Advanced Manufacturing and Prototyping for Understanding of the Processing-Structure-Property Relationship

DuraMAT
Durable Module Materials Consortium

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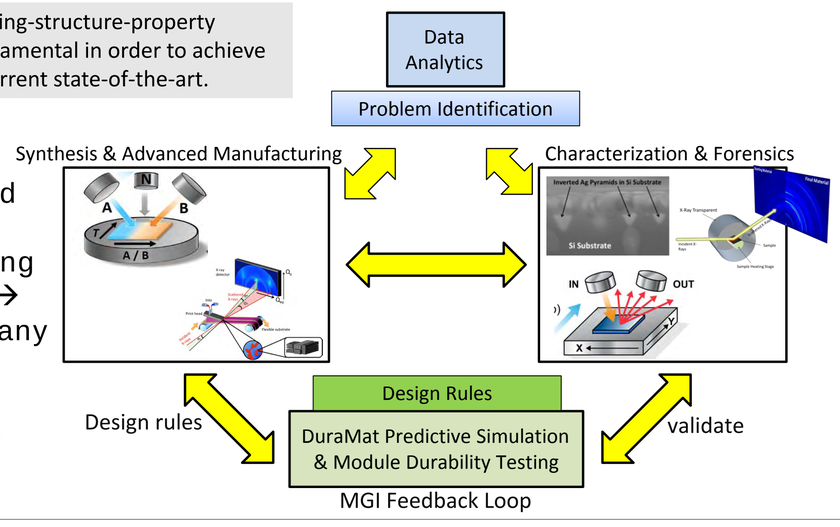
Abstract: In this work, we will combine efforts in printing from SLAC, Sandia, and NREL to develop a greater understanding of the processing-structure-property relationship in both existing module materials as well as new materials. SLAC has previously demonstrated in-situ x-ray scattering capability combined with roll-to-roll solution printing processing for thin film materials. For DuraMat this platform will be expanded to module packaging components, such as, but not limited to, backsheets, encapsulants, and sealants. The material's structural evolution during film formation and solution drying can be monitored in real time. This versatile platform at SLAC could incorporate either flexible (plastic or glass substrate) or rigid flat substrates (for enhanced signal-noise ratio). Sandia and NREL have also both been leaders in developing coating and printing processes for PV development and will partner in this effort. Work at Sandia's AML laboratory also focuses on developing new materials for printing and coating processes, and accelerates process development with high-fidelity process simulations. Additionally, NREL has excelled in developing in-line metrology for greater understanding of printing processes. Together this team will provide DuraMat and the PV industry with a platform for rapidly prototyping new processing methods as well as rapid validation of new printable materials.

Aiding the DuraMat Mission

Being able to understand the processing-structure-property relationship for new materials is fundamental in order to achieve the property that outperforms the current state-of-the-art.

- Provide a route to rapid development of new materials and processing
- Tool set development → widely applicable to many materials systems and processing routes
  - *Not just a single lab capability!*



MGI Approach

- Data Analytics
  - Problem Identification
- Predictive Simulation
  - Design Rules
  - Down selection of new materials
- Materials Discovery & Forensics
  - Combinatorial and high throughput synthesis
  - Testing and validation

Team Capabilities (Examples & DuraMat Upgrades)

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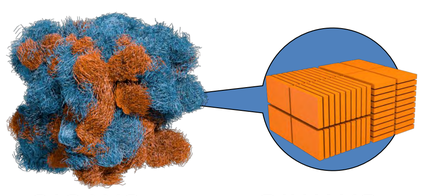
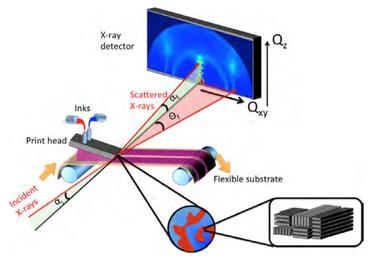
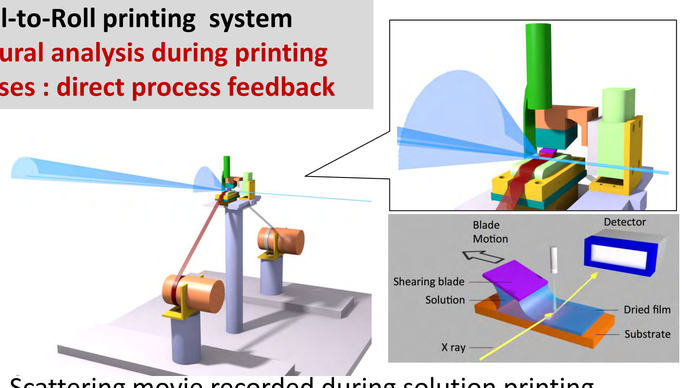


