May 20th, 11:00 AM

Advanced Nanomanufacturing for Wearable Human Performance Monitoring Sensor Platforms

Jeffrey Morse
University of Massachusetts - Amherst

Advanced Nanomanufacturing for Wearable Human Performance Monitoring Sensor Platforms

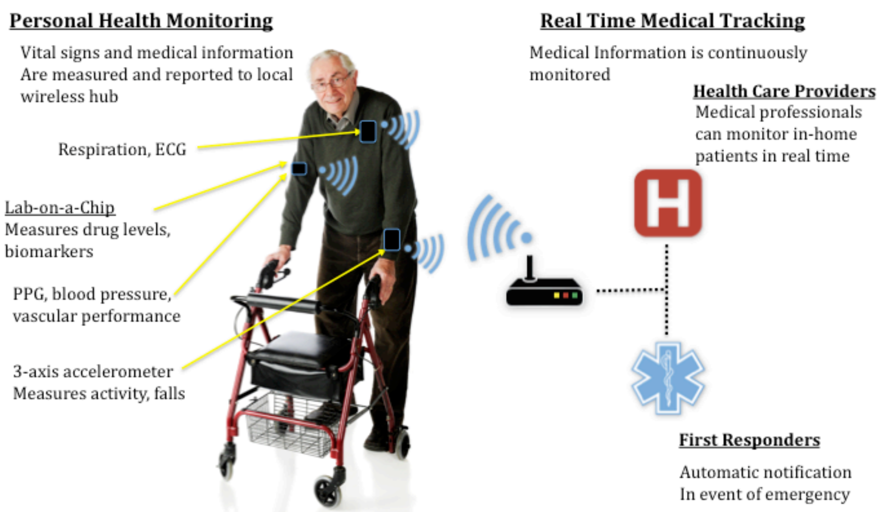
Jeffrey Morse, Managing Director
National Nanomanufacturing Network

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



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

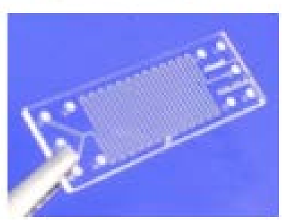
Advanced Mobile Diagnostics
Intuitive Information Displays
Sensor-Incorporated Garments
Simple Go/No-Go Indicators

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

Point-of-Care Chemical and Microfluidic Sensors

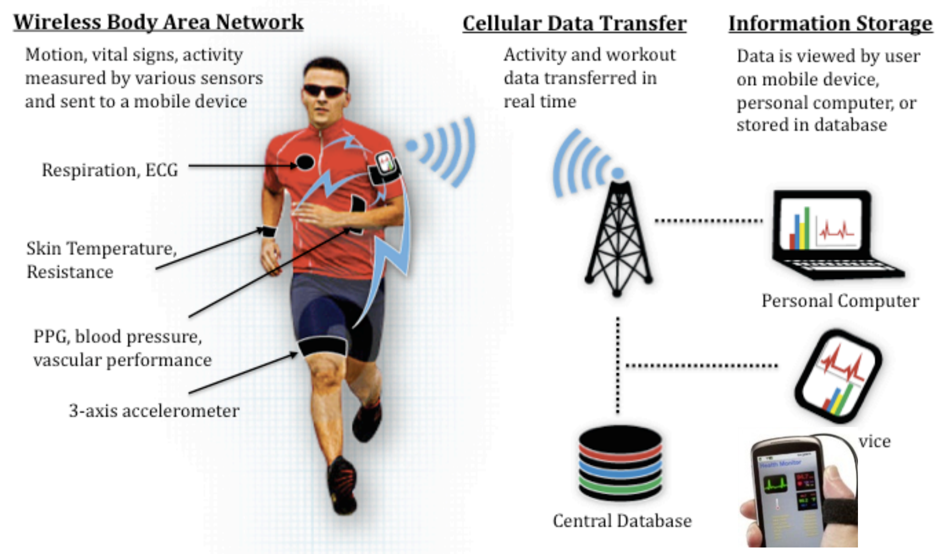






New Paradigm for Patient Care Diagnostics

Activity and Fitness Monitoring



The Concept: Enabling a New Paradigm in Personalized Health Monitoring

Home Health Monitoring Prevention and Intervention

Personal Health Monitoring

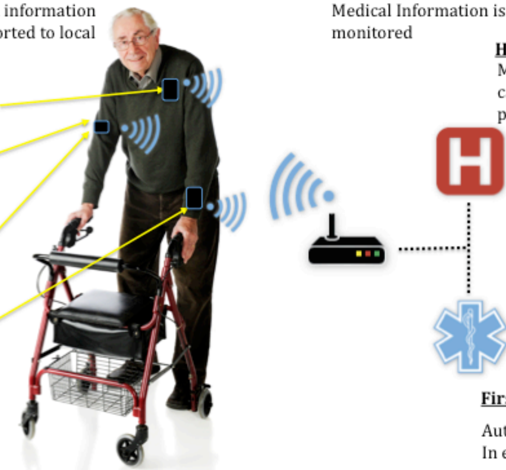
Vital signs and medical information Are measured and reported to local wireless hub

