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Changing Your World One Flexible Chip at a Time

2018 FLEX

Complex Flexible Hybrid Electronic Labels

2018FLEX Session 9.1: Flexible Electronics Applications

14 February 2018

NEXTFLEX

AIR FORCE RESEARCH LABORATORY

BOISE STATE UNIVERSITY

Doug Hackler
President & CEO

The Motivation

Labels are cheap - used everywhere, but not very bright

Temperature trackers work great
- but are very expensive

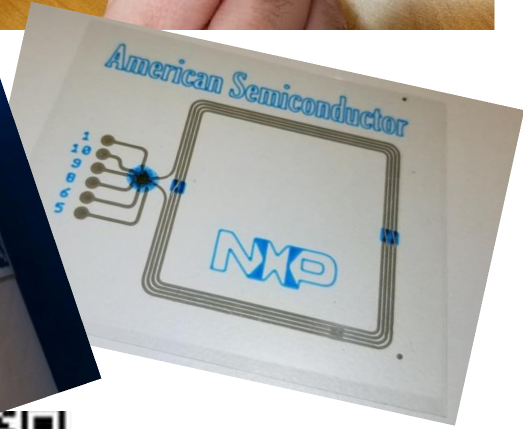
$62.50

$32.00

$49.49

The Goal

Labels/Trackers that are Intelligent (smart), Flexible, Conformal, Wireless, Inexpensive and Easy for everyone's use



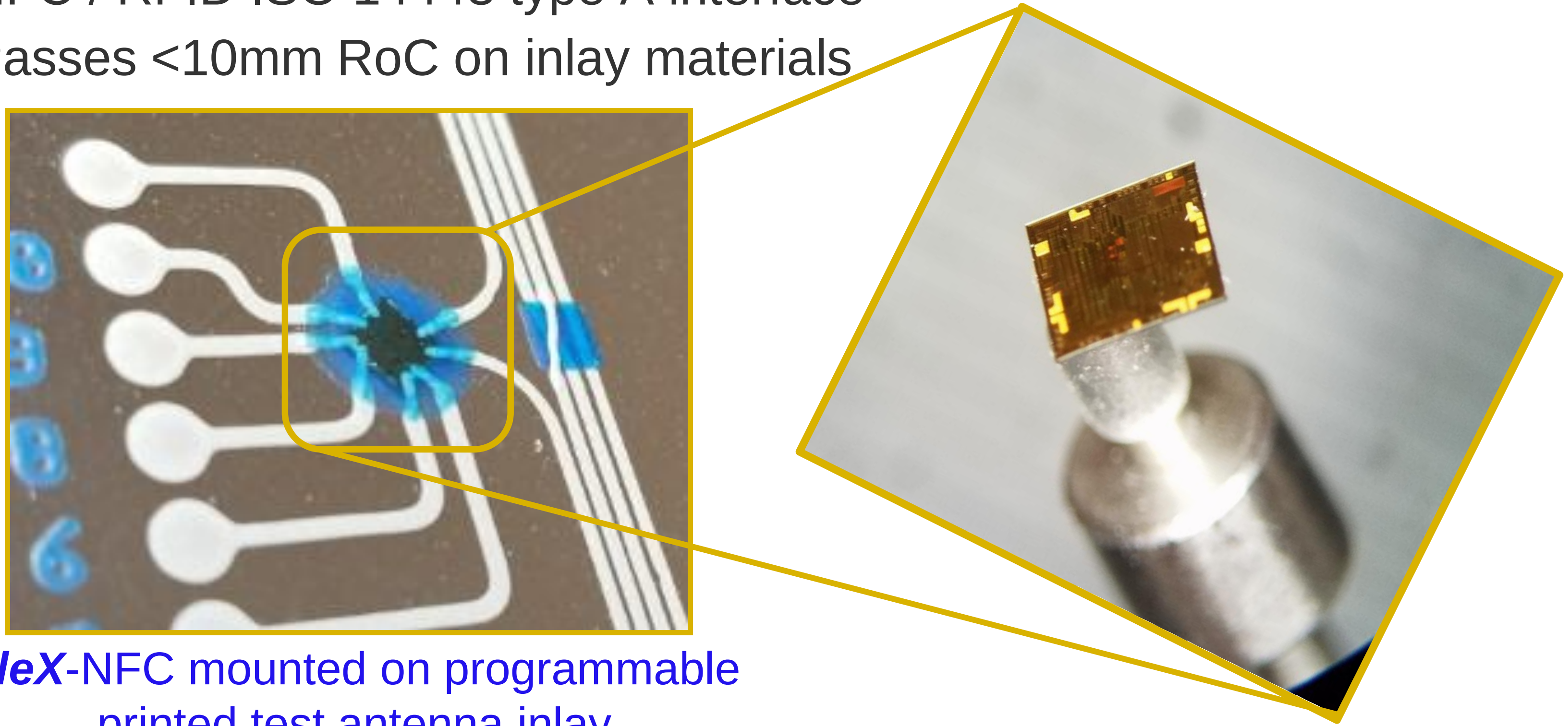
Smart Labels need Smart Chips

- Technology in this presentation is based on two new flexible ICs
- AS_NHS3100 – a FleX SoP conversion of NXP's NFC SOC
- AS_EM4325 – a FleX SoP conversion of EM Microelectronics RFID IC
- These die are available from American Semiconductor
- FleX SoP conversion is a post-fab process. The conversion changes the physical format of the commercial die.

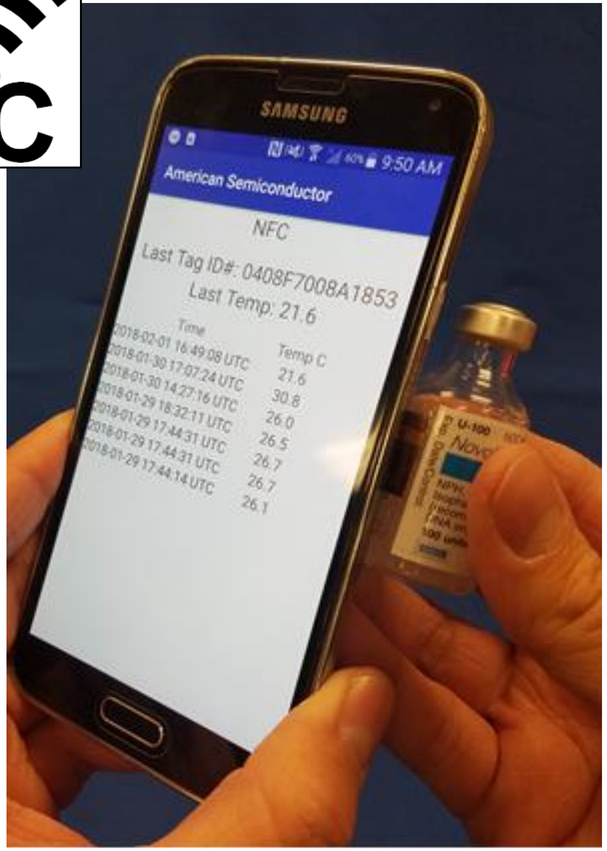
NXP and EM Microelectronics DO NOT GIVE ANY WARRANTIES, EXPRESSED OR IMPLIED, ON THE POST FABRICATION CONVERSION PROCESS STEPS AND HAVE NO LIABILITY FOR THE CONSEQUENCES OF SUCH ACTIVITIES

