

Electrochemical O₂ pumping for portable medical oxygen Units

OSCG, 2025

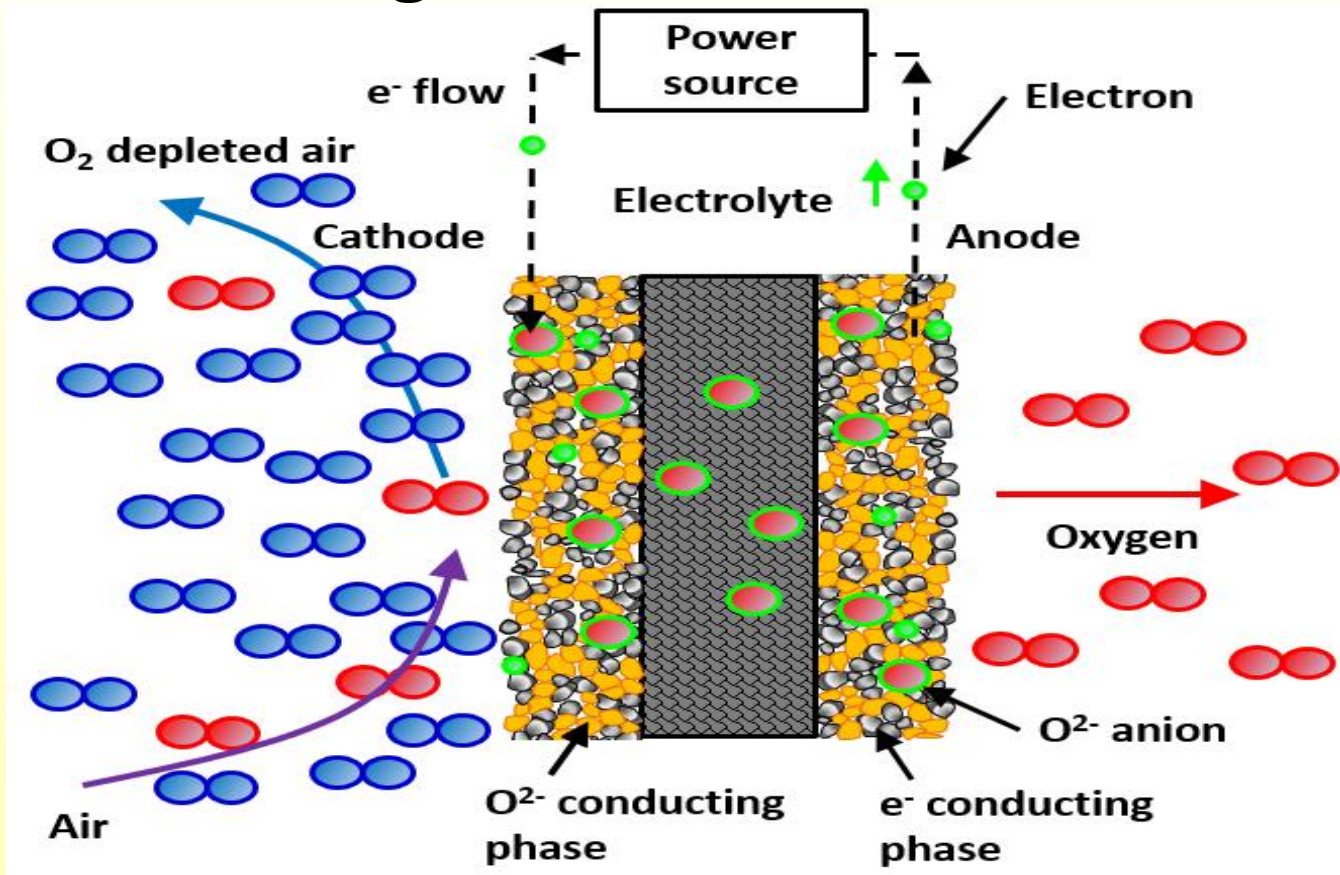
Global Research and Development, Columbus Ohio

Aug 27, 2025



O₂ pumping mechanism

Voltage driven electrochemical pump using nano-thick inorganic membranes



**not to scale*

Nano Membranes vs Micron Membranes

Properties	Nano	Micron
Operating Temperature	500-650°C	800-950°C
Tubes vs Planar	Tubes- Less area to seal	Planar- More area to seal
O ₂ flux	At a set temperature and pressure, nano membranes have higher O ₂ /m ²	Mirco-thick electrolyte limits O ₂ flux relative to nano-thick
O ₂ pump module lifespan	Lower temperature lead to exponentially longer lifetimes	Thicker materials more resilient to inter-diffusion, but higher temperatures promote it
BoS lifespan	No moving parts, lower temperatures enable greater material choice, <u>seals and isolation proven to 650°C</u>	No moving parts, hot components limited in material choice
Start up times	Lower temperature to reach, faster survivable ramp Faster delivery of O ₂	Depending on component thicknesses, rapid heat up will degrade O ₂ pump layers

Mission Program Goals and Capabilities

AF-Desired Goals for their Mission Program

- **Concentrated Oxygen purity: $\geq 99.9\%$**
- **Steady-state Oxygen flow up to 15 SLPM in selectable increments beginning at 3 SLPM**
- **Size: Not to Exceed 2 cubic feet (ideally 12" x 12" x 24")**
- **Power: ≤ 600 Watts with supply voltage of 120 VAC at 60 Hz**
- **Weight: ≤ 30 pounds**
- **Concentrated Oxygen Pressure: auxiliary outlet port with ≥ 60 psi capability**
- **User Interface: Touch screen for monitoring and operation**
- **Safety: External surface temperature shall remain in range that is safe to touch**
- **Shall have capability to interface with patient oxygen mask**
- **Fully functional from ground level to 40,000 ft pressure altitude equivalent**

