Circuit Miniaturization Using Nanoparticle Conductors and Embedded Components

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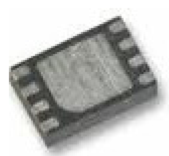
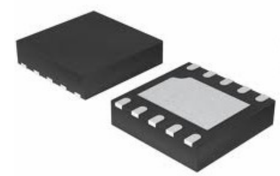
Component miniaturization

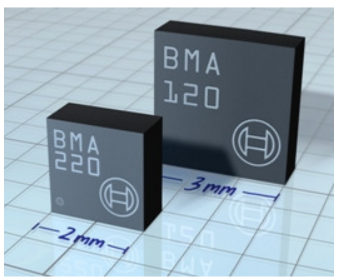
Sub-millimeter passives



6x6 mm² RX/TX/MCU

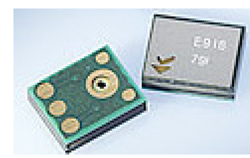


2x2 mm² Op Amps



2x2 mm² Accelerometer

4x4 mm² MCU



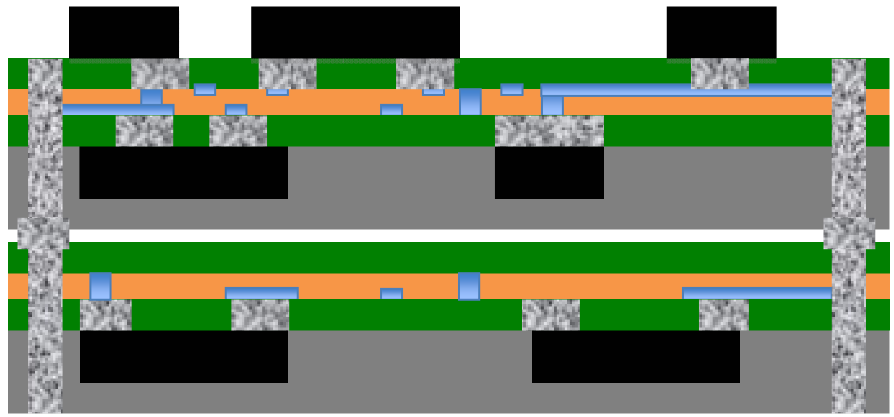
MEMS Microphones

- New miniature components offer opportunities for system miniaturization
- Need new interconnect and power concepts

Development Goals

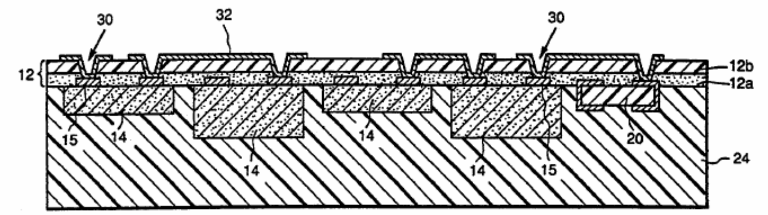
- Miniature systems using packaged components
- 3D construction with flexible form factor
- Low-cost assembly
- Green, lead-free processes
- Minimize capital equipment costs
- Small/Large batch compatibility
- Easy design change
- Modular testability