NEW: ***FleX***-NFC™ for Smart Labels

- FleX conversion of NXP NFC SOC
- ARM Cortex-M0+ processor
- 256kb Non-Volatile Flash Memory
- NFC / RFID ISO 14443 type A interface
- Passes <10mm RoC on inlay materials



FleX-NFC mounted on programmable printed test antenna inlay



Flexible NFC Temperature Monitoring Label

Smart Asset Monitor and Tracking Tag

Supported in part by: NEXTFLEX

Key Project Objectives

1. Deliver Smart-Tag production prototypes
2. Establish a FHE manufacturing flow
3. Install Smart-Tags and a reader infrastructure at NextFlex
4. Identify critical manufacturing gaps for production of FHE
5. Deliver Technology Product Demonstrators
6. Develop the FHE workforce

Workforce development partner: BOISE STATE UNIVERSITY

Smart-Tag Layout and RF Simulations

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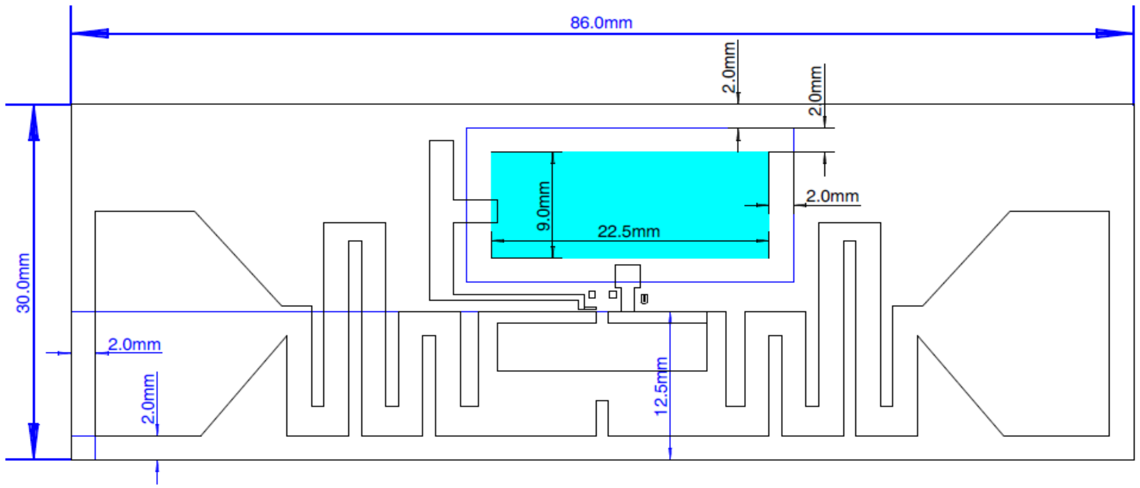
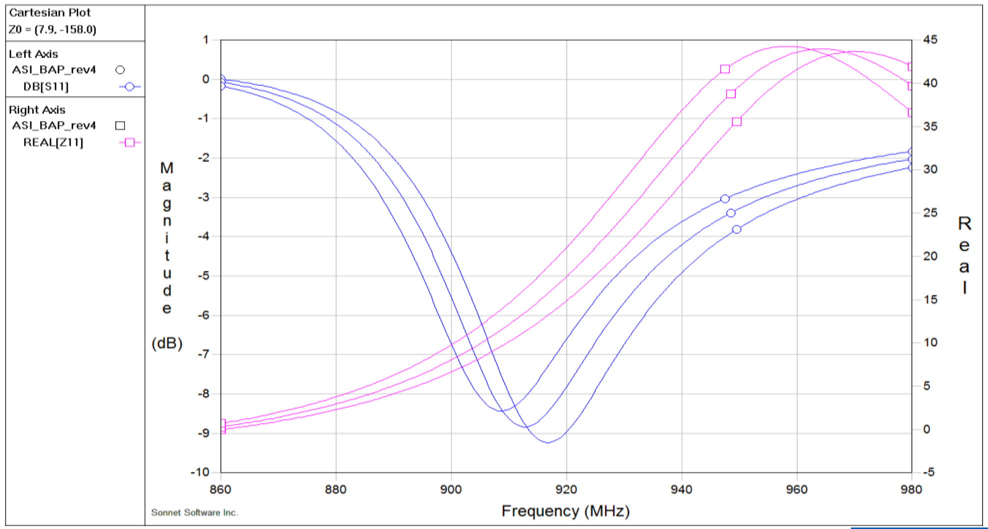
- Smart-Tag design layout: RFID antenna, FleX AS_EM4325 IC and flexible battery
  - Flexible battery designed for 2mAh capacity
  - Pad-up and flip-chip designs completed to support both assembly styles
- Design using simulations to optimize performance for 902-928MHz operation





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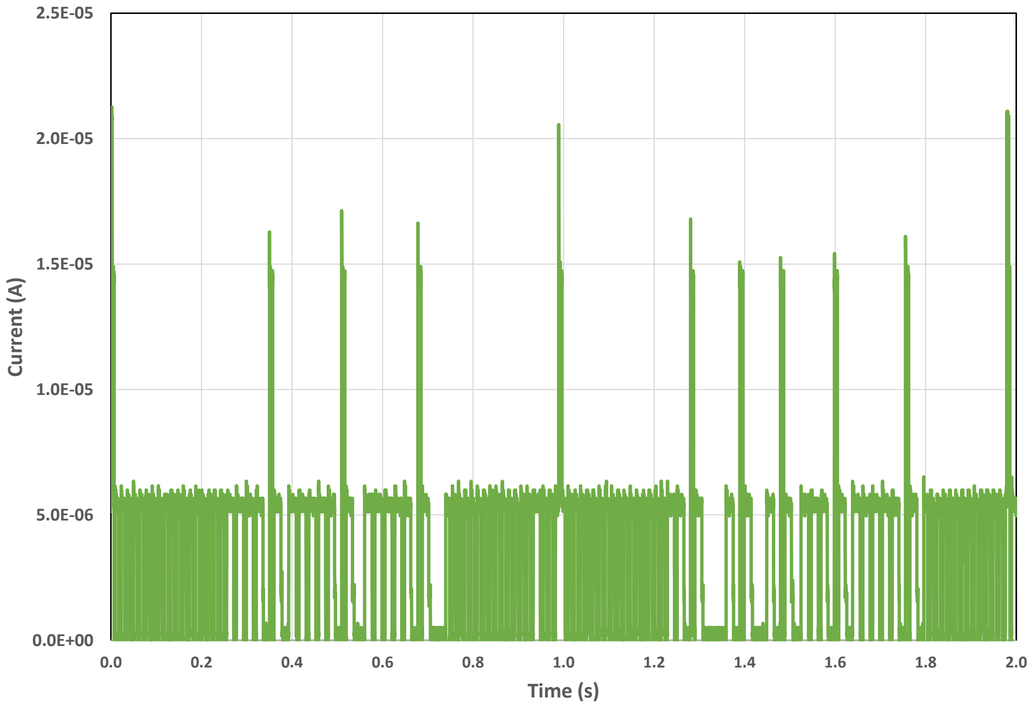
Power Measurement and Battery Modeling

