

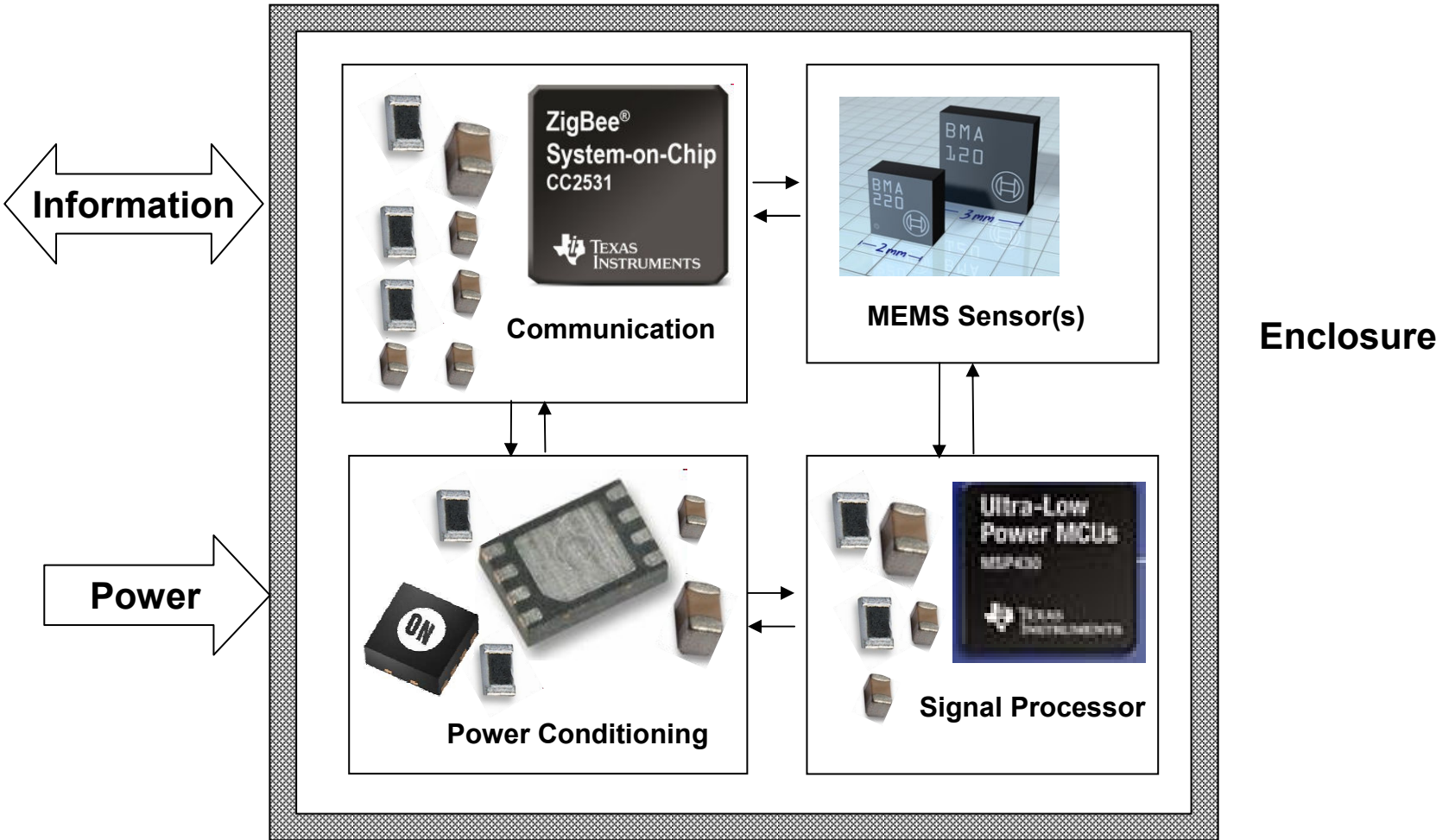
Providing the Infrastructure for Connecting to the World: One Sensor at a Time

C. Paul Christensen

Potomac Photonics

www.potomac-laser.com

MEMS Sensor systems



Sensor infrastructure determines size, shape and cost



Sensor Integration Goals

A. Miniature size with flexible form factor

- i. **Smallest component sizes**
- ii. **Fine-feature interconnect**
- iii. **3D construction/flexible footprint**

B. Low-cost assembly

- i. **Minimize capital/labor/materials costs**
- ii. **Minimal waste stream**

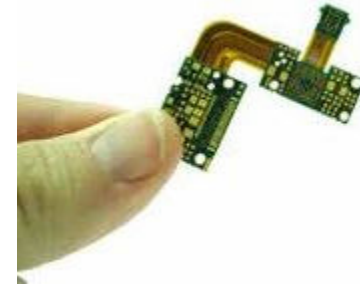
C. Quick-turn with small/large batch compatibility

- i. **Packaged components**
- ii. **CAD/CAM processes**

Conventional PCB Technology



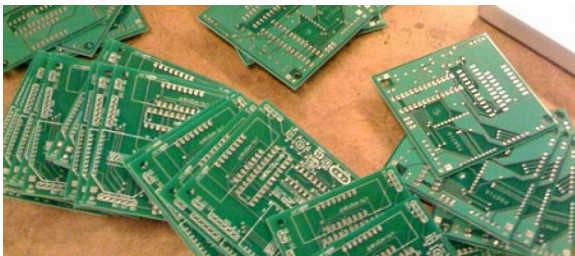
- Highly-Developed, proven technology
- Many competent vendors



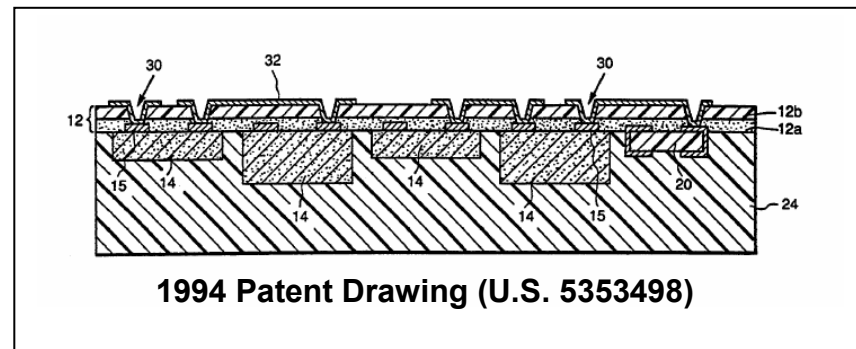
But...

There's room for improvement

- Feature sizes < 50 microns are challenging
- Basically a 2D technology
- Lots of capital equipment, floor space, industrial waste

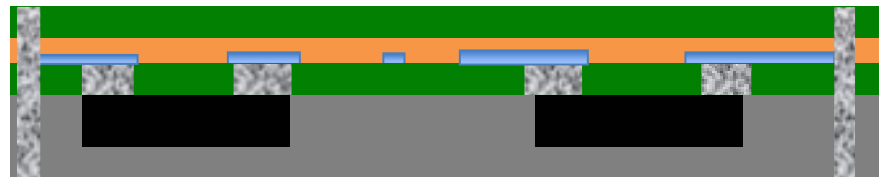


Embedded 3D Fabrication



- Many different/similar techniques
 - **GE (1994 patent), Freescale, Verdant Electronics, Imbera, Ga Tech, Fraunhofer,etc.**
- Well known benefits
 - High component density
 - Eliminate solder connections
 - Shortens supply chain
- Potomac's contribution: **Simplicity**

Miniature module fabrication

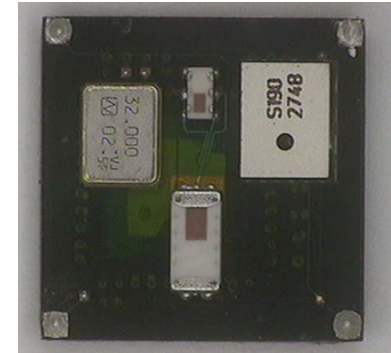
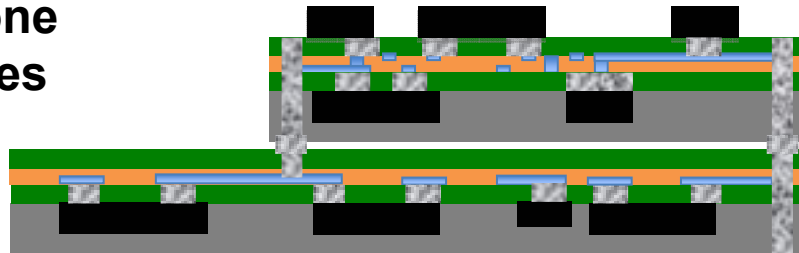