Approach



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

Embedded 3D Fabrication

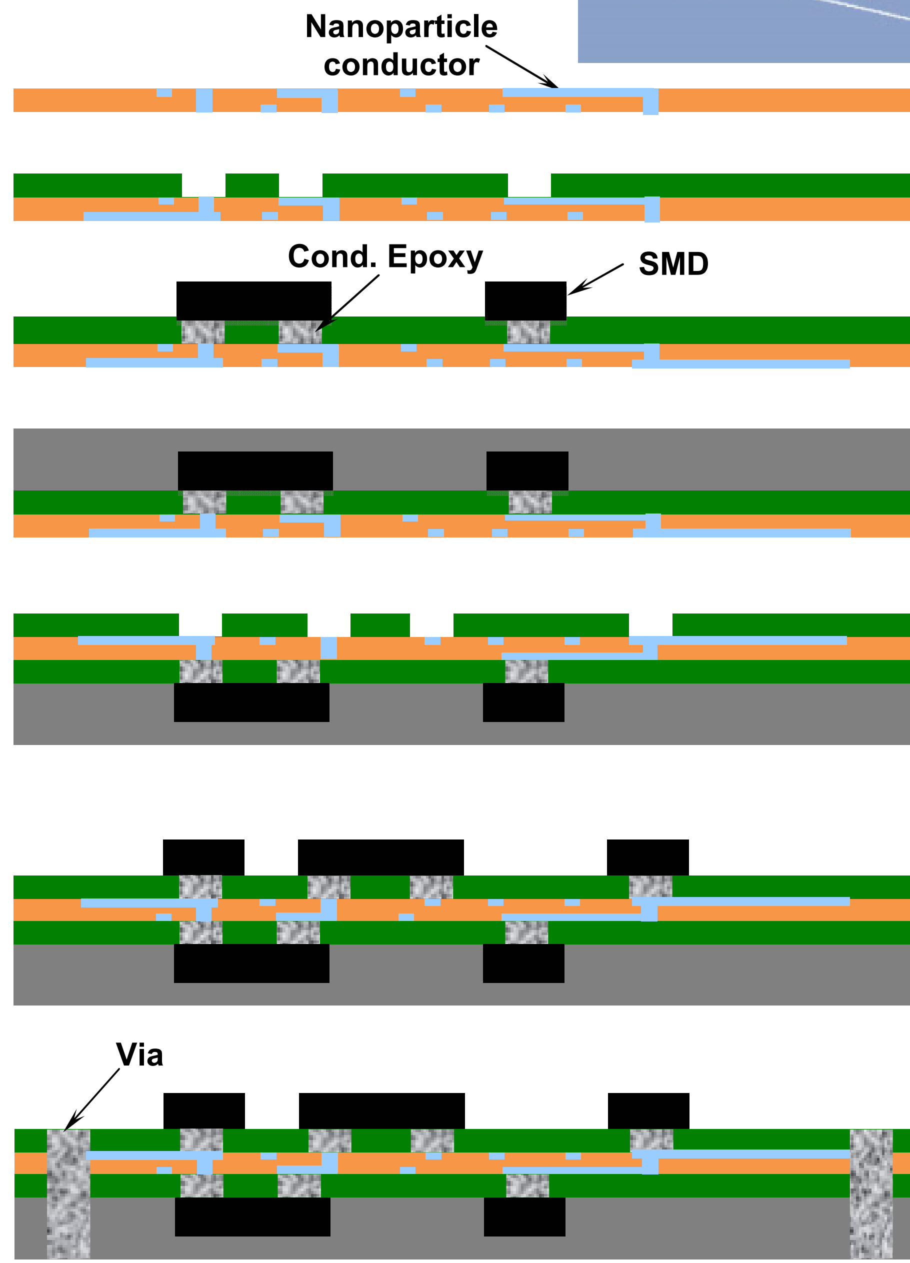


1994 Patent Drawing (U.S. 5353498)

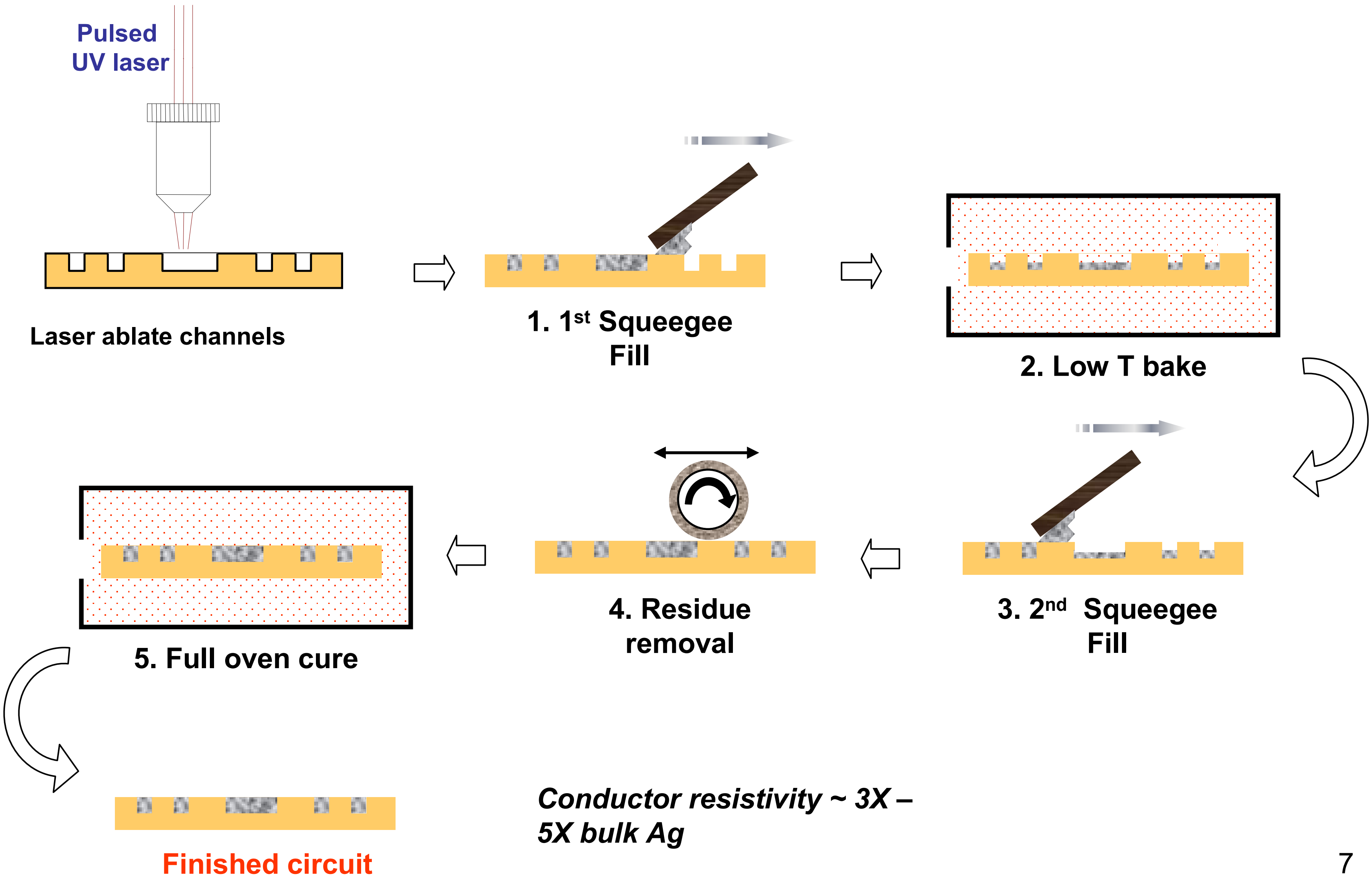
- Many different/similar techniques
  - **GE (1994 patent), Freescale, Verdant Electronics, Imbera, Ga Tech, Fraunhofer, ...etc.**
- **Well known benefits**
  - **High component density**
  - **Eliminate solder connections**
  - **Simplify supply chain**
- **Potomac's contribution: Simplicity**

Process

1. Pattern substrate and fill with nanoparticle silver
2. Apply and pattern cover layer.
3. Attach components
4. Encapsulate components
5. Invert. Apply cover layer to backside and pattern
6. Attach components (optional)
7. Drill and fill interconnection vias. Excise

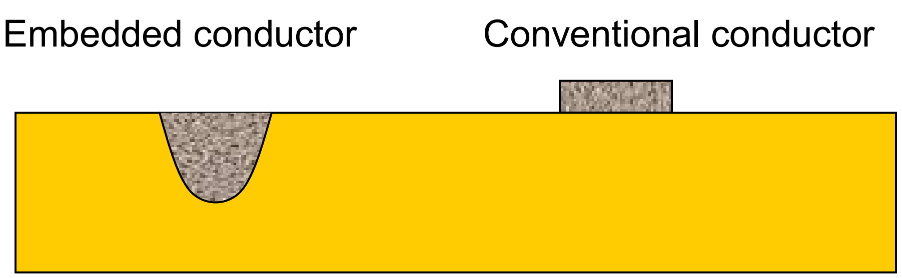


Conductor fabrication



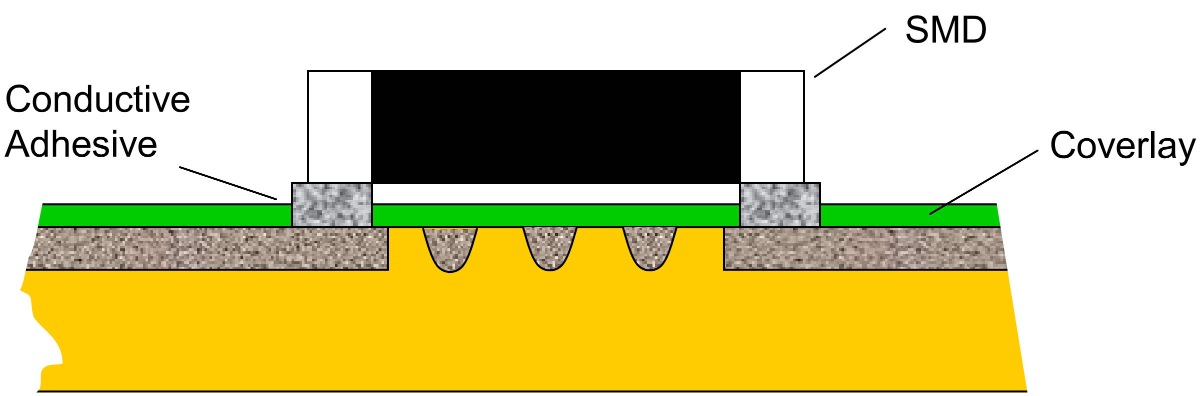
Conductor resistivity ~ 3X – 5X bulk Ag

Embedded Nanoparticle Conductors



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

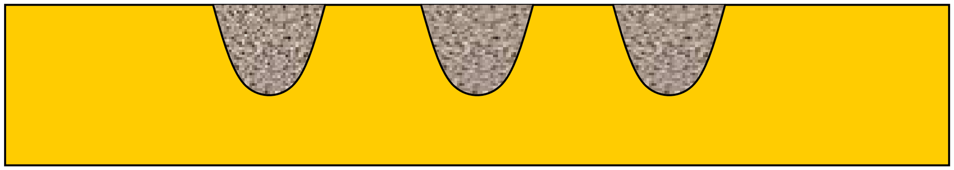
New Routing Options Allow Layer Reduction