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

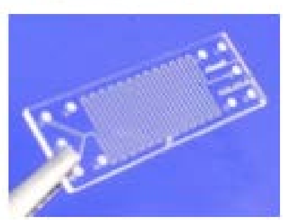
First Responders

Automatic notification In event of emergency

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

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

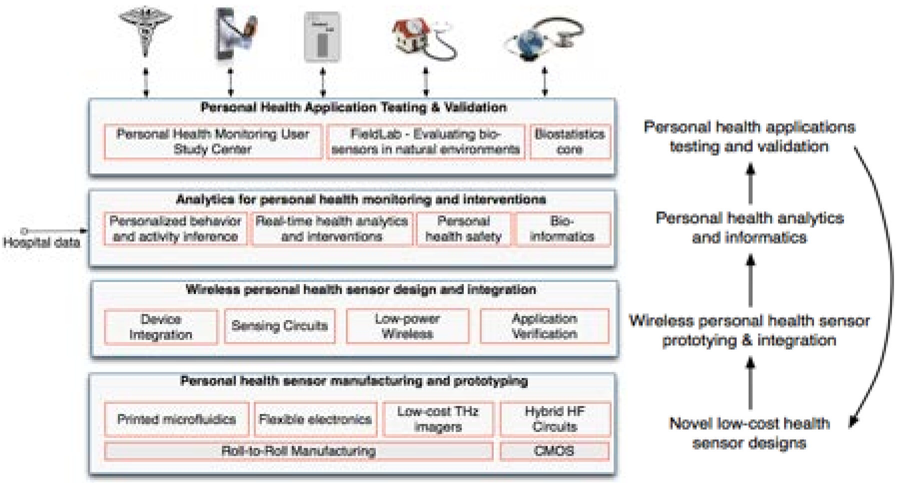
Personal Computer

vice

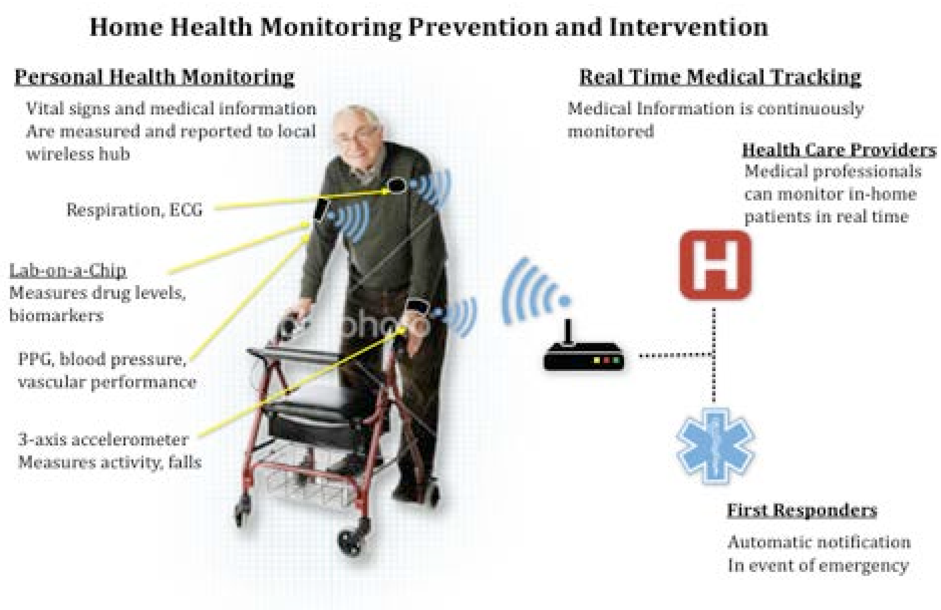
Central Database

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. <u>This Center is built upon and has been enabled by advances in the CHM.</u>

CHM
Center for Hierarchical Manufacturing
University of Massachusetts Amherst

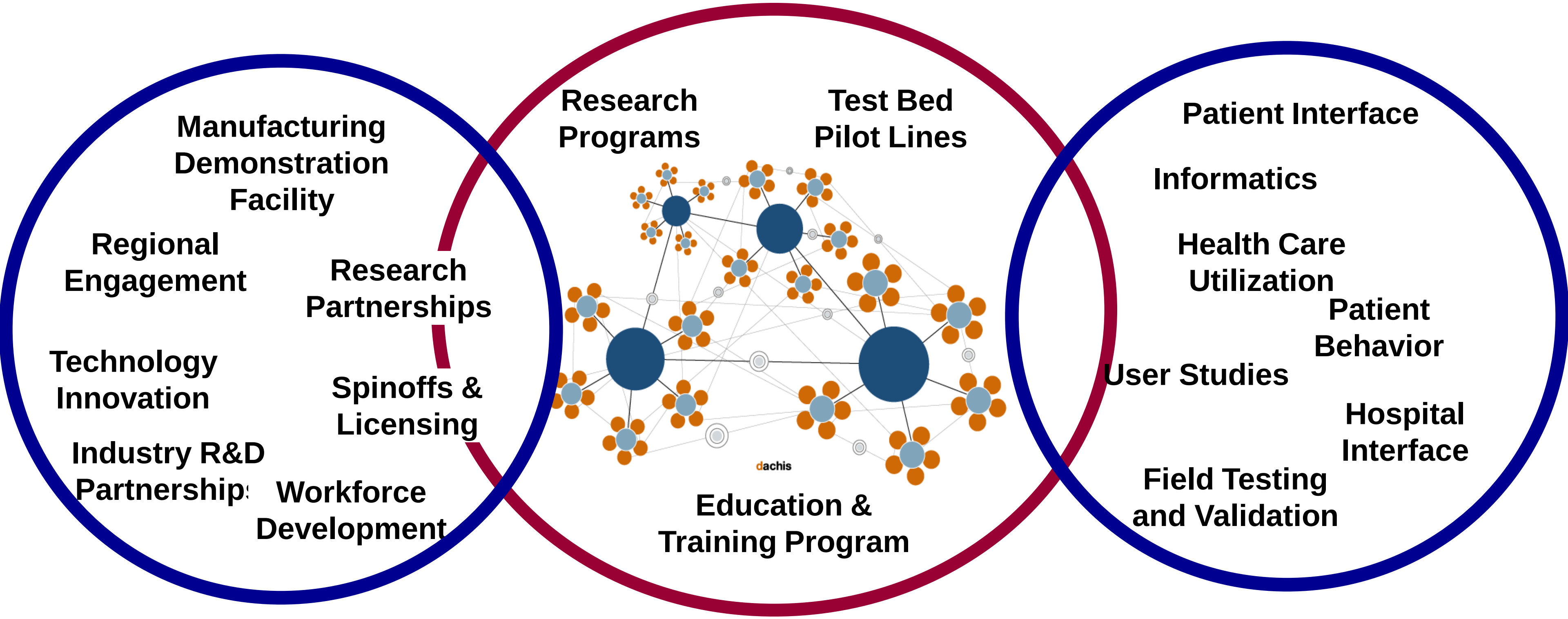
Mission

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

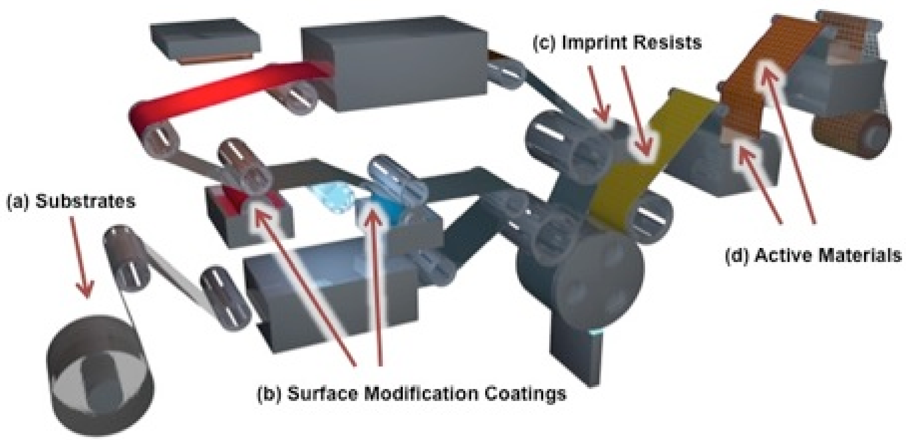


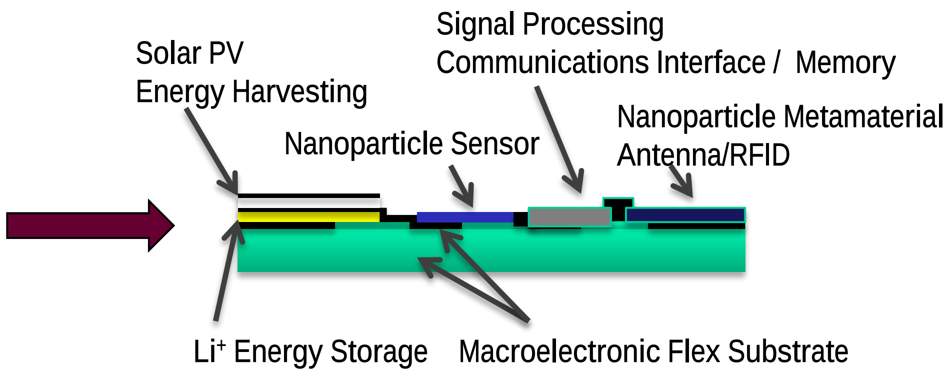
Sensor Technology
Imaging Technology
Wireless Technology
Information Technology
Manufacturing Technology
Point-of-Care Testing