1. Fabricate fine feature interconnects on thin substrates
 - Nanoparticle silver conductors
 - Laser direct-write processes
2. Attach packaged components using conductive adhesives
3. Encapsulate components
4. Stack modules

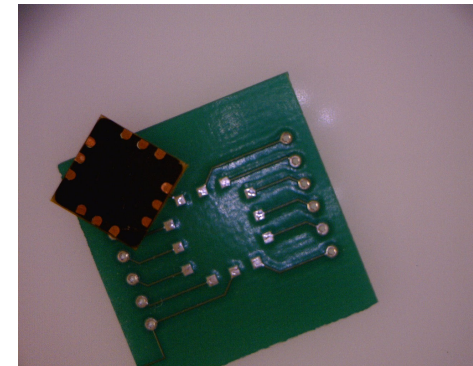
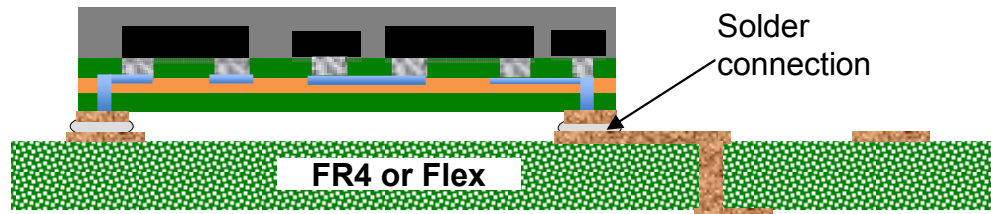
Using the modules



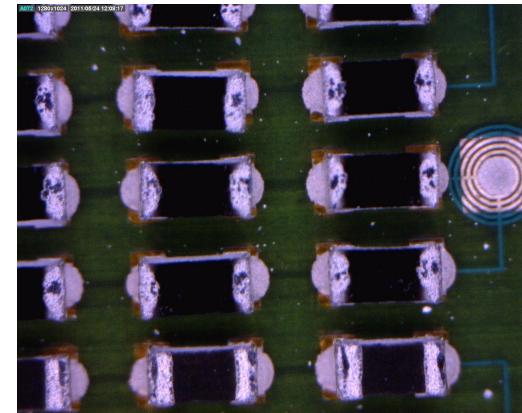
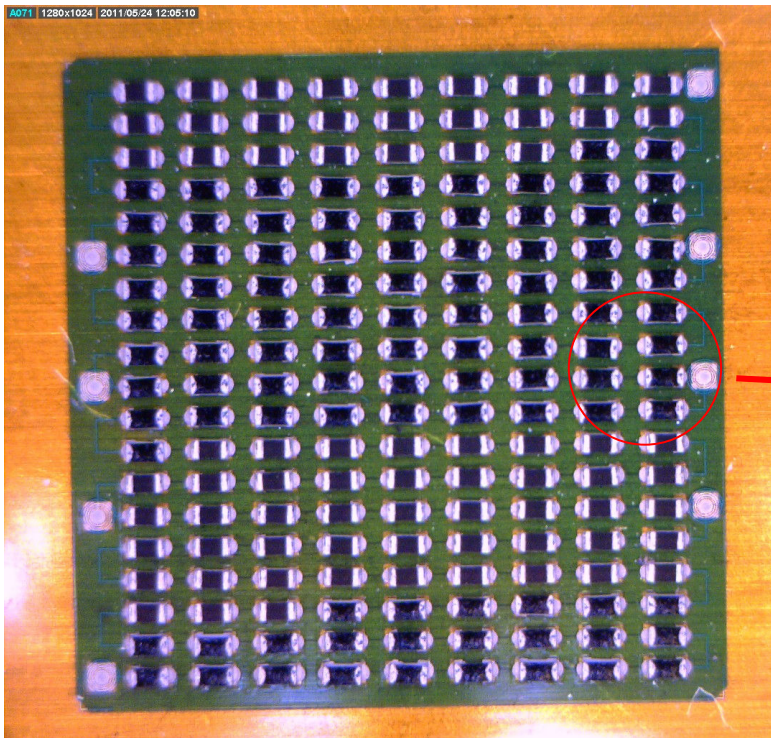
3D stand alone assemblies



Miniature subsystems connecting to rigid or flex circuit boards



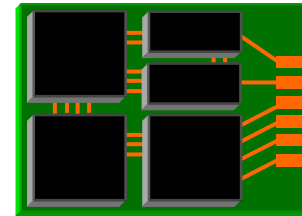
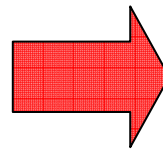
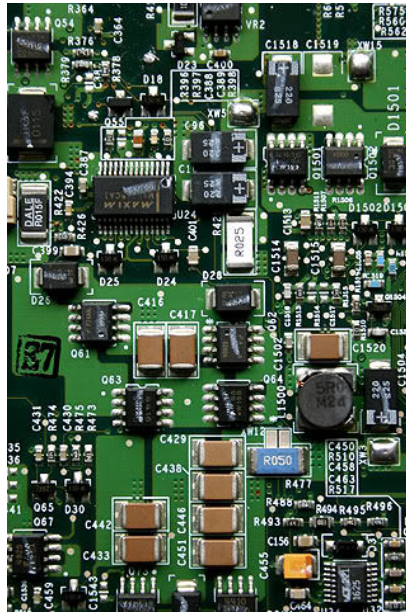
High packing density



0201 resistors

> 1000 components/cm³

Application Specific Integrated Modules



1. ASIC analog

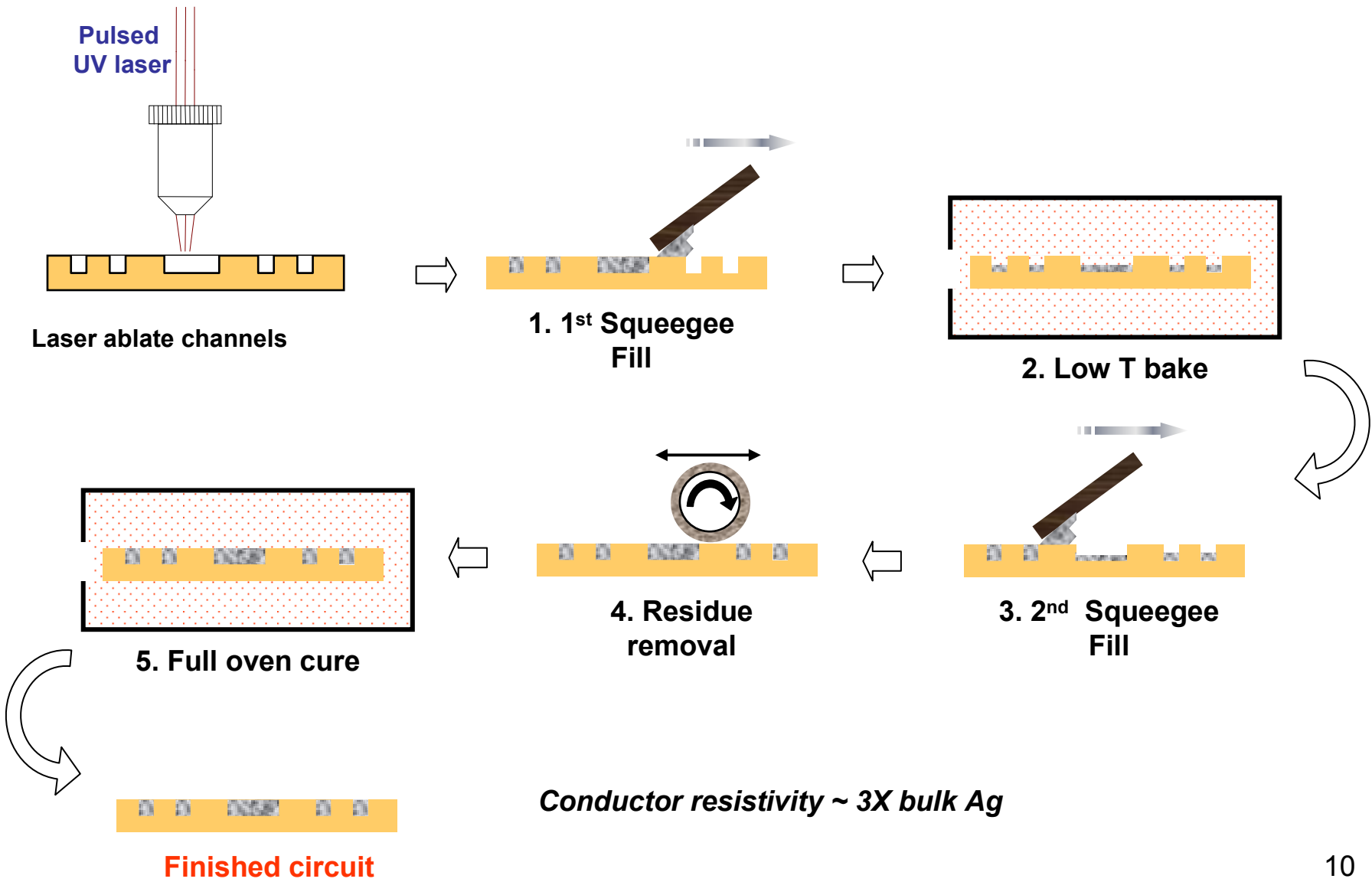
- Functional block approach to circuit construction

