Fabrication and Characterization of Ti_3C_2 MXene Electrodes for Studying Neural Circuits

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MANTH

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PI: Dr. Brian Litt

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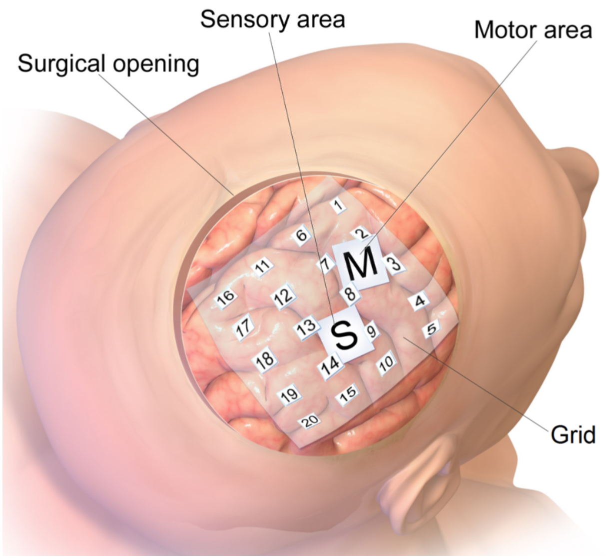
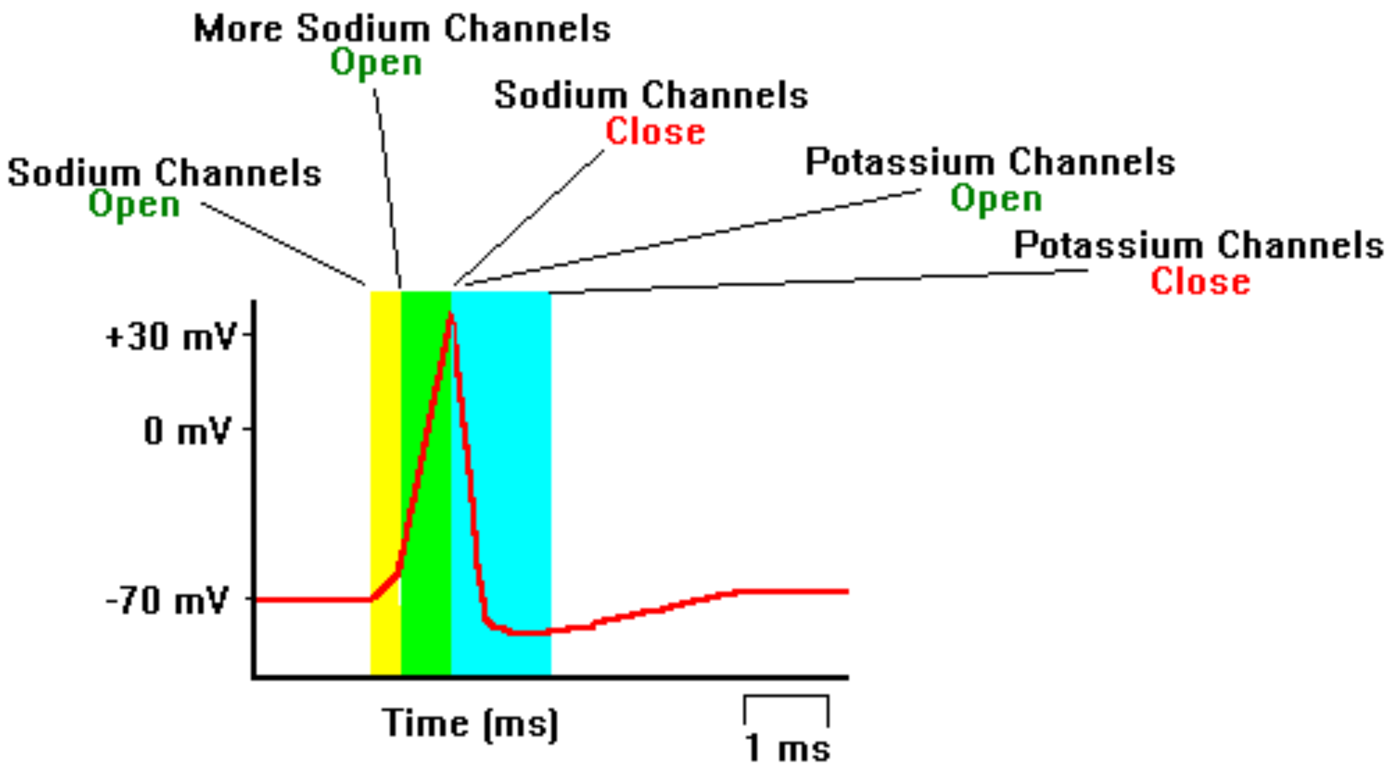
Intracranial EEGs record brain activity and are used to treat and study epilepsy.

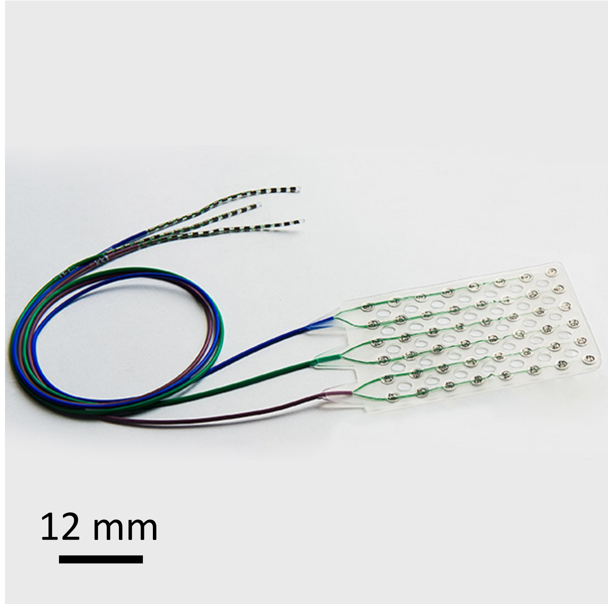




Blausen.com staff (2014). ". WikiJournal of Medicine 1 (2).
Dr. Eric Chudler "neuroscience for kids" https://faculty.washington.edu/chudler/ap.html

Flexible micro-electrodes are minimally invasive and have a high spatial resolution.