→

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

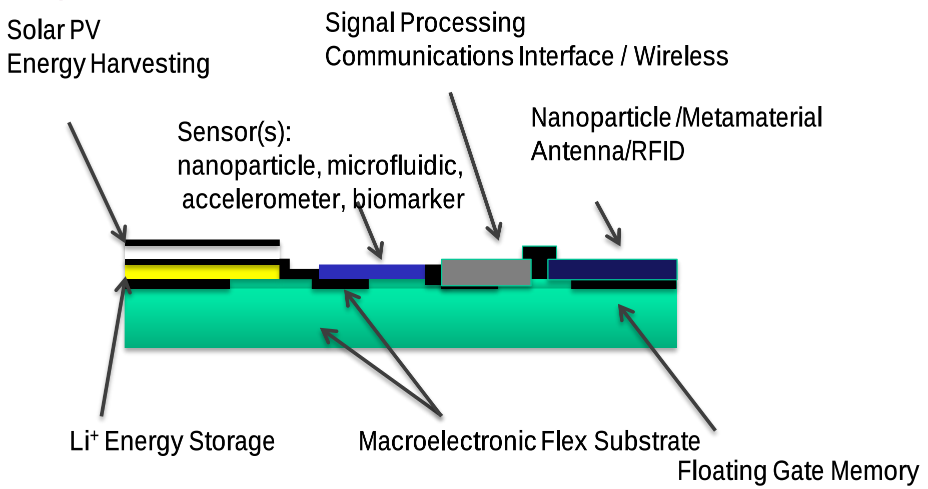




Focused Research Initiatives to:

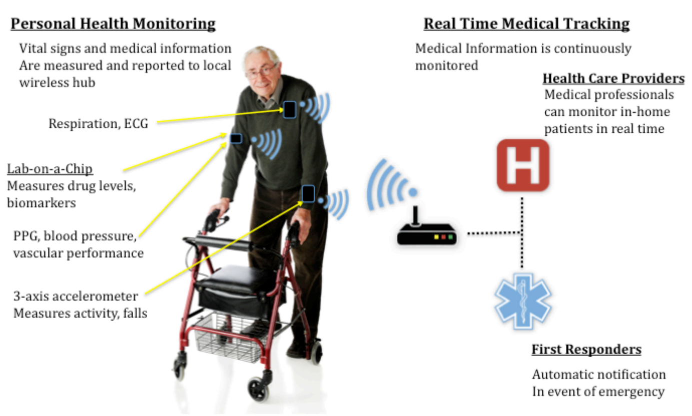
1. Enable large area, continuous manufacturing platforms including roll-to-roll
2. Create new materials and process methodology to enhance performance
3. Organize nanostructured active layers by self-assembly of hybrid materials (3-100 nm length scale)
   - nanoparticles, fullerenes, nanorods, nanotubes
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

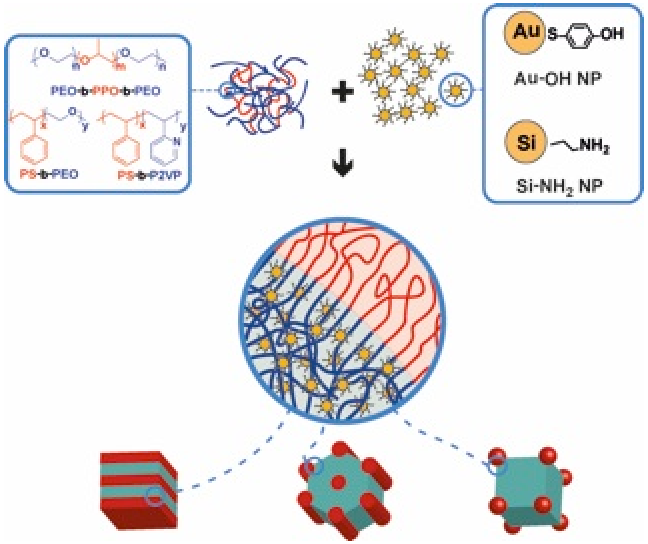
Personalized Health Monitoring



Distributed Sensing Networks & Security

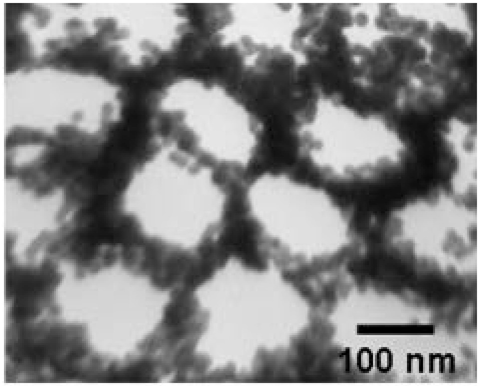
Building and Infrastructure Integrated Systems

Additive-Driven Self Assembly Enables Practical Fabrication of Devices

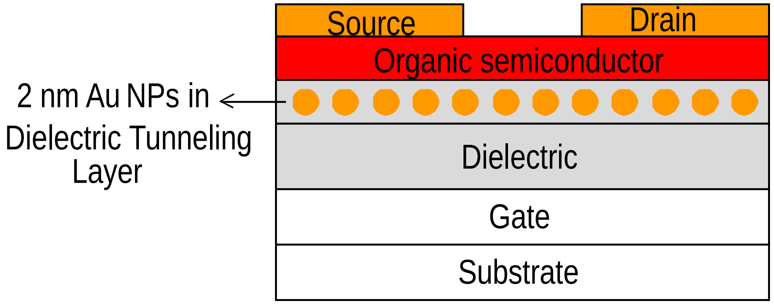


- Incorporation of nanoparticles, nanorods in well ordered materials
- Enabled by strong polymer-particle interactions
- Additive loadings greater than 70 wt.%
- Domain sizes from 3 nm to 125 nm – extends self-assembly for optical and meta materials
- Nanoparticle sizes up to 15 nm - extends self-assembly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

