an average of 86 mm Hg in the experimental limb and an average of 15 mm Hg in the control limb. The initial intramuscular pH concentrations were similar in the experimental and control limbs (6.85 vs 6.85, P = 0.94). The final pH in the experimental limb was 6.28 versus 6.79 in the control limb (P <0.001). The control and experimental groups were significantly different 45 minutes after ACS creation (6.68 control vs 6.45 experimental, P = 0.001). Using a pH threshold of 6.3 or less, our data were 72.7% (39.3%-92.7%, 95% confidence interval [CI]) sensitive and 100% (97.1%-99.5%, 95% CI) specific for compartment syndrome. Receiver operating characteristic curve analysis for pH demonstrated 0.875 area under the curve.



Conclusion: This study describes a novel technique for diagnosing ACS in a canine model. Our results are promising and show that intramuscular pH identifies muscle ischemia within 45 minutes of ACS creation with decent sensitivity and high specificity in this animal model and further work should be aimed at refining this technology.

OTA_AM17_Paper_012.pdf(665.9 KB) - download Source 6

ISFET Background

LUCAS RATAJCZYK - Oct 09, 2019, 12:07 AM CDT

Title: ISFET Background

Date: 10/08/19

Content by: Lucas

Present: Team

Goals: Compile background information about ISFETs and their operation

Content:

Source 1: C.-S. Lee, S. K. Kim, and M. Kim, "Ion-Sensitive Field-Effect Transistor for Biological Sensing," *Sensors*, vol. 9, no. 9, pp. 7111–7131, Sep. 2009.

- A paper dedicated to the application of ISFETs as sensors for biomolecules like DNA, proteins, enzymes, cells, etc.

Source 2: M. J. Schoning and A. Poghossian, Eds., *Label-free biosensing*. New York, NY: Springer Berlin Heidelberg, 2018.

- A textbook that has a chapter about ISFETs
- Great reference

Conclusions/action items:

Use this information as sources for the preliminary report and to inform further design decisions.

Reference Electrodes

LUCAS RATAJCZYK - Dec 11, 2019, 1:44 AM CST

Title: Iridium Oxide Contact

Date: 10/28/19

Content by: Lucas

Present: Team

Goals:

Content:

While looking into reference electrode research, Hunter had encountered something called Iridium Oxide which was supposed to be a good coating for a nonpolarizable electrode (metal with a layer of electrolyte on it that acts as a buffer with the actual solution - for more, see the entry summarizing information from BME 462). Dr. Nimunkar had been mentioning that we should try and set up meetings with people around here (Madison area) who might be able to help us with our research so I decided to do a quick search for UW Madison and Iridium Oxide and found a paper (citation and pdf below) with some of the authors being from UW Madison. One was listed as a corresponding author: Sundaram Gunasekaran. I plan to email him and try to set up a meeting to discuss some of the more confusing aspects of the research we've been encountering and whether or not Iridium-oxide is a good option for us.

UPDATE: After repeated attempts to establish contact (none of which were answered), I give up on him. If we run into issues later and need his help, I'll try calling him ((608) 262-1019) or, as a last resort, dropping by the offices listed for him on the UW directory (231 Agricultural Engineering Building - 460 Henry Mall, or 115 Agricultural Engineering Laboratory - 540 Elm Drive).

Conclusions/action items:

Email Dr. Gunasekaran (guna@wisc.edu) to set up a meeting

LUCAS RATAJCZYK - Dec 11, 2019, 3:38 AM CST

Title: Electrodeposition of Iridium Oxide

Date: 11/12/19

Content by: Lucas

Present: Team

Goals: Compile some information about how to use electrodeposition to apply a layer of iridium-oxide to a metal.

Content:

We were all rather confused about how to get the thin layer of iridium oxide onto the metal to make the nonpolarizable electrode out of it. Today's team meeting was largely focused on finding out how to do that so we found some papers that mentioned how the researchers actually did this (most seem to take it for granted that the reader knows how to do so.

Source 1: Anodically electrodeposited iridium oxide films microelectrodes for neural microstimulation and recording (https://www.sciencedirect.com/science/article/pii/S0925400508008113)

Y. Lu, T. Wang, Z. Cai, Y. Cao, H. Yang, and Y. Y. Duan, “Anodically electrodeposited iridium oxide films microelectrodes for neural microstimulation and recording,” Sensors and Actuators B: Chemical, vol. 137, no. 1, pp. 334–339, Mar. 2009.

> *2.1. Electrode fabrication*
> *A Platinum microelectrode was fabricated by sealing a platinum wire (d = 100 μm, 99.95%) into a glass capillary. Prior to use, electrodes were polished with sandpaper and ultrasonically cleaned in acetone and deionized water successively. In all electrochemical experiments, electrodes were mounted in a three-electrode cell with a saturated calomel electrode (SCE) as reference electrode and a large-area platinum electrode as counter electrode.*
> *2.2. Electrodeposition*
> *The deposition solution was prepared similarly to the method reported by Yamanaka [20]. 3 mM hydrogen hexachloroiridate hydrate (H2IrCl6·6H2O) was dissolved in deionized water by magnetic stirring, and 100 mM oxalic acid (H2C2O4·2H2O) was added to form a stable complex of iridium oxide. The pH of the solution was then adjusted to 10.5 by gradually adding K2CO3. The resulting solution was allowed to age for at least 5 days in the dark at room temperature until it turned dark blue. An absorption spectra of the freshly prepared and stabilized deposition solution was measured using a Shimadzu UV-240 Ultraviolet-Visible spectrometer. The deposition solution can be used after preservation at room temperature for more than 2 months.*
> *EIROFs were fabricated by an anodic electrochemical process with a Potentiostat/Galvanostat (Princeton Applied Research, Model 273A, U.S.) in the stabilized deposition solution at room temperature. The electrodeposition process was carried out by cyclic voltammetry (CV) scanning between 0.05 and 0.55 V (vs. SCE) at a scanning rate of 50 mV/s for 50 cycles followed immediately by potential pulsing at the same potential limits for 400–1000 pulses.*

As you can see in the first sentence under section 2.2, the authors reference a "method reported by Yamanaka" which the others on the team also found in the papers they found so we looked into it (pdf and link below).

Source 2: Ruthenium Oxide Alternative to Iridium pH Electrode (https://www-sciencedirect-com.ezproxy.library.wisc.edu/science/article/pii/S0925400519309797?via%3Dihub#fig0005)

R. H. G. Mingels, S. Kalsi, Y. Cheong, and H. Morgan, “Iridium and Ruthenium oxide miniature pH sensors: Long-term performance,” Sensors and Actuators B: Chemical, vol. 297, p. 126779, Oct. 2019.

This source gave some more detail about this EIROF thing we had seen mentioned earlier and how to make it.

> *2.2. Electrochemical iridium oxide film (EIROF)*
> *Electrochemical deposition was performed using a 3-electrode cell consisting of a Pt electrode (the sensor), a Pt counter electrode, and a commercial Silver/Silver-chloride (Ag/AgCl) reference electrode with 3 M internal filling (Single Junction, Sigma Aldrich, UK). An adhesion layer of Gold (Au) was first plated onto the platinum electrode using electrodeposition at constant current (1 mA cm−2) with a gold plating solution (Spa Plating Ltd., UK) and a PalmSense3 potentiostat (PalmSense b.v., The Netherlands). The Au plated electrodes were rinsed in DI water and immediately used for EIROF formation.*
> *EIROF deposition followed the method of Yamanaka [25]. Stock solutions were prepared as follows: 0.5 g of IrCl4 hydrate (Sigma Aldrich, UK) was dissolved in 100 mL of deionised (DI) water and stirred for 30 min. Next, 10 mL of 30% v/v hydrogen peroxide (Sigma Aldrich, UK) was added and left to stir for 10 min. After, 0.5 g of oxalic acid dehydrate (Sigma Aldrich, UK) was added and stirred for 10 min. Potassium carbonate (Sigma Aldrich, UK) was added gradually until a pH of 10.5 was achieved. The solution was left to stir overnight before aliquoting for further*

> *use. Aliquots were stored at 4 °C and allowed to reach room temperature before use. EIROF electrodeposition was performed using cyclic voltammetry with potential sweeps between +0.2 V and +0.7 V for a minimum of 125 cycles at a 50 mV s−1 scan rate, after which a blue EIROF film formed.*
>
> *2.5. Experimental details*
>
> *Initially the sensors were immersed in phosphate buffered saline (PBS) at elevated temperature (100 °C or 37 °C for 3 to 12 h respectively) and then imaged. All potentiometric measurements were performed with a temperature bath (SWB-20L-2, Cleaver Scientific Ltd., UK) set to 37.5 ± 2 °C, unless specified otherwise. For pH calibrations, commercial buffer solutions (pH 4, 6, 7, 9 and 10) were used (Hannah Instruments, UK). A commercial glass pH probe measured the pH immediately after sensor measurements were taken. Buffers were allowed to equilibrate by placing them in the temperature bath prior to pH recordings. The commercial pH probe was calibrated under the same conditions. A commercial double junction Ag/AgCl RE with 3 M KCl internal filling (Sigma Aldrich, UK) was used for the reference potential. The electrode potential stability was checked prior to the experiments against a master reference electrode from the open circuit potential (OCP). For long-term measurements, sensors were immersed in PBS. This solution evaporated with time but was replenished as needed with DI water. The pH of the solution was checked prior to calibration, and on a weekly basis.*
>
> *The OCP of EIROF and RUOF sensors was measured with a high input impedance port (pH/ORP adapters (Robot Shop, UK) running in pH mode with a minimum resolution of 1 mV and NI DAQ USB6211 (National Instruments, USA)). Data were recorded initially every second, and then at 30 min intervals. Data was processed using an 1800 points average filter (30 min period) to reduce noise.*
>
> *Calibration was performed for a minimum of 30 min in each buffer solution. The final, stable part of the graph (between 500–1000 data points), was used to compute the average and standard deviation of a linear regression fit (in Origin 9.1). The impedance of the sensors was measured with a PalmSense3 potentiostat with a 100 mVp-p excitation signal; 1 Hz – 50 kHz. For the measurements, sensor chips with two electrodes were used (area = 0.092 cm [2]; electrode separation =2 mm).*

Yamanaka Paper link: https://iopscience-iop-org.ezproxy.library.wisc.edu/article/10.1143/JJAP.28.632/pdf

K. Yamanaka, “Anodically Electrodeposited Iridium Oxide Films (AEIROF) from Alkaline Solutions for Electrochromic Display Devices,” Jpn. J. Appl. Phys., vol. 28, no. Part 1, No. 4, pp. 632–637, Apr. 1989.

Conclusions/action items:

Get the necessary materials for electrodeposition of iridium oxide and hopefully make an iridium oxide electrode for the final design.

LUCAS RATAJCZYK - Dec 11, 2019, 3:39 AM CST

Sensors and Actuators B: Chemical

Anodically electrodeposited iridium oxide films microelectrodes for neural microstimulation and recording

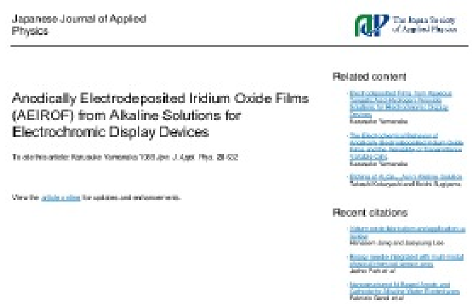
Yi Lu, Tanyuan Wang, Zhengxu Cai, Yuliang Cao, Hanxi Yang, Yanwen Y. Duan *

Lu_et_al._-_2009_-_Anodically_electrodeposited_iridium_oxide_films_mi.pdf(791 KB) - download Source 1 pdf

LUCAS RATAJCZYK - Dec 11, 2019, 3:39 AM CST

Mingels_et_al._-_2019_-_Iridium_and_Ruthenium_oxide_miniature_pH_sensors_.pdf(6.2 MB) - download Source 2 pdf

LUCAS RATAJCZYK - Dec 11, 2019, 3:40 AM CST



Yamanaka_-_1989_-_Anodically_Electrodeposited_Iridium_Oxide_Films_A.pdf(1.1 MB) - download Yamanaka Paper pdf (source 3)

LUCAS RATAJCZYK - Dec 11, 2019, 4:13 AM CST

Title: Notes from BME 462 about electrodes

Date: 11/13/19

Content by: Lucas

Present: Lucas

Goals: Compile information about electrodes from BME 462 lectures that may be useful for the project.

Content:

Electrodes convert the ionic currents in the body into electrical ones for circuitry.

Electrode-Electrolyte Interface: The point of contact between the electrode and the electrolyte where the conversion occurs. No free charge carriers crosses this boundary, the charge transfer is indirect. Metal cations naturally leak into the electrolyte and eventually reach some equilibrium where the charge difference between the metal (now negative because positive cations have left their electrons behind) and the electrolyte (now positive because metal cations are positive). When the anions in the body that carry current come and interact with the metal cations, they disrupt this equilibrium and free some electrons from the other side (in the metal) which then move off into the circuit as current.

The part of the electrolyte that is directly adjacent to the metal actually is free of charge so there is a capacitive effect that is called polarization. Some kinds of electrodes try to emphasize this effect and are called polarizable electrodes (usually noble metals) and have no buffer zone on them. Conversely there are nonpolarizable electrodes which are a noble metal with a buffer layer consisting of the bonded form of the metal's cation with an anion in the electrolyte that are called nonpolarizable electrodes. For example, a nearly ideal nonpolarizable electrode is the Ag/AgCl electrode, which is a pure silver wire (Ag) with a buffer layer of AgCl (the bonded form of Ag^+ with Cl^-, the metal cation and a common anion in biological applications).

Polarizable electrodes are sensitive to motion because movement of the electrode relative to the electrolyte disrupts the equilibrium potential that had been developed and takes time to reestablish in the new position. However, they are also generally more biocompatible since the capacitive effect prevents a lot of the metal cations from leaching into the electrolyte (which is blood when implanted).

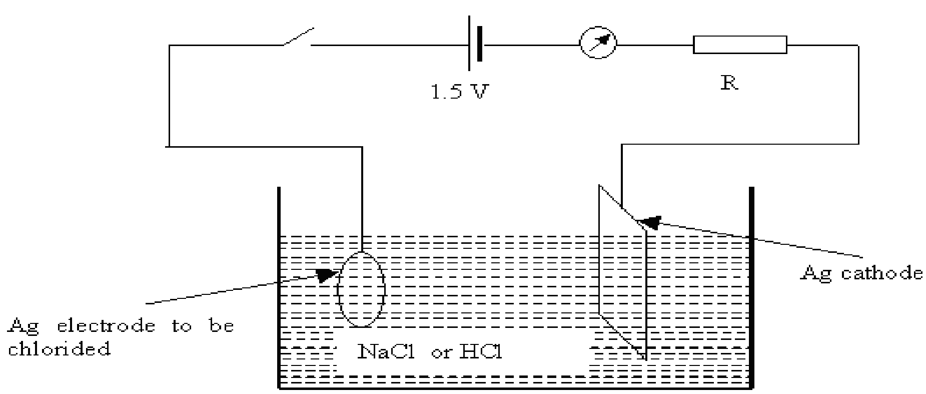
Nonpolarizable electrodes are the opposite: less biocompatible but more resistant to motion.

Electrodeposition:

A method of generating that buffer layer that surrounds nonpolarizable electrodes.

The diagram below shows the setup. When current flows in the system, the round silver piece becomes positively charged so Cl^- from the solution bonds to exposed Ag^+ on the metal surface to form AgCl on the silver piece. The other silver piece (cathode) becomes negatively charged and attracts the Na^+ or K^+ that is in the solution.

The current and time of exposure are related by the equation: I = 100mA * exp(-t/10s) [I = current (mA), t = time (s)] but I can't seem to find the equation relating these to the thickness of the AgCl layer.



The slide deck for this lecture from BME 462 is attached below this entry.

Conclusions/action items:

Hopefully, this information will prove useful when trying to understand the papers we encounter.

LUCAS RATAJCZYK - Dec 11, 2019, 4:14 AM CST

BME_462_Lecture_11_Slides.pdf(757.2 KB) - download

Electrode Characterization

LUCAS RATAJCZYK - Apr 28, 2020, 5:47 PM CDT

Title: Electrode Characterization

Date: 4/1/20

Content by: Lucas

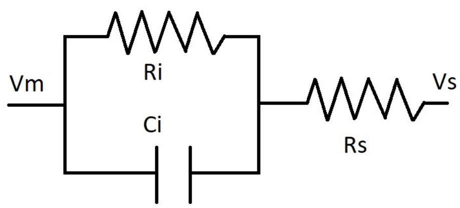
Present: Lucas

Goals: Set a map for things needed to characterize our electrodes by researching an electrode characterization paper.

Content:

Source 1: W. Franks, I. Schenker, P. Schmutz, and A. Hierlemann, "Impedance characterization and modeling of electrodes for biomedical applications," *IEEE Transactions on Biomedical Engineering*, vol. 52, no. 7, pp. 1295–1302, Jul. 2005, doi: 10.1109/TBME.2005.847523.

- Need a model of the physical processes contributing to impedance
- Equivalent circuit model
    - From this generate equations to explain behavior and validate equations by testing electrodes
        - Will we even be able to test the electrodes to validate our equations?
    - Since our electrodes are in contact directly with the inner tissue, we don't need the circuit blocks for skin or sweat glands
    - Interface resistance (Ri) and capacitance(Ci) in parallel with a solution resistance (Rs) in series with it.

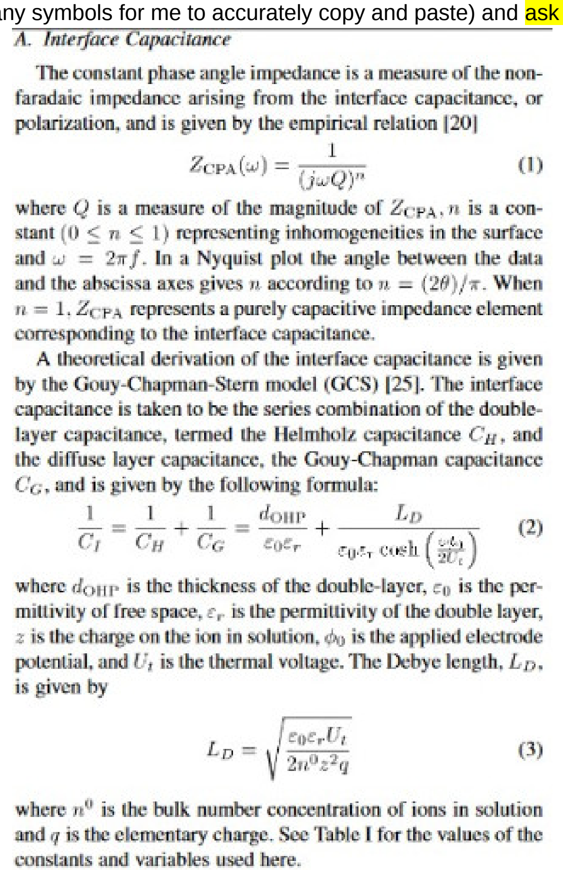


        - According to the authors, for a bare Pt electrode ($1\ cm^2$), Ri = 300 kΩ, Rs = 32 Ω, and Ci = 0.545 F/m^2
        - I included that bit about ignoring the skin and sweat gland bits of the circuit because I thought they would mention those considerations with their model but I think their electrodes are also implanted because they do not mention these. Which is great because it means the paper is even more applicable to our situation
- This paper does this for different types of electrodes with different organic coatings so they have a lot more parameters like incubation time etc.
- This paper largely focuses on the electrodes as a method of measuring the activity of excitable cells. Since we are using them to measure pH, perhaps I should look into pH electrode characterization instead of general electrode characterization.
- Mentions of "McAdams and colleagues" who did some work characterizing a platinum-iridium wire (90%-10%) in saline
    - E. McAdams,"Effect of surface topography on the electrode-electrolyte interface impedance,"Surface Topogr., vol. 2, pp. 107–122, 1989.
    - E. T. McAdams and J. Jossinet,"Physical interpretation of Schwan's limit voltage of linearity,"Med. Biol. Eng. Comp., vol. 32, pp. 126–30,1994.
    - E. T. McAdams, A. Lackermeier, J. A. McLaughlin, D. Macken, and J.Jossinet, "The linear and nonlinear electrical properties of the electrode-electrolyte interface,"Biosensors Bioelectron., vol. 10, pp. 67–74, 1995.
- A Kovacs (ha ha, I know how to pronounce this name because of Altered Carbon) apparently made an equivalent circuit model for this electrode that includes "an additional Warburg impedance due to the diffusion of faradaic current"
    - G. T. A. Kovacs,"Introduction to the theory, design, and modeling of thin-film microelectrodes for neural interfaces,"in Enabling Technologies for Cultured Neural Networks, D. A. Stenger and T. M. McKenna, Eds. London, U.K.: Academic, 1994, pp. 121–165.
- Apparently, the authors used "electrochemical impedance spectroscopy (EIS)" to characterize the electrodes but no source is given for a protocol. Will have to see if there's one later in the paper
- Electrode fabrication details provided in methods
    - Lots of terms for techniques and materials which we did not use ("Sputter deposition", PECVD, adhesion promoters, etc.)
    - Ooh, found the electrodeposition section, now I understand what's going on.
    - They coated the non-contact parts of their electrodes and the connected bare wire with PDMS to electrically insulate. This might be a good idea for our application.

- I found a section that I think describes how they tested the impedance but it requires a potentiostat. Since Jonah is blocked from his lab by COVID-19, we do not have access to a potentiostat and therefore cannot do this. Hopefully I am wrong but here's the quote:

> *Measurements were performed using a commercially avail-able Autolab PGSTAT30 potentiostat system with FrequencyResponse Analysis software (version 4.9, Eco Chemie B.V.,Netherlands). In this three-electrode system, a standard calomelel ectrode (SCE) is the reference electrode, the counter electrode is large-area Pt, and the electrolyte is physiological saline,0.9% NaCl. In addition to the time dependency measurements,neuron medium with 10% horse serum was used as the elec-trolyte in one set of measurements. The perturbation potential was 10 mV and the scan range was 10^-3 to 10^5 Hz, unless otherwise noted. Measurements were typically performed with respect to the open-circuit potential (OCP), the potential naturally occurring between the working and reference electrodes. The OCP is a function of the chemical composition of the interface,and can significantly affect the impedance results.*

- Organic residues on the electrode surface decrease that faradaic resistance they mentioned and makes the electrode polarizable
- When they were characterizing the microelectrodes, they had to reduce the frequency range to 10^-2 to 10^5 Hz because the current was too small (dozens of **nano**amps)
- According to the authors (actually their source 7 - the Kovacs source from earlier), **physiological saline has a resistivity of 72 Ohm*cm**
  - The **solution resistance for a round (cylindrical) electrode is ρ / 4r**, where r is the radius of the end and ρ is the solution resistivity (72 Ohm*cm)
  - I think they assume only the tip is in contact with the solution since they go on to say that this only depends on the geometric area in contact with the solution (adding ridges to the surface doesn't increase the geometric area) but there is no parameter for electrode "height" which would be needed if it was assumed the cylinder sides were in contact with solution.
- They do have an explanation of the interface capacitance but it is just enough over my head that I will just include a picture of the text (too many symbols for me to accurately copy and paste) and ask for help from Dr. Nimunkar during our next meeting.



A. Interface Capacitance

The constant phase angle impedance is a measure of the non-faradaic impedance arising from the interface capacitance, or polarization, and is given by the empirical relation [20]

$$Z_{\mathrm{CPA}}(\omega) = \frac{1}{(j\omega Q)^n} \quad (1)$$

where Q is a measure of the magnitude of Z_{CPA}, n is a constant $(0 \le n \le 1)$ representing inhomogeneities in the surface and $\omega = 2\pi f$. In a Nyquist plot the angle between the data and the abscissa axes gives n according to $n = (2\theta)/\pi$. When $n = 1$, Z_{CPA} represents a purely capacitive impedance element corresponding to the interface capacitance.

A theoretical derivation of the interface capacitance is given by the Gouy-Chapman-Stern model (GCS) [25]. The interface capacitance is taken to be the series combination of the double-layer capacitance, termed the Helmholz capacitance C_H, and the diffuse layer capacitance, the Gouy-Chapman capacitance C_G, and is given by the following formula:

$$\frac{1}{C_I} = \frac{1}{C_H} + \frac{1}{C_G} = \frac{d_{\mathrm{OHP}}}{\varepsilon_0 \varepsilon_r} + \frac{L_D}{\varepsilon_0 \varepsilon_r \cosh\left(\frac{z\phi_0}{2U_t}\right)} \quad (2)$$

where d_{OHP} is the thickness of the double-layer, ε_0 is the permittivity of free space, ε_r is the permittivity of the double layer, z is the charge on the ion in solution, ϕ_0 is the applied electrode potential, and U_t is the thermal voltage. The Debye length, L_D, is given by

$$L_D = \sqrt{\frac{\varepsilon_0 \varepsilon_r U_t}{2 n^0 z^2 q}} \quad (3)$$

where n^0 is the bulk number concentration of ions in solution and q is the elementary charge. See Table I for the values of the constants and variables used here.

- What I called Ri in my equivalent circuit sketch above, they call Rct (charge transfer resistance)
  - Rct = (R * T) / (J_0 * z * F)
  - R is the gas constant
  - T is the temperature
  - F is Faraday's constant
  - z was assumed to be 4 because it is the number of electrons consumed/produced by the reaction which allows current to directly flow from electrode to solution ($2H_2O$ <--> $O_2 + 4H^+ + 4e^-$)
  - J_0 was determined experimentally using the procedure in the quote below (which also sounds like it requires a potentiostat)

> *Cyclic voltammetry was used to determine J_0 under the following conditions: 5 mV perturbation signal with respect to the OCP, 0.5 mV/s scan rate, 0.15 mV step potential, averaged over 10 scans*

Conclusions/action items:

Research more detail about Ag/AgCl electrode and Pt/IrOx electrode characterization. Highlighted items above are points for further research and/or topics to bring up in meeting.