Grid electrodes



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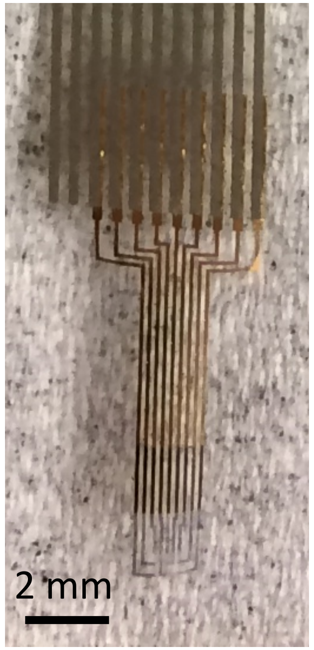
- Stiff
- Invasive
- Low spatial resolution

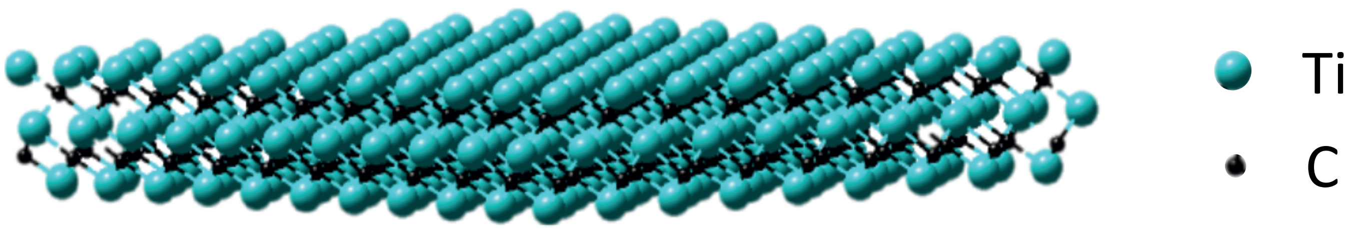
Our microelectrode array

- Flexible
- Less invasive
- High spatial resolution
- **High impedance**



MXene (Ti_3C_2) is 2D metal carbide with electrical properties similar to graphene. There is very little precedent for micropatterning MXene.

Recent tests show that MXene electrodes have a **lower impedance** than gold electrodes and are **simpler to fabricate** than graphene electrodes.



Ti_3C_2 MXene sheet

Ti_3C_2 MXene micropatterned electrode

Anasori, B.; Lukatskaya, M.; Gogotsi, Y. 2D Metal Carbides and Nitrides (MXenes) for Energy Storage. *Nature Reviews* **2017**, 2, 1-17.

Fabrication of MXene electrodes

1. Deposit first Parylene-C layer (5 µm) on Si wafer

2. Photolithography, Ti/Au deposition (10 nm/100 nm), metal liftoff

3. Coat with antiadhesive layer, deposit sacrificial Parylene layer (3.5 µm)

4. Photolithography, O_2 RIE etch to pattern sacrificial Parylene layer

5. Spin coat MXene, bake, deposit 30 nm SiO_2 protective layer

6. “Dry lift-off” – peel up sacrificial Parylene layer, rinse remaining antiadhesive