High Loadings, Large NPs, Large Periods



Self-Assemble Layers in Devices ex. Floating Gate Memory



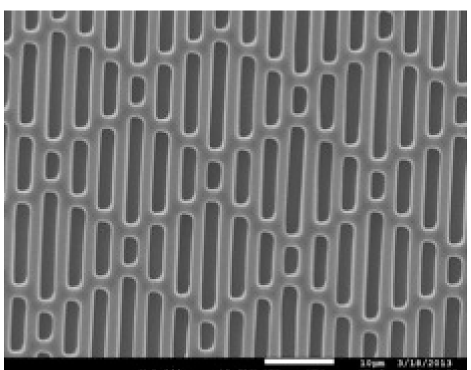
Additive Approach, Solution-Processable

Ordered Structures at Length Scales from 3 to 125 nm
Spontaneous Assembly from Solution, Complete Control of Morphology

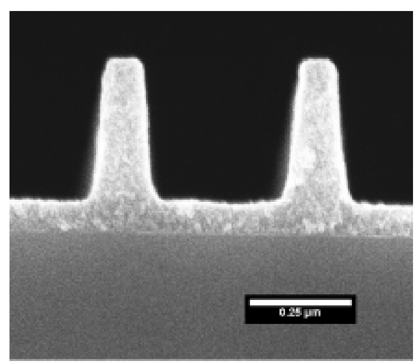
UV-Assisted Nanoimprint Lithography and New Resist Technology for Large-Area Patterning of Functional Devices

- 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

Patterned Surfaces and Devices



Direct Printing of Crystalline Metal Oxides



All R2R Fabrication of THZ Sensors

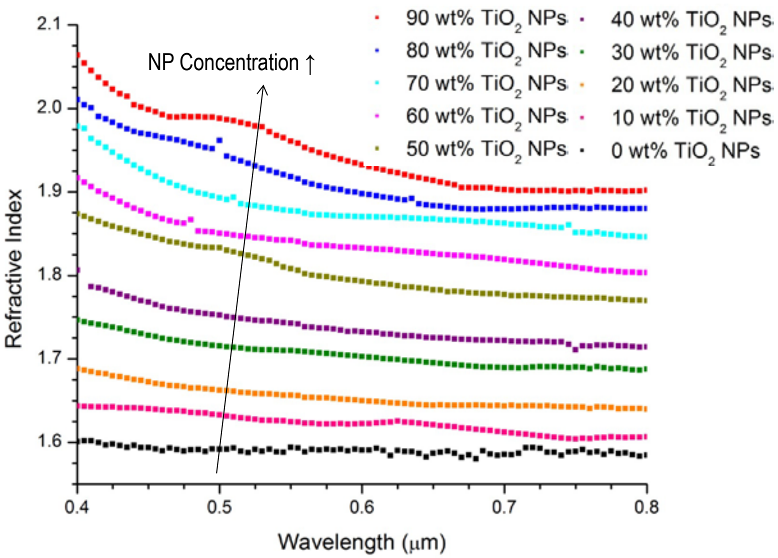
Rapid, Continuous Patterning of Features > 50 nm on Robust, Scalable Platform

New Resist Materials Enable New Applications

CHM
Center for Hierarchical Manufacturing
University of Massachusetts Amherst

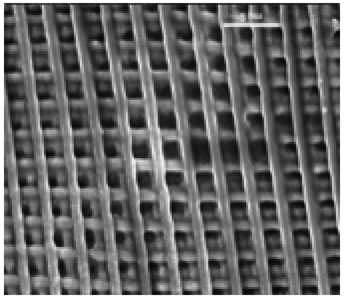
Polymer Nanoparticle Hybrids for Solution Processing of Optical and Electronic Devices

RI Control in NP/Polymer Hybrid

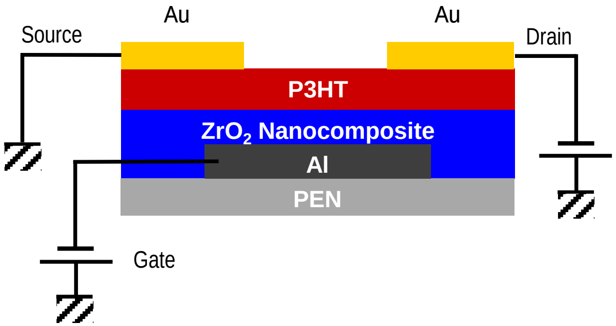


- Tune materials properties by controlling NP loading
- Example at right shows refractive index tuning of a nanoparticle polymer system
- Control of NP-polymer interactions enable particle loadings up to 90 wt.%
- Hybrids can be used as planar device layers (high k dielectrics)
- Hybrids can be used 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



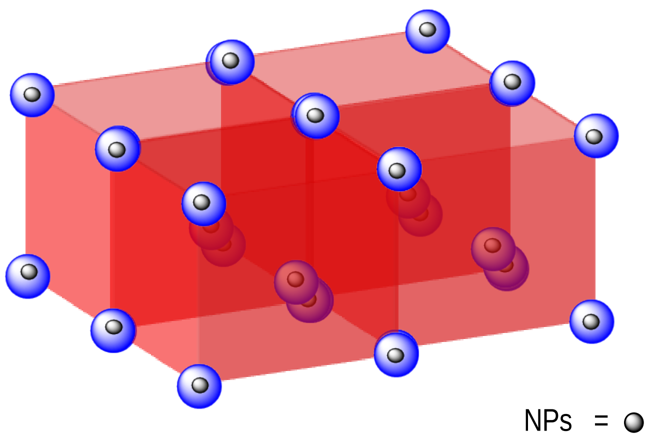
Additive Approach, Solution-Processable

Provide Alternatives to Batch Processes and High T and Vacuum Enable Large-Area Processing of Devices

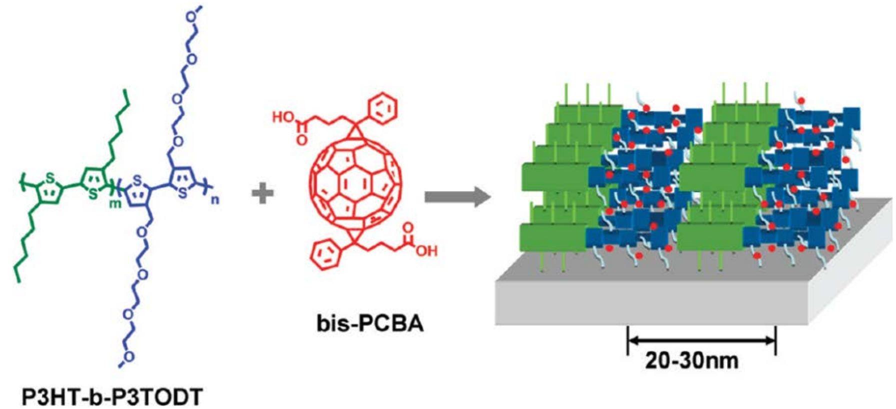
CHM
Center for Hierarchical Manufacturing
University of Massachusetts Amherst