DHA-ARMY Request for Information

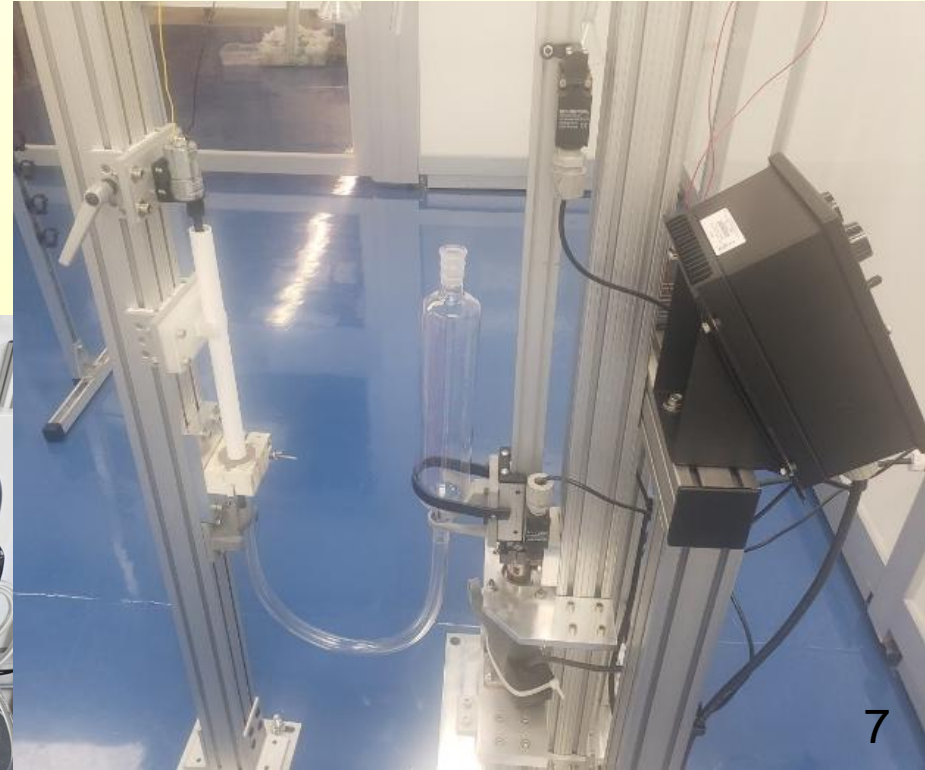
DHA- Army -RFI Portable Unit	RFI desired development threshold, continuous flow	Global Potential
Flow rate, continuous flow	7 liters/min, max	Yes
Purity-%, oxygen, min	93% +/-3%	99.5%+
Flow rate adjustable,	Yes	Yes
Volume, size, inches (D cylinder)	4.3 X 19 inches	TBD
Weight, lbs	15-24	15
Power requirements	110/220 VAC, 60-400 Hz, 10-28VDC	Yes
Switch	On/off	On/off
Display panel	Yes	Yes
Mil Stds	JECETS and/or Mil STD- 810	
FDA approval	Needed	Needed
Storage temperature environment	-28°F to 160°F	Yes
Operation, Humidity, % RH, temp.	95%+, 106F, 24 hrs	Yes
Battery backup, hrs	2-3	2-3
Altitude, ft	8000 ft?	8000-40,000 ft

Technology capabilities of Global's O₂ pump

- **O₂ pumps can be packaged in varied configurations for 1Lpm up to >200Lpm depending on application's needs**
- **Can be mobile or stationary**
- **Can deliver O₂ straight to patients or run ventilators**
- **No moving parts (or only intake fan), low maintenance**

Layer deposition optimization

- Flow-coater reconfiguration- Larger coating capacity, less vibration
- Doubled nano-particle synthesis capability
- Coating optimized for layers 1, 3-7, and new 2nd layer formulation (defect particles removed)
- Coating partially optimized for layers 8, 9, and 10



RTP optimization

RTP installation and optimization-

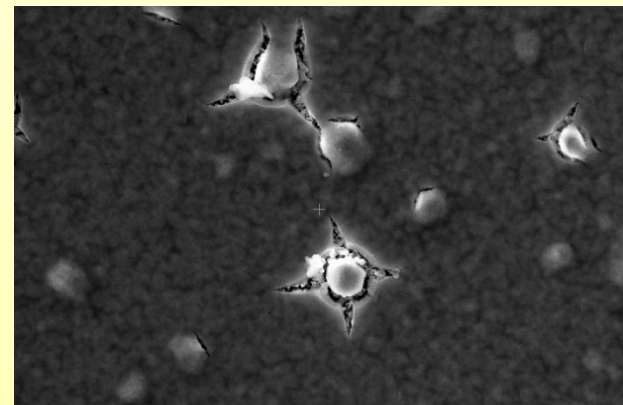
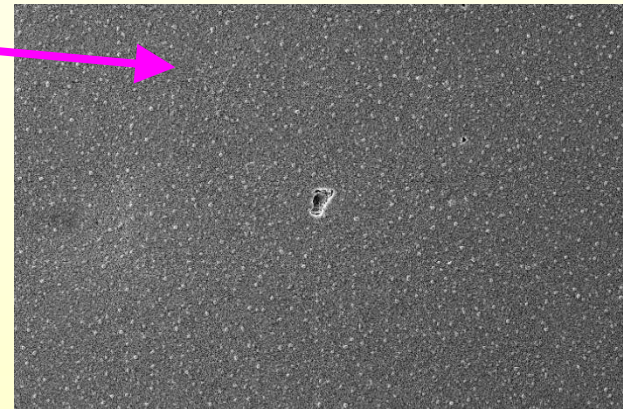
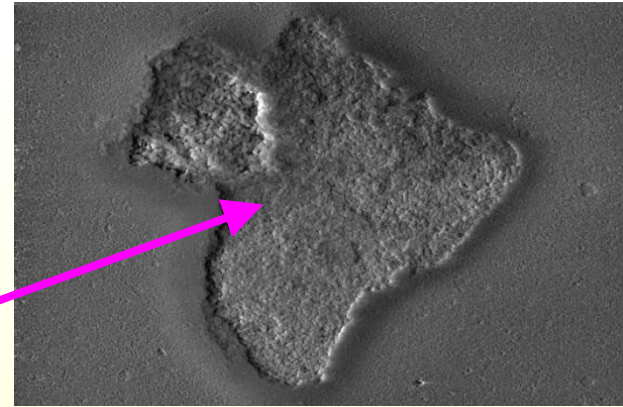
- Top and bottom thermal insulator components standardized, peeling, cracking, and tube fracture no longer experienced RTP'ing layers 1-10 and attachment of electrode contacts
- Layers optimized: 1-10, structurally; 1-7 performance, and densification observed as well as layer 'healing' in 6-8 above prior layer 2 defects
- Design for improved RTP unit being finalized, plans to fabricate and qualify it, then upgrade existing unit



RTP optimization and defect removal

Layer 2 defect

- Defects were observed in the early part of summer of 2025
- Targeted SEM analysis identified two kinds of defects:
 - ID surface defects on the tubular supports
 - Particles atop layer 2 after RTP treatment
- SEM analysis also showed that uniform layer formation atop tube ID defects was not possible and that the densification of the electrolyte layers (5-8) 'healed' cracks caused by coating atop layer 2 particles.

