InterPACK Workshop
Flexible Hybrid Electronics Packaging Needs and Manufacturing Methods

June 20, 2016

Jason Marsh
Director of Technology
Process for Formulating NNMI

2011
- Report to the President on Ensuring American Leadership in Advanced Manufacturing (NSTC)
- A National Strategic Plan for Advanced Manufacturing (NSTC)

2012
- National Network for Manufacturing Innovation: A Preliminary Design (NSTC & AMPO)

2013
- Report to the President: Accelerating U.S. Advanced Manufacturing (PCAST)

2014
- Revitalize American Manufacturing and Innovation Act of 2014

2015
- Passed House: Sept 15, 2014
  - 100 CoSponsors (51D, 49R)
- Passed Senate w/ 2015 Appropriations: Dec 11, 2014
  - 18 CoSponsors (10D, 7R, 1I)

Rep Tom Reed R NY-23
Sen Sherrod Brown D Ohio
Rep Joe Kennedy D MA-4
Sen Roy Blunt R Missouri

December 16, 2014
RAMI Bill & NNMI Signed by President
ESTABLISHED INSTITUTES

- Nearly $500M Federal funding catalyzed over $1.2B cost share from consortia
- Institutes have attracted hundreds of companies and universities as active partners from across the country

INSTITUTES IN DEVELOPMENT

- Smart Mfg. for Energy Efficiency
- Topic TBA

Other Institutes in Planning:

Open topic competition – addressing “white space” between mission agency topics

Selected topic competitions supporting Agency mission – using agency authorities and budgets
Establishment of NextFlex

Established | 28 August 2015
Lead | FlexTech Alliance
Hub Location | San Jose, California
Proposal Contributors | 145+ in 27 states
Federal Funding | $75 million over 5 years
Committed Matching | $96 million
Government Agencies Engaged | 17 DOD & OGAs
Disparate FHE Capabilities
- Centers of excellence with world class capabilities; Project-based interaction
- Evolved out of established, once US-led technologies

MII Funding Helps Connect Manufacturing
- Silicon Valley hub provides critical mass to "pull" industries together
- Fills missing infrastructure in modeling, design, new assembly, and test
- Creates links between today's separate capabilities, existing assembly and end-user needs
- FHE leverages other industry eco-systems and marketing channels
- Relationships and communications ensures efficiencies in investments
### Technology Readiness Levels (TRLs)

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
<th>MRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic principles observed and reported</td>
<td>1</td>
<td>Manufacturing feasibility assessed</td>
</tr>
<tr>
<td>2</td>
<td>Technology concept and/or application formulated</td>
<td>2</td>
<td>Manufacturing concepts defined</td>
</tr>
<tr>
<td>3</td>
<td>Analytical and experimental critical function and/or characteristic proof of concept</td>
<td>3</td>
<td>Manufacturing concepts developed</td>
</tr>
<tr>
<td>4</td>
<td>Component and/or breadboard validation in a laboratory environment</td>
<td>4</td>
<td>Capability to produce the technology in a laboratory environment</td>
</tr>
<tr>
<td>5</td>
<td>Component or breadboard validation in a relevant environment</td>
<td>5</td>
<td>Capability to produce prototype components in a production relevant environment</td>
</tr>
<tr>
<td>6</td>
<td>System/subsystem model or prototype demonstration in a relevant environment</td>
<td>6</td>
<td>Capability to produce prototype system or subsystem in a production relevant environment</td>
</tr>
<tr>
<td>7</td>
<td>System prototype demonstration in an operational environment</td>
<td>7</td>
<td>Capability to produce systems, subsystems or components in a production relevant environment</td>
</tr>
<tr>
<td>8</td>
<td>Actual system completed and qualified through test and demonstrated</td>
<td>8</td>
<td>Pilot line capability demonstrated; Ready to begin Low Rate Initial Production</td>
</tr>
<tr>
<td>9</td>
<td>Actual system proven through successful mission operations</td>
<td>9</td>
<td>Low rate production demonstrated; Capability in place to begin Full Rate Production</td>
</tr>
</tbody>
</table>
Flexible Hybrid Electronics

- Novel Form Factors
- Light-weight, rugged
- Low-cost approaches through new manufacturing
- Enabling novel-sensing capabilities

NextFlex is supporting a wide range of DoD missions

DOD EXAMPLES

Flexible ubiquitous Sensors

Conformable, compact, lightweight, flexible, low-power electronics and sensors

Bio-marker sensors (AFRL)
FHE IOT Building Blocks

- Sensor
- Power
- Transceiver
- Processor/Memory

- Size
- Weight
- Cost
- Life
Time vs Trigger Domain

- Device Cost to Information Value Ratio
- Monitor Reliably for the Intended Use Window
- Disposal is Considered in Design
- Improve Performance or Health of User
- Unobtrusive Form Factor
Why FHE?

