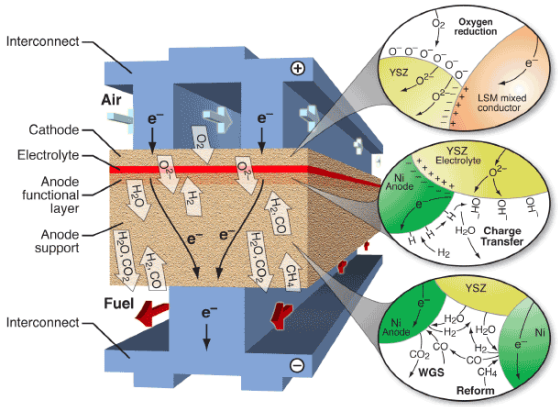
Laser 3D Printing of SOFCs

Project ID: FE069-p



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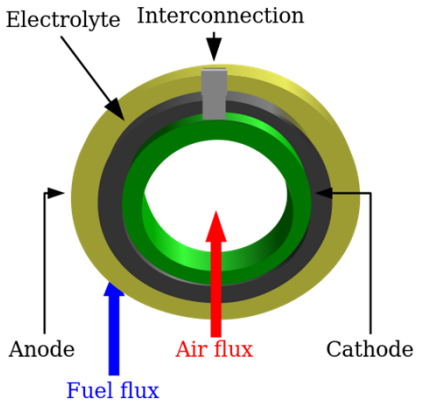

DOE 2018 Annual Review Meeting: June 13, 2018

Laser 3D Printing of SOFCs

DoE SBIR Phase II DE-SC0015199 (04/10/2017 - 04/09/2019)

14b. Additive Manufacturing for Solid Oxide Fuel Cell (SOFC) Components

Timeline and Budget

Direct 3D Femtosecond Laser Manufacturing of SOFC

- Project Start Date: 04/10/2017
- Project End Date: 04/09/2019
- Total Project Budget: $999K
  - Total DOE Funds Spent*: $426K as of 3/31/2018

Barriers

- Limited R&D on 3D printing of SOFC
- Challenge in multi-material AM
- Challenge in thickness control and interface quality

Partners

- Funded by DOE NETL
- Engaging with public companies for collaboration and potential investment, M&A.

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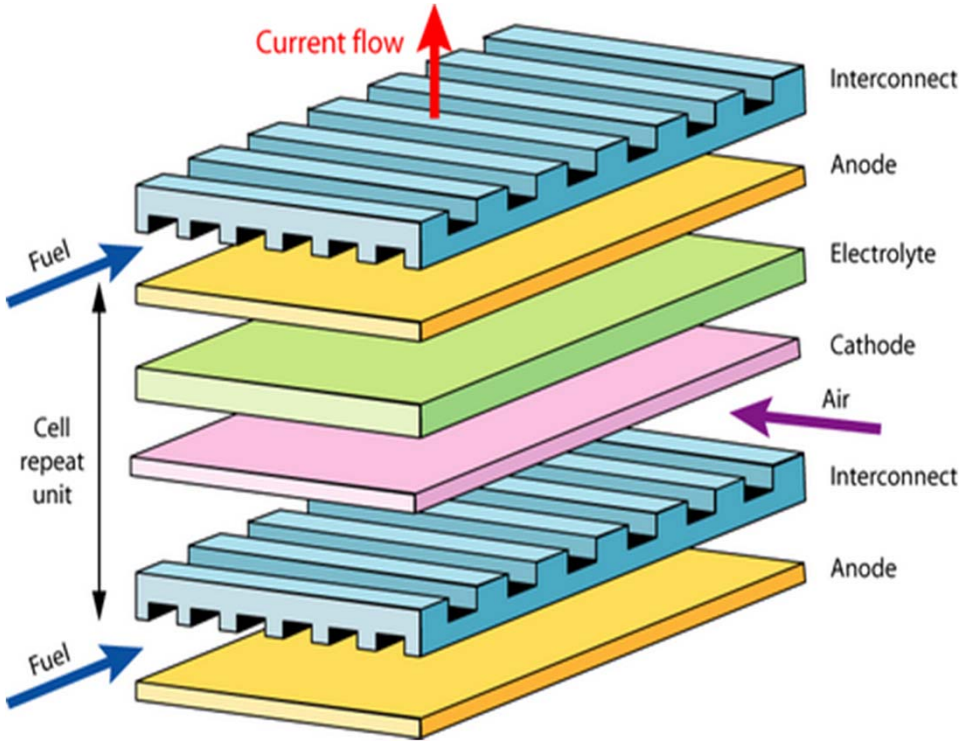
SOFC AM Phase II Objectives



Ni-YSZ

YSZ (8 mol% Y_2O_3)