LUCAS RATAJCZYK - Apr 02, 2020, 8:31 PM CDT

Impedance Characterization and Modeling of Electrodes for Biomedical Applications

I. INTRODUCTION

Franks_et_al._-_2005_-_Impedance_characterization_and_modeling_of_electro.pdf(416.1 KB) - download A pdf version of source 1

LUCAS RATAJCZYK - Apr 09, 2020, 8:31 PM CDT

Title: Electrode Impedance Characterization

Date: 4/8/20

Content by: Lucas

Present: Lucas

Goals: Learn more about the impedance characteristics of electrodes (originally thought this paper would be about Pt-Ir electrodes but it is just general electrode info with a section about silver-silver chloride electrodes)

Content:

Source 2: E. T. McAdams, A. Lackermeier, J. A. McLaughlin, D. Macken, and J.Jossinet, “The linear and nonlinear electrical properties of the electrode-electrolyte interface,”Biosensors Bioelectron., vol. 10, pp. 67–74, 1995.

- Warburg impedance is in series with the interface resistance and is especially a factor for low frequency signals
  - $Z_W = (1 - j)\sigma\omega^{-0.5}$
  - σ is diffusion coefficient
  - This may be an issue for our application since the pH readings should theoretically be a DC signal as it is held constant through homeostatic mechanisms. Although our product will be used to check for cases where these mechanisms are overwhelmed and damage is being inflicted, any changes should not be oscillatory.
  - "It would appear from eqn. 2 that the diffusion impedance does not permit the passage of DC current, as it tends to infinity as ω approaches zero. **This is not the case**, however, as eqn. 2 is an over-simplification and a more rigorous derivation of the expression for Z, leads to a finite impedance at w = 0 (Schuhman, 1966)" - Note that eqn. 2 is the equation I gave above for Warburg impedance
  - When frequency is small but still above 1 Hz, the model can be simplified to just the interface capacitance in series with the solution resistance.
- Silver - Silver Chloride Electrodes:
  - When in contact with chloride gel, Ag/AgCl electrodes have:
    - Low and stable electrode potential
    - Small interface impedance
    - Small Ri (non-polarizable electrode)
  - Electrode potential is stable when in a solution whose main negative ion is Cl^- which may be good because the body has a lot of that but decreasing blood pH is caused by metabolic production of protons and negative ions (ex: splitting an H off an -OH group). Also, I may be misremembering but I think that most proteins and other cellular molecules are anionic, which may decrease the stability of the reading.
  - Silver chloride has conductivity of about 10^5 - 10^6 Ωcm
  - Increasing AgCl layer thickness increases the "solution resistance" which I will now be calling Rtotal since it includes both the solution resistance and the electrolyte impedance.
    - 1 mm thick and 1 cm^2 layer = 10 - 100 Ω

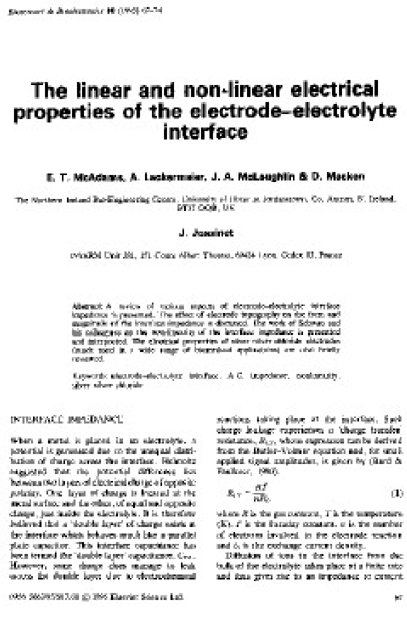
Conclusions/action items:

Move on to the next source since this one didn't have much relevant info.

Let the team know about the info I did manage to learn from this one.

- An equation for the impedance in series with the interface resistance
- A little bit about Ag/AgCl electrodes and how they work best (more stable readings) in a Chloride rich solution (may be bad)
- No new info about how to experimentally determine the circuit model parameters

LUCAS RATAJCZYK - Apr 09, 2020, 6:23 PM CDT



The linear and non-linear electrical properties of the electrode–electrolyte interface

E. T. McAdams, A. Lackermeier, J. A. McLaughlin & D. Macken

J. Jossinet

INTERFACE IMPEDANCE

$$R_{CT} = \frac{RT}{nFi_0} \quad (1)$$

McAdams_et_al._-_1995_-_The_linear_and_non-linear_electrical_properties_of.pdf(668.7 KB) - download A pdf version of Source 2

LUCAS RATAJCZYK - Apr 23, 2020, 3:21 PM CDT

Title: Pt-Ir Electrodes

Date: 4/16/20

Content by: Lucas

Present: Lucas

Goals: To learn more about how physical parameters influence the equivalent circuit model for a Pt-Ir electrode

Content:

Source 3: E. T. McAdams and J. Jossinet, “Physical interpolation of Schwan’s limit voltage of linearity,” Medical & Biological Engineering & Computing, vol. 32, no. 2, pp. 126–130, Mar. 1994.

- Faradaic resistance (Ri) is derived from the "Butler-Volmer equation"
- As I am skimming this document, it seems to be a continuation of the same style of research as the previous sources, which were too vague with regards to the physical properties of the electrode. Therefore, I will be moving on to a new source. If needed, I/we can always return to this as it is attached in pdf form below.

Source 4: A. Blau et al., “Characterization and optimization of microelectrode arrays for in vivo nerve signal recording and stimulations,” Biosensors & Bioelectronics, vol. 12, no. 9–10, pp. 883–892, 1997.

- According to this paper, the authors evaluated the iridium oxide electrodes using "scanning force microscopy and impedance spectroscopy"
    - What is this impedance spectroscopy? It sounds like what we would want to do with our electrodes
- I might look more into it if we need but there is an older source reported here that supposedly talks about the biocompatability of iridium and platinum ("Blau et al. 1997a")
    - They say iridum oxides has "good biocompatability"
- AHA! A definitive statement that electrodeposited iridium has a low electrode impedance even at low frequencies! Now I just need to put an actual number and/or equation to "low electrode impedance"

> *The most important effect of electrochemical platinum deposits is their almost constant impedances between 1 and 100 kHz. However, for nerve signal recording the frequency range down to 10 Hz is also of interest. As shown in Fig. 5, iridium deposits satisfy the requirement of a constant low electrode impedance from below 10 Hz to higher frequencies in 0.9% NaCl (physiological sodium chloride solution).*

- Lo and behold in the next line:
    - "The electrode after electrochemical iridium deposition could be modeled as a simple R_E (R_{Ct} Q_{D1}) circuit with the resistance of the electrolyte R_E = 48 Ω (relative error r.e.: 0.39%), the charge transfer resistance R_{Ct} = 1.06 kΩ (r.e.: 18.97%) and a constant phase element Q_{D1} = 1.5 $mFs^{(s-1)}$ (r.e.: 0.89%) with n = 0.92 (r.e.: 0.49%) for the electrode/electrolyte double layer with a total immersed electrode area of 10 mm^2."
- This is great but once again, there is little mention of how the physical size of the electrode or the thickness of the IrOx layer impacts these values. Ideally we would try to replicate the procedure by which they generated these values (block quote below) but it seems this would require a potentiostat (stupid COVID-19)

> *Electrode spectroscopy*
>
> *Impedance spectra were recorded between 1 mHz and 1 kHz and between 1 mHz and 100 kHz, respectively, with the above-mentioned potentiostats and in one case with an additional EG & G lock-in amplifier (model 5210) and EG & G Electrochemical Impedance Software (M398). The influence of the AIROF thickness on the impedance properties of the electrode was examined at electrodes which were oxidized with different numbers of activation cycles. Equivalent circuit elements were calculated with the program Equivalent Circuit V4·51, distributed by EG & G and developed by Boukamp at the University of Twente, the Netherlands. The CDC was determined from the area under the cyclic voltammetry curves.*

- A few notes about the above quote:
    - The "above-mentioned potentiostats" were the "computer controlled EG & G potentiostats" models 6310 and 273 and used EG & G Research Electrochemistry Software M270
    - They mention how they look at the effect of IrOx film thickness on impedance properties but the only data I can find in the paper which relies on activation cycles as they say they used to approximate layer thickness (more activation cycles = more layers of IrOx) is the relation with "maximum charge delivery capacity [mC/cm^2]" which I do not know how to relate to impedance or any of the other circuit model parameters. I

included this figure below (figure 6)

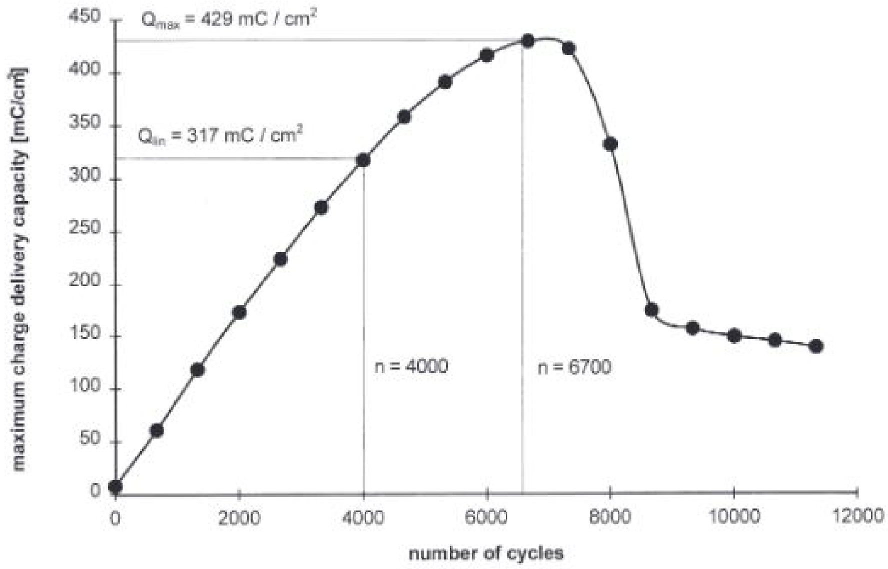


Fig. 6. Reversible charge delivery capacity of sputter deposited iridium/iridium oxide thin film electrodes as a function of potential cycles. The CDC is determined from the area under the CV spectra.

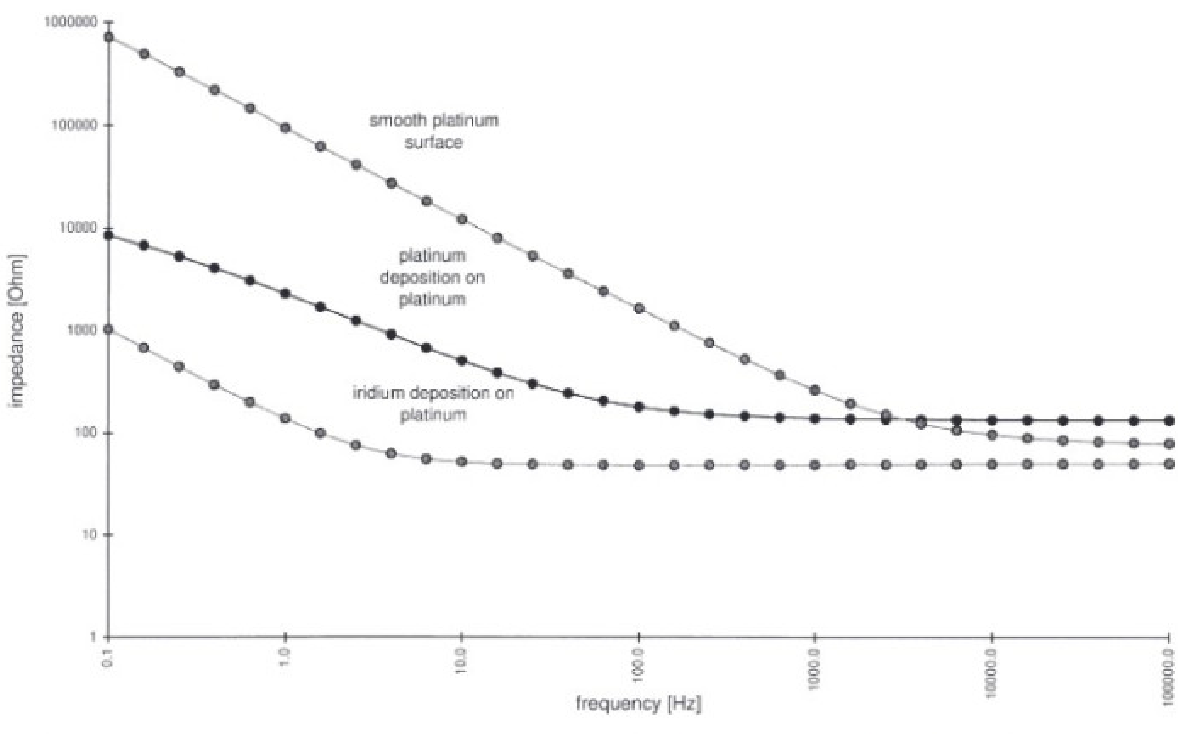


Fig. 5. Impedance diagram before and after electrochemical platinum and iridium deposition, respectively, onto smooth platinum microclectrodes.

Conclusions/action items:

Present these findings to the group and Dr. Nimunkar to see if we can use this frequency vs impedance graph and the values from earlier.

If we cannot, continue the search, otherwise begin working on a different aspect of the project.

LUCAS RATAJCZYK - Apr 17, 2020, 11:10 AM CDT


Transducers and electrodes

Physical interpretation of Schwan's limit voltage of linearity

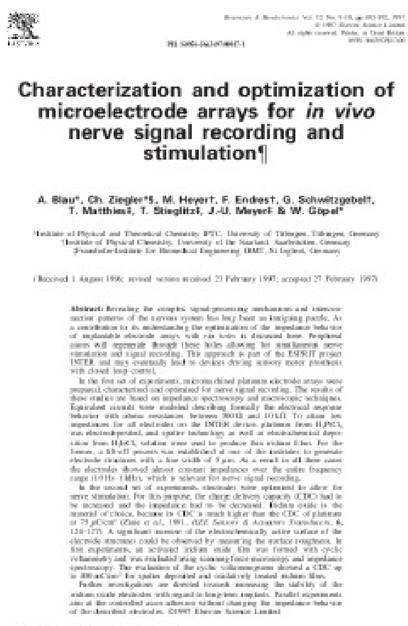
E. T. McAdams[1] J. Jossinet[2]

Abstract—The electrode/electrolyte interface impedance can be represented by the parallel combination of a non-faradaic pseudocapacitance and a faradaic, charge transfer resistance. The non-linearity of the overall electrode/electrolyte interface impedance is largely due to that of the faradaic resistance which is derived from the Butler-Volmer equation. As the charge transfer resistance dominates the interface impedance at low frequencies, it is in this region that non-linearities are first observed. The voltage limit of linearity has been investigated and found to increase gradually for higher frequencies. Although relatively linear compared with the charge transfer resistance, the non-faradaic impedance becomes non-linear at large applied voltage amplitudes and dominates the high frequency non-linear behaviour of the overall interface impedance. Mid-frequencies are affected by a combination of the faradaic and non-faradaic non-linearities.

Keywords—Electrical impedance, Electrodes, Non-linearity, Voltage limit of linearity

BF02518908.pdf(1.1 MB) - download Source 3 in pdf format

LUCAS RATAJCZYK - Apr 17, 2020, 11:10 AM CDT


Characterization and optimization of microelectrode arrays for *in vivo* nerve signal recording and stimulation¶

A. Blau*, Ch. Ziegler*§, M. Heyer†, F. Endres†, G. Schwitzgebel†, T. Matthies‡, T. Stieglitz‡, J.-U. Meyer‡ & W. Göpel*

Blau_et_al._-_Characterization_and_optimization_of_microelectrod.pdf(588.4 KB) - download Source 4 in pdf format

ISFET Idea 10-02-19

LUCAS RATAJCZYK - Oct 08, 2019, 11:03 PM CDT

Title: ISFET Design Ideas

Date: 10/02/19

Content by: Lucas

Present: Team

Goals: Generate some design solutions for the ISFET's limitations

Content:

Issues:

1. The reference probe must be in the solution (blood) with the ISFET
2. The ISFET ribbon cable is very small relative to the needle length

Solutions:

- (Issue 1) Use the needle itself as the reference probe
    - The needle may not act as an Ag/AgCl electrode and be unable to be cheaply made with and Ag/AgCl electrode tip
- (Issue 1) Have both the ISFET bare die and the reference probe inside the needle tip but separated by a wall of insulation
    - Can we purchase anything like this?
    - Would the insulation be sterilizable?
    - May have issues with a doctor needing to insert the ISFET, the reference, and the insulation into the needle in a stressful environment
        - Package the three already bound together?
- (Issue 1) Purchase a probe that has the ISFET and reference already connected (presented by Jonah)
    - Where can we find such a probe?
    - Would it be expensive as a disposable probe?
    - How easy would it be to sterilize this?
- (Issue 2) Draw some of the intracompartmental blood into the needle where it will then encounter the ISFET
    - Would this be less accurate than pH measurements *in situ*?
    - Higher pressure associated with ACS would aid the blood extraction process
- (Issue 2) Buy an ISFET that comes with a longer ribbon cable (presented by Syafiqah)
    - How expensive would such a product be?
    - Could this be sterilized or implemented as a disposable probe?
- (Issue 2) Create our own ribbon cable or purchase a ribbon cable and attach the bare die to it ourselves (presented by Hunter)
    - Requires access to the nanofabrication center (very expensive) and skill with dealing on that scale

Conclusions/action items:

Some of the ISFET's main issues are potentially solvable, we must now evaluate which solutions to them are available to us (price, manufacturing skill, product availability).

Biomethodology of Swine

LUCAS RATAJCZYK - Mar 10, 2020, 8:30 PM CDT

Title: Biomethodology of Swine

Date: 3/10/20

Content by: Lucas

Present: Lucas

Goals: Take notes on the RARC training module for learning the biomethodology of swine (pigs) prior to testing in cadavers and live pigs

Content:

- Swine have been used a lot in biomed research
- Two main types used:
    - Domestic pigs (normal ones used on farms)
        - Short term studies
        - Usually young ones used because they're big and hard to handle once grown
        - Later sexual maturation
    - Minipigs (smaller ones specifically made for research)
        - Docile
        - Some bred to be specifically free of certain pathogens
        - Longer lifespan, good for chronic and longer-term studies
        - Skin sensitivity studies performed on hairless breeds of minipigs
- Domestic pig scientific name: Sus scrofa domestica
- Similarities between pigs and humans:
    - Internal organ arrangement and size
    - Weight
    - Nutrient requirements
- Pigs have firm nose reinforced with cartilege
- **Rooting** = exploring environment with nose as primary interface
- Pigs don't like to be on slippery surfaces
- Mature **Boars** (uncastrated males) and **Barrows** (castrated males) have tusks with sharp edge for slicing. Trimmed periodically because the tusks grow throughout life.
- **Sows** (females that have given birth) may have canine teeth. So can **Gilts** (females that haven't had birth yet).
- Piglets have sharp neonatal "needle teeth" that need to be trimmed or ground down to prevent damage to other piglets trying to suckle or to the mother being suckled.

> *The sow's breeding season extends over the whole year, except when she is pregnant or suckling young piglets. Gilts can generally be bred at 6 to 7 months of age. **Estrus** is indicated by a vaginal discharge of mucus accompanied by swollen, congested external genitalia and by mounting behavior. Handlers detect estrus as receptivity to breeding when they press a hand on the female's back and the animal assumes a breeding stance. Increasing the feed allowance 7 to 10 days before breeding is thought to lead to an increased litter size.*

Table 26.1

Table 26.1. Swine biological data.

	Domestic	Miniature	Micro-miniature
Body weight (kg)	Adult male: 200–300 Adult female: 200–300 Newborn: 1.3–1.9	Adult male: 70–90 Adult female: 70–90 Newborn: 0.6–1.0	Adult male: 35–55 Adult female: 35–55 Newborn: 0.4–0.7
Normal body temperature	38–39 °C 100.4–102.2 °F	38–39 °C 100.4–102.2 °F	37–38 °C 98.6–100.4 °F
Heart rate (beats per minute)	94–106	98–112	68–98
Respiration rate (breaths per minute)	17–23	21–29	11–29
Life span (years)	15–25	10–15	10–15
Daily consumption	Feed: 2–3 kg per 100 kg BW Water: 80–120 mL per kg BW	Feed: 1.0–2.1 kg per 100 kg BW Water: 80–120 mL per kg BW	Feed: 1.0–2.1 kg per 100 kg BW Water: 80–120 mL per kg BW
Puberty age (months)	Male: 5–8 Female: 6–8	Male: 4–6 Female: 4–6	Male: 4–6 Female: 4–6
Sexual cycle duration (days)	19–23	18–24	18–24
Sexual cycle type (in lab conditions)	Polyestrous; nonseasonal	Polyestrous; nonseasonal	Polyestrous; nonseasonal
Gestation period (days)	110–116	111–114	111–114
Litter size/# of young	7–12	5–8	5–8
Begins eating solid feed (days)	12–16	12–16	12–16
Age at weaning (weeks)	4–6	4–5	4–5

- Estrus stopping within 21 days of breeding is reasonable indication of pregnancy. Can be confirmed with radiographical methods.
- **Farrowing** = giving birth to a litter of piglets. Sows are isolated in a separate pen to farrow. This pen has guardrails that are slightly off the floor and away from the pen's walls so that the piglets can have a guaranteed mom-free zone to prevent accidental smothering. Newborns susceptible to chilling and hypothermia, usually have a heat lamp in the pen.
- Though social, pigs don't herd well and can become aggressive without warning. When exposed to humans for a while, the pigs get used to it though. Will compete in training for food rewards.
- Have very strong jaws and use their teeth to test objects in environment. Nibble first then bite and pull to test. Pigs may nibble boots and/or clothes but must be shooed away before they decide to bite and pull as this can knock you over or do damage.
- Never kneel in an occupied pig pen, they will knock you over and destroy you. Have a partner to keep them at bay or empty the pen first.
- Pigs like to be scratched behind the ears or on the belly (same for rubbing). This will get them to like you.
- Pigs like clean environment and will use a corner as a "waste" area (usually near their watering area).
- Keep food in a different area to minimize food spoilage. Wow its almost like they expect us to put the food bowls in the pigs' poop area.
- Usually vocal when being herded or hungry but not aggressive.
- Dominance in pig hierarchy is established early in life so most issues are with young boars (especially uncastrated ones). Must carefully observe groups with these ones to minimize damage from dominance disputes.
- Handling
    - Minipigs
        - Gently (on one arm like child)
        - Like to be petted
        - Crouch with the small ones to be less intimidating
        - Food treats are GOOD motivator
    - Domestic
        - Not very good with humans (harder to manipulate)
        - May need restraint devices and multiple people to manipulate
        - Will scream when picked up or physically restrained
        - Need hearing protection if you have prolonged exposure to the screams (ouch)
        - Can be trained to cooperate with some restraint methods but more difficult than with minipigs
    - Common method of restraint for all pig types is a hammock/sling that holds the animal up off the floor with legs going through holes
    - **Terris confinement stand**: Small pen-like structure that confines the standing pig without total immobilization
    - **V-trough**: Can restrain small pigs on back during non-painful procedures but requires two staff members in addition to the person performing the procedure.

    - **Snare**: Restrains large standing domestic pigs. Rope or metal noose fastened around the snout (going through the mouth). Pig will lean back and scream once this is done. Not good for repeat or prolonged use as it is more stressful and damaging to the pig's mouth and gums. Good for non-painful procedures. Originally developed for farm animals and is too rough for minipigs.
- Identification: Usually have ear tag but may have microchip at base of ear. Can also tattoo the ears or put a notch in them but these are more stressful to the pig
- Diet:
    - Don't house in cages (acceptable for short times)
    - Limit group sizes to 10-15 for stable hierarchy
    - Provide adequate access to food supply to prevent fighting over feeding access
    - Try not to move animals between groups because this will cause hierarchy distruption until restabilized
    - Must make sure to secure the feeding and watering mechanisms to withstand rooting
    - Need to trim hooves periodically (can cause disease, difficulty walking, etc. if not done)
    - Domestic pigs usually housed outdoors
    - Minipigs usually housed indoors and are gender separated
    - If pigs housed individually, must give them space to contact adjacent pigs with their noses for contact
    - Pigs are omnivorous and always ready to eat (sounds like humans)
    - Lab pigs shouldn't be fed more than 2% of their body weight per day
    - Swine obesity is hard to correct
    - Outdoor pigs usually have more room to exercise and thus, can have slightly more food per day
    - Young ones fed twice a day but older ones only once per day (older = > 7months)
    - Automated drinking systems good to allow as much water as they want. Must have access below should er height.
- Pain indications:
    - Lack of movement but aggressive
    - Change in behavior and gait
    - Squeal if a painful area is touched
    - Check them when they're active and eating
- Environmental enrichment includes metal balls and other stuff for them to root and play with. Autoclaved straw or hay counts but also has added benefit of thermal insulation. Straw reduces aggressive behavior when introduced young but may increase gastric emptying times. Straw should be provided during farrowing because the sows need to nest. Swap out the toys regularly because they get bored. Will get upset when favorite toy(s) taken away or they're taken from the toy(s).
- Euthanasia: Lethal dose of barbiturates. Cardiac injection of KCl while anesthetized or a bolt shooter thing (American Gods Chernobog thing)

Conclusions/action items:

Participate in the cadaver and live animal testing.

Automation Code

LUCAS RATAJCZYK - Feb 25, 2020, 11:42 PM CST

Title: Automation Code/Drift Test Start

Date: 02/01/20

Content by: Lucas

Present: Lucas and Jonah

Goals: Create code to automate the pH reading process to allow for easier 48-hour drift tests.

Content:

The final code is attached below this entry but requires a secondary, freely-available software from Roger Meier's Freeware to record the Arduino's serial output to a text file. I included the files necessary for the software, CoolTerm, below as well. To use it, change the connection settings to match those used to upload to the Arduino and, when done uploading the code, click the big "Connect" button. It will now act just like Arduino's built-in serial monitor except that you can go back under the connection tab and start recording to a text file using the "Capture to text file" buttons in the drop down connection menu. We decided to save it to a text file to avoid setting up an SD card reader (and buying an SD card). However, this also means that we need to change the computer settings to prevent it from automatically closing and stopping the recordings. The CAE computers do not allow us to change these settings but they only say the computer will go to sleep. I tested it by turning the monitor off and back on and the program was still running. I also waited an hour for it to automatically go to sleep and then reopened the computer and the recordings had continued uninterrupted.