- Flexible
- Stretchable
- Conformable
- Transparent
- Biocompatible
- Lightweight
- Cost Effective
<table>
<thead>
<tr>
<th>Power</th>
<th>Datalink</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form Factor</td>
<td>Duty Cycle</td>
<td>Temperature</td>
</tr>
<tr>
<td>Energy Density</td>
<td>Standby Protocol <em>(wakeup time)</em></td>
<td>EM Radiation</td>
</tr>
<tr>
<td>Charge Capacity</td>
<td>Baud Rate</td>
<td>Contact Impedance</td>
</tr>
<tr>
<td>Voltage</td>
<td>Connectivity Distance</td>
<td>Optical Response <em>(fluorescent assays)</em></td>
</tr>
<tr>
<td>Operating Temperature</td>
<td></td>
<td>Accelerometer/Strain</td>
</tr>
<tr>
<td>Bend Radius</td>
<td></td>
<td>Analytes</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td>Gas</td>
</tr>
<tr>
<td>Time Stability <em>(Leakage)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposable <em>(REACH, RoHS, etc)</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Form Factor
- Energy Density
- Charge Capacity
- Voltage
- Operating Temperature
- Bend Radius
- Cost
- Time Stability *(Leakage)*
- Disposable *(REACH, RoHS, etc)*

- Duty Cycle
- Standby Protocol *(wakeup time)*
- Baud Rate
- Connectivity Distance

- Temperature
- EM Radiation
- Contact Impedance
- Optical Response *(fluorescent assays)*
- Accelerometer/Strain
- Analytes
- Gas

- **Datalogging**
  - 6LoWPAN
  - 802.15.4
  - ANT
  - Bluetooth
  - Bluetooth low energy *(Wibree)*
  - DASH7
  - ISA100.11a
  - MiWi
  - NFC

- **Sensor Applications**
  - OCARI
  - ONE-NET
  - OSIAN
  - Thread
  - TIBUMAC
  - TSMP
  - WirelessHART
  - ZigBee
  - Z-Wave

- **Material Properties**
  - Temperature
  - EM Radiation
  - Contact Impedance
  - Optical Response *(fluorescent assays)*
  - Accelerometer/Strain
  - Analytes
  - Gas
The Problem with Pure PE

- Unimpressive Mobility @ Operating Temp
- VT Shift
- It works in Display?
  - $2 \times 10^{-9}$ Duty Cycle
- Amorphous Silicon/Metal Oxides
- Polymer
- Carbon Nanotubes/Graphene (promising mobility)

Photo: imec HPE
Challenges

- Temperature
- Resolution
- Substrate Flex or Stretch
- Bio Compatible Materials
Printing (& Curing)

- Aerosol Jet
- Inkjet
- Extrusion
- Screen
- Gravure
- Photonic
- Thermal
- Catalytic
Thinning

- Carrier Bond
- Edge Trim to Eliminate Bevel
- Mechanical Grind
- CMP
- Plasma
- Bumping
Singulation

- Dicing & Edge Cleanup
- Plasma Singulation
- Femtosecond Laser
Die Handling

- Tape Frame/Reel
- 15-50 µm thick die
- 3,000-20,000 CPH
Integration

- Conductive Adhesive
- Solder
- ACF/ACP
- Thermo-Compression
- TLPS Materials
- Direct Print
- Wirebond?
Integration @ 50µm
Differentiating from Subtractive
Conformal Antennas

Photos: Si2, Optimec, Dupont
Can’t Live with Low Temp?

