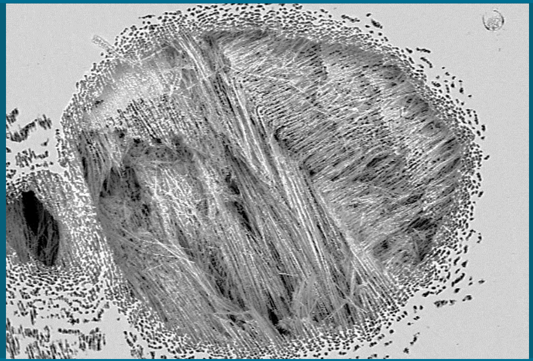
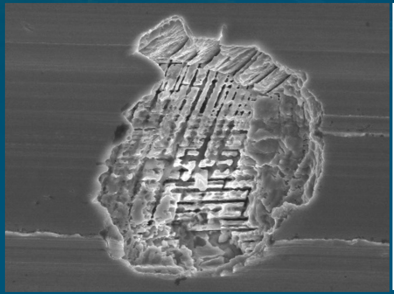
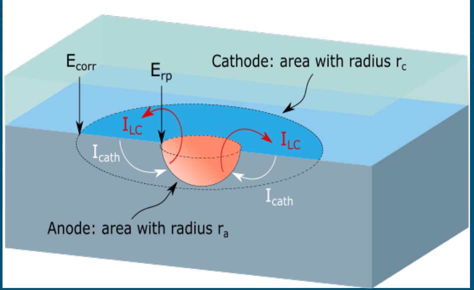
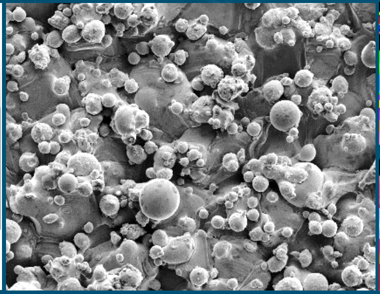
Sandia National Laboratories

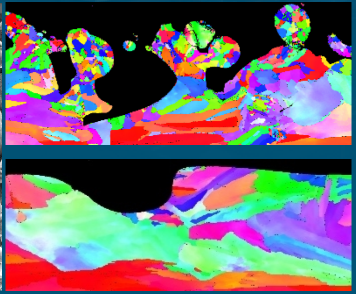
Custom Cathode Optimization for Electropolishing Additively Manufactured 316L Stainless Steel











RGSAM 2024
October 21st , 2024
– Albuquerque, NM

PRESENTED BY

Kasandra Escárcega Herrera

Graduate Student Intern- Materials Reliability Group

Key contributors: Michael Melia, Mary Louise Gucik, Jay Taylor

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Acknowledgements

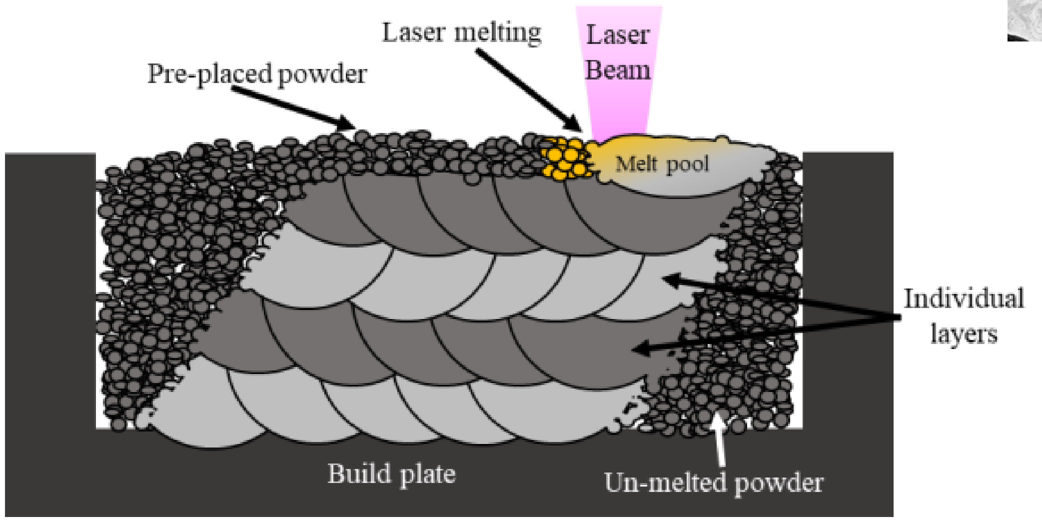
Funding: The Advanced Manufacturing and Development program through the Office of Engineering and Technology Maturation (NA-115).

People: David Saiz, Jamie Stull, Alex Mirabal

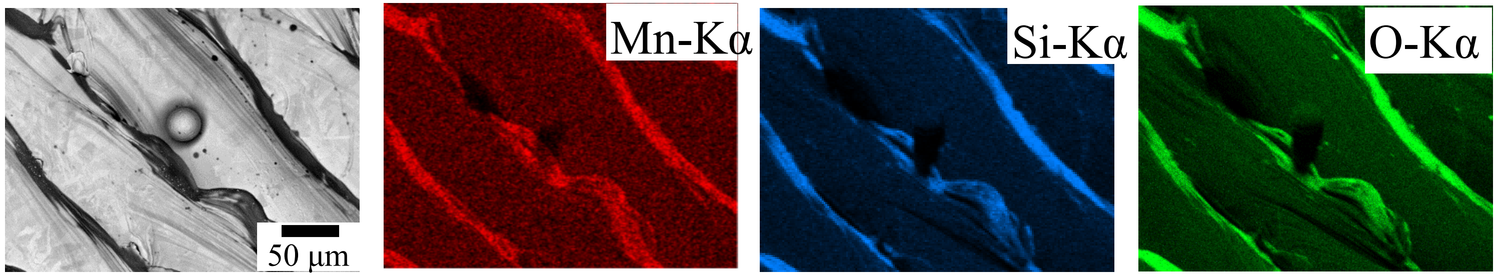
Thanks to the symposium organizers for the opportunity to give this presentation.

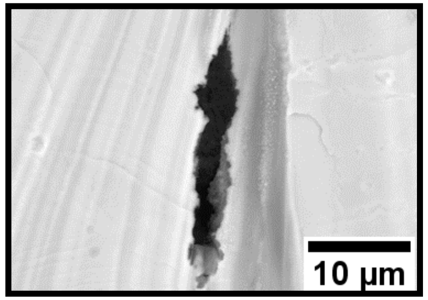
Background

Laser Powder Bed Fusion (L-PBF) is an additive manufacturing (AM) process using a laser to fuse together powder particles layer-by-layer. This study focuses on parts produced with 316L stainless steel powder.

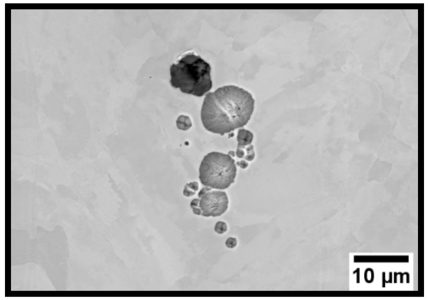


- Un-melted powder particles will cling-on to melted surface
- Manganese silicate present at melt track boundary

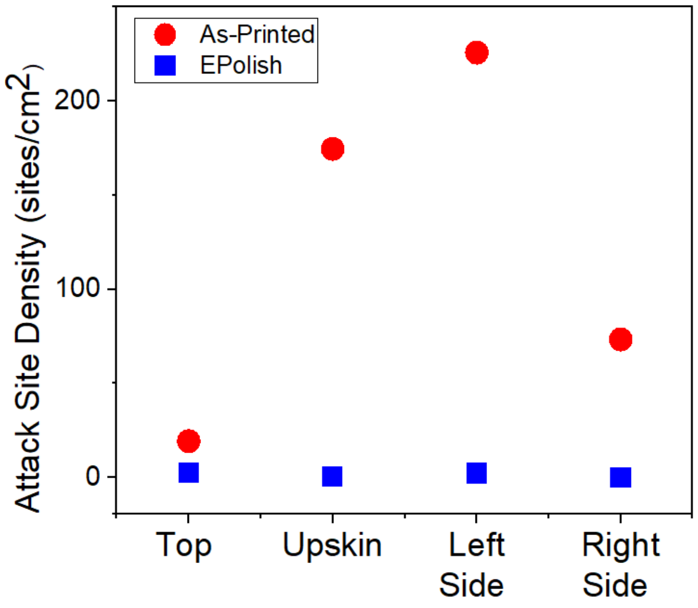




Pit propagation along melt track



Corrosion attack on EP surface



Melia et al., "How build angle and post-processing impact roughness and corrosion of additively manufactured 316L stainless steel", Corrosion Science, 2020.

(UUR)

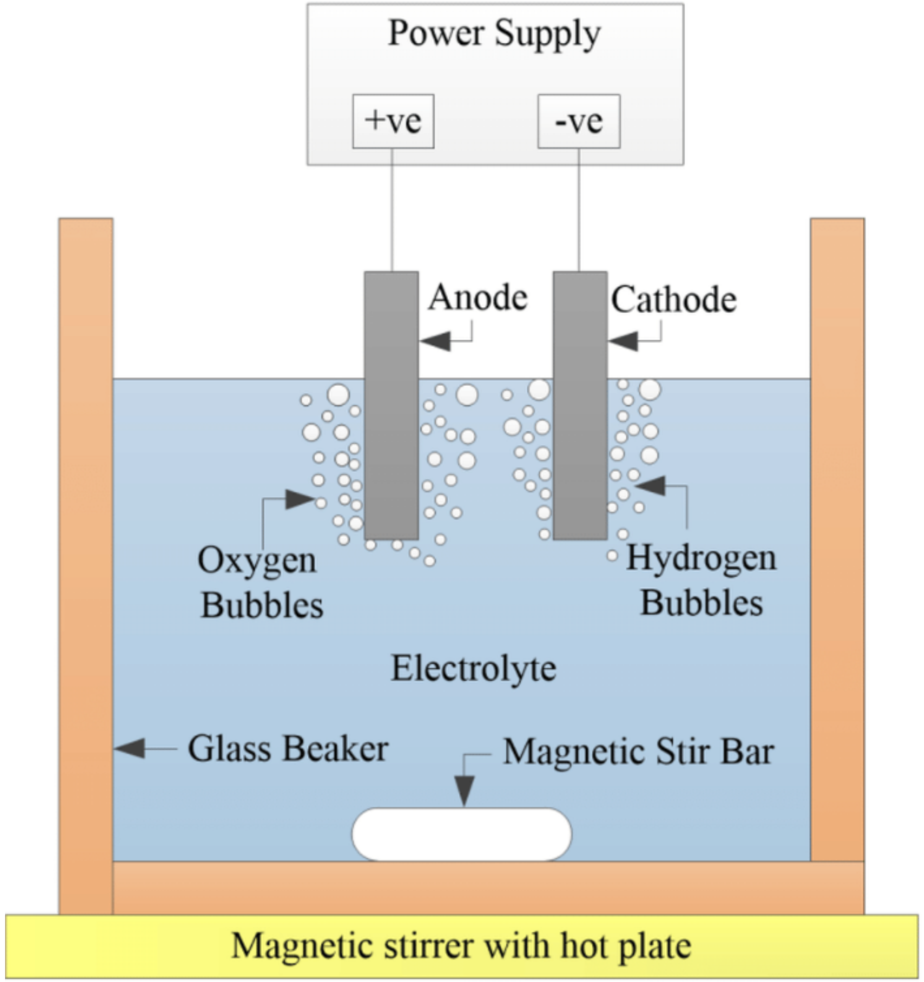
What is Electropolishing?

Electropolishing (EP):

- “Reverse plating process”, removing material instead of depositing it.
- (+) anode and (-) cathode placed in an electrolyte bath.
- Current passed through the system, removing ions from the anodes surface which dissolve into the electrolyte, resulting in a smoother surface finish.
- End-goal is a shiny part free from impurities.
- EP can help finish parts that cannot otherwise be polishing through traditional techniques.
- However, ion transfer occurs more rapidly on edges and corners which impact edge-retention and may alter part shape in unwanted ways.
- Can combat this my modifying cathode shape and electrode spacing.

Typical electrolytes for most materials use concentrated acids.

For this study, we investigated how an environmentally friendly electrolyte based on polyethylene glycol (PEG) and sodium chloride compares to a traditional acid-based electrolyte.