7. Deposit second Parylene-C layer (5 µm)

8. Photolithography, O_2 RIE etch to pattern electrode openings and device outline

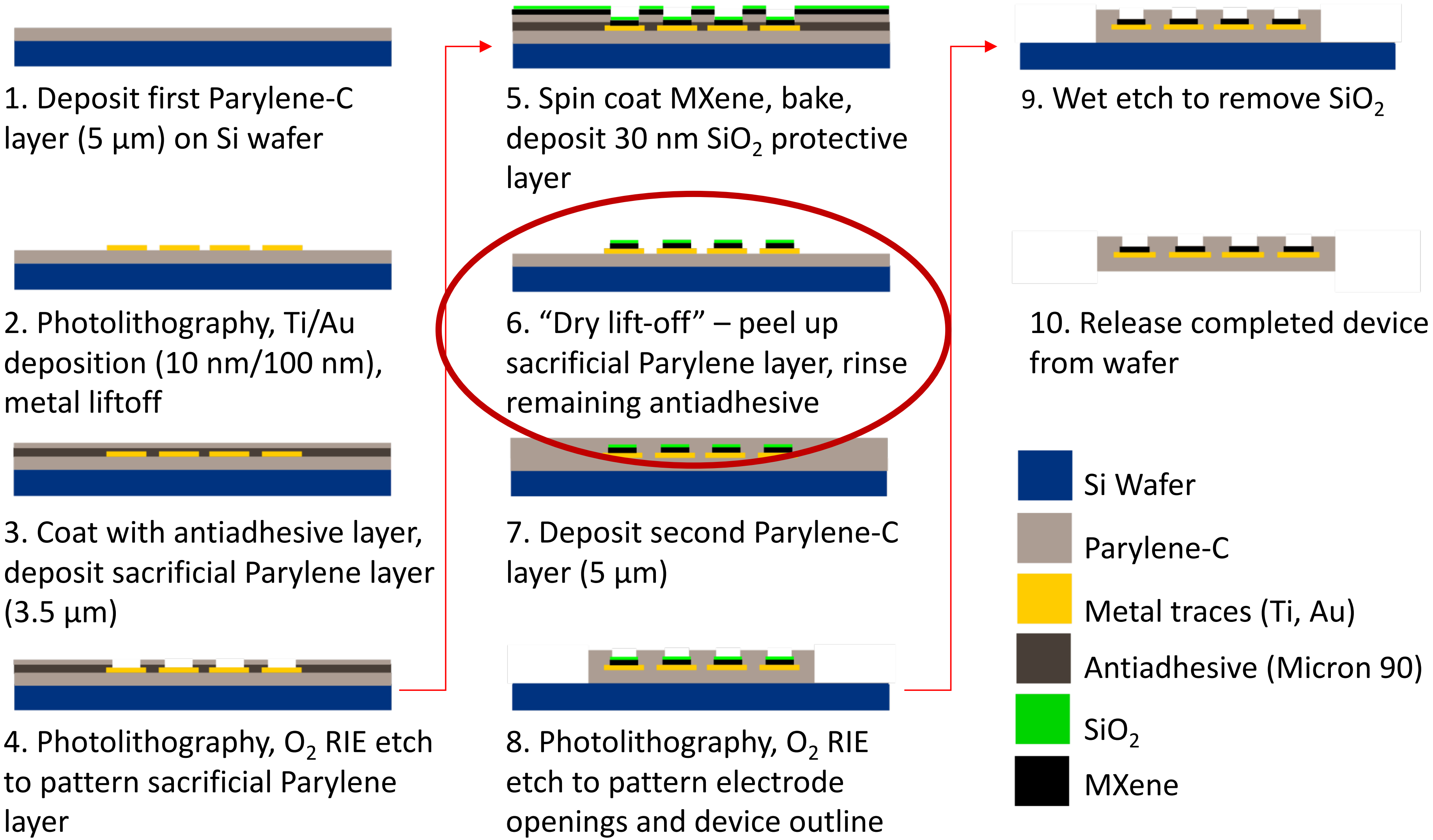
9. Wet etch to remove SiO_2

10. Release completed device from wafer

- Si Wafer
- Parylene-C
- Metal traces (Ti, Au)
- Antiadhesive (Micron 90)
- SiO_2
- MXene

Courtesy of Nicki Driscoll

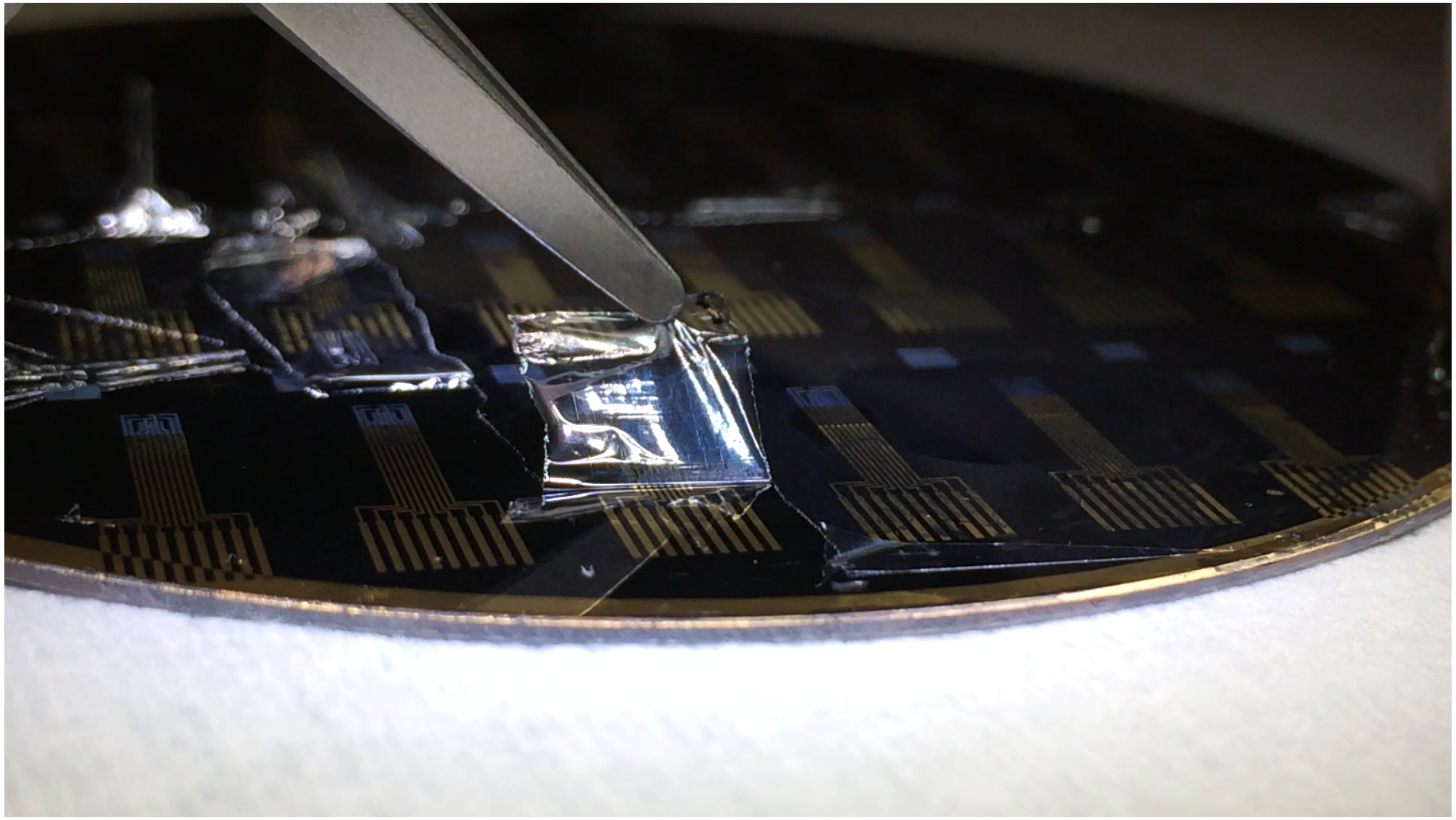
Fabrication of MXene electrodes



Courtesy of Nicki Driscoll

Fabrication Steps

Dry liftoff involves removing the sacrificial layer of Parylene C while leaving the desired patterns coated with MXene.