- Narrow linewidths and embedded geometry allows more routing between pads.
  - Reduce via count
  - Reduce layer count
  - Simplify signal leadout from arrays
  - Route under surface mount passives

Applicable to a Variety of Substrates

Embedded conductor pattern



Substrates

- Organic
  - Polyimide
  - ABF
  - EPTFE
  - Liquid crystal polymers
- Inorganic
  - Alumina

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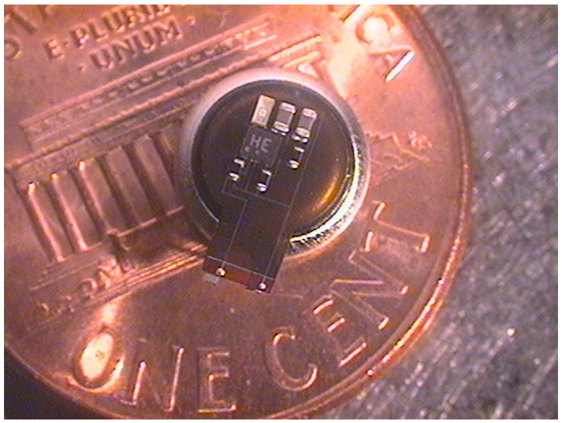
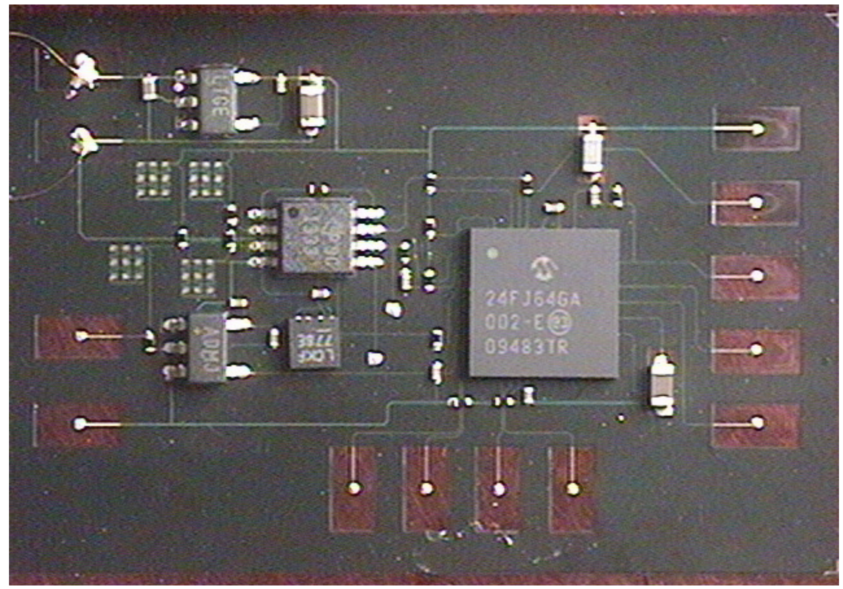
Examples: Polyimide substrate



Battery-powered LED flasher



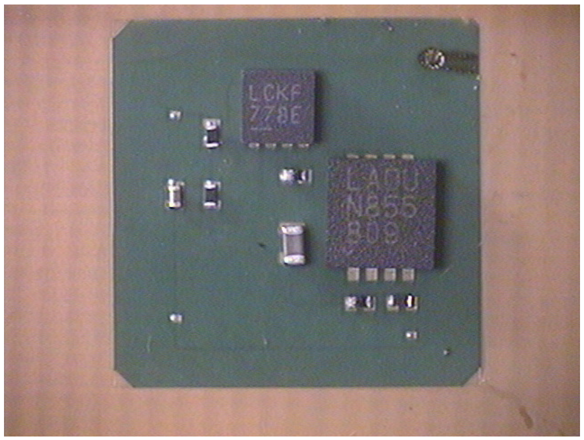
23 mm

35 mm

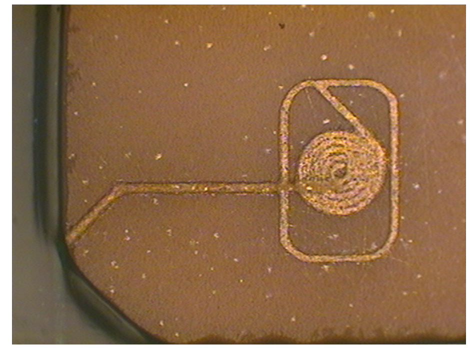
Strain gauge interface

Single Layer Circuits !