1. High component density inside miniature modules

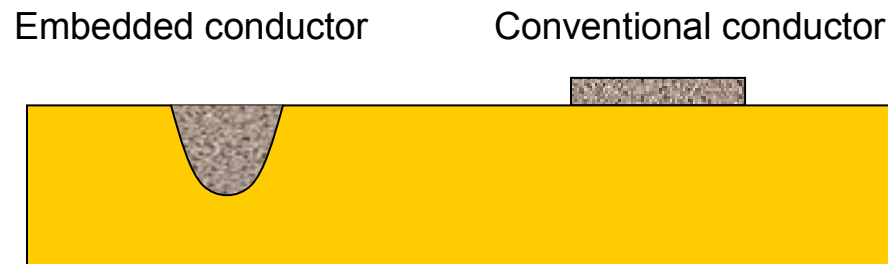
2. Test modules separately

- Improved yield

Nano-silver conductor fabrication

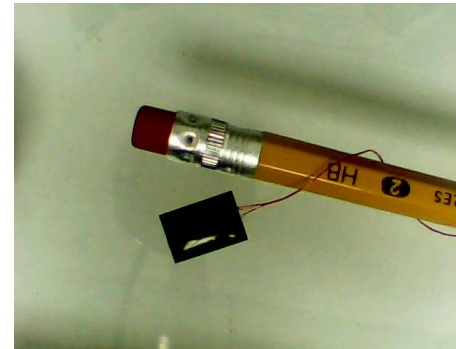


Embedded nanoparticle silver conductors

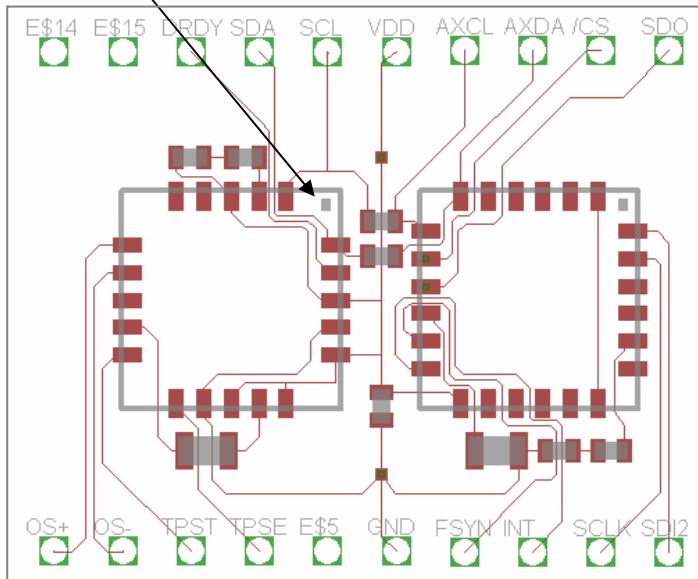


- Nanoparticle conductor advantages:
 - Eliminate photolithography
 - Conductor width limited only by laser focal spot size.
 - <10 micron trace/space demonstrated
 - Controllable aspect ratio
 - Additive, green process

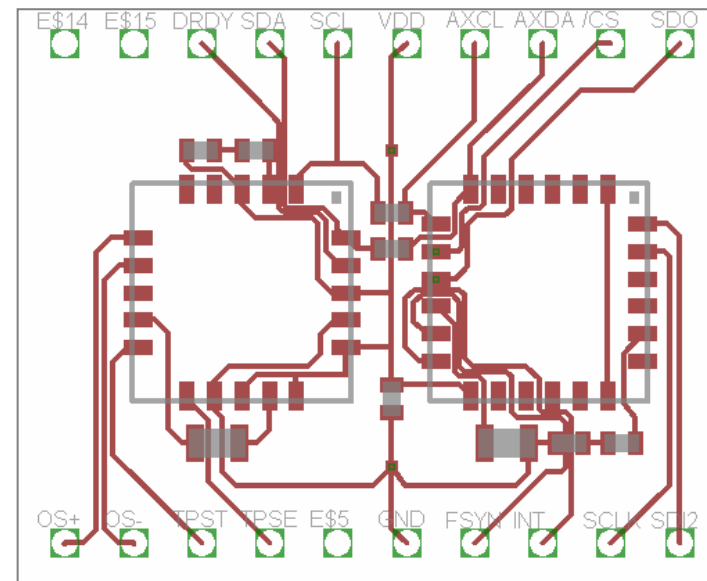
Narrow traces reduce layer count and cost



4 mm x 4 mm
sensor



15 micron trace/space

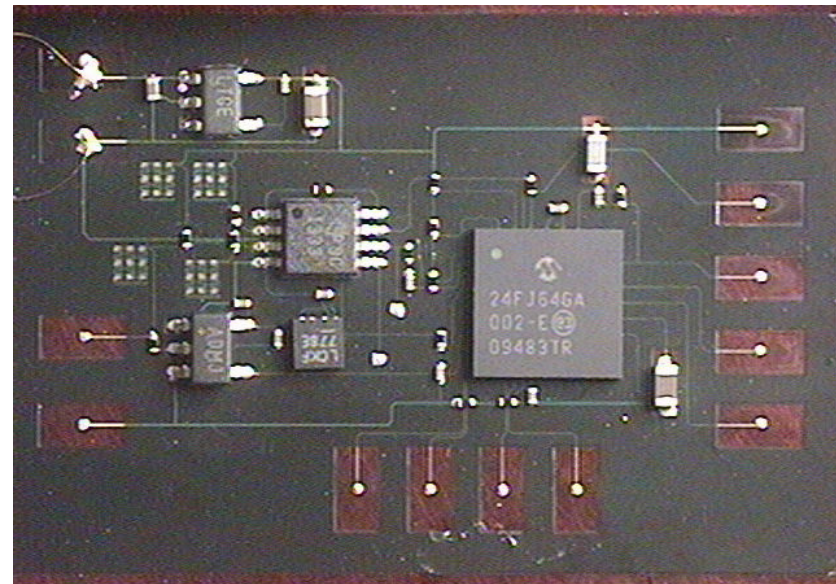


100 micron trace/space

Examples: Polyimide substrate



Battery-powered LED flasher



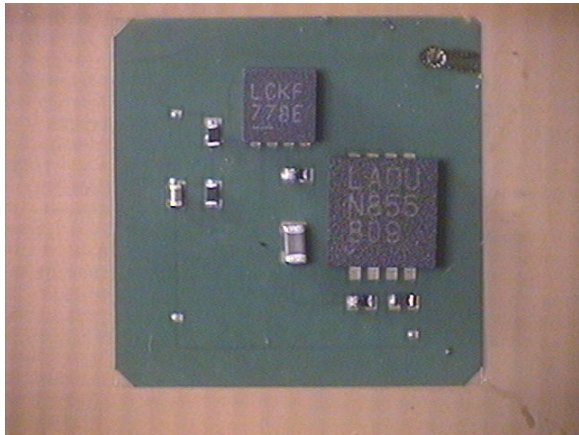
← 35 mm →

↑ 23 mm ↓

Strain gauge interface

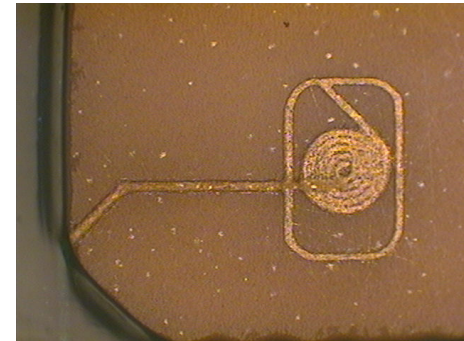
Single Layer Circuits !