Conclusions/action items:

Check back on the setup in a few hours.

LUCAS RATAJCZYK - Feb 25, 2020, 11:34 PM CST

AutomaticVoltageToSerialZipped.zip(543 Bytes) - download The automatic voltage reading code for the Arduino

---

LUCAS RATAJCZYK - Feb 25, 2020, 11:32 PM CST

CoolTermWinZipped.zip(16.9 MB) - download The CoolTerm serial monitor software available form Roger Meier's Freeware.

LUCAS RATAJCZYK - Feb 25, 2020, 11:41 PM CST

Title: Automation Code/Drift Test Restart

Date: 02/01/20

Content by: Lucas

Present: Lucas

Goals: Set up the 48-hour drift test with a laptop to avoid the automatic shutdown feature of the CAE computers.

Content:

So that failed. The computer will apparently automatically log you out and close all your programs if you leave it asleep long enough. I was only gone for ~5 hours so that short of a time between check-ins by team members would still be unsustainable as I am the only one of us with access to this room and the others would not likely be willing to check in that often anyway (I doubt I would be in their situation). To fix this, I went and rented a laptop from College library (3 day rental leaves time to spare for 48-hour drift test) and was able to change the settings so it never went to sleep when plugged into the charger. Once I did this and had the software running on the laptop and the Arduino, I waited a while (~20 minutes) to make sure the program still recorded and then left.

Conclusions/action items:

Check in on the setup every few hours to make sure it is working.

02-04-20 Drift Test

LUCAS RATAJCZYK - Apr 28, 2020, 5:40 PM CDT

Title: 48-Hour Drift Test Results

Date: 02/04/20

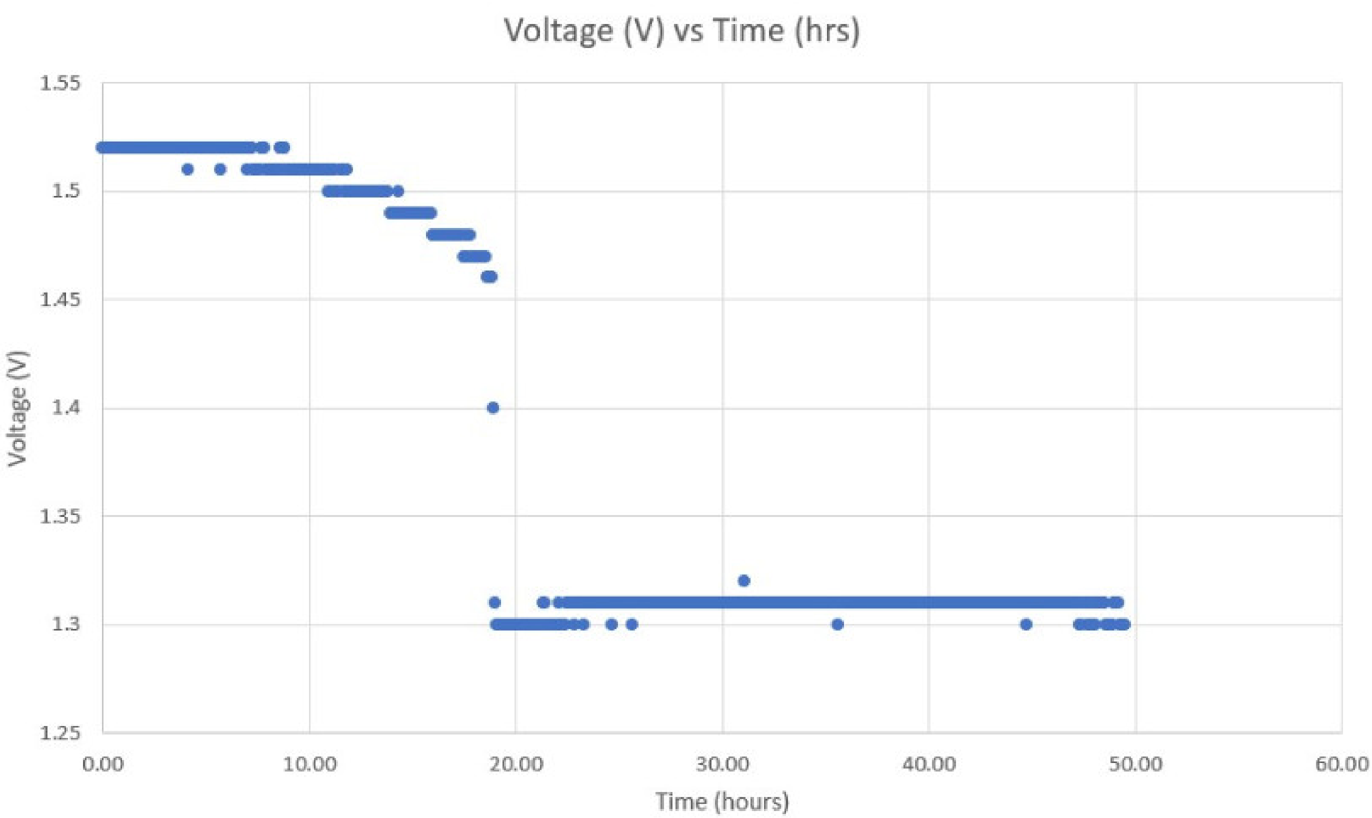
Content by: Lucas

Present: Lucas

Goals: Collect the drift test results and plot them.

Content:

I have included the Excel sheet and text file with the raw data below this entry. The setup worked wonderfully. The laptop was still on and recording so I waited for its next measurement and then shut it down and uploaded the text file to Google Drive. On my own laptop, I copied the text file data into an Excel worksheet and plotted it with respect to time. The resulting plot is shown below:

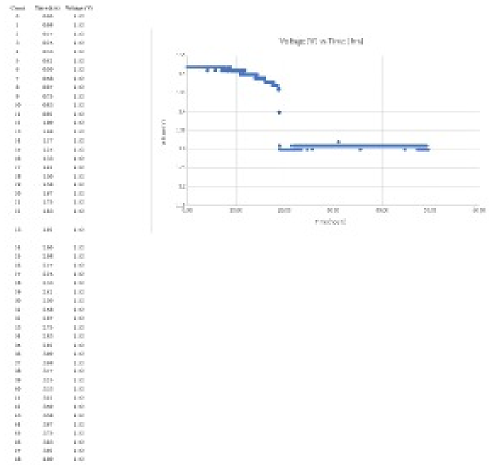


As you can see, the voltage was pretty steady until the 18th hour where it dropped to ~1.3V and stayed there for the rest of the time. I can only guess at the stability for the measurements from the lost hours as I didn't remake the electrode before redoing the setup with the laptop (Jonah approved). I want to redo this with a fresh electrode, or maybe one that has either a thicker AgCl layer or multiple layers on it. I suspect that the drop-off is the depletion of the AgCl layer of Cl^- and I hope that creating an AgCl electrode with layered AgCl can delay the drop-off point.

Conclusions/action items:

Upload the Excel worksheet with this data and redo the drift test with a new electrode to extend the operational time of the sensor. Goal is 48 hours per Dr. Doro's request.

LUCAS RATAJCZYK - Feb 25, 2020, 11:54 PM CST



48_Hour_Drift_Test_02-02-20.xlsx(35.1 KB) - download

LUCAS RATAJCZYK - Feb 25, 2020, 11:54 PM CST

```
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.51
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
1.52
```

Drift_Test_02-02-20_Results.txt(3.5 KB) - download

02-19-20 Drift Test

LUCAS RATAJCZYK - Feb 26, 2020, 11:53 AM CST

Title: 48-Hour Drift Test

Date: 02/19/20

Content by: Lucas

Present: Lucas and Jonah

Goals: Conduct a 48-hour drift test with the layered Ag/AgCl reference electrode.

Content:

I made sure to get the laptop beforehand this time. We ran into some issues where the analog front-end on the Winsense ISFET was outputting voltages that were nothing like last time's pH-voltage relationship (some were even negative). We think the front-end might be broken since it does this with the big Ag/AgCl reference that was provided with the ISFET as well. We're just going to calibrate, choose a solution that has a positive output voltage (pH 4 in this case) and do the drift test anyway. It shouldn't matter since any change (up or down) during the drift test is bad so the weirdness will hopefully not impact the data.

Conclusions/action items:

Check in on the setup periodically to ensure it is working.

LUCAS RATAJCZYK - Apr 28, 2020, 5:38 PM CDT

Title: Drift Test Results

Date: 02/21/20

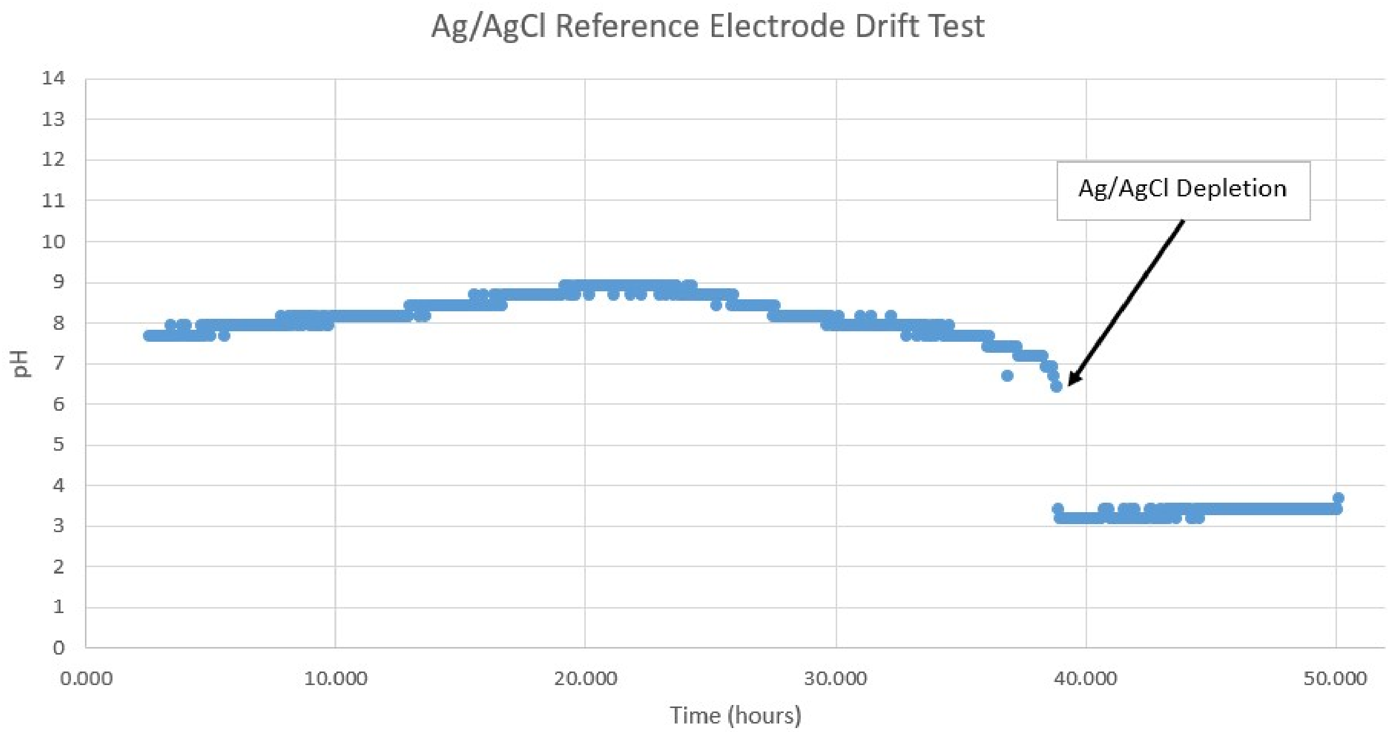
Content by: Lucas

Present: Lucas

Goals: Collect the results from the laptop and compile it into an Excel doc and plot it.

Content:

I did exactly as I said in the goals (and the other drift test results entry from 02/02/20). The results were:



There was some super erratic data which I didn't plot here so that you could get a closer look at the majority of the data but I left the weird data in the Excel sheet attached to this page. We think the reason for the steep drop around 40 hours is due to the depletion of the AgCl layer on the electrode (runs out of Cl^-). That is a HUGE improvement (now doesn't deplete until ~40 hours). It should hopefully be more than enough of a monitoring period to satisfy Dr. Doro (at least for the time being) sine this 48-hours thing is apparently a pretty insignificant requirement which he doesn't care so much about. We'll still need to ask him to be sure though. And I am worried about the fact that the pH steadily increased until it was 9 at the 20th hour and then came back down before depletion. What is causing this increase and can we fix it or will we need to specify that the product is not suited for prolonged use? Could it be that the AgCl layer itself is reacting with something in the solution? After all, the AgCl electrode looks yellow-green after the drift test but wouldn't AgCl with the Cl- removed just be silvery? Perhaps there is a reaction in the solution which is adding something else to the layer.

Conclusions/action items:

Upload the Excel worksheet and the text file with the data to Google Drive (and here). Do a drift test with the IrOx electrode paired with another layered Ag/AgCl reference. Ask Dr. Doro if the 40-hour validity is good enough (he said this criterion wasn't that important as they mostly plan to do spot-checks of the pH but may one day want to do the 48-hour monitoring).

Trying to fix the Sentron ISFET

LUCAS RATAJCZYK - Dec 11, 2019, 12:39 AM CST

Title: ISFET Cleaning

Date: 10/06/19

Content by: Lucas

Present: Lucas and Jonah

Goals: Attempt to fix the Sentron ISFET by cleaning the ISFET probes.

Content:

When trying to use the Sentron ISFET from last semester's group, we kept getting bad voltage values that didn't change in response to us (me and Jonah) switching the pH solution the sensor was sitting in. Sometimes it would drop to 0 but for the most part it stayed around 1/2 the max ADC value of the Arduino. But this happened unreliably and without any seeming pattern to it.

To try and fix this, we found a section in the Sentron manual for the ISFET that talks about daily cleaning of the sensor so we want to try that. The procedure is very simple and as follows:

1. Wash the sensor with DI water to remove any small debris
    1. They have this at the end after the rest of the procedure but they say this is important so why put it at the end where an impatient person may just start the procedure
2. Brush the sensor gently with a toothbrush
3. Soak it in soapy water for 5 minutes and stir it occasionally
4. Scrub the sensor with the soapy water
5. Rinse it with DI water

I've attached the manual below this entry so you can see what we followed. The cleaning procedure is section 3.1 on page 9.

Next, we tested the ISFETs again but still had the same issues so the it clearly wasn't just dirty and in need of cleaning. There is a section in the manual immediately after the cleaning procedure we just followed about revitalizing the reference electrodes that seems like it might fix the ISFET. We would have tried that right away tonight but it requires a saturated KCl solution to be made which they say needs to sit for at least 2 hours and it's kind of late so we'll do that next time we meet.

Conclusions/action items:

Try to revitalize the reference electrodes and see if that works.

LUCAS RATAJCZYK - Dec 11, 2019, 12:39 AM CST


Sentron

SI line pH PROBE MANUAL

For products:

ConeFET	3280-010
CupFET	3200-010
LanceFET	2270-010
LanceFET+H	2274-010
MicroFET	9270-010
MiniFET	9202-010

pH_probe_Manual_rev02.pdf(511.8 KB) - download The manual for the Sentron ISFET

LUCAS RATAJCZYK - Dec 11, 2019, 12:18 AM CST

Title: Reference Electrode Revitalization

Date: 10/08/19

Content by: Lucas

Present: Team

Goals: Attempt to revitalize the reference electrodes for the Sentron ISFET

Content:

Since we've been having issues with getting the Sentron ISFET setup to work, we hope that the reference revitalization process that is mentioned in the Sentron pH probe Manual (attached below) will fix it and allow us to get usable values from the prototype of previous semesters.

Basically, the manual says to soak the references in a saturated KCl solution (keep adding KCl to DI water and stirring until KCl stops dissolving then leave it for 2 hours) for 20 minutes

Thankfully, room 2005 of the Engineering Center's Building (ECB) has KCl and DI water so I just did this there with no problems.

Conclusions/action items:

Test the ISFET with the newly revitalized reference electrodes.

LUCAS RATAJCZYK - Dec 11, 2019, 12:54 AM CST

Title: Testing the ISFETs Post-Revitalization

Date: 10/14/19

Content by: Lucas

Present: Lucas and Jonah

Goals: Test the ISFETs with the revitalized references

Content:

We tested the ISFETs again today with the revitalized references but still ran into the same issues we've been having all semester. I am kind of fed up with this "prototype" from previous semesters. It clearly no longer works so unless we are doing something wrong, which is unlikely since we've had our setup checked by one of the members of the group from last semester (Alex Goodman) over the phone. Besides, even if this does work, Alex said we would need to have the reference electrode in the same solution so there is no way we can use this for the final prototype. Even the ISFET itself would only maybe fit into the 11-gauge needle and the reference is slightly bigger than that. Hunter and Syafiqah have been looking into alternatives and found a smaller ISFET from a company called Winsense that we might buy. Hopefully that one works. Jonah also agrees and we've decided to confirm the Sentron ISFET as unusable.

Conclusions/action items:

Talk with Dr. Nimunkar about what other options we have to replace the ISFET and look more into the Winsense ISFET.

UI Creation

LUCAS RATAJCZYK - Dec 11, 2019, 2:45 AM CST

Title: User Interface (UI) Creation

Date: 12/05/19

Content by: Lucas

Present: Lucas

Goals: Make the UI

Content:

Previously, Jonah and I had briefly discussed what UI components we might want in the full UI (in addition to the LCD from the original preliminary design matrix) and decided that we would have the following components:

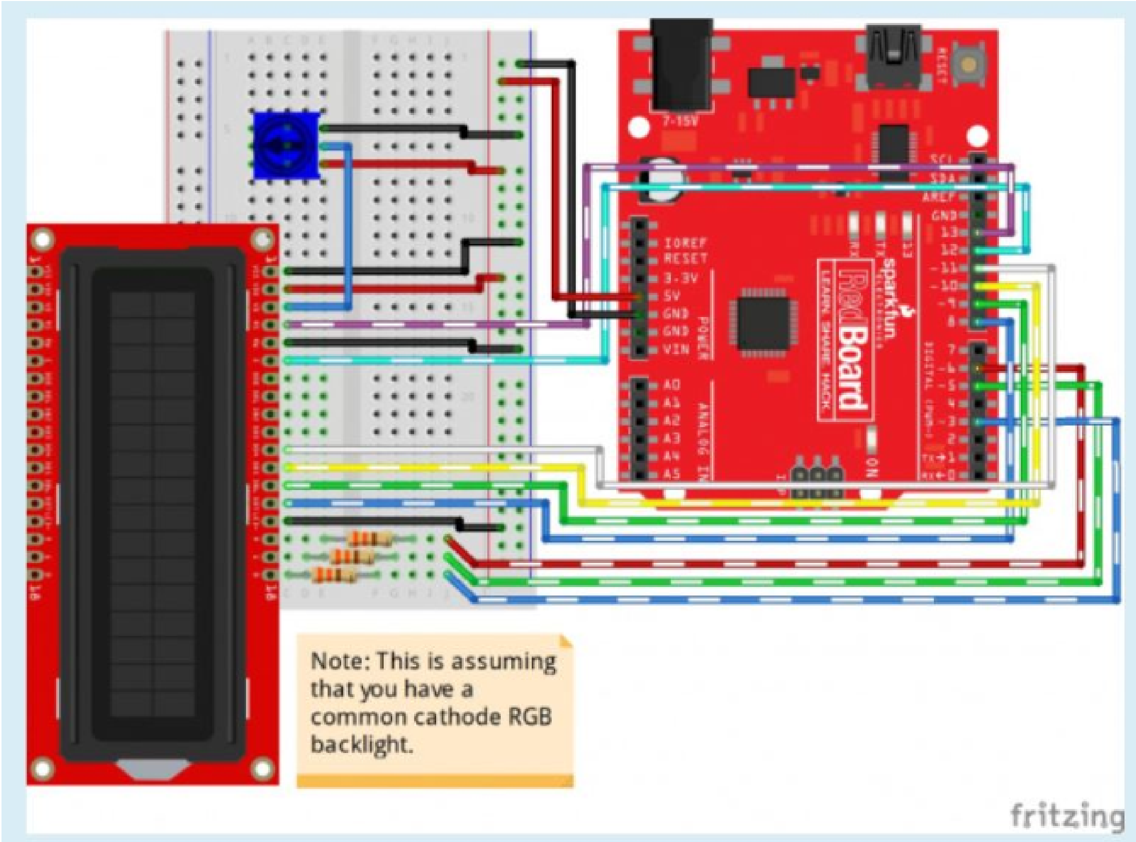
- LCD
- Arduino Nano Every
- Rocker Switch
- Latching Toggle Switch

The LCD is obviously just to display the pH and any other info the user may need. The Arduino Nano Every is a microcontroller that looks very similar to the Nucleo that we're using in BME 462 except that it is blue. It also uses the Arduino IDE, which makes it a little easier to use the LCD since Arduino has a built-in LCD library that allows you to set up an LCD with one line of code and then display things on it with simple print statements. Code is attached below this entry. One important feature of the Arduino Nano Every is that it can supply 5V since this is needed for the LCD. The Rocker and Latching Toggle switches are both included to allow user input. One is used to control power to the device and the other is to turn on and off the recording feature.

Since this is the night before final poster presentations (queue heart attack? . . . nope still here), I did not have time to implement all of these features. I mostly focused on getting the LCD working and displaying the pH. Below, I have made an ordered list to show everything I did:

1. Soldered the header pins of the Arduino Nano Every onto the board (the solder in ECB's green design room is very thick and difficult to work but I got the hang of it after about 15-20 minutes
2. Soldered header pins to the LCD (these headers were not included with the LCD but I had extra from BME 462 that worked)
3. Hooked up the LCD to the Arduino and got it displaying a basic "hello" using the example found here (https://learn.sparkfun.com/tutorials/basic-character-lcd-hookup-guide#arduino-examples-liquidcrystal-library) as a guide. I also copied a screenshot of the diagram I used most from that website below for convenience
4. Changed the code to calculate the difference between two analog pins (voltage and ground outputs from the analog front-end) and then convert that voltage difference to pH and display that on the LCD.
5. Implemented a switch to start and stop taking pH measurements as a holdover until I have the time and resources to make this be the switch that would control the power supply to the Arduino (to turn it on and off)

LCD Hookup Diagram:



Note: The big blue square is a potentiometer that can be used to control the LCD's contrast.

Problems:

- I had some issues uploading my code to the Arduino until I realized that I had simply chosen the wrong board type (Nano is NOT the same as Nano Every)
- Soldering took longer than expected because the MakerSpace was closed by the time I was soldering so I had to use the green room in ECB
- The voltage values output by the analog front-end were not changing as expected when I put the probe in the different solutions (am I cursed? This is similar to what happened with the Sentron prototype earlier but this one actually showed some response to pH, just not as consistently as in previous testing). I am hoping that this is simply something I did wrong when constructing the probe-front-end setup since I've never done that before. Even though the instructions in the kit were very clear and I followed them closely.
- The switch was also acting finicky but I attribute this to the very unstable setup of the pin connections. The large solder in the green room would have fused all the switch's pins together so I tried to use alligator clips on very small and closely-grouped pins, which was bound to be faulty. In the future, I want to take that switch into the MakerSpace and solder some wires to the switch's pins.

Conclusions/action items:

We have a working microcontroller and LCD display, a finicky button, and an oddly-behaving analog front-end for the sensor.

In the future, I want to:

- Implement the data recording functionality and hook up a switch to control it
- Make one switch control the power supply to the Arduino
- Work with Jonah and/or Syafiqah to fix the analog front-end and sensor (they have more experience with that setup since they did the calibration and drift testing)

LUCAS RATAJCZYK - Dec 11, 2019, 2:44 AM CST

read_pH.ino(3.5 KB) - download The Arduino code as of 12/05/19

ISFET Automation Meeting

LUCAS RATAJCZYK - Feb 01, 2020, 11:09 AM CST

Title: ISFET pH Measuring Automation Meeting

Date:

Content by: 2/1/20

Present: Jonah and Lucas

Goals: Create an Arduino program that can automatically measure the pH from the Winsense analog front-end and save that information to a text file on a computer

Content:

According to the YouTube video found here -> https://www.youtube.com/watch?v=Iz_AETY9o5E, it is possible to save the Arduino Serial Monitor output to a text file using a separate software that also reads the Serial Port the Arduino is using to communicate with the computer and which will automatically save the Serial Monitor text to a text file and update it. The software is called CoolTerm can be found/downloaded here -> https://freeware.the-meiers.org/

Conclusions/action items:

09/27/2019 - Compartment Syndrome

NUR SAIDIN - Sep 27, 2019, 11:56 AM CDT

Title: Compartment syndrome

Date: 09/27/2019

Content by: Syafiqah Saidin

Present: none

Goals: Explaining compartment syndrome

Content:

Compartment is group of muscle tissue, muscle nerves, blood vessels that is covered by a sheath of connective tissue called fascia. When there is a swelling inside of the compartment, the fascia does not expand and therefore cause an increase of pressure. This will constrict the blood vessels that supplying oxygen and nutrients to the muscle cells and can result in cellular death (necrosis) and ischemia. If left untreated, it can lead to permanent damage and amputation.

The syndrome can develop when there is bleeding or swelling in the the muscle compartment. Acute compartment syndrome may be develop following a fracture, wearing a cast or tight bandage, after injury in the arm or leg, or a severely injured muscle. Chronic compartment syndrome may come from heavy workout or intense frequent exercises.

Compartment syndrome is a surgical emergency that require immediate attention to avoid amputation. Figure 1 below shows the compartment of the muscle and how does the syndrome develop.