Examples:
Alternative Substrates

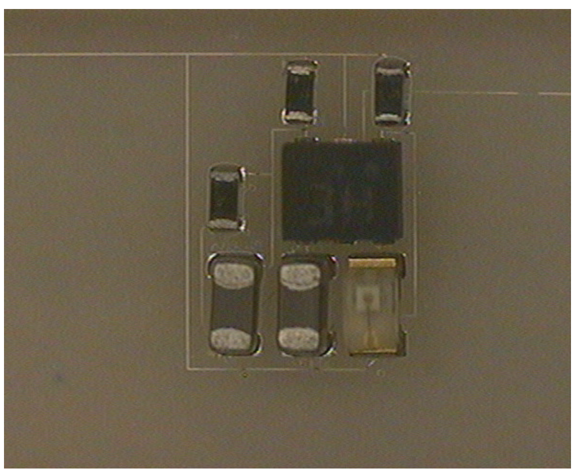


← ABF →

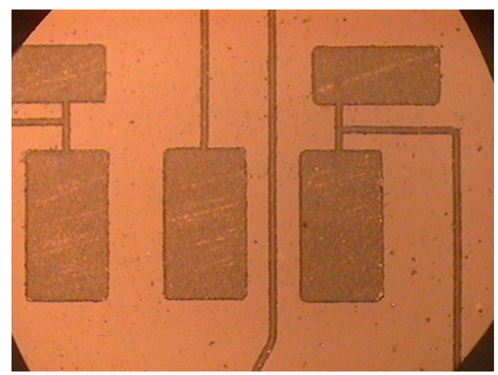


Working circuits

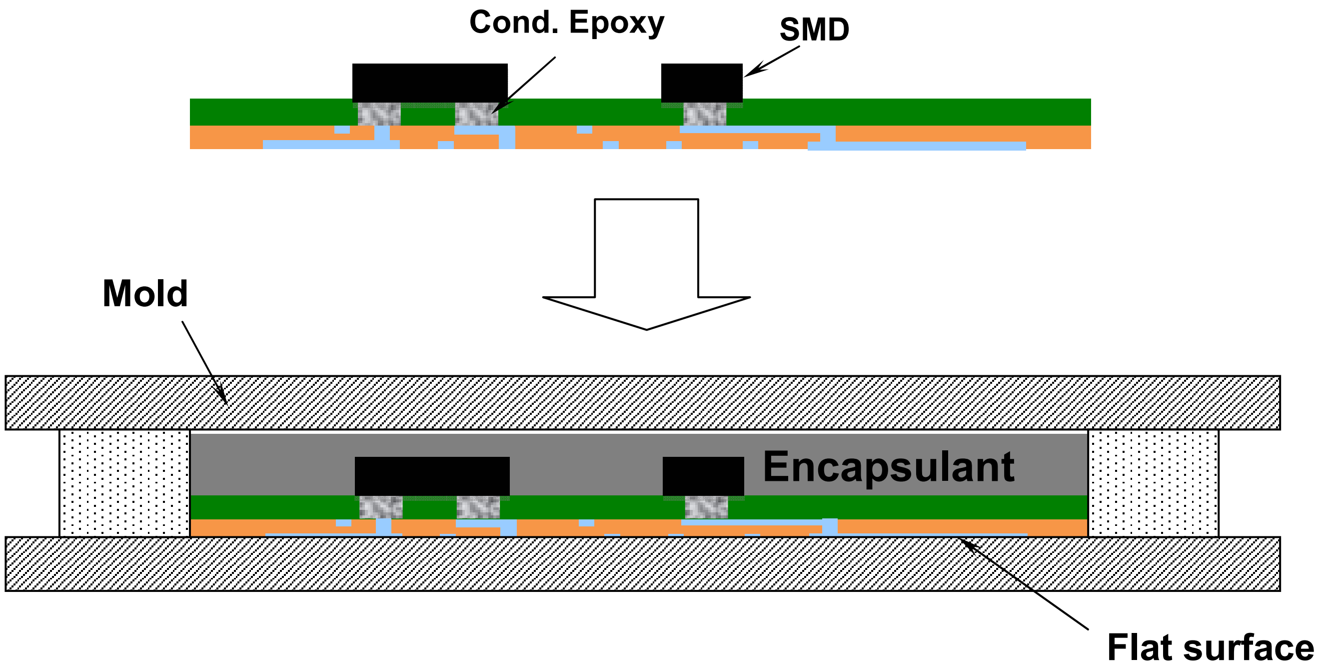
Pads and 15 micron traces



← Alumina →

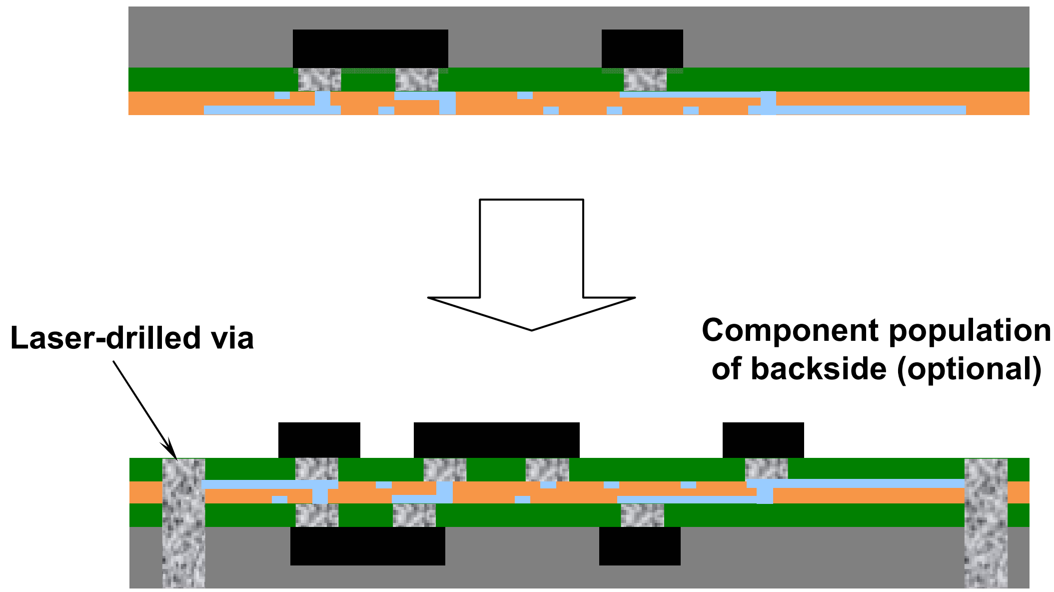


Encapsulation



- 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

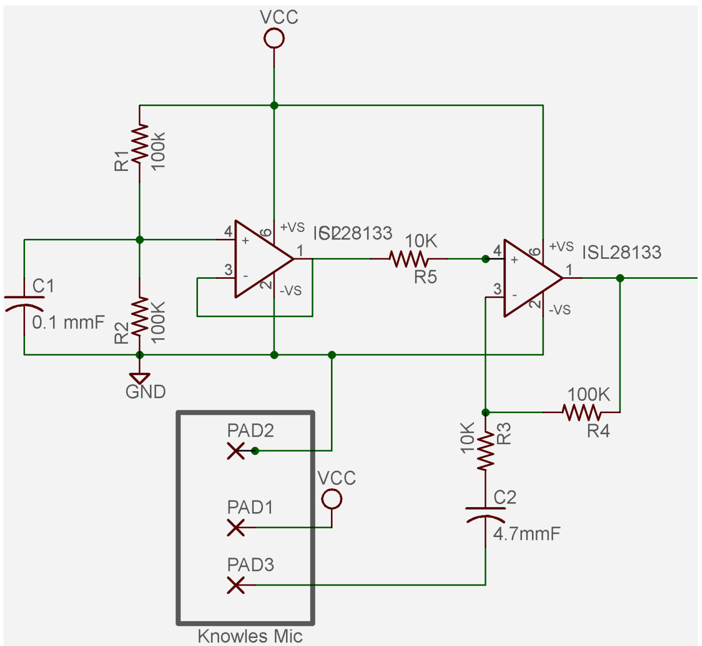
Connection to and between modules



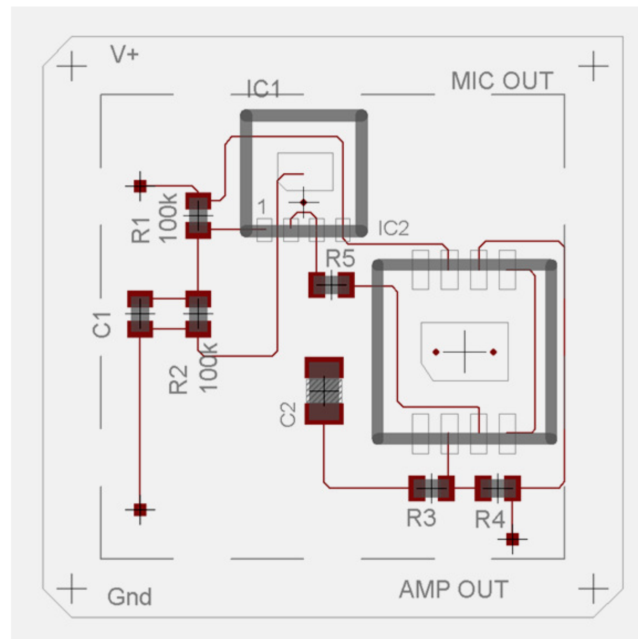
- Conductive vias for interconnection of modules
  - Laser drilled
  - Epoxy filled
  - Many other options