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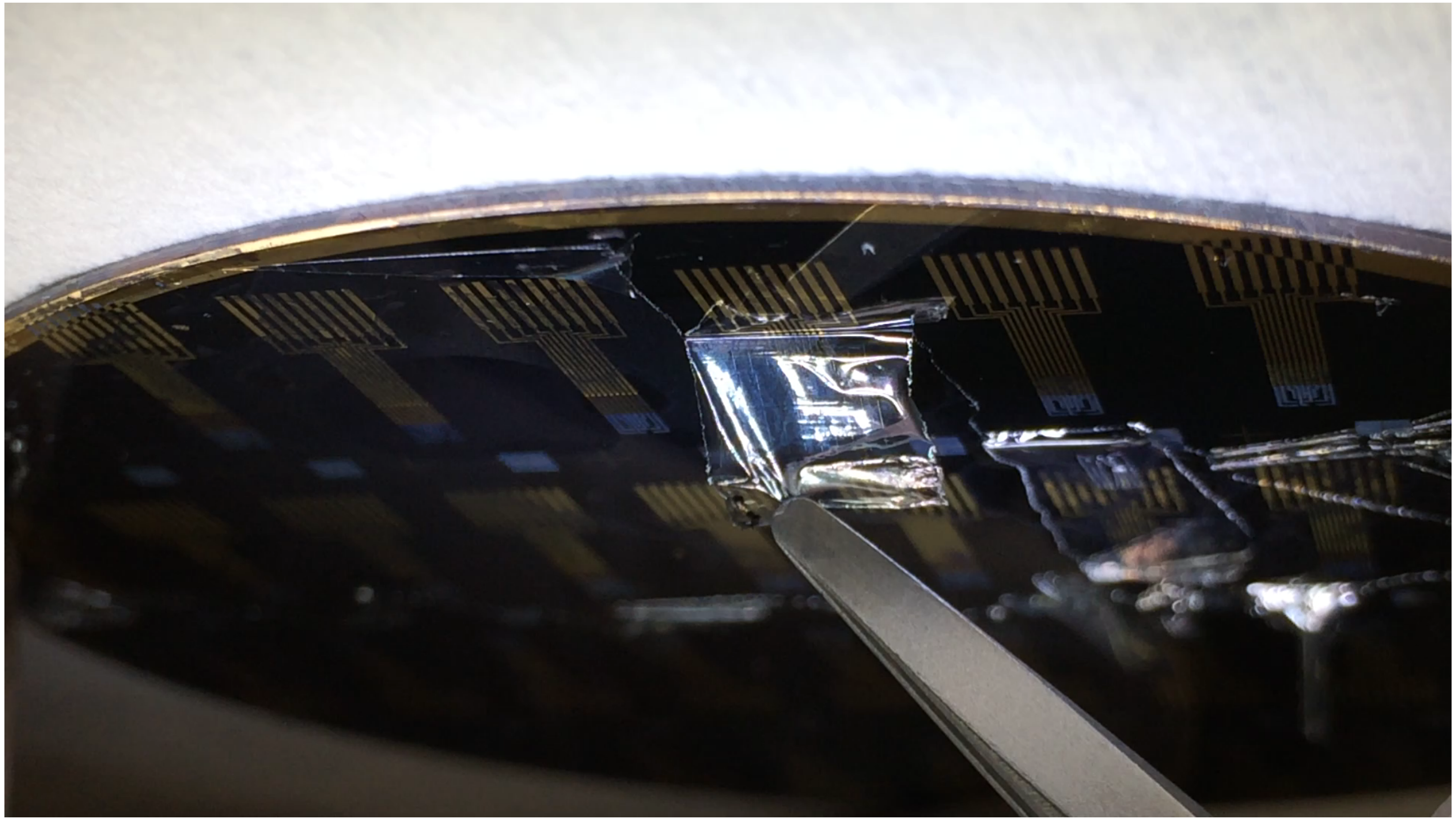

Factors to Optimize

- **Bake temperature** for MXene after spin-coating

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- **Bake temperature** for MXene after spin-coating
- **Mylar vs chrome** photomasks
- **Hydrophilic vs hydrophobic** sacrificial Parylene C layer

Baking the MXene at 130 °C gives the best dry liftoff results.

Bake Temperature (°C)	**Dry Liftoff Success**
100	Water boiling point
110	Yes
120	Yes
130	Yes
140	No
170	Parylene C glass transition

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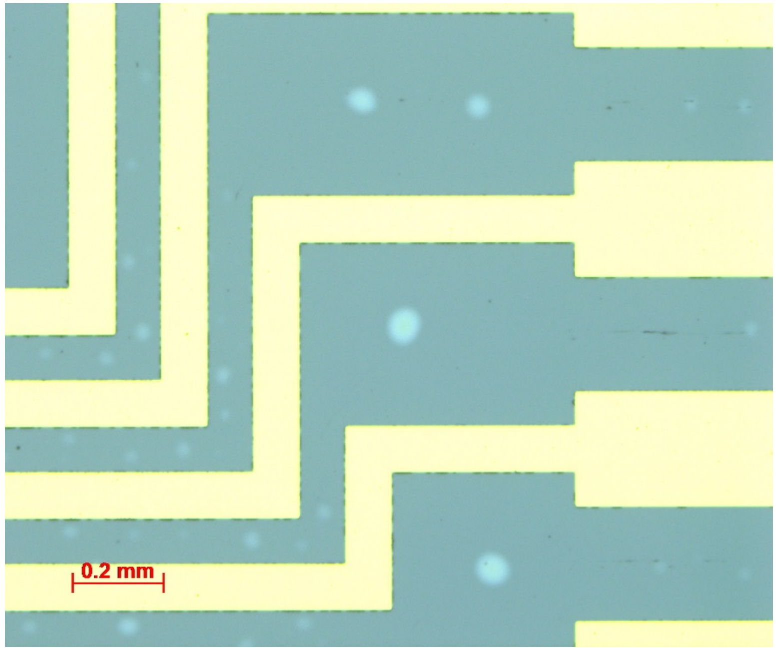
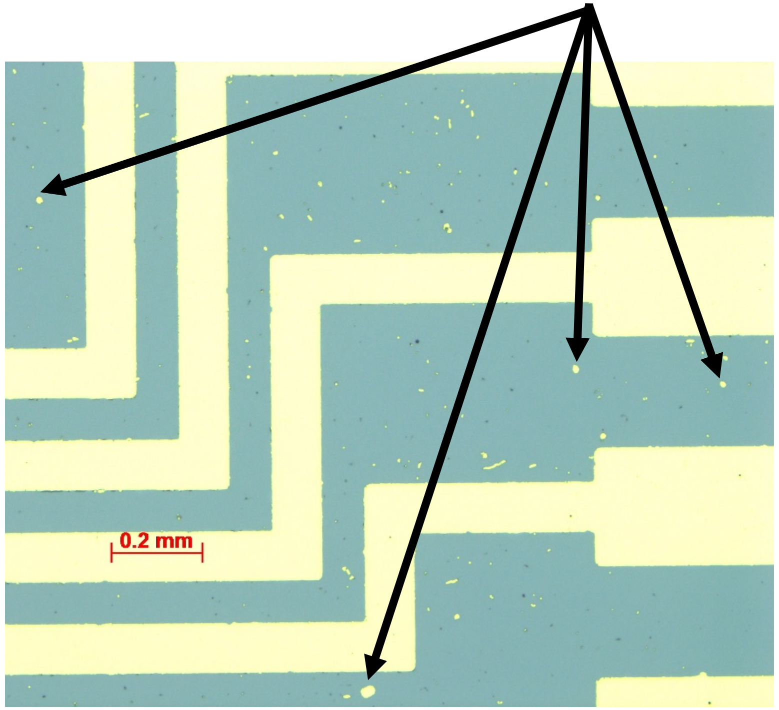
Using chrome photolithography masks give more well-defined electrode patterns.



