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Advanced Nanomanufacturing for Wearable Human Performance Monitoring Sensor Platforms

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Advanced Nanomanufacturing for Wearable Human Performance Monitoring Sensor Platforms

Jeffrey Morse, Managing Director
National Nanomanufacturing Network

James Watkins, Director
NSF Center for Hierarchical Manufacturing

Center for Personalized Health Monitoring
The Concept: Enabling a New Paradigm in Personalized Health Monitoring

### Home Health Monitoring Prevention and Intervention
- **Personal Health Monitoring**
  - Vital signs and medical information are measured and reported to local wireless hub.
  - Respiration, ECG
  - Lab-on-a-Chip: Measures drug levels, biomarkers
  - PPG, blood pressure, vascular performance
  - 3-axis accelerometer: Measures activity, falls

- **Real Time Medical Tracking**
  - Medical information is continuously monitored.

- **Health Care Providers**
  - Medical professionals can monitor in-home patients in real time.

- **First Responders**
  - Automatic notification in event of emergency.

### Biometrics, Human Augmentation and Performance Monitoring for Military
- **Stress/Fatigue**
  - Pocket Lab
  - Biomarkers

- **Biometrics**
  - EKG
  - Blood Pressure
  - Body Temp
  - Blood oxygen
  - Pulse/heart rate

- **Future Solutions**
  - Advanced Mobile Diagnostics
  - Intuitive Information Displays
  - Sensor-Incorporated Garments
  - Simple Go/No-Go Indicators

- **Trauma**
  - Impact
  - Blast
  - Chem/Bio Exposure

### Point-of-Care Chemical and Microfluidic Sensors

### Activity and Fitness Monitoring
- **New Paradigm for Patient Care Diagnostics**
- **Wireless Body Area Network**
  - Motion, vital signs, activity measured by various sensors and sent to a mobile device.
  - Respiration, ECG
  - Skin Temperature, Resistance
  - PPG, blood pressure, vascular performance
  - 3-axis accelerometer

- **Cellular Data Transfer**
  - Activity and workout data transferred in real time.

- **Information Storage**
  - Data is viewed by user on mobile device, personal computer, or stored in database.

- **Personal Computer**
- **Central Database**
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**Home Health Monitoring Prevention and Intervention**

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**Young Athlete Safety**

- **Monitor Cumulative Impact and Return Risk Score**
  - alerts for immediate removal from play & assessment
- **Monitor Fatigue, Stress, Hydration**
  - establish return to play, rest and recovery guidelines
- **Optional Sport-Specific Performance and Effort Monitoring**

**Point-of-Care Chemical and Microfluidic Sensors**

**New Paradigm for Patient Care Diagnostics**

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CPHM will Catalyze New Opportunities
UMass Amherst Center for Personalized Health Monitoring and Biometric Sensors Utilizes CHM Process Platforms

- The Commonwealth of Massachusetts has earmarked $90,000,000 in capital funds for life sciences research in Western Massachusetts

- The University of Massachusetts Amherst was awarded $46,000,000 in capital funds to establish the Center for Personalized Health Monitoring (CPHM)

- The CPHM uses material and process platforms developed by the CHM

The CPHM will include the $25,000,000 Center for Advanced Roll-to-Roll Manufacturing for the Life and Nano Sciences, an open access facility that will deploy leading edge technology and pilot tools for sensor systems, packaging and associated flexible electronics platforms and enhance University-Industry partnerships. This Center is built upon and has been enabled by advances in the CHM.
Mission

To be a world-leading research, partnership and demonstration facility for accelerating the commercialization of low-cost, multi-function, wearable, wireless sensor systems for personalized health care and biometric monitoring.

Focal point for an interdisciplinary center at UMass Amherst that:

• Innovates and develops sensor systems in partnership with industry through a vertically integrated process

• Develops novel bio, chemical, electronic, and nano personal health sensor designs using low cost manufacturing platforms

• Designs for low-power, wireless networking, on-board memory and optimum form factor

• Evaluates and test in controlled but highly realistic conditions

• Bridges sensor design, human interaction and informatics to inform health care trends and utilization

• Foster Massachusetts leadership in health care delivery and an emerging biomedical device field
Comprehensive, Synergistic Initiative for Maximum Impact to Massachusetts Life Science Industry

- Sensor Technology
- Imaging Technology
- Wireless Technology
- Information Technology
- Manufacturing Technology
- Point-of-Care Testing

Low-Cost, High-tech, Wearable Wireless Sensor Systems For Health Monitoring
The CHM is Systematically Resolving Critical Barriers to Cost-Effective, Continuous Manufacturing of Nanotechnology-Enabled Devices