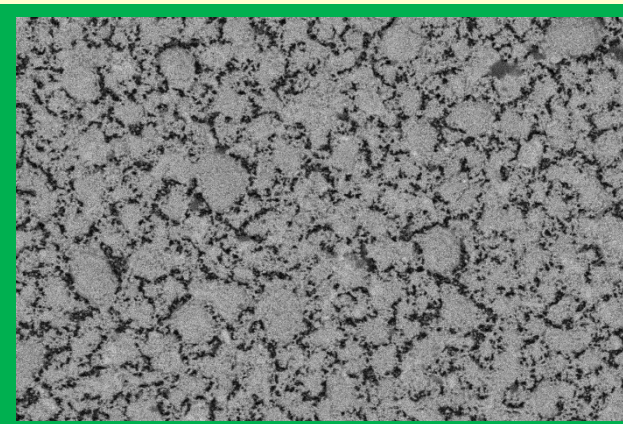
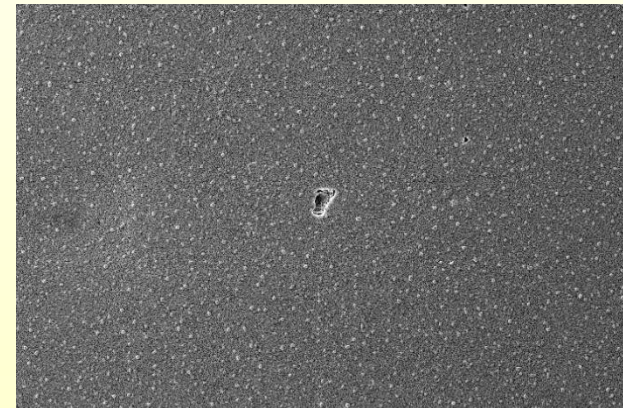
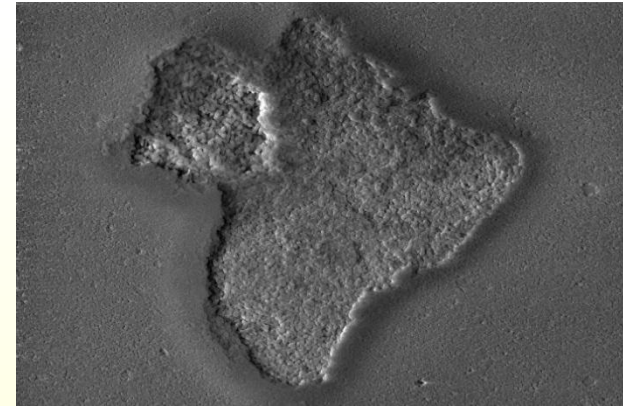


Cracking of layer 3 around particles atop layer 2

RTP optimization- Layer 2 defect removal

Layer 2 defect - removal

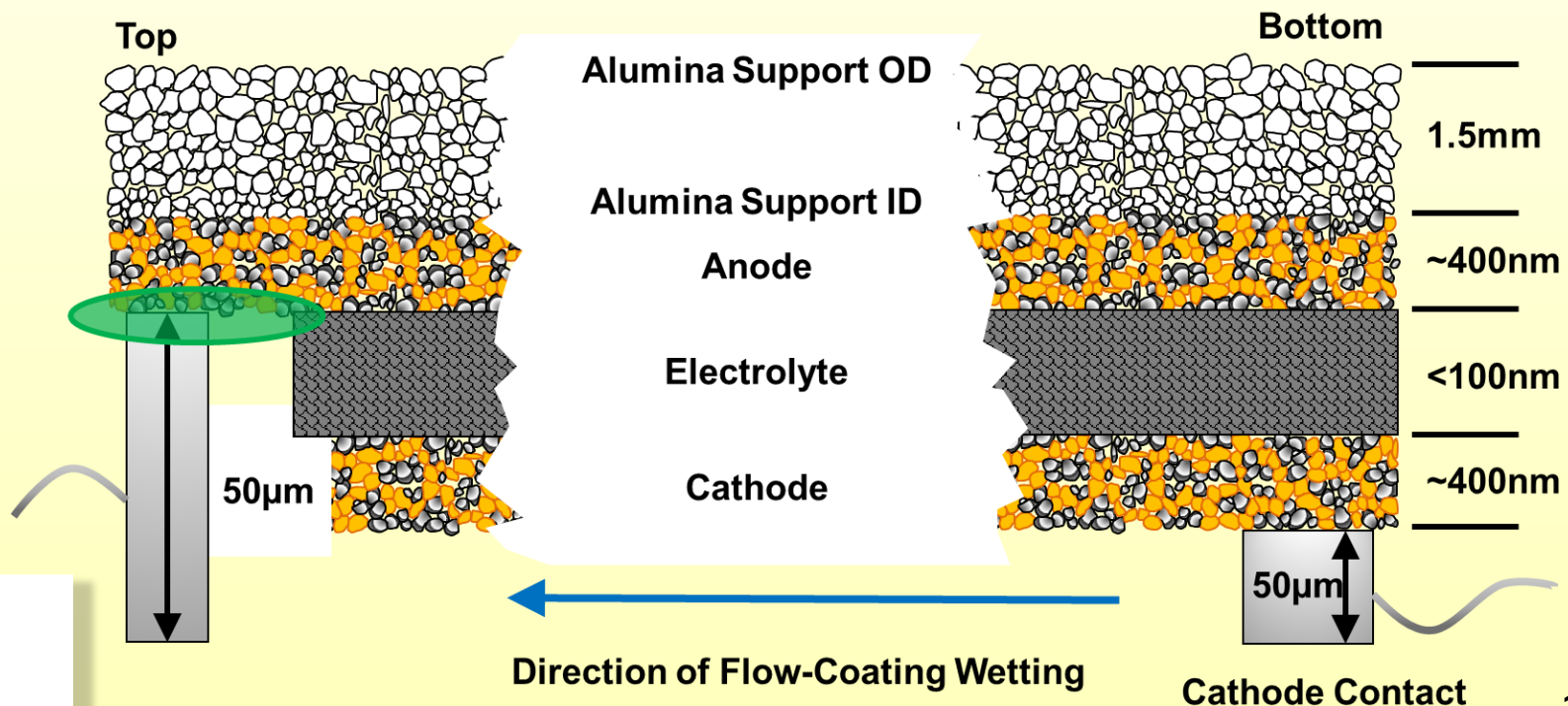
- SEM analysis performed on layer 2 post-drying, during stages of optimized RTP program
- Layer 2 remained uniform and structurally intact, however particles remained atop it. Longer and/or higher temperature thermal processing saw fewer particles, but much larger ones.
- DLS performed on flow-coating dispersion revealed no larger particles within the dispersion
- Defect was removed by altering layer 2 dispersion to a binder concentration closer to layer 1 concentration
- RPT'ing parameters did not require altering