GISAXS: Phase segregation

GIWAXS: Molecular packing



In-situ
Roll-to-Roll printing system
Structural analysis during printing processes : direct process feedback



Scattering movie recorded during solution printing

DuraMat planned upgrades:
- In-line metrology (Raman, PL, etc)
- Heating, glass substrates, modified depositions

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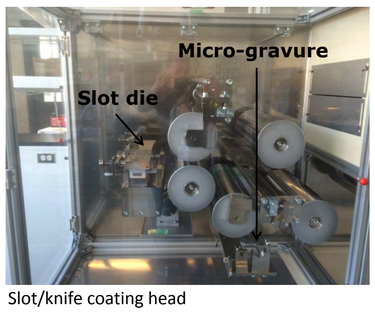
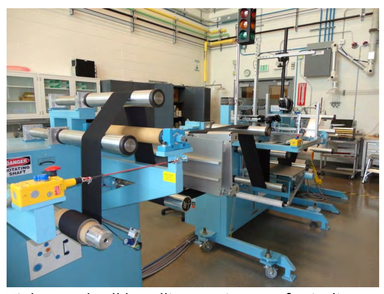
Current Capabilities ***Rapid Prototyping and Process Development***

- **Small-scale ink processing/Characterization**
  - Mixing, viscosity, rheometry
- **Small-scale coating**
  - Spin, knife, rod
- **Spray coating**
  - Ultrasonic, aerosol jet, ink jet, electro-spin/spray
- **Scalable coating**
  - Slot die, microgravure: sheet coater & R2R coater
  - ALD: sheet coater, setting up R2R coater
- **In-line inspection development**
  - Real-time optical, infrared imaging
  - Industrial web-line for validation
- **Extensive ex situ characterization**



- Slot/knife coating head
- Micro-gravure coating head
- 300 mm coating width
- 2 ovens with 4 independently controllable drying sections
- Speed up to 20 m/min

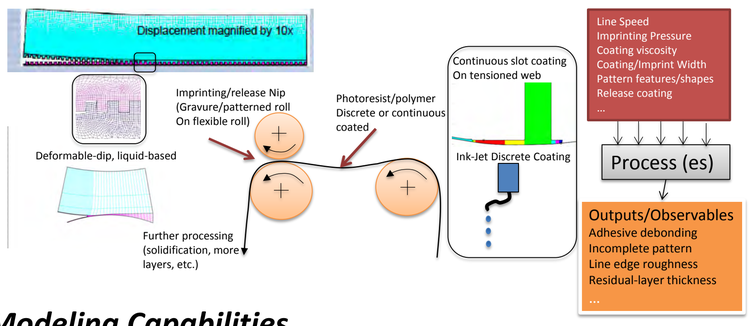


High speed roll handling equipment for in-line inspection & metrology development as well as potential for expansion for processing

- Web width: 6-18”
- Line Speed: 1-100 ft/min
- Line Tension: 0.5 to 5 lbs per linear inch

Sandia National Laboratories

Multiscale Simulators for Roll-to-Roll Continuous Processing



Modeling Capabilities

- Advanced software & high-fidelity models of precision thin-liquid film coating
  - e.g. slot-die, curtain, slide, roll, and gravure coating
  - Industry input (3M, Corning, P&G, Avery Dennison) for the purposes of process design and scale-up.
- Models include the ability to predict:
  - process operability
  - The effects of non-ideal fluid flow rheology
  - coupled structural mechanics, and more

Please see additional posters for more information on Sandia's Printing Capabilities

- DuraMat planned upgrades:
  - Models will be adapted for the design and scale-up of processes

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New Multifunctional Coatings

- **design** and **develop** a multifunctional coating material
  - anti-soiling
  - anti-reflection
  - self-cleaning properties
- Key design criterion: **manufacturability**.
- Predictive Simulation, Module Durability Testing, Materials Discovery, Field Deployment DuraMat capabilities.

Predictive Simulation
- Design rules:
  - manufacturing process design
  - materials design.
- new material formulations, patterned models for anti-soiling and self-cleaning, and optical models for light management

Materials Discovery and Forensics
Combinatorial synthesis methods
Rapid Testing with matrixed cells
In-situ microstructural analysis

Promising Candidate Materials
Tested by Field Deployment Capability

Summary and Outlook

Together this team will provide DuraMat and the PV industry with a platform for rapidly prototyping new processing methods as well as rapid validation of new printable materials.

(1 year) Within the first year the team will work together to define a process challenge with the guidance of industry. The team with modify and update any current capabilities to meet these challenges.

(5 year) This capability team will provide rapid validation, testing, and prototyping of new processing protocols and new functional materials.