Development of Roll-to-Roll Simultaneous Multilayer Deposition Methods for Solid-State Electrochemical Devices Using Highly Particulate Loaded Aqueous Inks

Contract Number DE-AC05-00OR22725
Saint-Gobain High Performance Material & Oak Ridge National Laboratory
Project Period: August 1, 2018 – July 31, 2020

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Overview

Project title

- Development of Simultaneous Multilayer Roll-to-Roll (SM-R2R) Deposition Methods for Solid-State Electrochemical Devices Using Highly Particulate Loaded Aqueous Inks

Timeline

- Project Start Date: 08/01/2018
- Budget Period End Date: 08/01/2019
- Project End Date: 08/01/2020

AMO MYPP Connection

- 3.1.8 Roll-to-Roll Processing
- 3.3.2 Advanced Manufacturing for Clean Electrical Power Generation

Barriers and Challenges addressed

- Continuous processing
- Scalability
- Materials compatibility
- Defects

Project Budget and Costs

Budget	DOE Share (incl. ORNL)	Cost Share	Total	Cost Share %
Overall Budget	$ 850,353	$ 212,591	$ 1,062,944	20%
Approved Budget (BP-1 & 2)	$ 850,353	$ 212,591	$ 1,062,944	20%
Costs as of 3/31/19	$ 234,936	$ 63,206	$ 298,143	20%

Project Team and Roles

Saint-Gobain

- Jeff Peet – PI
- J. Alex Lee – Project leader
- Brian Barry – Pilot line coating trials
- Nicole Love – Pilot line coating trials

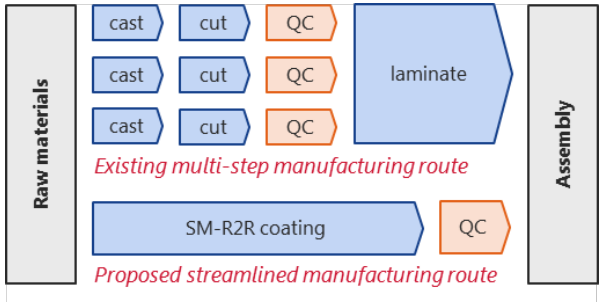
Oak Ridge National Labs (ORNL)

- Sujit Das – Technoeconomic Analysis
- Kanchan Upadhyay – Technoeconomic Analysis

Project Objectives

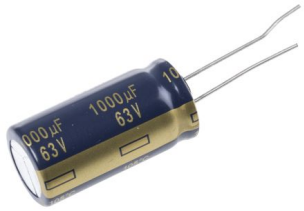
Project aims

- lower production cost,
- increase performance, and
- reduce lifecycle energy consumption for…



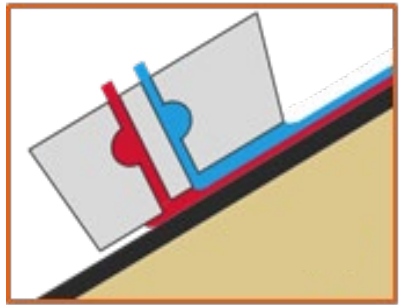
Devices commonly cast from highly particulate loaded aqueous inks

- Fuel cells
- Lithium-ion batteries
- Photovoltaics
- Capacitors



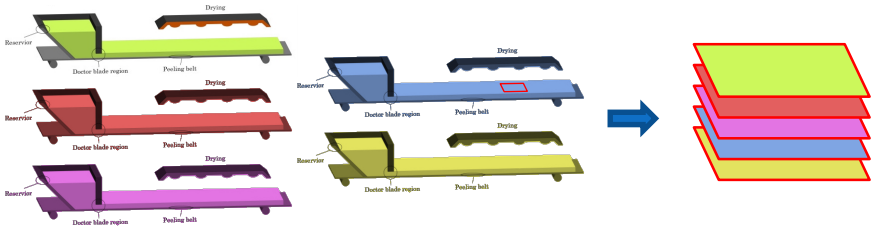
Technical objective

- Fabricate & characterize devices R2R cast with up to 6 layers simultaneously
- Evaluate potential benefit for various applications
- Develop cross-sector design rules for SM-R2R ink formulation