Example: Amplifier module fabrication

Layout

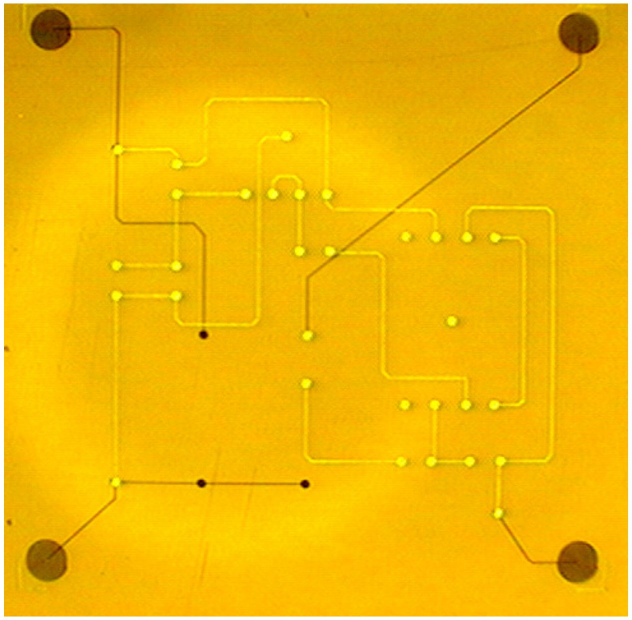


Schematic

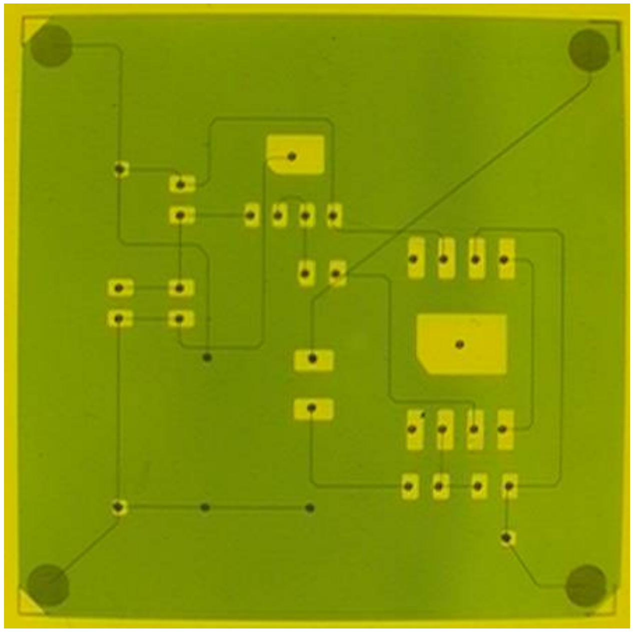


All CAD/CAM processes are driven by layout

Conductors and Coverlay

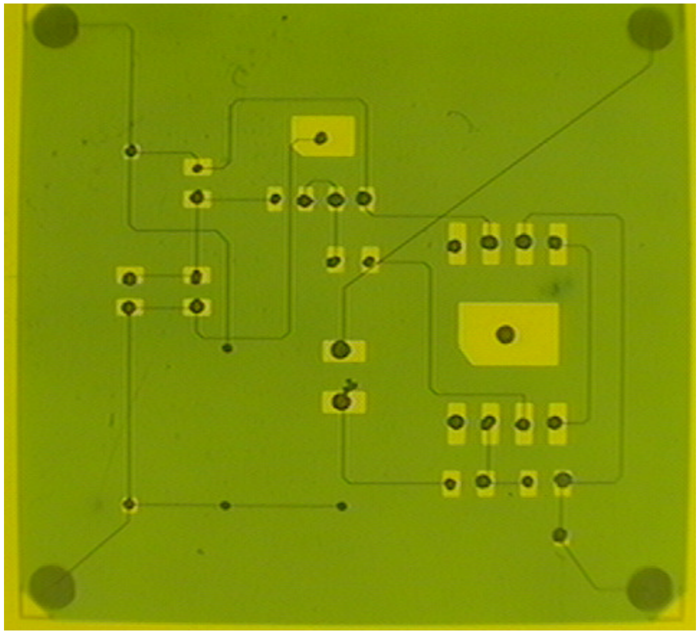


Laser pattern and fill frontside and backside conductors

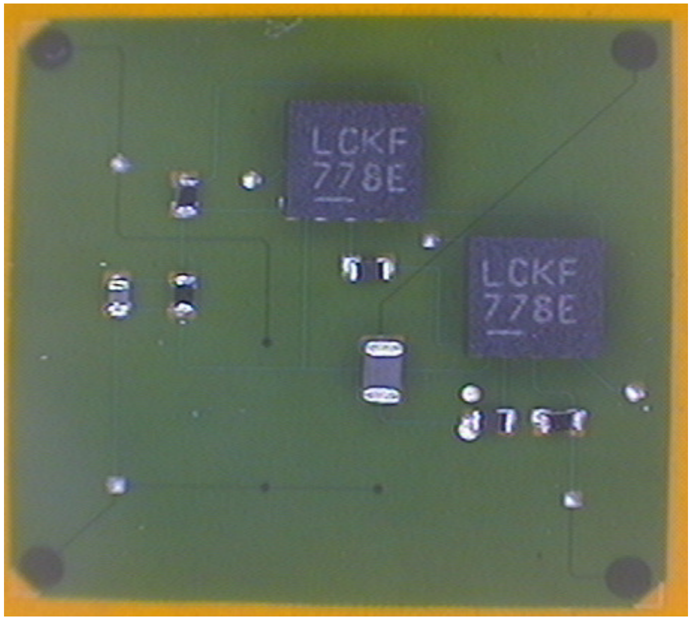


Apply, laser image and develop (aqueous) frontside coverlay

Dispense adhesive and populate



Dispense epoxy using locations derived from layout

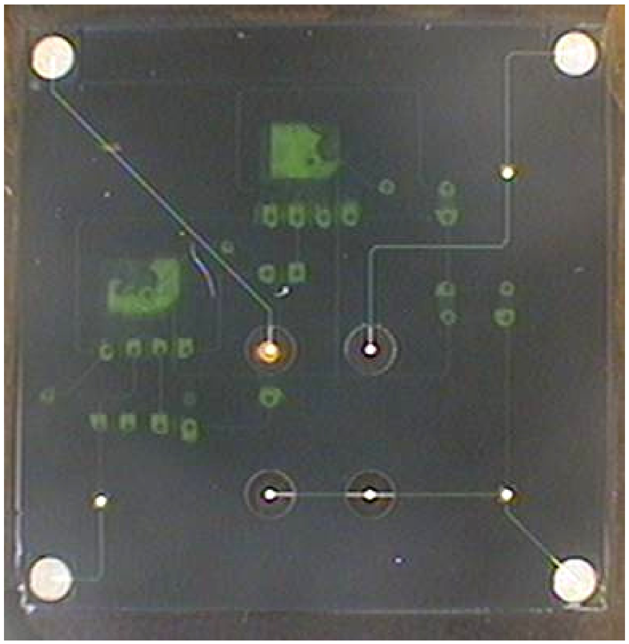


Pick and place components using locations derived from layout

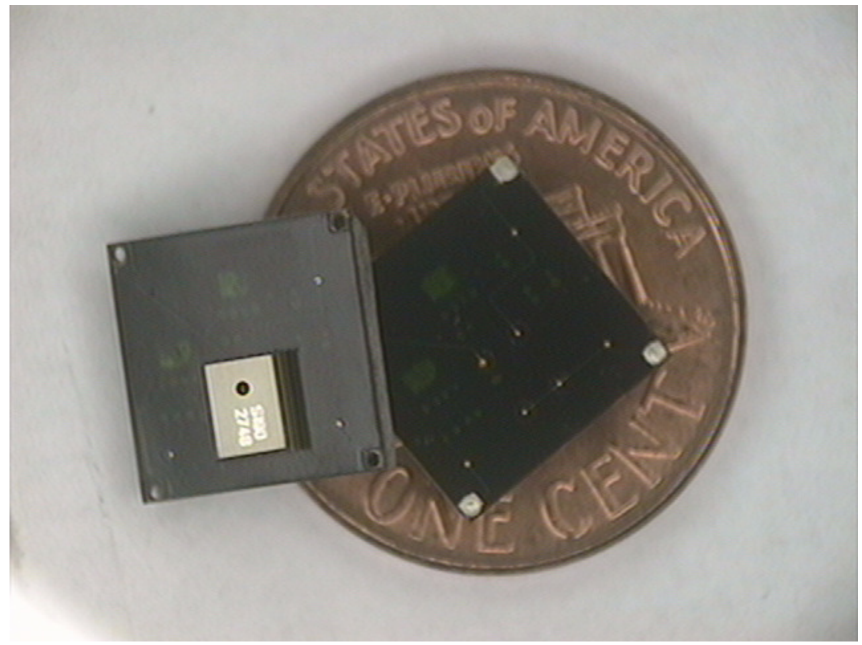
Must have high accuracy and repeatability

