U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE – DoD Multi-topic
Ft worth, TX workshop
R2R Breakout Session
October 8, 2014

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www.manufacturing.energy.gov

OUTLINE

Institute elements

Challenges and Rational

Deposition/Printing Technologies

Equipment and Process Control (Integration)

Substrate Materials

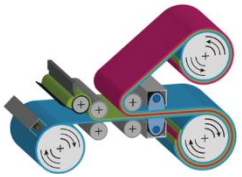
Applications Technology Application Areas

(Electronics, Buildings, Membranes, Energy Specific)

Metrology

Development Path/Expectation

Summary



High Value Roll-to-Roll Processing (R2R)

Printed RFIDs

Possible Institute Elements

- Establishments of the 2-D R2R platform as a foundational manufacturing technology for energy applications
- Embedded electronics to enable “smart” applications
- Enabling High-rate, industrial-scale manufacturing platforms for continuous large-area roll-to-roll processing.
- Equipment for small-scale (e.g., microelectronics) to medium-scale (windows and window films) to large-scale (membranes for biofuel and natural gas processing) applications
- Development of detailed “Roadmaps” introducing initial technologies at TRL/MRL 3 - 4 with production demonstrations in 2-3 years and enabling select sustaining products from Industry at 5 – 7 years.

High Value Roll-to-Roll Processing (R2R)

Challenges/Needs/Metrics

- Meters-per-minute rates on plastic film, paper, fabric or foil achieving feature dimensions as small as ten nanometers encompassing billions of identical devices. (100k mm^2/min.)
- Develop paths for the electronic manufacturing service to move from plate-to-plate standard lithography to continuous R2R processing or blend of the technologies.
- Large format "smart" process equipment including "feed-back" process control, metrology, quality control/assurance, and embedded sensing
- Cost/Area vs.Throughput (25%/5 years)
- Materials cost for substrates? (5%/year)
- Size Scale (Kerfless, mm to Sub-micron to nano)

Why Us, Why Now?

- High risks and costs for R2R technologies preclude investment by a single company, but can be addressed effectively using a public-private partnership
- An Institute will accelerate technology development to higher TRL/MRL with concurrent technology transfer to industry.
- Flexible electronics, which is well supported using R2R technology, is currently a DOD technology development priority and has been discussed for inter-agency collaboration to enable leveraging of mutual assets.

Deposition Technologies (Thick vs Mid vs Thin Film Methods)

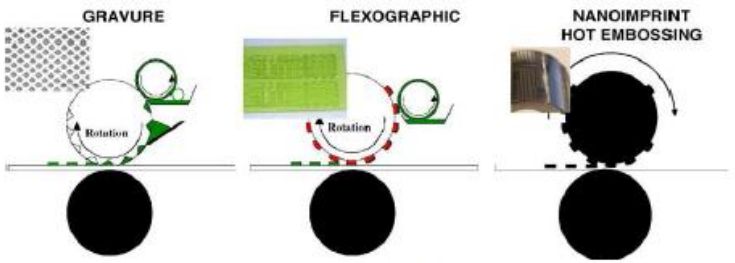
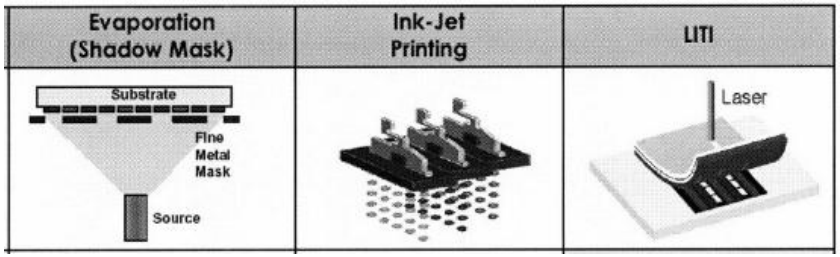
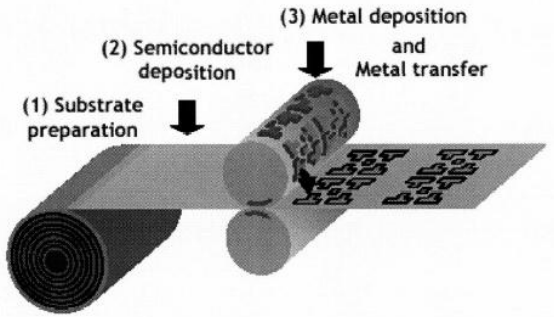
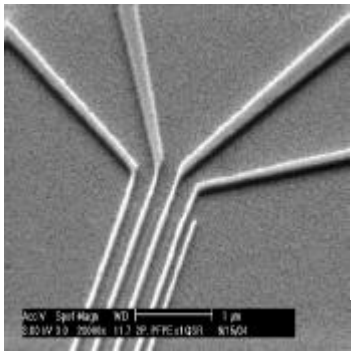