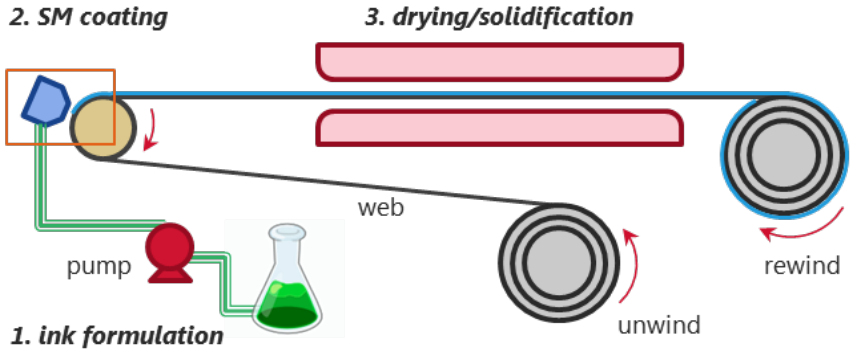


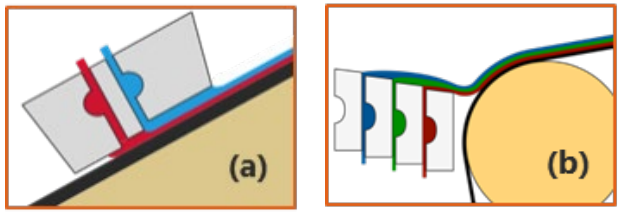
Technical Innovation

Current practice:
single layer tape casting (knife)



Next generation:
simultaneous multilayer coating





Physical basis for concept

- Wet-on-wet simultaneous coating has precedence in photographic film industry
- As long as ink media are co-miscible (low/no interfacial tension), fluid mechanics are similar to single layer coating
- Layer viscosity pairing determines coatability

Technical Innovation

What does SM-R2R coating enable?

- Thinner films than feasible by single layer coating methods
- Tuned interfacial properties may be enabled though process and formulation design

What are the new challenges?

- Ceramic slurries with large particles are challenging to process; industry experience with SM-R2R coating of slurries is limited
  - Fluids handling issues (pumping, settling, complex rheology)
- Challenges of drying of suspensions with many length-scales and controlling drying-induced defects (cracking, delamination, dewetting, etc.) scale with total thickness

Potential Impacts?

- Consolidation of multiple coating steps has the potential to reduce operating and capital costs proportional to the number of layers are being integrated (e.g., 1/6 of the cost for 6 layers)
- Applicable to multiple markets and applications

Technical Approach

Phase 1: 2 layer slot simultaneous coatings

- Use 2 layer slot coating to optimize film formation & drying
- Test each pair of the layer stack for compatibility
- Build devices from each pair to compare with tape casting
- Map out potential benefits & drawbacks (e.g. morphology, flexibility)
- Work with ORNL to build framework for techno-economic analysis

Phase 2: 3-6 layer simultaneous coatings

- Use multilayer slide coating to cast 3-6 layers simultaneously
- Fabricate & test functional devices and compare with the benchmark
- Complete techno-economic analysis comparing various applications

Advisory Board

- Board guides technical focus areas and how to structure TEA
- Evaluate and help refine technical approach – already evaluated favorably

David Wood, Oak Ridge National Labs
Balu Balachandran, Argonne National Labs
Mike Lanagan, Penn State University
Peter Schweizer, Schweizer Coating Consulting

Timeline & milestone table

#	Task	Lead	YEAR 1												YEAR 2											
			Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
			08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07
1	**Inks characterized & 2-layer SM-R2R coating**	**SG**																								
1.1	Literature review				M					M																
1.2	Inks characterized; 1-layer slot trials, spec'ed 2-layer die				M																					
1.3	Development of the first 2-layer coating							M	M																	
1.4	Coatability assessment of remaining layer pairs																									
1.5	Production and testing of the first 2-layer coating																									
1.6	Development of 6-layer slide die specifications										M	M														
2	**2-layer optimization and fuel cell integration**	**SG**																								
2.1	Production & testing of the remaining layer pairs													M												
2.2	Integration of the first 2-layer coating into fuel cells													M												
3	**Techno Economic Analysis framework for SM-R2R**	**ORNL**																								
3.1	Complete and document process modeling framework													M												
	Go/No-Go Decision Point (Phase 1)													G												
			Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
			08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07
4	**6-layer coating and electrochemical testing**	**SG**																								
4.1	SM 2-layer electrochemical testing of fuel cells																M									
4.2	Production and testing of 6-layer coatings																			M			M			
4.3	SM 6-layer electrochemical testing of fuel cells																								M	
5	**Techno-Economic Analysis applied to SM-R2R**	**ORNL**																								
5.1	Assessment and recommendations for various SSEDs																								M	
	End of the Project Goal																									
5	**Project management and reporting**	**SG**																								