Example: Amplifier module fabrication

Encapsulation, Through Vias, and Excision



Encapsulated circuit with patterned backside coverlay



Completed modules

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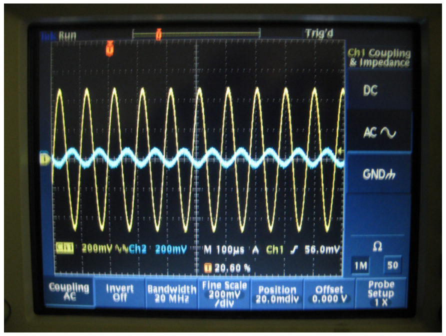
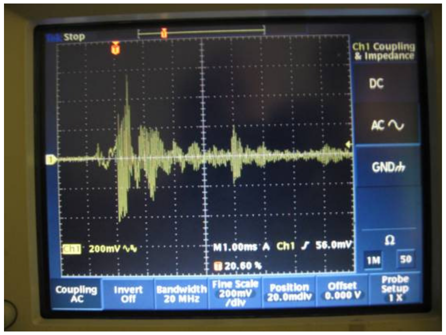
Electrical Test

Several intermediate testing opportunities during module production

- **After interconnect fab**
- **After component attach**
- **After encapsulation**
- **Before stacking**



10X Amp Gain
(after component attach)

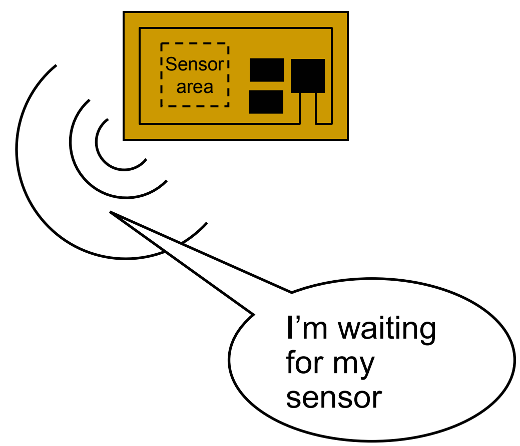


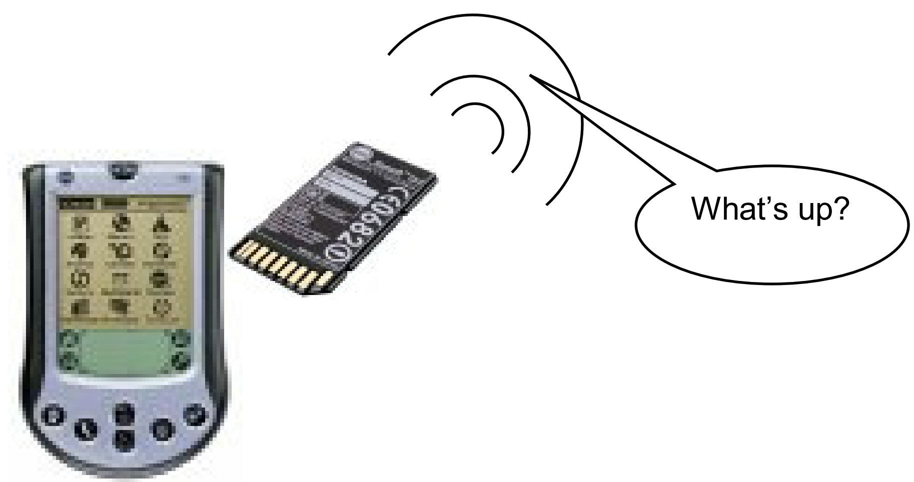
Amplified microphone output
(after module completion)

Feasibility study: Wireless sensor platform

Support by National Science Foundation

- Potomac transmitter/receiver using wireless chipset and rechargeable thin film battery
  - Sugar cube size
  - Can attach sensors





Wireless sensor requirements

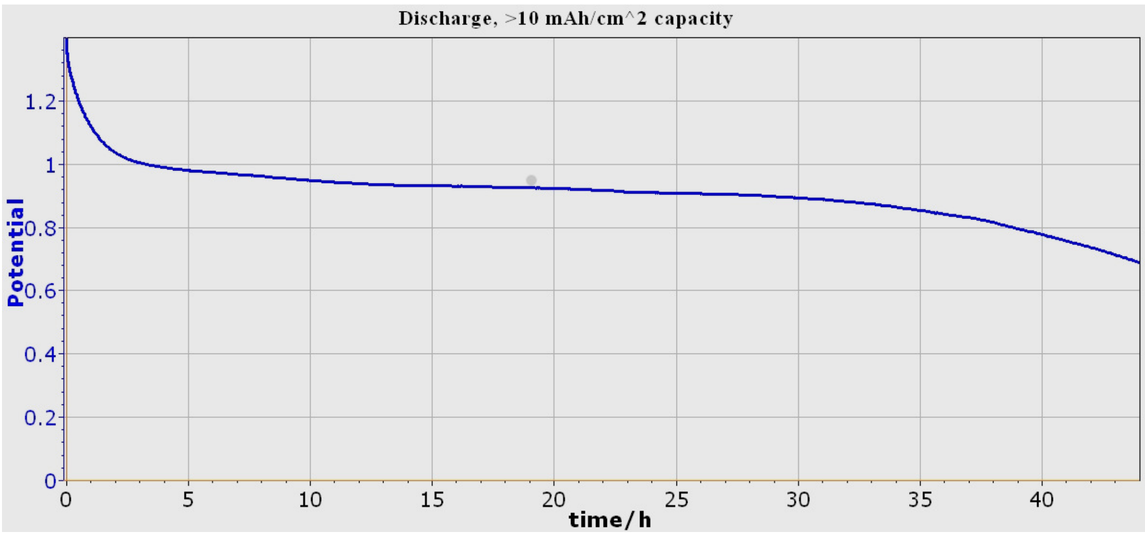
- Every sensor must have:
  1. Sensing component
  2. Signal conditioning
  3. Communication
  4. Power source
  5. Enclosure

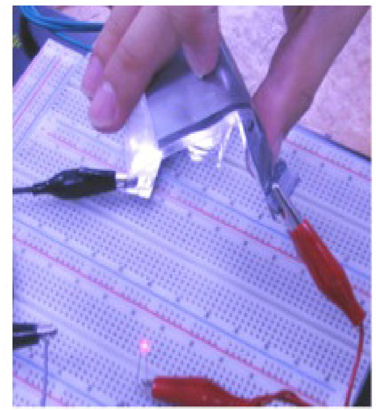
Infrastructure platform

- Infrastructure platform determines size and cost of sensor node

- Miniaturization requires high energy density battery or high efficiency energy scavenging