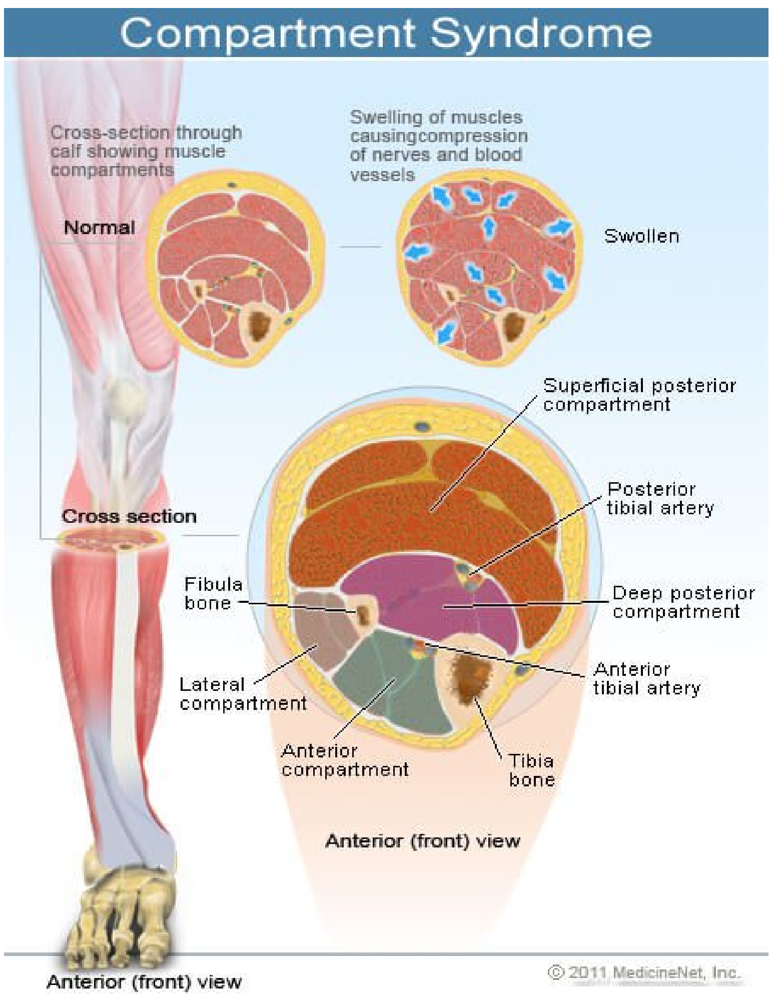


Figure 1: The cross-section of the calf showing muscle compartments.

Conclusions/action items:

Compartment syndrome is a surgical emergency and it is important to detect the swelling in the compartment as soon as it develops.

NUR SAIDIN - Sep 27, 2019, 10:54 AM CDT

Title: Compartment syndrome

Date: 09/27/2019

Content by: Syafiqah Saidin

Present: none

Goals: Explaining markers in detecting compartment syndrome

Content:

As compartment syndrome relates with the rise of the pressure inside the osseofascial compartment, assuming pressure as the best biomarkers might be our best guess. However, there is a 35% false-positive diagnosis of compartment syndrome was found in patients that have tibial shaft fractures using the compartment pressure measurements as the indication. False diagnosis results in undergoing the expensive fasciatomy that the patients do not really need. There is currently no gold standard in detecting compartment syndrome. Our client, Dr Chrostopher Doro, believes that detecting the pH inside the compartment will give us the correct biomarkers for this syndrome. This is because, once there is an acute compartment syndrome, the oxygen level in the muscle cells will decrease, followed by oxidative phosphorylation. To compensate, the muscle will perform anaerobic glycolysis which will decrease the pH, glucose, pyruvate, partial pressure of oxygen, and increase lactate production. consistent glycolysis leads to exhaustion and eventually muscle death. All in all, using pH as potential biomarkers is hypotheiszed to produce reliable standard in detecting compartment syndrome. Attached is the slides that were presented to us by Dr. Doro about the compartment syndrome.

Conclusion:

pH as the reliable biomarkers in diagnosing compartment syndrome.

NUR SAIDIN - Sep 27, 2019, 10:55 AM CDT

Compartment_BME.ppt(6.9 MB) - download

03/04/2020 - Toxicity of Ag

NUR SAIDIN - Mar 06, 2020, 11:59 AM CST

Title: Toxicity of Ag+ and AgCl

Date: 03/04/2020

Content by: Syafiqah

Present: myself

Goals: Study the toxicity of AgCl and Ag+ and its effect in the body

Content:

1. Reduced cytotoxicity of silver ions to mammalian cells at high concentration due to the formation of silver chloride

[1] S. Zhang, C. Du, Z. Wang, X. Han, K. Zhang, and L. Liu, “Reduced cytotoxicity of silver ions to mammalian cells at high concentration due to the formation of silver chloride,” Toxicology in Vitro, vol. 27, no. 2, pp. 739–744, Mar. 2013, doi: 10.1016/j.tiv.2012.12.003.

Releasing active Ag+ from nanosilvers can exert toxic effects on cultured cells by increasing lactate dehydrogenase (LDH) leakage, producing oxidative stress, and inhibiting mitochondrial function. Interaction with Cl- , which leads to AgCl formation provide protection mechanism against silver toxicity on both red blood cells and human msenchymal cells (hMSC). Ag+ exhihbited higher cytotoxicity than AgCl colloid. AgCl at higher concentration was found aggregate within 30m [1].

A B S T R A C T

Silver-containing antimicrobial agents are used in various medical products. However, their toxicity to mammalian cells has not been sufficiently evaluated. Numerous studies have unveiled evidence of significant antimicrobial properties associated with Ag ions. In cell culture media or human body fluids, the free Ag^+ has rich opportunities to complex with Cl^-. Surprisingly, studies on the toxicity of solid form $AgCl_{(s)}$ to mammalian cells are quite limited. In this study, we evaluated the cytotoxicity of Ag ions and silver chloride colloids on red blood cells and human mesenchymal stem cells (hMSCs). The adverse effects of silver chloride on red blood cells and hMSC were viewed by SEM and LIVE/DEAD viability staining, respectively. Among different tested chemical forms of silver, AgCl was identified to be the least cytotoxic. Moreover, a decline in the cytotoxicity of AgCl at significantly high concentrations was observed. We attributed the reduced cytotoxicity to aggregated AgCl which limited the bioavailability of free Ag^+ ions.

Figure 1: The abstract taken from the article [1].

Conclusions/action items:

10/08/2019 - Odin Technology - Valkyrie

NUR SAIDIN - Oct 09, 2019, 12:31 AM CDT

Title: Odin Technology - Valkyrie

Date: 10/08/2019

Content by: Syafiqah

Present: myself

Goals: Explain about a competing design

Content:

The Valkyrie from Odin Technologies primarily focus on the same physiological condition with us which is muscle compartment syndrome. It is a non-invasive device that can be wrapped around the patient's leg and measure the blood flow with oxygen concentration in blood using infrared mechanisms. If there is a decrease in blood flow or increase in pressure it will alert the physicians. This device also provide a continuous monitoring, portable and wireless. It is really easy to use this device and the physicians can monitor patient's condition without being need to be at their side at all times.

Based on what I observed, this design really fulfilled all of the criteria that our client wants however based on what our client said, this design does not accurate in diagnosing compartment syndrome.

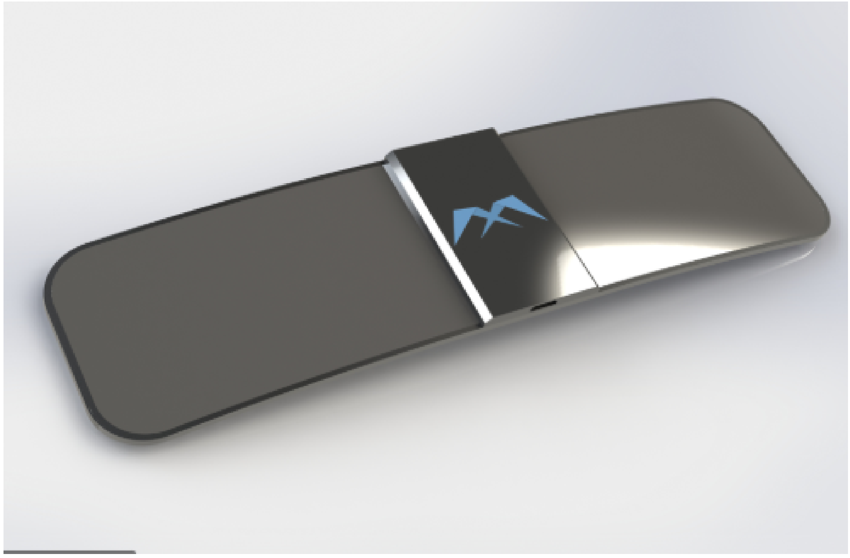


Figure 1: The Valkyrie sensor that is used to diagnose compartment syndrome by Odin Technologies.[1]

References:

[1] Odinhealthtech.com. (2019). [online] Available at: https://www.odinhealthtech.com/ [Accessed 9 Oct. 2019].

Conclusions/action items:

This design does have the same goal and function with the one we want to make but it does not fulfill the criteria that our client want which is to be able to fit in 16 gauge needle.

10/08/2019 - Bare Dies

NUR SAIDIN - Oct 09, 2019, 1:05 AM CDT

itle: Bare Die

Date: 10/08/2019

Content by: Syafiqah

Present: myself

Goals: Explain what is bare die

Content:

Bare die is basically a semiconductor that is package-free, an integrated circuit that is cut out from wafer. It is smaller in size and weight that reduce space used on the board. Despite its small size, the bare die can have extra functionality in space constrained systems and add the capabilities of operating in harsh environment. It also reduces the path lengths of the components which improved the reliability by reducing the number of interconnects with the die. The advantages of using bare dies provide higher level of integration of the system with improved functionality and electrical performance.

SInce I barely know about bare die, I need to know its function, what does it do, and how can this tiny pieces of chip work in our design project.

Conclusions/action items:

We need this bare die in order to optimize our design that require limited space with very small design. Use of bare die along with the ISFET sensor to acquire the pH reading in the muscle compartment. However, we need to protect the or encapsulate the bare die. Another issues that we have having a connection with the bare die with wires. Requires microscale technology and techniques;

NUR SAIDIN - Oct 09, 2019, 1:48 AM CDT

Title: Bare Die

Date: 10/08/2019

Content by: Syafiqah

Present: myself

Goals: Explain about bare die bonding

Content:

Die bonding attaches the bare die to a substrate or package. The processes include eutectic bonding, adhesive bonding, silver-glass bonding, and solder flip chip.

1) Eutectic bonding [1]

Melt a preform of alloy mixtures if two or more dissimilar metals in the joint between the die and the substrate. Preform of golf and silicone has combined melting point of 363ºC. This process uses very high temperature processes and needs inert gas usage to prevent oxidation. Not sure if the die that we have can withstand the high temperature.

2) Adhesive bonding [1]

Attach the die to the substrate using adhesive materials that can be electrically insulating or conducting. Conducted the adhesive bond at room temperature. This process that can be done at low temperature with possible rwork option. However, there is possibilities of contamination, voids in bond, and is sensitive to harsh environments.

3) Silver-Glass bonding [1]

Similar adhesive with adhesive bonding but this process require heat around 360ºC to 450ºC. Not sure if the die we have able to withstand the heat.

4) Solder flip chip

Use solder bumping process that requires high melting point solder . The solder bump used as standoffs and combined with the eutectic bumps on the substrate. Compatible with surface mount processes.

References:

[1] ES Components | A Franchised Distributor and Manufacturer. (2019). *What Is Bare Die? — ES Components | A Franchised Distributor and Manufacturer*. [online] Available at: https://www.escomponents.com/what-is-bare-die [Accessed 8 Oct. 2019].

[2] Dieproducts.org. (2019). [online] Available at: http://www.dieproducts.org/tutorials/assembly/bare_die_mounting.pdf [Accessed 9 Oct. 2019].

Conclusions/action items:

Need to decide which methods that we want to use. Discuss with the guy from clean room, Hal.

10/08/2019 - Winsense pH Sensor

NUR SAIDIN - Oct 09, 2019, 8:46 AM CDT

Title: Winsense pH Sensor

Date: 10/08/2019

Content by: Syafiqah

Present: myselg

Goals: Find smaller sensor

Content:

Winsese ISFET sensor has longer cable which is what we wanted as it needs to fit along the syringe. The sensor chip is 1.4mm in width, 3.55mm in length and 0.65mm thickness.

Figure 1: The reference electrode of the Winsense pH sensor

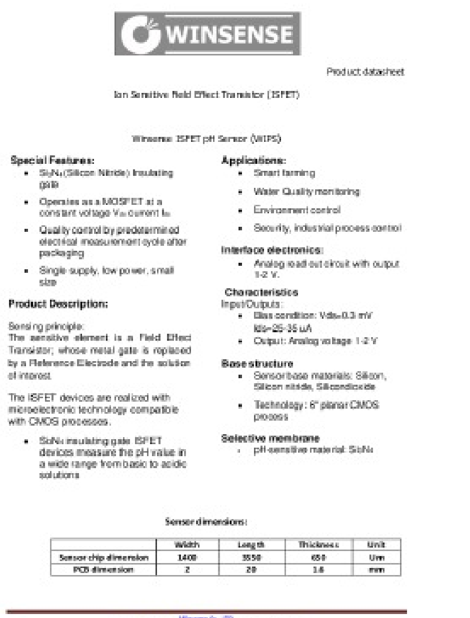
Figure 2: The ISFET sensor from Winsense

Pictures from : https://www.youtube.com/watch?v=0nAAENA0kho

Conclusions/action items:

Need to find smaller reference electrode.

NUR SAIDIN - Oct 09, 2019, 8:46 AM CDT



WINSENSE

Product datasheet

Ion Sensitive Field Effect Transistor (ISFET)

Winsense ISFET pH Sensor (WIPS)

Special Features:
- Si_3N_4 (Silicon Nitride) Insulating gate
- Operates as a MOSFET at a constant voltage V_{ds} current I_{ds}
- Quality control by predetermined electrical measurement cycle after packaging
- Single supply, low power, small size

Product Description:

Sensing principle:
The sensitive element is a Field Effect Transistor; whose metal gate is replaced by a Reference Electrode and the solution of interest.

The ISFET devices are realized with microelectronic technology compatible with CMOS processes.

- Si_3N_4 insulating gate ISFET devices measure the pH value in a wide range from basic to acidic solutions

Applications:
- Smart farming
- Water Quality monitoring
- Environment control
- Security, industrial process control

Interface electronics:
- Analog read-out circuit with output 1-2 V.

Characteristics
Input/Outputs:
- Bias condition: Vds=0.3 mV
  Ids=25-35 uA
- Output: Analog voltage 1-2 V

Base structure
- Sensor base materials: Silicon, Silicon nitride, Silicondioxide
- Technology: 6" planar CMOS process

Selective membrane
- pH-sensitive material: Si_3N_4

Sensor dimensions:

	Width	Length	Thickness	Unit
Sensor chip dimension	1400	3550	650	Um
PCB dimension	2	20	1.6	mm

winsense_isfet_ph_sensor_wips_datasheet.pdf(561.4 KB) - download

10/17/2019 - Small pH sensor catheter for acidity test in gullet and stomach

NUR SAIDIN - Oct 17, 2019, 10:49 PM CDT

Title: A Small pH Sensor Catheter of the Endoscope for Acidity Test of Gullet and Stomach

Date: 10/17/2019

Content by: Syafiqah

Present: Hunter and Syafiqah

Goals: Find out the viable option for smallest reference electrode

Content:

This paper introduced the use of ISFET pH sensor in endoscope's working channel for diagnosing gastroesophageal reflux disease (GERD). It has similar in vivo function with our design project. The pH sensor catheter was tested in buffer solution and animals. They have successfully miniaturized the reference electrode with the pH sensor that has Ag/AgCl electrode. The fabrication of the reference electrode used Ag/AgCl wire, KCl gel, and an ion-exchangeable glass. Many experiments have been conducted to get the optimized size of the aperture size f the ion exchange membrane. The catheter was divided into two parts: ISFET chip and the reference Ag/AgCl electrode in KCl gel. The catheter was covered in silicon epoxy in order to protect the components from harsh acidic and basic environment. The silicon epoxy was chosen because it is insulated, nonadhesive,thermostable, inactive, and resistant to acids and alkalis. The ISFET chip was wire-bonded on a PCB with a width of 2.5mm and diameter of 3mm. WIth the catheter, the diameter is 2.7mm and length of 8mm.

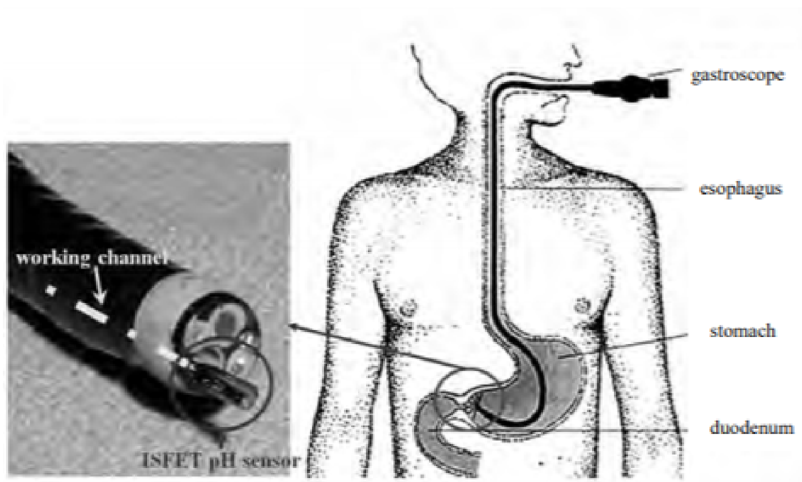


Figure 1: The overall view of the catheter with the ISFET pH sensor in the endoscope [1]

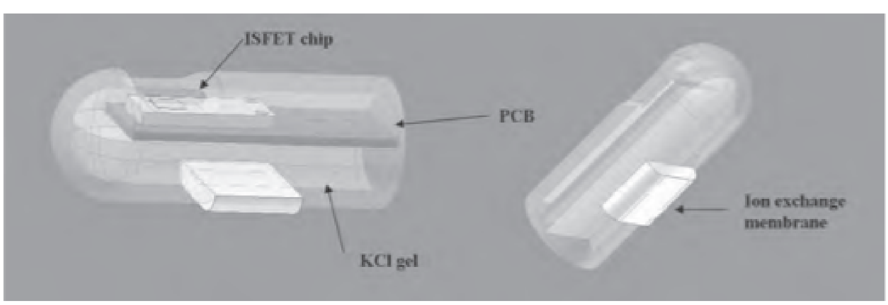


Figure 2: The ISFET pH sensor catheter. The top part consists of the ISFET chip and the bottom part is the Ag/AgCl reference electrode in KCl gel [1].

References:

[1] Roh, Ji-Hyoung, Kyu-Sik Shin, Nam-Kyu Cho, Don-Haeng Lee, Byung-Moo Moon, and Dae-Sung Lee. "A Small PH Sensor Catheter of the Endoscope for Acidity Test of Gullet and Stomach." A Small PH Sensor Catheter of the Endoscope for Acidity Test of Gullet and Stomach 20

(November 19, 2008): 417. https://doi.org/10.18494/sam.2009.571.

Conclusions/action items:

Their application is similar with what we want in our design. Since we cannot find any reference electrode with a smaller dimension, we might need to make our own reference electrode or incorporate both the pH sensor and the reference in one chip. The second option is would be really complicated.

NUR SAIDIN - Oct 17, 2019, 10:50 PM CDT

Sensors and Materials, Vol. 20, No. 8 (2008) 417–424
MYU Tokyo

S & M 0739

A Small pH Sensor Catheter of the Endoscope for Acidity Test of Gullet and Stomach

Ji-Hyoung Roh[1,3], Kyu-Sik Shin[1], Nam-Kyu Cho[1], Don-Haeng Lee[2], Byung-Moo Moon[3,*] and Dae-Sung Lee[1,**]

[1]Nano Sensor Research Center of Korea Electronics Technology Institute, 68 Yatap-dong, Bundang-gu, Seongnam-si, Gyeonggi-do 463-816, Korea
[2]Digestive Disease Center of Inha University Hospital, 7-206 3-Ga, Sinheung-dong, Jung-gu, Incheon 400-711, Korea
[3]Department of Electrical Engineering, Korea University, 5-1 Anam-dong, Sungbuk-gu, Seoul 136-701, Korea

(Received August 1, 2008; accepted November 19, 2008)

Key words: gastroesophageal reflux disease (GERD), pH, ISFET, endoscope

The detection of pH in the gullet and stomach is highly significant for the diagnosis of gastroesophageal reflux disease (GERD), particularly with the use of a pH sensor *in vivo*. Most conventional pH sensors are used singly and could not be inserted in the endoscope's working channel. Because the ion sensitivity field-effect transistor (ISFET) chip has become very small, we have made the pH sensor smaller than a conventional glass pH sensor, and have used it. In this paper, we introduce a small *in vivo* pH sensor catheter of 2.7 mm diameter and 8 mm length, which can be put in the endoscopy's working channel of 3 mm diameter. The catheter was evaluated in buffer solution (pH 2–12) and its sensitivity was 43 mV/pH. It was confirmed that the catheter properly functioned during an animal experiment.

1. Introduction

With the advance of semiconductor sensor technology, DNA chips, lab-on-a-chip sensors, protein sensors and other similar devices have been used in medical diagnosis. There are few sensors that can probe the gastrointestinal (GI) tract. However, such sensors have limits in diagnosing stomach disorder. Physicians of digestive diseases have raised the need for a pH sensor catheter for the diagnosis of ulcers, tissue inflammation, hypo- or hyper- chlorhydria, achlorhydria, and esophageal acid exposure. Some wireless pH sensors have been developed recently, and physicians want to use a pH catheter during an endoscope use.[1–3]

The pH of the gullet and stomach is significant and useful for the diagnosis of GERD, particularly for functional diseases of GERD. Most conventional pH sensors are too large to put into an endoscope's working channel. Because an ion-sensitive field effect

Corresponding authors: e-mail: *bmmoon@korea.ac.kr; **leeds@keti.re.kr

pH_Sensor_Catheter_For_Acidity_Test.pdf(299.2 KB) - download

10/17/2019 - Needle-like IrO/Ag combined pH microelectrode

NUR SAIDIN - Oct 18, 2019, 12:25 AM CDT

Title: Needle-like IrO/Ag combined pH microelectrode

Date: 10/17/2019

Content by: Syafiqah

Present: Hunter and Syafiqah

Goals: Find viable option to fabricate smaller reference electrode

Content:

The pH microelectrode was fabricated and placed inside a needle with the needles as the reference electrode. The pH microelectrode is made from Iridium Oxide (IrO_2) by polymeric precursor method **(Pechini method)** and deposited in a platinum mirowave. Then, the electrode will be placed inside a stainless steel needle with 1.4mm diameter. The external surface of the needle was painted with conductive silver ink and acts as the reference electrode. The Pt/IrO_2 pH microelectrode is covered in 0.8mm Teflon tube, which then fixed with polymeric resin inside the needle. The IrO_2 was exposed at the tip of the needle.

The needle-like pH microelectrode is tested and compared with the commercial glass pH probe and the result showed smaller than 35 differences. There was a concern that the presence of Li+, Na+, or K+ affect the pH curve measured. However, the ANOVA test showed that there was a 95% confidence level that the interference from those elements was not significant. After 3 years, the device still functions properly.

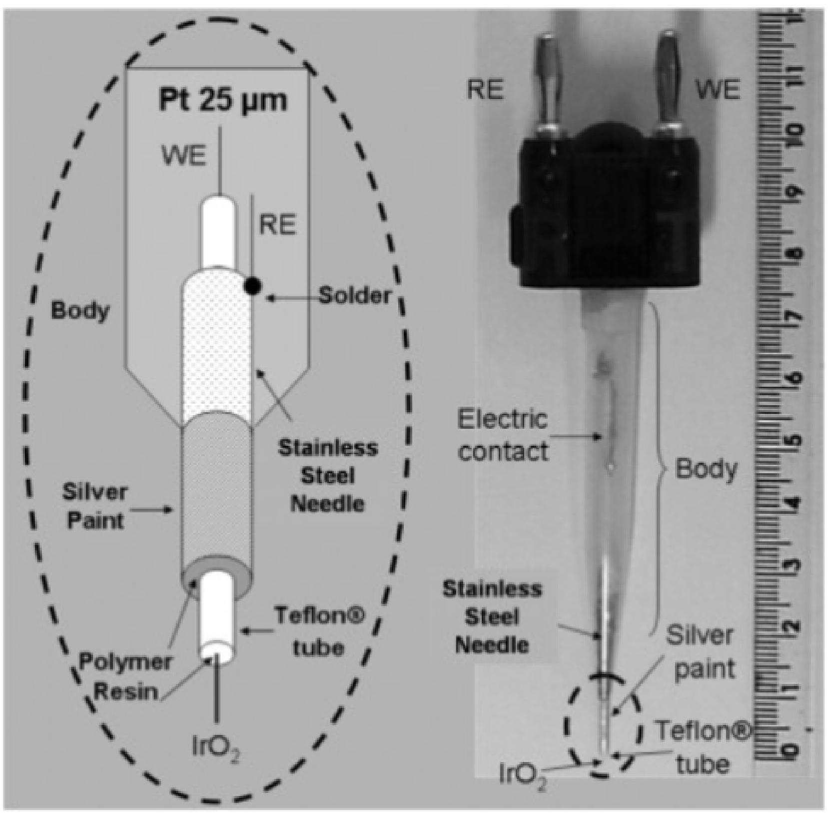


Figure 1: The IrO_2/Ag pH microsensor inside the stainless steel needle{1}.