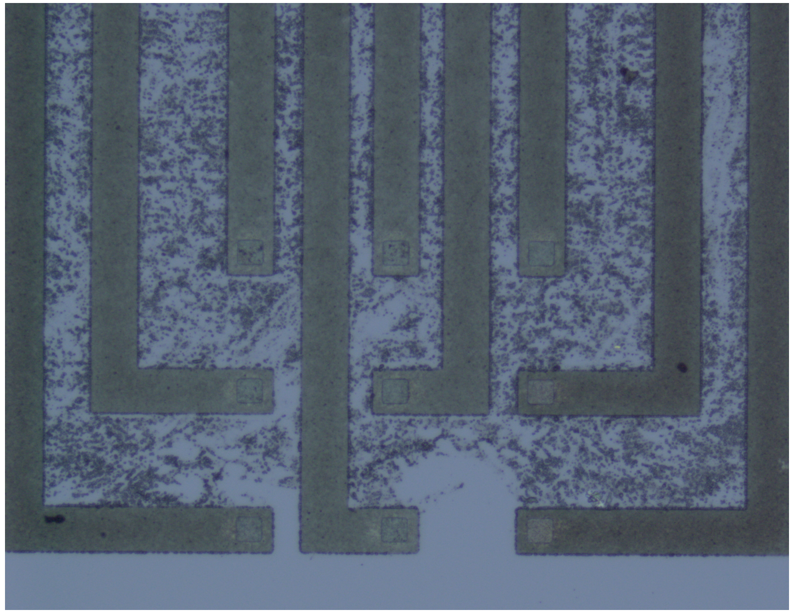
Electrode made with a **chrome** photolithography mask

vs



Electrode made with a **Mylar** photolithography mask

After dry liftoff, MXene stays in the micropatterns when it is spun on a hydrophobic sacrificial Parylene C surface.



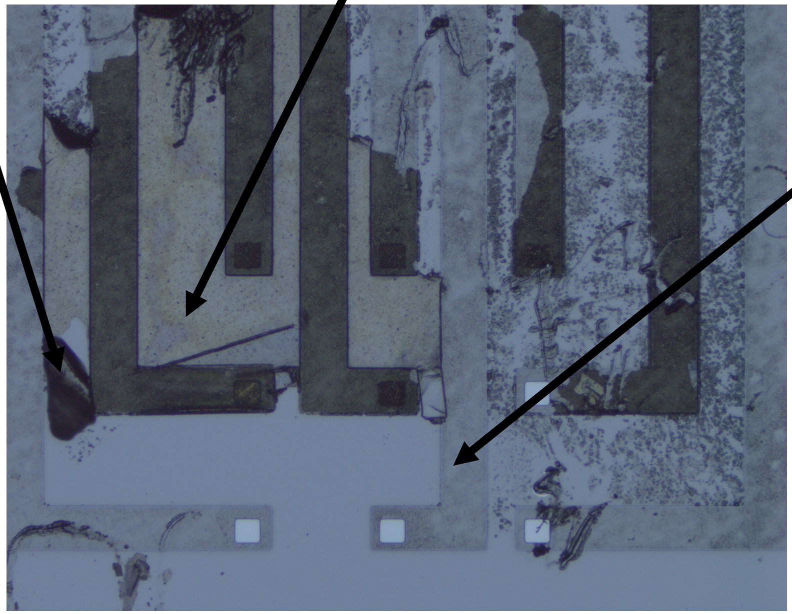
Electrode with a **hydrophobic sacrificial Parylene C** layer