FlexEl, LLC
Advanced Thin Film Battery

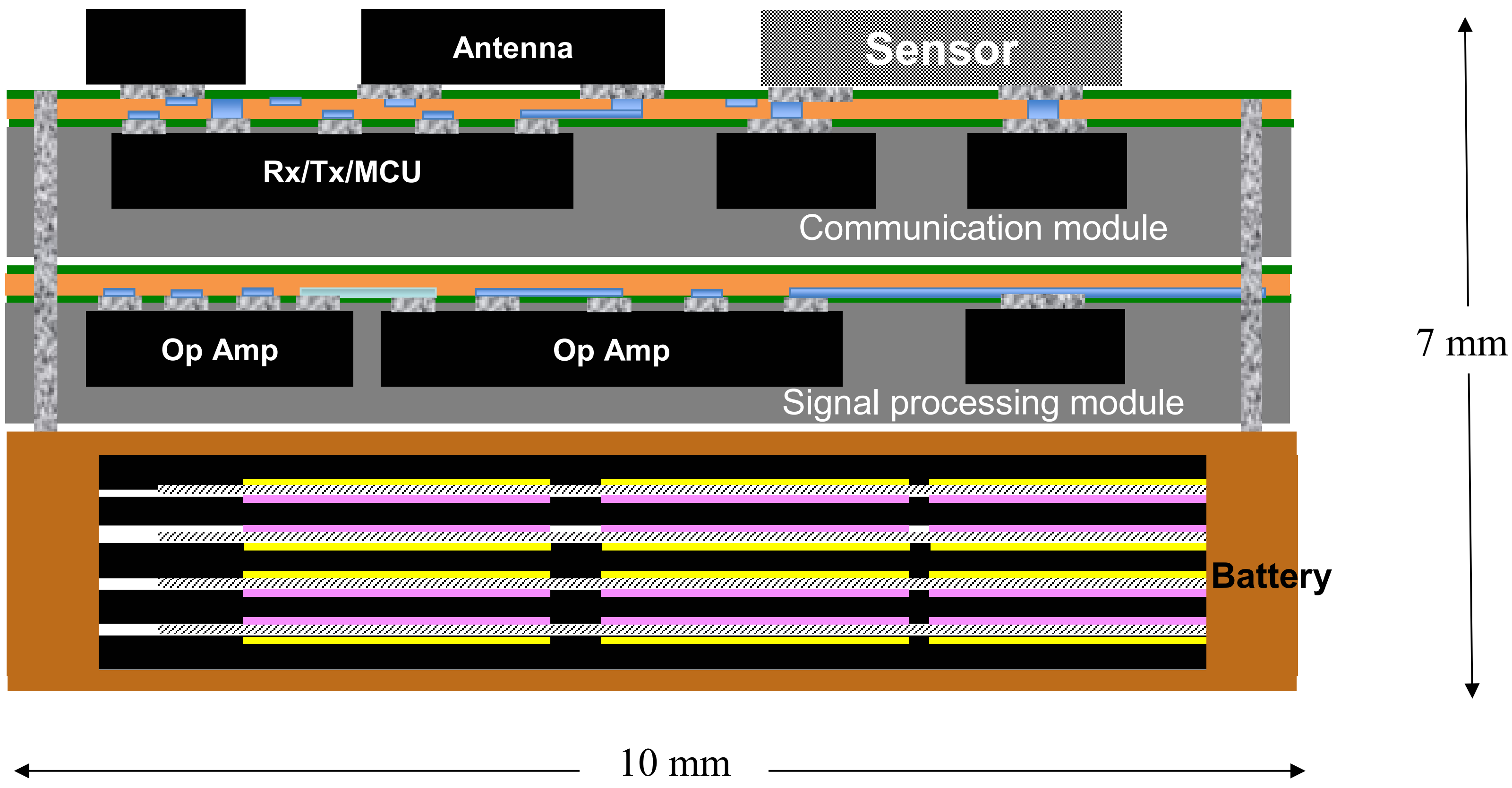




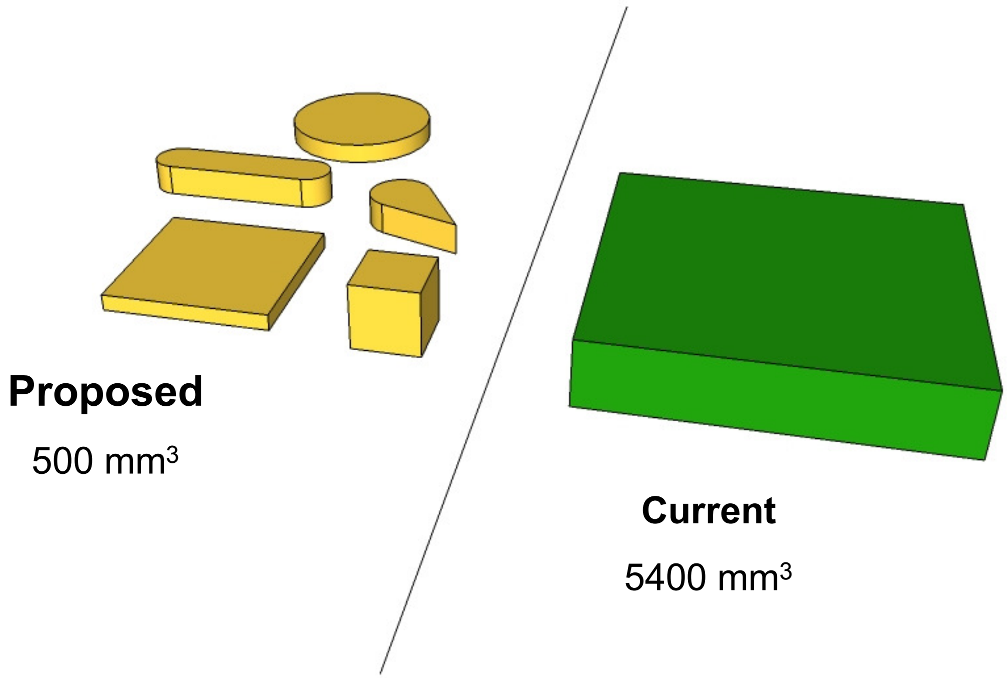
- New RuOx chemistry gives >10 mA-hr/cm2
- < 0.3 mm thickness
- 10 x 10 mm^2 footprint

