Center for High-Rate Nanomanufacturing

nano Manufacturing Center of Excellence

Nanoscale Polymer Processing

Joey Mead, Professor of Plastics Engineering
Deputy Director, NSF Center for High-rate Nanomanufacturing
Co-Director, UMass Lowell Nanomanufacturing Center

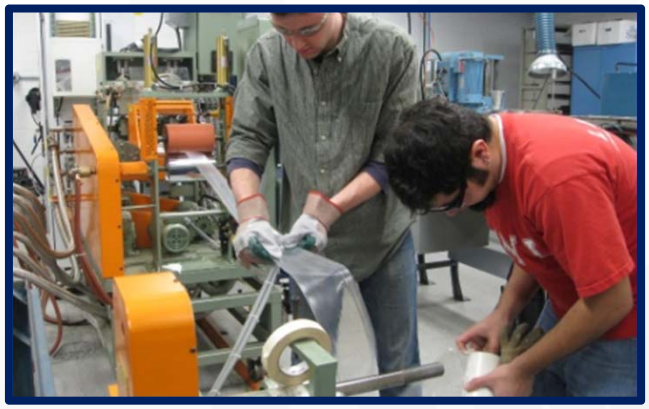
UMASS LOWELL

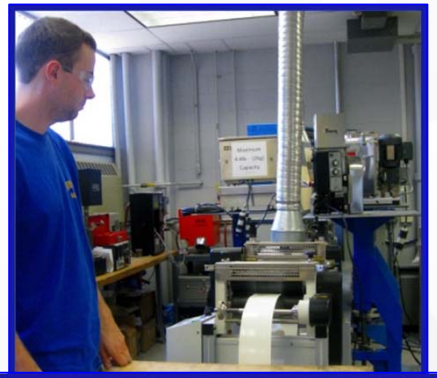
Why Polymer Nano?

- Polymers are lightweight and conformal
  - *Nano provides performance with less material*
  - *Thermoplastics can be recycled – sustainability*
- Multiple materials can be integrated, layers
- Polymers are easily processed in high rate, low cost manner
  - *Easily fabricated in large area sheets in roll to roll or continuous manner*
- Wide range of applications
  - *e.g., Lightning strike protection, icephobic surfaces, organic photovoltaic cells*

World Class Polymer Manufacturing

- Macro, Micro and Nanoscale Plastics Processing
- Design and Tooling Expertise

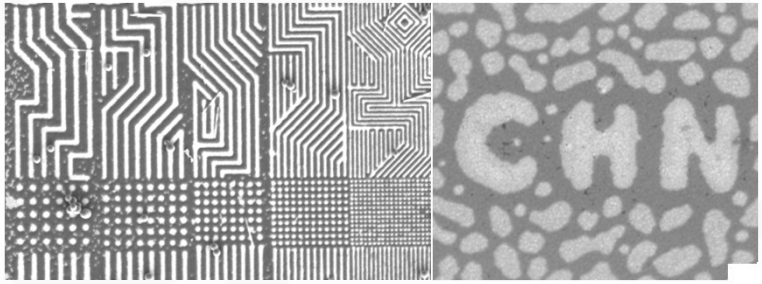




Excellent Platform for Nanomanufacturing

Core Competencies in Nanomanufacturing – Tools and Processes

Polymer Nanomanufacturing
(current toolset)



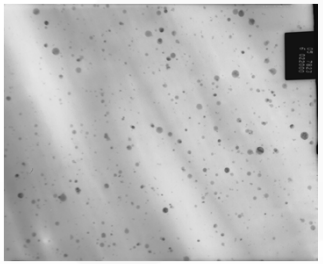
Directed Assembly
Nanoparticles, Nanotubes, Polymers
(next gen toolset)

Responsible Nanomanufacturing
Nanoparticle exposure, Nanotoxicity, Recycling

Polymer Nanocomposites

Mixture of polymer and nanoscale filler

- Provides improved or unique material properties at low loading
- Wide range of nanofillers – clay, silver, carbon nanotubes



Good dispersion is critical

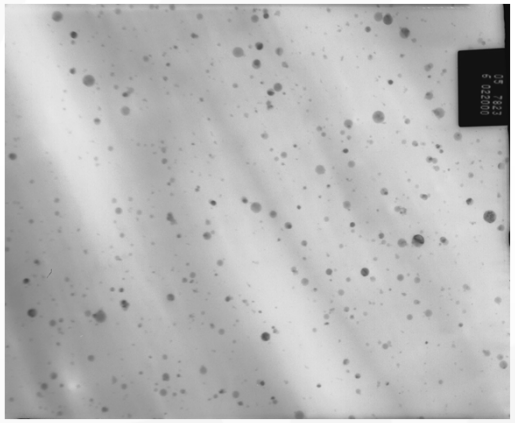
- Quantification of degree of dispersion

Nanomanufacturing using *commercially relevant melt mixing*

Multiple industry sponsored research projects in this area - Cabot, Chasm, Raytheon, Nypro

- Kim et al., *J. Appl. Polym. Sci.,* 109, 2524 (2008)
- Kim et al., *Polym. Eng. Sci.*, 47, 2049 (2007)
- Kang et al., *Macromol. Mater. Eng.,* 292 329 (2007)

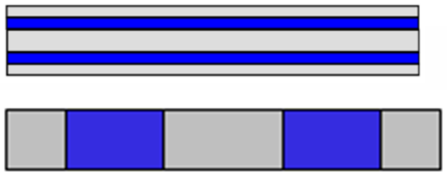
Polymer Nanocomposites

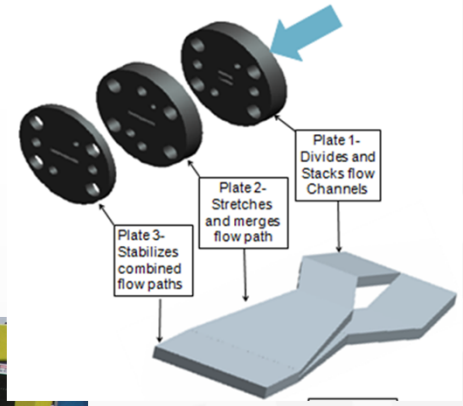


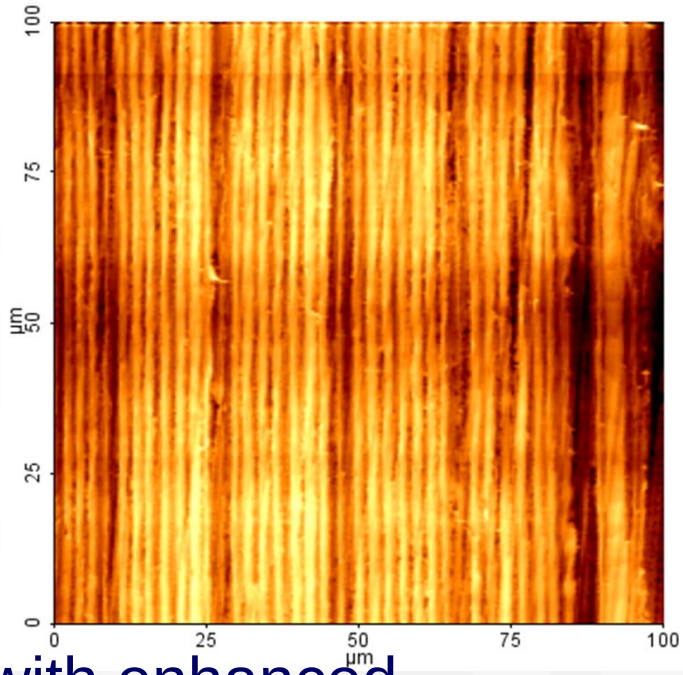
- Provides improved or unique material properties
  - Barrier properties
  - Flame retardance
  - Mechanical properties
  - Antimicrobial
  - Lightweight EMI shielding

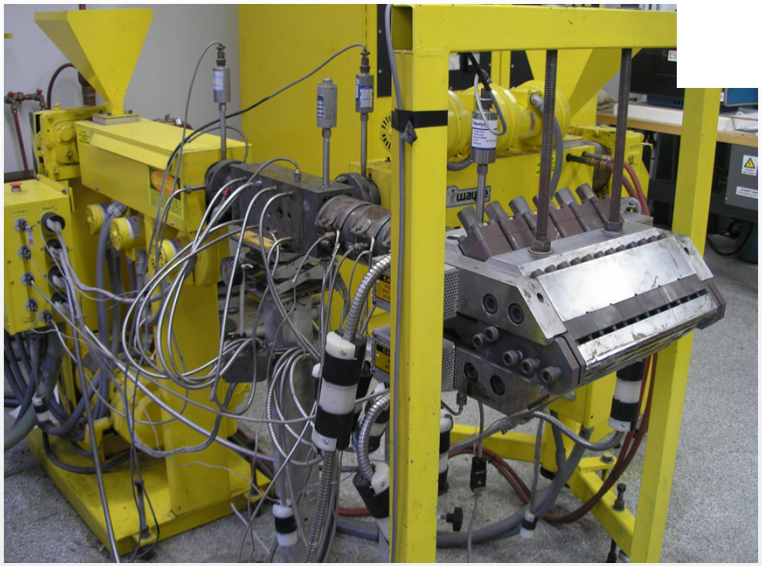
Nanolayered Materials by Coextrusion

Continuous production of films with 2000+ layers





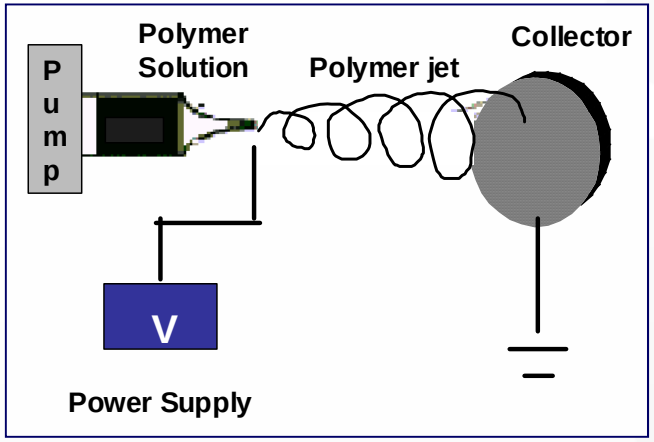


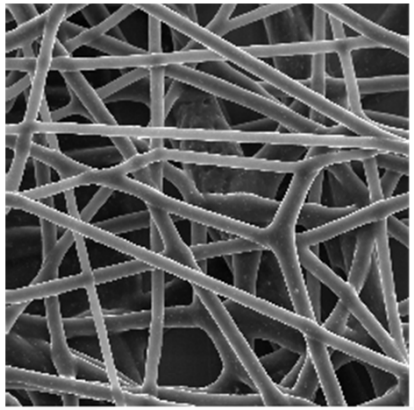


- Materials with enhanced toughness
- Multi-functional materials
- Optical materials
- Barrier materials - packaging

•Nakamura, Barry, Cohen, Ogale, Orroth, Soni, Mead, Proc. Soc. Plas. Eng. ANTEC 2010, p. 2019.
•Nakamura, Barry, Cohen, Ogale, Orroth, Soni, Mead, Proc. Soc. Plas. Eng. ANTEC 2010, p. 2037.
•Ho, Lee, Viriyabanthorn, Sung, Barry, Mead, Proc. Soc. Plas. Eng., ANTEC 2004, p. 376.

Electrospun Fibers

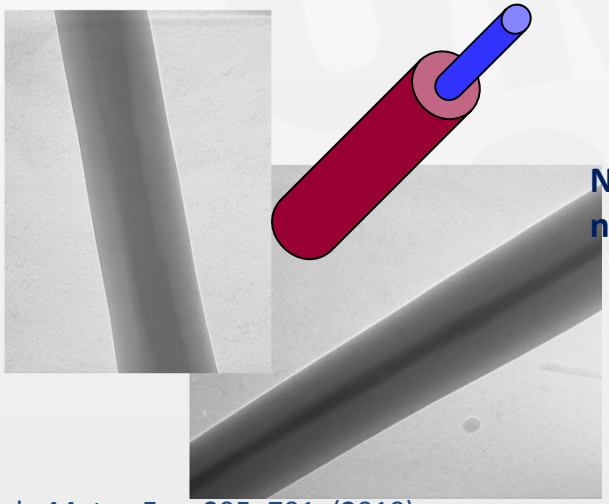




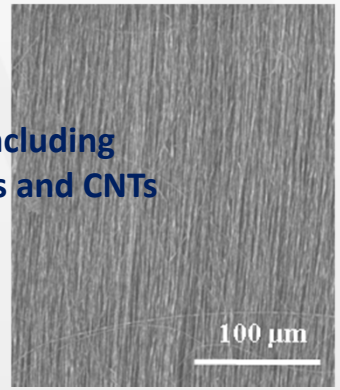
Typical result: non-woven mat

Stretchable, breathable protective clothing – elastomer membrane

Controlled architecture fibers
Applications: wires, filter media



Controlled mat architecture
Template directed

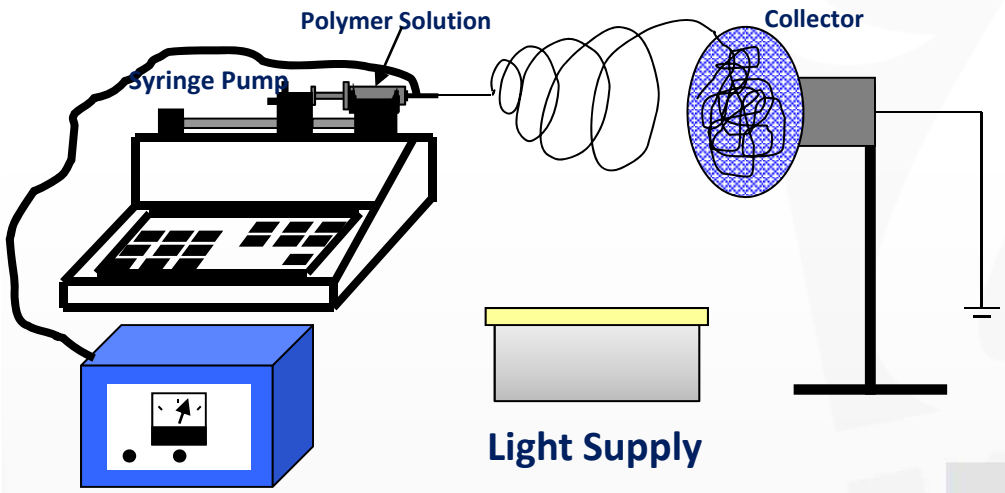


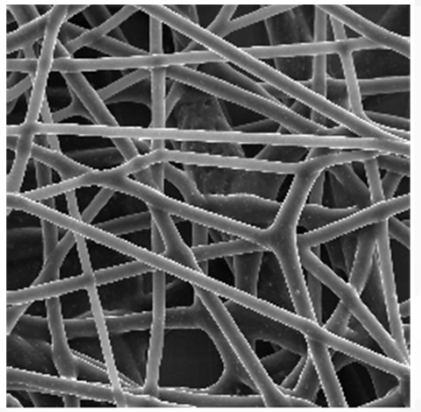
Nanofillers including nanoparticles and CNTs

NSF DMI-0200498

- Kumar et al., *Mater. Eng.* 295, 701 (2010)
- Murphy et al., *Rubber Chem. and Technol.*83,4 (2010)
- Threepopnatkul et al, *Rubber Chem. Technol.*80, 2 (2007)

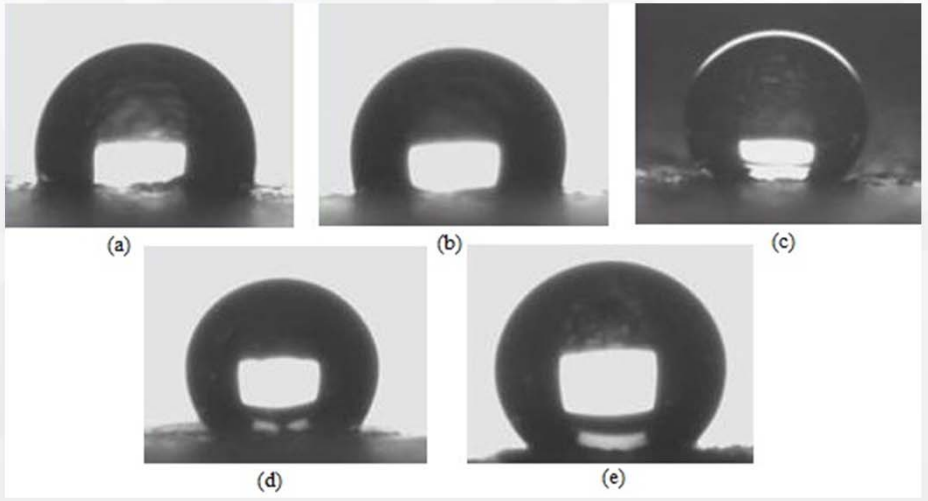
Creating Superhydrophobic Surfaces by Electrospinning of Butyl Rubber





SEM image of electrospun butyl rubber fibers

Carbon Black Loading (phr)	Viscosity (cP)	Contact angle(°)
30	300	126
30	600	128
30	1200	124
50	100	139
50	600	136



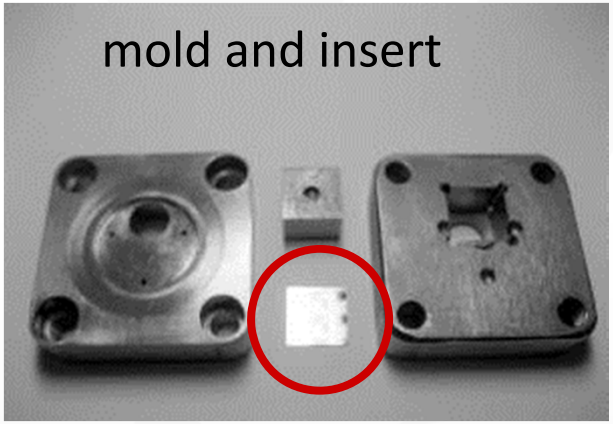
Contact angle images of water droplets on electrospun butyl rubber fibers at different levels of carbon black loading (a) 10 phr, (b) 20 phr, (c) 30 phr, (d) 40 phr, and (e) 50 phr.

- Panwar A et al., ACS Rubber Meeting, Oct 7-10, Cleveland, OH, 2013
- Murphy et al., *Rubber Chem. and Technol.*83,4 (2010)
- Threepopnatkul et al, *Rubber Chem. Technol.*80, 2 (2007)

Injection Molding Nanoscale Features

Std. molding machine

+



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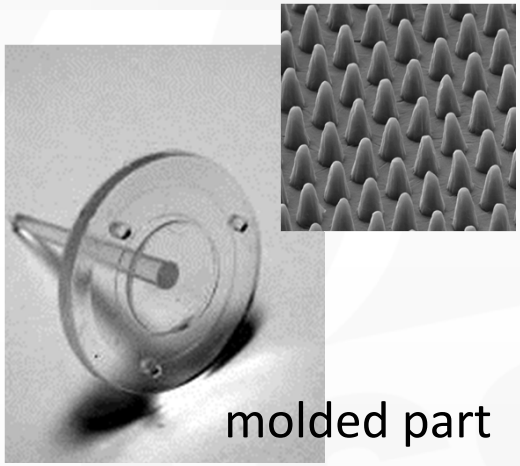
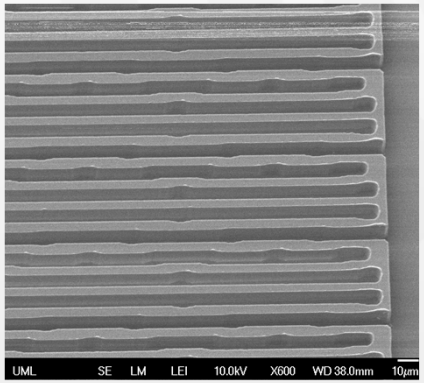
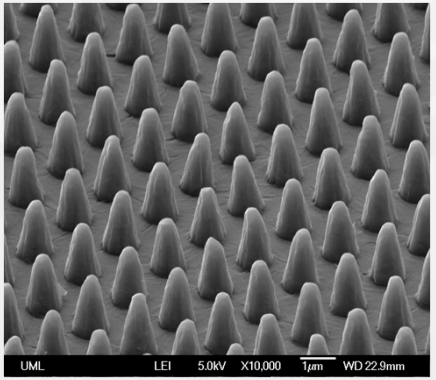


Expertise in processing and tooling
Min. feature size: 100 nm, tooling limited

Applications

- Lab-on-chip devices
- Optical gratings
- Self-cleaning surfaces
- Tissue scaffolds

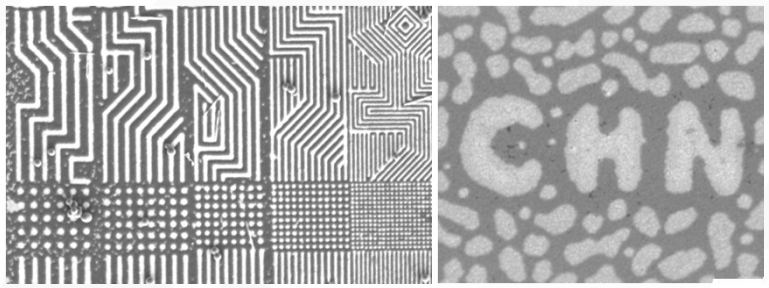




Two companies currently sponsor research in this area

Core Competencies in Nanomanufacturing – Tools and Processes

Polymer Nanomanufacturing
(current toolset)

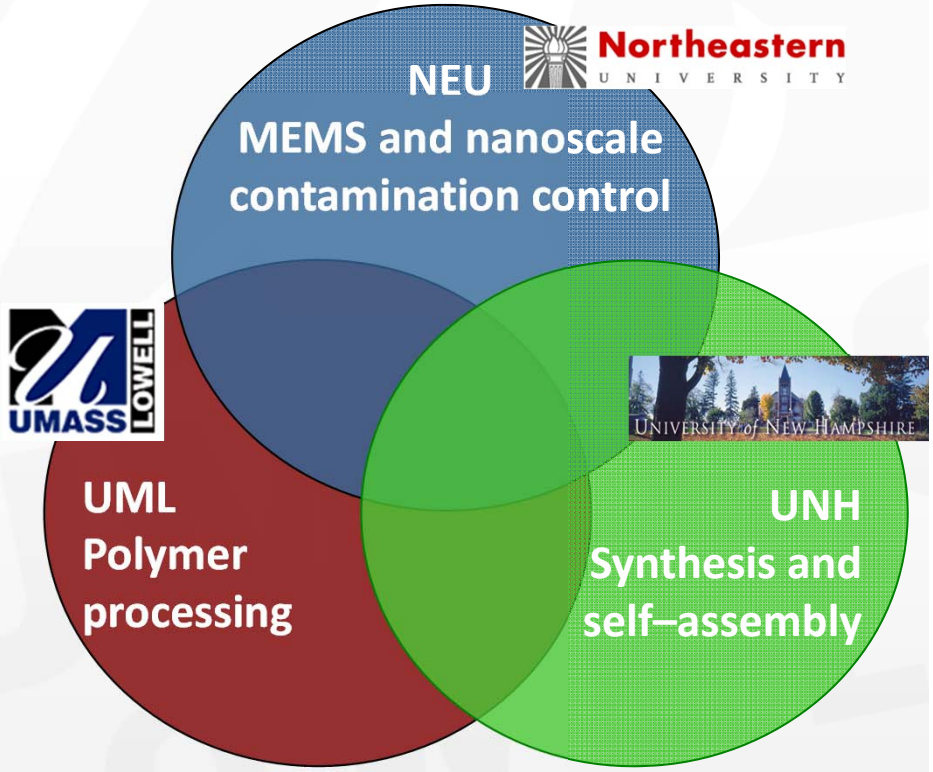


Directed Assembly
Nanoparticles, Nanotubes, Polymers
(next gen toolset)

Responsible Nanomanufacturing
Nanoparticle exposure, Nanotoxicity, Recycling

NSF-Nanoscale Science and Engineering Center for High-rate Nanomanufacturing (CHN), est.2004

Adv. Mat., **21(7), 735-832 (2009).**

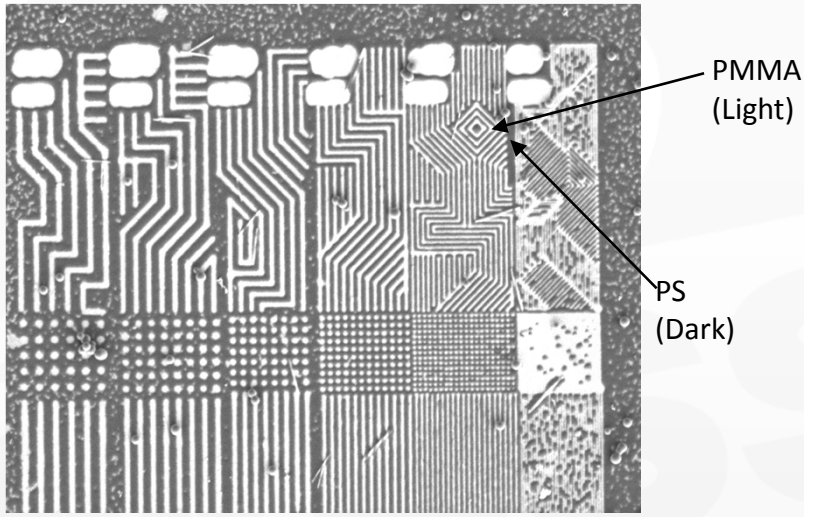


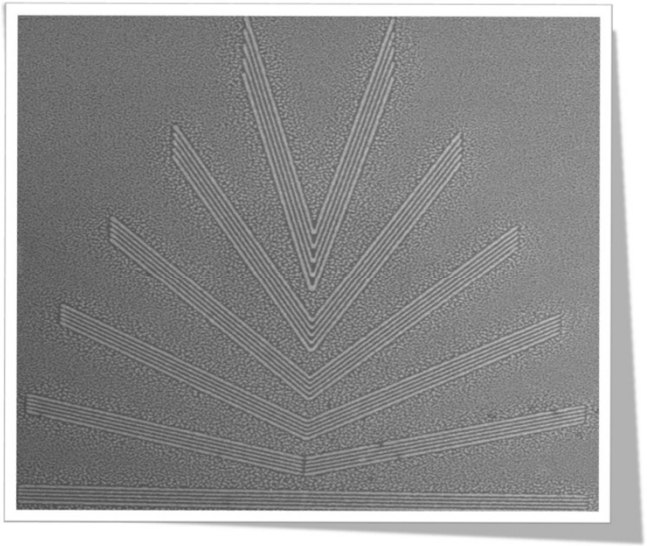
Center for High-Rate Nanomanufacturing

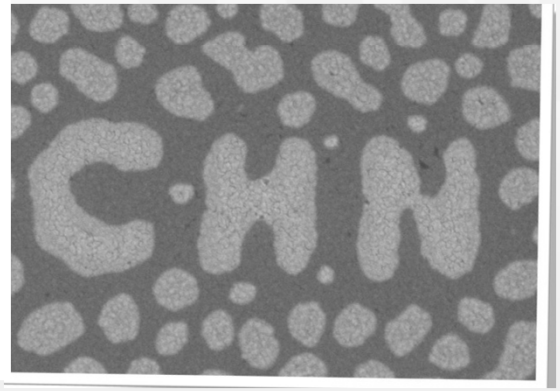
Director: Ahmed Busnaina, NEU, Deputy Director: Joey Mead, UML
Associate Directors: Carol Barry, UMassLowell; Nick McGruer, Jacqueline Isaacs, NEU; Glen Miller, UNH; Thrust Leader: David Tomanek, MSU

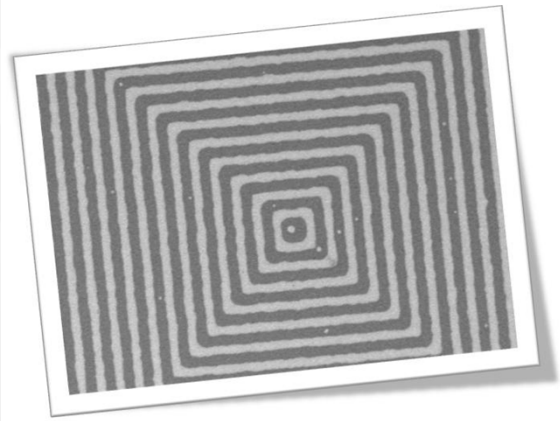
Assembly of Polymer Blends

- Multiple polymer systems
- Rapid Assembly
- Design flexibility (multiple scales)





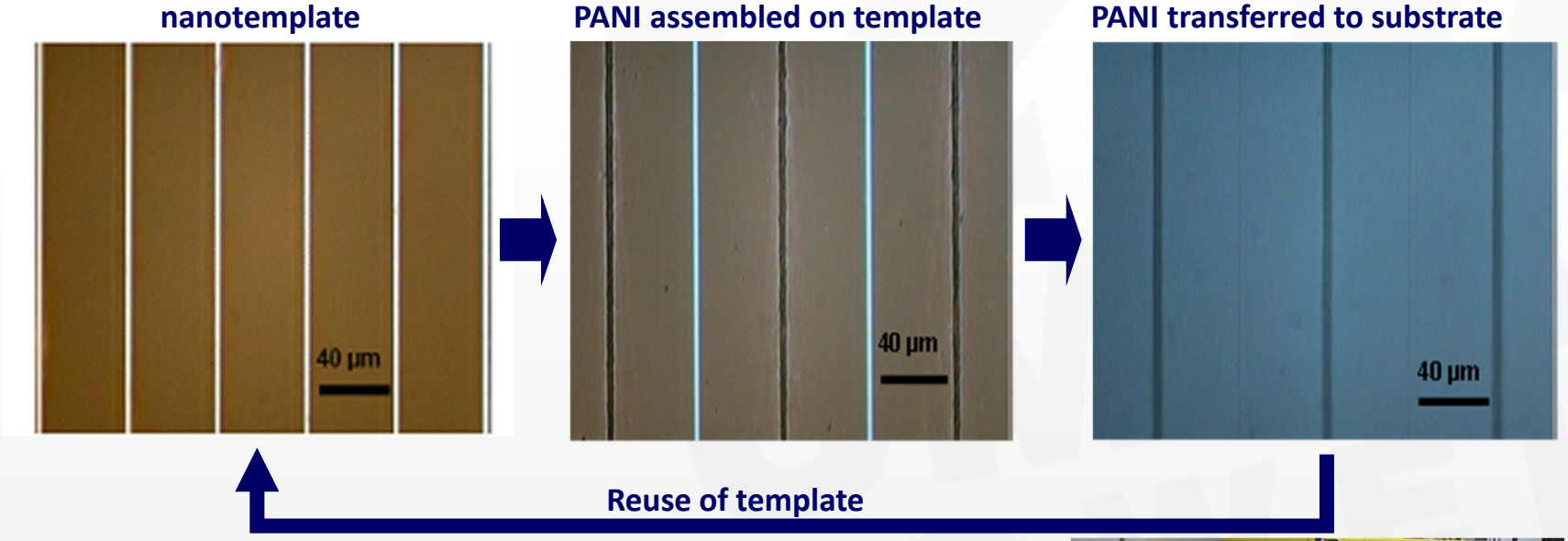




Wei, M. L. Fang, J. Lee, S. Somu, X. Xiong, C. Barry, A. Busnaina, and J. Mead, *Advanced Materials*, 21(7), 735 (2009).
Chiota et al., *Small,* 2009 Dec; 5(24):2788-91

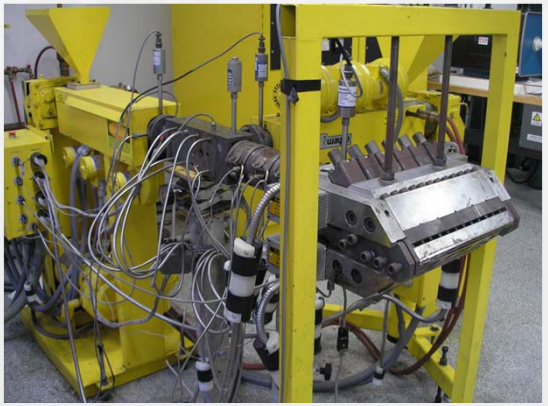
Assembly and Transfer of Nanoelements

- Assembly of nanoelements (conducting polymer, CNTs, etc.,)
- Transfer to polymer – our processes allow for wide choice of materials – any thermoplastic polymer



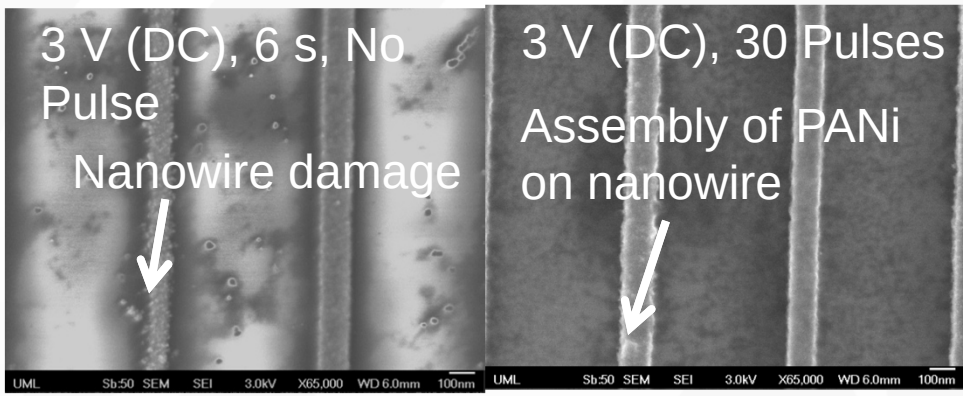
Thermoforming machine and mold picture

Easily scaled to reel to reel/continuous process



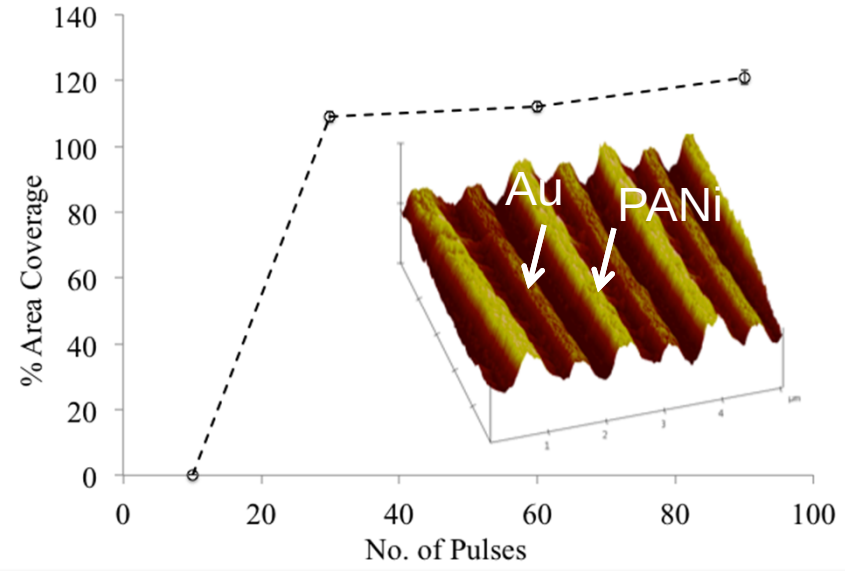
Pulsed Electrophoresis: Durability at Nanoscale

- Reduces cycle time
- Reduces heat build up
- Allows higher voltages to be used
- Damage to the nanowire templates eliminated

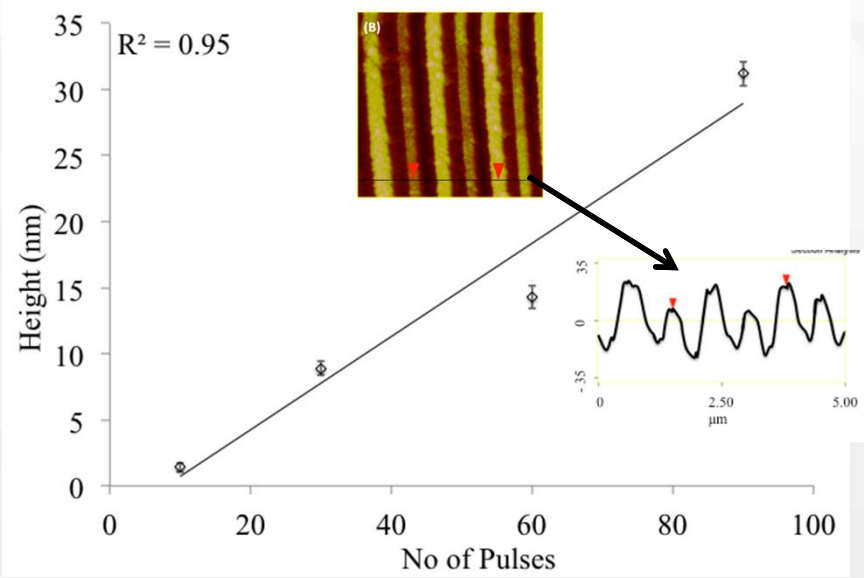


Assembly of PANi at Nanowire templates

Mead et. al. *Nanotechnology* 23 (2012)

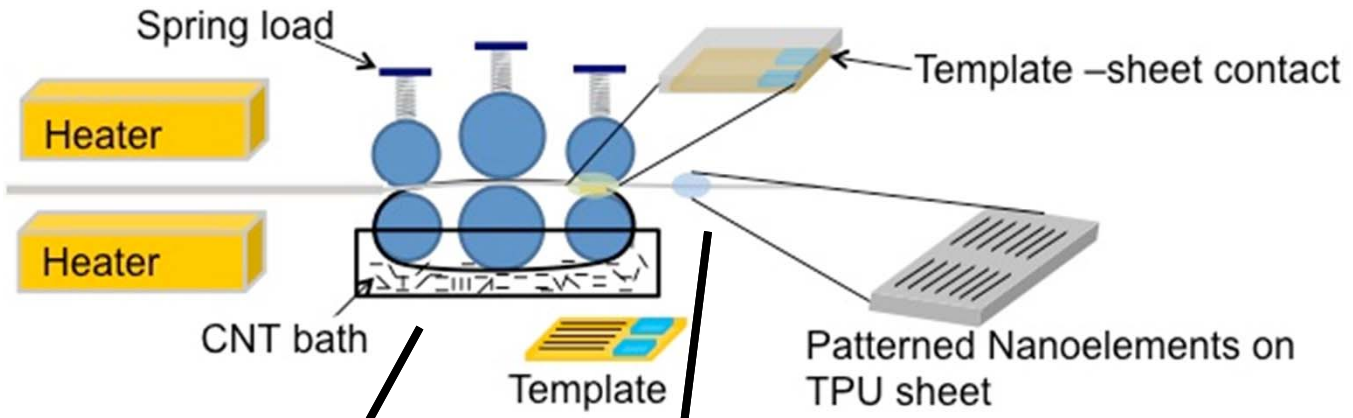


Pulsed Electrophoresis provides control on area coverage with no bridging

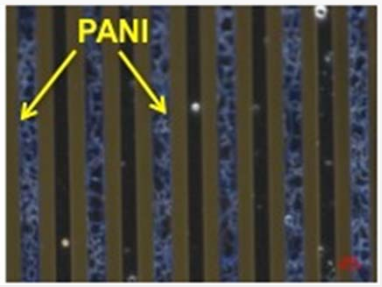


Pulsed Electrophoresis provides control on deposition height

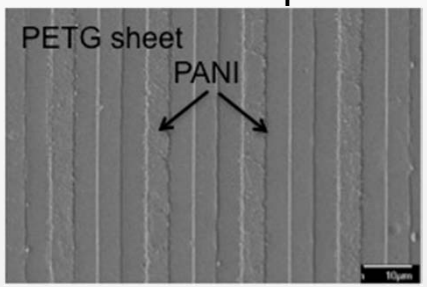
Scaling to Roll to Roll Assembly and Transfer

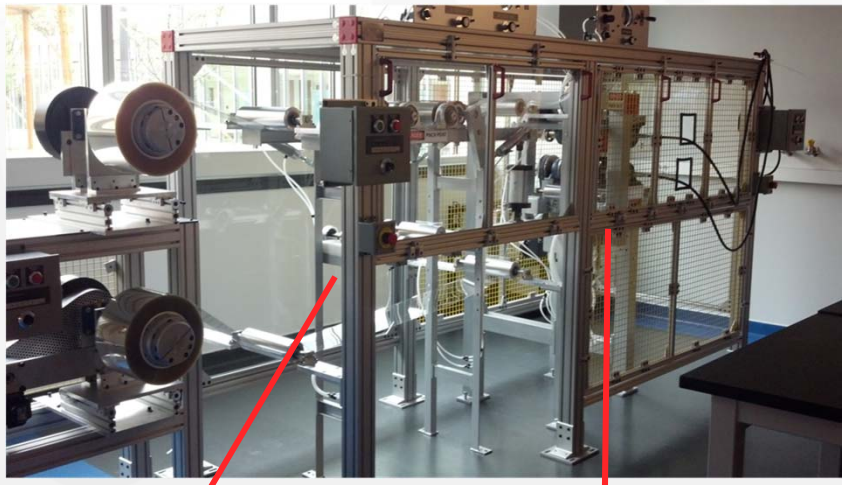


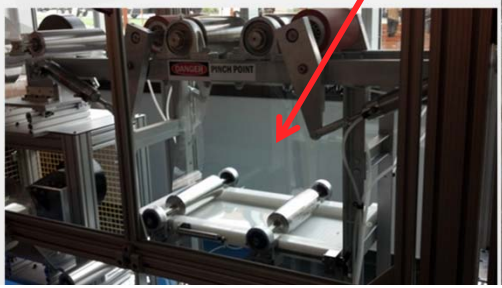
Assembly of PANI



Transfer of PANI on PETG sheet in R2R process





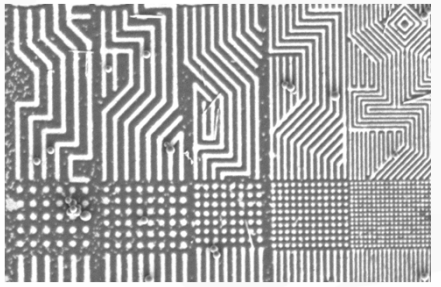


Integration of processes

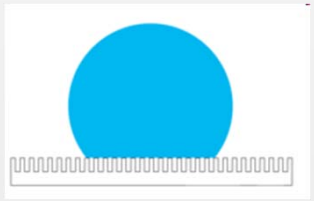
Directed assembly

Transfer

Structured Surfaces

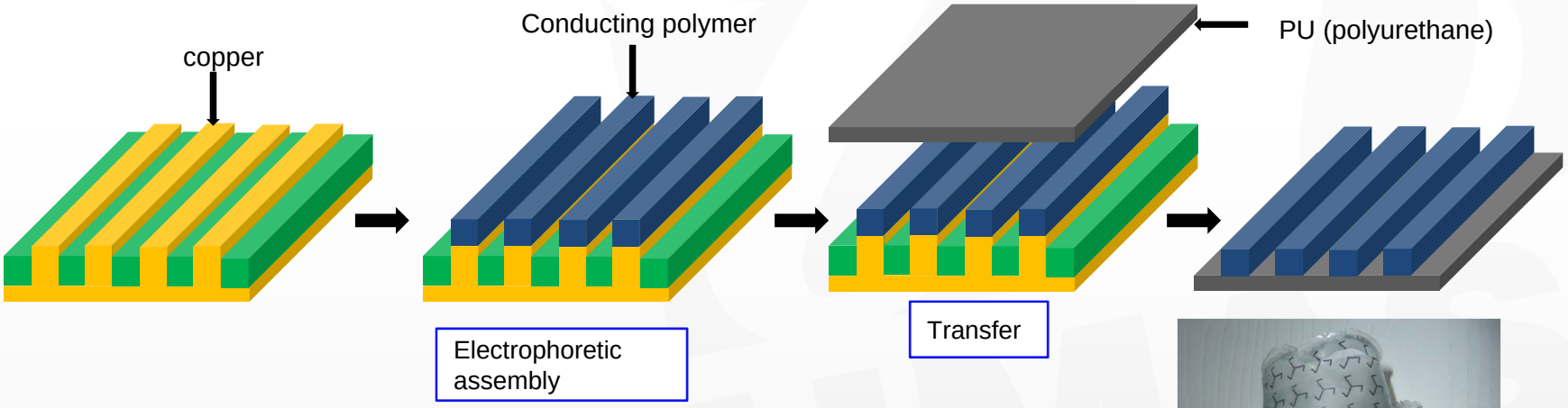


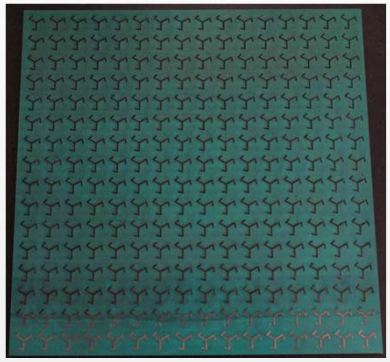
- Hydrophobic
- Optical gratings
- Patterned polymers for cell growth
- Flexible electronics at the nanoscale
- Icephobic
  - Collaboration with Shenkar College (Israel)
  - Develop manufacturing process
  - Nanorough ultrahydrophobic surfaces can impart icephobicity
  - Most surfaces not durable

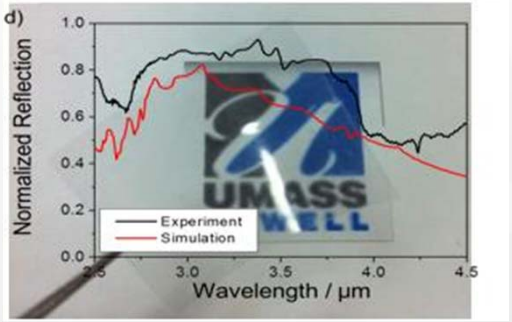


Fabrication of Chiral Metamaterial

Electrophoretic Assembly and Transfer



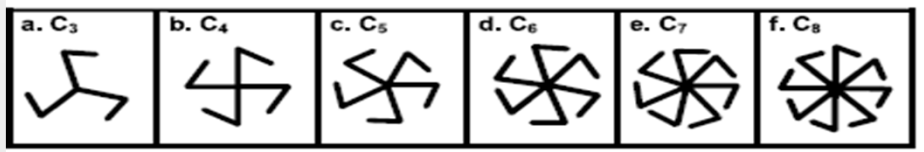




Mid-infrared

L. Fang, M.Wei, N. Wongkasem, H. Jaradat, A. Mokhlis, J. Shen, A. Akyurtlu, K. Marx, C. Barry, & J. Mead, Microelectronic Engineering 107 (2013) 42–49

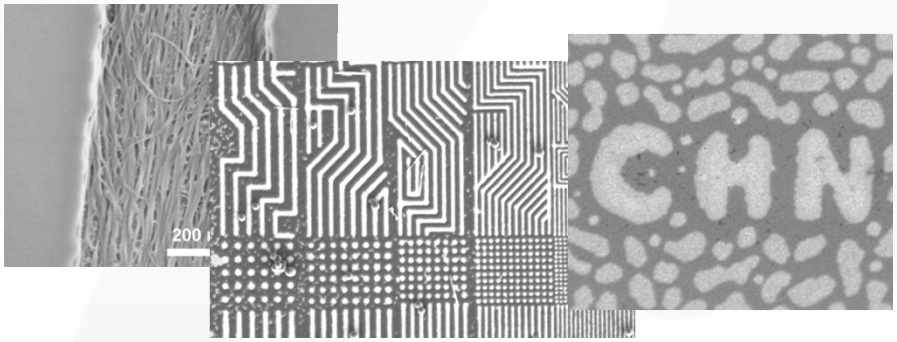
Modeling provides designs and dimensions



N Wongkasem et al, J. Opt. A: Pure Appl. Opt. **11 (2009) 074011**

Core Competencies in Nanomanufacturing – Tools and Processes

Polymer Nanomanufacturing
(current toolset)