Figure 2 Schematic of roll to roll patterning techniques[7]

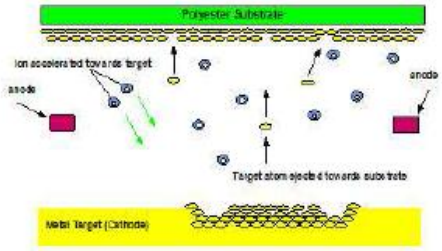




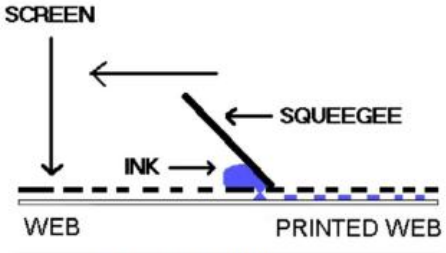
Direct or Off-set Printing Method



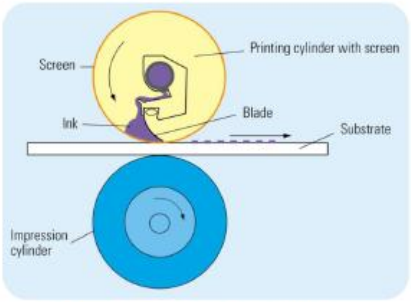
a) Very large multilayer sputtering system



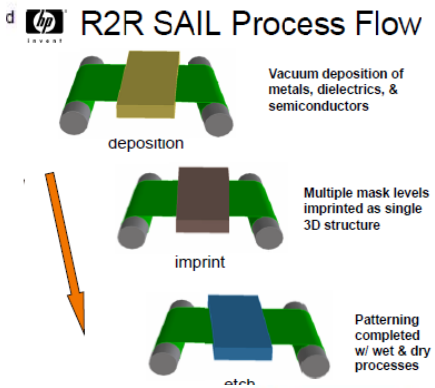
b) Schematic of sputtering process in which inert gas ions are accelerated into target, expelling atoms of the target onto the film

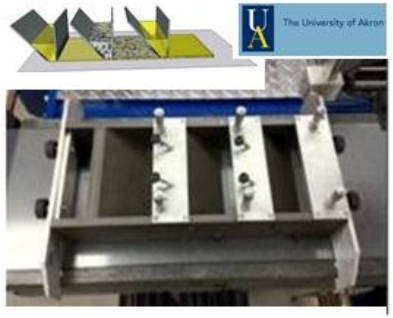


screen printing



Rotary screen printing



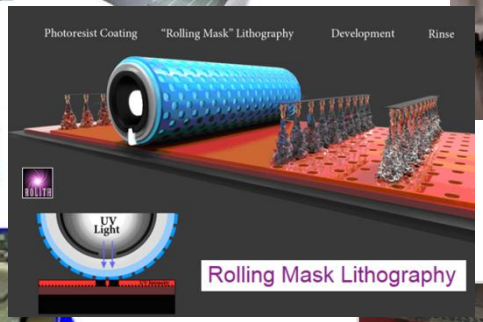


Multilayer Blade Casting (Electromagnetic assist)

40 nm features on 50µm polyimide film at 5 m/minute

Process Equipment/Sensor-Control Integration

R&D → Pilot → Volume Production

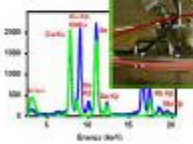


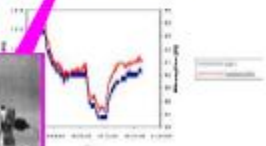
Parallel Detecting, Spectroscopic Ellipsometer (PDSE)

IR/visible material characterization (bandgap, conductivity, surface properties, etc.)