Reference:

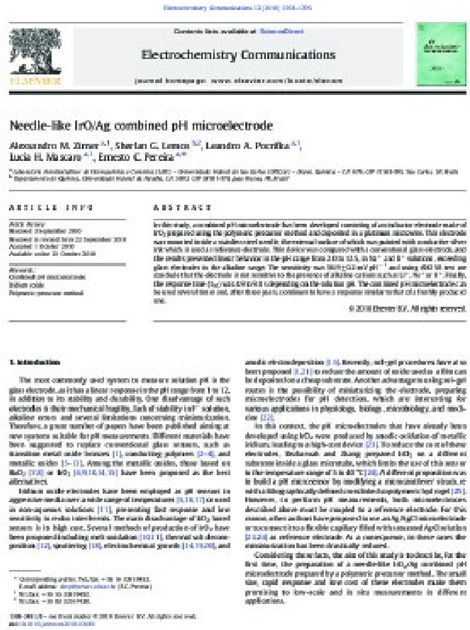
[1] Zimer, Alexsandro M., Sherlan G. Lemos, Leandro A. Pocrifka, Lucia H. Mascaro, and Ernesto C. Pereira. “Needle-like IrO/Ag Combined PH Microelectrode.” Electrochemistry Communications 12, no. 12 (December 2010): 1703–5. https://doi.org/10.1016/j.elecom.2010.10.001.

Conclusions/action items:

This design is really similar with what we envision and the Lucas's idea. I wish that we would have found this paper earlier. There is a high chance that we need to made our own reference electrode since there is no commercialized reference electrode fit the size that we want. If we wanted to also made our own microelectrode pH sensor, we wouldn't need to buy the chip from Sentron or Winsense. The only concern that I have is the price as silver is expensive. Need to discuss with the team on which way we want to go at this point.

Look up Pechini method

NUR SAIDIN - Oct 17, 2019, 11:51 PM CDT


Electrochemistry Communications

Needle-like IrO/Ag combined pH microelectrode

ARTICLE INFO

ABSTRACT

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Needle-like_IrO_Ag_combined_pH_microelectrode.pdf(451.1 KB) - download

10/18/2019 - pH Sensors Based on Iridium Oxide

NUR SAIDIN - Oct 18, 2019, 10:25 AM CDT

Title: An overview of pH Sensors Based on Iridium Oxide: Fabrication and Application

Date: 10/18/2019

Content by: Syafiqah

Present: myself

Goals: Understanding iridium oxide application as pH sensors

Content:

This paper introduces iridium oxide as the a stable material for pH sensor and various method to fabricate it. It is a popular material being used as reference electrode in pH measurements. This material can provide rapid and stable response with high conductivity at low temperature. The response of Iridium Oxide o pH is based on the transition between oxidation states of Ir(III) oxide and Ir(IV) oxide. The tradition glass pH sensor use solution phase activities while iridium oxide electrode depends on the H+ activity and its oxidation state. The fabrication method id the iridium oxide electrode plays an important role in the pH response. The IrO pH sensor fabrication type mentioned include:

1) Sol-gel process: IrO_2 on fleixible substrate. Cheap, good reversibility and reproducibility. Use polymeric precursor approach. Challenge: drying process - possible of creating cracks on the iridium oxide film.

2) Electrochemical or thermal oxidation: Potentiondynamic cycling or Ir electrode in 0.5M H_2SO_4 aqueous solution.

3) Sputtering: For neural stimulation electrodes. Fabricated in mixed Argon and oxygen environment with pressure. pH sensitivity decreases with increasing temperature. Expensive.

4) Anodic or cathodic electrodeposition: Based on a complex $IrCl_4$ and oxalate component. Coat the IrO_x layer on a glass substrate with titanium electrodes. pH range from 4 to 10. Most researchers followed Yamanaka solution with some modification.

Reference:

[1] Kakooei, Saeid, Mokhtar Che Ismail and Bambang Ariwahjoedi. “An overview of pH Sensors Based on Iridium Oxide: Fabrication and Application.” (2013).

Conclusions/action items:

Fabricating our own reference electrode is an option since we cannot find any commercial reference electrode with the size that we want. Need to discuss with the team what to do.

NUR SAIDIN - Oct 18, 2019, 10:25 AM CDT

International Journal of Material Science Innovations (IJMSI) 1 (1): 60-73, 2013
ISSN xxxx-xxxx
© Academic Research Online Publisher

Review Article

An overview of pH Sensors Based on Iridium Oxide: Fabrication and Application

Saeid Kakooei*, Mokhtar Che Ismail, Bambang Ari-Wahjoedi

Centre for Corrosion Research, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Tronoh 31750, Malaysia
* Corresponding author. Tel.: [illegible]
E-mail address: [illegible]

ARTICLE INFO

Article history
Received: [illegible]
Accepted: [illegible]

Keywords:
pH Sensor;
Iridium Oxide;
Electrodeposition;
Sputtering;
Sensor Fabrication

Abstract

In recent years, there has been an increasing interest in the adoption of emerging sensing technologies for instrumentation within a variety of structural systems. Iridium oxide as an stable and interesting material for pH sensor in various temperature and pressure was paid attention by a lot of researchers. In this study an overview of different methods for fabrication of IrO_2 pH sensors and their application are presented.

1. Introduction

During the past decades IrO_2 became a superior material for reference electrode[1, 2] and pH measurements in different fields such as biological media [3, 4], food industry [5], nuclear field [6, 7], and oil and gas industry [8-10]. Iridium oxide can provide a rapid and stable response in different media because of its high conductivity and low temperature coefficient. Potentiometric response of the Iridium oxide to pH is a function of transition effect between two oxidation states Ir(III) oxide and Ir(IV) oxide, which can be shown as follow[11]:

$$Ir(IV)oxide + qH^+ + ne^- \leftrightarrow Ir(III)oxide + rH_2O$$

In 1996, Rose *et al.*[12] measured dissolved oxygen, pH, and ion currents on mild steel corroded surface using three closely spaced microelectrodes. They proposed a real time mapping of the pH distribution on the mild steel corroded surface.

Iridium_oxide.pdf(207.2 KB) - download

10/30/2019 - Fabrication of Iridium oxide

NUR SAIDIN - Nov 01, 2019, 12:46 AM CDT

Title: Fabrication of Iridium Oxide

Date: 10/30/2019

Content by: Syafiqah

Present: myself

Goals: Find way of miniaturizing the pH electrode or the reference electrode

Content:

This paper discussed on the detailed fabrication steps of iridium oxide pH sensors only. The paper does not discuss about the fabrication of the reference electrode, but they used Ag/AgCl eletrode. It is a sol-gel based iridium oxide (IrO) thin film pH sensor.

1. A method for fabricating a sol-gel based iridium oxide pH sensor comprising the steps:

(a) depositing at least one metal layer on a substrate;

(b) coating the substrate with a photoresist layer and photolithographically creating a pattern of an electrode;

(c) etching the at least one metal layer according to the pattern to define a sensor configuration;

(d) supplying a microfluidic mold having a reservoir region and a channel;

(e) aligning the microfluidic mold onto the sensor configuration created in step (c) so that the channel aligns with the electrode;

(f) dispensing an iridium oxide sol-gel solution onto the sensor configuration via the reservoir to create a pH sensing electrode comprising iridium oxide;

(g) detaching the polymer layer from the sensor configuration;

(h) thermally curing the pH sensing electrode created in step (f);

(i) coating the pH sensing electrode with an encapsulation layer; and

(j) opening a sensing electrode site,

thereby producing the pH sensor.

Figure 1: Method of fabrication sol-gel based Iridium Oxide pH sensor

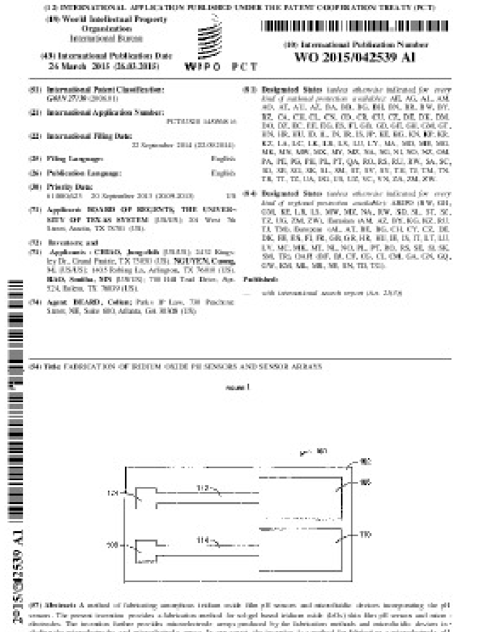
Reference:

[1] Chiao, Jung-Chih, Cuong Nguyen, and Smitha Rao. “Fabrication of Iridium Oxide Ph Sensors and Sensor Arrays.” Google Patents. Google, March 26, 2015. https://patents.google.com/patent/WO2015042539A1.

Conclusions/action items:

If we ever need to fabricate the Iridium Oxide electrode, we can try refer to this.

NUR SAIDIN - Nov 01, 2019, 10:49 AM CDT


(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 March 2015 (26.03.2015)

WIPO PCT

(10) International Publication Number
WO 2015/042539 A1

(54) Title: FABRICATION OF IRIDIUM OXIDE PH SENSORS AND SENSOR ARRAYS

WO 2015/042539 A1

Fabrication_of_Iridium_Oxide_pH_Sensors_and_Sensor_Arrays.pdf(1009.5 KB) - download

11/1/2019 - Sol-gel Deposition of Iridium Oxide for Biomedical Micro-Devices

NUR SAIDIN - Nov 01, 2019, 10:48 AM CDT

Title: Sol-Gel Deposition of Iridium Oxide for Biomedical Micro-Devices

Date: 11/1/2019

Content by: Syafiqah

Present: myself

Goals: Finding alternative to fabricate Iridium Oxide electrode

Content:

Abstract

Go to:

Flexible iridium oxide (IrO_x)-based micro-electrodes were fabricated on flexible polyimide substrates using a sol-gel deposition process for utilization as integrated pseudo-reference electrodes for bio-electrochemical sensing applications. The fabrication method yields reliable miniature on-probe IrO_x electrodes with long lifetime, high stability and repeatability. Such sensors can be used for long-term measurements. Various dimensions of sol-gel iridium oxide electrodes including 1 mm × 1 mm, 500 μm × 500 μm, and 100 μm × 100 μm were fabricated. Sensor longevity and pH dependence were investigated by immersing the electrodes in hydrochloric acid, fetal bovine serum (FBS), and sodium hydroxide solutions for 30 days. Less pH dependent responses, compared to IrO_x electrodes fabricated by electrochemical deposition processes, were measured at 58.8 ± 0.4 mV/pH, 53.8 ± 1.3 mV/pH and 48 ± 0.6 mV/pH, respectively. The on-probe IrO_x pseudo-reference electrodes were utilized for dopamine sensing. The baseline responses of the sensors were higher than the one using an external Ag/AgCl reference electrode. Using IrO_x reference electrodes integrated on the same probe with working electrodes eliminated the use of cytotoxic Ag/AgCl reference electrode without loss in sensitivity. This enables employing such sensors in long-term recording of concentrations of neurotransmitters in central nervous systems of animals and humans.

Figure 1: The abstract for the research paper discussing the fabrication of iridium-oxide micro-electrode

Iridium Oxide has been widely used in neuroscience application due to it's stabilty, biocompatibility, high charge density, and corrosion resistance in electrolyte solutions which able to withstand in long-term experiments. The paper utilized Iridium oxide as the reference electrode for biomedical recording and referred them as pseudo-reference electrode. They used sol-gel deposition process with iridium oxide, and photolithography using chromium and gold conducted with double heat treatment [1].

Reference:

[1] Nguyen, Cuong M, Smitha Rao, Xuesong Yang, Souvik Dubey, Jeffrey Mays, Hung Cao, and Jung-Chih Chiao. "Sol-Gel Deposition of Iridium Oxide for Biomedical Micro-Devices." Sensors (Basel, Switzerland). MDPI, February 12, 2015. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4367406/.

Conclusions/action items:

Could be used if we ever need to fabricate our own iridium oxide reference electrode. This paper provide us some good information on the capability of iridium oxide uses in vivo and how to fabricate it. Need to know where and who to reach out in order to proceed.

NUR SAIDIN - Nov 01, 2019, 10:50 AM CDT

Sensors **2015**, *15*, 4212-4228; doi:10.3390/s150204212

OPEN ACCESS

sensors

ISSN 1424-8220

www.mdpi.com/journal/sensors

Article

Sol-Gel Deposition of Iridium Oxide for Biomedical Micro-Devices

Cuong M. Nguyen [1,*], Smitha Rao [1], Xuesong Yang [1], Souvik Dubey [1], Jeffrey Mays [1], Hung Cao [2] and Jung-Chih Chiao [1]

[1] Department of Electrical Engineering, University of Texas, Arlington, TX 76019, USA; E-Mails: smitha@uta.edu (S.R.); xuesong.yang@mavs.uta.edu (X.Y.); souvik.dubey@mavs.uta.edu (S.D.); jeffrey.mays@mavs.uta.edu (J.M.); jcchiao@uta.edu (J.-C.C.)

[2] Department of Electrical Engineering, ETS, Montreal, QC H3C 1K3, Canada; E-Mail: Hung.Cao@lacime.etsmtl.ca

* Author to whom correspondence should be addressed; E-Mail: cmnguyen@mavs.uta.edu; Tel.: +1-817-888-4226.

Academic Editor: Yasufumi Enami

Received: 17 December 2014 / Accepted: 6 February 2015 / Published: 12 February 2015

Abstract: Flexible iridium oxide (IrO_x)-based micro-electrodes were fabricated on flexible polyimide substrates using a sol-gel deposition process for utilization as integrated pseudo-reference electrodes for bio-electrochemical sensing applications. The fabrication method yields reliable miniature on-probe IrO_x electrodes with long lifetime, high stability and repeatability. Such sensors can be used for long-term measurements. Various dimensions of sol-gel iridium oxide electrodes including 1 mm × 1 mm, 500 µm × 500 µm, and 100 µm × 100 µm were fabricated. Sensor longevity and pH dependence were investigated by immersing the electrodes in hydrochloric acid, fetal bovine serum (FBS), and sodium hydroxide solutions for 30 days. Less pH dependent responses, compared to IrO_x electrodes fabricated by electrochemical deposition processes, were measured at 51.1 ± 0.4 mV/pH, 53.1 ± 1.3 mV/pH and 41 ± 0.6 mV/pH, respectively. The on-probe IrO_x pseudo-reference electrodes were utilized for dopamine sensing. The baseline responses of the sensors were higher than the one using an external Ag/AgCl reference electrode. Using IrO_x reference electrodes integrated on the same probe with working electrodes eliminated the use of cytotoxic Ag/AgCl reference electrode without loss in sensitivity. This enables

Sol-Gel_Deposition_of_Iridium_Oxide_for_Biomedical_Micro-Devices.pdf(1.8 MB) - download

04/02/2020 - Fabrication of IrOx film pH microsensor on Pt

NUR SAIDIN - Apr 03, 2020, 11:33 AM CDT

Title: A fabrication of iridium oxide film pH micro-sensor on Pt ultramicroelectrode and its application on in-situ pH distribution of 316L stainless steel corrosion at open circuit potential

Date: 04/02/2020

Content by: Syafiqah

Present: myself

Goals: Researching the mathematical model that resembles our prototype for pH sensing mechanism

Content:

The fabrication method and anodic electrodeposition method of the electrodes used was similar with what we have, which is based on Yamanaka. The mechanism at the iridium oxide film can be seen as follows [1]:

$$2[IrO_2(OH)_{(2\text{-}x)}\cdot(2+x)H_2O]^{(2-x)-} + (3\text{-}2x)\ H^+ + 2e^- \leftrightharpoons [Ir_2O_3(OH)_3\cdot 3H_2O]^{3-} + 3H_2O \quad (1)$$

And the redox potential is expressed as below:

Therefore, the redox potential can be expressed as indicated below:

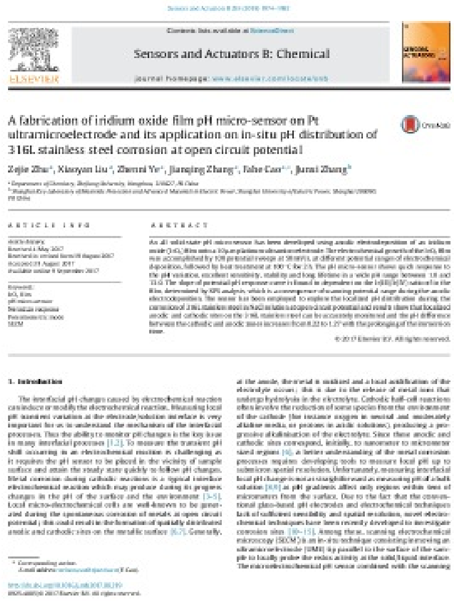
$$E = E^0 - \frac{2.303RT\times(3-2x)}{2F}pH = E^0 - \frac{59.1\times(3-2x)}{2}pH \quad (2)$$

Reference:
[1] Z. Zhu, X. Liu, Z. Ye, J. Zhang, F. Cao, and J. Zhang, “A fabrication of iridium oxide film pH micro-sensor on Pt ultramicroelectrode and its application on in-situ pH distribution of 316L stainless steel corrosion at open circuit potential,” Sensors and Actuators B: Chemical, vol. 255, pp. 1974–1982, Feb. 2018, doi: 10.1016/j.snb.2017.08.219.

Conclusions/action items:

Can be used for a part of the simulation

NUR SAIDIN - Apr 03, 2020, 11:34 AM CDT


Contents lists available at ScienceDirect

Sensors and Actuators B: Chemical

A fabrication of iridium oxide film pH micro-sensor on Pt ultramicroelectrode and its application on in-situ pH distribution of 316L stainless steel corrosion at open circuit potential

Zejie Zhu, Xiaoyan Liu, Zhenni Ye, Jianqing Zhang, Fahe Cao, Junxi Zhang

ARTICLE INFO

ABSTRACT

1. Introduction

main.pdf(2.7 MB) - download

04/09/2020 - Microelectrode Needle Design

NUR SAIDIN - Apr 10, 2020, 12:57 AM CDT

Title: Microelectrode Needle Design

Date: 04/09/2020

Content by: Syafiqah

Present: me

Goals: Find microelectrode design that will increase fluidic contact

Content:

1. Iridium oxide based coaxial pH ultramicroelectrode

In this design, IrOx film is electrodeposited on plated Au microelectrode at the outside of the borosilicate capillary using electrodeposition method similar with what we have been using. Inside the capillary is an Ag/AgCl reference electrode with electrolyte (saturated KCl and 2% agar in water).. The figure below shows the design of this electrode:

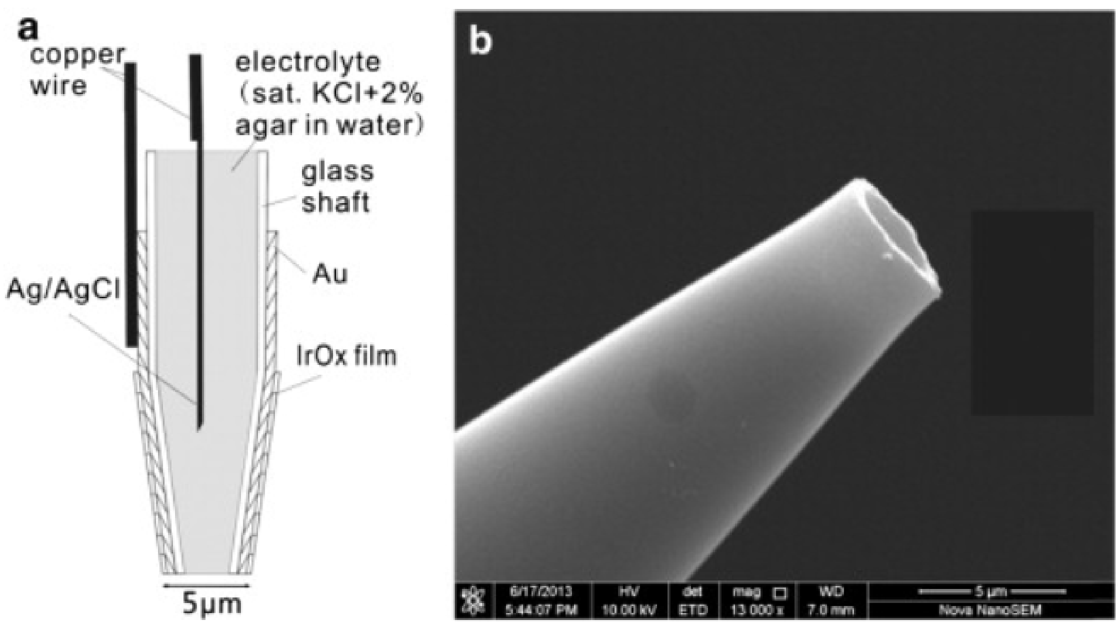


Figure 1: (a) The cross-section of the microelectrode. (b) SEM image of the microelectrode tip [1]

For our application, this design has high contact with the surrounding fluid when inserted inside the muscle compartment. It might be more complicated to fabricate and expensive due to usage of gold plate. We can coat the outside of stainless steel needle instead. The application of electrolyte inside the capillary increase the exchange of ion and consequently also increase the amount of contact with the fluid. We can also apply an ion-sensing membrane at the end of the tip to contain the electrolyte inside the needle.

2. Hydrogen-selective Microelectrodes Based on Silicon Needles

In this design, the needle is made from silicon and four microelectrodes are fabricated and attched inside the wall. This design is more complicated and takes more time to fabricate. Figure 2 below shows the cross-section of the needle with microelectrodes attached.

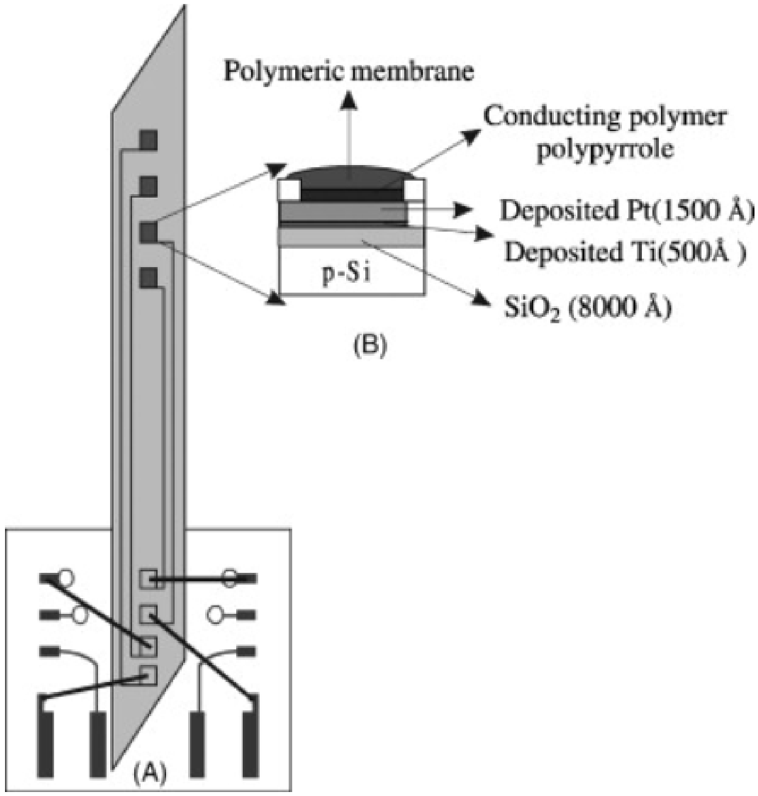


Figure 2:Needle-shaped silicone substrate with cross-section of microelectrode

The design is more complicated for our purpose. However, with microfabricated electrode attached inside the wall, we can use smaller needle. We might need to eliminate the use iridium oxide and ag/agcl electrode.

Reference:

[1] X. Huang, Q. Ren, X. Yuan, W. Wen, W. Chen, and D. Zhan, “Iridium oxide based coaxial pH ultramicroelectrode,” Electrochemistry Communications, vol. 40, pp. 35–37, Mar. 2014, doi: 10.1016/j.elecom.2013.12.012.

[2] N. Zine et al., “Hydrogen-selective microelectrodes based on silicon needles,” Sensors and Actuators B: Chemical, vol. 91, no. 1, pp. 76–82, Jun. 2003, doi: 10.1016/S0925-4005(03)00069-8.