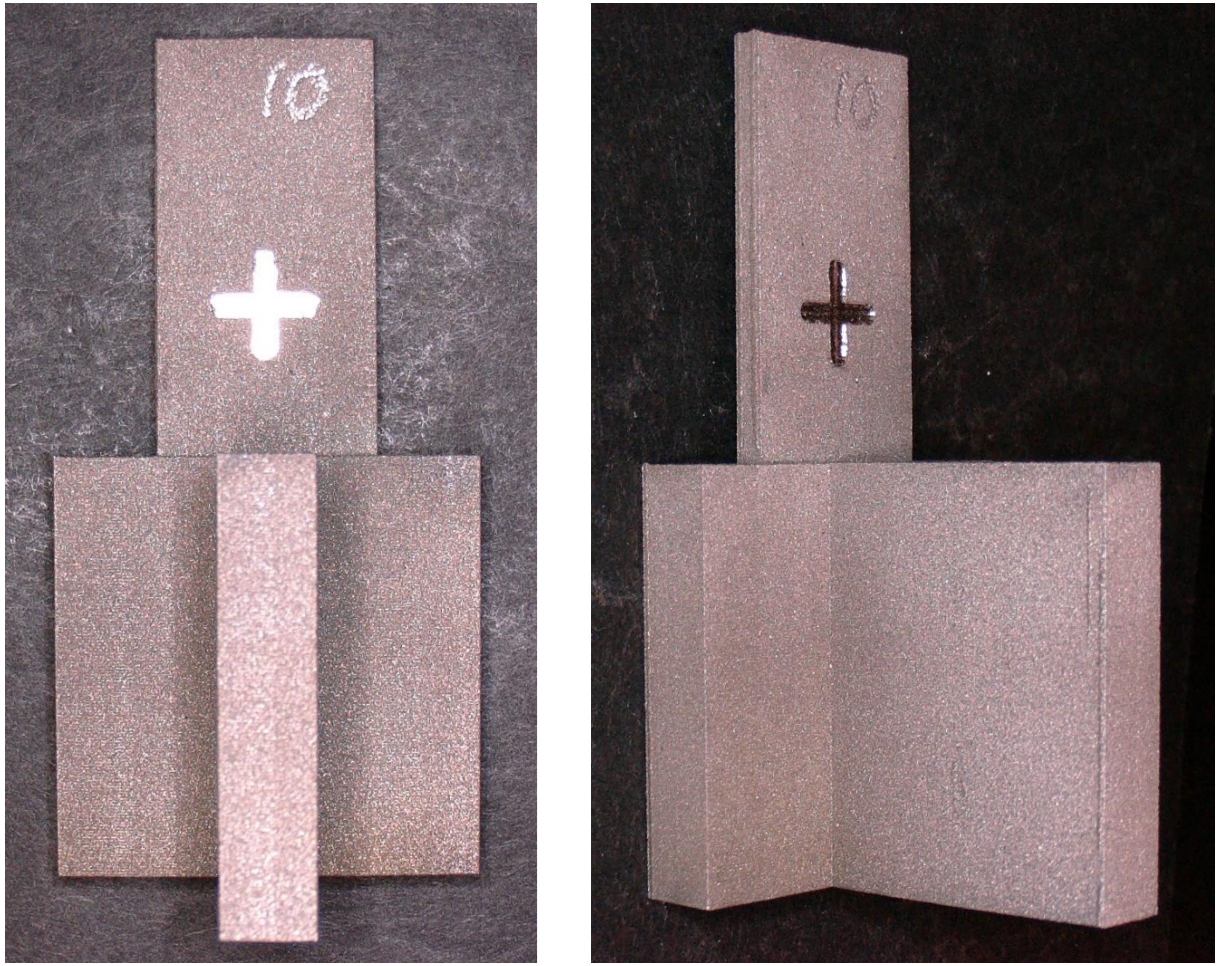


Schematic of Electropolishing Setup

Kumar et al., “Parametric investigation of electropolishing to enhance the surface characteristics of maraging steel with organic electrolytes”, The International Journal of Advanced *Manufacturing Processes*, 2022. (UUR)

Project Objectives

- Electropolishing 316L stainless steel T-shapes parts using cathodes of increasing conformity with a close electrode gap.
- Comparing electropolishing results between a traditional acid electrolyte and an environmentally friendly polyethylene glycol electrolyte.
- Using COMSOL to guide future cathode designs.

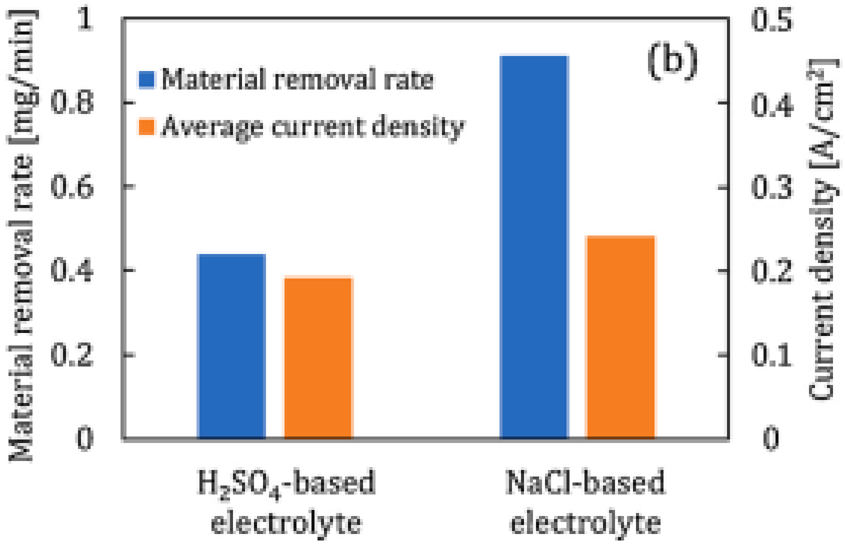


Optical images of T-shaped anodes in the as-printed state

Existing Literature

On Electrolytes:

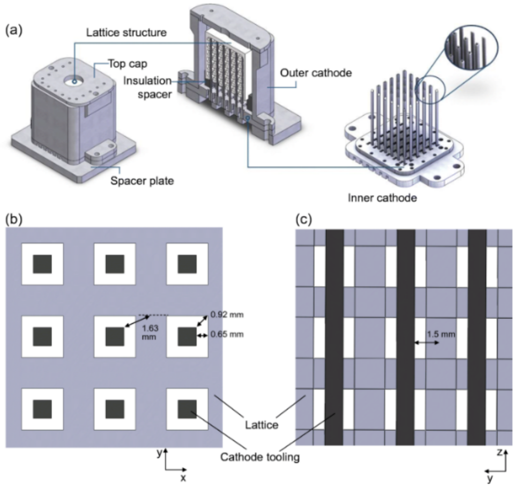
- Han found that the NaCl-based electrolyte resulted in comparable electropolishing effects to the conventional acid electrolyte and actually removed more material.



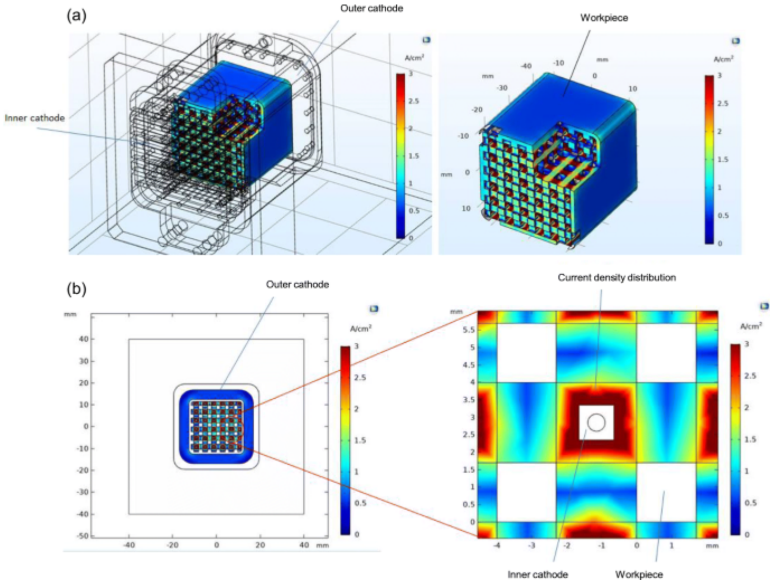
*Material removal rates and average current densities with different types of electrolytes

On Conformal Cathodes:

- Polishing AM Inconel 718 lattice anodes with conformal cathode that slots into lattice structure.
- Found that they were able to remove significant amount of material on the inner structure as well as reduce roughness even with a small electrode gap.
- Also used COMSOL to model current density distributions across lattice anode.



**Lattice anode and inner cathode



**Electropolishing simulation

*Han, Fengzhou Fang, "Eco-friendly NaCl-based electrolyte for electropolishing 316L stainless steel", *Journal of Manufacturing Processes*, 2020.

(UUR)

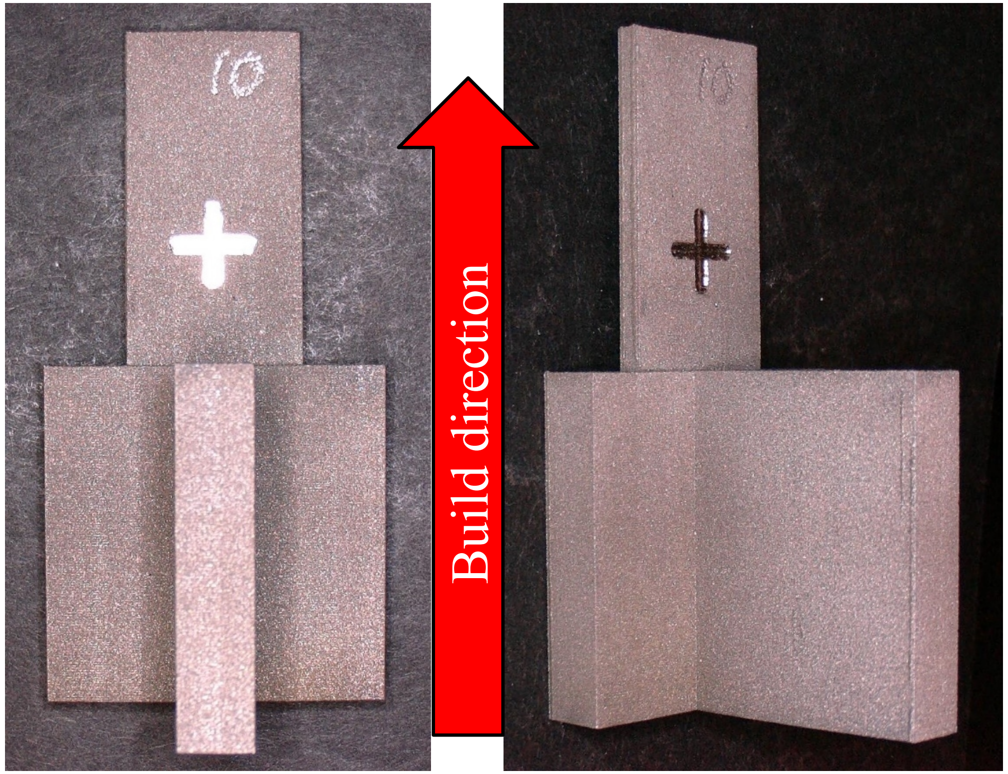
Lynch et al., "Surface finishing of additively manufactures IN718 lattices by electrochemical machining", *The International Journal of Advanced Manufacturing Processes*, 2021.