X-Ray Florescence (XRF)

Composition control and system behavior





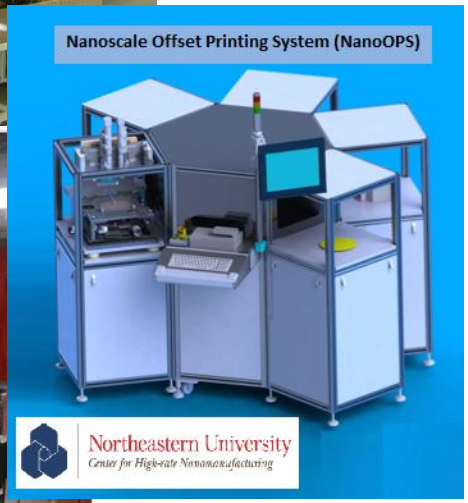
Atomic Absorption Spectroscopy (AAS)

Elemental flux measurement

Thick-film deposition (Screen-Print and Casting

Electrochromic deposition

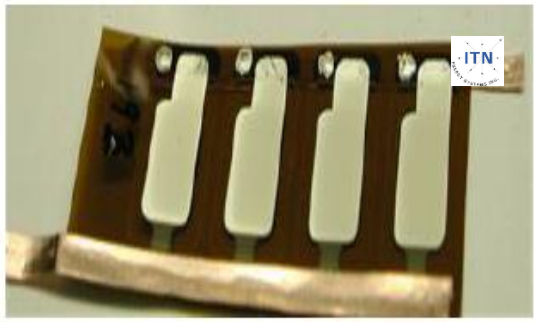
CIGS continuous deposition Chamber



Additive/Subtractive micro-electronic printing on Flex-Glass

Materials - Substrates

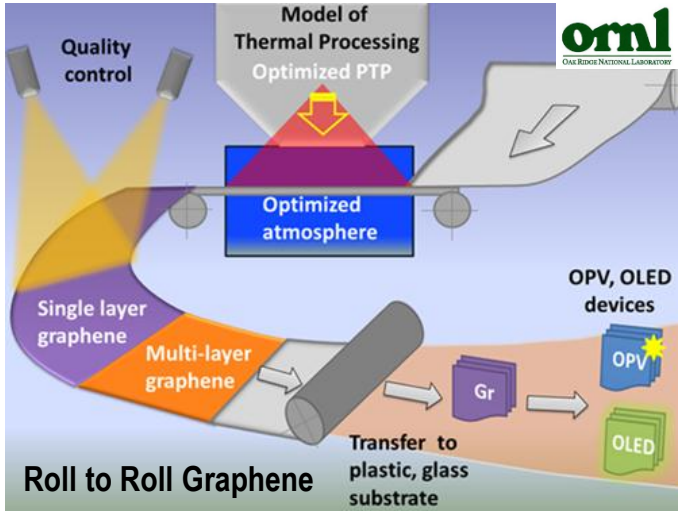
Metal Foil