Conclusions/action items:

Need to find simulation software to stimulate the design

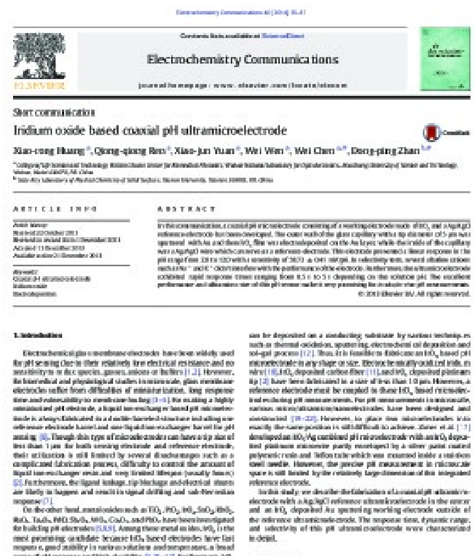
NUR SAIDIN - Apr 15, 2020, 10:53 PM CDT


Hydrogen-selective microelectrodes based on silicon needles

N. Zine, J. Bausells, A. Ivorra, J. Aguiló, M. Zabala, F. Teixidor, C. Masalles, C. Viñas, A. Errachid

Hydrogen-selective_microelectrodes_based_on_silicon_needles.pdf(225.1 KB) - download

NUR SAIDIN - Apr 15, 2020, 10:53 PM CDT


Electrochemistry Communications

Short communication

Iridium oxide based coaxial pH ultramicroelectrode

Iridium_oxide_based_coaxial_pH_electrode.pdf(344.3 KB) - download

12/03/2019 - Final Design - ISFET and Electrodeposited Ag/AgCl reference

NUR SAIDIN - Dec 11, 2019, 12:58 AM CST

Title: Final Design: ISFET and Ag/AgCl reference electrode

Date: 12/03/2019

Content by: Syafiqah

Present: Team

Goals: Fabricating final prototype

Content:

This semester we are too focused on finding the smallest reference electrode for the ISFET. However, we have found an alternative non-ISFET based pH sensor by using Iridium Oxide, which is similar with the entry *Needle-like Ir/Ag combined pH microelectrode* on 17th October. Due to extended shipping time, the materials that we ordered for fabricating IrOx electrode arrived pretty late and we do not have enough time to make and test it. So, we tested three different Ag/AgCl reference electrodes with the ISFET sensor. The three reference electrode includes the one from Winsense kit, the 450micron from World Precision Instrument, and the electrodeposited electrode. Each reference electrode is tested with the ISFET by putting it in a pH 7 buffer solution to observe any drift from the voltage. If small drift is observe, that means that the ISFET with the reference used are very stable. Having a stable voltage/pH values is very important in our design as we need to measure and record at least 48 our of intramuscular pH. Based on the result (as seen in the Team_Activities/Testing_and_results-Experimentation_Drift_Testing_Data entry), both the Winsense and the electrodeposited electrodes have very small variances and stable voltage output. As Winsense reference electrode is very big to put inside the needle, we decicded to use the electrodeposited Ag/AgCl reference that is way more thinner and smaller. The final design of the ISFET and the reference is shown in the diagram below:

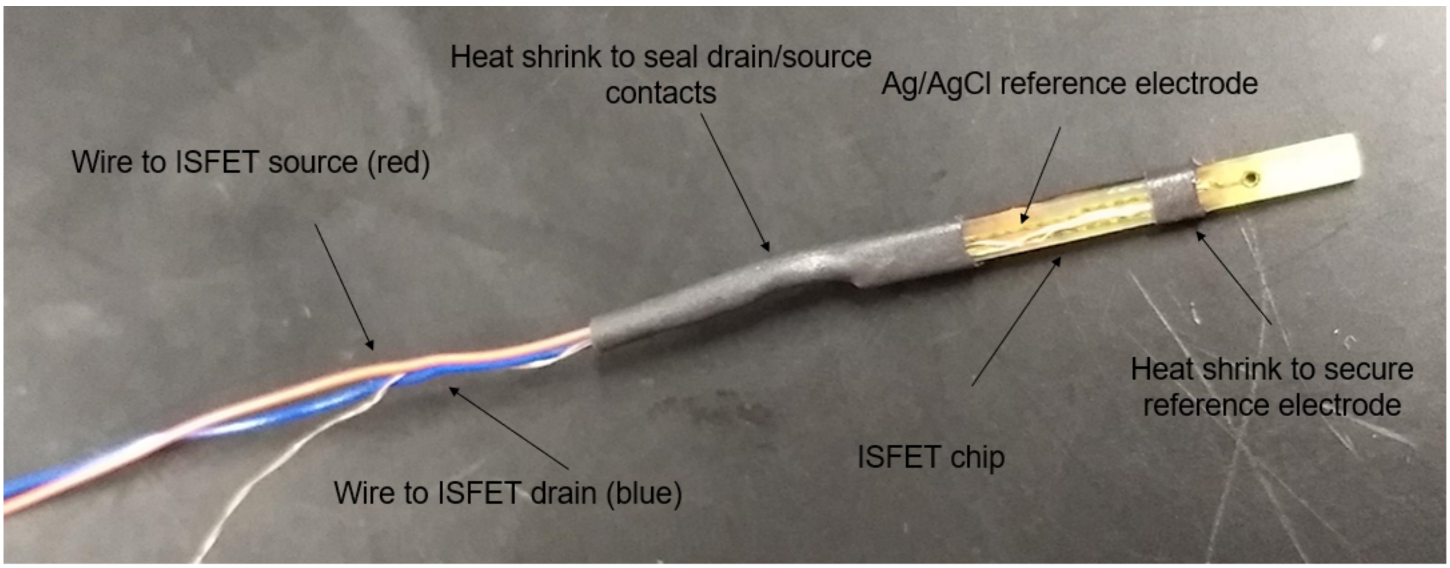


Figure 1: The assembly of the ISFET sensor and theelectrodeposited Ag/AgCl reference electrode attached with heat shrink.

Conclusions/action items:

Test the prototype

2020/01/27 - IrOx Electrodepositing solution

NUR SAIDIN - Feb 26, 2020, 7:52 AM CST

Title: Preparation of Electrodepositing Solution

Date: 01/27/2020

Content by: Syafiqah

Present: Hunter

Goals: Prepare the electrodepositing solution to fabricate Iridium Oxide electrode

Content:

The electrodepositing solution was prepared to be used when fabricating the iridium oxide electrode. The materials that we used include iridium tetrachloride, hydrogen peroxide, oxalic acid, and anhydrous potassium carbonate. The steps for preparing this solution is as follows [1]:

1. Dissolve 75mg iridium tetrachloride in 50mL water
2. Stir 30 min
3. Add 0.5mL 30% hydrogen peroxide (aq) and stir 10 min
4. Add 250mg oxalic acid dihydrate and stir 10 min
5. Adjust pH slowly to 10.5 by adding small portions of anhydrous potassium carbonate
6. Leave at room temperature for 2 days to stabilize

The color of the solution change from greenish-yellow to blue-black after two days.

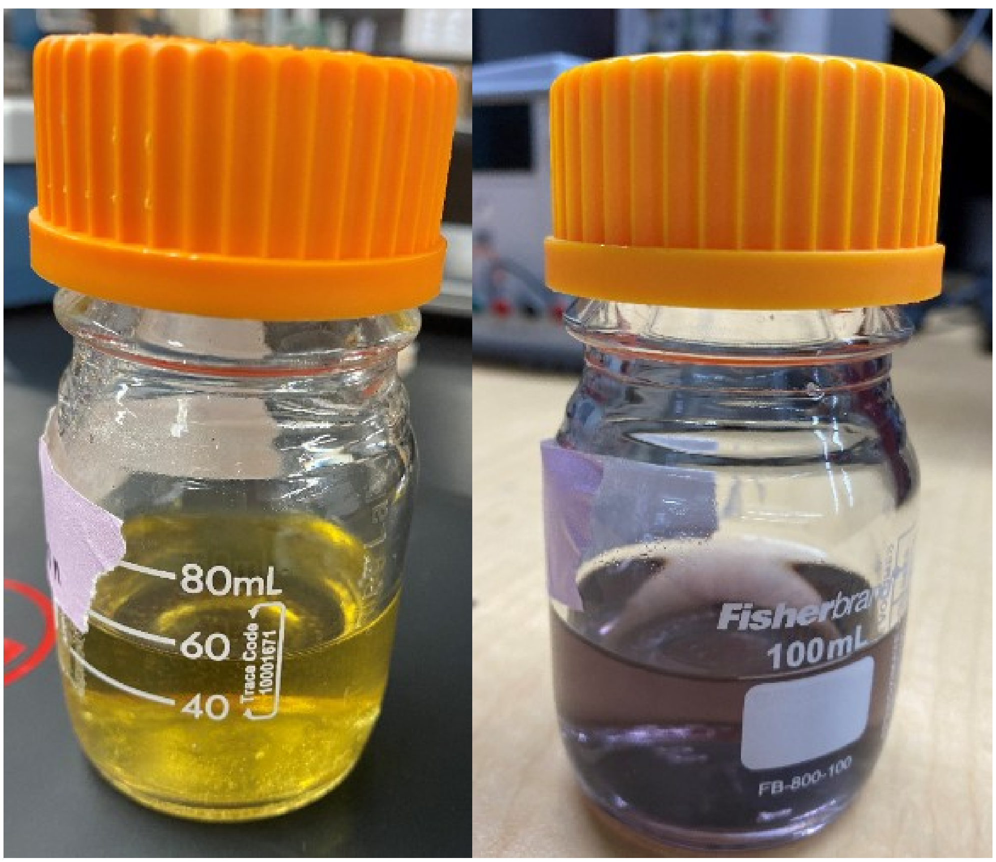


Figure 1: The solution before (left) and after (right) left for 48 hours.

Reference:

[1] S. A. M. Marzouk, S. Ufer, R. P. Buck, T. A. Johnson, L. A. Dunlap, and W. E. Cascio, “Electrodeposited Iridium Oxide pH Electrode for Measurement of Extracellular Myocardial Acidosis during Acute Ischemia,” *Anal. Chem.*, vol. 70, no. 23, pp. 5054–5061, Dec. 1998, doi:

10.1021/ac980608e.

Conclusions/action items:

Can proceed to electrodeposition of iridium oxide electrode.

2020/02/02 - Electrodeposition of IrOx 1

NUR SAIDIN - Feb 26, 2020, 7:39 AM CST

Title: Electrodeposition of IrOx with Pt/Ir wire

Date: 02/02/2020

Content by: Syafiqah

Present: Hunter

Goals: Fabricate IrOx electrode

Content:

The fabrication protocol for electrodeposition of IrOx electrode used a three-cell electrode setup with a potentiostat to supply a triangular and square wave voltages. We figured we can use the oscilloscope as a potentiostat but we were having difficulties when supplying the waveforms to the circuit. So we do the electrodeposition using the same method with Ag/AgCl reference electrode. This is done by connecting the thin Pt/Ir wire (the wire that will be electrodeposited) to the positive terminal and thicker Pt/Ir wire to the negative terminal. The wires were connected with 470Ω resistor and supplied with 1.5V DC. Blue-black deposit was observed at the thin wire.

Figure 1: Two wires of Pt/Ir were immersed in the electrodepositing solution and connected to the power supply by alligator clips.

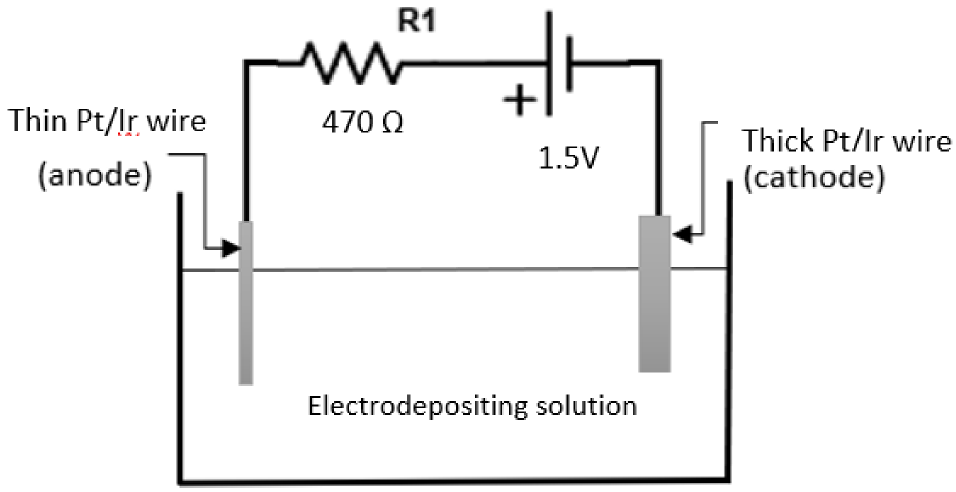


Figure 2: Schematic electrodeposition setup of IrOx electrode.

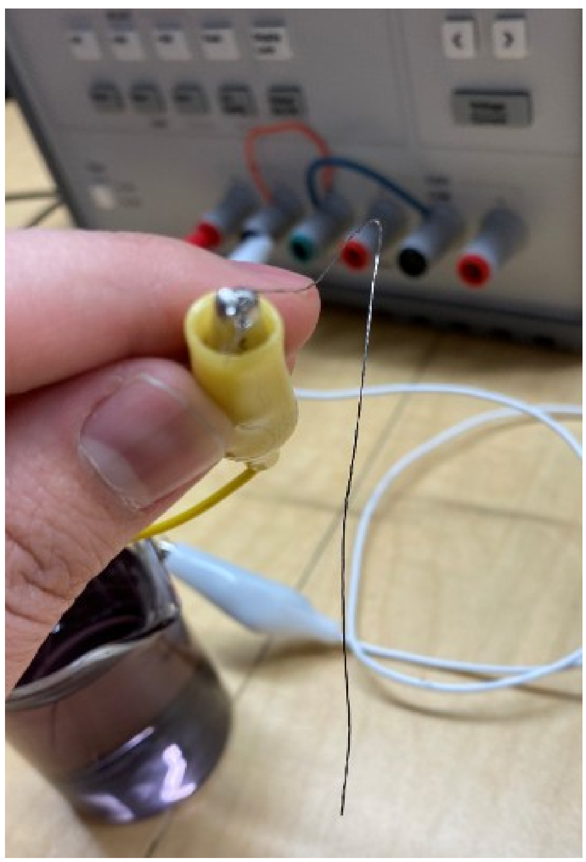


Figure 3: Blue-black deposit was observed on the Pt/Ir wire,

Conclusions/action items:

We think that the setup just electrodeposited one layer of IrOx on the Pt/Ir wire. The layer might be thin, unstable, and flake easily. We need to test whether the electrode work

2020/02/11 - Electrodeposition of IrOx 2

NUR SAIDIN - Feb 26, 2020, 7:53 AM CST

Title: Electrodeposition of IrOx on Pt-Ir wire

Date: 02/11/2020

Content by: Syafiqah

Present: Jonah, Lucas, Hunter

Goals: Electrodeposit IrOx on Pt-Ir wire

Content:

A three-electrode cell was used with thin Pt-Ir wire (the one that we wanted to coat) as the working electrode, thicker Pt-Ir wire as the counter electrode, and Ag/AgCl as the reference electrode. These three electrodes are immersed in the electrodeposition solution and connected to the potentiostat (acquired from Jonah's lab at WIMR). Triangular waveform from 0 to 0.55V at 50mV/s is supplied for 50 cycles. Followed by pulses of square waveform from 0 to 0.55V at 0.5s interval for 1600 cycles. This is to improve the adhesion of the IrOx to the substrate by making more layers [1].

Figure 1: The set up of the electrodeposition of IrOx.

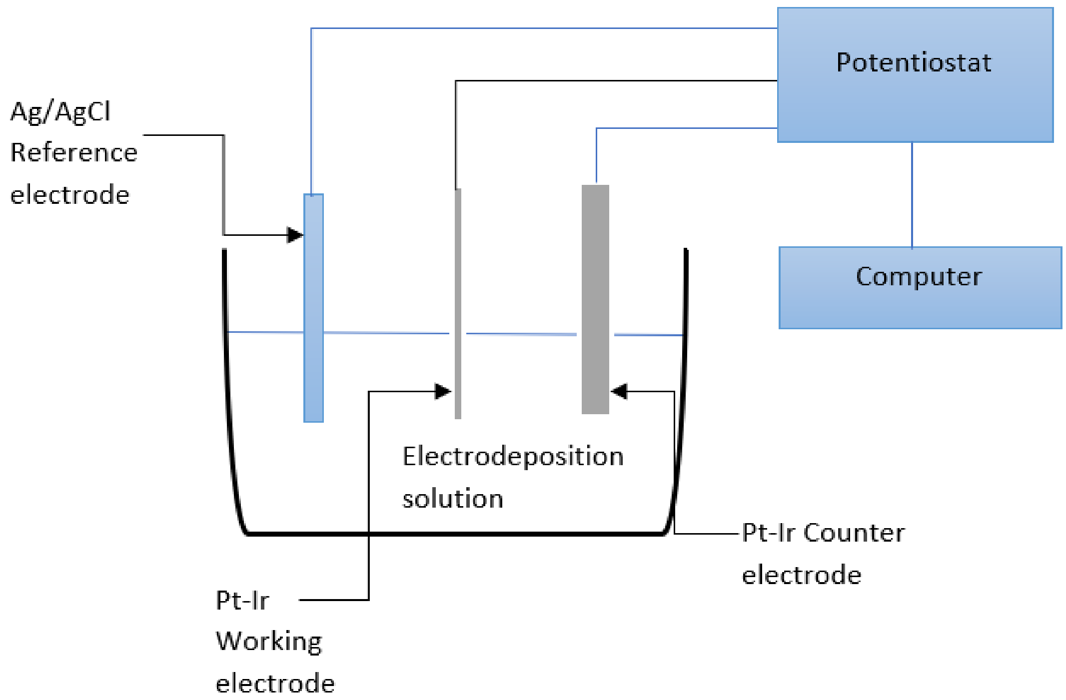


Figure 2: The setup of the electrodeposition step.

We also test the IrOx that we did last time (with normal electrodeposition method with DC current) with Ag/AgCl reference and put it inside pH buffer solution of 4,7, and 10. We connected both electrodes with a digital multimeter and the voltage changes as the pH changes!!! Basically, it works.

Rereference:

[1] R. D. Meyer, S. F. Cogan, T. H. Nguyen, and R. D. Rauh, “Electrodeposited iridium oxide for neural stimulation and recording electrodes,” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 9, no. 1, pp. 2–11, Mar. 2001, doi: 10.1109/7333.918271.

Conclusions/action items:

We need to test this IrOx eletcrode and do a 48-hour drift test. Need to order more Pt-Ir wire to make more electrodes.

2020/04/17 - Delivery design

NUR SAIDIN - Apr 29, 2020, 10:43 AM CDT

Title: Delivery design

Date: 04/17/2020

Content by: Syafiqah

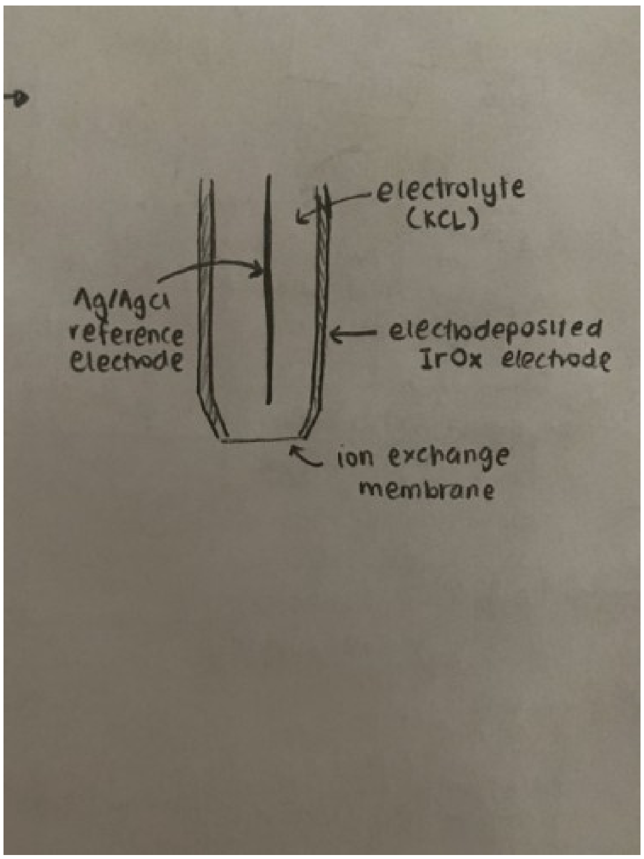
Present: me

Goals: Design delivery methods

Content:

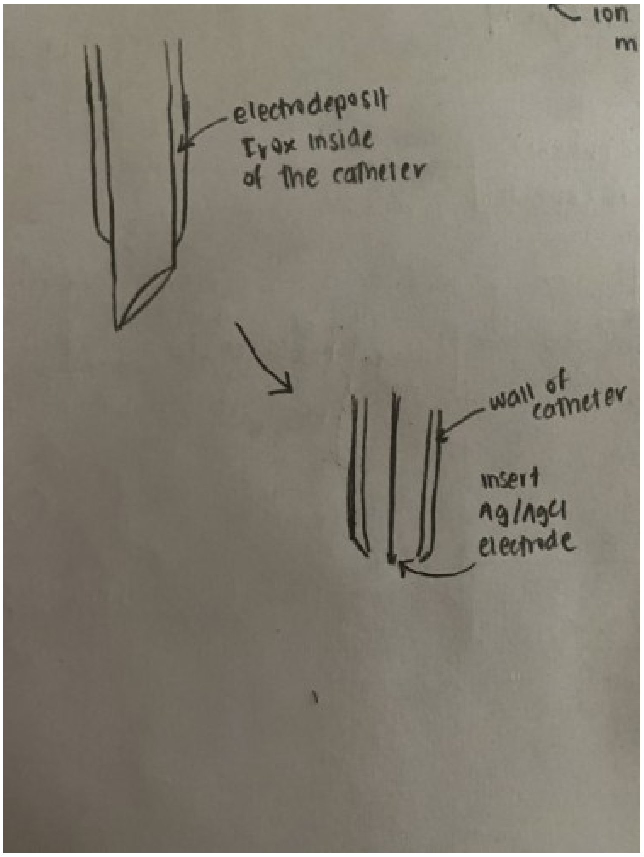
Design 1

This design electrodeposited the IrOx outside of the catheter, with the KCL electrolyte and Ag/AgCl electrode on the inside. AT the tip there is an ion exchange membrane.



Design 2

Electrodeposited at the inside of the catheter. Take out the needle after insertion and put the Ag/AgCl electrode inside.



Conclusions/action items:

I have a hard time using Solidworks, hence the sketch. Based these two designs, I think the second design would work best for the project as it would allow more contact with fluid and we can use smaller needle than what we currently using in cadaver testing. Need to discuss with team about my design and Hunter's and choose one that we will consider for future work

11/25/2019 - Testing Winsense ISFET and its reference electrode

NUR SAIDIN - Dec 11, 2019, 1:29 AM CST

Title: Testing ISFET and Winsense Reference Electrode

Date: 11/25/2019

Content by: Syafiqah

Present: Jonah, me

Goals: Testing the ISFET and the Winsense reference electrode

Content:

The Winsense kit that we bought from Thailand consists of an ISFET pH sensor, an Ag/AgCl reference electrode, and the ISFET pH read-out circuit box. The circuit box was first need to be powered with a 9V battery (Jonah bought from KwikTrip). There are five pin connections on the analog front end which include: +V, the output voltage terminal; D, the drain input terminal; S, source input terminal; G, the reference electrode terminal; and GND, the ground terminal. The +V and GND terminal are connected to the multimeter to read the voltage, the G terminal to the reference electrode and the D and S terminals to the drain and source wires of the ISFET respectively. After all the wires are connected, the ISFET and the reference were first rinsed with deionized water and wiped gently. Both are then put inside the buffer solution with pH of 4, 7, and 10. The voltage reading were recorded for each solution. Note that the sensor was cleaned wiped before and after put into the buffer solution with deionized water. This is to ensure that there is no residue from previous solution on the ISFET chip. We observed that the reading of the voltage increases as the pH increases. WIth the voltage values recorded, we plotted the voltage against the pH and obtain a linear regression line equation. From that we can get the pH equation. We then put the sensor inside a random pH buffer solution and convert the voltage values into pH. The calculated pH obtained is very close to the actual value with difference range around 0.05.

Conclusions/action items:

The Winsense ISFET and its reference electrode is very stable and accurate, Will compared with other reference electrode.

12/2/2019 - Fabrication of Ag/AgCl electrode

NUR SAIDIN - Dec 11, 2019, 1:11 AM CST

Title: Fabrication of Ag/AgCl electrode through electrodeposition

Date: 12/2/2019

Content by: Syafiqah

Present: Jonah, Hunter, Syafiqah

Goals: Fabricate Ag/AgCl electrode

Content:

The Ag/AgCl electrode is fabricated using electrodeposition process. The materials that we used include silver wires, Potassium Chloride (KCl), and distilled water. Refer to Team_Activites/Fabrication/Elctrodeposition_of_Ag/AgCl for detailed steps of fabrication. The diagram below is an example of electrodeposition process. Note that the diagram is not the real representation of the process that we used. The chloride ion from the KCl will attracted to the anode, the thin Ag wire that will be electroplated, and the electron will flow to through the circuit.

$$Ag(s) + Cl^-(aq) \leftrightarrow AgCl(s) + e^-$$

The ionized Ag+ will react with the Cl- and deposited AgCl on the thin Ag wire.

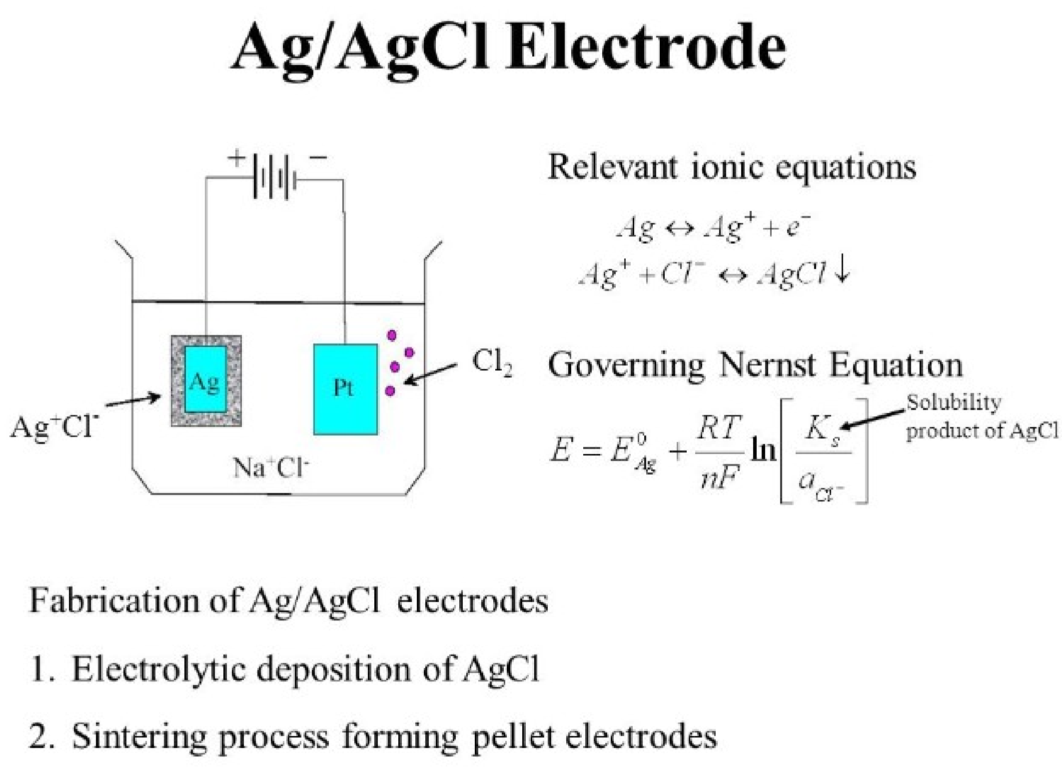


Figure 1: The electrodeposition process of Ag/AgCl [1].