- Completed power measurements for EM4325 IC in all operating modes:
  - Sleep
  - Temp Sense
  - Transmit



- Completed modeling of the system power consumption to estimate required battery capacity based upon:
  - Target lifetime
  - Temperature measurement interval
  - RFID data read interval

Target Lifetime	21	days
Sleep Current	2.8	uA
Sleep Current (Lifetime)	1.4	mAh
Temp Measure Current	21.2	uA
Temp Measure Time	7.3	ms
Temp Measure Interval	1	s/sample
Temp Measure Current (Lifetime)	0.08	mAh
RFID Read Current	1000	uA
RFID Read Time	100	ms
RFID Read Rate	12	reads/hr
Temp Measure Current (Lifetime)	0.17	mAh
Total Current (Lifetime)	1.66	mAh

Antenna Inlays with Integrated Batteries

- Co-optimization of manufacturing flow and layout with partners
- Completed manufacturing of the RFID antenna inlays
- Completed manufacturing and integration of flexible batteries

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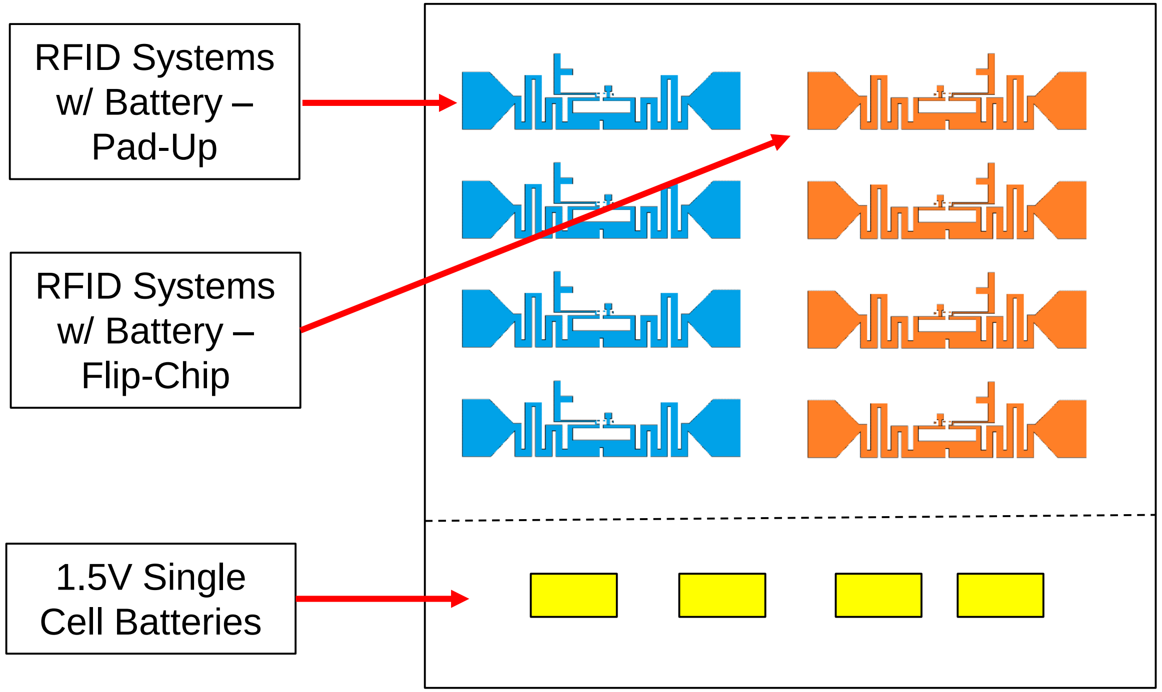
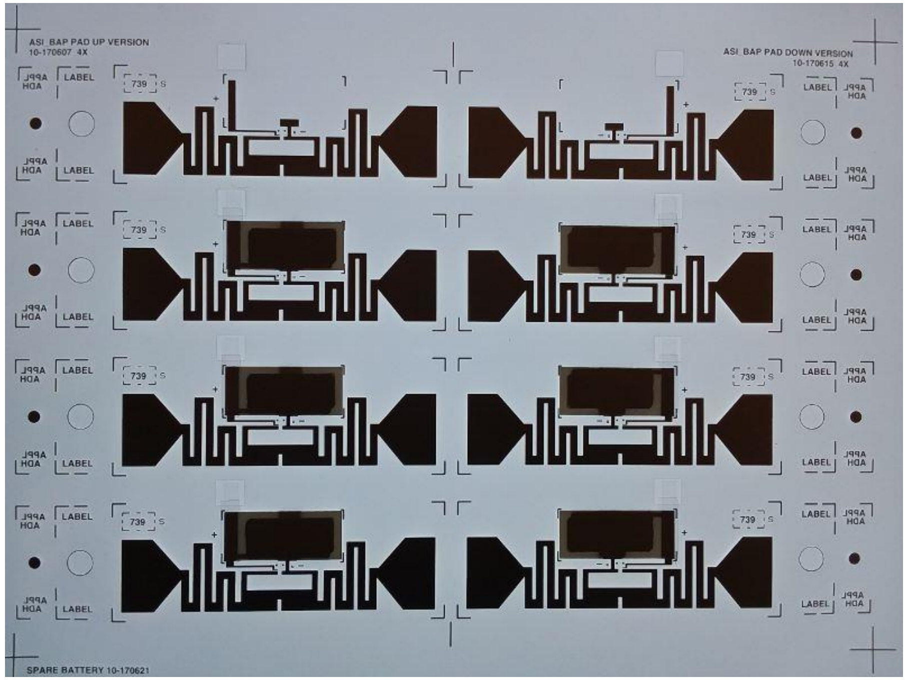
Enfucell

Layout Floor Plan



Inlays with Integrated Batteries



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Graphic Labels

- Manufactured graphics labels with pressure sensitive adhesive (PSA) for frontside of the Smart Tags
- Completed manufacturing of the PSA for backside of the Smart Tags