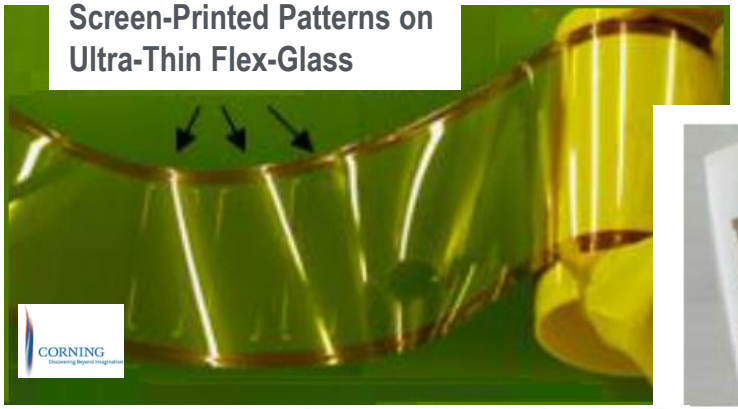


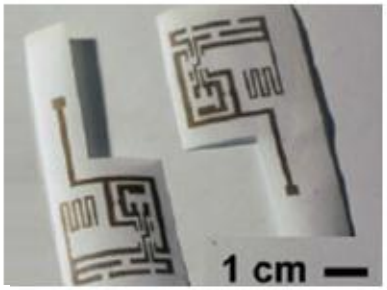
Polyimide

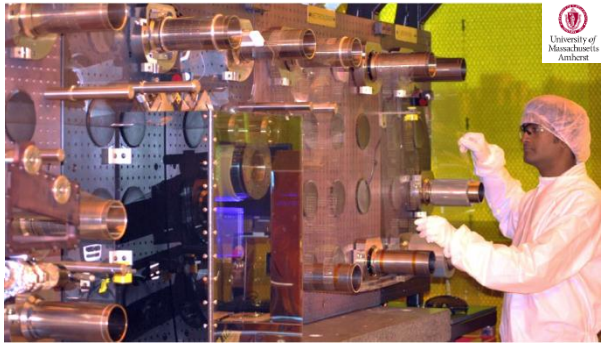
MCC, YSZ, Spinel

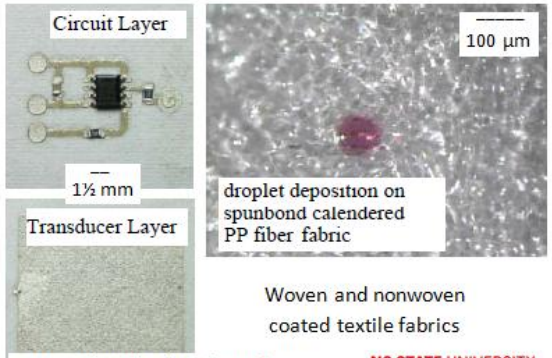
Flexible Ceramic





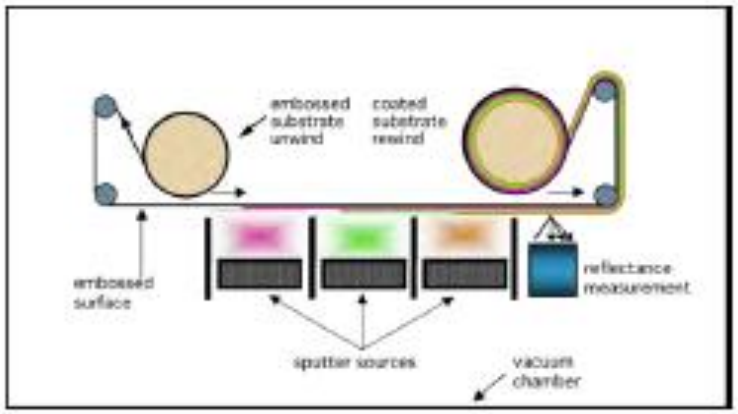


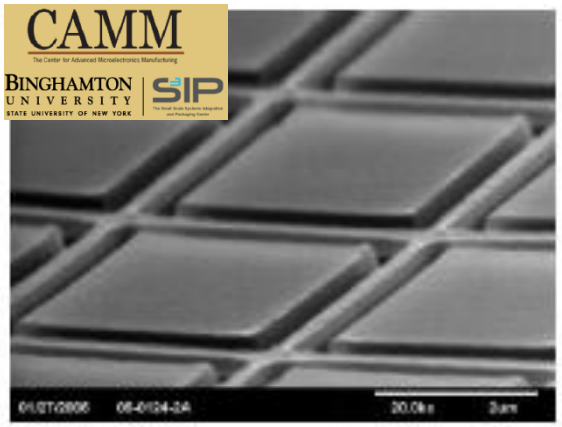




Other polymer materials: Polyester (Mylar™) , Polyethylene (PE), Polyethylene Naphthalate (PEN), Polyethylene Terephthalate (PET), Polycarbonate (PC), Vinyls, Insulated Metal (IMS), Thermal Conductive (TAC)