Figure 2: The setup of the Ag/AgCl electrodeposition

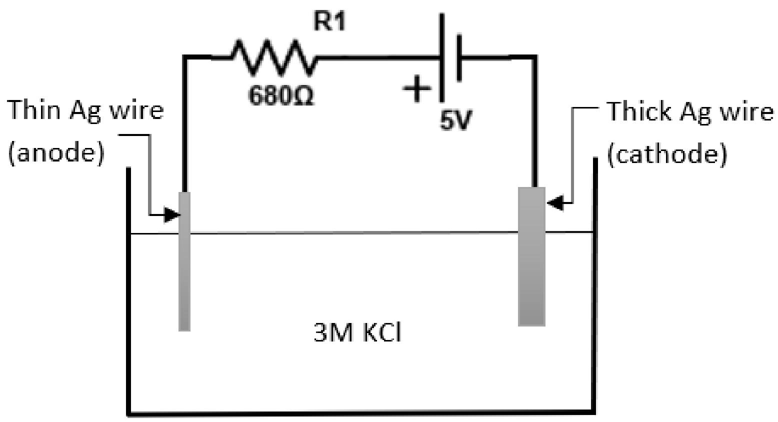


Figure 3: The circuit setup of the electrodeposition of Ag/AgCl electrode. The thin Ag wire is connected to the positive terminal (anode) and thick wire to the negative terminal (cathode).

Reference:

[1] “Biopotential Electrodes (Ch. 5) - Ppt Video Online Download.” SlidePlayer. Accessed December 3, 2019. https://slideplayer.com/slide/4214704/.

Conclusions/action items:

Test with Winsense electrode.

12/3/2019 - Testing 450micron and Electrodeposited reference electrode

NUR SAIDIN - Dec 11, 2019, 1:44 AM CST

Title: Testing ISFET with 450micron and Electrodeposited Ag/AgCl reference electrode

Date: 12/3/2019

Content by: Syafiqah

Present: Team

Goals: Testing ISFET with 450micron and electrodeposited reference electrode. Compare all three reference electrodes.

Content:

We have tested the 450micron reference electrode from World Precision Instrument and the electrodeposited Ag/AgCl. Each has been cleaned with deionized water and wiped before put into the buffer solution with pH of 4, 7, and 10. The voltage increases with increasing pH. The linear regression plot from both reference are as follows:

pH	Voltage				
4	0.943			Input	Output
7	1.081	No rinsing between measurements to avoid additional loss of AgCl	pH -> Voltag	10	1.234
10	1.237		Voltage -> pH	1.238	10.0816326

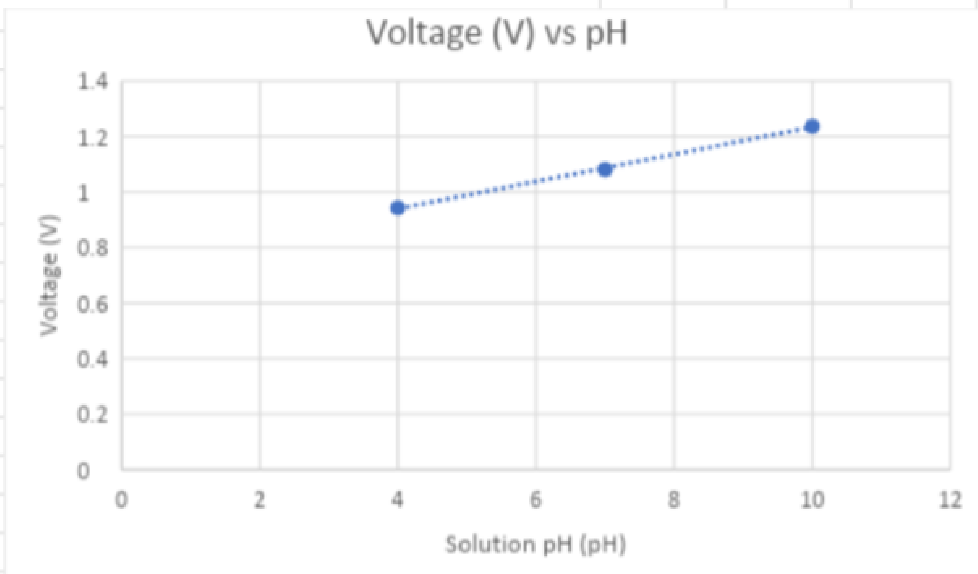


Figure 1: The result and Voltage vs. pH plot of the ISFET with 450micron reference electrode.

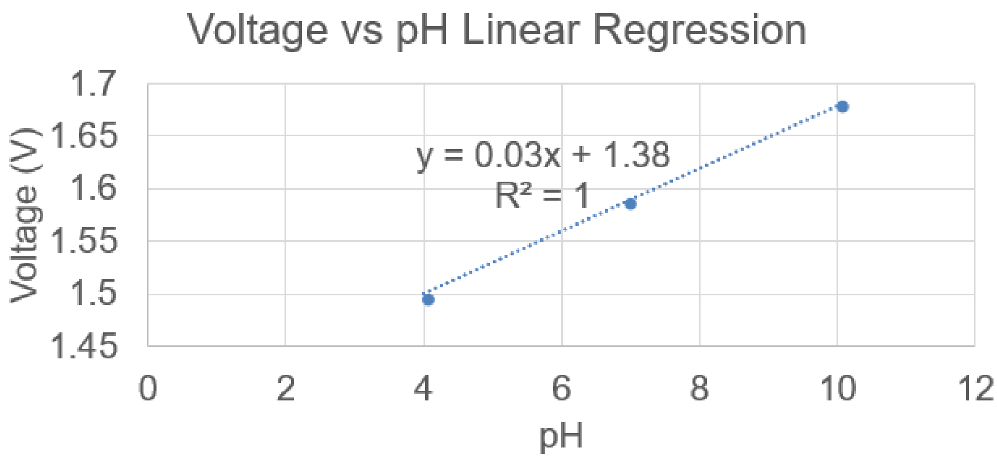


Figure 2: The result and voltage vs. pH plot of the ISFET and the electrodeposited Ag/AgCl reference electrode.

Conclusions/action items:

We just so happy that the Ag/AgCl reference electrode that we made is working. Do drift test to check the stability of the reference.

03/11/2020 - Cadaver Testing

NUR SAIDIN - Apr 03, 2020, 11:50 AM CDT

Title: Cadaver Testing

Date: 03/11/2020

Content by: Syafiqah

Present: me and Jonah

Goals: Compare our electrodes and commercial one in detecting pH in semi-solid substrate

Content:

We test our electrode inside the muscle compartment of a cadaver. The details of the procedure is in the folder Team_activities/Testing_and_Results/Experimentation/Cadaver_Testing

Conclusions/action items:

There are some random "noise" with the reading when inserting the elcetrodes through the stainless steel needle. Need to look this up.

10-06-2019 PreSens PH-MP5

HUNTER HUTH - Oct 06, 2019, 11:09 PM CDT

Title: PreSens PH-MP5

Date: 10-06-2019

Content by: Hunter Huth

Present: Myself

Goals: Describe the PreSens PH-MP5 sensor

Content:

PreSens manufactures a needle-like pH sensor used for reading the pH inside of tissue samples. This product reads pH samples between 5.5 and 8.5 with an accuracy of +/- .1 (not accurate enough for our purpose) It is unclear whether the pH sensor is in the tip of the needle, but it seems to extract a very small amount of solution and test the pH of the sample. The needle is not a hyperdermic needle as well, so this product could not be for use in humans. The internal components none the less could have patent Issues. The sensor must be precisely vertical to operate as well, which is not feasible clinically. The product seems to use a fiber fed through a needle to sense pH, but the exact mechanism is unsure.

https://www.presens.de/products/detail/profiling-ph-microsensor-pm-hp5.html

Figure: The PreSens micro pH sensor. It has an extensible tip

Conclusions/action items:

Research the mechanism that this product uses to sense pH at such a small size.

Commercial Ribbon Cables 10-06-2019

HUNTER HUTH - Oct 06, 2019, 10:28 PM CDT

Title: Commercial Ribbon Cables

Date: 10-06-2019

Content by: Hunter Huth

Present: Myself

Goals: Discuss a custom Ribbon Cable manufacturer

Content:

A company out of Sweden, Sandvik Coorporation, manufactures custom wires used for medical equipment. They are capable of making custom ribbon cables with thickness between .0127mm and .75mm with a width of .051 mm and 3.05 mm. https://www.materials.sandvik/en/products/wire/exera-fine-medical-wire/product-forms/ribbon-wire/ We need a wire that is in total 1 mm in width with a pitch of .25mm for a total of four leads. This cable must be able to withstand a solder reflow oven.

SANDVIK

Conclusions/action items:

Contact Sandvik Coorporation about cost to produce a custom ribbon cable for our required constraints.

9-20-2019 Sentron pH ISFET Bare Die chip

HUNTER HUTH - Oct 06, 2019, 10:49 PM CDT

Title: Sentron Bare Die ISFET pH sensor

Date: 9-20-2019

Content by: Hunter Huth

Present: Myslef, Jonah, Lucas, Syafiqah

Goals: Summarize the Bare Die sensor from Sentron and describe what must be accomplished to use it

Content:

The Sentron bare die sensor is on the millimeter scale, and is difficult to work with because the leads are under .25 mm in width. These cannot be soldered using conventional methods. During a team meeting, we used a microscope to get a picture of the Bare die ISFET sensor and measured the box it fits inside to create a scale. We must devise a plan to connect the four leads to the micro controller and AD Converter. The sensor needs to be able to be implanted at least 4 inches, so the cable must be about 5 inches before reaching any larger electrical components. The ribbon cable must also have four leads with a pitch of .25mm.

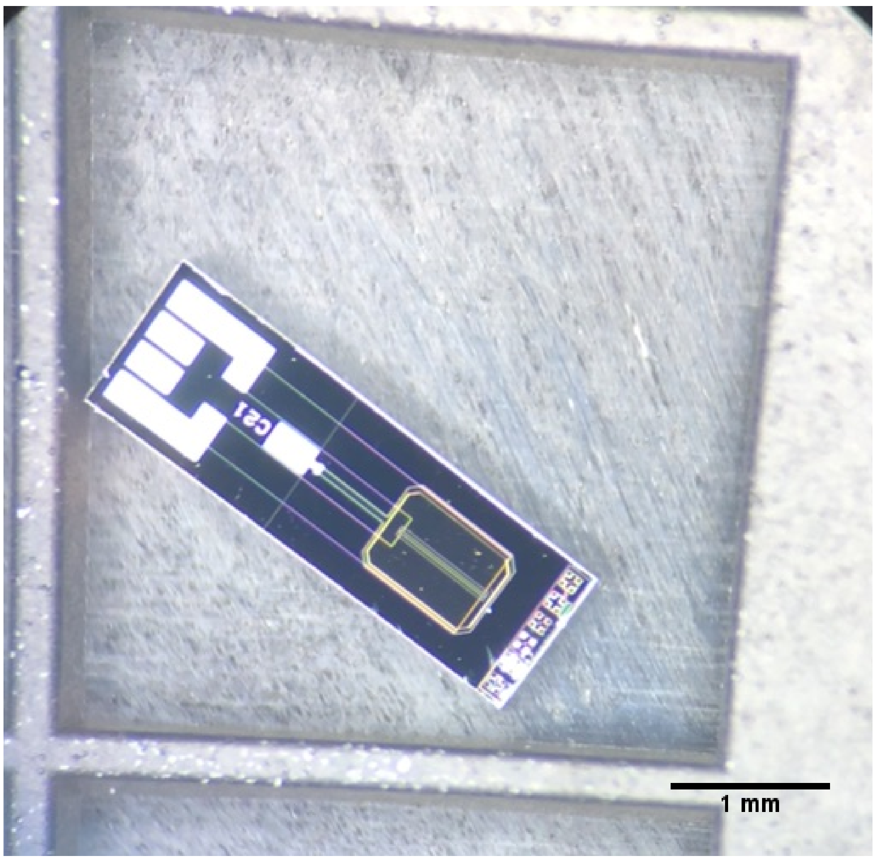


figure. The bare die sensor which is inside the complete micro ISFET sensor sold by Sentron.1mm in width, and four leads, which have a pitch of about .25mm.

Conclusions/action items:

- Discuss with Wisconsin Center for Nanoscale technology
- Contract Sentron about purchasing more Bare Die sensors
- Research Commercial Ribbon Cables

2019/17/10 Review article on micro reference Electrodes

HUNTER HUTH - Oct 17, 2019, 5:31 PM CDT

Title: Review article on Micro reference electrodes

Date: 10/17/2019

Content by: Hunter Huth

Present: Myself and Syafiqah

Goals: Discuss a paper which reviews a collection of research on micro Reference electrodes and their application.

Content:

This paper outlines a series of previous publications, which investigated minimizing reference electrodes for ISFET sensors. The majority of electrodes were the usual Ag/ AgCl material. The smallest Ag/Agcl electrodes typically involve a Hydrogel KCL solution deposited around the electrode. The paper says that ISFETs meant for pH measurements are typically used with an Iridium Oxide reference electrode because of their Hydronium sensitivity. Conveniently these reference electrodes tended to be the smallest with .1mm X 1mm and 1500 micrometers^2. There may be commercially available Iridium Oxide reference electrodes on the market. [1]

All material in this section was found in the Paper cited below

[1] Shinwari, M., Zhitomirsky, D., Deen, I., Selvaganapathy, P., Deen, M. and Landheer, D. (2010). Microfabricated Reference Electrodes and their Biosensing Applications. *Sensors*, 10(3), pp.1679-1715.

Conclusions/action items:

1) read the cited reference papers from the above article on Iridium Oxide Electrodes

2) Search for commercially available Iridium Oxide reference electrodes

2019/10/17 Iridium Oxide Reference Electrodes for neurochemical sensing

HUNTER HUTH - Oct 17, 2019, 6:02 PM CDT

Title: Iridium Oxide Reference Electrodes for Neurochemical Sensing

Date: 2019/20/17

Content by: Hunter Huth

Present: Myself and Syafiqah

Goals: Describe a paper which used Iridium Oxide reference electrodes.

Content:

This section will specifically review the fabrication of the electrodes and the results

Fabrication:

1. Michigan Neural Probes-
   1. Micromachine on silicon wafers using a deep boron diffusion etch stop with EDP release.
   2. Use polysilicon interconnects with anodically grown iridium Oxide film
   3. single mask added for added metal layer of Pt electrodes.
   4. six site probes include " 1.5x103μm2IrOx reference electrode, a single 1.5x103μm2 Pt counter electrode, three circular Pt working electrodes for electrochemical recording, and three circular IrOx electrodes for electrical recording" [1]
2. Simpler Design -
   1. Pt used for the interconnect with anodically grown irdium oxide
   2. probes include single "1.5x103μm2IrOx reference electrode, a single 1.5x103μm2 Pt counter electrode, and six circular Pt working electrodes for electrochemical recording ranging in radius from 4 to 50μm" [1]

Results:

The electrodes had very comparable results to commercially available pH electrodes until the ~20 day mark was met after being soaked in solution. After 20 days a rapid decline in pH response was observed

[1] R. K. Franklin *et al.*, "Iridium oxide reference electrodes for neurochemical sensing with MEMS microelectrode arrays," *SENSORS, 2005 IEEE*, Irvine, CA, 2005, pp. 4 pp.-.
doi: 10.1109/ICSENS.2005.1597971

Conclusions/action items:

The reference electrodes are small enough for our applications, but require difficult to obtain materials including Pt and Iridium Oxide. This fabrication would also require clean rooms for fabrication. The electrodes would also need to have a protocol for packaging that would preserve their pH sensitivity until use.

2019/11/12-Electrodeposition of Iridium on platinum

HUNTER HUTH - Nov 12, 2019, 8:47 PM CST

Title: Electrodeposition of Iridium on Platinum

Date: 2019/11/12

Content by: Hunter Huth

Present: Myself

Goals: Describe a process for electrodeposition of Iridium Oxide on platinum

Content:

1. Create an aqueous solution of 4mM $IrCl_4$ in 40 mM oxalic acid, and 340 mM K_2CO_3.
    1. dissolve $IrCl_4$ in oxalic acid
    2. slowly add K_2CO_3 until a pH of ~10.3 is achieved.
    3. Let sit for 48 H, for Ir^{3+}/ Ir^{4+} equilibrium.
2. create a three electrode cell with Pt counter electrode nad Ag/Agcl Reference electrode
3. cycling 50 times between 0 v and 0.55 v against Ag/Agcl at 50 mv/s
4. pulse at 0 and 0.55 V for 1600 pulses with .5 s at each pulse

R. D. Meyer, S. F. Cogan, T. H. Nguyen, and R. D. Rauh, “Electrodeposited iridium oxide for neural stimulation and recording electrodes,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 9, no. 1, pp. 2–11, Mar. 2001.

Conclusions/action items:

this process could be used for depositing iridium on a platinum wire. We could use an oscilloscope for creating the potentials or a raspberry pi.

2020/21/2 Catheter materials for inner tubing

HUNTER HUTH - Feb 21, 2020, 7:40 PM CST

Title: Catheter materials for inner tubing

Date: 2/21/2020

Content by: Hunter Huth

Present: Myself

Goals: Describe different materials to use in our catheter

Content:

1. PE: High desity poly ethylene is a carbon chain with no chlorinated ends.
    - pros
        - good toughness and wear
        - commonly used in tubing for drains and catheters
    - cons
        - multi-lumen extrusion is questionable.
2. PVC: polyvinyl chloride is a carbon chain with one chlorinated vinyl bond.
    - pros
        - cheap
        - extrudable in multi-lumen
    - cons
        - short term use only. plasticizers can be leached which causes embrittlement.
3. PTFE: Carbon chain with all vinyl bonds fluorinated
    - pros
        - extrudable in multi lumen
        - used commonly in tubing and catheters
        - extreme precision during manufacturing
    - cons
        - uses are typically short term
4. FEP: fluorinated ethylene propylene has one vinyl CF3
    - pros
        - used commonly in long term sutures
        - same extrusion properties as PTFE
    - cons
        - more expensive
        - harder to find

[1] B. D. Ratner, A. S. Hoffman, F. J. Schoen, and J. E. Lemons, *Biomaterials Science: an Introduction to Materials in Medicine*. Saint Louis: Elsevier Science, 2014.

Conclusions/action items:

Contact companies about custom extrusions and the possibilities of purchasing already existing IV catheters.

2020/4/09-Template - Micro Electrode Designs

HUNTER HUTH - Apr 09, 2020, 7:35 PM CDT

Title: Micro Electrode Designs

Date: 4/9/2020

Content by: Hunter Huth

Present: Myself

Goals: Research existing micro electrode delivery methods

Content:

Microelectrodes have been used for chemical recordings, and electrical simulation. The general layout for a micro electrode can be seen in the figure below.

Fig. 1

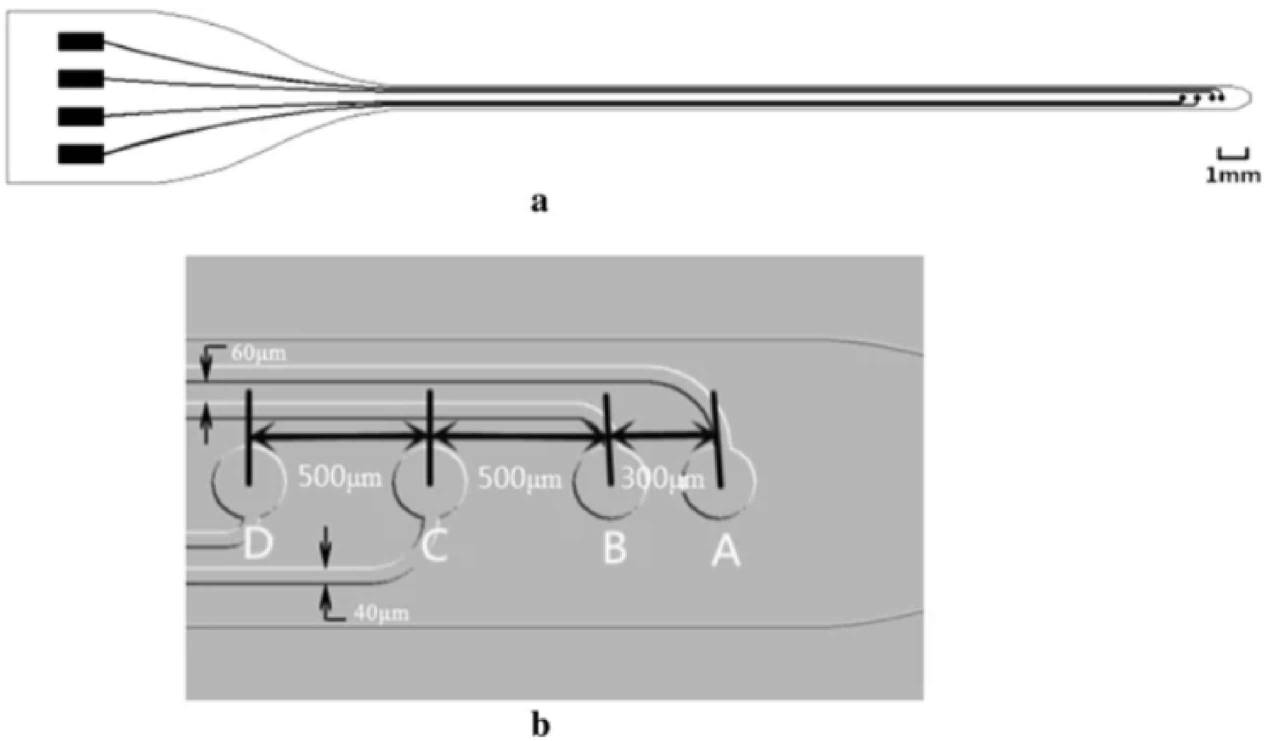


Figure: This is a microelectrode designed for electrical simulation. Uses four pads.[1]

The above design type wold minimize insertion size and maximize solution contact by placing the electrodes on the outside instead of inside a needle. The biggest concern with this design would be durability during insertion. To reach deep tissue compartments, it would need the strength to pierce tissue. The electrode must not break off into the patient as well from torque. The outer layer of this electrode is Parylene-C. The electrode was deposited in layers as shown in the figure below in steps "a" through "h."

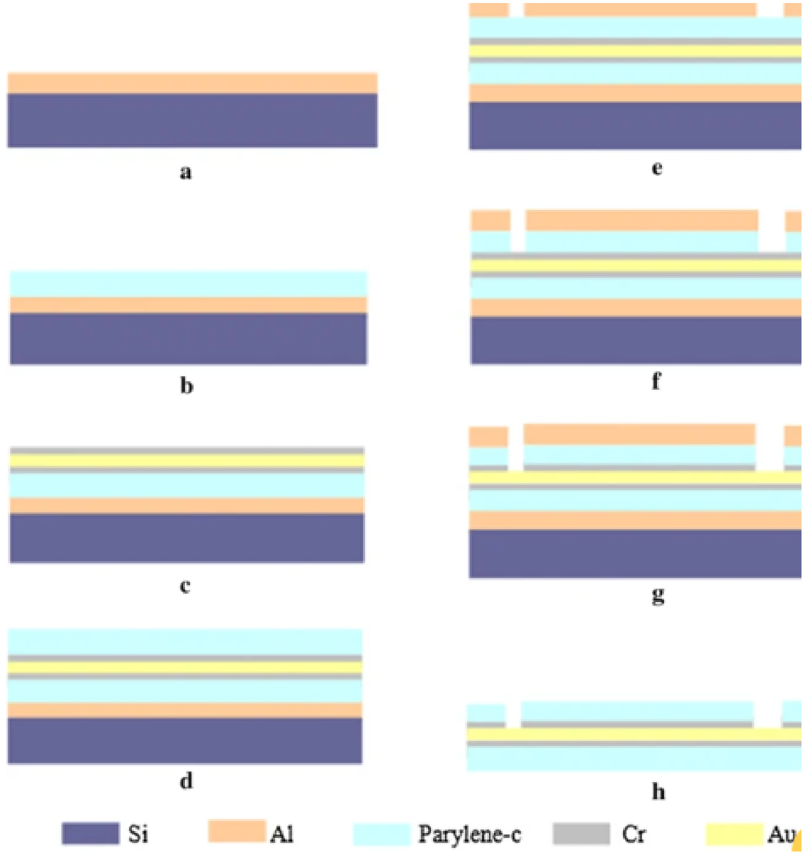


Figure 2: Process of depositing a micro electrode in layers. The final electrode has a parylene-c exterior, a Chromium lining with a gold interior.

[1] Cui, H., Xie, X., Xu, S. *et al.* Electrochemical characteristics of microelectrode designed for electrical stimulation. *BioMed Eng OnLine* 18, 86 (2019). https://doi.org/10.1186/s12938-019-0704-8

Conclusions/action items:

This method could be possible for the delivery of our device into the muscle compartment, but it has some limitations. The strength would need to be improved, and the manufacturing process might be too difficult based on our resources.

10/8/2019 Design for a minimized probe

HUNTER HUTH - Oct 08, 2019, 11:10 PM CDT

Title: Design for Minimized Probe

Date: 10/8/2019

Content by: Hunter Huth

Present: Myself, Jonah, Lucas Syafiqah

Goals: Propose a design to configure the reference electrode and ISFET sensor in the tip of a 16 gauge needle.

Content:

The Reference electrode determines the effect of ions on the the Field effect transistor, which would impact the pH reading from H+ cations. the ISFET is sensitive to different types of ions, and the reference electrode determines the concentration of these ions to normalize the pH reading of the ISFET sensor. I propose a design where the tip of the needle is an Ag/AgCl reference electrode, and the ISFET sensors is above it in solution. The part of the needle that is the wall of the reference electrode would have to be non conductive, and in most applications Teflon is used. [1] Conveniently, it is common that hyperdermic needles are coated in Teflon [2], so we would need to find to apply the coating to the inside of the needle. The needle must also have a way for fluid to fill the cavity allowing the ISFET to be exposed to bodily fluids. A different pathway of placing the ISFET below the reference could be explored.