CHM Examples: Devices and Device Layers

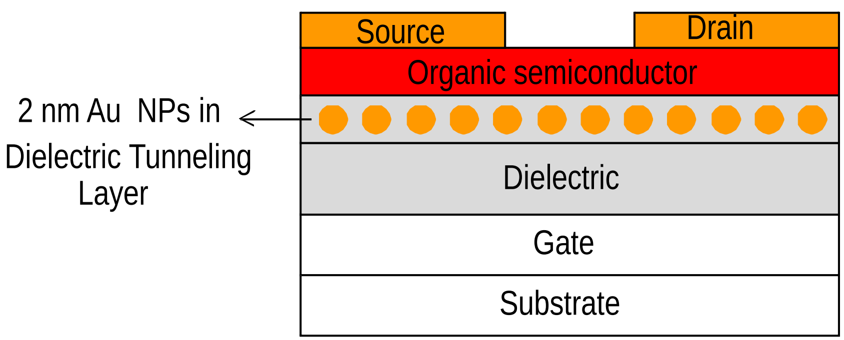
Ordered Metamaterials



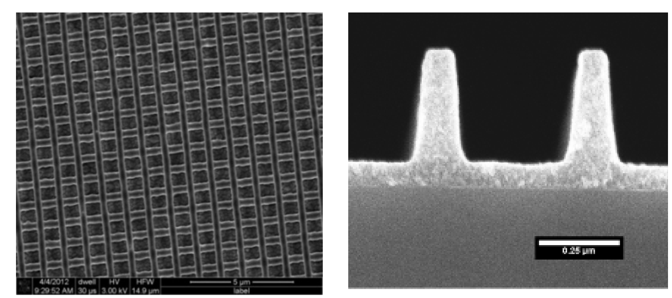
PV Heterojunctions



Device Architectures on Flex



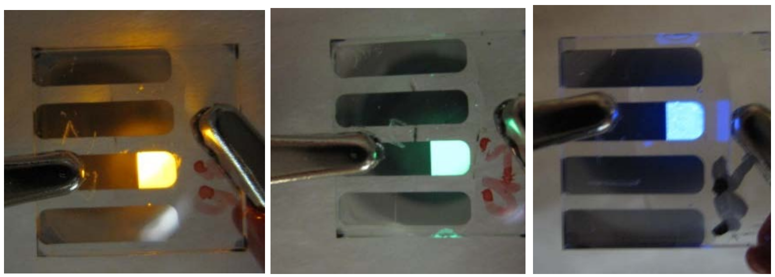
Printed Hybrid and Inorganic Nanostructures



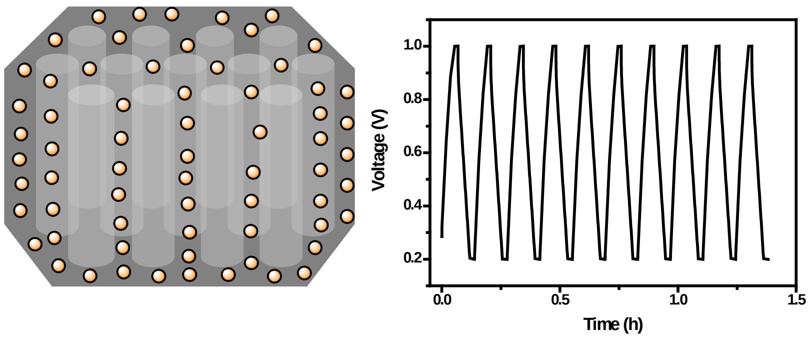
- Many applications require large active areas
- Both morphology control and morphological stability are needed