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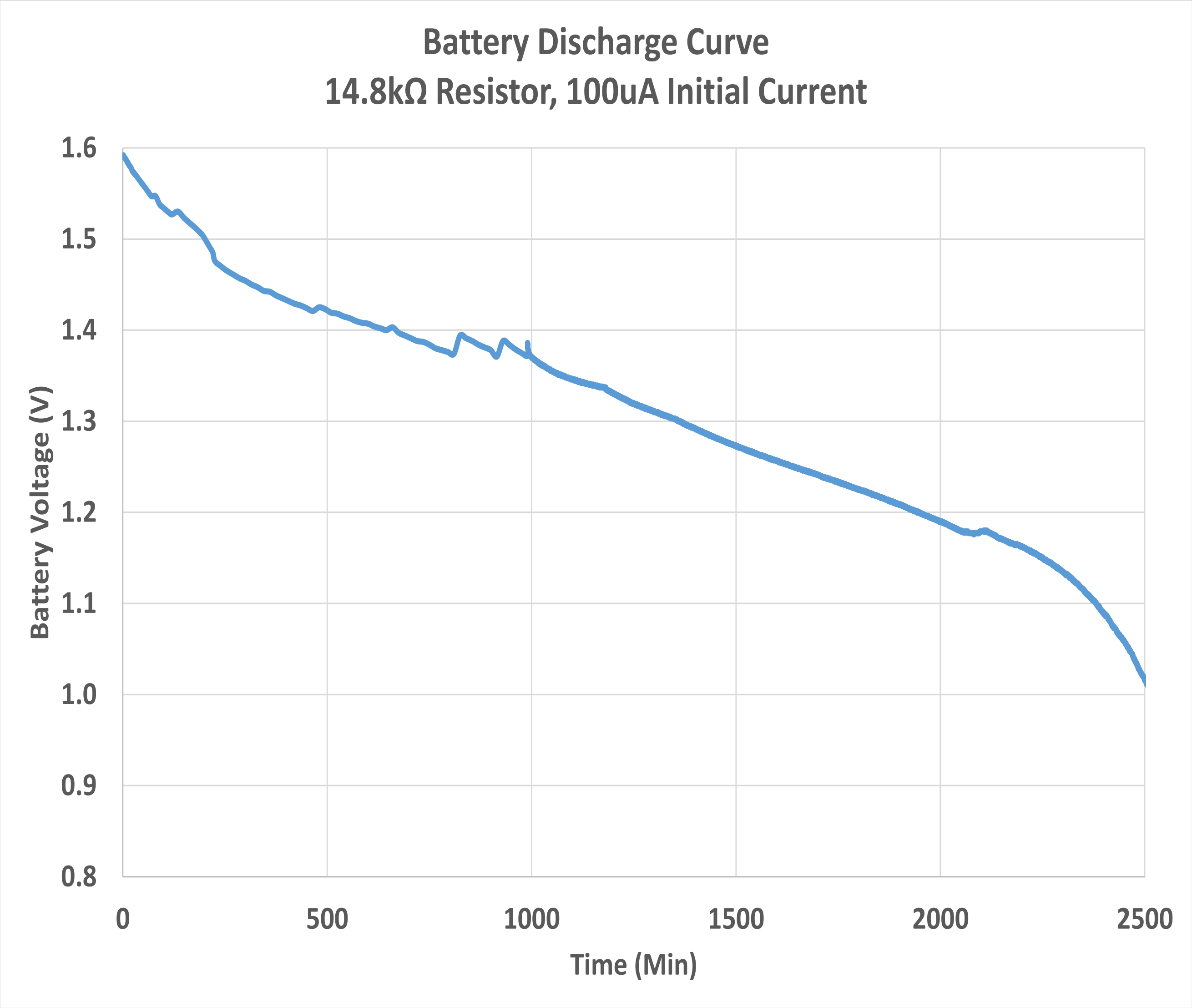
Enfucell Flexible Battery Capacity Testing

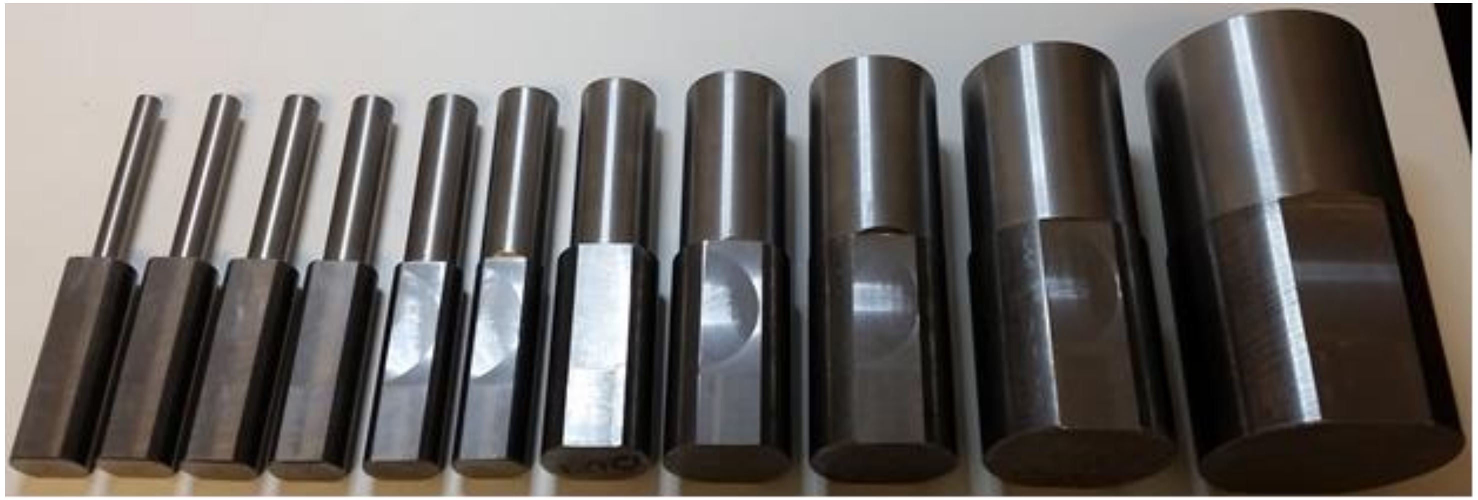
Capacity Testing

- Target Operating Life: ≥ 2 weeks
- Target Capacity: ≥ 2mAh
- Measured Total Capacity: 3.8mAh
- Measured Useful Capacity: 2.5mAh
  - Vbatt > 1.25V



Flexible Battery
Radius of Curvature Testing

- American Semiconductor Test Procedure ASITEST003
- Convex and concave flexure
- Mandrels with radii of 40, 30, 25, 20, 15, 12, 10, 8, 7, 6, and 5mm
- The Enfucell battery survived with full functionality through 5mm radius of curvature



RoC Precision Test Mandrels

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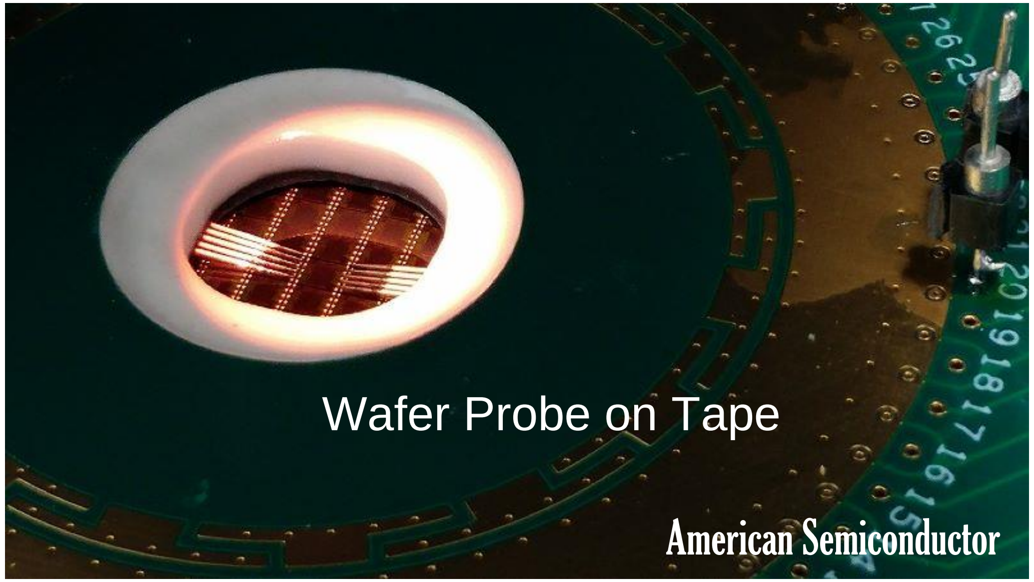
AS_EM4325 FleX-RFIC
FleX™ Semiconductor-on-Polymer™

- EM4325 wafers have completed FleX SoP wafer conversion
- EM4325 is an advanced RFID Temp IC from EM MICROELECTRONIC (A COMPANY OF THE SWATCH GROUP)
- Post conversion RF probe validates read, write and temp measurement
- Flexible SoP wafers are currently out for dicing



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Prototype Status & Testing

- Conventional thin ICs assembled on inlays for initial Smart-Tag function validation
- Completed application testing for key Smart-Tag features
  - ✓ Program All Control Settings
  - ✓ Measure Temperature at Defined Intervals
  - ✓ High Temp Alarm
  - ✓ Low Temp Alarm
  - ✓ Transmit Temperature and Alarm Data
- Smart-Tag application lifetime testing is currently in progress
  - Configured to monitor temperature once every second
  - Data is read out from the app at least 5 times per day
  - Test started 1/31 and is still in progress
  - On 8th day, the Smart-Tag was chilled to test low temp alarm and it passed
  - The testing of this tag is still in progress

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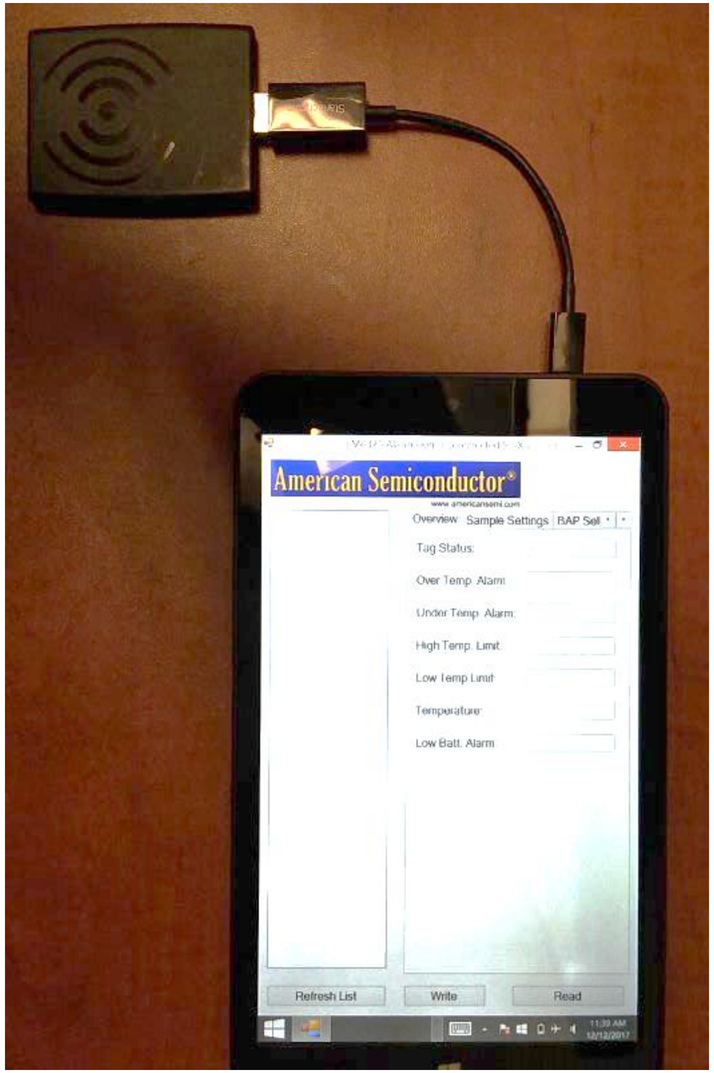
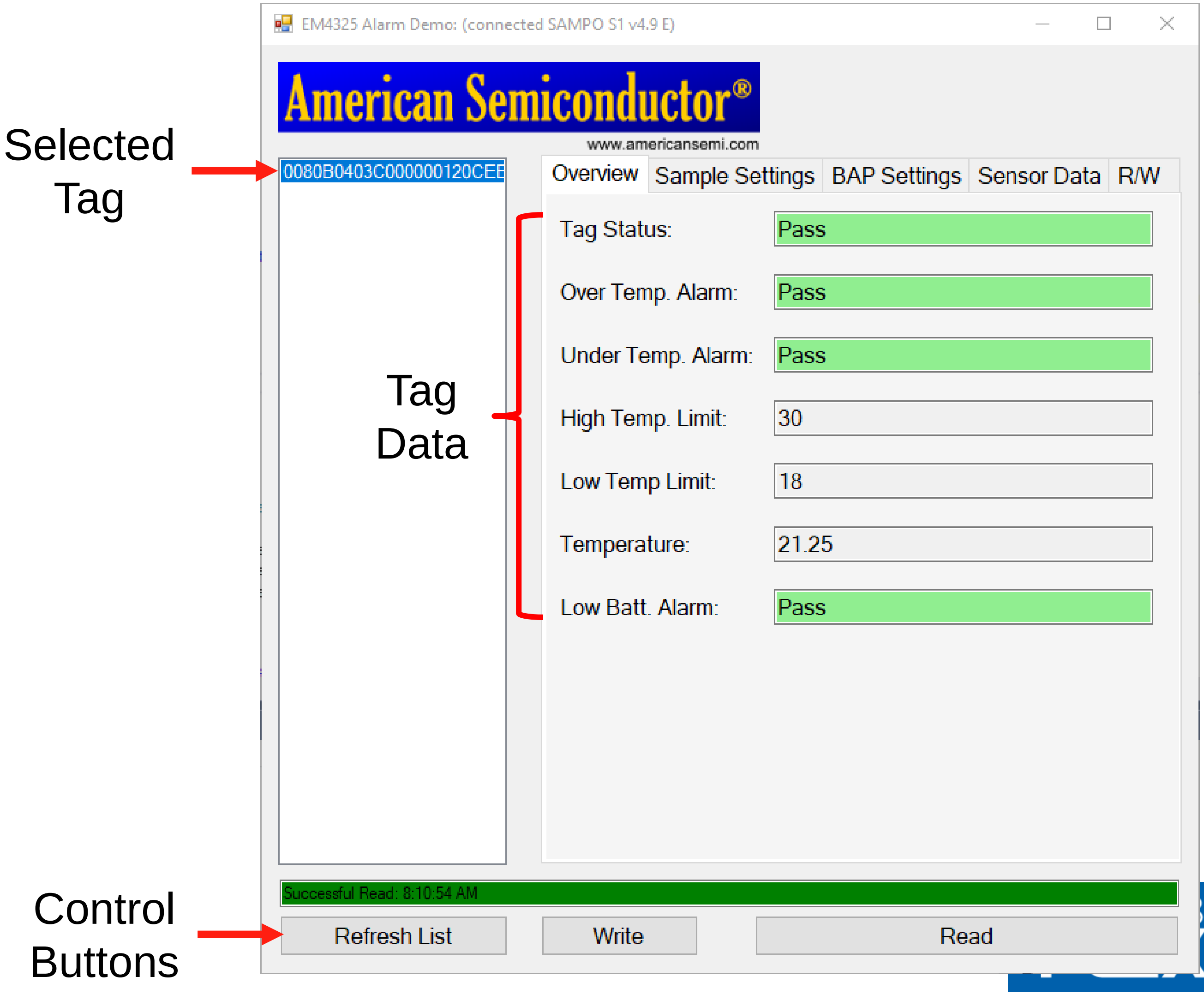
Portable Reader and Application Software