vs

MXene is left between features

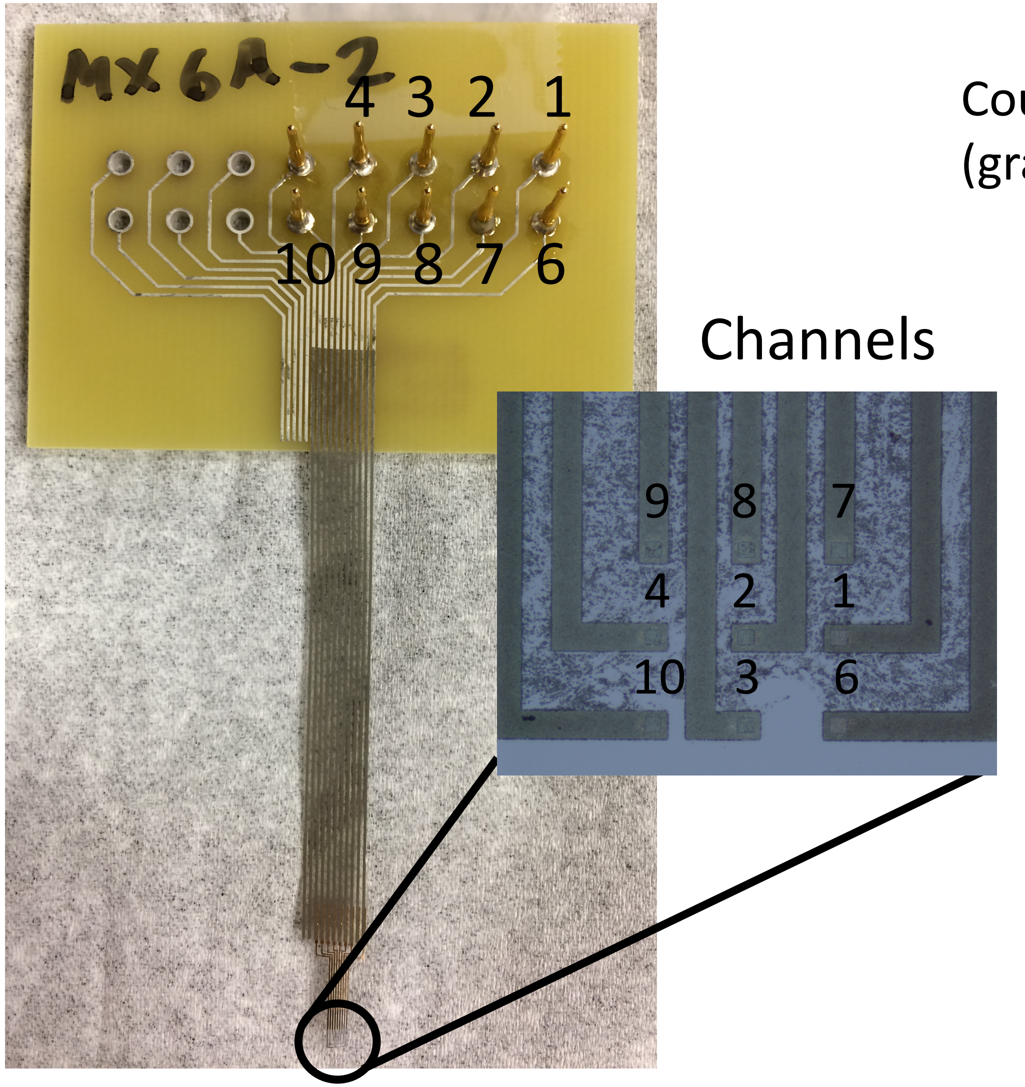
Parylene C breaks between features

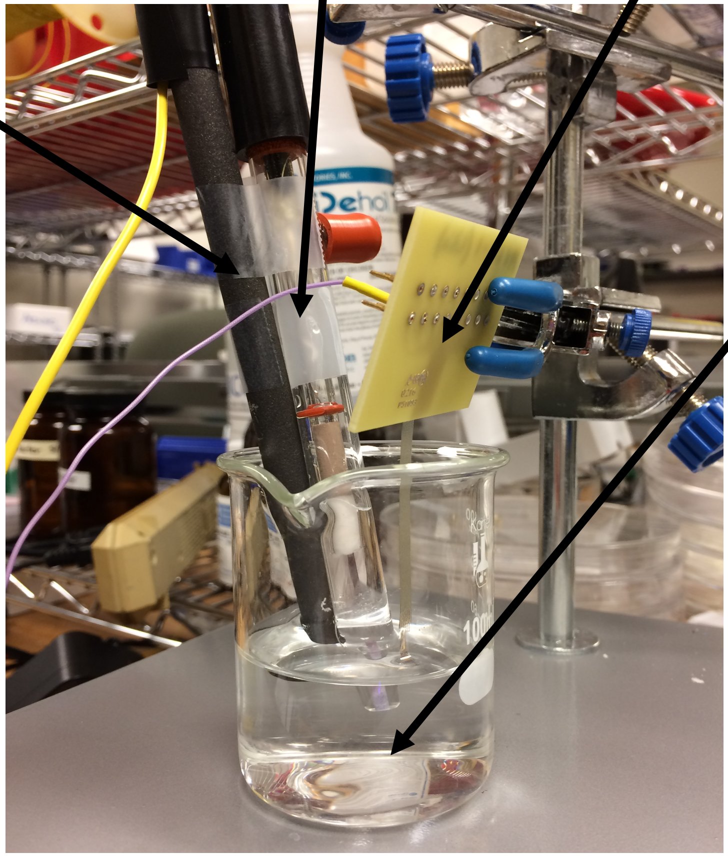
MXene is removed after dry liftoff



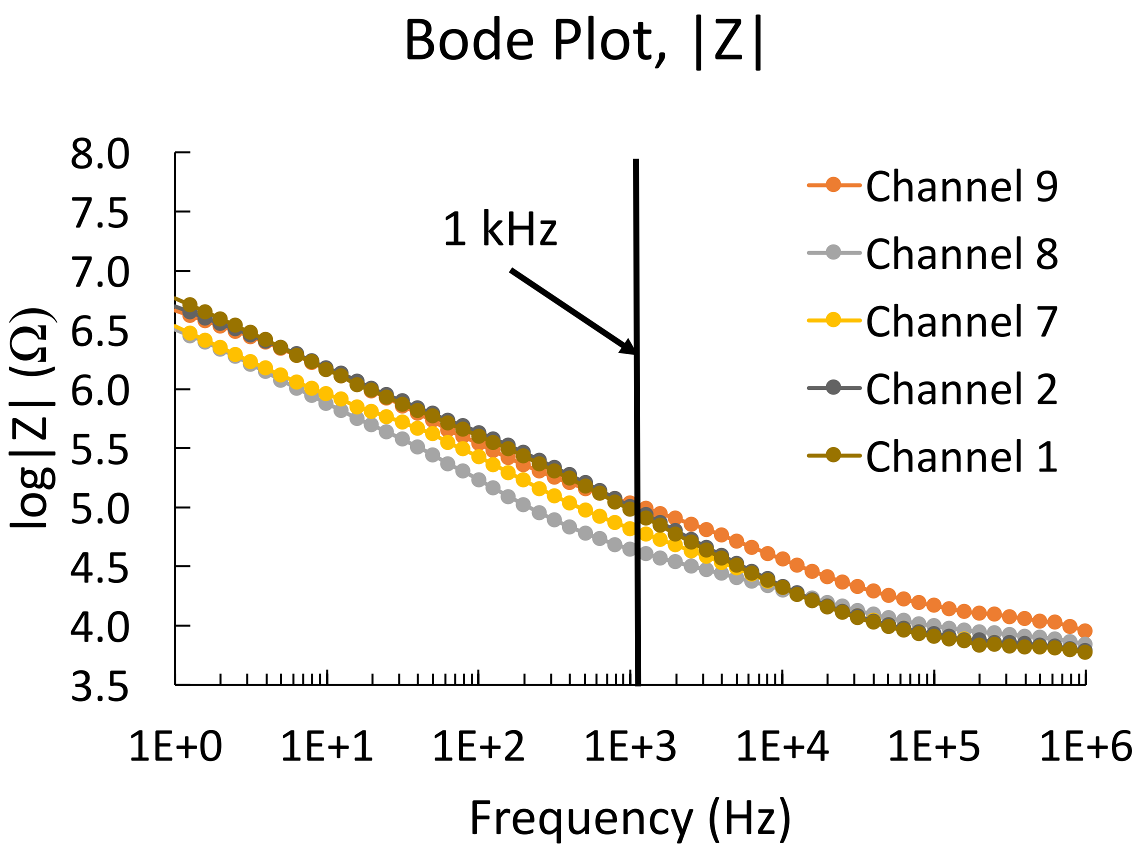
Electrode with a **hydrophilic** (O_2 plasma etched) **sacrificial Parylene C** layer