Examples: Alternative Substrates

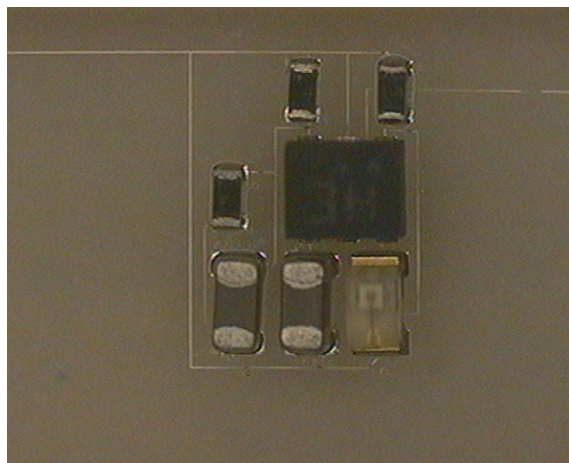


Working circuits

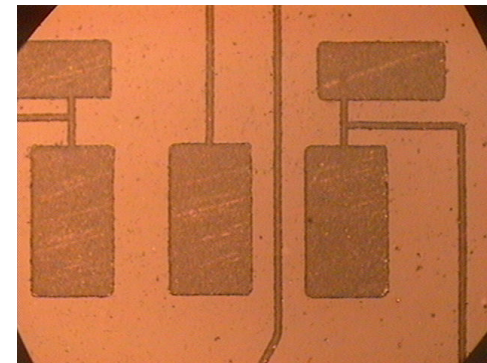
← ABF →



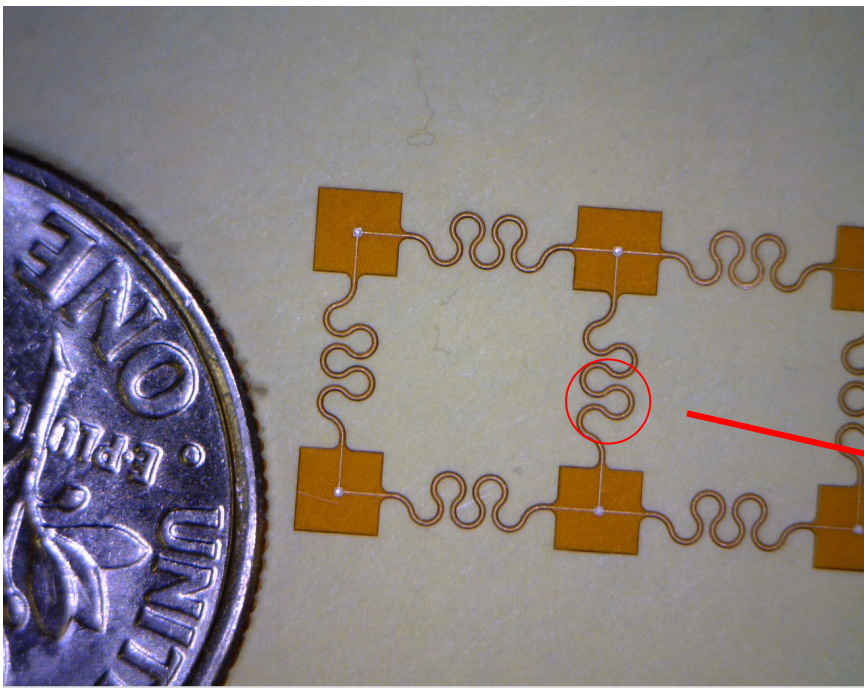
Pads and 15 micron traces



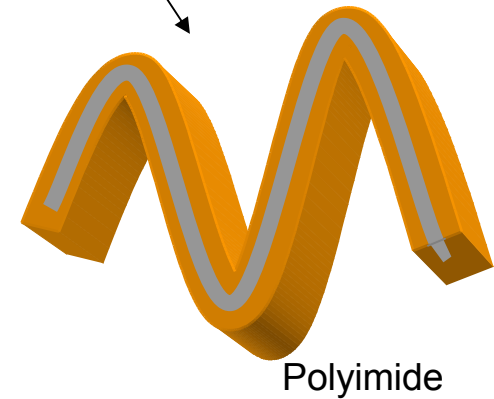
← Alumina →



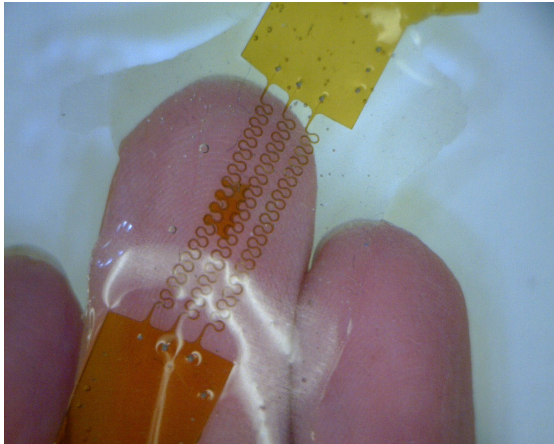
Stretchable Interconnects



Embedded conductor



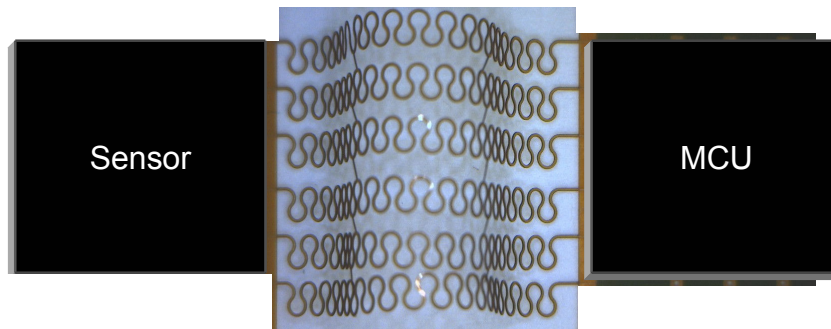
Quasi-conformal circuitry



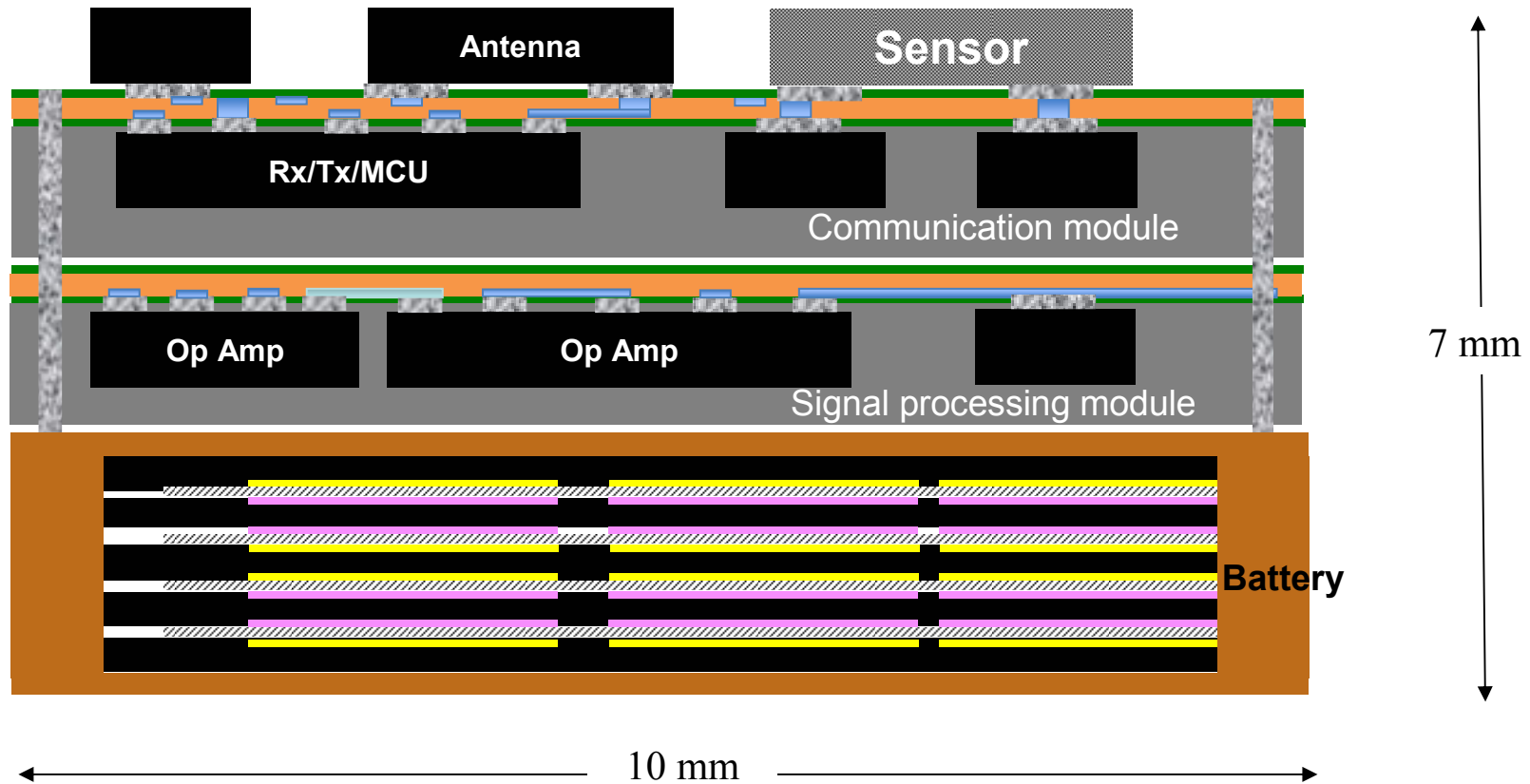
Embedding in elastic polymer

Stretchable circuits connect miniature modules

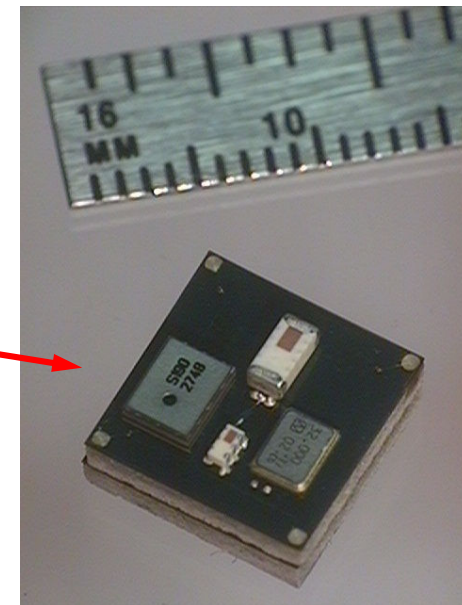