- Nordic Stix connected to tablet via the USB port



- Custom app for configuring tags and collecting data



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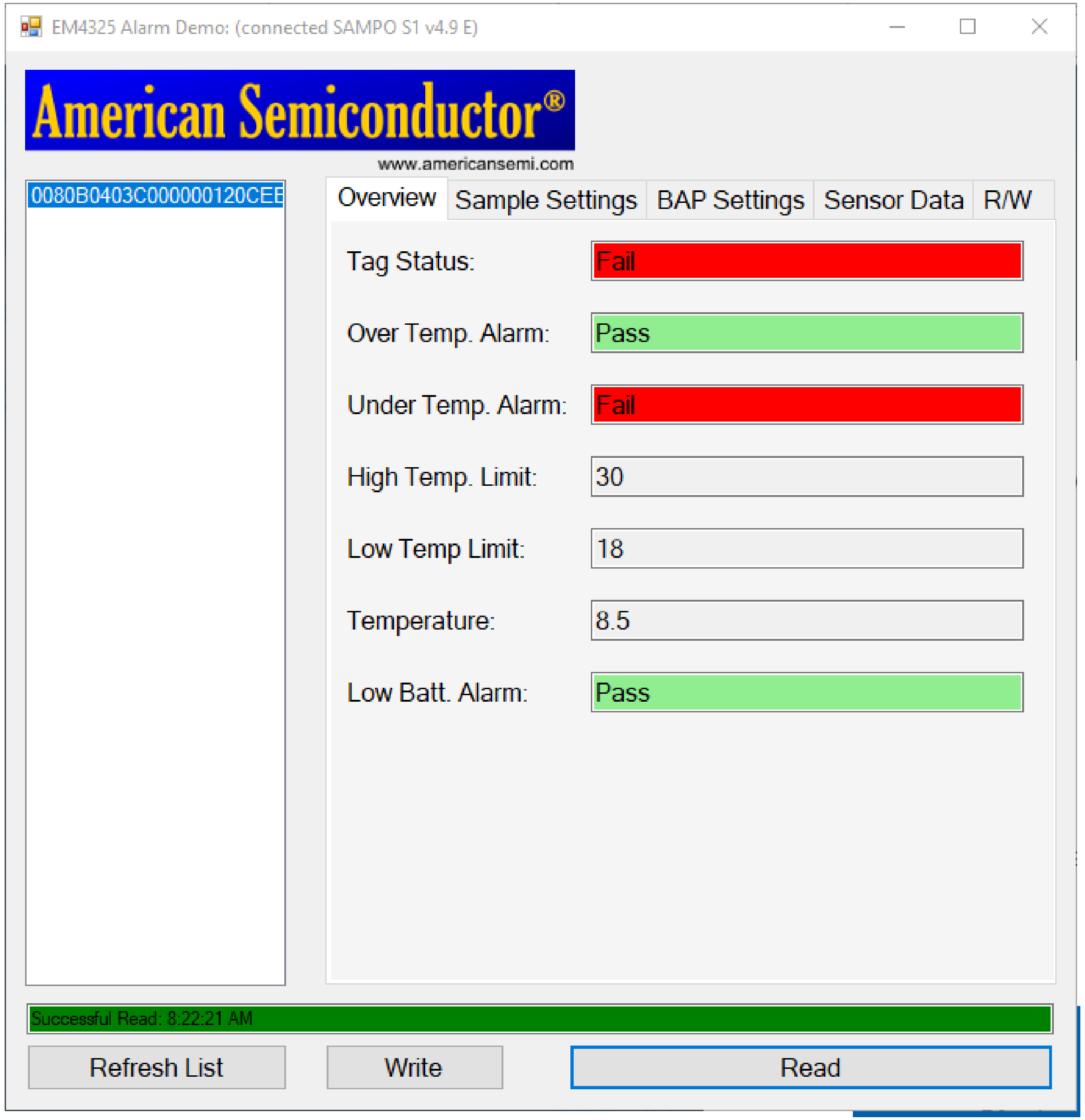
Smart Tag Reader App Features

Inventory Tags with Reader	✓
Configure Tags for Temperature Sampling Rates	✓
Configure High and Low Temperature Alarms	✓
Display Current Tag Temperature	✓
Read Tag Alarm History	✓
Read and Write Tag Settings	✓
Support Multiple Tag Context Switching	✓
Display Tag Battery Condition	✓
Displays Tag Read/Write Operation Result	✓



FHE Workforce Development

BOISE STATE UNIVERSITY

- **Two** BSU internships, began summer 2017
- Bi-weekly updates with interns, faculty and ASI engineering

- **Project #1**: Physical Characterization of Anisotropic Conductive Adhesives
- Intern: **Angel Rodriguez**, Mechanical Engineering Sophomore
- Faculty: Dr. David Estrada, Materials Science and Engineering
- ➡ See at Session 19: *Anisotropic Conductive Adhesives on Flexible Hybrid Electronics*

- **Project #2**: Printing of Interconnect Arrays for Flexible Silicon Circuits on Flexible Substrates
- Intern: **Jasmine Cox**, Electrical Engineering Sophomore
- Faculty: Dr. Harish Subbaraman, Electrical and Computer Engineering
- ➡ 2018FleX Student Poster: *Inkjet Printing of Dense Interconnect Arrays for Flexible Silicon Circuit Integration on Flexible Substrates*

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Thank You

Immediately following this session during the Afternoon Break: See FHE Label and Tag Demonstrators at the DuPont booth in the exhibit hall

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Program Technical Phases

1. Initial Prototype Fabrication and Testing (IN PROGRESS)
   - Using traditionally thinned ICs
   - Milestones: Complete manufacturing and testing of initial prototypes
2. Production Prototype Fabrication and Testing (IN PROGRESS)
   - Using FleX™ Silicon-on-Polymer™ ICs
   - Milestones: Complete manufacturing and testing of production prototypes
3. Reader Development and Technical Support (IN PROGRESS)
   - Support for both hand-held and infrastructure readers
   - Milestones: Hardware, software and documentation complete for both reader types
4. NextFlex Delivery and Training
   - Tag and reader installation in San Jose
   - Milestone: System installation complete
5. Workforce Development (IN PROGRESS)
   - FHE internship program
   - Milestones: Completion of semester and summer internship training periods