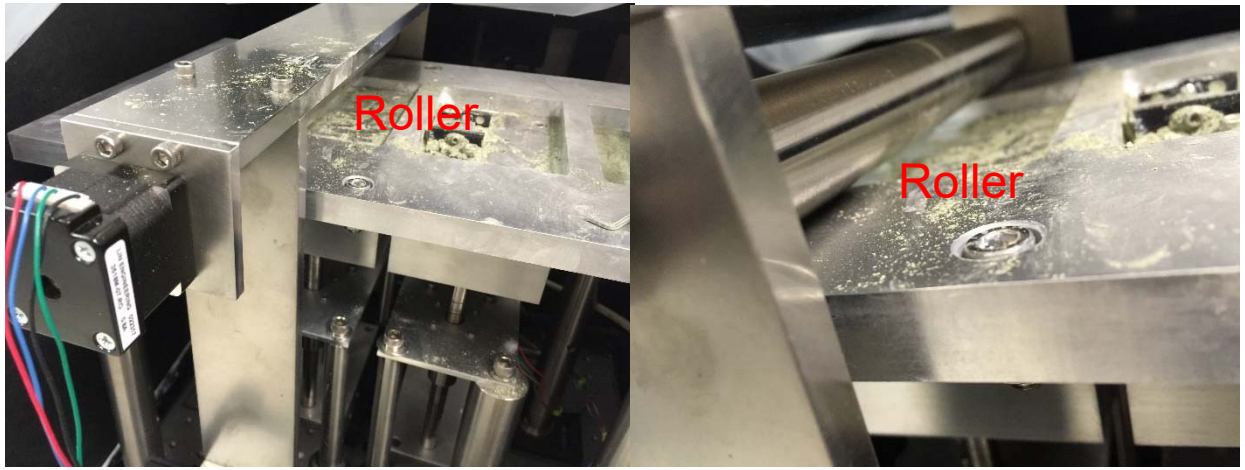
LSM: La0.8Sr0.2MnO3, (La0.8Sr0.2)0.98 MnO3, La0.85Sr0.15MnO3, (La0.85Sr0.15)0.98 MnO3, (LaxSr1-x)yMnO3

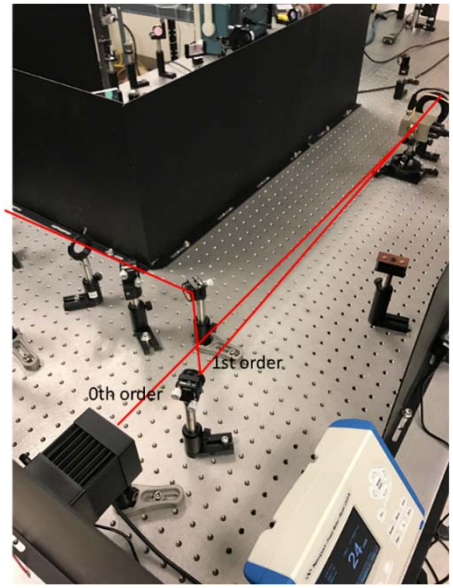
Component	Material	Thickness	Porosity
Anode	Ni/YSZ	0.3-0.6 mm	~ 40%
Electrolyte	YSZ	5-10 µm	< 5%
Cathode	Conducting ceramic	10-50 µm	~ 30%

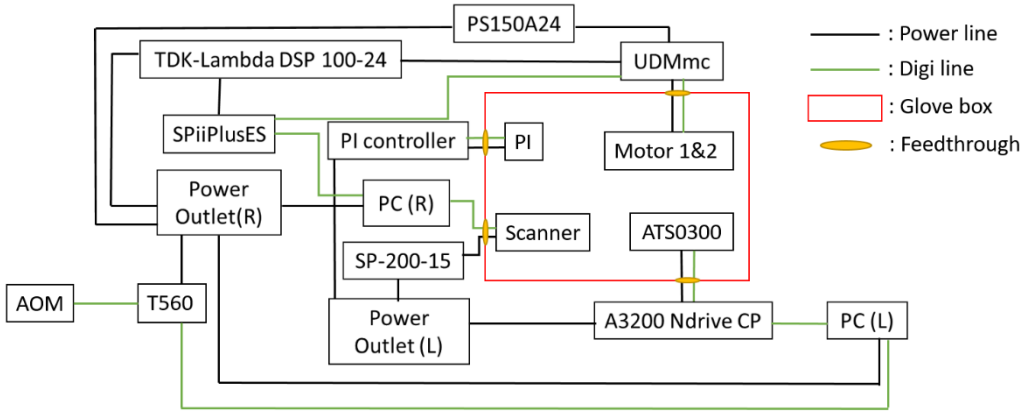
Key Objectives in Phase II:

- Multi-layer and multi-material additive manufacturing
- Subtractive manufacturing
- SOFC fabrication and test

fs Fiber Laser Based AM Setup







Electrical control schematic

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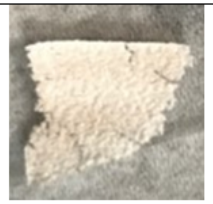
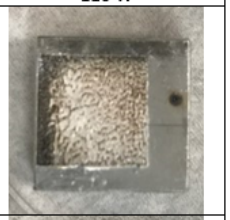
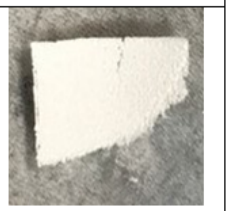
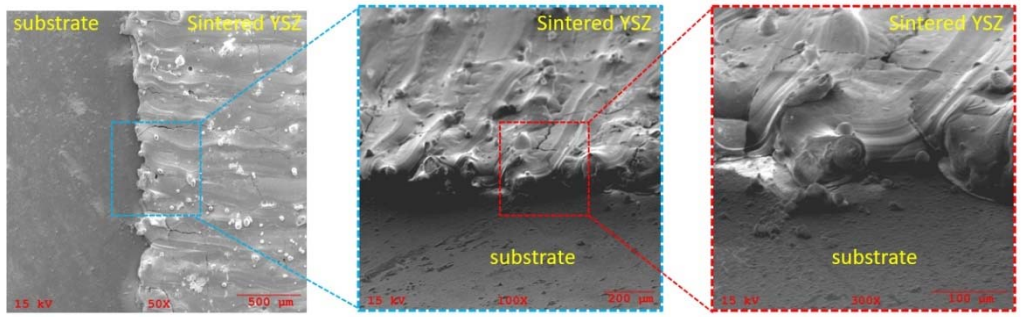
Phase II Major Milestones

