Polymer Chemistry

Chemical Analysis and Polymer Branch
Materials Science Division
Engineering and Technology Directorate
Kennedy Space Center, Florida

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Lab Overview

Mission

To develop and apply new technologies in polymer and material chemistry that benefit NASA's programs and mission

Team

2 NASA scientists, 1 co-op, and 4 contractors

Areas of Expertise

Polymer Nanocomposites
Next Generation Wire Materials
Carbon Nanotube and Nanofiber Materials
Conductive Polymers
Polymer Processing
Fire and Polymers
Foam and Insulation Materials

Numerous Collaborative Efforts

NASA Centers (JSC, LaRC, MSFC, GSFC, GRC)
KSC Directorates (Shuttle, Ares, Orion, Ground support operations)
Academia (Alberta, FIT, GT, Harding, Illinois-Urbana Champagne, UCF, UF, USF)
Industry Space Act Agreements (Thermax, DeWAL, Sharklet, Crosslink, Sabic, Amalgam)
Industry Contracts (ARCanano, Epner)
**What Are Polymers?**

**POLY MERS** are made of many **MONO MERS**

Many Units

One Unit

H H C=C / C=C H H

Ethylene

Polymerization

H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H H
1844
Charles Goodyear patents **vulcanization** process.

1907
Leo Bakeland created the first completely synthetic polymer, Bakelite (Phenol/formaldehyde).

1920
Vinyl Chloride resin mass production begins (Invented in 1835).

1930
Polystyrene mass production begins (Invented in 1839 by Eduard Simon).

1930s-40s
Polyethylene mass production begins.

1960s-70s
Kevlar and high performance polymer industries take off.

We now use more **plastic** than steel, aluminum and copper combined.
Composites/Materials Development at KSC

- Smart Materials and Detection Systems
- Self healing materials
- Flame retardant materials
- Aerogel composites
- Aerogel for environmental remediation
- Chemochromic hazardous gas detectors
- Antimicrobial polymers
- CNTs and conductive polymer technologies
Why Wiring?

- **Aged Wire**
  - Cracks and frays over time
  - Hard to detect damage
  - Extensive maintenance related damage during ground processing work

- **Space Shuttle Orbiter**
  - 183 miles of wiring buried deep within structure of vehicle
  - Difficult to manually inspect
Next Generation Wiring Materials

Wire System Failures

STS-93 (July 1999)
  Short circuit in 14 AWG Kapton® insulated wire
TWA 800 (July 1996)
  Frayed Kapton® wire in center tank area
SwissAir 111 (September 1998)
  Damaged wire in plane's entertainment system

Manual Repair Technologies for Kapton and Teflon wires

In situ Damage Detection systems for vehicle health monitoring

Self-Healing insulation
Wire System Materials

Insulation and Repair Materials

Present Wiring Repairs

Manual Repair Concept

Outer Insulation

Chemical Heater

Fusible Polymer

Insulation

Damaged Insulation

Repaired Insulation

Casting of wire repair materials

Laboratory Repair Process
Wire Systems Integration

- **Smart Connectors**
  - Small, lightweight, ultra reliable
- **In-situ wire damage detection system**
  - Capable of wire damage detection "on-the-fly"
- **Integrated vehicle health monitoring (IVHM)**
  - System-of-systems level, providing high level of reliability
Self-Healing Wire Repair

See Video
“Smart Wiring” Summary

• Early wire fault detection and self-repair includes the development of an *in situ* detection system to detect and locate an electrical compromise on an energized “live” wire.

• The *in situ* detection monitoring system uses Time Domain Reflectometry (TDR) to locate failures such as opens, shorts, and intermittent faults in existing wiring systems.

• A new wire construction that contains a conductive composite detection layer for early detection to wire insulation damage and self-healing capabilities are also included in this “Smart Wiring” system.

• Applicable to Game Changing Technologies, Cross-cutting Capabilities, Flagship Inflatable Technology Demonstrations, and 21st Century Launch Complex.