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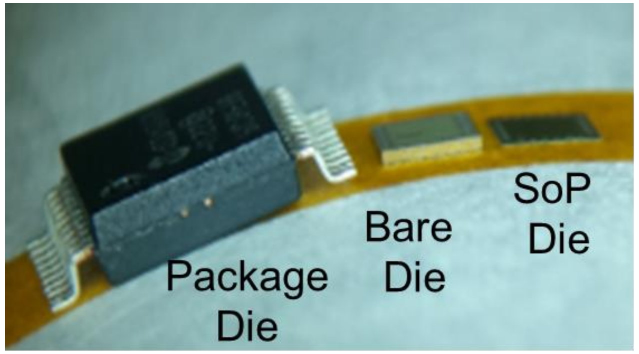
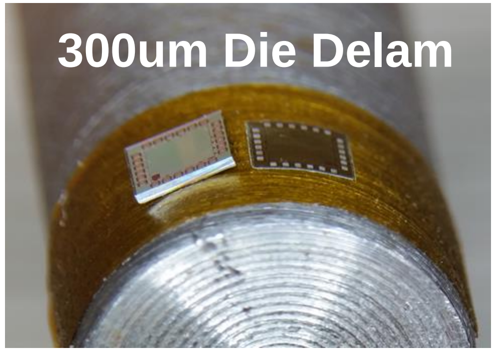
Motivation

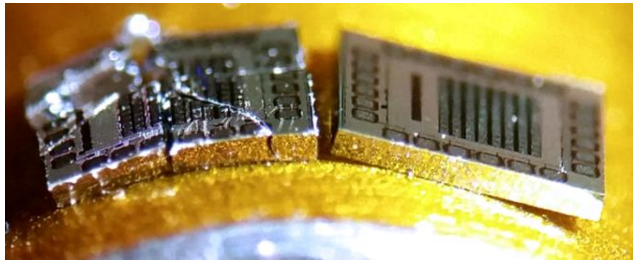
The Problem

Standard Packages and Traditionally Thinned Die Will Not Work

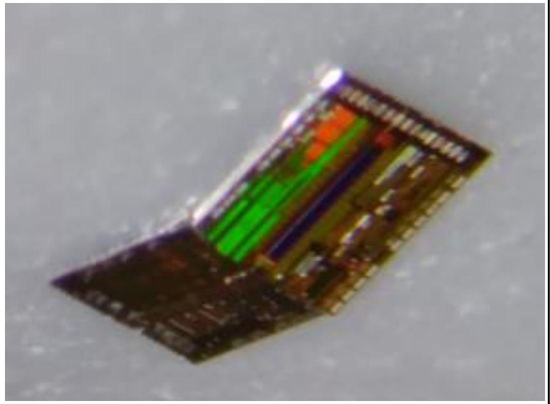




300um Die Fail at 15mm ROC



35um Die Fail at 10mm RoC



The Goal

Smart, Flexible, Conformable and Reliable Environmental Monitoring

Program Overview

- **Project Objective:**
  Deliver small, low profile, environmental monitoring smart asset tracking tags with wireless communication capabilities to track temperature sensitive inventory for two weeks

- **Project Team**
  - American Semiconductor
  - Boise State University

- **18-Month Program**
  - Program Start: Dec 2016
  - Program End: June 2018

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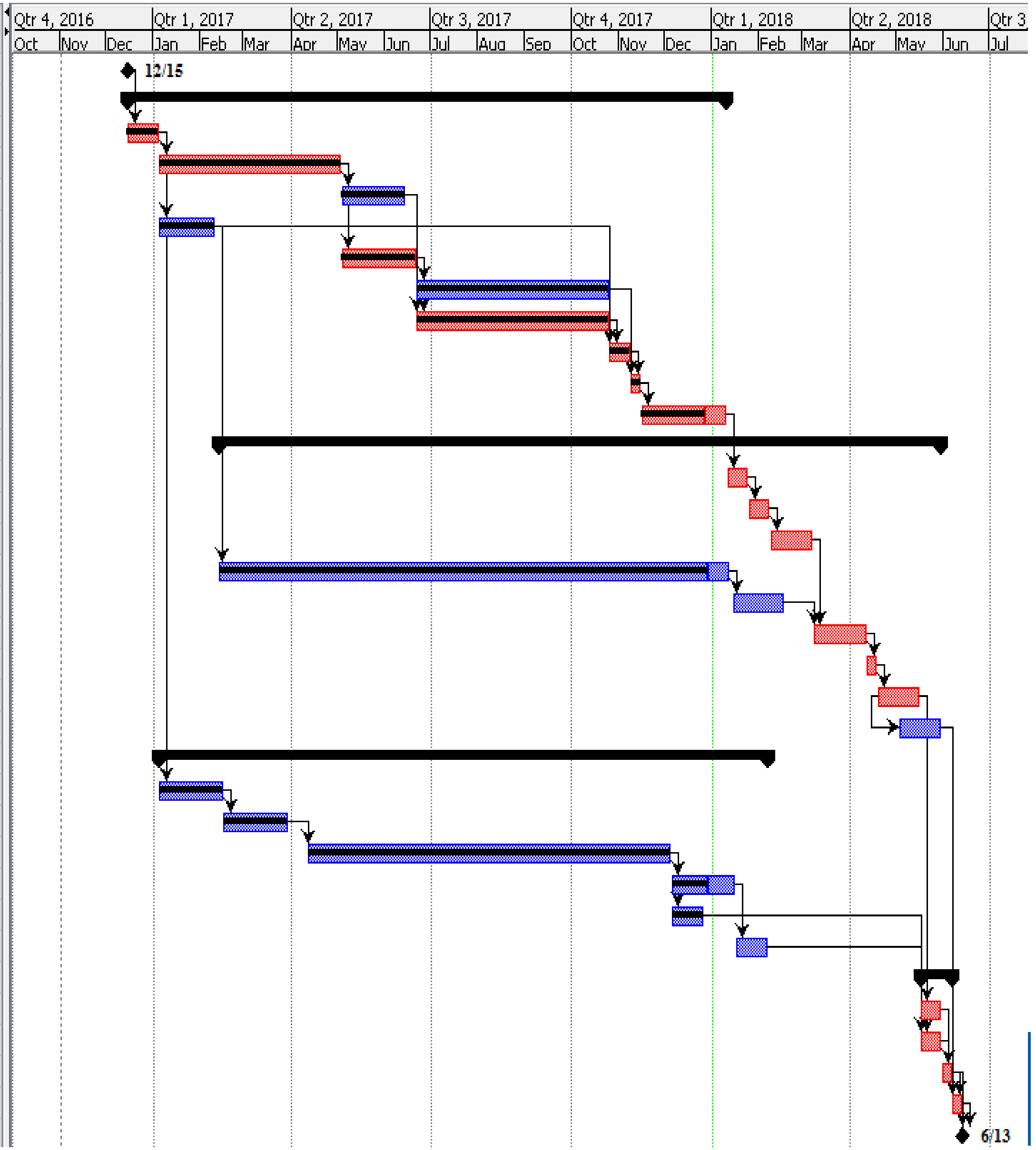
Program Schedule

- Continuing for on-schedule completion
- Initial prototype design and fabrication coordination with vendors was slower than planned which has used up most of the slack in the schedule