current

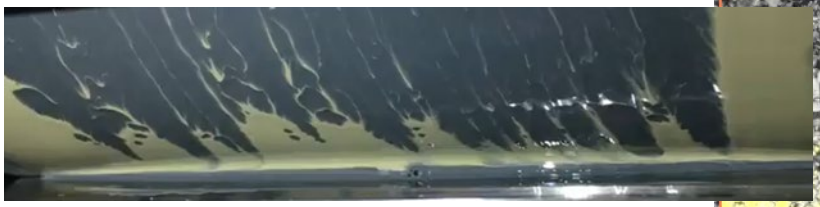
Results and accomplishments – technical

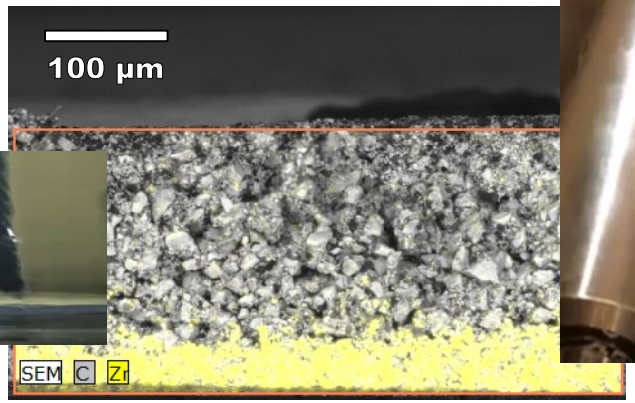
Single- and dual-layer slot coating verified as viable coating method

- Single-layer R2R slot coated films integrated into devices
- Dual-layer R2R slot coated ceramic films demonstrated with target layer thicknesses and distinct inter-layer (copy milestone)

Remaining work to project-end

- Optimize dual-layer slot coating for all device layer pairs and demonstrate device performance meeting or exceeding baseline
- Initiate multilayer slide coating process trials
- Produce defect-free simultaneously coated multilayer (up to 6 layer) film
- Demonstrate device performance meeting/exceeding baseline using SM-R2R coated film

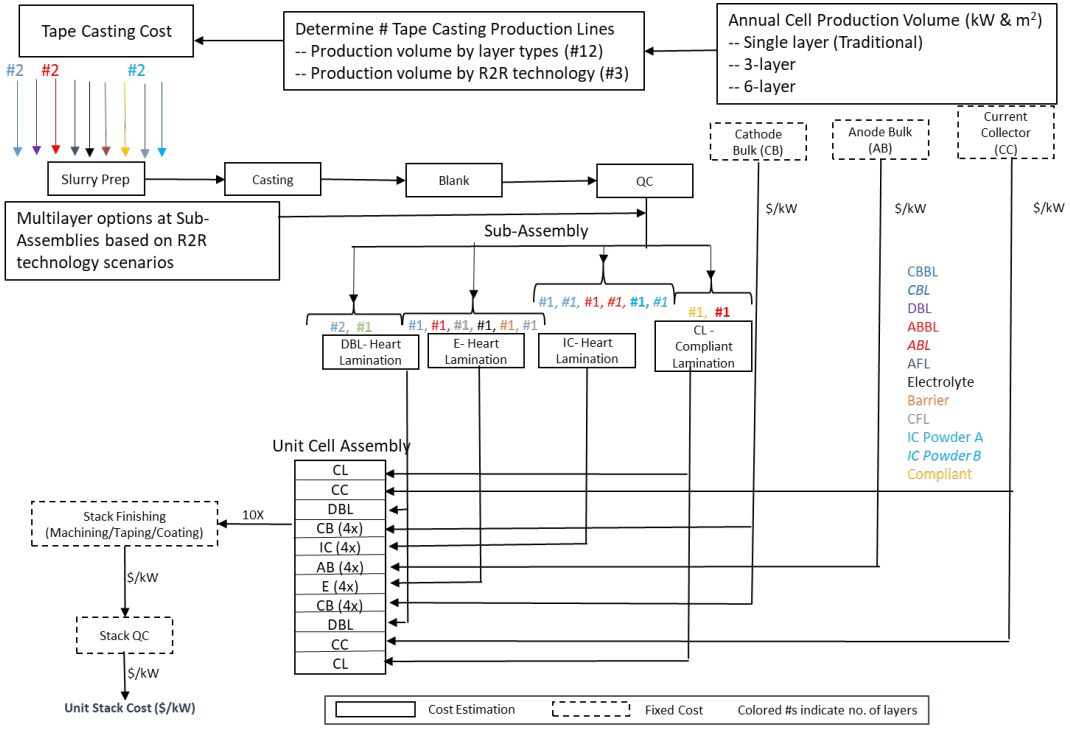




Techno-Economic Analysis

Develop a system level tape casting cost modeling framework to determine the competitiveness of multilayer R2R manufacturing technology for solid state energy applications

- Estimate system level cost impacts with a focus on cost modeling of major process steps of tape casting and the resulting impacts on sub-assemblies
- Technical and economic parameters considered by process step: cycle time, yield, material cost, capital
- Cost estimated by process step at the major categories, i.e., materials, capital, energy, and labor (including sensitivity analysis of key parameters and impacts of economies of scale)
- Identify major cost drivers (e.g., yield, capital, labor, and energy) by process step of the Multilayer R2R technology economic competitiveness



Transition (beyond DOE assistance)

Commercialization by Saint-Gobain

- Markets where Saint Gobain has programs or participates

Commercialization by Saint-Gobain partners

- Markets where Saint-Gobain is a raw material provider

Other markets

- Other markets identified in techno-economic analysis
- Other markets identified by advisory board
  - Multilayer capacitors
  - Solid state batteries
- Commercialization & tech transfer strategy will vary