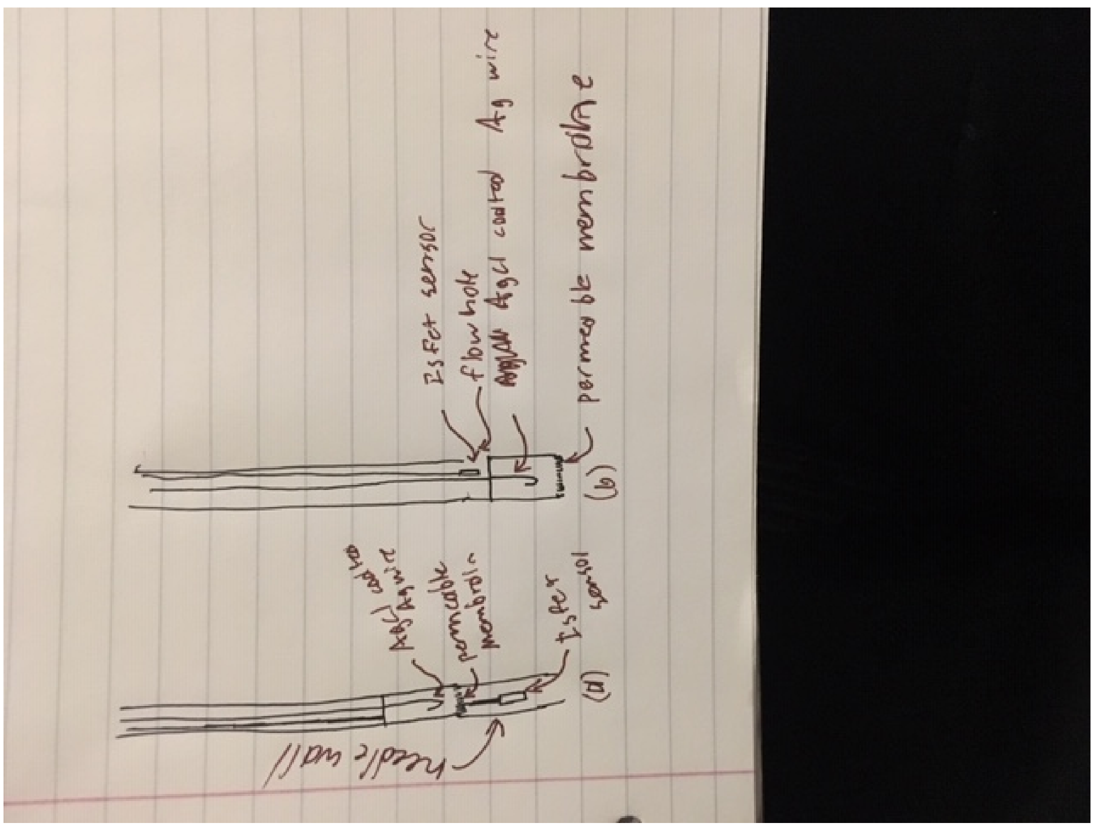


Figure: (a) shows the configuration with the ISFET below the Reference electrode, and (b) shows the configuration with the ISFET above the reference electrode.

[1] East, G. and del Valle, M. (2000). Easy-to-Make Ag/AgCl Reference Electrode. *Journal of Chemical Education*, 77(1), p.97.

[2] Product Release. (n.d.). *Why are Needles Coated in Teflon? - Product Release*. [online] Available at: https://www.product-release.com/product-release-news/why-are-needles-coated-in-teflon/ [Accessed 9 Oct. 2019].

Conclusions/action items:

A hybrid of a needle with a reference electrode would be difficult to implement, so manufacturing methods need to be researched.

2019/11/20 - IrOx Needle with Ag/AgCl reference

HUNTER HUTH - Dec 10, 2019, 2:27 AM CST

Title: IrOx needle with Ag/AgCl refrence

Date: 2019/11/20

Content by: Hunter Huth

Present: Myself

Goals: Explain a design that uses a needle as a pH sensing electrode.

Content:

This design uses electoplating of IrOx on stainless steel as described in the Electrodeposition of IrOx section. This design would use IrOx to detect hydrogen ions and Ag/AgCl as a reference electrode fed through the middle of the needdle. The figure below shows a diagram of what the tip of the needle would look like. A challenge is making sure the Ag/AgCl reference does not touch the IrOx reference electrode. The benefits of this design or its compact size and simplistic design, but the voltages produced could be very small.

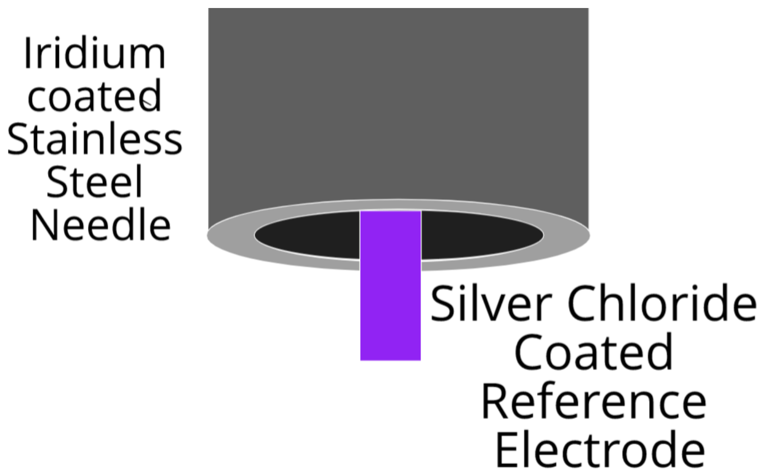


Figure: A design for IrOx plated needle and an Ag/AgCl reference.

Conclusions/action items:

This design must be fabricated and testing against a conventional pH probe and a ISFET based needle design.

2019/11/18-Two Wire design

HUNTER HUTH - Dec 10, 2019, 9:50 PM CST

Title: Two Wire Design

Date: 2019/11/18

Content by: Hunter Huth

Present: Myself

Goals: Describe a design involving two wires that create a potential two sense pH

Content:

This design uses two wires, a Pt-Ir coated in IrOx and a Ag/AgCl reference electrode, fed through a stainless steel needle. The design would need to have the wires insulated to not come in contact with the walls of the needle or each other, but there must still be sufficient contact with the solution to create a potential. The tip of the needle may need to be coated with the wires at different lengths to prevent contact. The wires would be created through electrodeposition described in other sections.

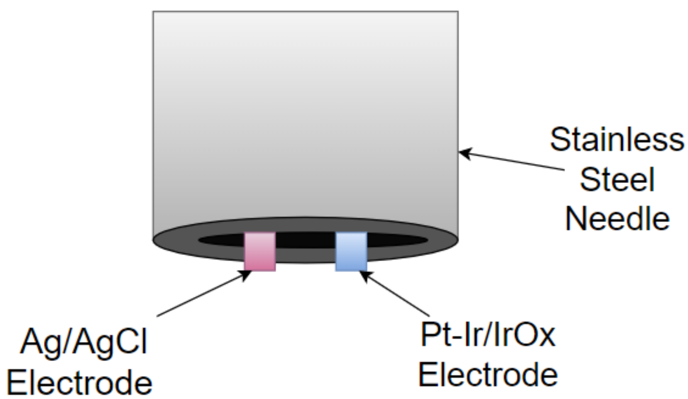


Figure: This design for two wire designing that uses an Ag/AgCl reference along with a Pt-Ir/IrOx electrode.

Conclusions/action items:

This design needs to be fabricated and tested alongside a standard pH electrode.

2020/2/2 Obstacles to still overcome

HUNTER HUTH - Feb 02, 2020, 4:15 PM CST

Title: Obstacles to still over come

Date: 2020/2/2

Content by: Hunter

Present: Myself

Goals: Describe the current obstacles before animal testing

Content:

1: Find a working procedure for electrodeposition of IrOx.

2: Build an amplification circuit for IrOx electrode

3: Find a way to configure the two wires inside the needle to not cause contact with needle or each other.

Conclusions/action items:

These obstacles are daunting, and we need to have solutions to have a working pH probe.

2020/25/02-MultiLumen Catheter Design

HUNTER HUTH - Feb 25, 2020, 11:58 PM CST

Title: Multi-Lumen Catheter Design

Date: 2/25/2020

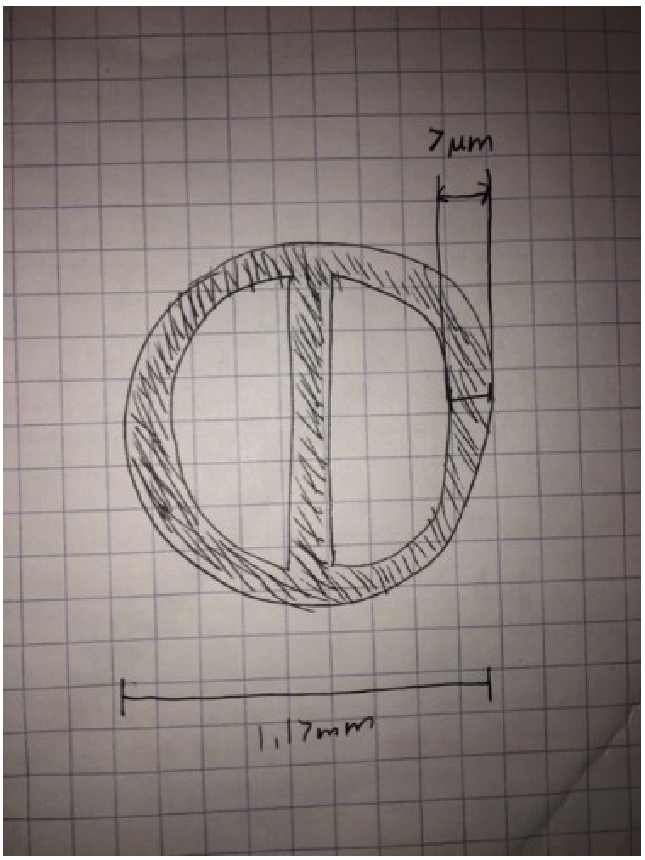
Content by: Hunter Huth

Present: Myself

Goals: Describe a multi-lumen catheter for electrode placement

Content:

To deliver The two electrodes to the muscle compartment while reducing contact outside of the compartment, and removing any risk of contact between the two electrodes. A design of a FEP tubing that would fit inside the needle that has two "D" shaped lumens could be extruded. When discussing this design with an extrusion company, they mentioned an idea of actually extruding a multi lumen tube out of PEEK, and uses this stiffer material as the needle itself. The company quoted my custom extrusion to run for about $5000-$7000 dollars. They sent a extrusion that they could sell stock for a significantly smaller fee.



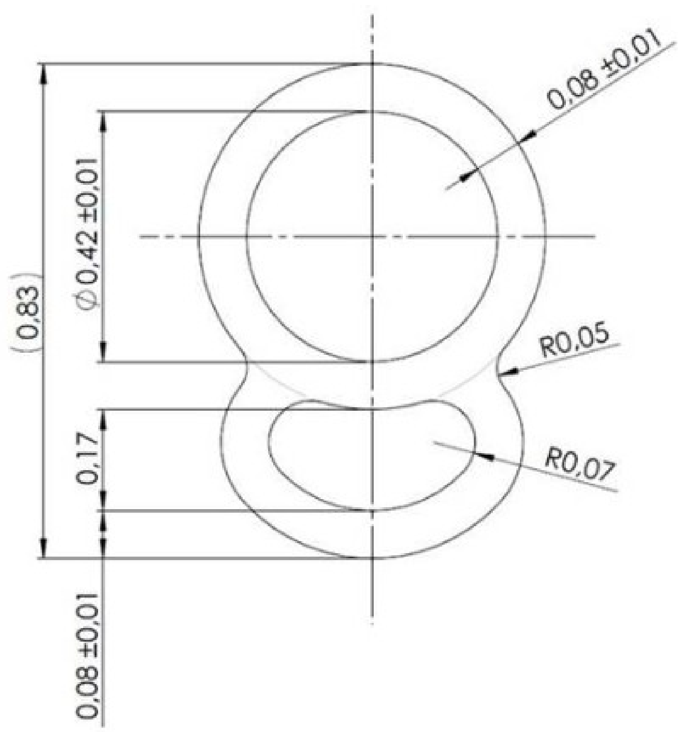


Figure: Left is the custom extrusion design and right is the design they sell stock.

Limitations of the stock design could be a limit in fluid flow because of the smaller lumens. The goal is to have a strong enough wall to not be crushed from pressure inside the body while also having a large enough internal compartment for maximum fluid flow. This design could involve holds at the tip of the catheter to allow extra flow.

Conclusions/action items:

Reach out to more extrusion companies for pricing and attempt to find cheaper alternatives.

2020/3/05-Lubricious catheter design

HUNTER HUTH - Apr 27, 2020, 11:02 PM CDT

Title: Lubricious catheter design

Date: 03/05/2020

Content by: Hunter Huth

Present: Myself

Goals: Describe a lubricous catheter design discussed with extrusion companies

Content:

I have been discussing a design idea with extrusion companies that involve a lubricious catheter. The needle goes down the center lumen, which is used to pierce through the tissue, and the outer lumens would carry the electrodes. The needle would be removed after placement leaving the catheter with the electrodes.

Figure: This is a cross section of the lubricious catheter design

Conclusions/action items:

Waiting to hear back from the company about samples and cost estimates.

2020/04/9-Design for placing electrodes on outside of needle

HUNTER HUTH - Apr 09, 2020, 7:45 PM CDT

Title: Design for placing the needle on the outside of the electrode

Date: 4/9/2020

Content by: Hunter Huth

Present: Myself

Goals: Design for new electrode delivery device

Content:

This design is based of the article cited at the bottom of the page. This method is a design that would allow the electrodes to be on the outside of the needle to improve solution contact.

Fabrication steps

1. Insulate outside of stainless steel needle
2. Use adhesive to attache electrodes to outside
3. use a second insulator around the electrodes with holes to allow for solution contact

Benefits of this design

- More fluid contact
- smaller needle size
- strength
- Ease of fabrication

Cons of this design

- needle cannot be left in patient (only for spot checking)
- Outer layer might be have more friction than stainless steel.
- Toxicity concerns

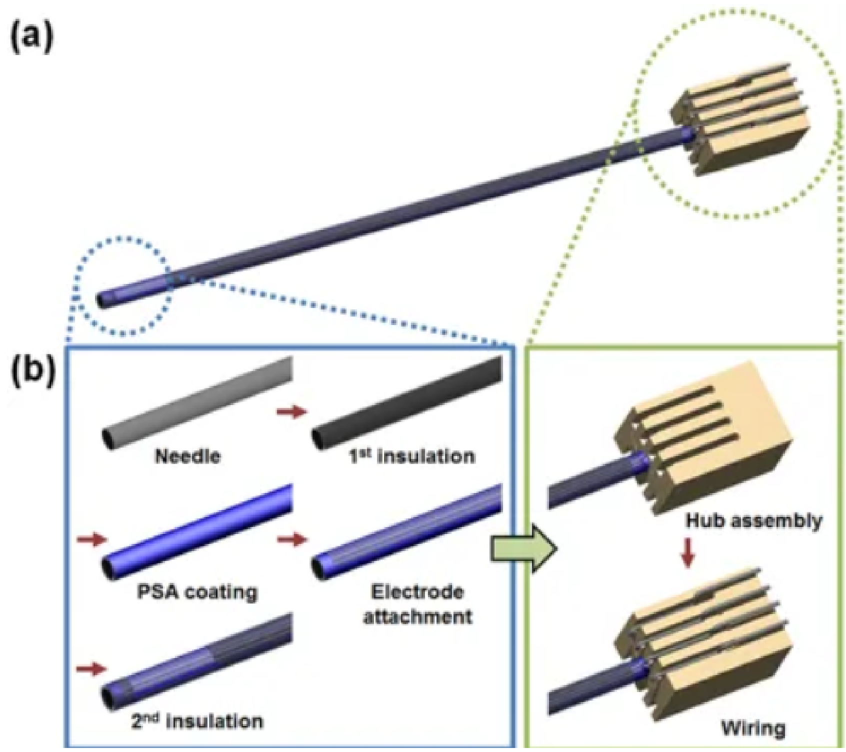


Figure: Design from the article that includes the step by step layering of the electrode.

[1] Park, J., Choi, W., Kim, K. *et al.* Biopsy Needle Integrated with Electrical Impedance Sensing Microelectrode Array towards Real-time Needle Guidance and Tissue Discrimination. *Sci Rep* 8, 264 (2018). https://doi.org/10.1038/s41598-017-18360-4

Conclusions/action items:

This device could be a potential path way for a spot checking device.

2020/4/17- Two-Lumen electrode placement design

HUNTER HUTH - Apr 17, 2020, 10:13 AM CDT

Title: Two Lumen electrode placement design

Date: 2020/4/17

Content by: Hunter Huth

Present: Myself

Goals: Describe a design that uses a two lumen catheter

Content:

This design involves placing catheter that has a needle in one lumen to add insertion strength and the other lumen has a parylene-c electrode with leads for IrOx and Ag/AgCl. The fluid contact would be best if there was also a mechanism to slightly push the parylene-c microelectrode array outside the lumen after insertion. The risk of breaking the array is minimized by only sticking it out 1-2 mm.

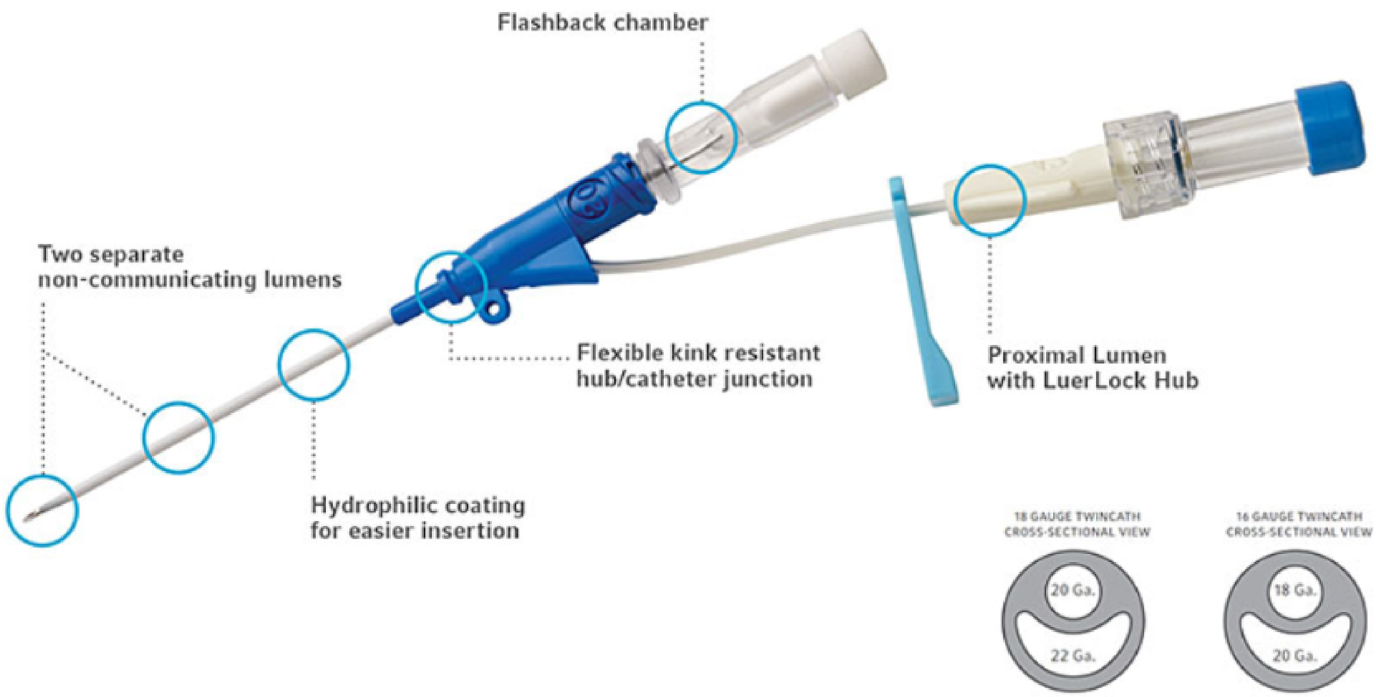


Figure 1: This catheter has two Lumens originally intended for multiple drug delivery. For our design the circular lumen would hold the needle, which would be removed after insertion. The crescent lumen would hold a parylene-c micro electrode array. [1]

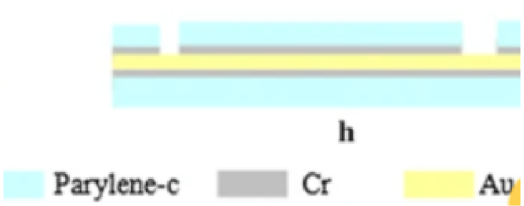


Figure 2: This is a cross section of a micro electrode design. These are used for measuring biological signals and chemical sensing particularly in the brain.

The catheter and the micro-electrode array, array both well researched and currently used clinically. There are plenty of resources for fabrication and manufacturing of these materials. There are companies that manufacture these products commercially, but they are expensive. The inventories for parylene-c micro electrodes do not exactly match our specifications, but they could manufacture custom electrodes at a cost.

Advantages of this design:

- Well researched
- bio compatible for long term implantation
- Commercially available

Disadvantages of this design

- Expensive
- difficult to fabricate
- complicated mechanics with pushing the electrode out of the catheter.

[1] https://www.teleflex.com/usa/en/product-areas/vascular-access/peripheral-access/arrow-twin-cath-peripheral-catheter/index.html

[2] Cui, H., Xie, X., Xu, S. *et al.* Electrochemical characteristics of microelectrode designed for electrical stimulation. *BioMed Eng OnLine* 18, 86 (2019). https://doi.org/10.1186/s12938-019-0704-8

Conclusions/action items:

This design would be great for a 48-hr implantable pH sensing device, but comes at a hefty price tag. These commercial electrodes can be upwards of ~4000, so for our purpose their production is expensive.

2020/10/02 Animal Training

HUNTER HUTH - Feb 26, 2020, 12:01 AM CST

Title: Animal Training

Date: 2020/25/02

Content by: Hunter

Present: Myself

Goals: Document completion of animal training

Content:

I have successfully completed animal training to participate in the animal testing proportion. I was not sent any certificates so I have nothing to attach

Conclusions/action items:

Complete Animal Testing.

9/26/2019 Meeting with Hal Gilles WCNT

HUNTER HUTH - Oct 08, 2019, 11:20 PM CDT

Title: Meeting with Hal Gilles

Date: 9/26/2019

Content by: Hunter Huth

Present: Myself

Goals: Describe the content of a meeting with WCNT

Content:

Hal Gilles is the coordinator for the clean room and is an expert in creating microelectronics. He has a lot of experience working with and developing micro processors, so he is a valuable resource when working with the small scale of the pH sensor. During the meeting we discussed different methods for working with these electronics, and he suggested using wire bonding or a silver epoxy to directly attach the leads to a ribbon cable that meets our specifications. Wire bonding would require a housing to add mechanical strength since the wires would be incredibly fragile. He suggested that using an epoxy to directly attach the ISFET "Face Down" on the ribbon cable might meet our criteria better. The ribbon and ISFET could be coated in an insulating material to make the assembly more bio inert afterwards. He gave me the contact for a Jihye Bong, who is working with electronics on a similar scale towards a similar application.

Conclusions/action items:

1) Contact Jihye Bong for consulting purposes.

2) Try to find a commercial ribbon cable that meets our criteria.

10/8/2019 Email with Winsense

HUNTER HUTH - Oct 08, 2019, 11:26 PM CDT

Title: Email with Winsense

Date: 10/8/2019

Content by: Hunter Huth

Present: Myself

Goals: Discuss email with winsense about using their ISFET pH sensor

Content:

I emailed Winsense inquiring about their ISFET pH sensor Bare chip. I asked about pricing and temperature constraints in the scope of using a solder reflow oven with it. There exact response

:"Dear Hunter,

The bare chip is usually wie bonded to a pcb with gold or silver wires.
Then the pcb can be soldered to cables.
The pads on chip of the isfet is made of Aluminum though. We have never soldered directly to the isfet on chip bonding pads.

Rgds,

Wutthinan"

They currently have been wirebonding to a PCB board to integrate this component in electronic circuits. This is what Hal mentioned in my meeting with him, but this would increase the size of the chip, which would make it too large to fit inside a 16 gauge needle. The aluminum leads hint at them being able to withstand the solder reflow oven.

Conclusions/action items:

1) Email back to determine cost for ordering their ISFET sensor

2) Test these chips with a solder reflow oven.

2014/11/03-Entry guidelines

John Puccinelli - Sep 05, 2016, 1:18 PM CDT

Use this as a guide for every entry

- Every text entry of your notebook should have the **bold titles** below.
- Every page/entry should be **named starting with the date** of the entry's first creation/activity, subsequent material from future dates can be added later.

You can create a copy of the blank template by first opening the desired folder, clicking on "New", selecting "Copy Existing Page...", and then select "2014/11/03-Template")

Title: Descriptive title (i.e. Client Meeting)

Date: 9/5/2016

Content by: The one person who wrote the content

Present: Names of those present if more than just you (not necessary for individual work)

Goals: Establish clear goals for all text entries (meetings, individual work, etc.).

Content:

Contains clear and organized notes (also includes any references used)

Conclusions/action items:

Recap only the most significant findings and/or action items resulting from the entry.

2014/11/03-Entry guidelines

John Puccinelli - Sep 05, 2016, 1:18 PM CDT

Use this as a guide for every entry

- Every text entry of your notebook should have the **bold titles** below.
- Every page/entry should be **named starting with the date** of the entry's first creation/activity, subsequent material from future dates can be added later.

You can create a copy of the blank template by first opening the desired folder, clicking on "New", selecting "Copy Existing Page...", and then select "2014/11/03-Template")

Title: Descriptive title (i.e. Client Meeting)

Date: 9/5/2016

Content by: The one person who wrote the content

Present: Names of those present if more than just you (not necessary for individual work)

Goals: Establish clear goals for all text entries (meetings, individual work, etc.).

Content:

Contains clear and organized notes (also includes any references used)

Conclusions/action items:

Recap only the most significant findings and/or action items resulting from the entry.

2014/11/03-Template

John Puccinelli - Nov 03, 2014, 3:20 PM CST

Title:

Date:

Content by:

Present:

Goals:

Content:

Conclusions/action items:

2014/11/03-Template

John Puccinelli - Nov 03, 2014, 3:20 PM CST

Title:

Date:

Content by:

Present:

Goals:

Content:

Conclusions/action items: