Nanoscale Polymer Processing

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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

• 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

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

• Murphy et al., Rubber Chem. and Technol. 83, 4 (2010)
• Threepopnatkul et al, Rubber Chem. Technol. 80, 2 (2007)

NSF DMI-0200498
Creating Superhydrophobic Surfaces by Electrospinning of Butyl Rubber

<table>
<thead>
<tr>
<th>Carbon Black Loading (phr)</th>
<th>Viscosity (cP)</th>
<th>Contact angle (°)</th>
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<td>50</td>
<td>600</td>
<td>136</td>
</tr>
</tbody>
</table>

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 + mold and insert = molded part

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


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)

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

Reuse of template

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

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

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
Electrophoretic Assembly and Transfer

Electrophoretic assembly

Conducting polymer

PU (polyurethane)

Mid-infrared

Modeling provides designs and dimensions


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Nanocomposite Recycling

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

Nanomanufacturing: Enabled by Polymers

Nanomanufacturing Process Toolbox
- 3D Nanostructures
- Nanocomposite Mixing
- Nanoelement and Polymer Assembly
  - Multilayer extrusion
  - Transfer

Nanoelement
- CNTS
- Nanoclay
- Polymers
- Nanoparticles (silver, alumina, etc.)

Application
- Batch - Continuous - Roll to Roll
- Printable Electronics (Flexible)
- Photovoltaics
- Sensors
- Metamaterials
- Icephobic
- Hydrophobic
- Multifunctional (EMI, Structural)
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?