Item	Delivery Month	Major milestones
1	3	Experiment setup of AM for Ni-YSZ anode
2	6	Experiment results & optimization of Ni-YSZ anode
3	9	Optimization of AM for YSZ-electrolyte
4	12	Optimization of Multi-layer anode and electrolyte
5	12	Make small fuel cell. Continuation application
6	15	Experiment results of SOFC fabrication, packaging, and thermal management. SM process optimization. Make small cells and do optimization
7	18	SOFC testing results and design scaling and optimization
8	21	Optimization of SOFC AM system and stabilizing the process
9	24	Prototype and marketing report
10	24	Publications
11	24	Final patent report on Phase II project
12	24	Wrap up all the deliverables

Multi-layer YSZ AM Process

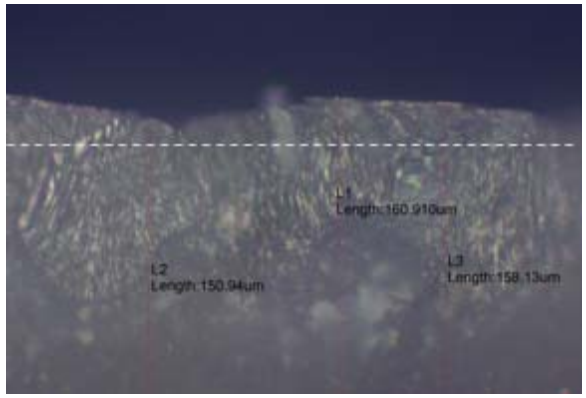
SCANNING SPEED - mm/S	Laser power: 60 W	Laser power: 90 W	Laser power: 110 W
150			
250			
400			
800			

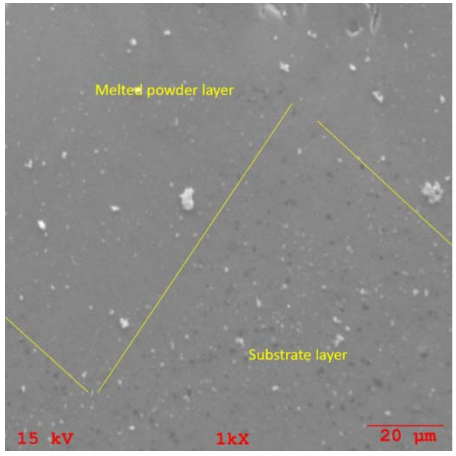


Two layers YSZ AM

After optimization

18 um thick YSZ on YSZ





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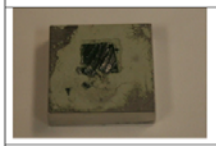
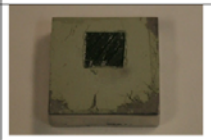
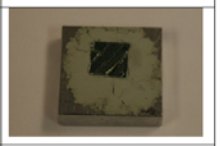
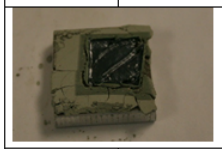
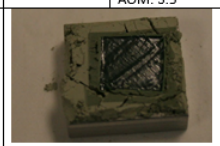
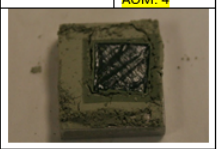
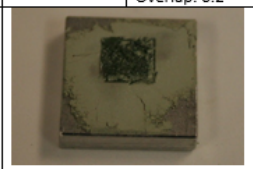
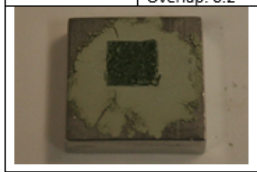
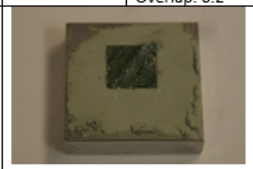
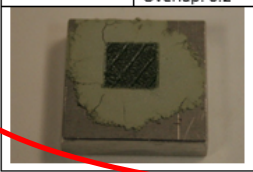
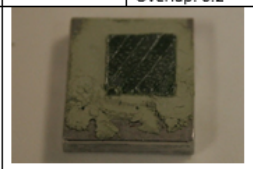
Multi-layer Ni-YSZ AM and Optimization

Powder: Ni-YSZ-TC (60% by weight NiO, 40% by weight (Y2O3)0.08(ZrO2)0.92)

Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 200mm/s Overlap: 0.5	Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 200mm/s Overlap: 0.3	Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 200mm/s Overlap: 0.2
		
1st Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.05 Speed: 200mm/s Overlap: 0.2	1st Layer Power: 200w 2nd Layer Power: 200w	Power: 200w Type: Stripe
		

1st Layer Power: 230w Type: Line Speed: 4000mm/s	2nd Layer Power: 230w Type: Stripe Tile Size: 2 Spacing: 0.03 Speed: 50mm/s Overlap: 0.5 Line: 45	1st Layer Power: 230w Type: Line Speed: 4000mm/s	2nd Layer Power: 230w Type: Stripe Tile Size: 2 Spacing: 0.03 Speed: 50mm/s Overlap: 0.5 AOM: 3.5	1st Layer Power: 230w Type: Line Speed: 4000mm/s	2nd Layer Power: 230w Type: Chess Tile Size: 2 Spacing: 0.03 Speed: 50mm/s Overlap: 0.5 AOM: 3
					