Focused Research Initiatives to:

1. Enable large area, continuous manufacturing platforms including roll-to-roll
2. Create new materials and process methodology to enhance performance
3. Organize nanostructured active layers by self-assembly of hybrid materials (3-100 nm length scale)
   - nanoparticles, fullerenes, nanorods, nanotubes
4. Develop high speed, continuous patterning processes for devices on a web (50-5000 nm features)
5. Employ solution-based processing, eliminate vacuum and high T
6. Utilize additive approach where possible
7. Integrate devices and systems
8. Build tools for partner access and technology demonstration
One Goal: Integrated Low-Cost, Flexible Device or Patch

The NSF Center for Hierarchical Manufacturing is developing nanotechnology-enabled and high-performance, hybrid device layers for advanced device fabrication using novel R2R platforms and tools. These advances can be combined with silicon-chip pick-and-place assembly for expanded sensor platform capability.

Personalized Health Monitoring

- **Personal Health Monitoring**
  - Vital signs and medical information
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Real-Time Medical Tracking

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Distributed Sensing

Networks & Security

Building and Infrastructure

Integrated Systems
Additive-Driven Self Assembly Enables Practical Fabrication of Devices

- Incorporation of nanoparticles, nanorods in well ordered materials
- Enabled by strong polymer-particle interactions
- Additive loadings greater than 70 wt.%
- Domain sizes from 3 nm to 125 nm – extends self-assembly for optical and meta materials
- Nanoparticle sizes up to 15 nm - extends self-assembly for quantum dots, plasmonics
- Integration of self-assembled layers in devices
- Large-area coating

Self-Assemble Layers in Devices
ex. Floating Gate Memory

Additive Approach, Solution-Processable

Ordered Structures at Length Scales from 3 to 125 nm
Spontaneous Assembly from Solution, Complete Control of Morphology
UV-Assisted Nanoimprint Lithography and New Resist Technology for Large-Area Patterning of Functional Devices

- Developed new roll-to-roll UV-NIL tool with industry partner, 6” web width
- Features as small as 50 nm at feet-per-minute rate
- Development of new nanoparticle based resists for printing of directly patterned crystalline metal oxide films (conductors and dielectrics)
- Creation of anti-microbial and ultrahydrophobic surfaces
- Complete R2R fabrication of sensors and optical materials
- Development of in-line metrology with MIT and NIST

Rapid, Continuous Patterning of Features > 50 nm on Robust, Scalable Platform
New Resist Materials Enable New Applications
Polymer Nanoparticle Hybrids for Solution Processing of Optical and Electronic Devices

- Tune materials properties by controlling NP loading
- Example at right shows refractive index tuning of a nanoparticle polymer system
- Control of NP-polymer interactions enable particle loadings up to 90 wt.%
- Hybrids can be used as planar device layers (high k dielectrics)
- Hybrids can be used as inks for patterning and printing processes (e.g. ink jet or NIL)
- Solution processable in CHM Nanocoater

RI Control in NP/Polymer Hybrid

<table>
<thead>
<tr>
<th>NP Concentration ↑</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 wt% TiO₂ NPs</td>
<td>2.1</td>
</tr>
<tr>
<td>80 wt% TiO₂ NPs</td>
<td>2.0</td>
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<tr>
<td>70 wt% TiO₂ NPs</td>
<td>1.9</td>
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<td>1.7</td>
</tr>
<tr>
<td>40 wt% TiO₂ NPs</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Printing of Optical and 3-D Photonic Structures

Device Layers for Printed Electronics

Additive Approach, Solution-Processable

Provide Alternatives to Batch Processes and High T and Vacuum
Enable Large-Area Processing of Devices
CHM Examples: Devices and Device Layers

Ordered Metamaterials

PV Heterojunctions

Device Architectures on Flex

- Many applications require large active areas
- Both morphology control and morphological stability are needed

Printed Hybrid and Inorganic Nanostructures
Many applications require large active areas. Both morphology control and morphological stability are needed.
The NSF Center for Hierarchical Manufacturing is developing nanotechnology-enabled and high-performance, hybrid device layers for advanced device fabrication using novel R2R platforms and tools. These advances can be combined with silicon-chip pick-and-place assembly for expanded sensor platform capability.
DoD Currently Supports UMass Amherst’s R2R Biosensor Research

National BioNano Manufacturing Consortium
Air Force Research Laboratory
• UMass Amherst is a founding member
• Project Goals: Demonstrate a micro-fluidic biosensor system implemented in a flexible/conformal platform for the purpose of detecting analytes accessible through intimate contact with skin.