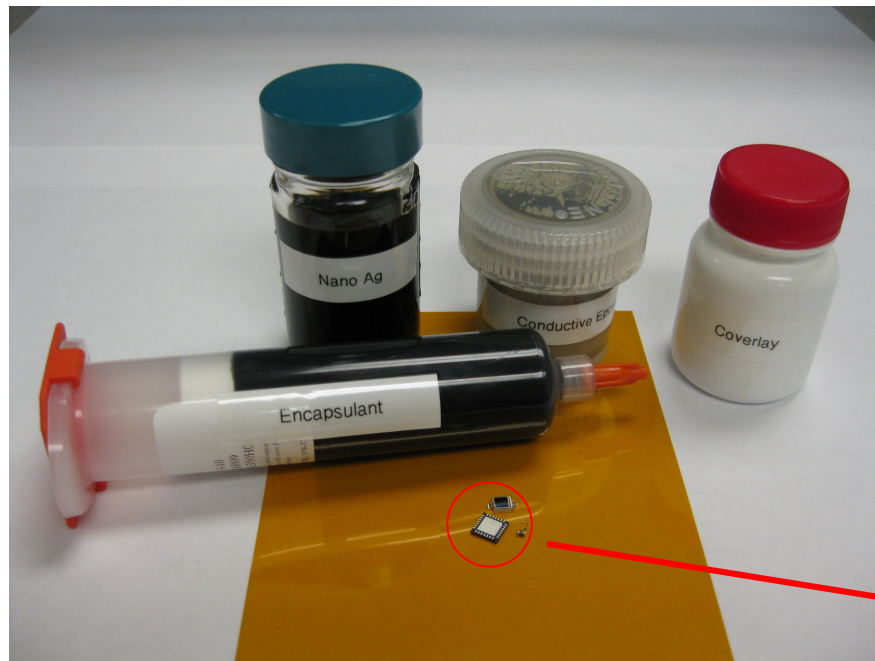
- **Wearable sensors**
- **Conform to irregular shapes**



System example: NSF Wireless sensor platform mockup



Miniature systems based on additive processes

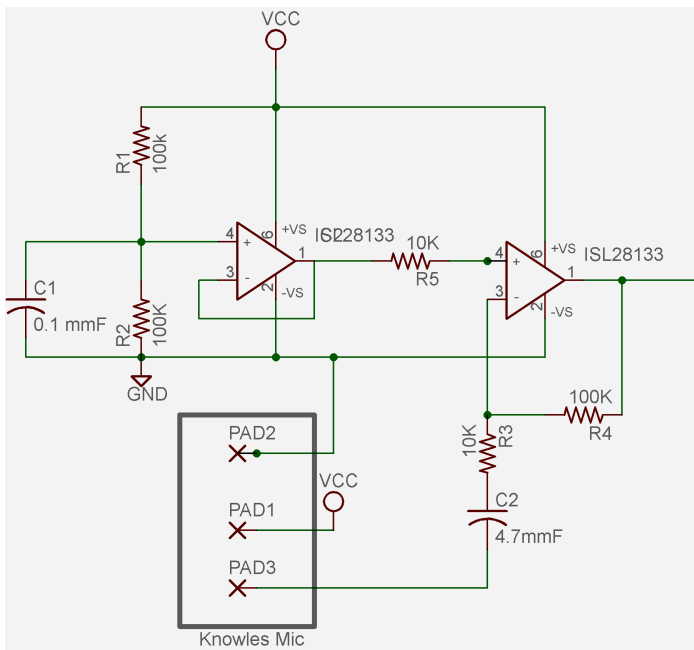


- Process temperatures $< 200\text{ C}$
- Negligible waste stream

Example: Microphone/Amplifier module fabrication

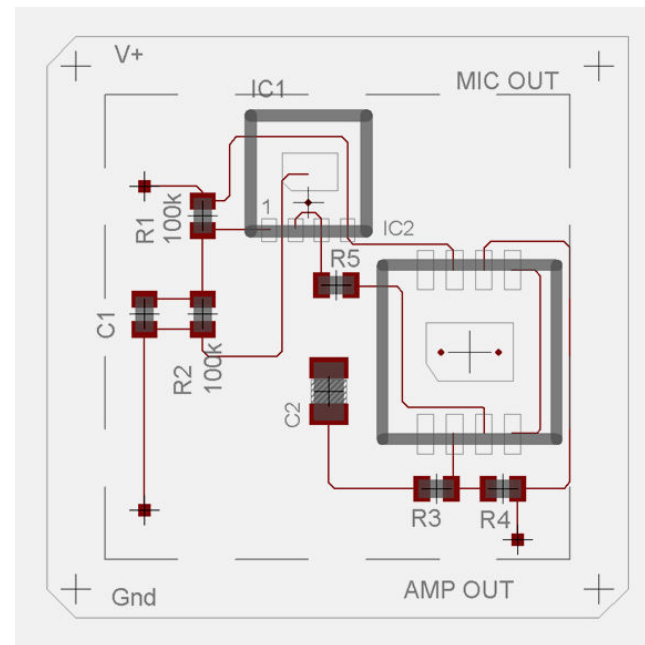


Layout



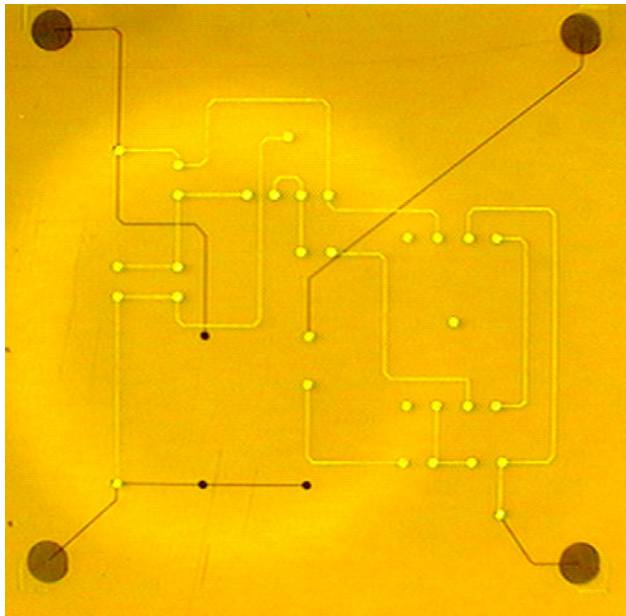
Schematic

← 10 mm →

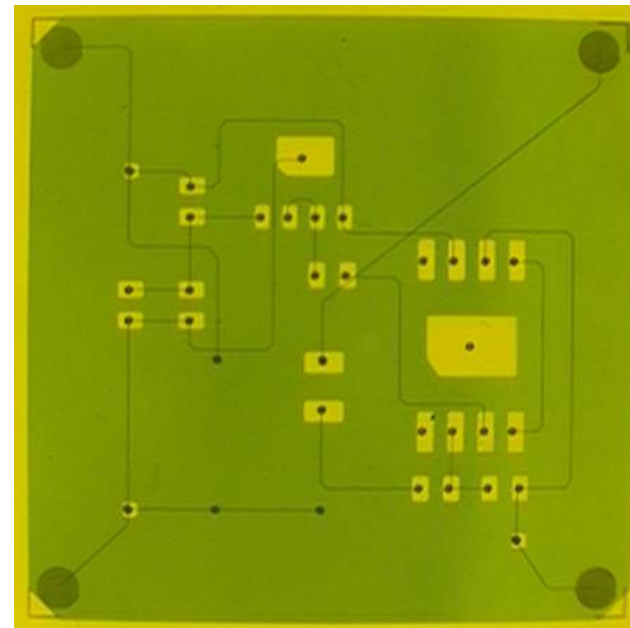
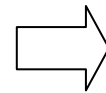