1st Layer Power: 230w Type: Line Speed: 4000mm/s	2nd Layer Power: 230w Type: Stripe Tile Size: 2 Spacing: 0.03 Speed: 60mm/s Overlap: 0.5 AOM: 3.5	1st Layer Power: 230w Type: Line Speed: 4000mm/s	2nd Layer Power: 230w Type: Stripe Tile Size: 2 Spacing: 0.03 Speed: 70mm/s Overlap: 0.5 AOM: 3.5	1st Layer Power: 230w Type: Line Speed: 4000mm/s	2nd Layer Power: 230w Type: Chess Tile Size: 2 Spacing: 0.03 Speed: 70mm/s Overlap: 0.5 AOM: 4
					

1st Layer Power: 200w Type: Line Speed: 2000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 200mm/s Overlap: 0.2	1st Layer Power: 200w Type: Line Speed: 2000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 300mm/s Overlap: 0.2	1st Layer Power: 200w Type: Line Speed: 2000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 400mm/s Overlap: 0.2
					
1st Layer Power: 200w Type: Line Speed: 2500mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 400mm/s Overlap: 0.2	1st Layer Power: 200w Type: Line Speed: 4000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 400mm/s Overlap: 0.2	1st Layer Power: 200w Type: Line Speed: 4000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 200mm/s Overlap: 0.2
					
1st Layer Power: 200w Type: Line Speed: 4000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 200mm/s Overlap: 0.2	1st Layer Power: 200w Type: Line Speed: 4000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1 Spacing: 0.03 Speed: 150mm/s Overlap: 0.2	1st Layer Power: 200w Type: Line Speed: 4000mm/s	2nd Layer Power: 200w Type: Stripe Tile Size: 1.3 Spacing: 0.03 Speed: 150mm/s Overlap: 0.2
					

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Optimized Ni-YSZ AM Process

1st Layer	2nd Layer
Power: 230w Type: Line Speed: 400mm/s	Power: 230w Type: Chess Tile Size: 2 Spacing: 0.03 Speed: 70mm/s Overlap: 0.5 AOM: 4

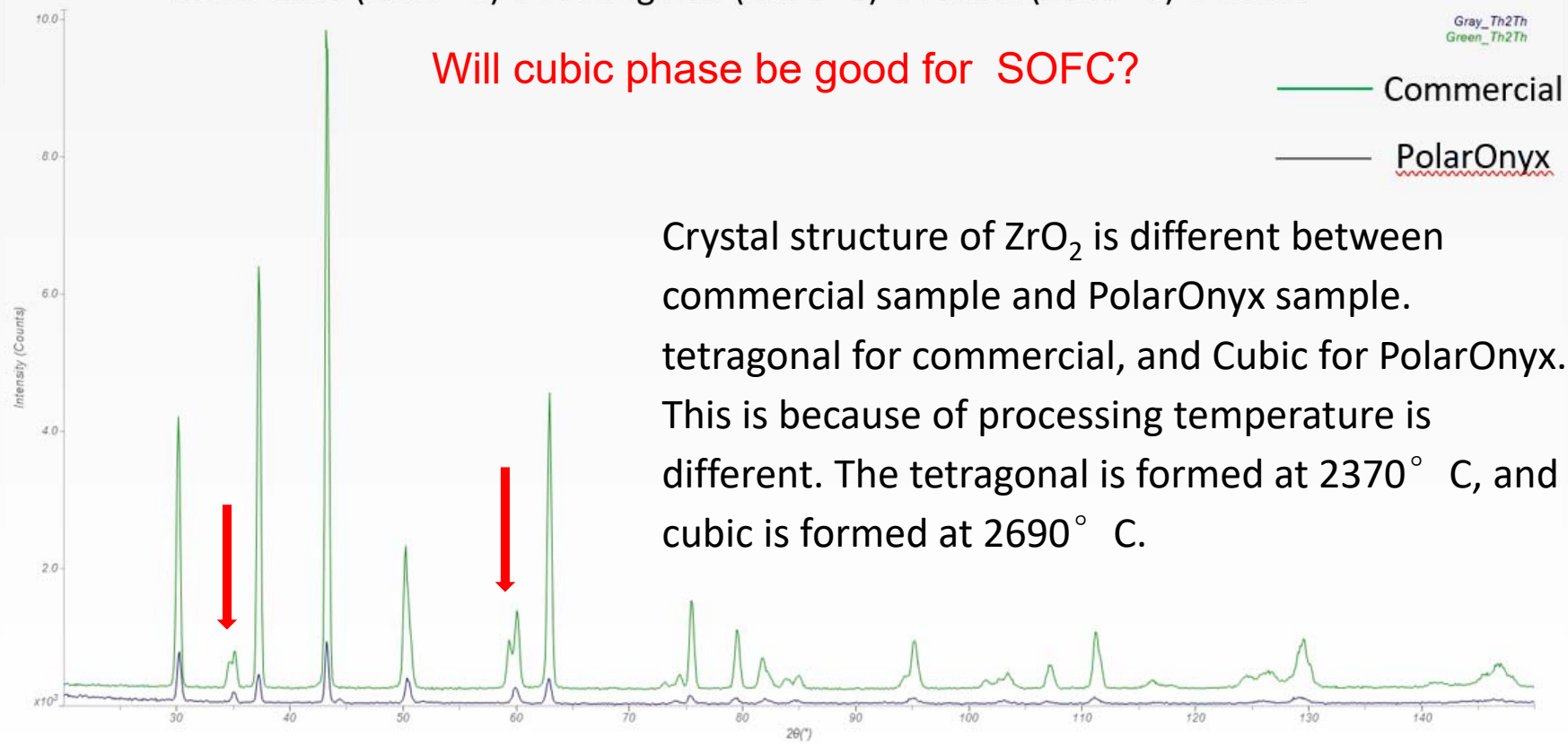
Uniform and smooth surface is made with good repeatability.