- Flexible Glass (500°C)
- Flexible Ceramics (1000°C)
Integrated Lines

Print, Die Placement, Ablation, Etch, Bonding, Encapsulation
Display Production Capability

- AMAT Cluster Machines
  - Over 900 of these installed worldwide
  - Entry price $5M
  - High operating cost
  - Vacuum deposition & CVD

R2R CVD for advanced flexible electronics
### 3D Printing & FHE

<table>
<thead>
<tr>
<th>Material</th>
<th>Metal</th>
<th>Polymer</th>
<th>Dielectric</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Module</td>
<td>Inkjet</td>
<td>Extrusion</td>
<td>SLA</td>
<td>SLS</td>
</tr>
<tr>
<td>Lighting</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Auto</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Medical</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Photos: Holst Center
Challenges For Smarter Devices

- Pin count, bond pitch
- Power consumption, thermal management
- Device value and reliability requirements
- Signal integrity for additive materials
Strategic Road-mapping Framework

“What” we do
- Led by Tech council
- Strong end-user participation
- Demos describe “What” the institute is doing in manufacturing
- Revised annually

“How” we do it
- Industry Led at WG level
- Clear boundaries, detailed roadmaps and deliverables feeding into TPDs
- Develop “How” – gap analysis
- Drive Project Calls
- Revised semi-annually

In March we had 660 attendees at FLEX2016 from Industry, academia, government (FTA run)
Technical Working Groups: 140 participants focused on the Roadmapping
### Human Monitoring Systems

<table>
<thead>
<tr>
<th>Year</th>
<th>Medical</th>
<th>Extreme Performance</th>
<th>Occupational</th>
<th>Wellness</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>Wearable vital sign monitors for clinical decision making; Smart bandages for wound monitoring and healing</td>
<td>Wearables sensors for performance monitoring - hydration, electrolyte, gait, impact (sensors for helmet, knee/elbow pads), injury event; tactile display for sensory substitution; Also relevant for occupational exertion area</td>
<td>Wearable sensors for monitoring cognitive load attention, and sleep deprivation; indicating proper use of personal protection equipment - all industrial and military application</td>
<td>Wear and Forget (such as instrumented wardrobe) health and wellness status-check system akin to the “check engine light”</td>
</tr>
<tr>
<td>2017</td>
<td>Wearable non-invasive sensors for body temperature, fluid-based biomarkers, and ultrasound sound sensors for infectious and chronic disease monitoring</td>
<td>Wireless injury event warning system for first responders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>Wearable sensors for protein bio-marker for stress, fatigue, infection; drug metabolite sensing for optimal delivery; rehab assisting device</td>
<td>Smart patches for soft tissue monitoring to assess micro stress strain and fatigue of musculo-skeletal and vascular systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>Wearable smart monitoring system for rehabilitation assistance</td>
<td>Smart adaptable athletic wear for temperature and pressure control</td>
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<tr>
<td>2020</td>
<td></td>
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<td></td>
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<tr>
<td>2021</td>
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<tr>
<td>2022</td>
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</tbody>
</table>
NextFlex Program Construct

Project Call Process Flow

- **Working Groups Industry, Govt, Academia**
  - Mfg processes cross-cutting with TPDs
  - TPDs used to demo mfg processes

- **Technical Council Industry, Govt, Academia**
  - Cross-reference common mfg requirements
  - Identify specific necessary gaps
  - Propose % Institute Allocations & Projects

- **Governing Council Industry, Govt, Academic**
  - Decide on allocation
  - Balance long-term strategy

Institute’s Pilot Line

- **Capabilities**
  - Mfg consistent
  - Low volume
  - Complimentary to industry and members
  - Significant for long-term sustainability
  - Provide service to projects
Growing a Lean and Flexible Workforce Program – Nationally and Locally

NextFlex coordinated meeting between San Jose Workforce Investment Board and Bestronics

NextFlex coordinated HS tour of the Jabil Blue Sky Center

5 Focus Areas
- FHE Materials Scale Up
- Thinned Device Processing
- Device / Sensor Integrated Printing / Packaging
- System Design Tools
- Reliability Testing & Monitoring

Initiated Taxonomy Study
Kicked off coordination for Internship and Apprenticeship Pilots in OH and CA
Hacking 4 Defense pilot programs
Commenced Outreach Tours within the Hub Region