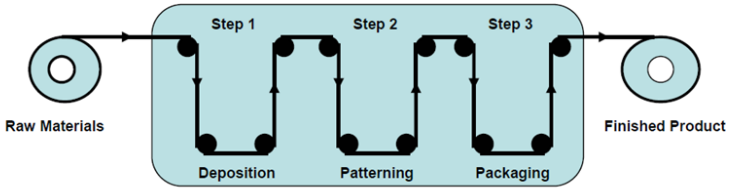
R2R Technology Areas





Technology Areas

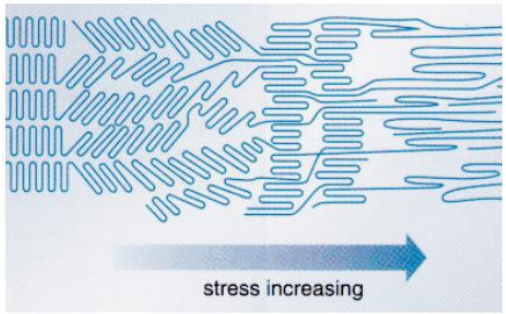
- Membranes (Fossil and Separation)
- Flexible Electronics and Interconnects (active and passive, etc.)
- Battery Technology
- PEM and SOFC Fuel Cells
- Flexible - Photovoltaics
- Formatted, Higher Quality Depositions
- Photonics, Magnetics, Conductors/superconductors, electrochromics, Transducers/MEMs, TFTs
- Structural Electronics/Infrastructure Health Monitoring/sensors

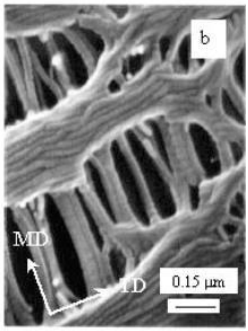


Technology Areas

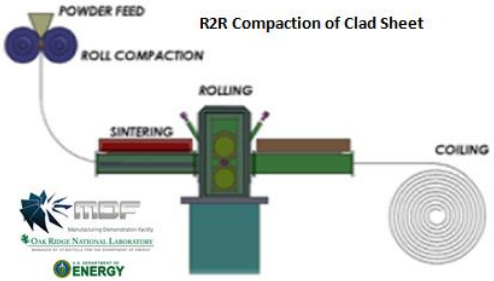
Manufacturing Issues

- Reproducible Scalable Solutions
- Metrology and In-Process Control
- Quality Control and systems
- Cost-Competitive, Economic Solutions
- Process Equipment and Materials



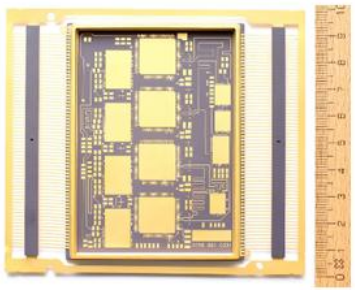


Size Specific Crystalline/Semi-crystalline Polymer Membrane Stretch preparation

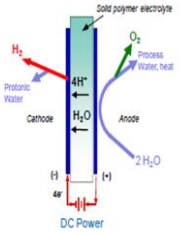


R2R Compaction of Clad Sheet

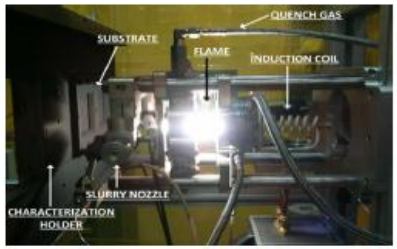
Metals Processing

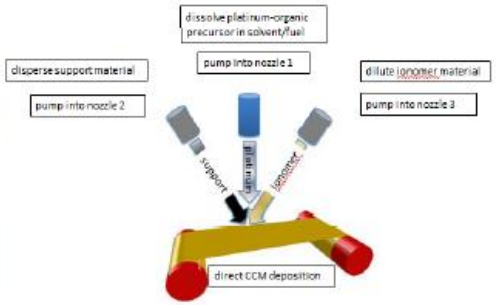


Co-Fired Ceramic Composites (LTCC and HTCC)

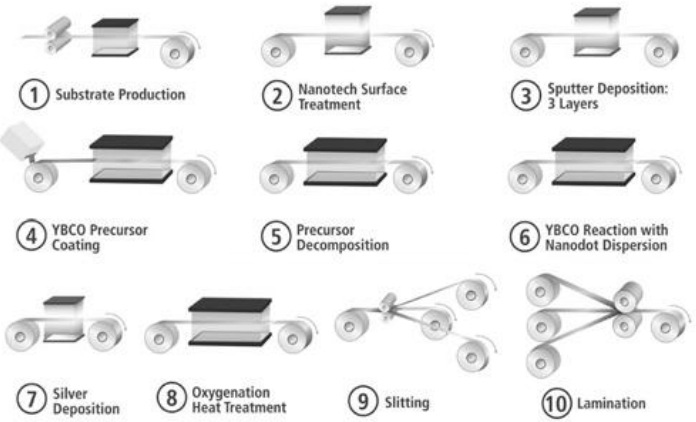


Electrolyzer MEAs





Current RSDT equipment at UCONN (left) and a schematic of proposed roll-to-roll process (right).