Ni-YSZ AM is very sensitive to process parameters (power, speed, hatch, scan pattern, powder, substrate, etc.). Only small process window works.

Ni-YSZ Anode Substrate

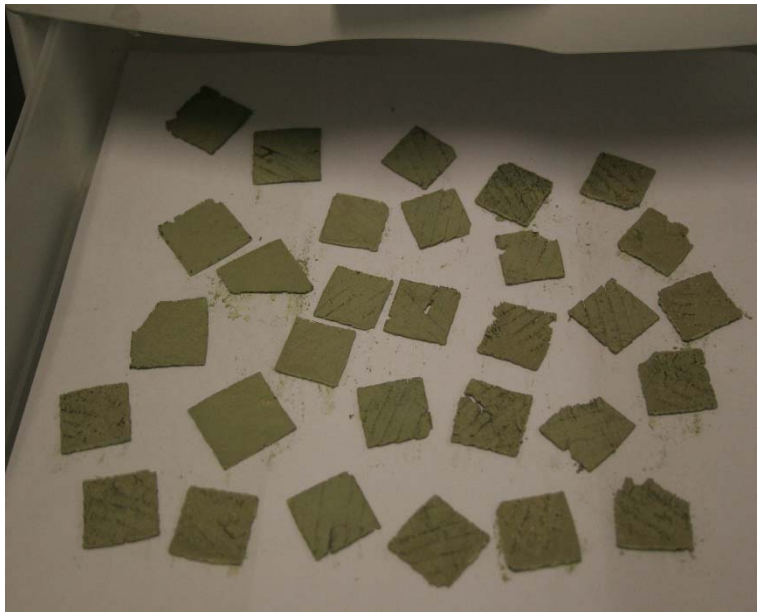
monoclinic (1173 °C) ↔tetragonal (2370 °C) ↔cubic (2690 °C) ↔melt

Will cubic phase be good for SOFC?

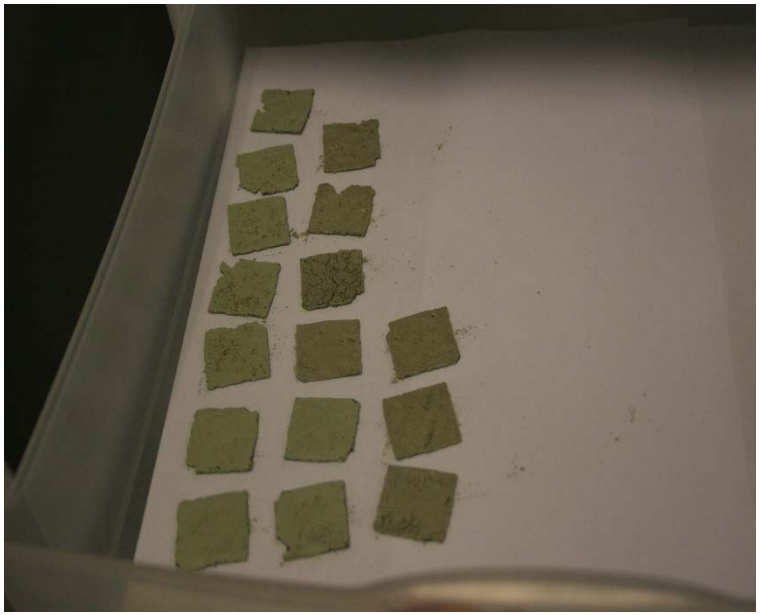


Crystal structure of ZrO_2 is different between commercial sample and PolarOnyx sample. tetragonal for commercial, and Cubic for PolarOnyx. This is because of processing temperature is different. The tetragonal is formed at 2370° C, and cubic is formed at 2690° C.