Sample Printing Parameters

Anodes and cathodes printed on 3D Systems ProX-200 LPBF with 316L powder. Print parameters and powder chemistry shown below

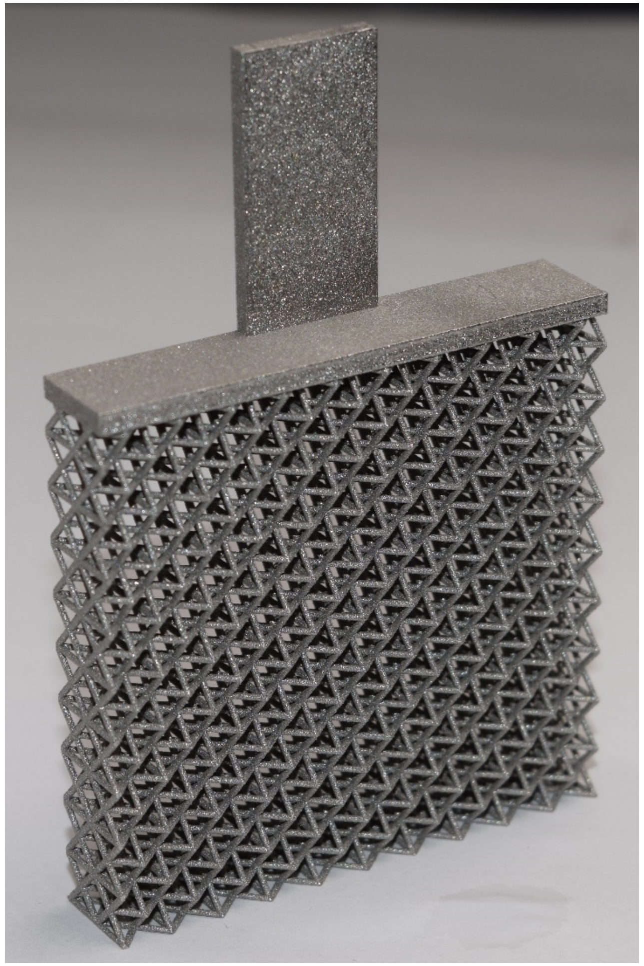
Machine Model	Power (W)	Scanning velocity (mm/s)	VED (J/mm^3)	Hatch Spacing (µm)	Layer thickness (µm)	Scan Pattern
3D Systems ProX200	113	1400	54	50	30	Hexagon

Wt %	Al	C	Cr	Cu	Fe	Mn	Mo	N	Ni	O	S	Si
	0.003	0.018	17.12	0.15	67.2	1.28	2.19	0.12	11.18	0.11	0.013	0.49

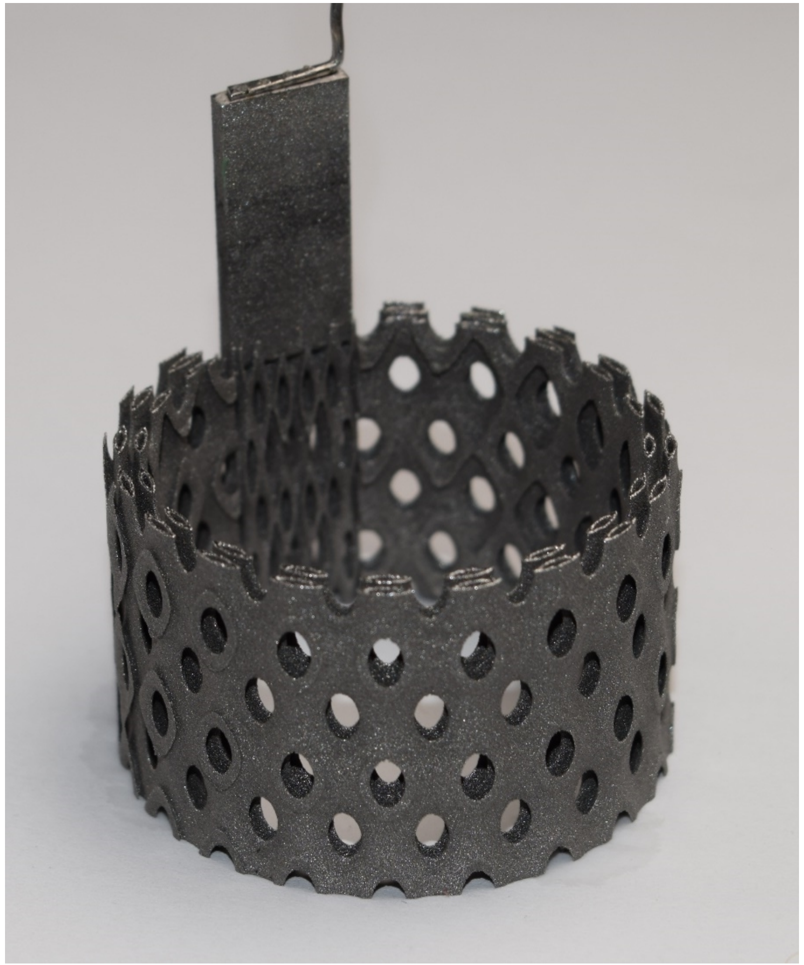


Optical images of T-shaped anodes in the as-printed state

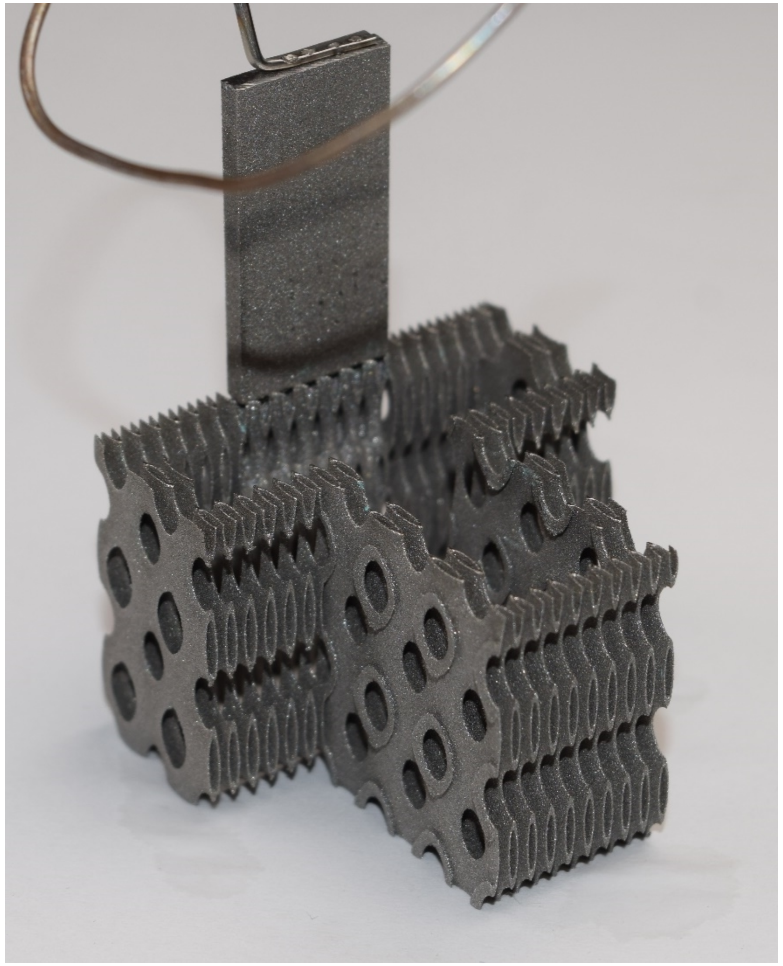
Cathodes



Flat Cathode

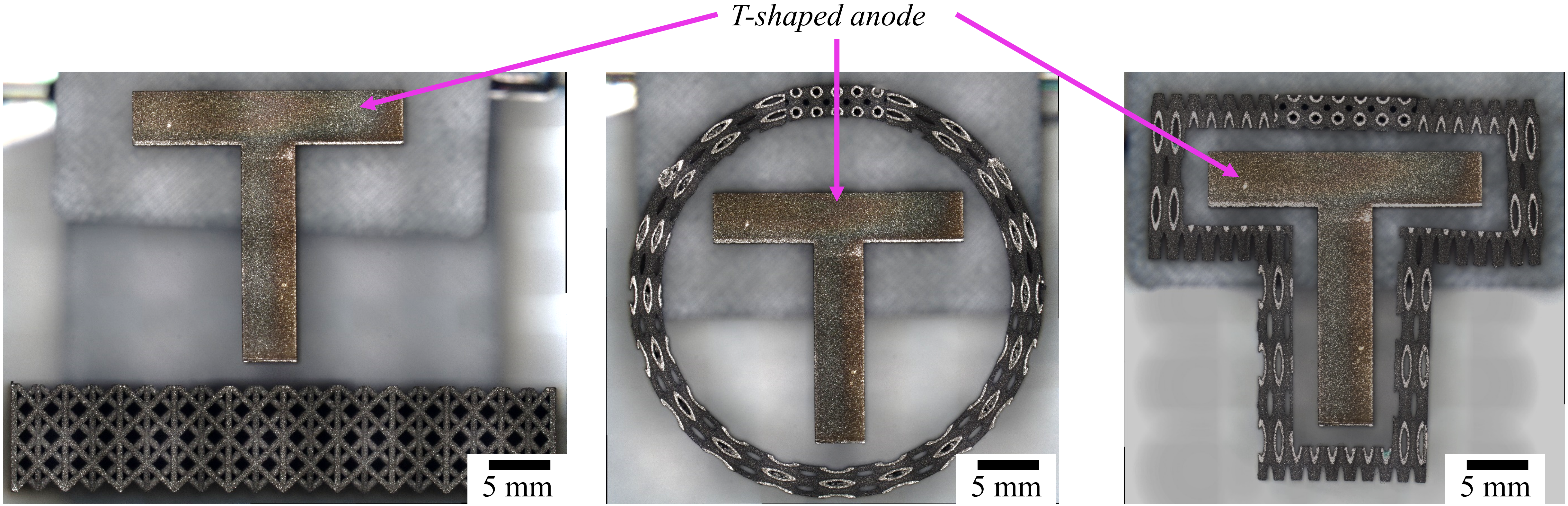


Cylindrical Cathode



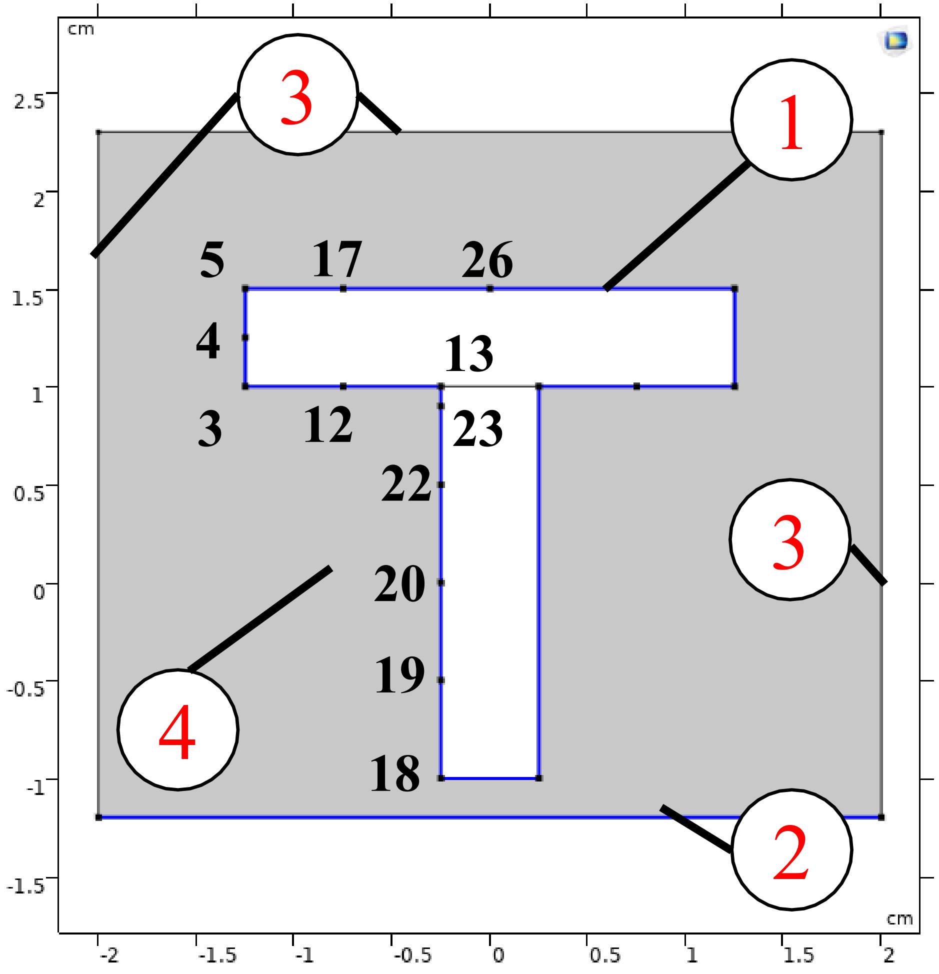
Conformal Cathode

Cathodes (0.2cm Spacing)