R2R processing of high-temperature YBC Superconductor on Ni at AMSC

Pilot Processing Equipment Supporting MEA Membrane Fabrication for Proton OnSite

Technology Areas Transparents, Windows and Window Films

Daylight Redirecting Films (3M)

Electrochromic Windows (Sage, View)

VI Transparent Insulation

Metric	Proposed Target
R-value	R-20
Cost	<$1/ft^2
SHGC	0.2-0.8

Payback < 1 year

Market Ready in < 5 years

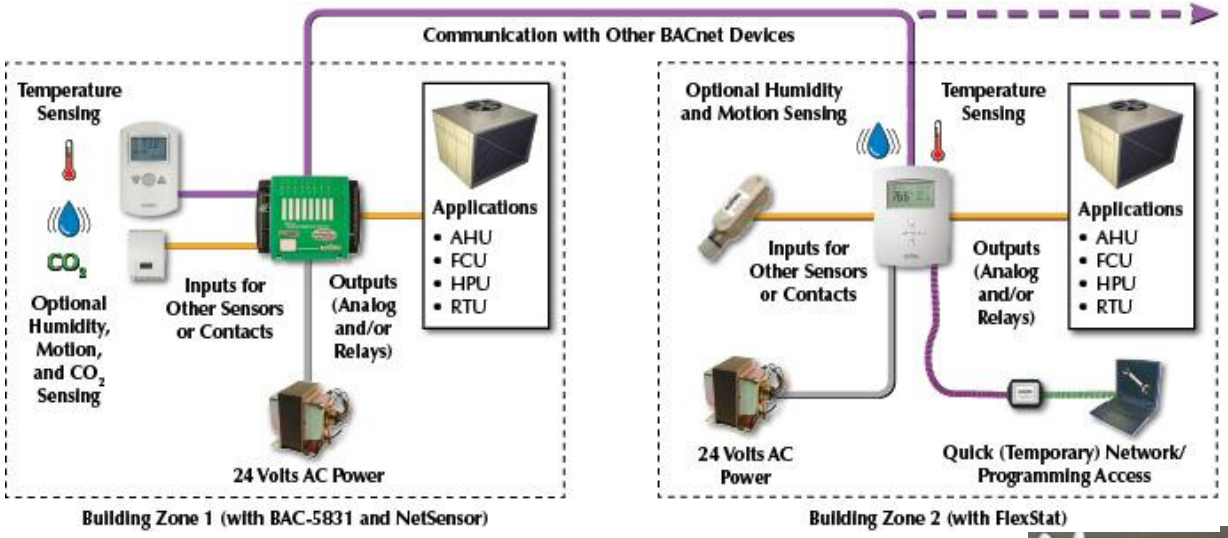
Low-e Window Films (Solutia)

Manufacturing Challenges/Barriers

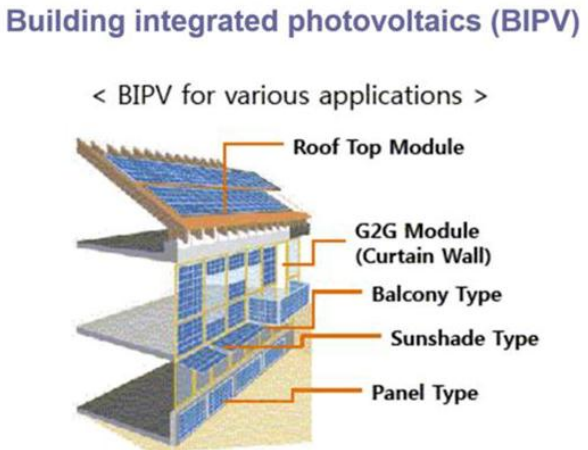
- Large/Customized area
- Process automation and integration
- Low defect tolerance, Clarity
- Improved yields (dynamic products)