Ni-YSZ Anode Substrate

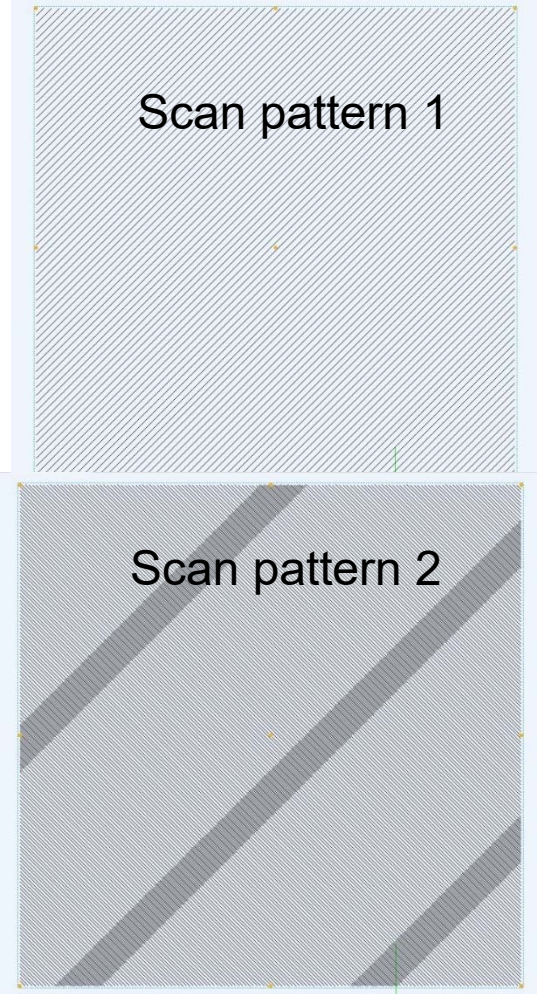


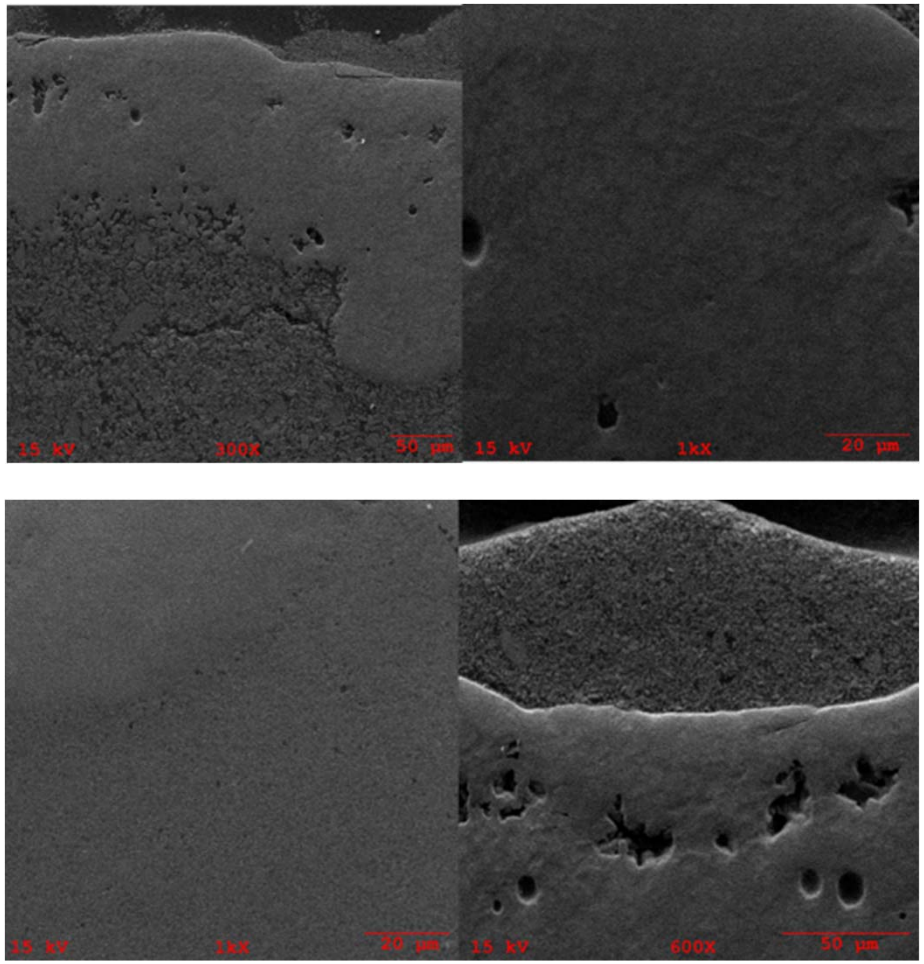
Substrate made



Selected for next step

YSZ on Ni-YSZ





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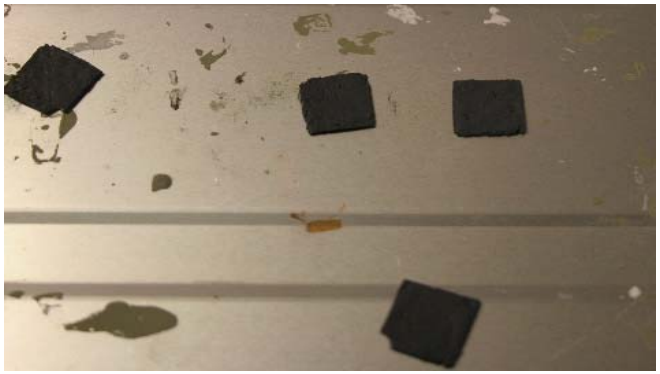
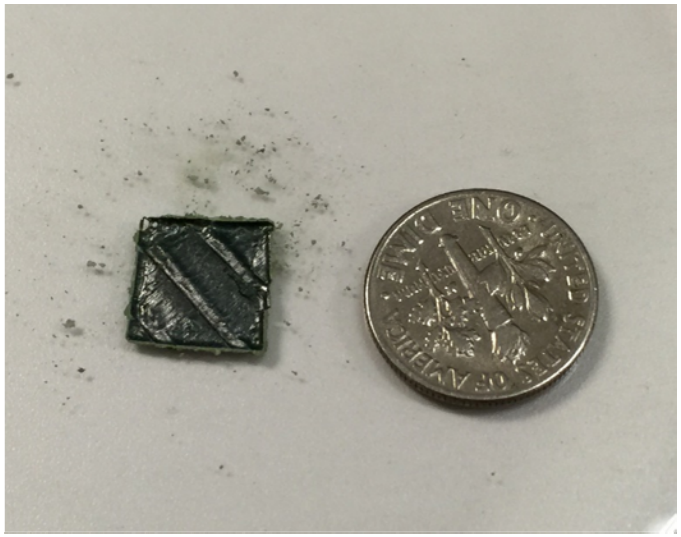
10x10 mm SOFC Samples





Succeeded in making a few complete cells with controlled thickness.