All CAD/CAM processes are driven by layout

Conductors and Coverlay

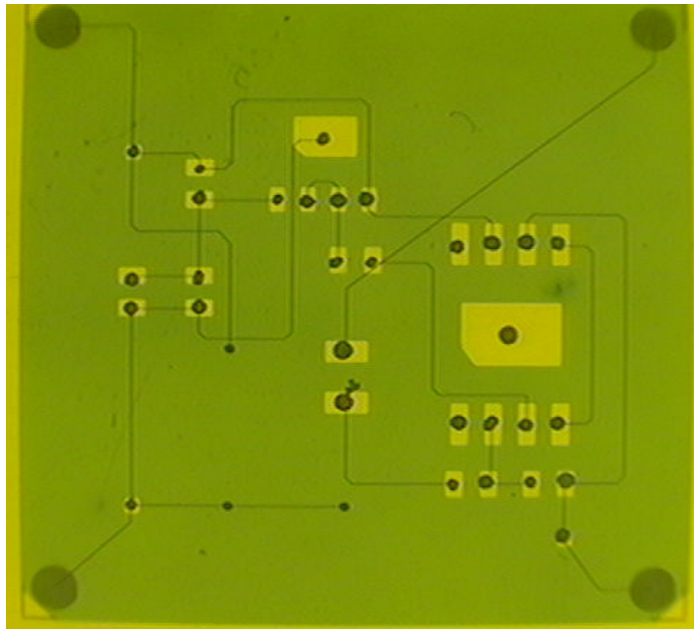


**Laser pattern and fill
frontside and backside
conductors**

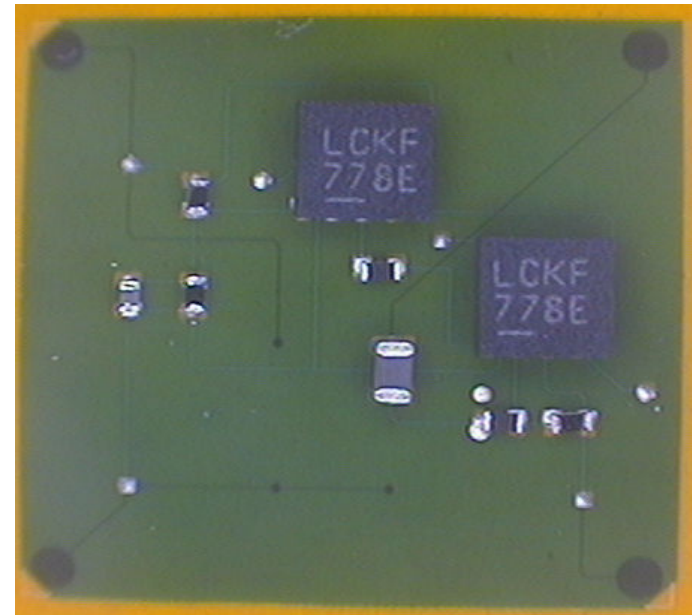
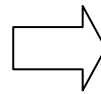


**Apply, laser image and
develop (aqueous) frontside
coverlay**

Dispense adhesive and populate



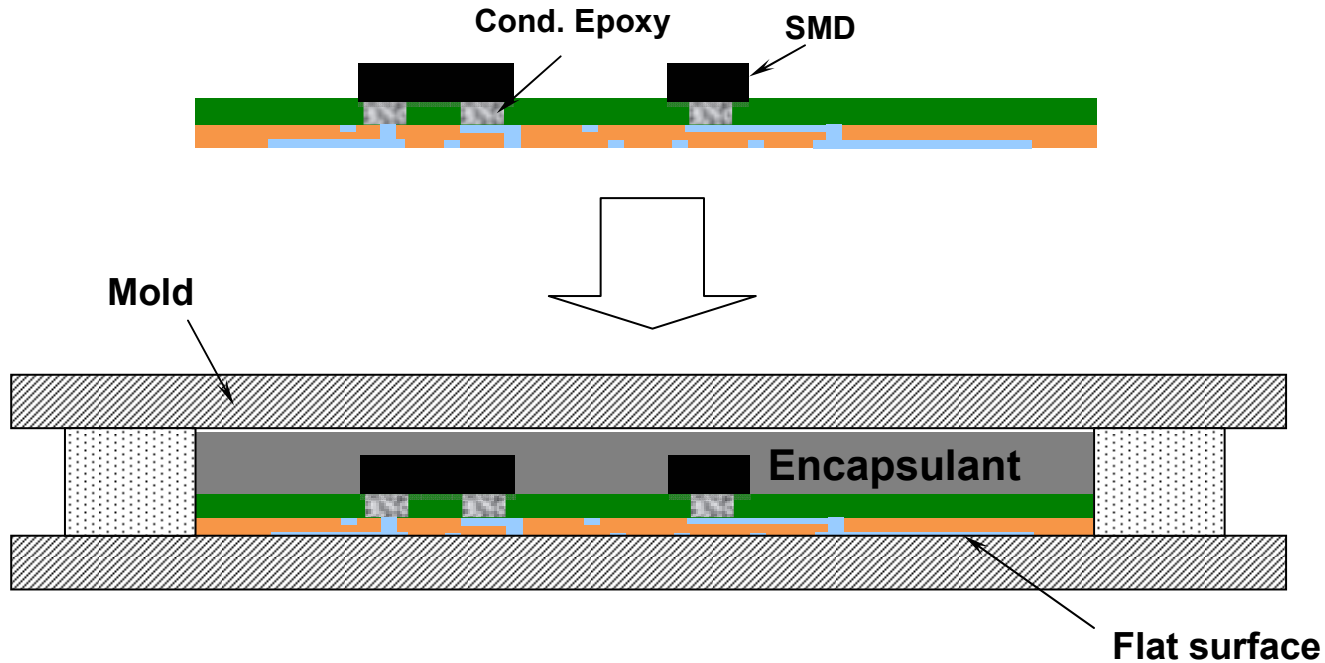
Dispense epoxy using locations derived from layout



Pick and place components using locations derived from layout

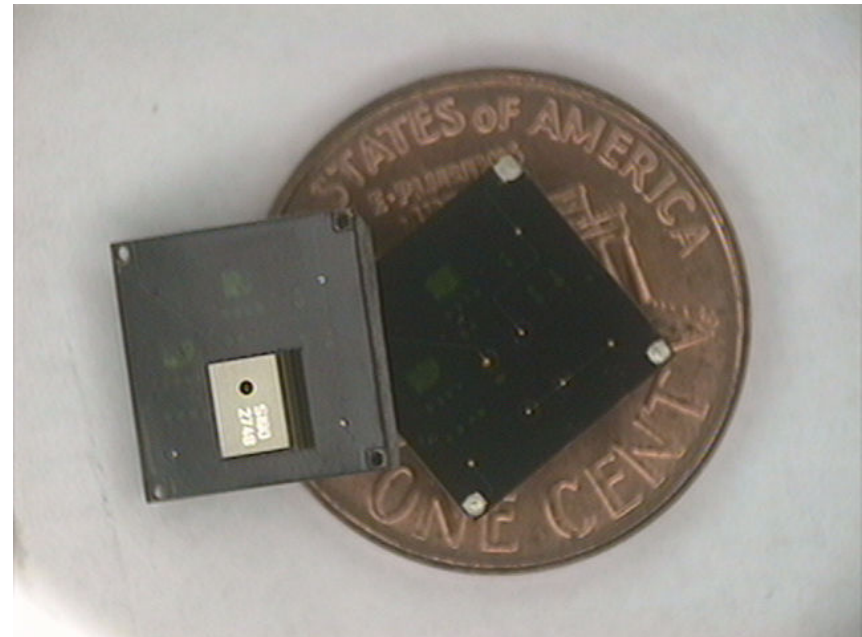
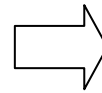
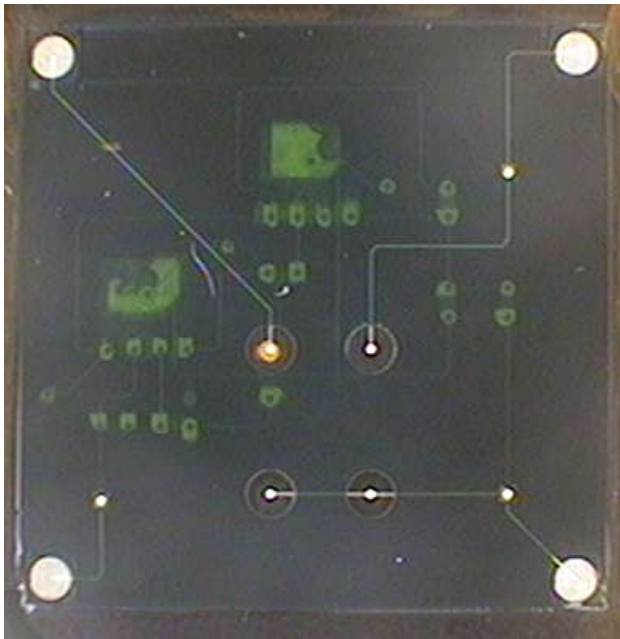
Must have high accuracy and repeatability

