May 20th, 11:00 AM

Advanced Nanomanufacturing for Wearable Human Performance Monitoring Sensor Platforms

Jeffrey Morse
*University of Massachusetts - Amherst*

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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

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

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

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

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

**Activity and Fitness Monitoring**

- **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

**New Paradigm for Patient Care Diagnostics**
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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**

**New Paradigm for Patient Care Diagnostics**
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 tests 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

Industry R&D Partnerships
- Manufacturing Demonstration Facility
- Regional Engagement
- Technology Innovation
- Industry R&D Partnership
- Workforce Development

Research Programs
- Research Partnerships
- Spinoffs & Licensing

Education & Training Program

Test Bed Pilot Lines
- Patient Interface
- Informatics
- Health Care Utilization
- Patient Behavior
- User Studies
- Hospital Interface
- Field Testing and Validation

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.

Solar PV Energy Harvesting

Signal Processing Communications Interface / Wireless

Sensor(s): nanoparticle, microfluidic, accelerometer, biomarker

Nanoparticle /Metamaterial Antenna/RFID

Li+ Energy Storage

Macroelectronic Flex Substrate

Floating Gate Memory

Personalized Health Monitoring

Distributed Sensing Networks & Security

Building and Infrastructure Integrated Systems

Personal Health Monitoring

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Respiration, ECG

Lab-on-a-Chip

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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

High Loadings, Large NPs, Large Periods

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
Polymer Nanoparticle Hybrids for Solution Processing of Optical and Electronic Devices

RI Control in NP/Polymer Hybrid

- 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

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

Printed Hybrid and Inorganic Nanostructures

- Many applications require large active areas
- Both morphology control and morphological stability are needed
Bio-Mimetic Anti-Microbial Surfaces

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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

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

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

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
Sensor Surface Functionalization and Bio-Recognition Elements

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

- Carboxylate for biomolecule conjugation
- Zwitterionic headgroup for antifouling
- OEG spacer for biocompatibility and biomolecule stabilization
- Siloxane attachment for stable, versatile attachment

Right side:
- Bio-recognition element (OABP)
- Drain current vs. Orexin A concentration graph
- Custom FET with components integrated onto a flexible PCB
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