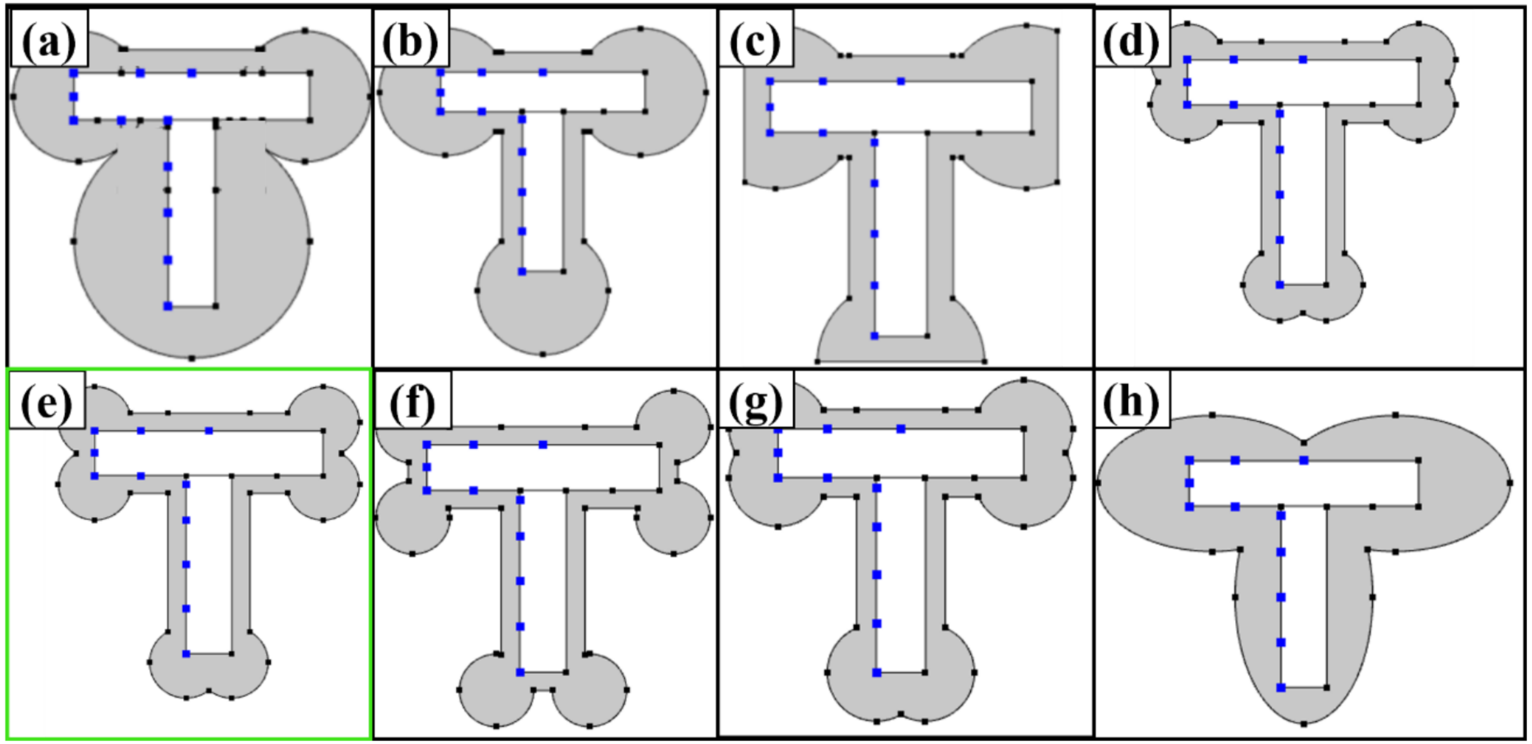


Flat Cathode Cylindrical Cathode Conformal Cathode

“Selective” Cathode Design

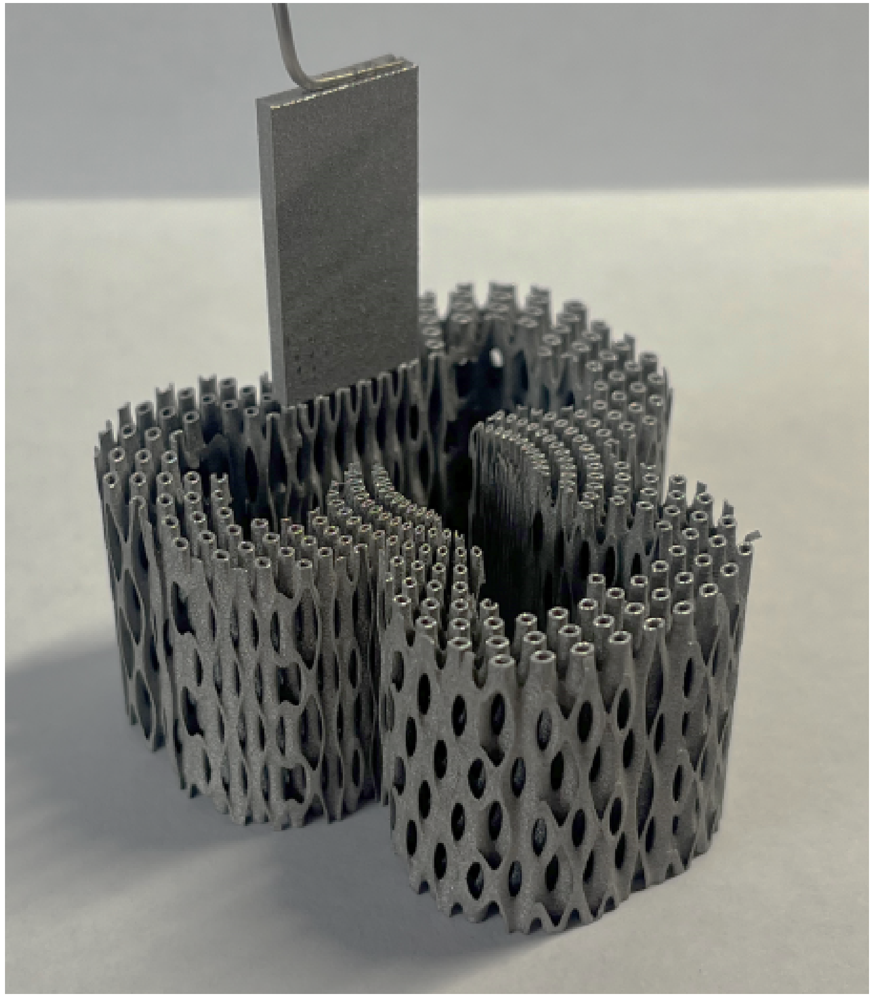


	Boundary	Definition
Boundary	1	Anode / Electric Ground
	2	Cathode / Current Density
	3	Insulation
Domain	4	Electrolyte Conductivity
	4	Electrolyte Insulation
Multiphysics	1	Deformation
	2 , 3	No Deformation

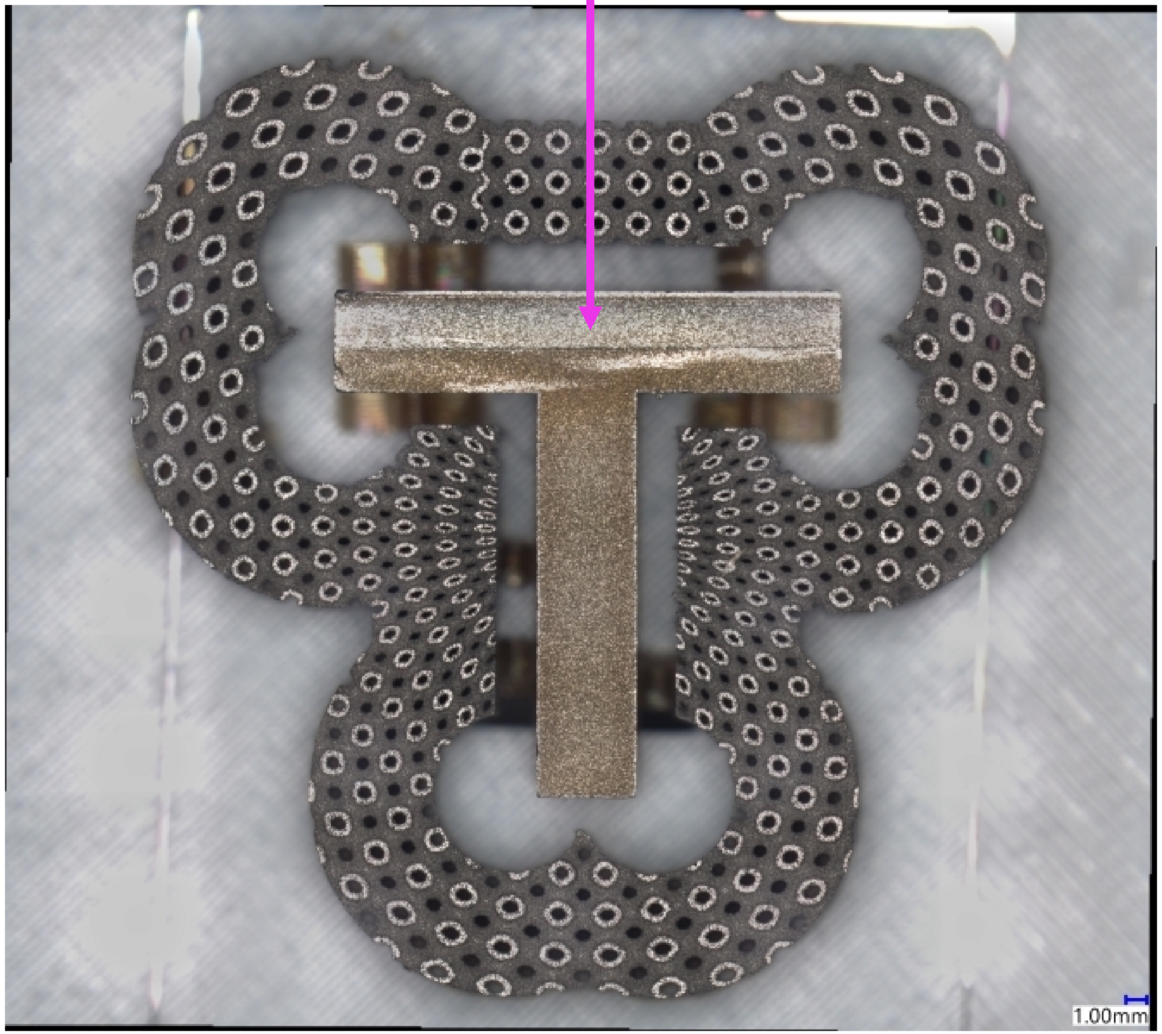


(UUR)