Modified layer 2 after RTP'ing,
no particles detected

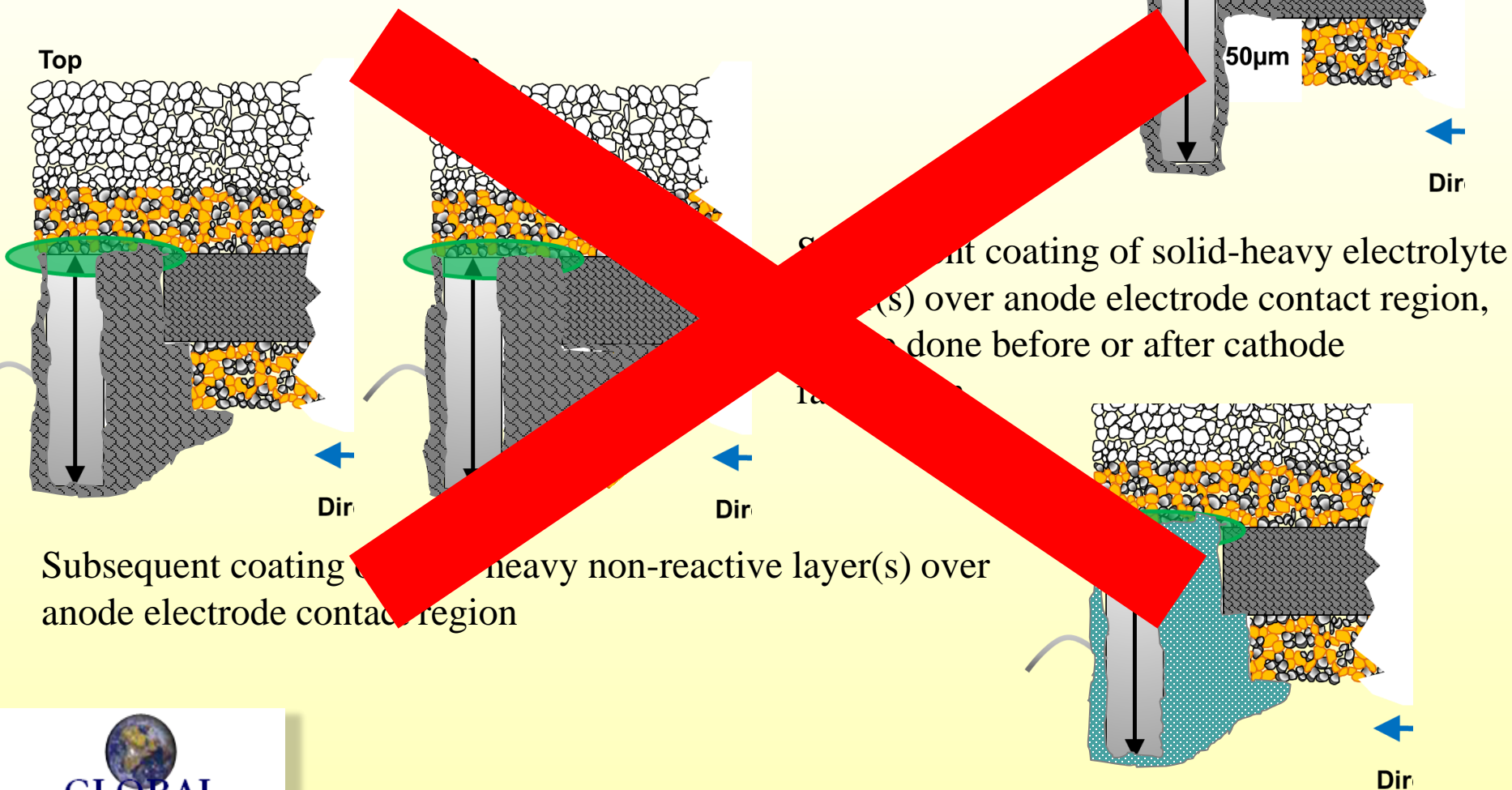
Bottom electrode contact seal

- Previously tubes coated with full length anode, and a partial length (1" short) electrolyte. The cathode is coated $\frac{1}{2}$ " shorter than electrolyte to prevent surface conduction
- This leaves a portion of length uncoated by any dense, O₂ selective layers
- The anode contact is very thick, relative to the layer thicknesses and also not dense, meaning it must be covered in this configuration



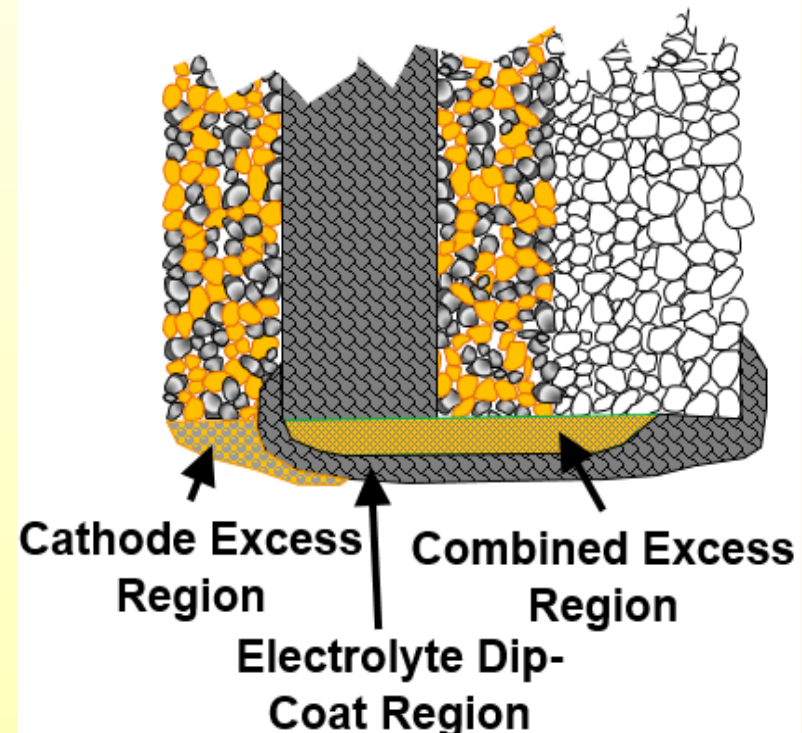
Approaches

Coat standard electrolyte layers over anode electrode contact
-unlikely to work due to thickness of contact relative to
electrolyte layers, will serve as a base case