Dynamic Multifunctional Materials for a Second Skin
Defense Threat Reduction Agency
• $13 million project; $1.8 million to UMass Amherst
• Designing materials and manufacturing processes for breathable soldier garments protecting against chemical/biological agents

Ongoing Program Support:
DOD/DARPA/DTRA are Significant Drivers and Funders of Printed Intelligence Platforms including Biometric Sensors
Wearable Paper-Based Microfluidic Biomarker Sensor Patch

- **UMass Amherst** (J. Watkins, J. Morse, V. Rotello, S. Nugen)
- **GE Global Research** (A. Alizadeh, R. Potyrailo, N. Nagraj, L. Carr, B. Li, J. Ashe)
- **U. Cincinnati** (J. Heikenfeld)
- **AFRL** (J. Hagen)
UMass Amherst Team Will develop Microfluidic Subsystem For Measurement of Stress/Fatigue Biomarkers from Sweat

**Detection Platforms**
- Bio-recognition Element Attachment
- Zinc Oxide FET
- Resonance Impedance RF
- Performance Screening

**Paper Microfluidics**
- Non-Specific Binding Prevention
- Sweat Flow Control - EW Valves

**Sub-System Integration**
- Sweat Stimulator
- Paper Microfluidics
- Detection Platform
- Hand-Crafted Integration
- Prototype Demonstration
- Performance Screening

**Manufacturing**
- R2R processing
- Inkjet Printing
- Substrate Integration

**Roadmaps Towards Full System Development**
- TRL / MRL Evaluation
- Dual-use Product Strategy
- Market Analysis
- Biomarker + Biometric Sensor Integration
- Manufacturing Pathway
- Collaborations and Joint Development

**Development Partners:** General Electric Corp.
University of Cincinnati
Bio-recognition element (OABP)

UMass: Universal design and synthesis of linker for bio-recognition element attachment to the sensor surface

- Carboxylate for biomolecule conjugation
- Zwitterionic headgroup antifouling
- OEG spacer biocompatibility biomolecule stabilization
- Siloxane attachment stable, versatile
Electrowetting Valves on Paper Fluidics Enable Accurate Sample Acquisition Over 24-72 Hour Period

Application of valves in the detection of nucleic acids in lateral flow assays.

a) Visualization of the flow of the “sample” (red dye) and “buffer” (blue dye)
b) Valves incorporated in the lateral flow assay. A positive result is shown.

i. Sample pad
ii. Conjugate pad
iii. Positive test line
iv. Positive control line
v. Absorbent pad

vi. Hydrophobic electrode/valve
vii. Hydrophilic electrode
viii. Buffer pad
ix. Wire/Negative terminal
x. Wire/Positive terminal
Large Area Antimicrobial Textured Layers

NIL and R2RNIL Challenge: Can we replicate Sharklet pattern?

PFPE daughter mold from 6 inch master
Mold Preparation:
• Negative of Sharklet features on 6 inch wafer was replicated on to PFPE on PET hybrid mold

Substrate Treatment:
• PET web was coated with an adhesion agent then a photoresist layer was applied
• This PET pre-treatment improves the quality of imprinted features in long runs

R2RNIL Conditions:
• Resist: NOA adhesive - 40 v/v % in PGMEA
• Speed: Imprinter was run at 10 -12 inches / minute
• Exposure at 365 nm
R2R Research and Demonstration Facilities

EXISTING R2R TOOLS

*R2R Test Frames/Tools*
- One high speed coater, 6”
- One R2R system with coater, 6”
- Coating heads: Gravure, Slot-die

*Related Processing/Metrology Tools*
- Stand-alone gravure coater
- 3 nanoimprinters
- 1 plasma etcher
- In-line NIL

$25M IN NEW R2R TOOLS AND FACILITIES READY BY 2015-16

- Five coaters and nanoimprint lithography tools, 6” to 12”, featuring gravure, slot-die, flexographic, and inkjet heads
- In-line tools for UV annealing/sintering, CVD/graphene, PEVCD, ALD, layer-by-Layer wet assembly, nanoimprint lithography, and metrology
- Ovens, wet etch, dry etch/RIE, sputter deposition, flow coating, spin coating, inkjet print
- Optical inspection/microscopy, particle counter, ellipsometry, profilometry, atomic force microscopy, electrical testing
- UV/IR/solar permeation/transport
- Dry room, controlled emissions, inert atmosphere
- Secondary processes: slitting/cutting, layer release/transfer, integration/bonding/assembly