• Currently partnering with wiring industry and NAVAIR.
Fire and Polymers

- Flame retardant strategies
  - Polymethoxyamide derivatives for high temperature engineering polymers (patent issued)
  - Carbon nanotube synergistic FR properties
  - Polyhedral Oligomeric Silsesquioxanes (POSS) FR properties

- Fire risk consultation
  - Wire insulation
  - Thermal insulation
  - Ablator

- Fire standards and risk
  - Ares I
  - Ares V
  - Orion

\[
\text{Cl} - \text{O} - \text{Cl} + \text{NH}_2 \longrightarrow \text{NMP, L, Cl, } -10^\circ C
\]
Aerogel materials are generally silica based, lightweight materials, fully breathable, and treated to be super-hydrophobic.

Aerogel granules are free flowing, fills small cavities, does not compact, no preconditioning required, and can be molded or formed using binders.

Aerogel granules (Nanogel®) by Cabot Corp.:
- 90% porous with a mean pore diameter of 20 nm.
- Bead bulk density \(\approx 80 \text{ kg/m}^3\) (5 lbs/ft\(^3\)).
- Individual beads are fragile (shear), but have high elastic compression of over 50% with no damage.
- k-value \(\approx 18 \text{ mW/m-K @ 25°C and 760 torr.}\)
- [www.cabot-corp.com/nanogel](http://www.cabot-corp.com/nanogel)

Aerogel blanket (Spaceloft®) manufactured by Aspen Aerogels:
- Bulk density 6 to 8 lbs/ft\(^3\).
- k-value \(\approx 12 \text{ mW/m-K @ 38°C and 760 torr.}\)
- Use temperature range -273°C to 650°C (-459°F to 1200°F).
Aerogel Composites

AeroFoam - polyimide foam + aerogel
Enhanced thermal and vibration damping performance. Structural integrity to the aerogel and cryogen storage capabilities.

AeroPlastic – thermoplastic + aerogel
Extruded process, composite reducing heat transfer by 40-60%. Cryogen storage and transfer applications such as piping and seal.

Fiber/Textile+ aerogel structural composites
Aerogels for Oil Remediation

Superdome Cap Structure - Anibal Karban (NE-M)

Aerogels for Environmental Remediation

Why Aerogel?

Lightest solid known (80 kg/m³) – floats on water
High oil absorbency – 250 gallons/m³
Super-hydrophobic material (repels water)
Environmentally friendly – inert amorphous silica
Stable – long consistent service life, no UV degradation
Commerically manufactured in bulk quantities
Aerogel incorporated into mesh bag, blanket, or filled boon for easy deployment
KSC's Solution

- Cabot Nanogel: Commercial small business collaboration through existing SAA with NASA KSC
- $2800 per m³ = 250 gallons oil
- 60,000 barrels of oil released per day
- 480,000 miles of boons to be deployed off Florida coast
- Inventory of aerogel for oil recovery

<table>
<thead>
<tr>
<th>Domestic inventory</th>
<th>Europe inventory</th>
<th>Sustainable capacity per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m³</td>
<td>2000 m³</td>
<td>600 m³</td>
</tr>
<tr>
<td>25,000 gallons</td>
<td>500,000 gallons</td>
<td>150,000 gallons</td>
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</table>
A patent-pending irreversible color changing H₂ gas sensor was developed at KSC in partnership with UCF and ASRC.

Changes color from a light tan to black in the presence of H₂.

Can be manufactured into any polymer part, tape, fiber, or fabric material for unlimited potential uses.
- Paint, Gloves, Coveralls, PPE

Operates under ambient and cryogenic temperatures.