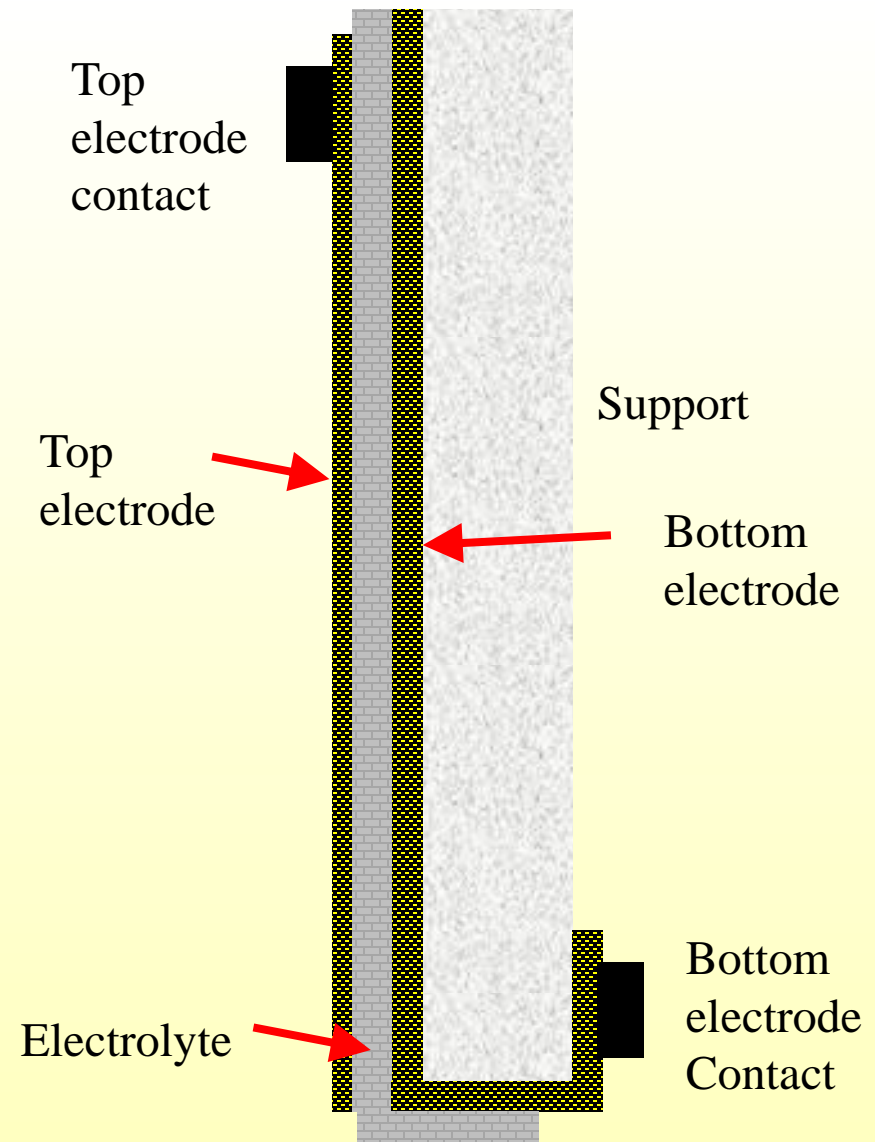
Tube edge isolation

- **Acidic removal of electron transport phase**
 - Experiments with submersion, temporary wetting, and exposure to acid vapor have shown this method is not suitable to a controlled removal of electrode material
 - Thus far results have not been confined to desired area and/or rapid enough despite use of highly concentrated acid solution
 - Removal of conducting phase effort was ceased as results were not sufficient,
- **Electronic tube isolation zone**
 - Samples from batches have been intentionally flow coated to allow for wetting of bottom of tube and lower section of tube's O.D.
 - All samples will continue to be coated in this manner for the complete electrolyte, then undergo electrical conductivity testing
 - All tests show electrolyte layers with and without top electrode layers coated in this manner are not e⁻ conductive



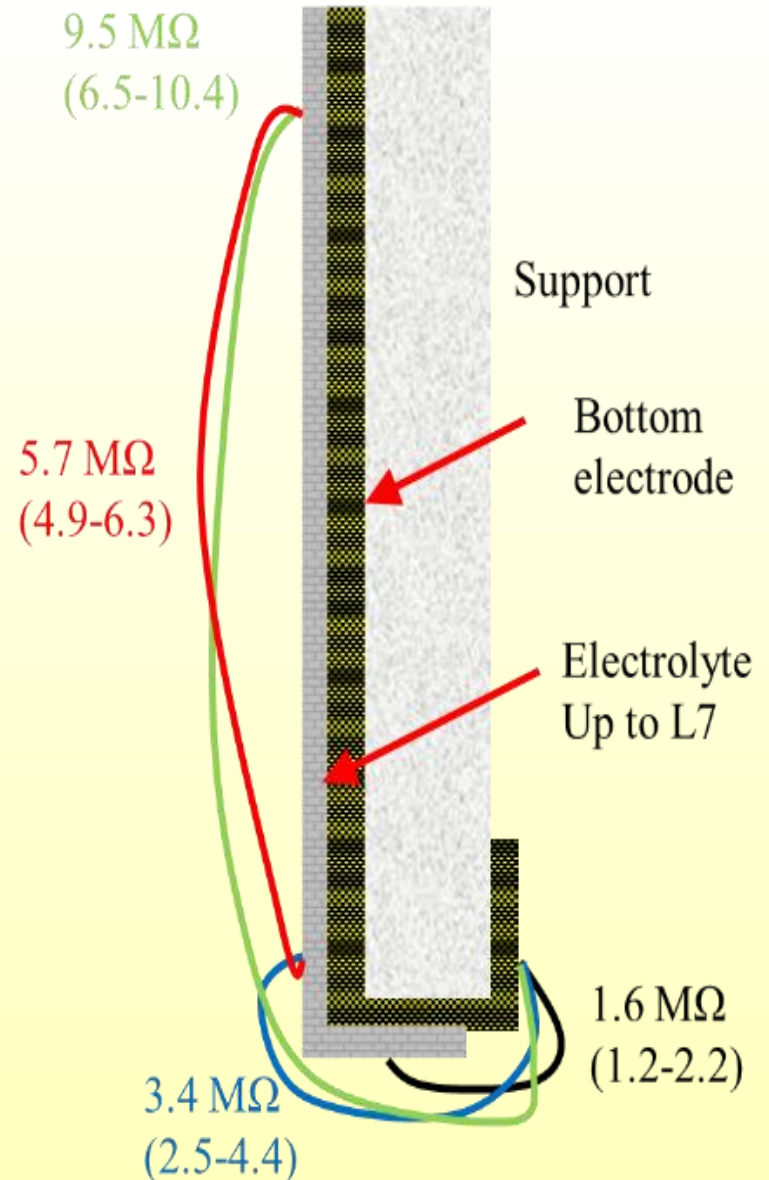
New electrode geometry- simplified sealing