Technology Areas
Flexible Electronics

Facility/Infrastructure Automation

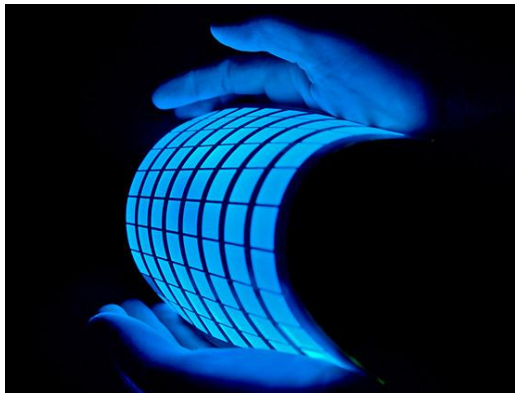


Passive Energy Generation



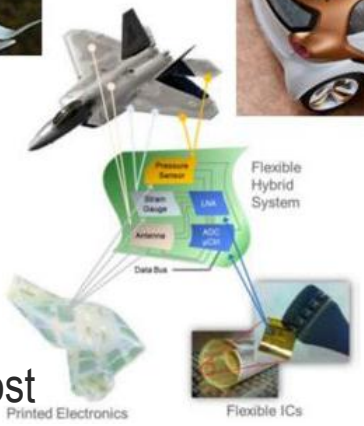
Building with Piezoelectric Flooring (PVDF, PZT,etc

OLEDs



Manufacturing Challenges/Barriers

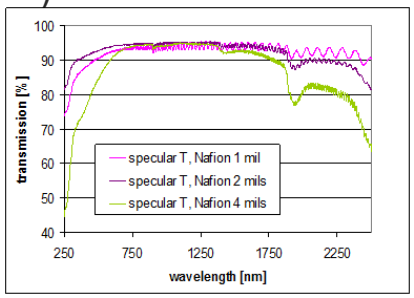
- Quality Substrates
- Resolution (sensors), patterning
- Process tolerance, temperature
- Inspection Tools, Metrology, Standards
- Defect density and repair
- Capacity, Yield and Size scale
- Materials/Equipment-availability and cost

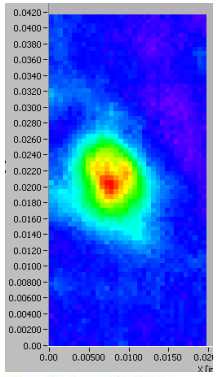


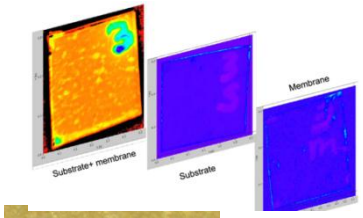
PV Metrology – R&D Effort Examples

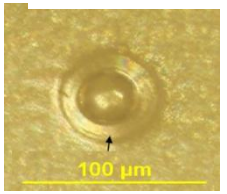
Optical Reflectometry

- Spectral (Reflection, Transmission, or Absorption)
- Very rapid data-acquisition (msec)
- Areal thickness measurement
- Identification of defects (10-100µm)
- Multi-layer, multi-component, etc.