**Irreversible Sensor**

<table>
<thead>
<tr>
<th>% H₂</th>
<th>T = 0</th>
<th>T = 1</th>
<th>T = 2</th>
<th>T = 3</th>
<th>T = 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>AE = 0.0</td>
<td>AE = 1.54</td>
<td>AE = 0.97</td>
<td>AE = 13.48</td>
<td>AE = 21.93</td>
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<tr>
<td>5%</td>
<td>AE = 0.0</td>
<td>AE = 1.09</td>
<td>AE = 2.08</td>
<td>AE = 16.99</td>
<td>AE = 28.98</td>
</tr>
<tr>
<td>10%</td>
<td>AE = 0.0</td>
<td>AE = 0.55</td>
<td>AE = 10.45</td>
<td>AE = 28.39</td>
<td>AE = 32.90</td>
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<tr>
<td>50%</td>
<td>AE = 0.0</td>
<td>AE = 0.54</td>
<td>AE = 31.77</td>
<td>AE = 35.32</td>
<td>AE = 36.4</td>
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<tr>
<td>100%</td>
<td>AE = 0.0</td>
<td>AE = 1.30</td>
<td>AE = 24.27</td>
<td>AE = 37.37</td>
<td>AE = 37.47</td>
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</table>

**Reversible Sensor**

0 seconds 1.3 seconds 25 seconds
STI-129 Transfer Line

Chemochromic Hydrogen Sensors

LPA OMBUU Deployment for STS 117, 118, 120, 122, 123

STS-118 LOAD-1 HP SKID (H2CONC-B)
STS-130 and 131 Operations

Hydrogen vent lines on Pad A slope.

Hydrogen tape affixed with cable wire on flanges in TSM

Comparison of Delta E Values for Different Pigment Loads

Percent Irreversible Hydrogen Sensing Pigment in Teflon Tape

STS-130 H2 Pressure Flange A3362
Comparison of 1% and 5% by weight KAuCl₄ on different substrates.
Antimicrobial Materials

Shuttle Potable Water
(4) 170 lb Inconel bellow tanks
Iodine (3-4 mg/L)

ISS Potable Water
Stainless tubing
Ionic Silver Biocide

Orion Potable Water
(5) Inconel 718 Tanks (14.3 gal)
Miles of Titanium water lines
Antimicrobial Materials
In collaboration with Sharklet Technologies and UF

Surface Morphology and Surface Chemistry

- Efficacy studies after 21 days decreases biofilm formation
- Easy to imprint during manufacture of polymer articles through a coining process
- Can be used in conjunction with antimicrobial polymers
Microgravity Flight Experiments

BIOLOGICAL ANALYSIS

Confirm efficacy of Pseudomonas fluorescents bacteria species with Sharklet® topography coupons and different surface treatments

- How well does it work in μG and lunar G compared to 1G?
Conductive Inks Formulations for Multiple Applications

- Uses standard Inkjet printing technology
- 4pt probe used to measure resistivity or conductivity
- Formulations are solution blends; including carbon nanotubes, polymers and nanometallics. Patent application in work.
- Printing on multiple types of flat surfaces, including fabrics for dust screen technology
- Printing on curved surfaces for detection in process
Testing and Processing Equipment

• Fire Testing
  – Cone Calorimeter
  – Oxygen Index**
  – UL94 fire test
  – NASA Std 6001 fire test
  – Radiant Panel*
  – NBS Smoke Chamber*
  – Two foot tunnel*
  – Glow wire ignition*

• Cryogenic Materials Testing
  – Cryogenic moisture uptake (CMU)**
  – Brittleness/Impact test**
  – Liquid helium cold finger test**
  – Single Pin-Socket Krytox
  – Contamination Electrical
  – Characterization under Cryogenic
  – Conditions**

• Specialty Test Equipment

• Cellular Solid Analysis
  – Pycnometer (closed/open cell)**
  – Surface area measurement**

• Thermal Analysis
  – Thermogravimetric analysis (TGA)
  – Differential Scanning Calorimetry (DSC)
  – Dynamic Mechanical Analysis (DMA)

• Physical Testing
  – Tensile Test
  – Compressive Test
  – Pull/Peel Test

• Electrical Testing
  – 4-point probe
  – Surface/Volume resistance

• Polymer Processing capabilities
  – Extrusion
  – Injection molder
  – Fiber spinning equipment
  – Melt, ball, and high intensity mixers

*in collaboration with Cryogenics Test Laboratory
**in collaboration with Florida Tech
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QUESTIONS?