<u>Next Steps</u>

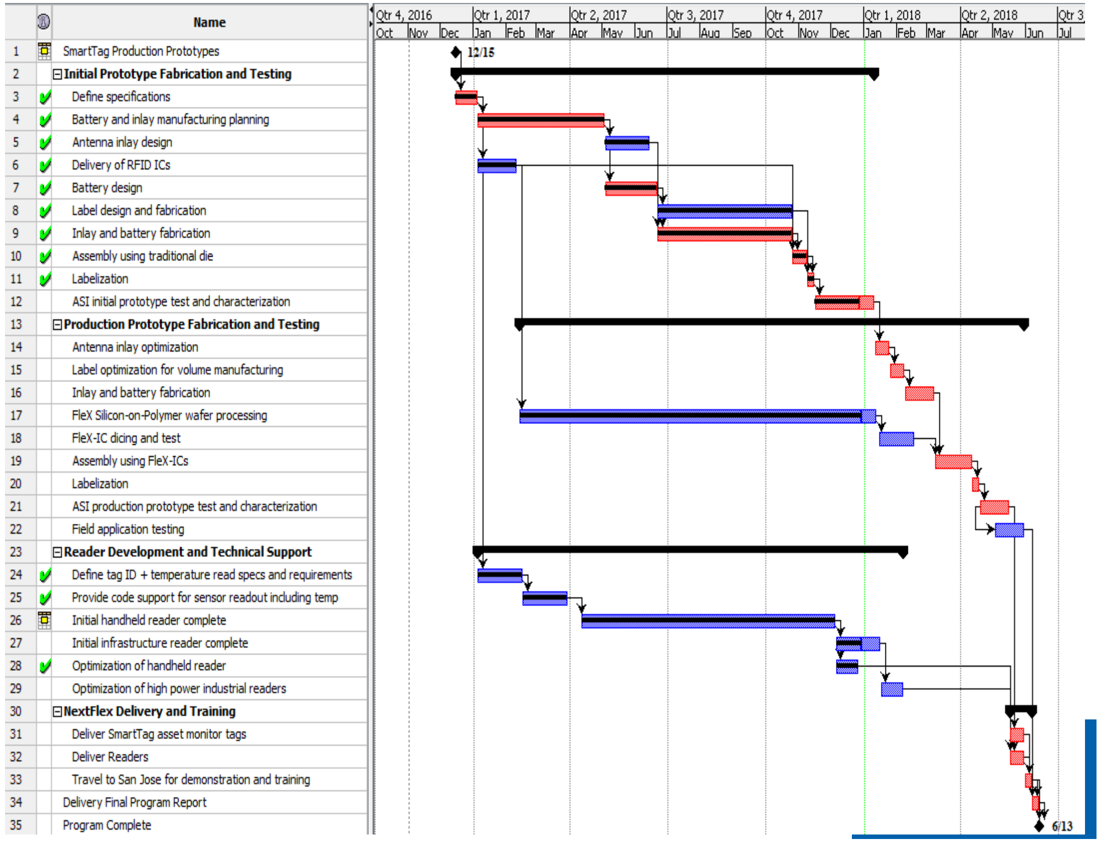
- Performance characterization of the Smart-Tag Initial Prototypes
  - RF read range
  - Operating lifetime as a function of control parameters
  - Temperature accuracy
  - Effects of curvature and substrate types
- Characterization of the Flexible Batteries
  - Storage degradation

		Name
1		SmartTag Production Prototypes
2		⊟ **Initial Prototype Fabrication and Testing**
3	✓	Define specifications
4	✓	Battery and inlay manufacturing planning
5	✓	Antenna inlay design
6	✓	Delivery of RFID ICs
7	✓	Battery design
8	✓	Label design and fabrication
9	✓	Inlay and battery fabrication
10	✓	Assembly using traditional die
11	✓	Labelization
12		ASI initial prototype test and characterization
13		⊟ **Production Prototype Fabrication and Testing**
14		Antenna inlay optimization
15		Label optimization for volume manufacturing
16		Inlay and battery fabrication
17		FleX Silicon-on-Polymer wafer processing
18		FleX-IC dicing and test
19		Assembly using FleX-ICs
20		Labelization
21		ASI production prototype test and characterization
22		Field application testing
23		⊟ **Reader Development and Technical Support**
24	✓	Define tag ID + temperature read specs and requirements
25	✓	Provide code support for sensor readout including temp
26		Initial handheld reader complete
27		Initial infrastructure reader complete
28	✓	Optimization of handheld reader
29		Optimization of high power industrial readers
30		⊟ **NextFlex Delivery and Training**
31		Deliver SmartTag asset monitor tags
32		Deliver Readers
33		Travel to San Jose for demonstration and training
34		Delivery Final Program Report
35		Program Complete



PC2.7 Smart Asset Monitor and Tracking Tag Bi-Monthly Update #6 for Nov – Dec 2017

- **Lead:** American Semiconductor
- **Supporting:** Boise State University (workforce development)
- **Overall Objective:**
  Deliver small, low profile, smart asset tracking tags with wireless communication capabilities to track temperature sensitive inventory for two weeks
- **Duration:** Dec 2016 – June 2018
- **Reporting Period Objectives:**
  - Begin functionality and RF testing of Smart-Tag initial prototypes
  - Continued FleX Silicon-on-Polymer wafer processing
  - Continue improving software and firmware for RFID reader solutions
- **Accomplishments for Reporting Period**
  - Assembled Smart-Tag Initial Prototypes using traditionally thinned ICs
  - Validated functionality of key Smart-Tag features
  - Continued RF testing of the Smart-Tag Initial Prototypes
  - Completed flexible battery capacity testing
  - Started flexible battery storage testing
  - Continued FleX Silicon-on-Polymer wafer processing
  - Continued software and firmware development RFID reader solutions
  - Continued workforce development program with 2 college interns
- **Open Items and Risks**
  - No current major open items or risk



Risks and Mitigation

- We continue to manage the risks associated with this program and do not currently see any reason to not expect the program to successful meet all program milestones and deliverables on schedule
- Below are the currently identified primary risks for the program

Risk	Likelihood	Impact	Mitigation
~~Unable to find a replacement field application testing partner~~	L	L	Ken Blecker of US Army ARDEC has agreed to perform testing
Unable to successfully FleX the RFID IC wafers with temp sense capability	L	M	Traditionally thinned die can be used in place of FleX die with loss of flexibility
~~Unable to procure flexible batteries that meet requirements~~	L	H	Batteries have passed initial testing

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Program Highlights

Nov 1 – Dec 31, 2017

1. Assembled Smart-Tag Initial Prototypes using traditionally thinned ICs
2. Validated functionality of key Smart-Tag features
3. Continued RF testing of the Smart-Tag Initial Prototypes
4. Completed flexible battery capacity testing
5. Started flexible battery storage testing
6. Continued FleX Silicon-on-Polymer wafer processing
7. Continued software and firmware development RFID reader solutions
8. Continued workforce development program with 2 college interns

Program Deliverables

1. Smart-Tag Asset Monitor and Tracking Tags
2. RFID reader with capability to read Smart-Tags
3. Reader installation, demonstration and training at NextFlex
4. Bi-monthly technical reports
5. Bi-monthly project reports including cost accounting and invoices
6. Final report

Printed Label Graphics

Printed RFID Antenna Inlay with Flexible Batteries