- Bottom electrode is allowed to coat around bottom and onto O.D. at one end of tube.
- Bottom electrode contact is placed on outside of tubular support onto coated region
- Electrolyte is coated entire I.D. surface
- Top electrode is coated nearly entire I.D. surface, stopped just shy of top to prevent potential shorting at top. Bottom is prevented from wetting by flow coating hose and/or masking end and O.D. off.



Verification by electrical conductance

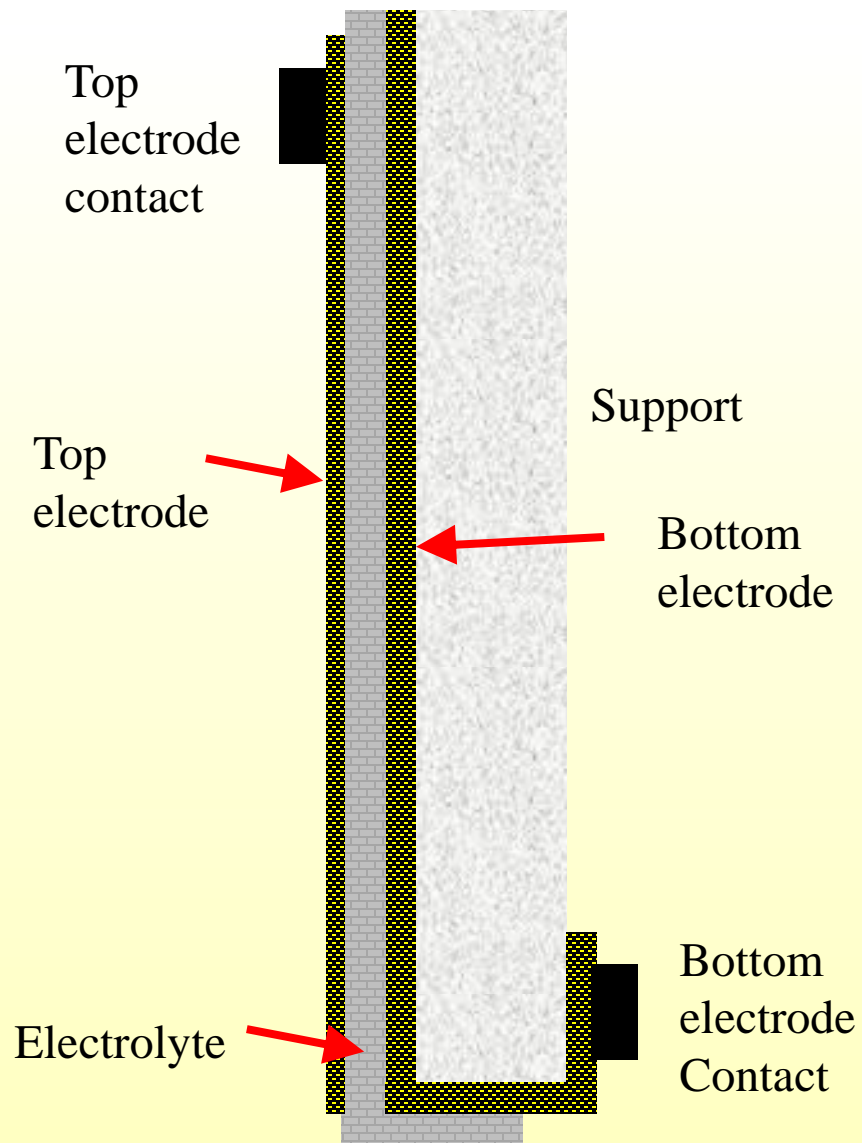
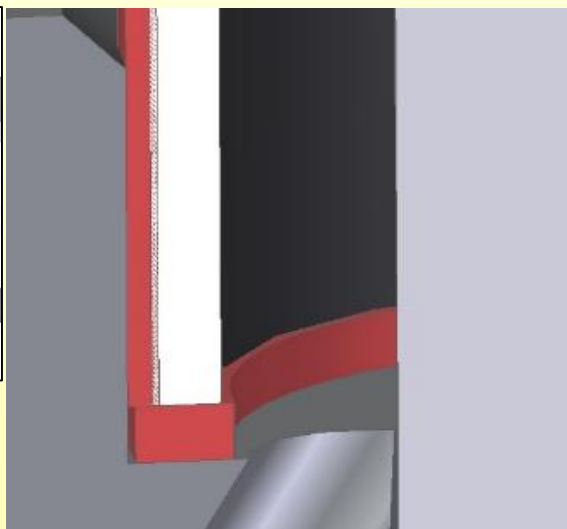
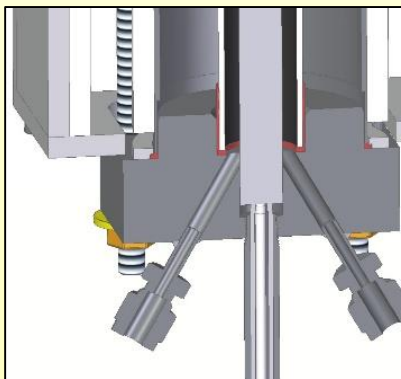
- Averaged resistances (measured ranges over multiple samples)
- Shows electrolyte is isolating despite being ~200nm thick
- Shows continuous electrolyte structure around bottom to ID edge of tubular support