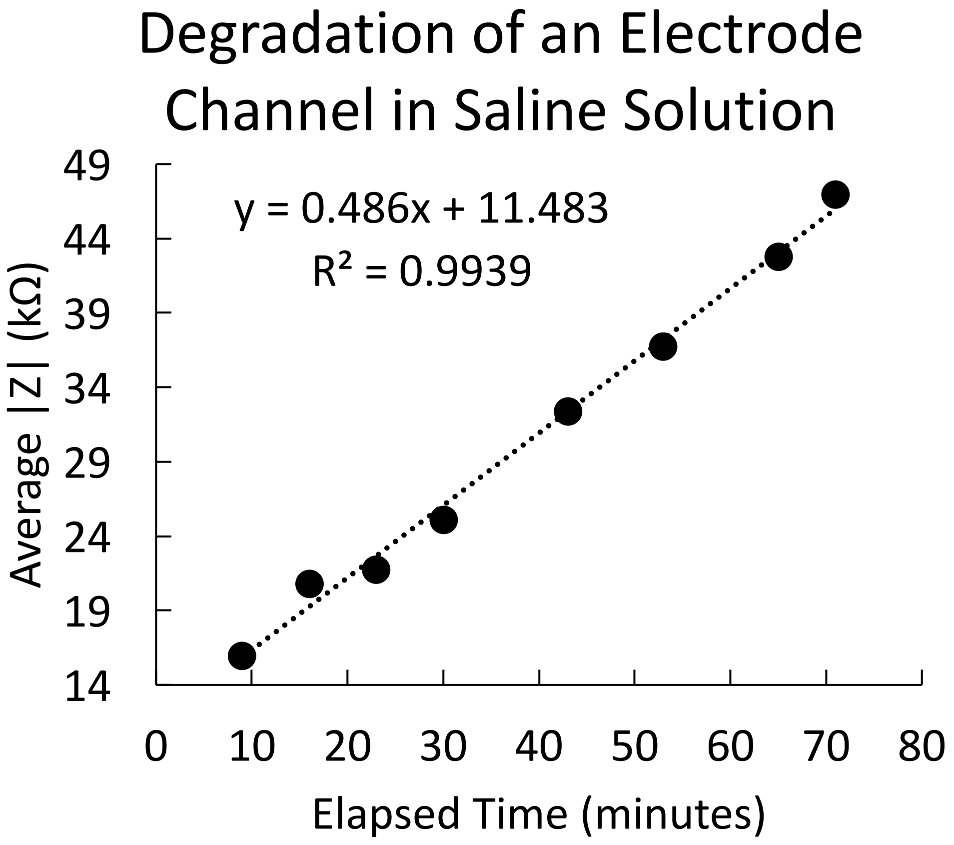
In vitro testing setup: Electrochemical Impedance Spectroscopy (EIS).





The microelectrodes have a low impedance, indicating good functionality.





Thank you!

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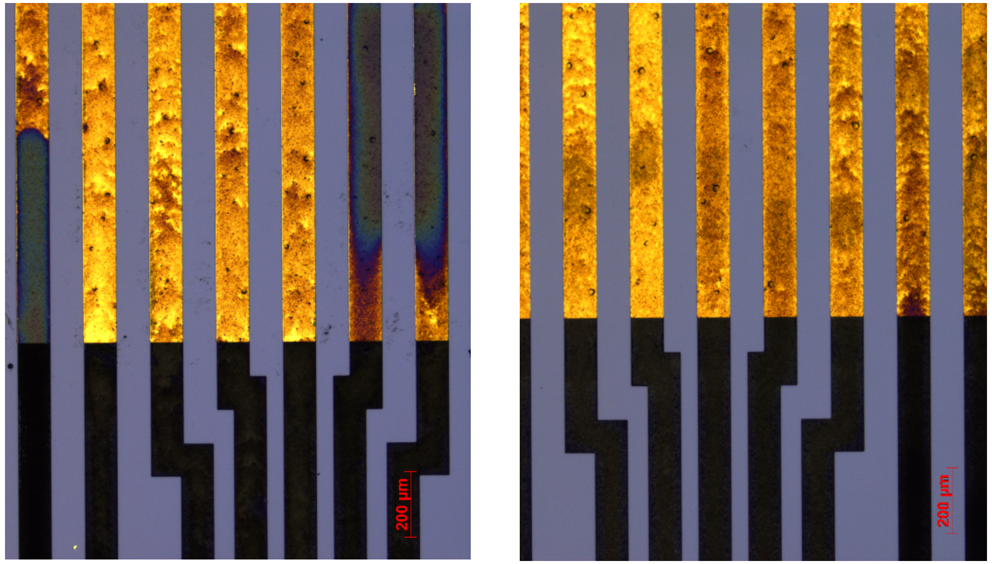
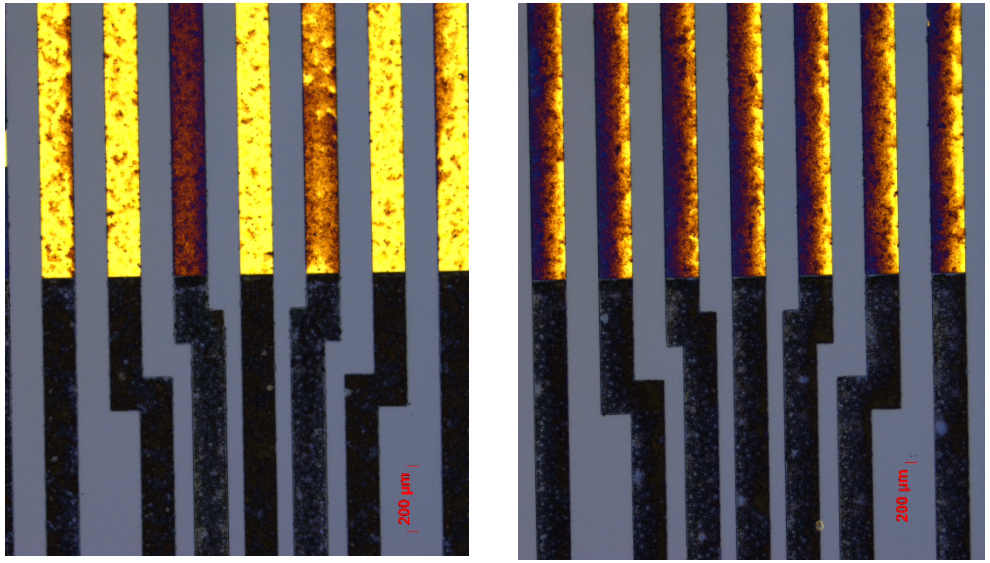
MXene also stays in the micropatterns when it is spun on a hydrophilic photoresist surface.