“Selective” Cathode



Selective Cathode

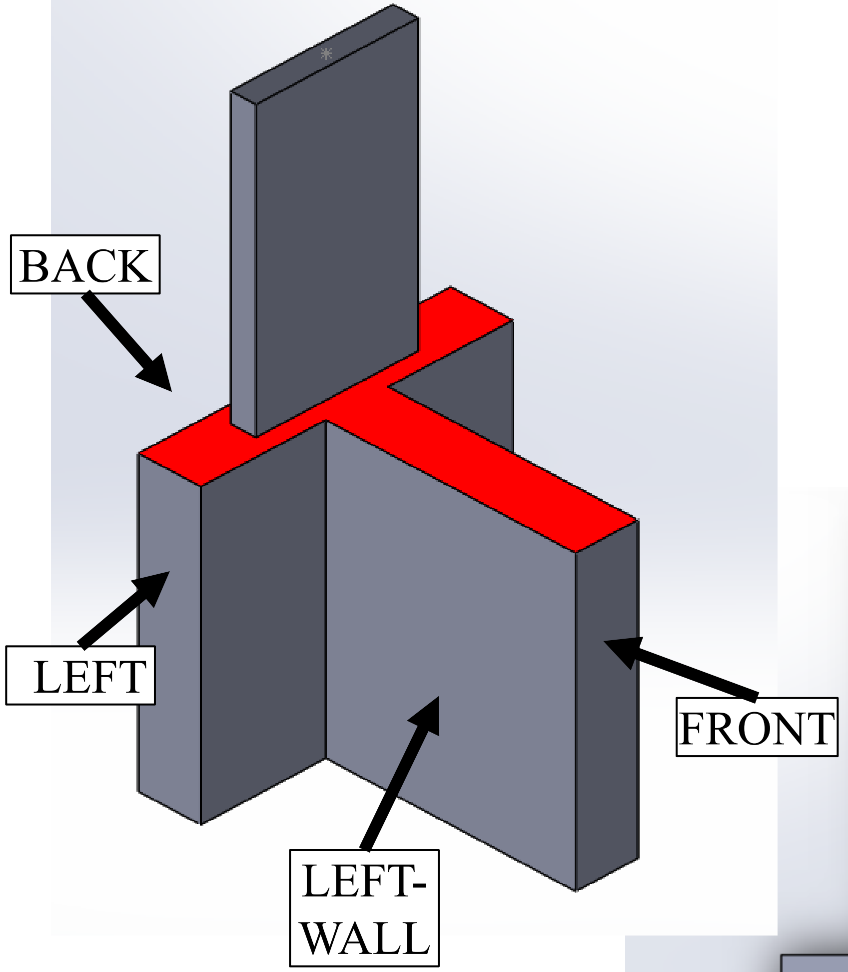


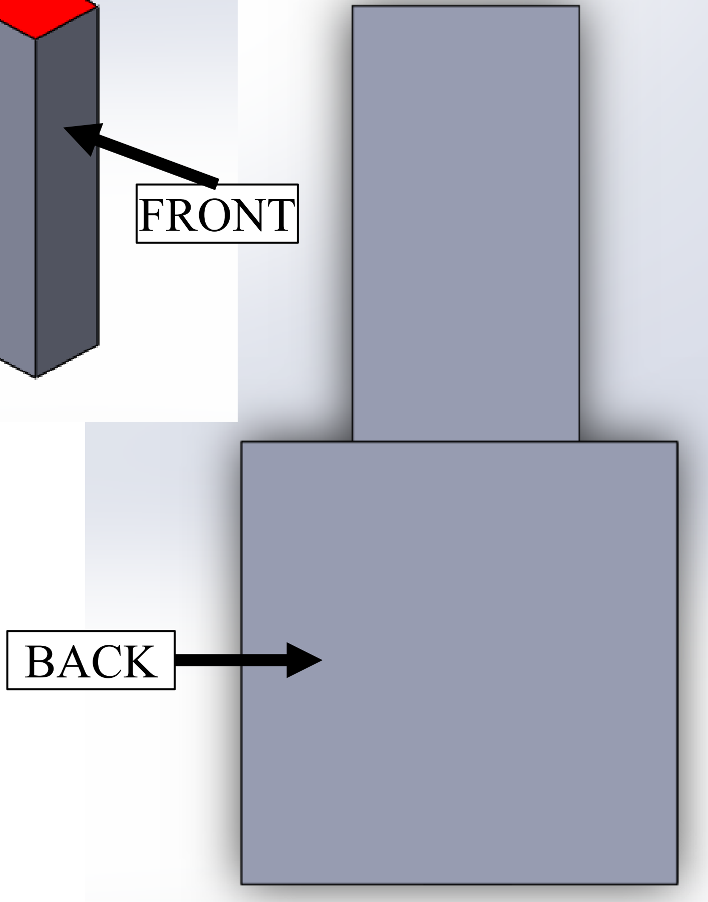
Experimental Process

"Top" and "Bottom" masked off before polishing

Before and After Polishing Process:

- T-shaped samples and cathodes ***cleaned***
- T-shaped samples ***imaged optically***, microscopically and macroscopically
- ***Roughness measurements*** acquired using white-light interferometer
- ***Mass measurements*** collected
- ***Reflectance measurements*** acquired on "Back" surface





Environmentally Friendly Electrolyte:

64vol% Polyethylene Glycol (PEG)

36vol% 6M NaCl

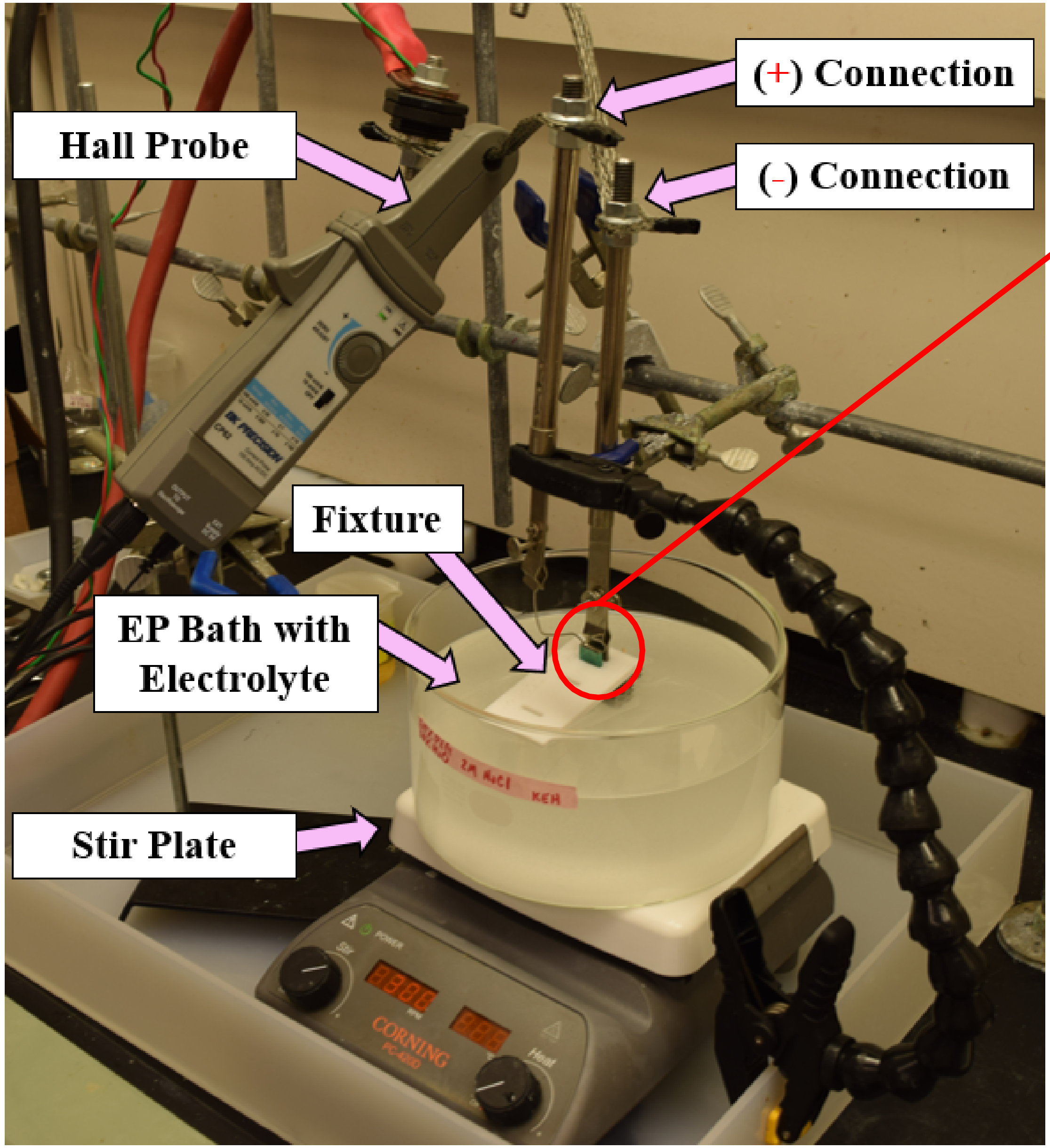
Conventional Electrolyte:

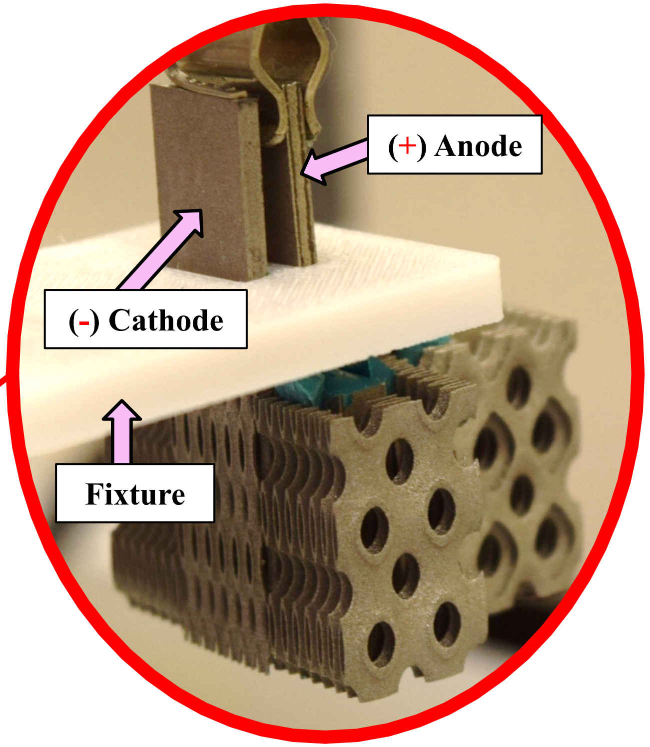
50vol% Phosphoric Acid

25vol% Sulfuric Acid

25vol% Glycerol

Experimental Setup





Current density values obtained from polarization scans:

30 mA/cm² for PEG

150 mA/cm² for Acid

Accounting for rough AM surfaces, actually aiming for:

80 mA/cm² for PEG

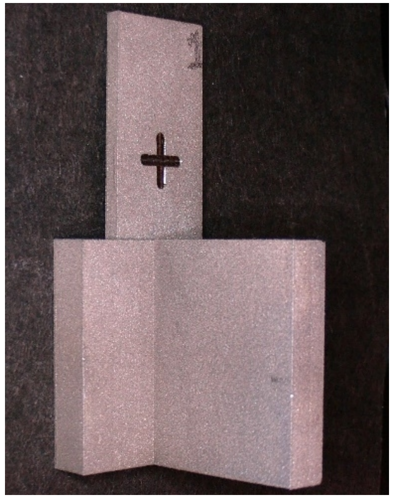
560 mA/cm² for Acid

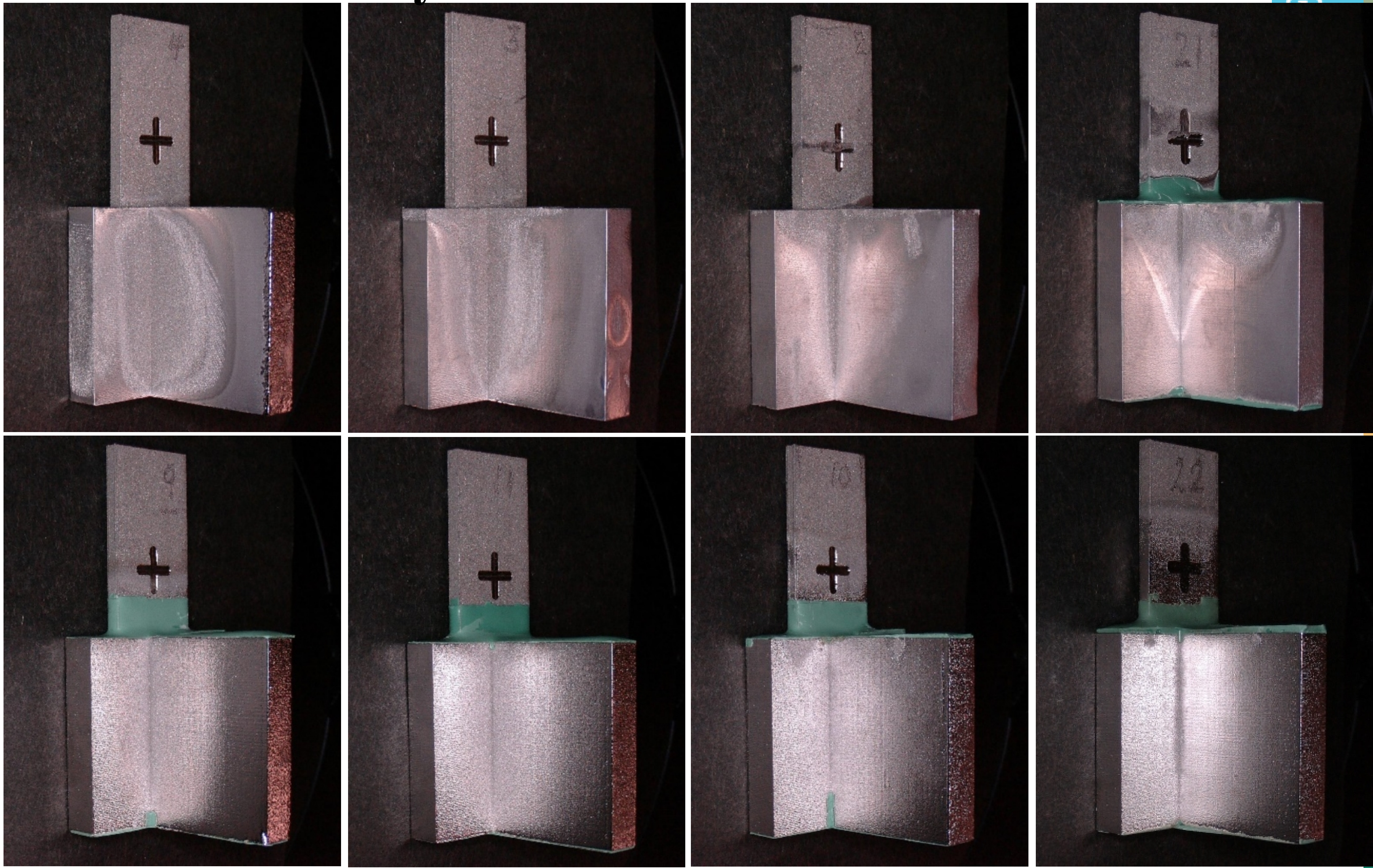
Polishing Parameters

	PEG Electrolyte	Acid Electrolyte
Current	2 A	14 A
Masking	Plater's Tape	Skotchkote™ Epoxy
Area Exposed	25 cm²	
Pulse	25 ms On / 25 ms Off	
Total Time	40 min (20 min polish time)	
Flow	Stir Bar @ 300RPM	