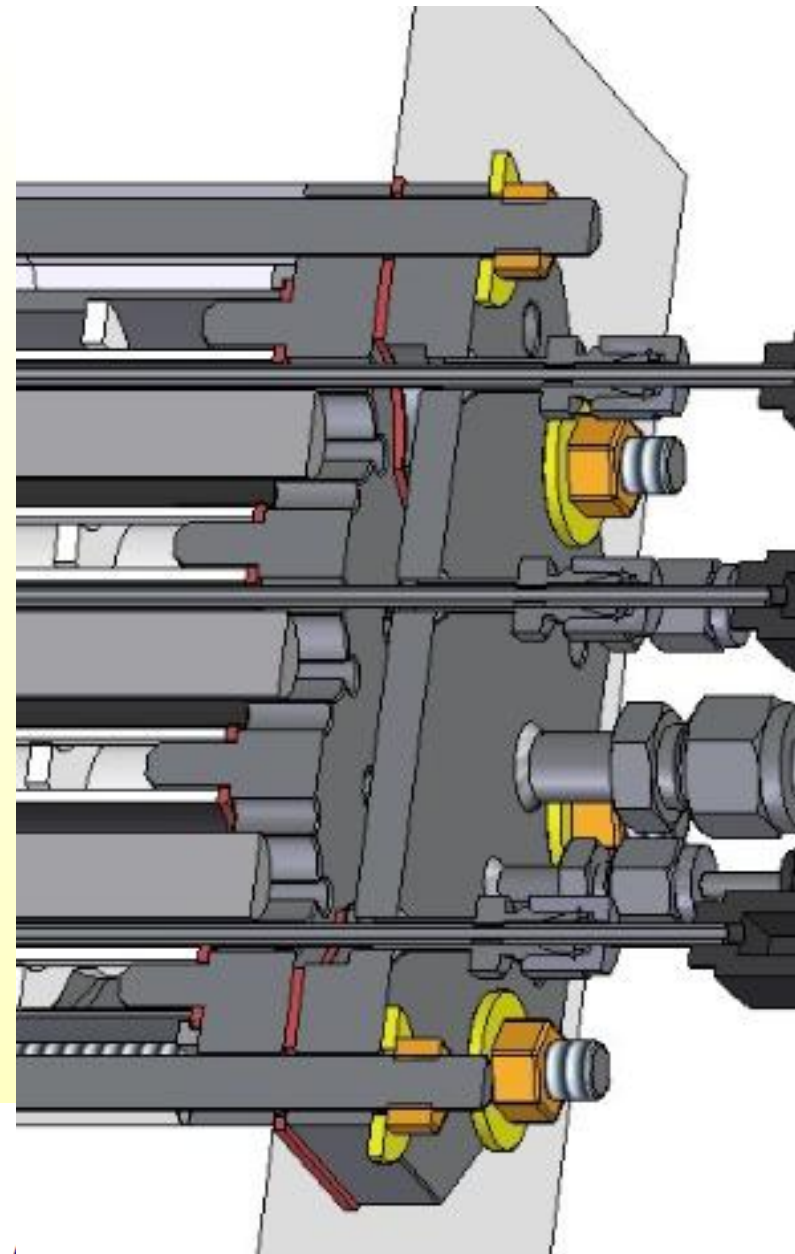
Isolation of tube from cell

New bottom electrode configuration, as well as prior end of tube coating allowed potential for shorting of sample through metallic characterization cell

- Isolative insert around ends of tube – method proven up to 600°C
- New isolating ceramic tube to endcap connector – concept important for multi-tubular designs



Gas sealing



Gas Sealing Improvements

- Modifications to characterization cells to allow for electrical isolation between metallic cell parts and the now electrode coated tube exterior portions have required a partial reworking of gas sealing:
- Ports:
 - Gas ports old - 1/4" Swagelok™ fitting welded on ✓, **but mechanically weak**
 - Gas ports new - 1/4" Swagelok™ fitting with high temperature sealed NPT coupling ✓
 - Thermocouple port old - 1/8" Swagelok™ fitting welded ✓, **but mechanically weak**
 - Thermocouple port new - 1/8" Swagelok™ fitting with high temperature sealed NPT coupling ✓
 - Thermocouple port new - 1/8" or 1/16" HiP Equipment™ TC adaptor with high temperature sealed NPT coupling ✓
 - Electrode lead port old - high temperature NPT sealant to isolator sheathe and lower temperature sealant between wire and sheathe, ✓ **for wire to sheathe seal, not fully reliable for isolator to 1/8" opening, failed in all attempts for isolator to 1/4" opening**
 - Electrode lead port new – HiP Equipment™ TC adaptor to isolator sheathe and lower temperature sealant between wire and sheathe, ✓ **for both seals**

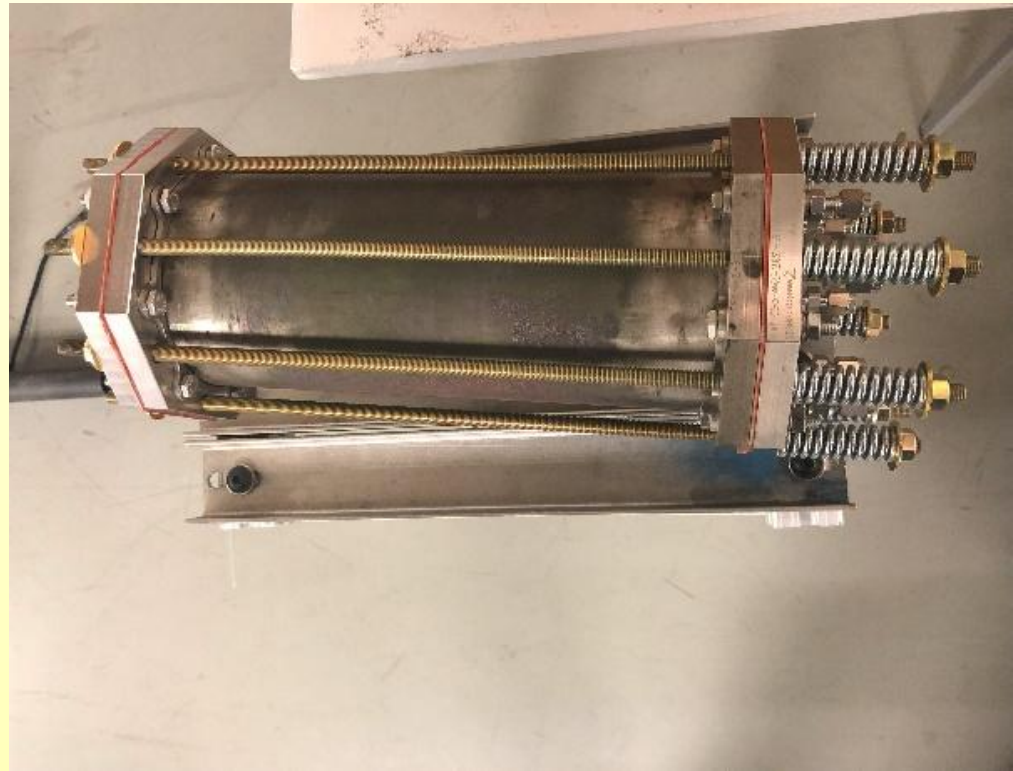
New seals reliably work, are easier to assemble, disassemble, and are electrically isolating for electrode leads