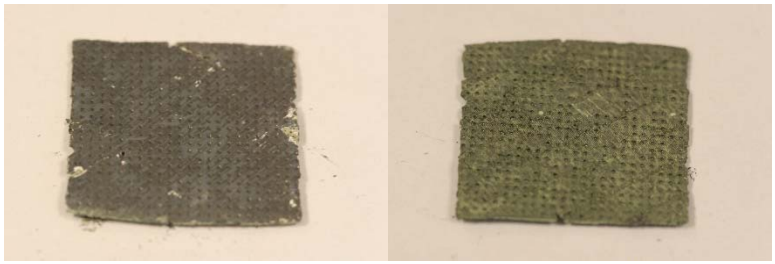
- Ni-YSZ Layer Thickness (After Remove Bottom Powder): ~ 280 µm
- YSZ Layer Thickness: 10µm – 25µm
- LSM Layer Thickness: 10µm -40µm

10 µm thick YSZ (electrolyte) can be processed on Ni-YSZ (Anode)

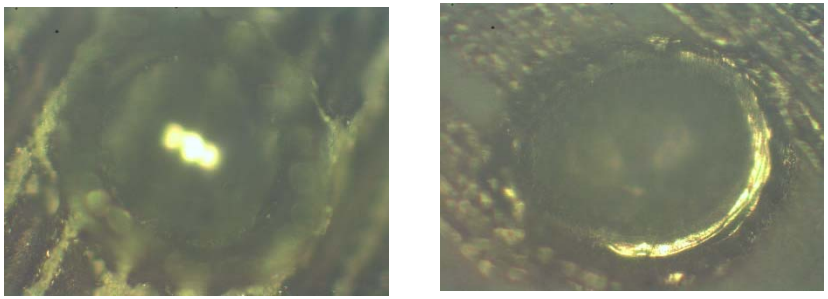
- Chess pattern works the best to mitigate residual stress induced by thermal gradience
- 12x12 mm area is achieved

SOFC for Testing

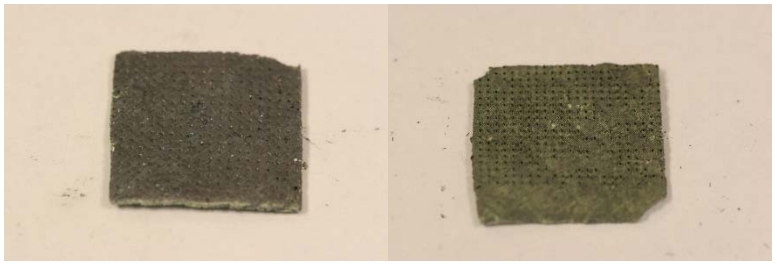
Sample 1



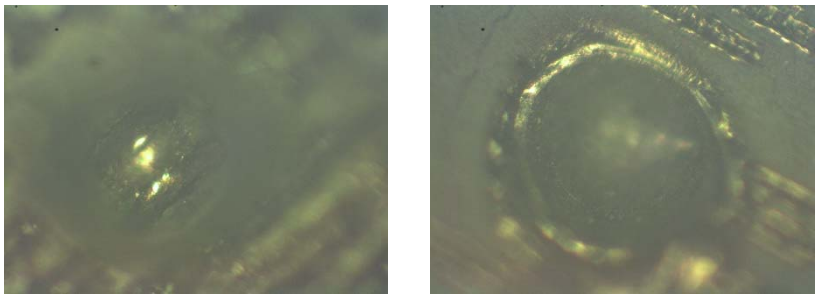
Anode Cathode



Sample 2



Anode Cathode



Subtractive Manufacturing (SM) is used to drill holes to enhance performance.