(UUR)

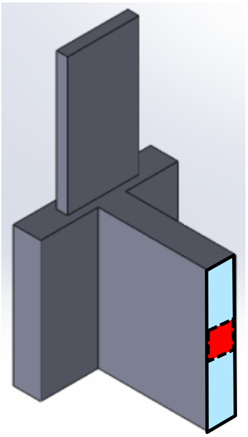
As-Printed

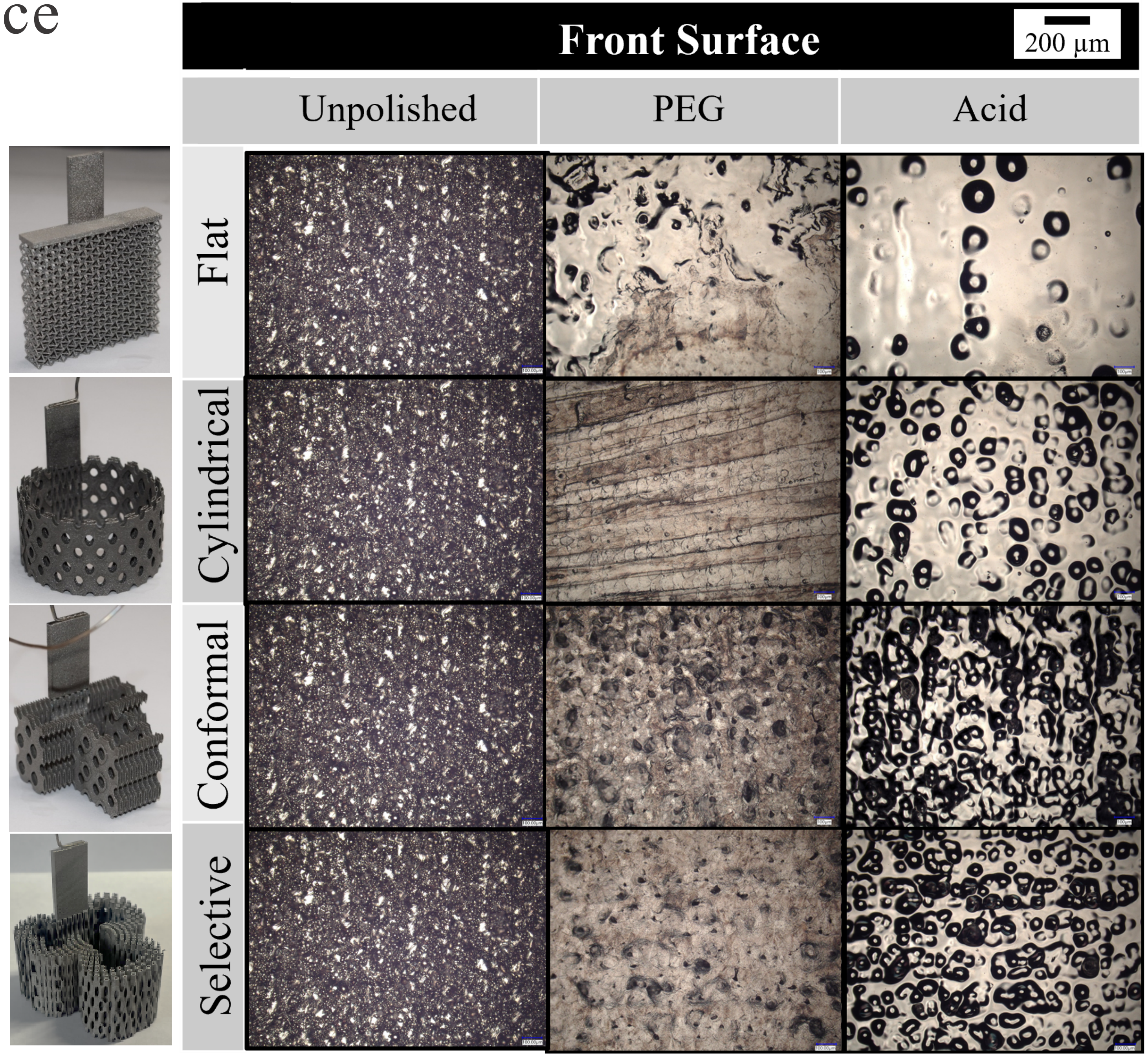




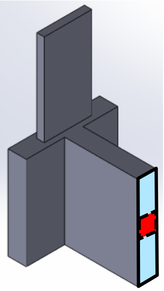
(UUR)

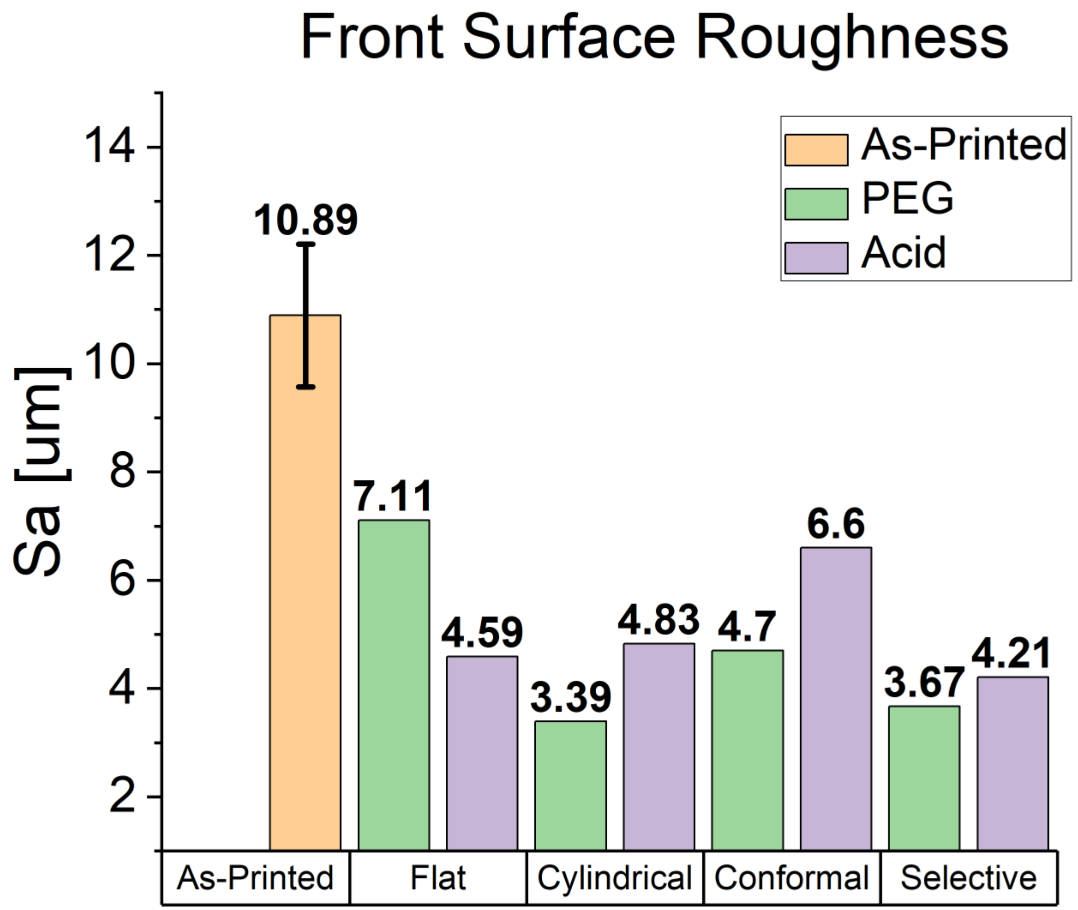
Front Face




Front Surface
200 µm
Unpolished
PEG
Acid
Flat
Cylindrical
Conformal
Selective

Results Summary: Front Face





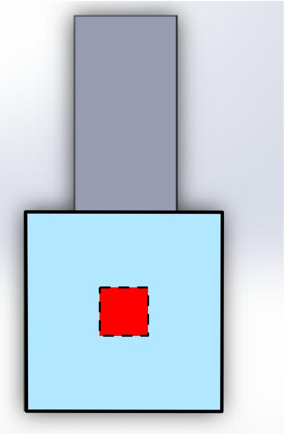
- Front face is the closest to each cathode, expecting to see the highest material removal.
- Conformal cathode elicited a more aggressive polishing process- higher dimple density for both electrolytes
- Flat and Cylindrical cathodes were generally smoother with the exception of the Flat cathode in PEG
- Variations in roughness likely due to factors other than cathode geometry, electrode spacing and current density, such as, diffusion impact EP
- Generally more material removal in acid electrolyte likely due to higher conductivity and current density

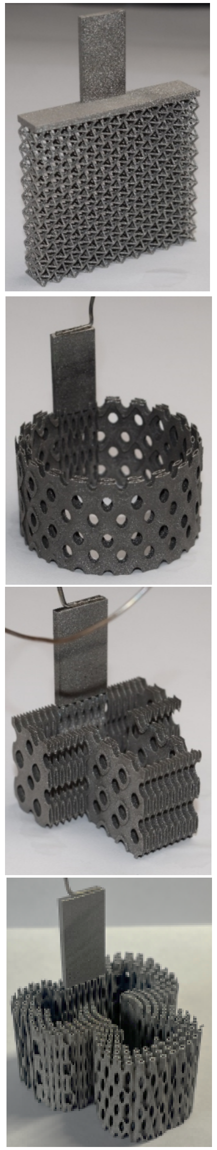
Mass Change

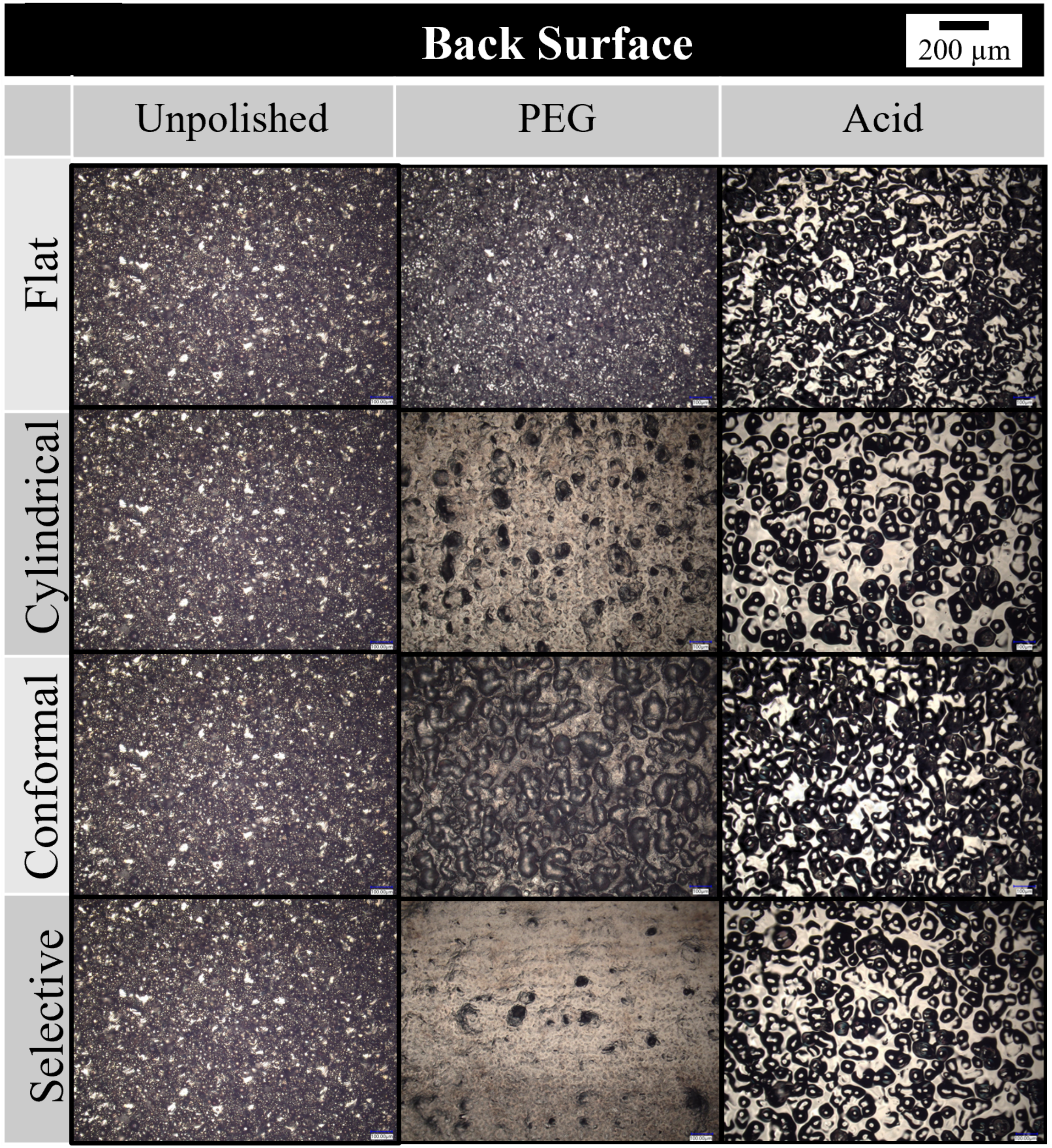
	PEG Electrolyte	Acid Electrolyte
Flat Cathode	- 0.643 g	- 1.021 g
Cylindrical Cathode	- 0.650 g	- 1.140 g
Conformal Cathode	- 0.514 g	- 0.929 g
Selective Cathode	- 0.634 g	- 1.047 g