CHM Examples: Devices and Device Layers

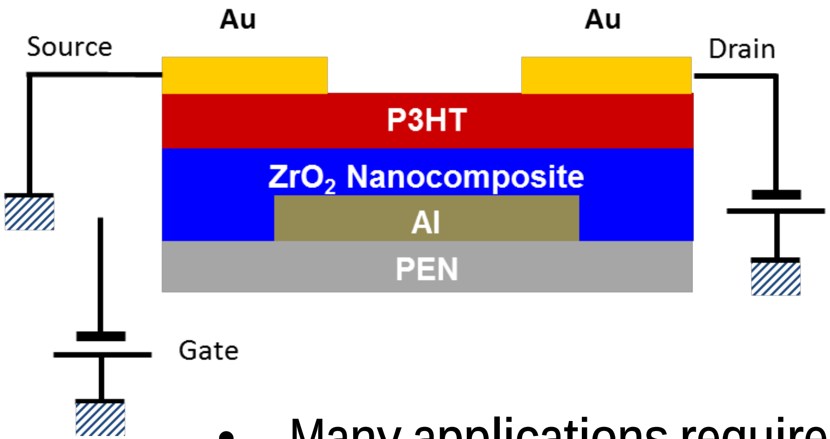
QD-Based LECs



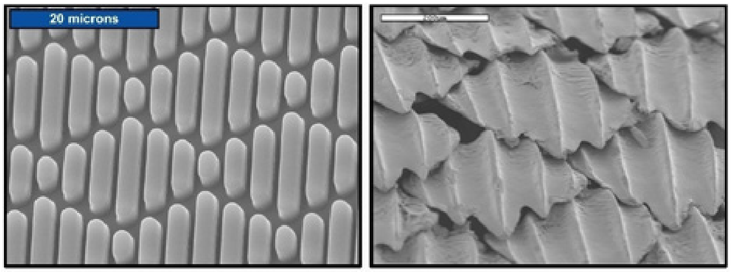
Nanostructured SuperCaps



Solution Coat-able High K



Bio-Mimetic Anti-Microbial Surfaces

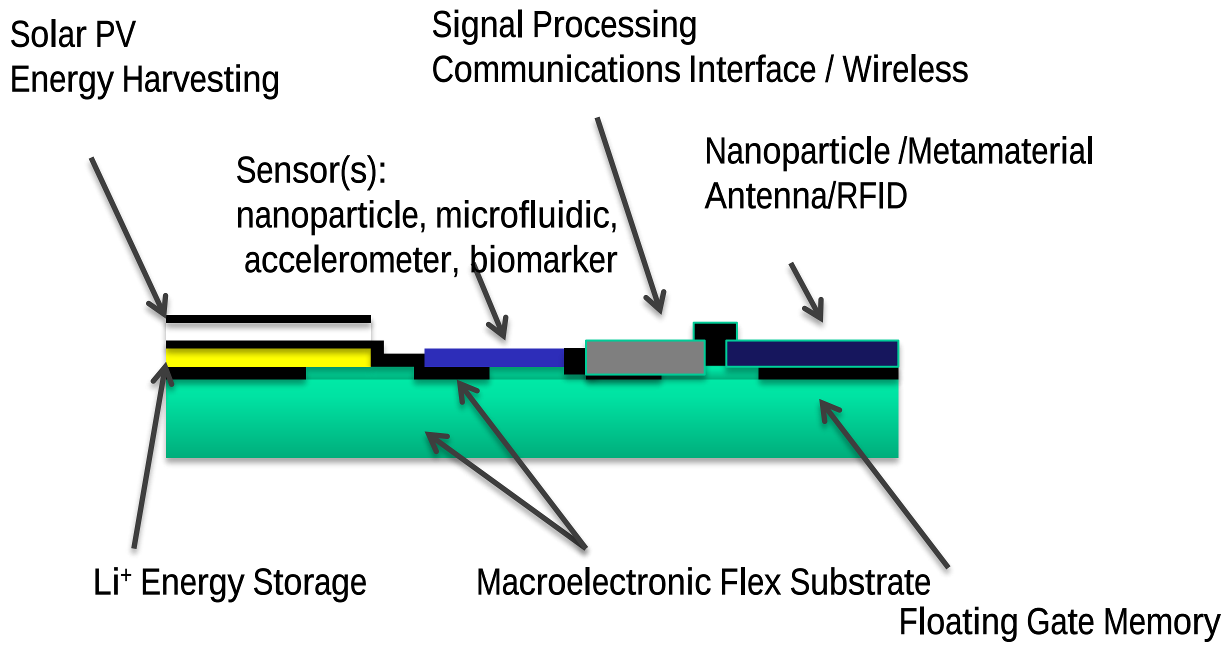


Sharklet™ Surface Technology *Galapagos Shark Skin*

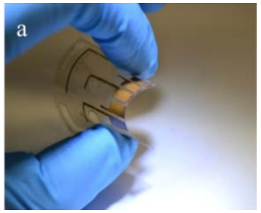
- Many applications require large active areas
- Both morphology control and morphological stability are needed

CHM Center for Hierarchical Manufacturing University of Massachusetts Amherst

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



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)

UMassAmherst

CHM Center for Hierarchical Manufacturing

University of Cincinnati

Novel Device Lab

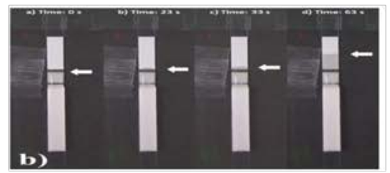
GE imagination at work

Air Force Research Laboratory

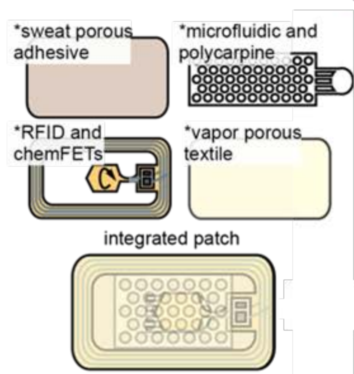
UMass Amherst Team Will develop Microfluidic Subsystem For Measurement of Stress/Fatigue Biomarkers from Sweat

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

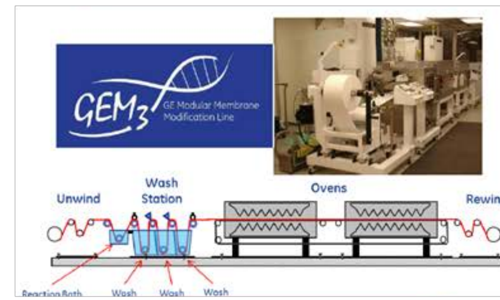
Paper Microfluidics
-Non-Specific Binding Prevention
-Sweat Flow Control- EW Valves



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



Manufacturing
-R2R processing
-Inkjet Printing
-Substrate Integration

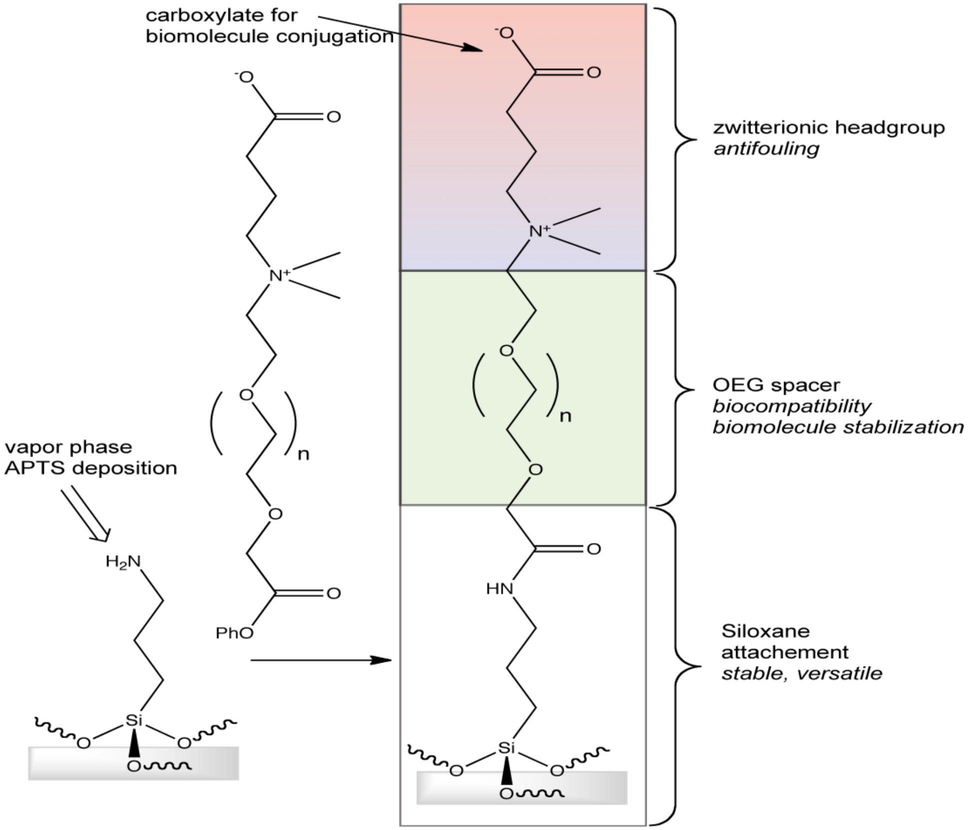


Roadmaps Towards Full System Development
-TRL / MRL Evaluation
-Dual-use Product Strategy
-Market Analysis
-Biomarker + Biometric Sensor Integration
-Manufacturing Pathway
-Collaborations and Joint Development

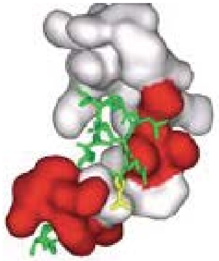
Development Partners: General Electric Corp.
University of Cincinnati

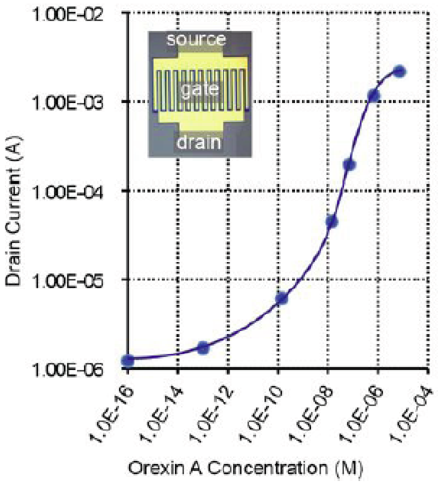
Sensor Surface Functionalization and Bio-Recognition Elements