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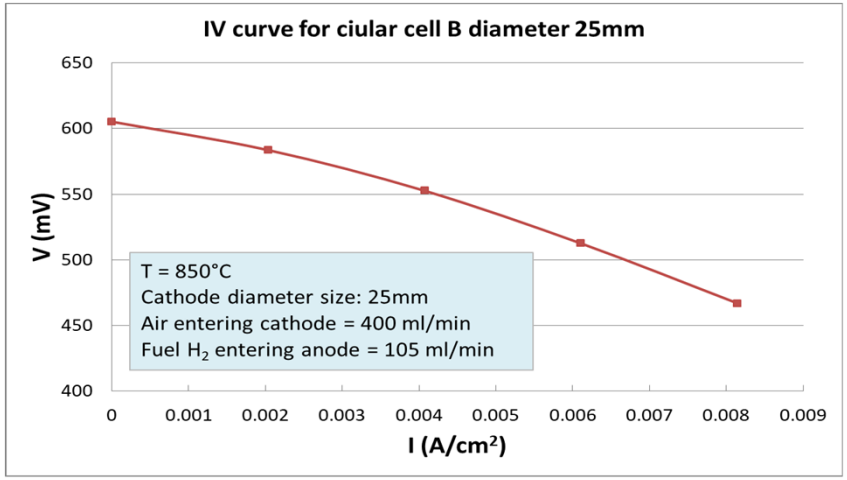
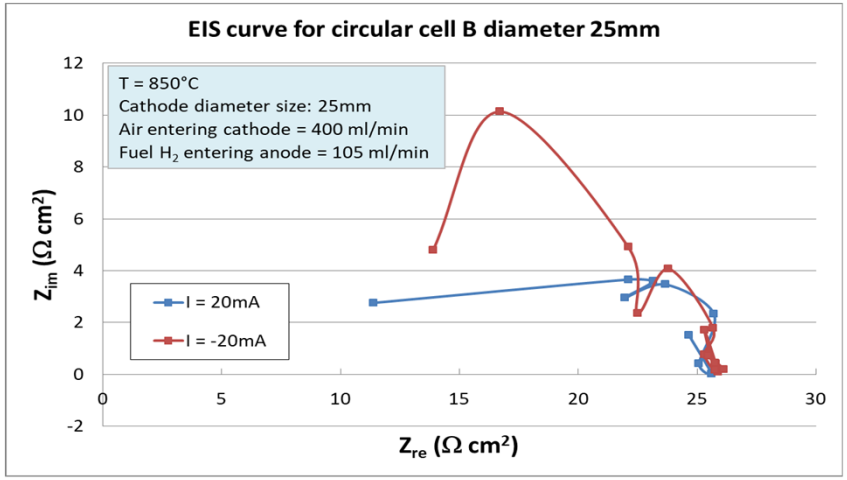
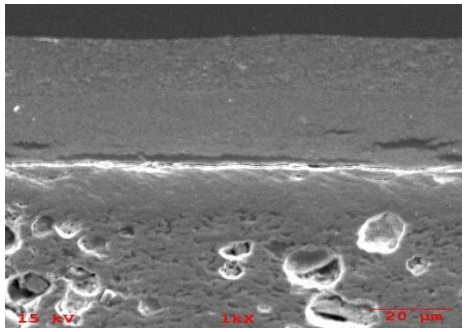
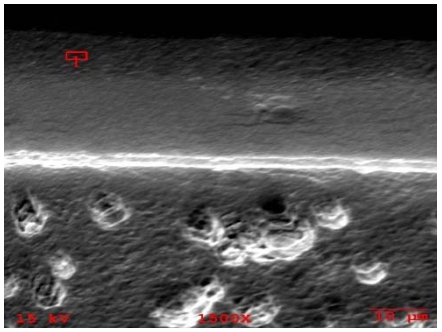
SOFC Test Results

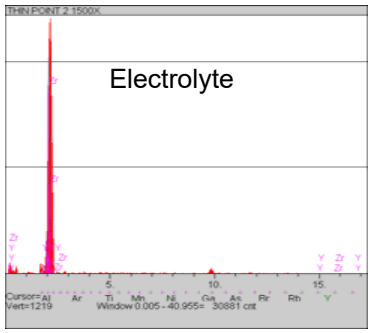
It is working and improvement is needed.

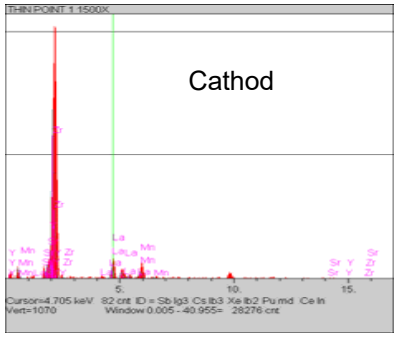












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Next Steps

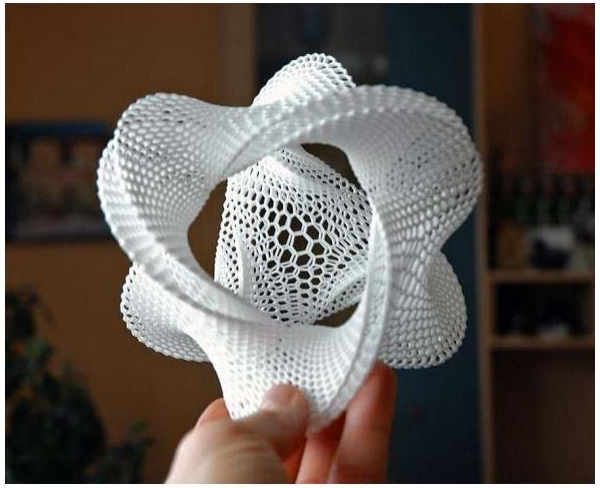
- Optimize process to get uniform thickness and interface control
- Optimize subtractive manufacturing (SM) to control porosity.
- Strengthen the Ni-YSZ anode substrate
- Scale the dimension

Priority: Performance improvement

Summary-Phase II Accomplishments

- Designed, developed, and assembled an AM system with fs fiber laser
- Developed YSZ AM with high repeatability and multi-layer process
- Developed Ni-YSZ as anode layer with 12x12 mm area and high repeatability and uniformity
- Developed triple-layer AM of YSZ (electrolyte), Ni-YSZ (Anode) and LSM (Cathode) with 10x10 mm area. World's first demonstration of a working SOFC using fs Laser AM.
- Modeled the AM process on thermal stress
- One publication

Thank You Very Much!



The future is in our hand!