(UUR)

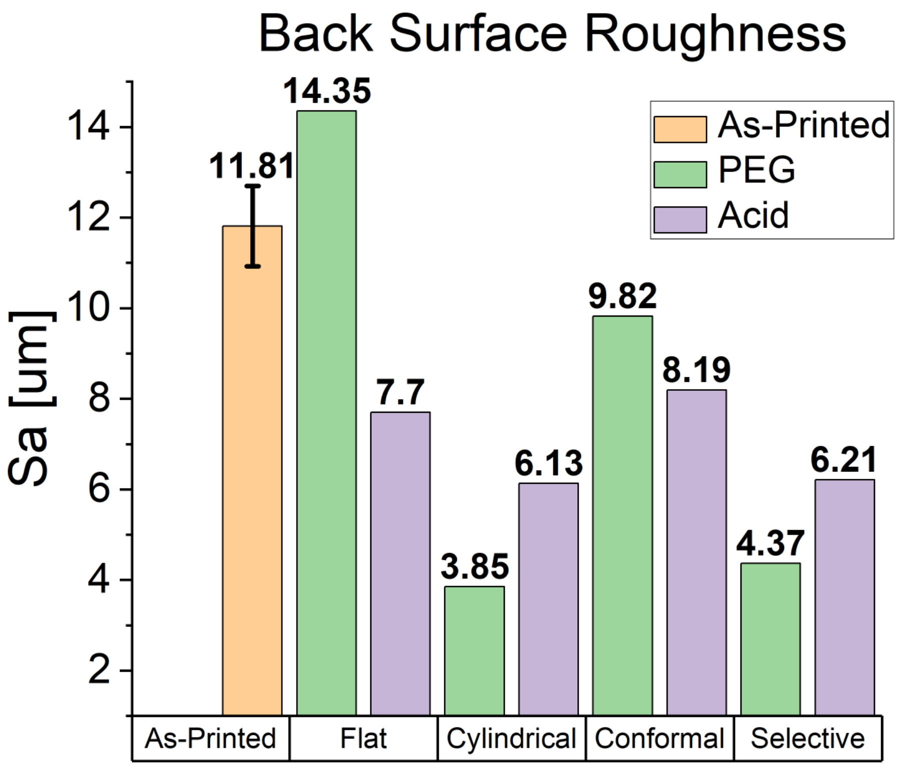
Back Face

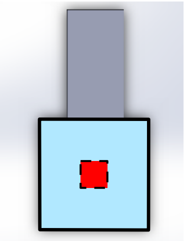





Back Surface
200 µm
Unpolished
PEG
Acid
Flat
Cylindrical
Conformal
Selective

Results Summary: Back Face





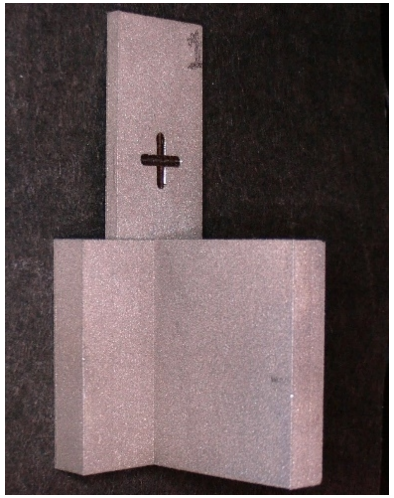
- Not removing entire original back surface in PEG electrolyte with flat cathode
- Roughness of back surface removed in both electrolytes with cylindrical and conformal cathodes
- Difficult to control back spacing for conformal cathode, could explain variations in the data
- Reflectance values increased for both electrolytes and increased more after polishing in acid, potentially due to more material removed (higher current density) compared to PEG

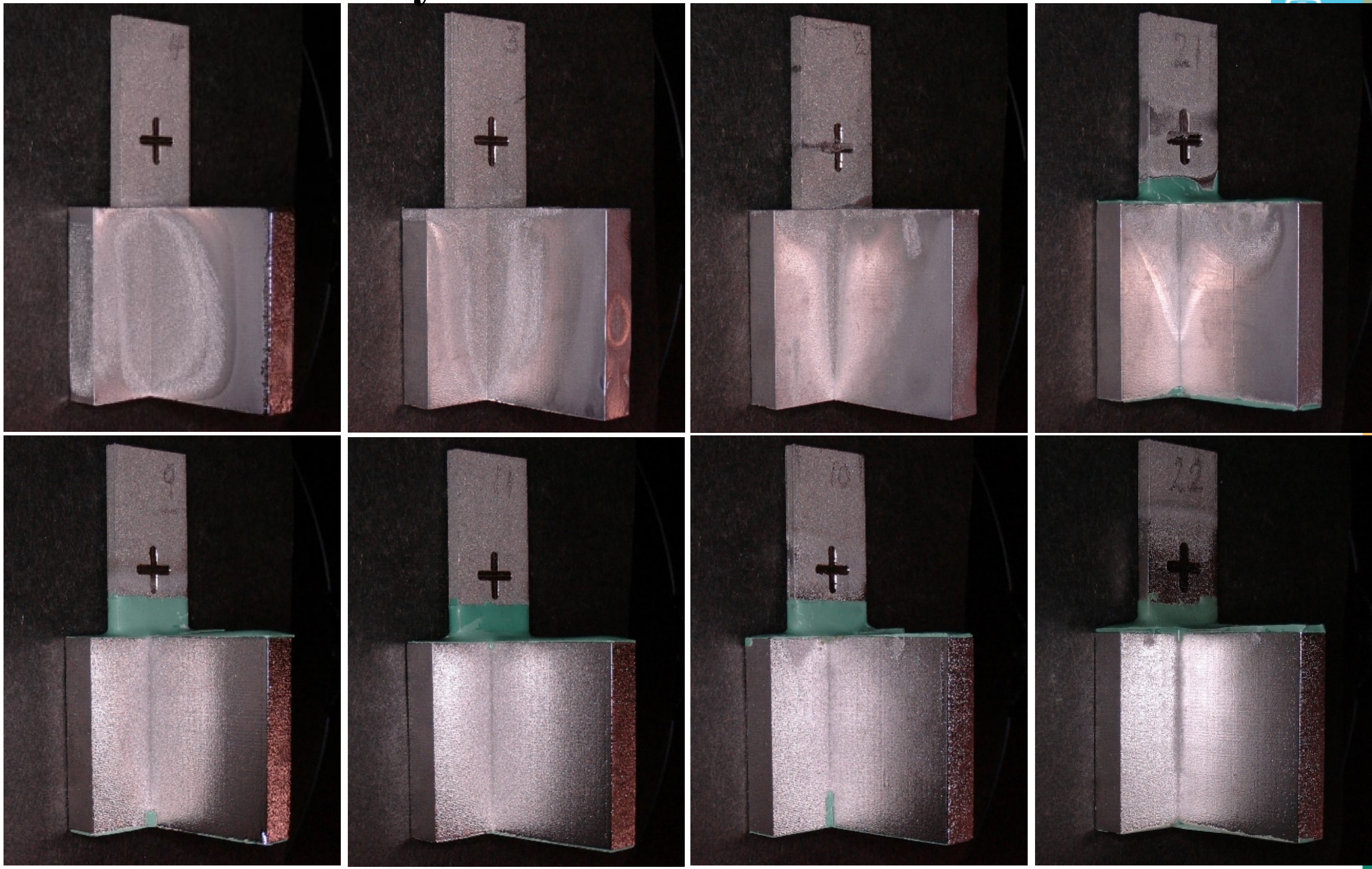
Reflectance Values

	PEG	Acid
Flat Cathode	+ 3.64 %	+ 32.49 %
Cylindrical Cathode	+ 16.95 %	+ 35.27 %
Conformal Cathode	+ 17.38 %	+ 33.74 %
Selective Cathode	+ 28.82 %	+ 31.46%

(UUR)

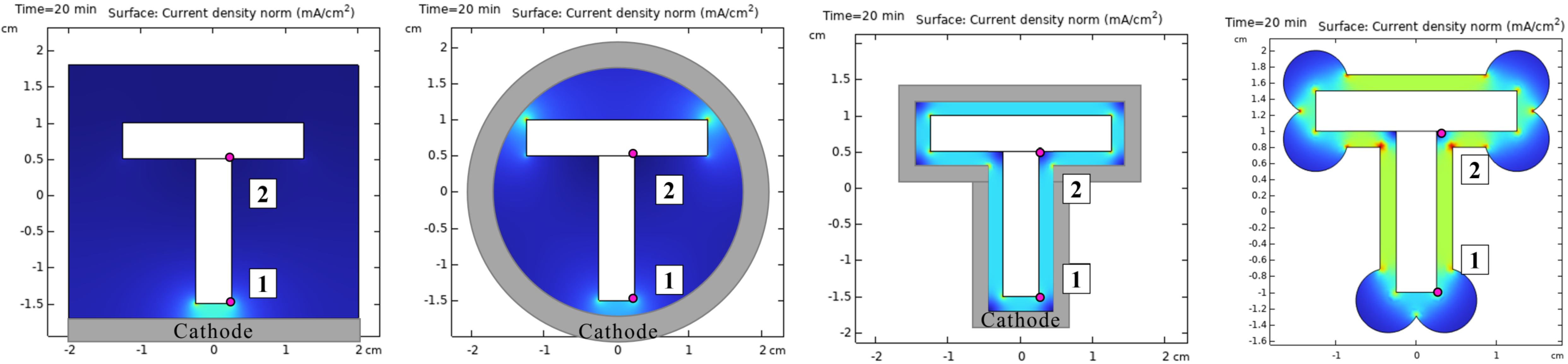
As-Printed





(UUR)

COMSOL Model: Current Density



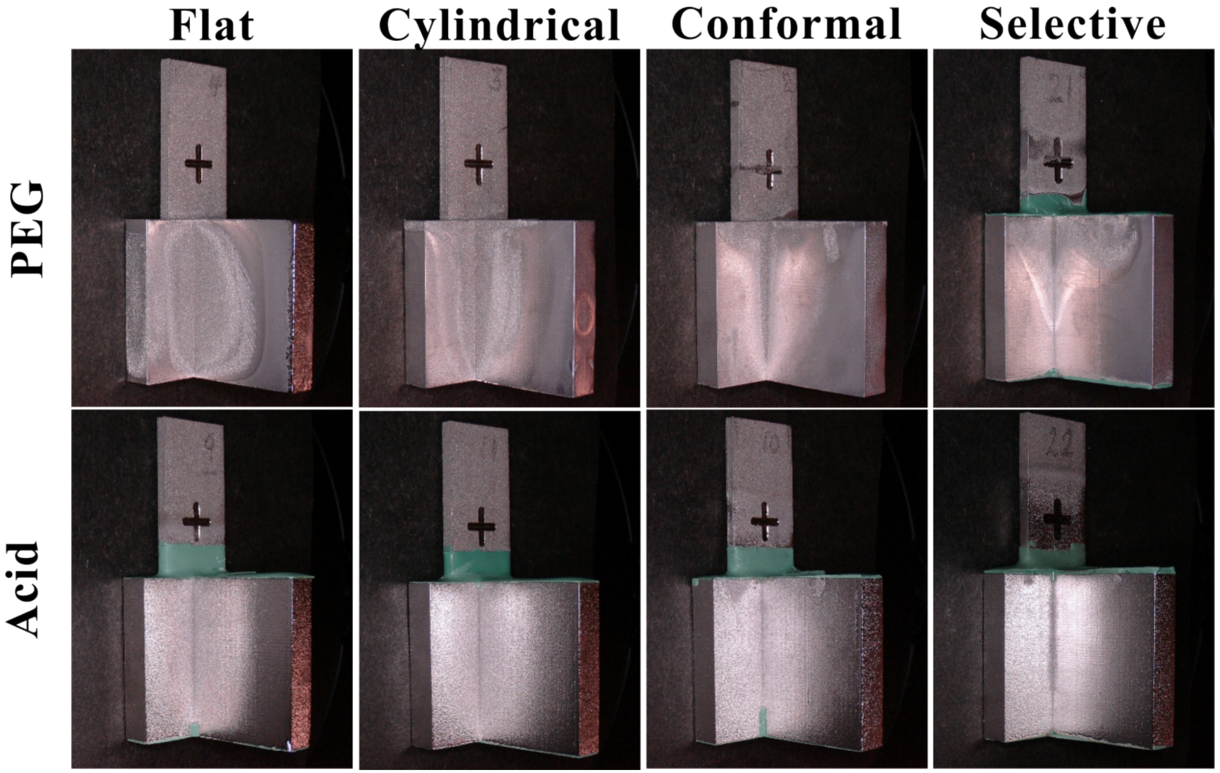
Current Density [mA/cm²]