Performance Characterization

- As optimization progresses layer by layer, subsequent structures will be characterized for selectivity and permeance
- Thus far testing on bottom electrode samples from shows no O₂/N₂ selectivity, as expected, and permeance of ~1/2 that of bare tube, 4E-7 (mol/[Pa m² s]) for complete bottom electrode structure
- Tests on tubes with electrolyte layers were in progress before defects observed, densification was measured by a permeance dropping to 3.1E-9 (mol/[Pa m² s])
- Tube defects known to be preventing uniform densification, likely electrolyte regions without defects are fully densified as attested to by measured electrochemical pumping observed in scoping experiment as low 250°C
- Once defects in tube removed, electrolyte layer densification will be retested before optimization of top electrode, layers 9 and 10, electrochemical testing will be included
- Prior pumping data showed 11 Lpm, Global is targeting increasing this to 20 Lpm to meet weight targets (for AF and DHA-Army needs)

Design of 15 Lpm module

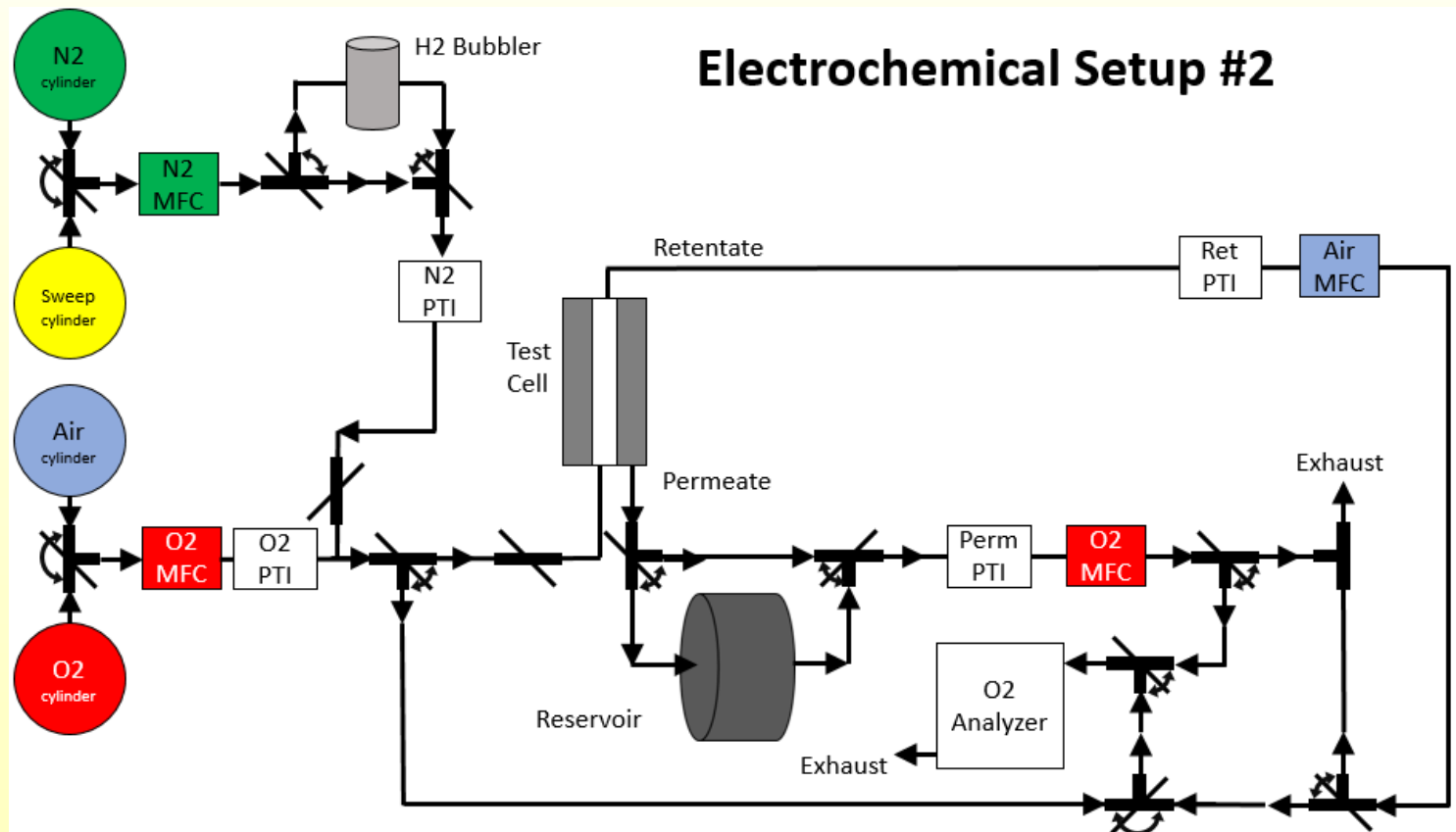
- Global has tested a 7-tube module thermal and air flow analysis with parallel flow
- Global is testing a 7-tube series module
- Thermal and air flow analysis of series module to follow
- Data will be used to tune our model of fluid and heat flow
- O₂ pumping results from benchmark single tube
- Data to be combined for 15 sLpm module design



Pressurization Study

Electrochemical characterization setup had a reservoir section and pressure transducers added

- Design made and components installed.



Potential next steps to lead to oxygen units

Steps planned to deliver a prototype O₂ pump system

- Testing on our O₂ pump breadboard system thermal and flow
- Operating breadboard system with benchmark O₂ pump structure coated tubes
- Continued O₂ pump structure optimization improvement
- Miniaturization and light-weighting of components for 7 or 15 sLpm prototype
- Testing of components on breadboard system in lifetime testing conditions
- Design of 7 or 15 sLpm prototype system including packaging, subsystem hardware, and software
- Construction and testing of 15 sLpm prototype



Acknowledgments

- **Funding for Global O₂ pump from**
DHA - previous funding
Air Force - funding

- **Contact information**

R. Aaron Bauer, Ph.D
539 Industrial Mile Road
Columbus Oh 43228
aaron_bauer@live.com