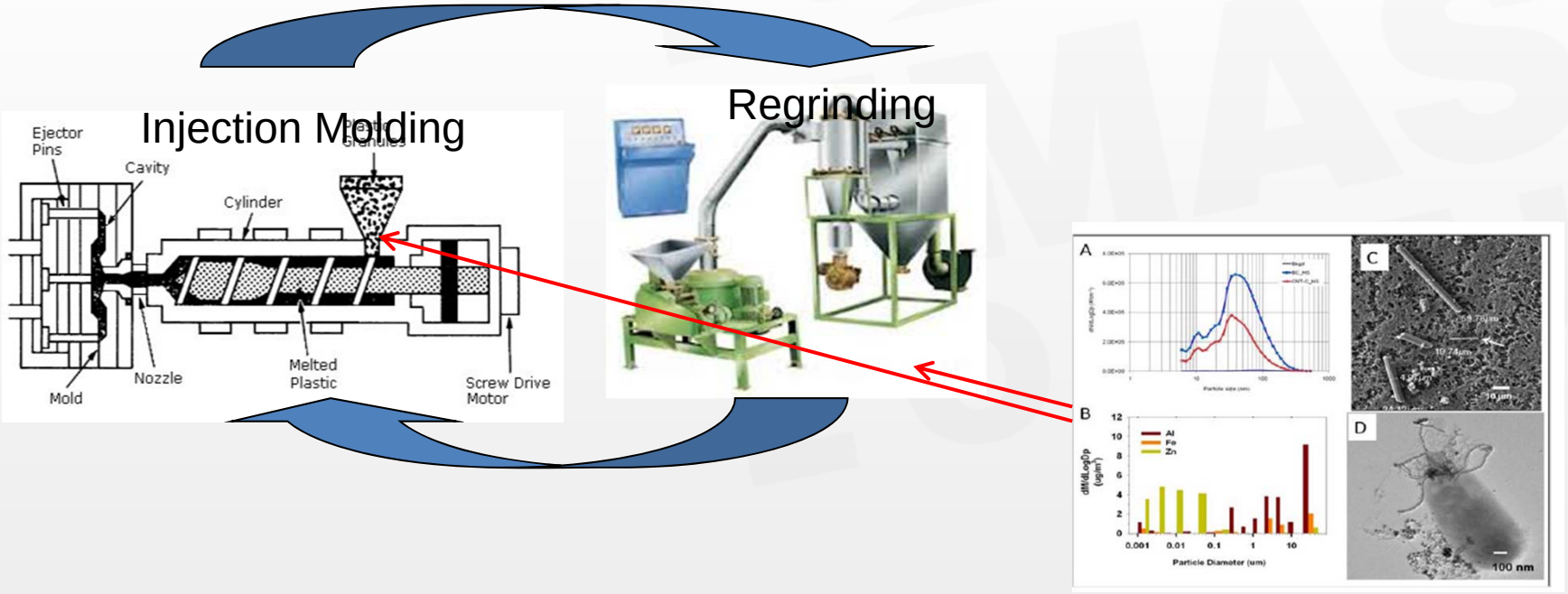


Directed Assembly
Nanoparticles, Nanotubes, Polymers
(next gen toolset)

Responsible Nanomanufacturing
Nanoparticle exposure, Nanotoxicity, Recycling

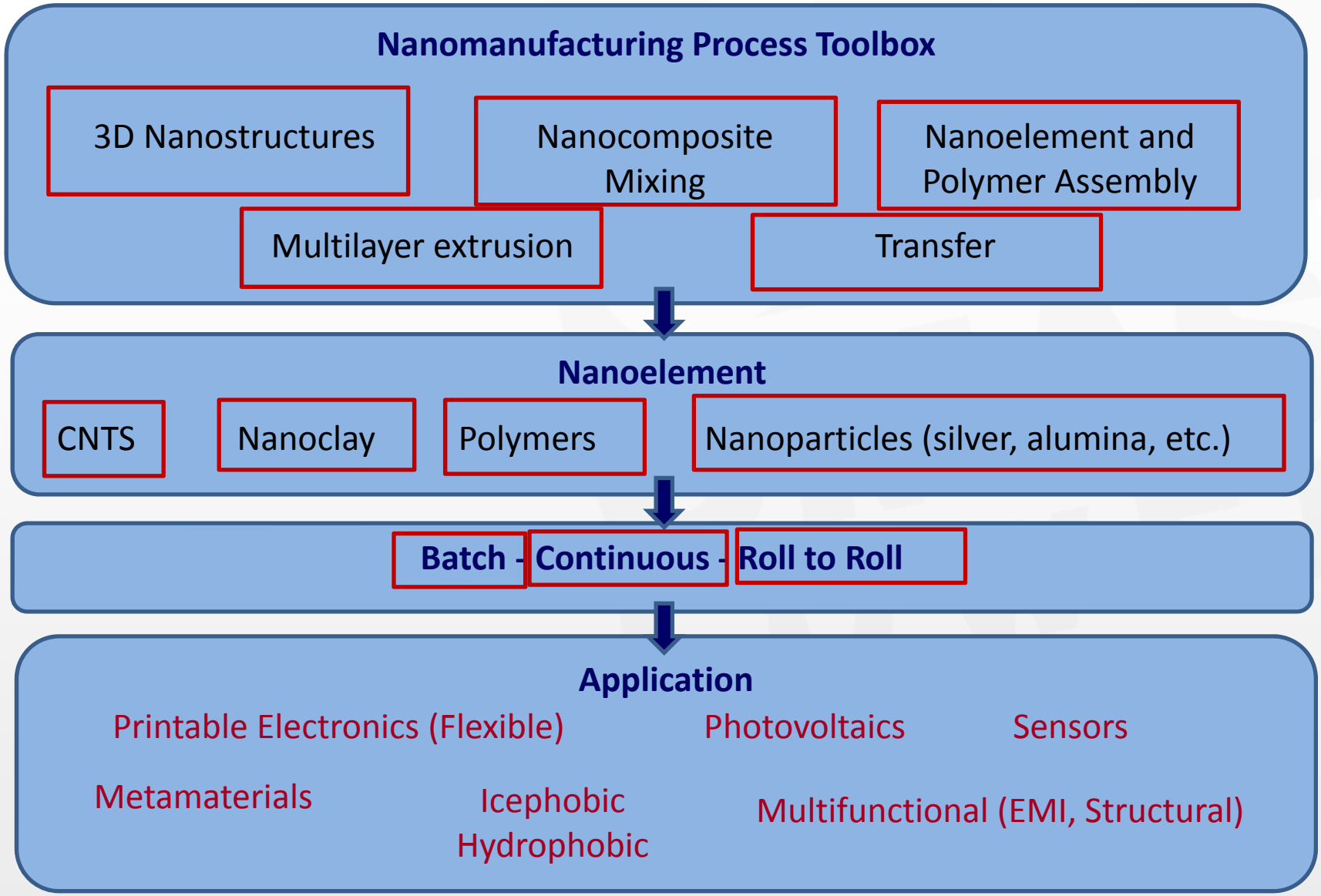
Nanocomposite Recycling

- Effect of recycling on material properties and viability of recycling
- Monitor exposure levels during grinding and machining



J. Mead, D. Bello, S. Wooskie, A. Panwar, J. Isaacs, J. Zhang, P. Boonruksa

Nanomanufacturing: Enabled by Polymers



Summary

- Nanomanufacturing needs to expand into more complex manufacturing processes.
- Polymer nanomanufacturing allows for integration with micro and macro manufacturing techniques.
- Unique capability in nanomanufacturing based on expertise in polymer and rubber manufacturing

Questions?