	Flat	Cylindrical	Conformal	Selective
Point 1	492.7	511.3	333.4	293.2
Point 2	0.1	70.1	94.9	130.8

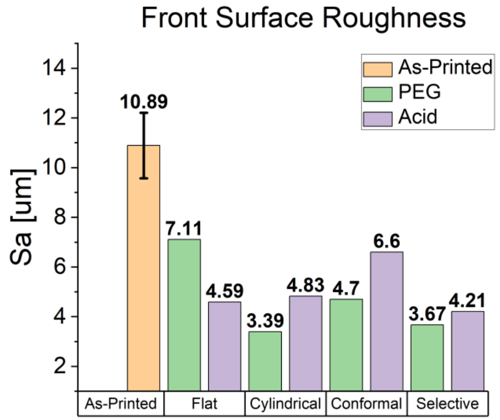
Conclusions

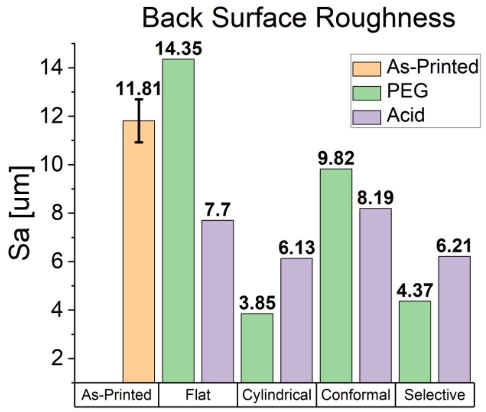
Electropolished T-shaped anodes with cathodes of increasing conformity and close electrode gap.

Compared between an environmentally-friendly PEG electrolyte and a traditional acid electrolyte.

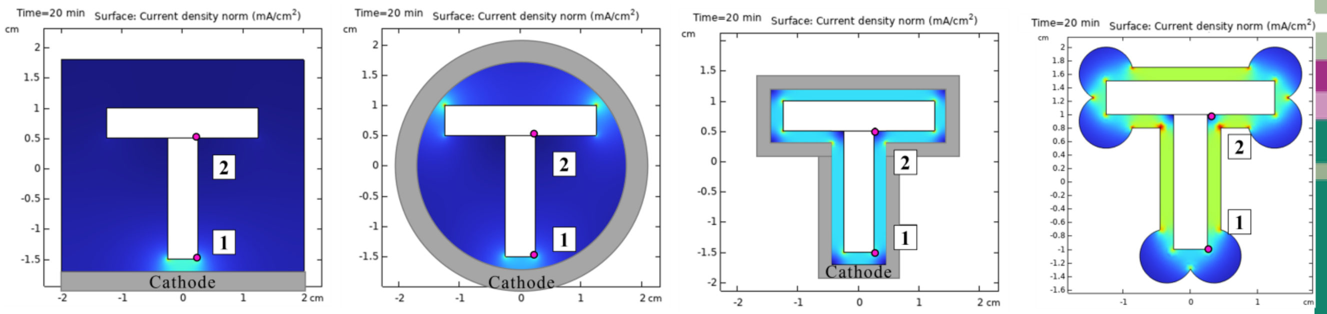


Removed roughness associated with original as-printed surfaces.





Utilized COMSOL to verify results obtained for different cathodes and guide cathode design which was subsequently tested. The future of this project looks at increased electrode spacings and 3D profilometry.



(UUR)

Thank You! Questions?

(UUR)

Sandia National Laboratories

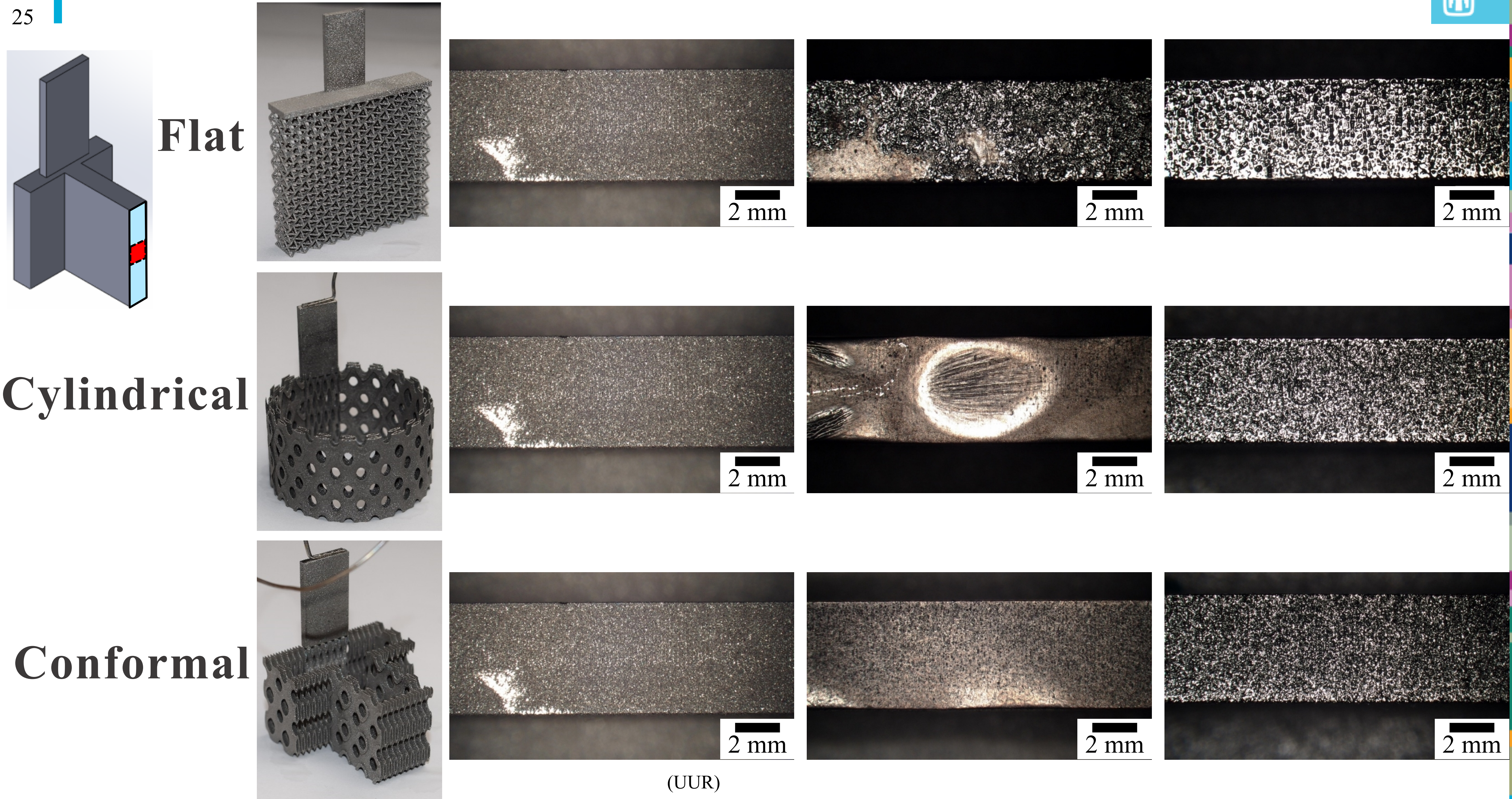
Thank You! Questions?

(UUR)

Additional Slides

Front Face

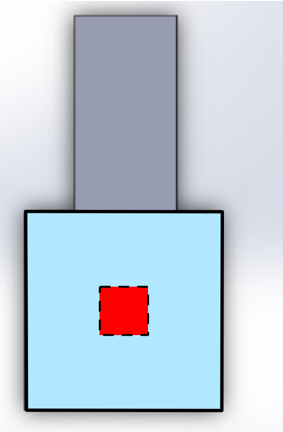
As-Printed | PEG | Acid



(UUR)

Back Face

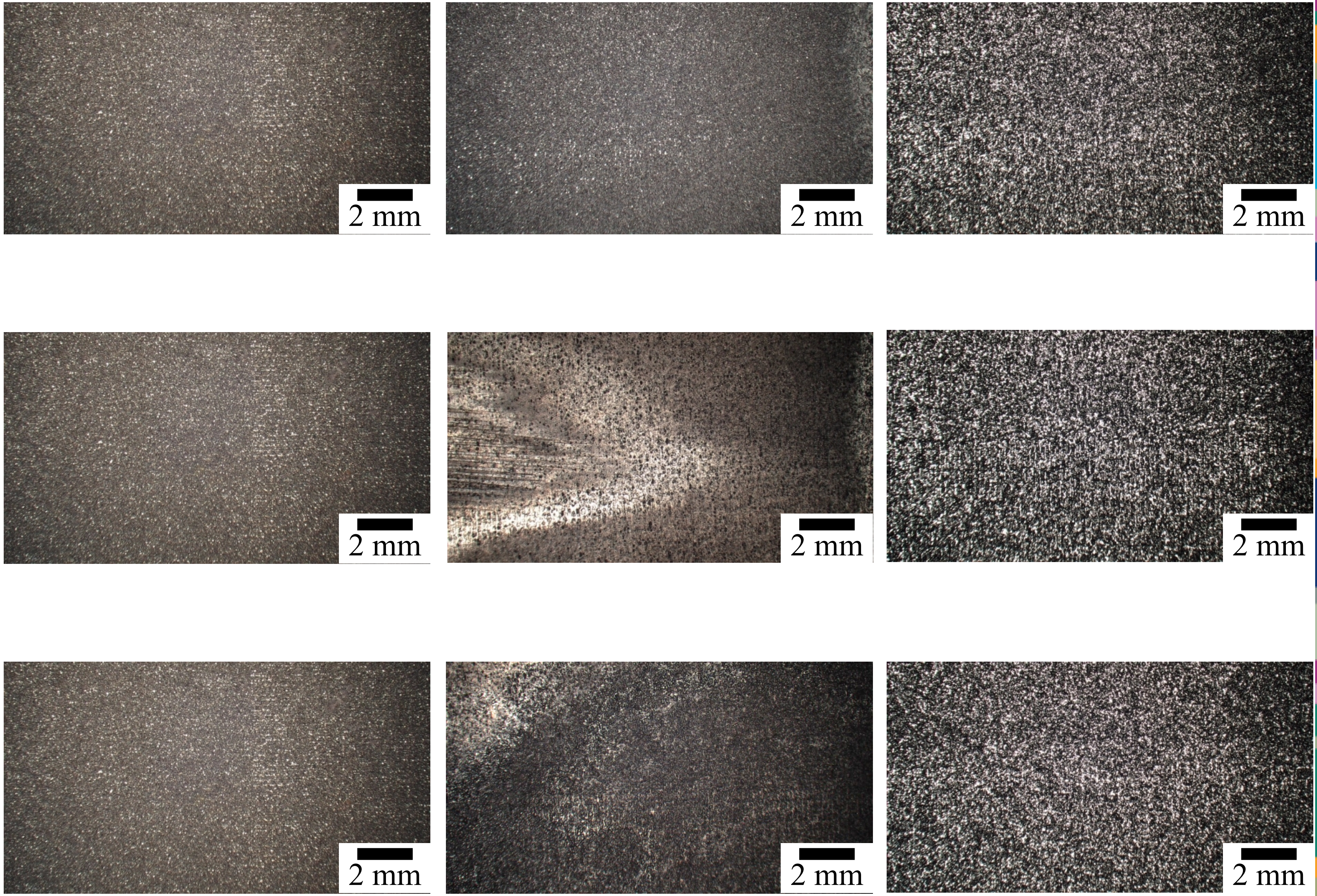
	As-Printed	PEG	Acid



Flat

Cylindrical

Conformal



(UUR)