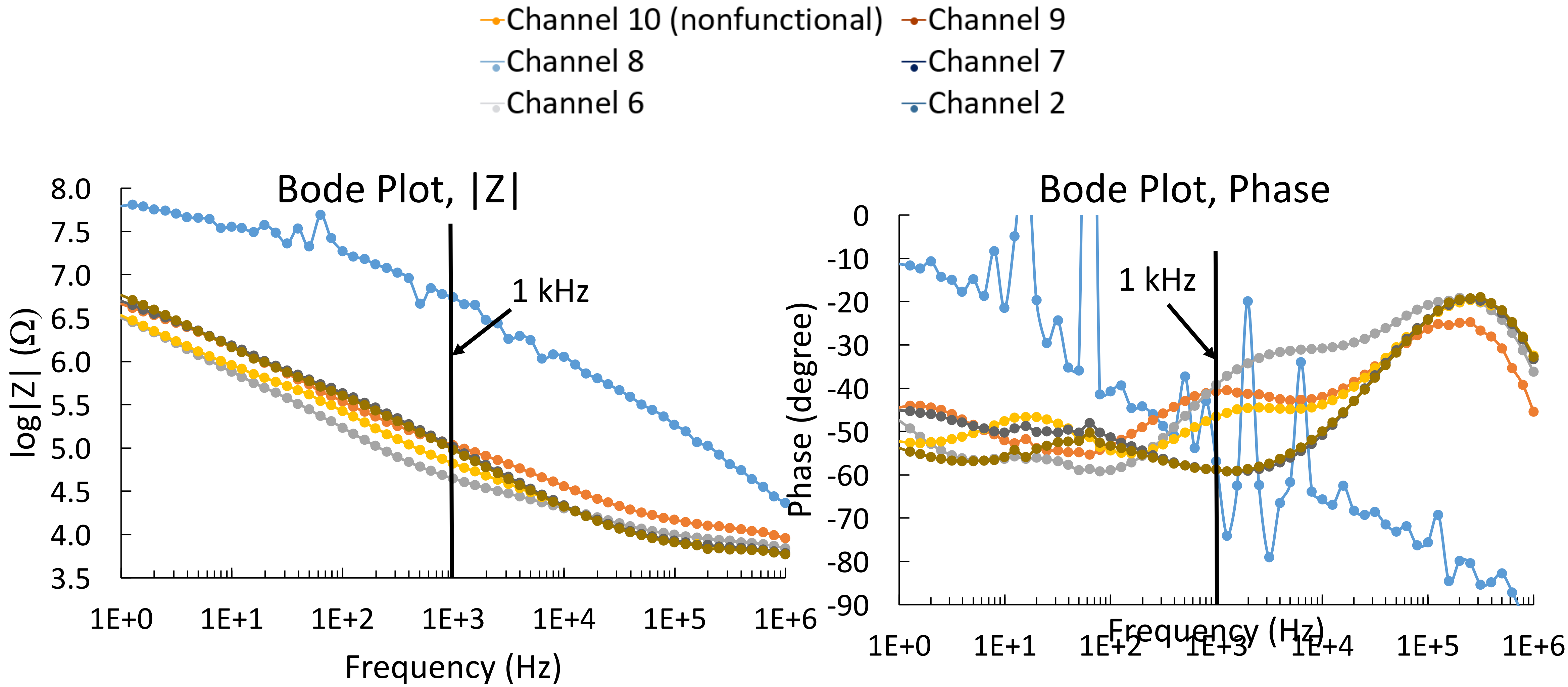
vs



Electrodes with a **hydrophobic sacrificial Parylene C** layer after dry liftoff

Electrode with a **hydrophilic** (O_2 plasma etched) **photoresist** layer after dry liftoff

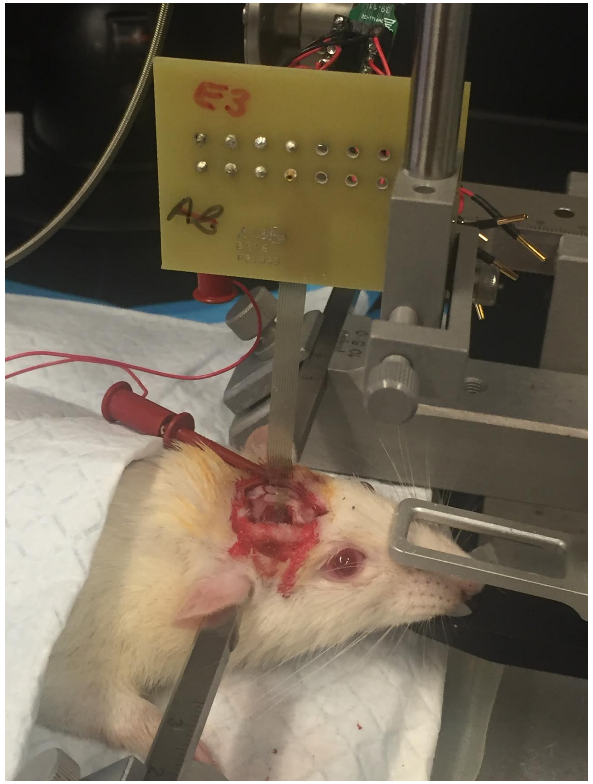
The microelectrodes have a low impedance, indicating good functionality.



Open Questions

- Hydrophobic sacrificial Parylene C layer or hydrophilic photoresist layer?
- How to prevent the MXene from oxidizing?
- How to spin the MXene thin enough to be transparent for optogenetic and imaging experiments?
- How will the MXene electrodes perform in a chronic experiment?

Next steps will include using the MXene electrodes for *in vivo* experiments.



Gold microelectrode array on a rat.

Courtesy of Nicki Driscoll