Outreach
Education / Employment
Apprenticeships
Internships
Hacking 4 Defense
Operating in FHE environments
Innovating in FHE environments
K-12 Full Spectrum TRL Tours
FabLab

Project Calls
Year 1 Pilots
Taxonomy

Hacking 4 Defense
Roadmap Identified Several Areas of Capability Gaps for FHE SOA

- Placement of Flexible Die
- Interconnect of Flexible Die
- Design & Modelling Software
- Ability to print circuits on 3D surfaces
- Stretchable circuits
- Additionally we took AMS and IAA TPD

Result: 13 topics launched and down-selected to 7 technical topics

<table>
<thead>
<tr>
<th>MTA-2</th>
<th>Ultra-Thin Die Assembly for FHE Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTA-4</td>
<td>Registration Methods for FHE</td>
</tr>
<tr>
<td>MTA-8</td>
<td>FHE Process Design Kit 1.0</td>
</tr>
<tr>
<td>MTA-11</td>
<td>Mechanical Test Methods</td>
</tr>
<tr>
<td>MTA-9</td>
<td>Materials Database</td>
</tr>
<tr>
<td>MTA-5</td>
<td>Printing On Topography</td>
</tr>
<tr>
<td>MTA-10</td>
<td>Stretchable Conductors</td>
</tr>
<tr>
<td>MTA-6</td>
<td>Real Time Metrology</td>
</tr>
<tr>
<td>MTA-3</td>
<td>Multi-Technology Printing Tool</td>
</tr>
<tr>
<td>MTA-1</td>
<td>Ultra-thin Die Preparation for FHE Assembly</td>
</tr>
<tr>
<td>MTA-7</td>
<td>Roll to Roll Expanded Capability</td>
</tr>
</tbody>
</table>

- PC Topic 2.1: Ultra-Thin Die Assembly for FHE Systems
- PC Topic 2.2: Multi-Process Integration Tool with Real Time Metrology
- PC Topic 2.3: Printing On Complex Surfaces
- PC Topic 2.4: FHE Process Design Kit (Phase 1)
- PC Topic 2.5: Mechanical Test Methods
- PC Topic 2.6: Flex-Hybrid Array Antenna
- PC Topic 2.7: Asset Monitoring for Time Critical Inventory
- PC Topic 2.8: Failure Modes in Wearable Performance Monitors
- PC Topic 2.WFD: Stand Alone Work Force Development [Topic 2.9]
Project Call Milestones

- **Institute Fast Start** – delivers fastest path to first Project Call
  - 67 days from award to PC1.0 release
- **11/5/15** – PC 1.0 Launched
  - 3 Topic Areas (Human and Asset Monitoring)
  - $5M in Federal Funding
- **12/15/15** – PC 1.0 – 70 Pre-Proposals Received
  - Broad geographic diversity in lead institutions
  - 21 Industrial leads
  - 70 Industrial partners
- **2/26/16** – PC 1.0 - 17 Full Proposals Received
- **4/15/16** – PC 1.0 - 8 Proposal Advanced to Development Agreements
- **5/5/16** – PC 2.0 Launched
  - 9 Topics for PC 2.0 with WFD
  - $10M in Federal Funding
- **5/11/16** – PC 2.0 Kickoff Webinar – 80+ registrants
- **6/6/16** – PC 2.0 Pre-Proposals Received – 60 Proposals
- **6/17/17** – PC 2.0 Pre-Proposals Down-selected for Full Proposal Invitation
NextFlex HQ Layout

- **Assembly Area (class 10,000 Clean Room)**
- **Test and Measurement Lab (class 10,000 Clean Room)**
- **Seminar, Training and Workforce Development**
- **Design Lab**
- **Printing and Additive Processing Area (class 10,000 Clean Room)**
- **Mechanical Lab**
- **Wearables Lab**
- **Materials Library**
- **Materials Registry**
- **Lobby**
- **Conf Board Room**
- **Ship Receive**
- **Break Room**
- **Lunch Room**
- **Cubicles**
- **Screen Exp**
- **Printing and Additive Processing Area (class 10,000 Clean Room)**
- **Nitrogen**
- **Conf**
More Information

www.NextFlex.us

Contact: Paul Semenza, Director of Commercialization
Phone: 408-797-2231
Email: psemenza@nextflex.us