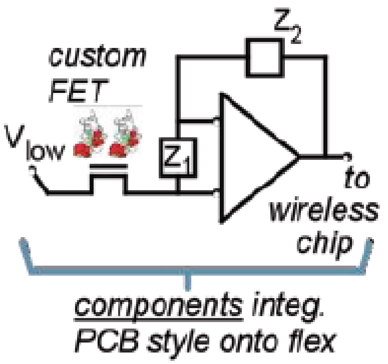
UMass: Universal design and synthesis of linker for bio-recognition element attachment to the sensor surface



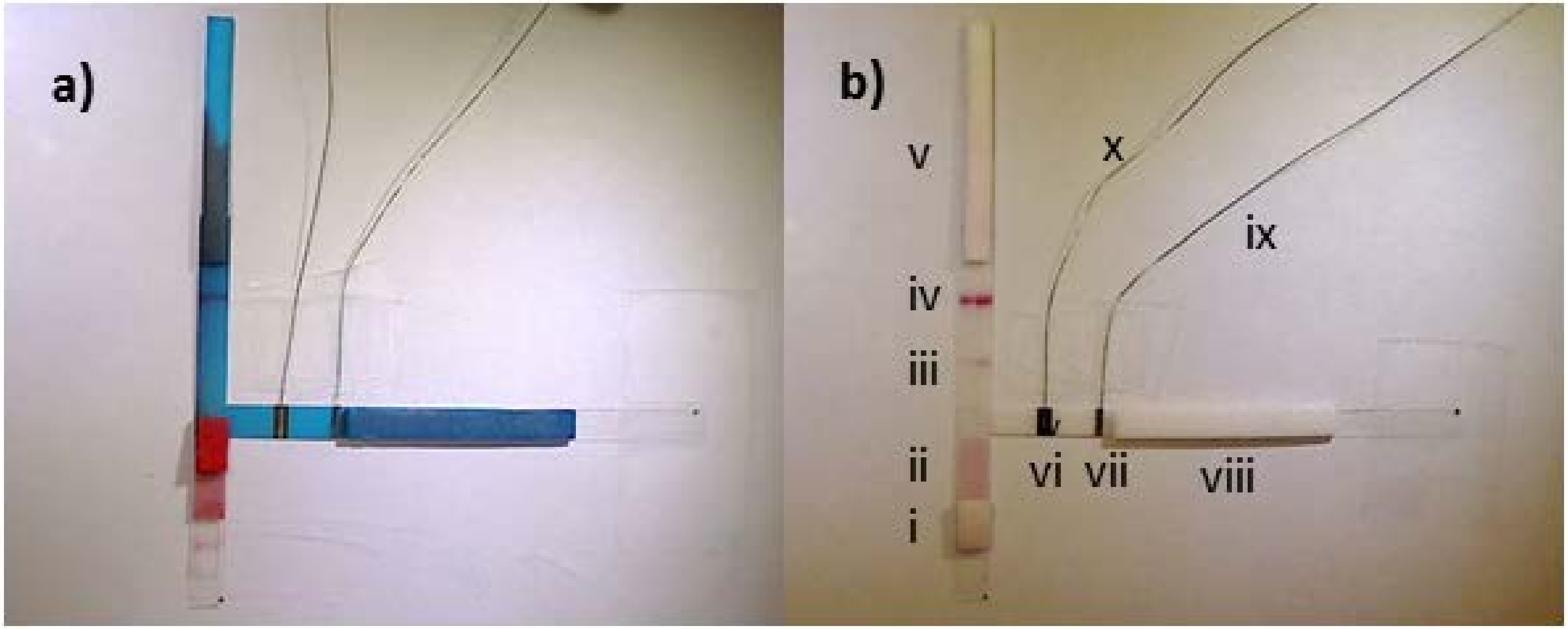
Bio-recognition element (OABP)







Electrowetting Valves on Paper Fluidics Enable Accurate Sample Acquisition Over 24-72 Hour P{eriod



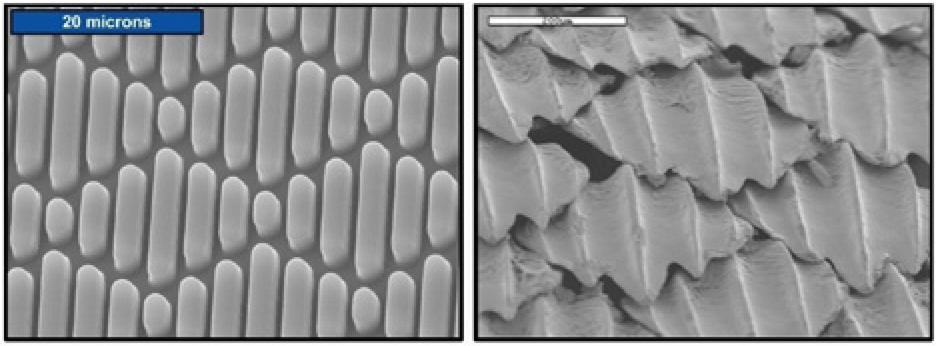
Application of valves in the detection of *nucleic acids* in lateral flow assays.

a) Visualization of the flow of the “sample” (red dye) and “buffer” (blue dye)

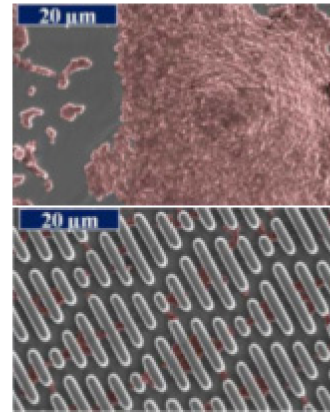
b) Valves incorporated in the lateral flow assay. A positive result is shown.