Encapsulation



- Vacuum/pressure encapsulation with thermal cure
 - Eliminate voids
 - Flat outer surfaces
- Encapsulant material requirements:
 - Compatible TCE
 - Adhesion to coverlay and components
 - Suitable flow and curing properties

Encapsulation, Vertical Vias, Backside Components



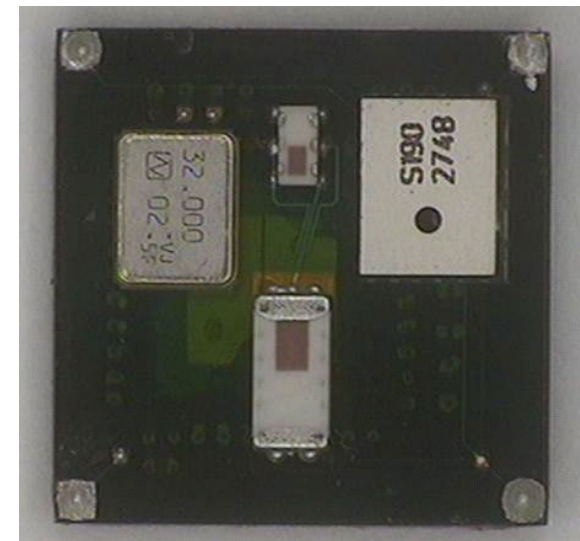
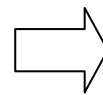
Encapsulated circuit with patterned backside coverlay

Completed modules

Communication Module



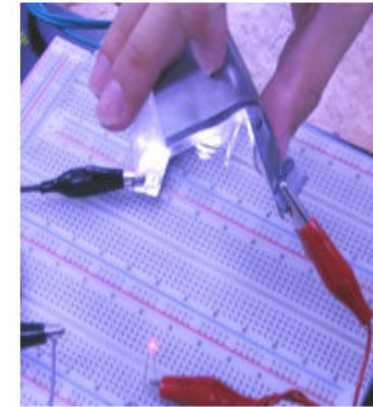
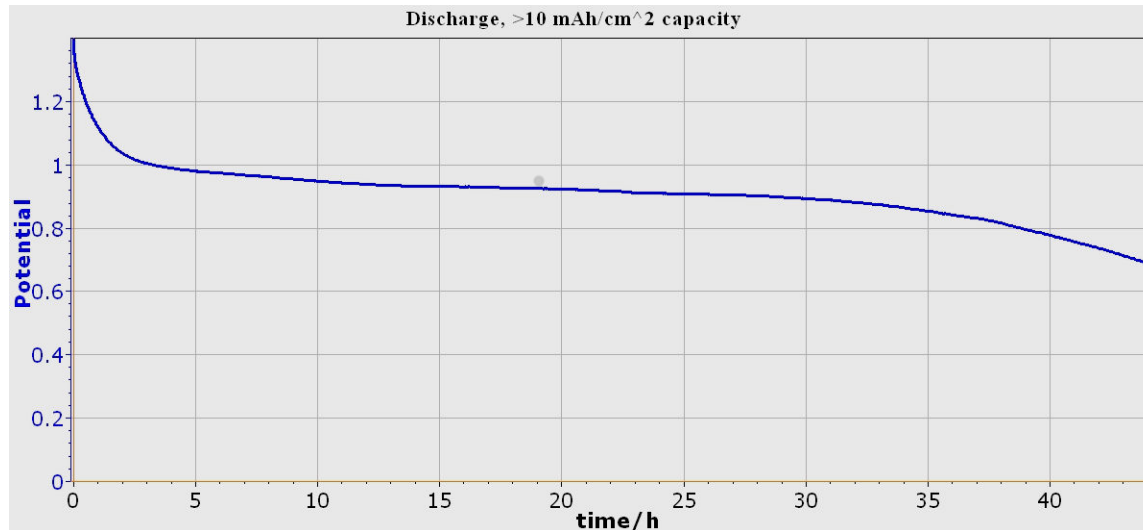
Wireless SoC with passives



Encapsulated module with exposed chip antenna and MEMS microphone

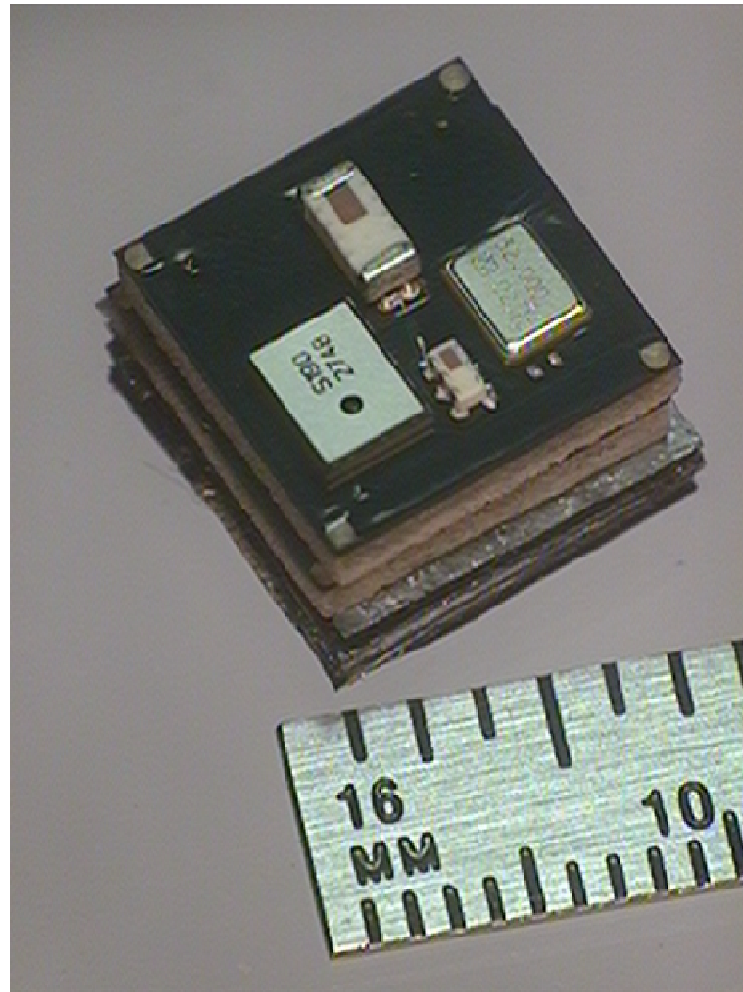
FlexEI, LLC

Advanced Thin Film Battery

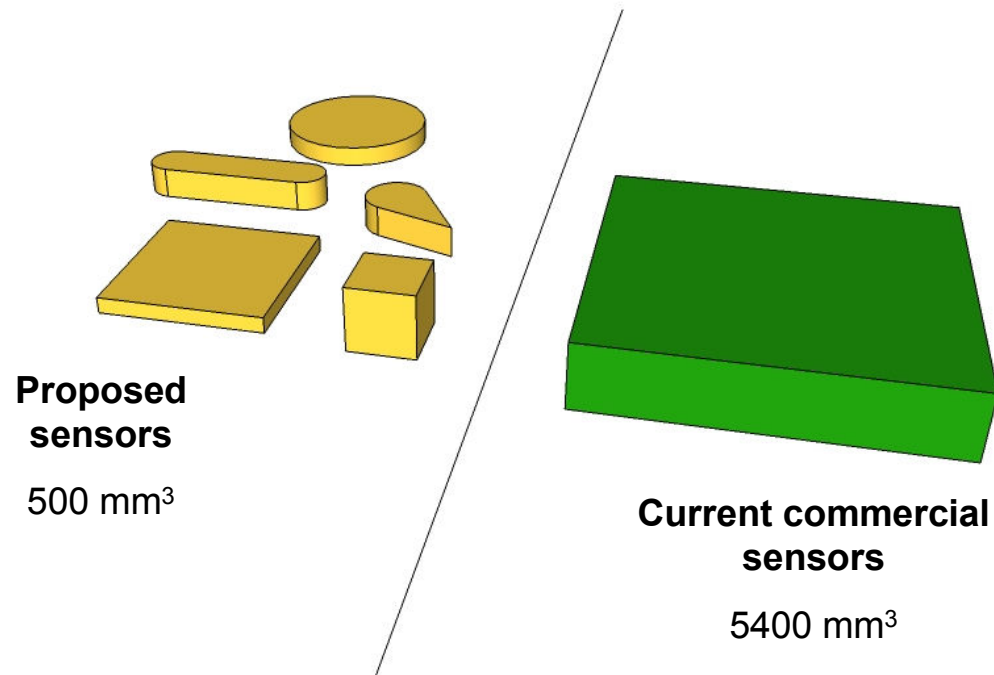


- New RuOx chemistry gives >10 mA-hr/cm²
- < 0.3 mm thickness
- 10 x 10 mm² footprint