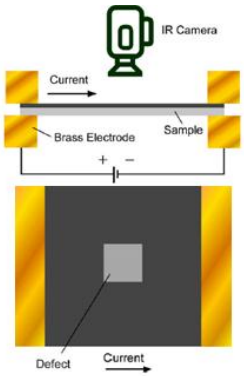


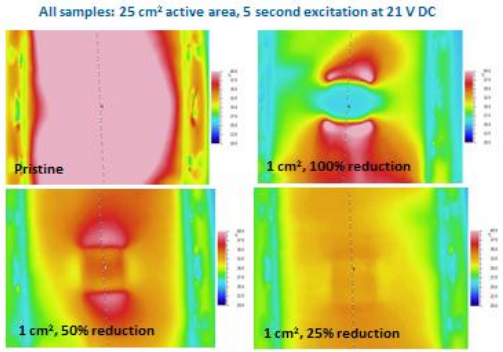




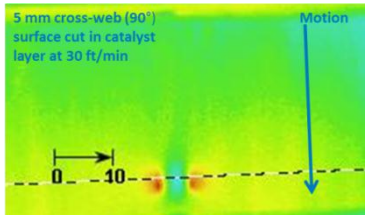
Active Infrared Thermography

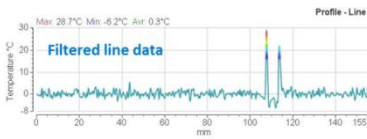
- Apply voltage across electrode layer
- Resulting current causes resistive heating
- Rapid data-acquisition (~sec)
- Areal measurement of resistive uniformity
- Pilot Tested at 10-60 ft/min.





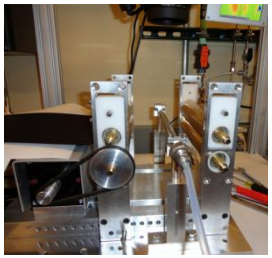
Aieta et al., *J. Power Sources*, **211** (2012), pp.4-11.

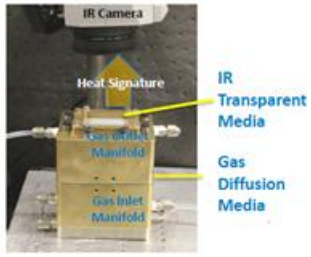


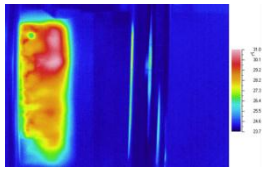


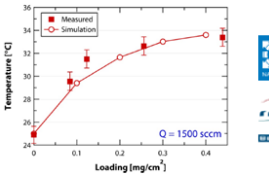
Reactive gas excitation

- Impinge reactive, non-flammable but reactive gas mixture onto electrode
- Detect uniformity of thermal response
- Demonstrated with moving sheets
- Evaluate at Δ Defect Loading





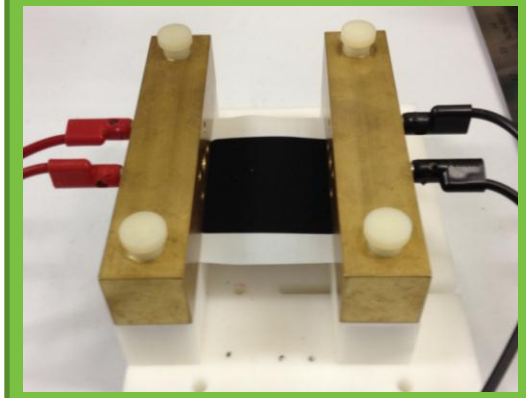




Range of Scale

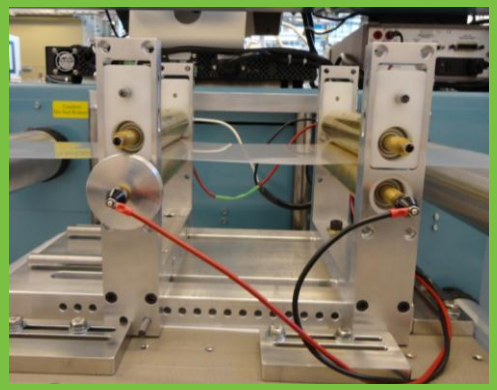
Bench-top

Technique development
Material validation



Prototype

Parametric studies
Process validation

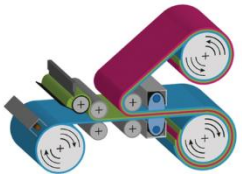


Full-scale

In-line validation
Industry roll goods

Summary

Technical/Scale Up Challenges: The challenges for R2R manufacturing are primarily in providing a low cost, high yield, materially-consistent and homogeneous, R2R-manufactured products that can scale up to high-speed production rates processed on proven technology “SMART” equipment meeting current and to-be established Quality Standards that are consistent with environmental, industry and commercial needs by overcoming issues with substrates, control drift, web drift, size scale, metrology, and alignment/registration, etc.



What's Next Today

- Hear from across DOE and DoD community
- Hear from across AMNPO & across Government, such as DOC's AMTECH Investments
- Hear from You: Industry and Research Community

Thank You

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