- 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

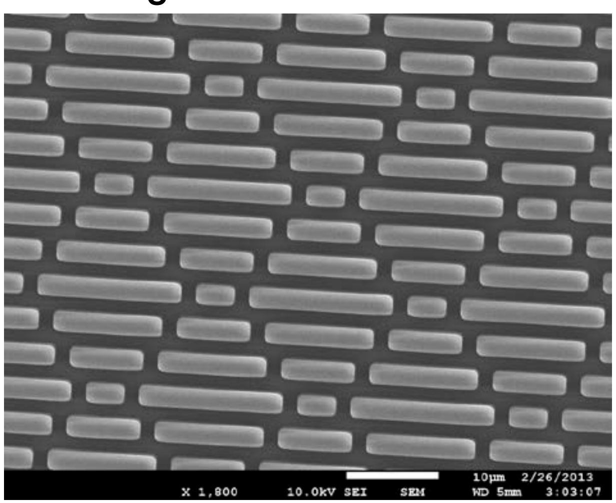


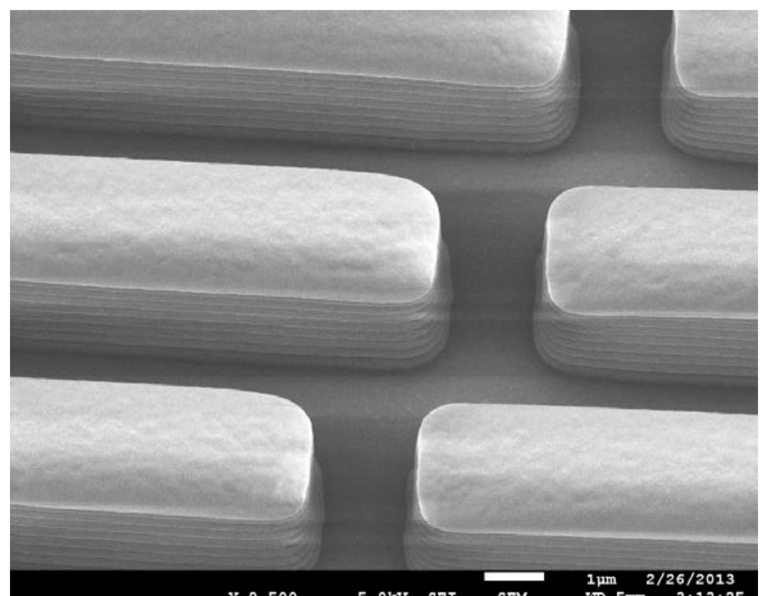
Sharklet™ Surface Technology *Galapagos Shark Skin*



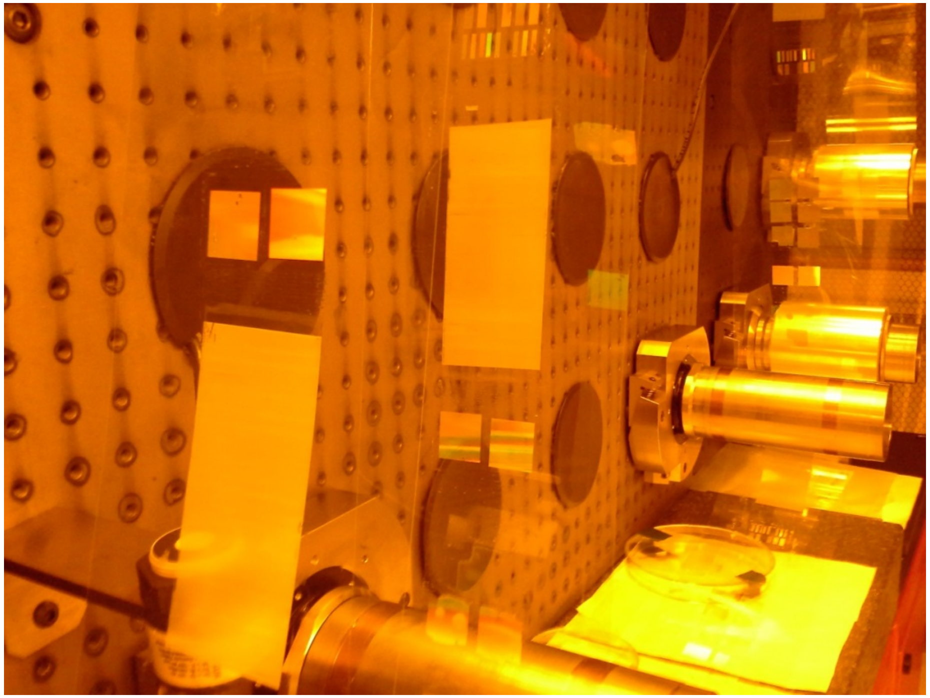
NIL and R2RNIL Challenge: Can we replicate Sharklet pattern?

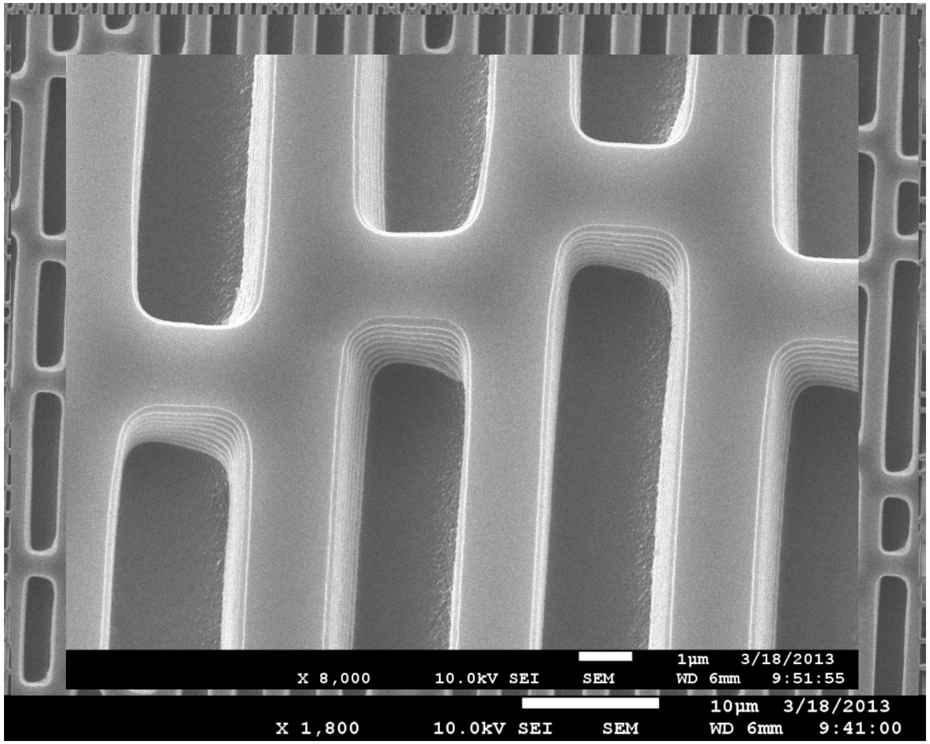
PFPE daughter mold from 6 inch master





R2RNIL on CHM Nanoemboss





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

Sharklet™ Technologies, Inc.

R2R Research and Demonstration Facilities

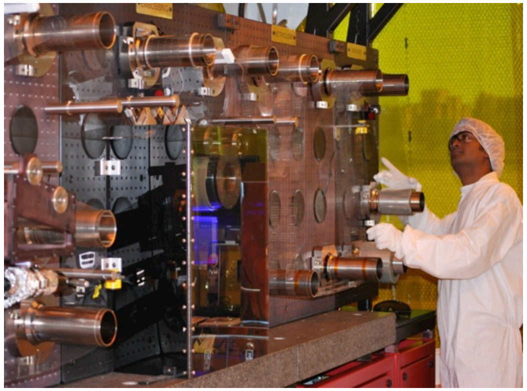
EXISTING R2R TOOLS

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