Complete wireless sensor



Size Reduction + Freedom of Form Factor



- Volume reduction through high density packaging and fine line interconnects.
- Laser based CAD/CAM process allow wide range of shapes

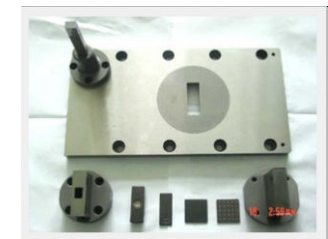
Capital Equipment Required



Integrated Laser/PnP/Dispense



Paste fill & clean station



Encapsulation mold

Capital Equipment NOT required



Resist exposure system



Etching/Plating tanks

Lamination
Press



Resist
stripper



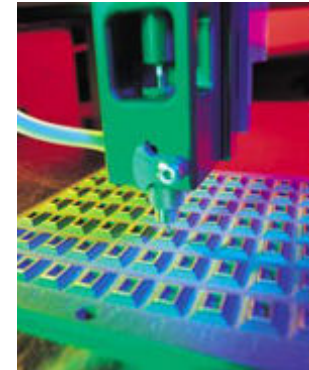
Scaling to higher volume



UV laser system



Encapsulation mold



**Epoxy
Dispenser**



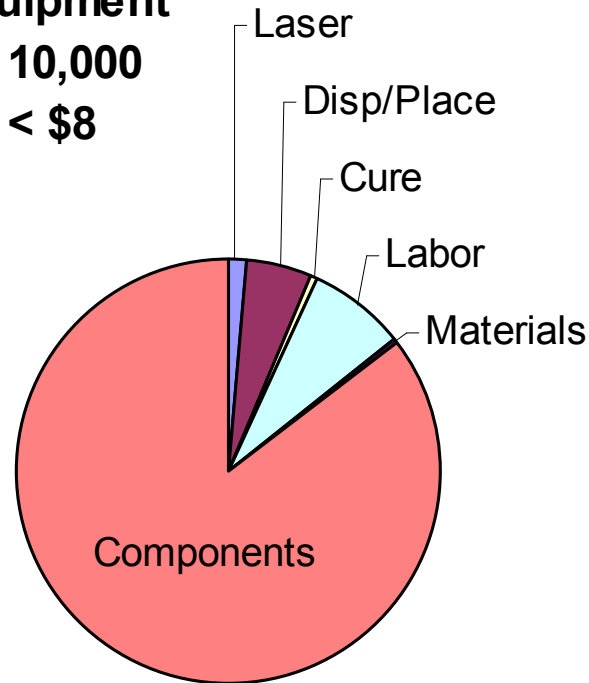
Paste fill & clean station



**Pick and
Place**

Module cost estimate

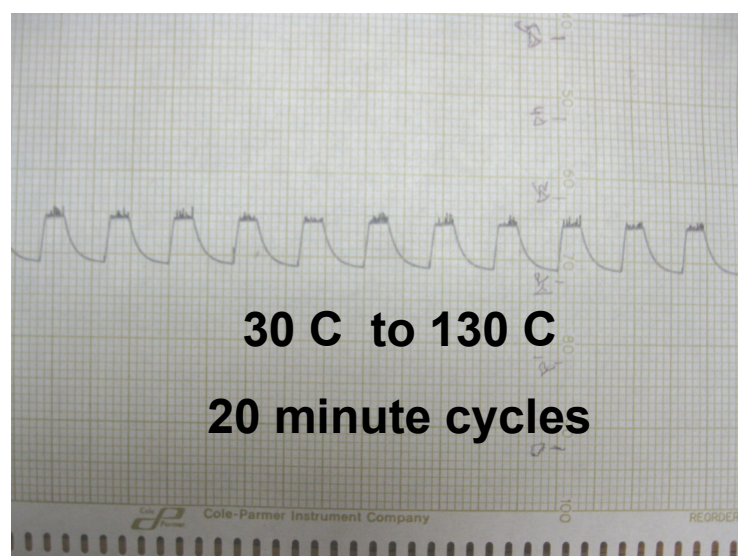
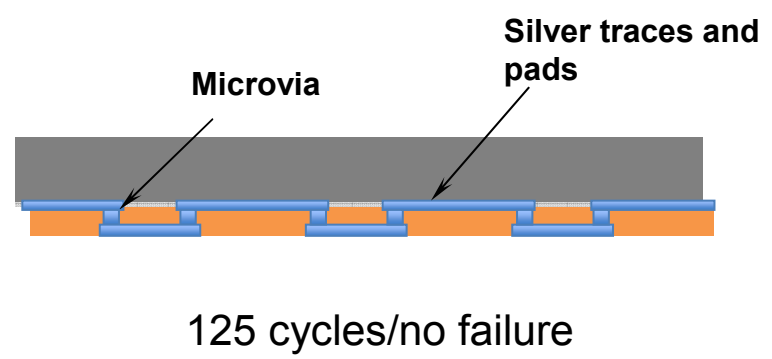
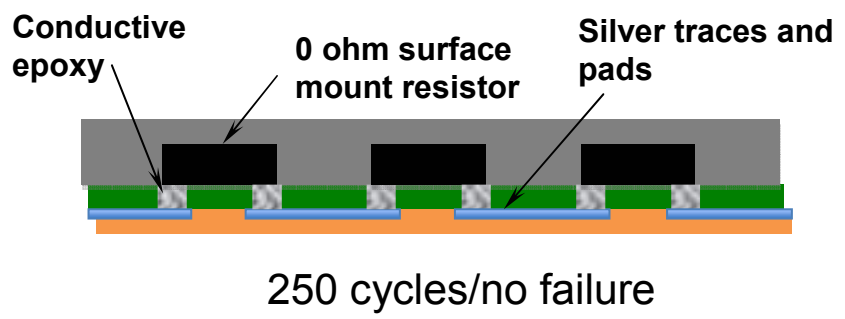
Automated Equipment
Batch Size = 10,000
Total cost < \$8



- **Component costs dominate**
- **Materials costs negligible**

Thermal cycling tests

40 element Daisy Chains



Chain resistance vs time

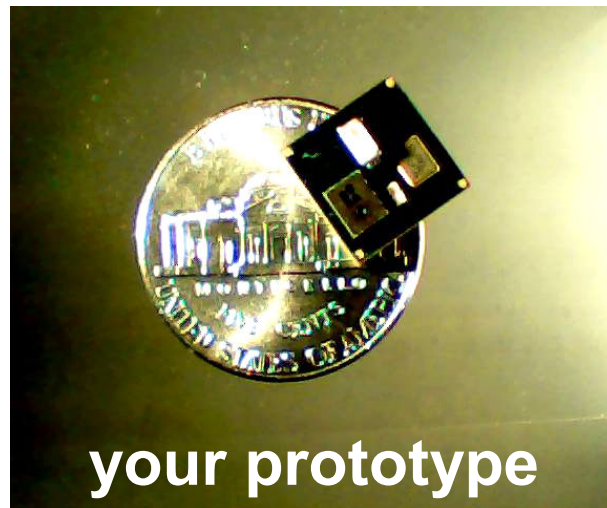
-50C to +150C Testing of 170-component Daisy Chains Underway

Summary

Development Goal	No	Yes
High Miniaturization		✓
Flexible, 3D form factors		✓
Low-cost assembly		✓
Green fabrication processes		✓
Small/large batch manufacturing		✓
Minimal capital equipment		✓

Collaboration and evaluation opportunities enabled by NSF

This work is partially supported by NSF SBIR Phase II Grant #IIP-1058133



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