NSF SBIR

Wireless sensor platform mockup

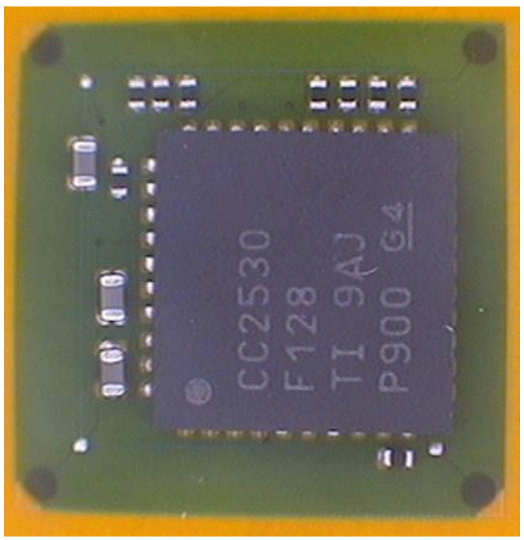


Size Reduction + Freedom of Form Factor

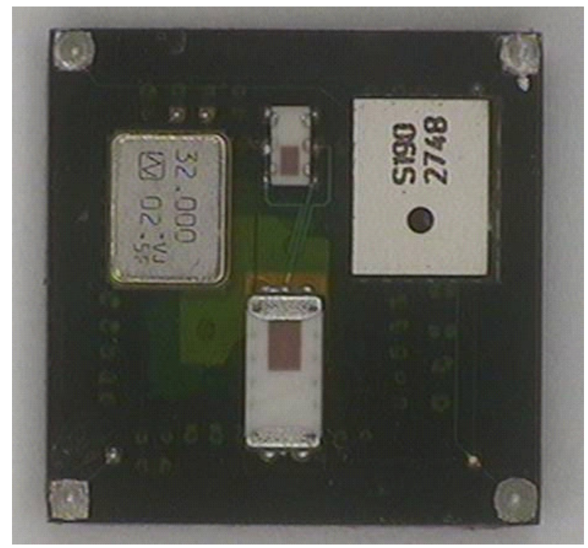


- Volume reduction through high density packaging and fine line interconnects.
- Laser based CAD/CAM process allow wide range of shapes

Communication Module

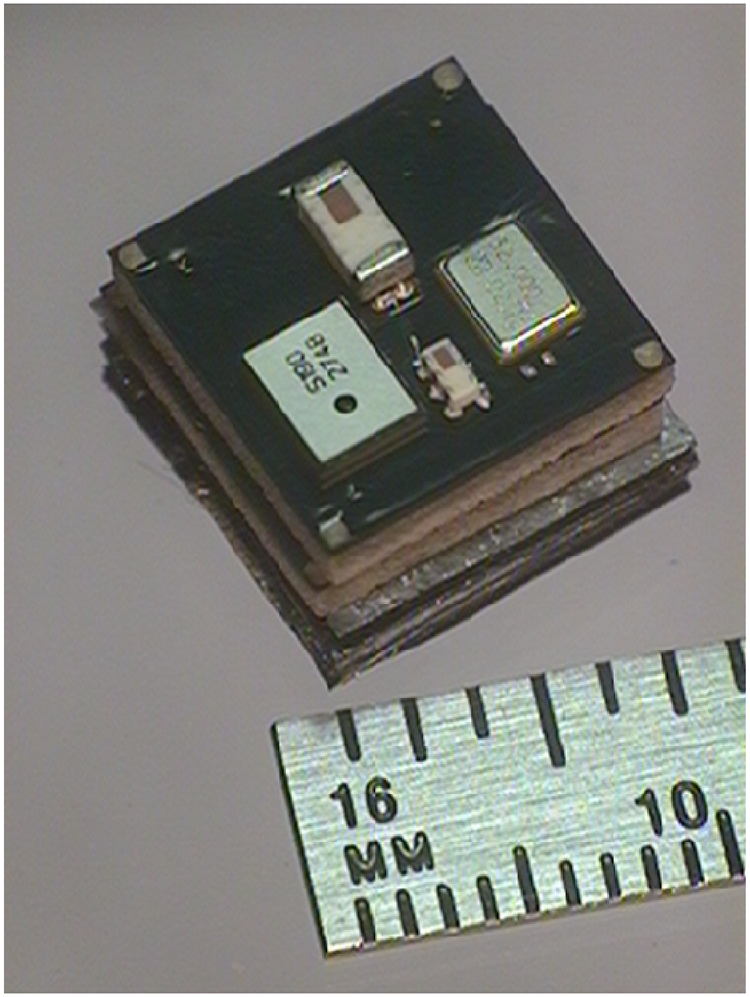


Wireless SoC with passives

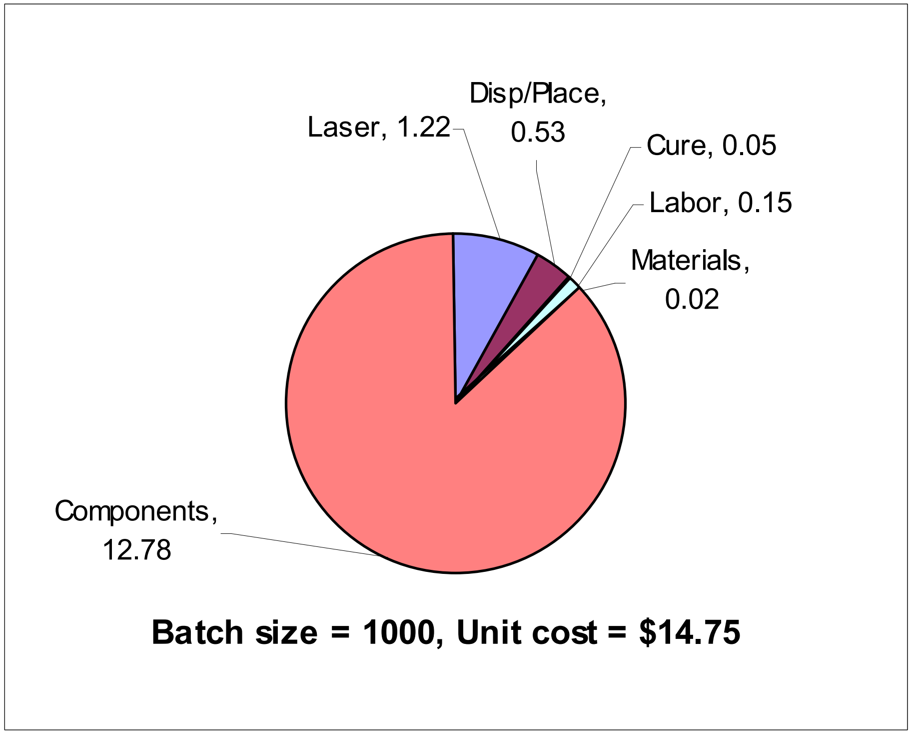


Encapsulated module with exposed chip antenna and MEMS microphone

Complete wireless sensor

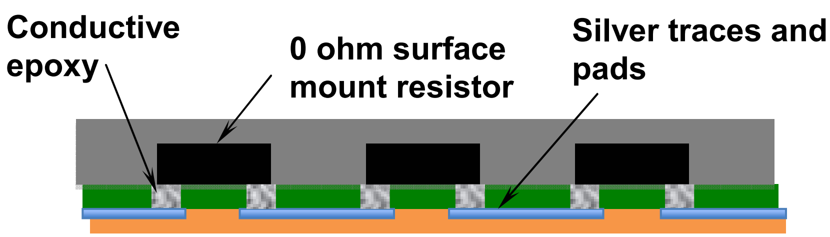


Sensor node cost estimate

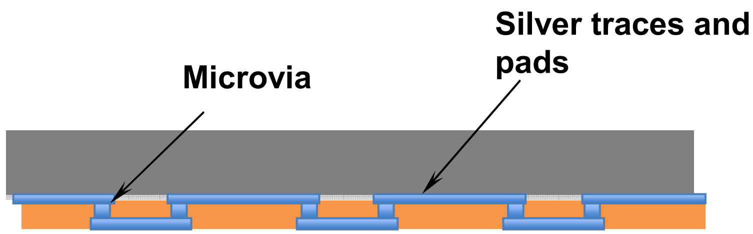


- Component costs dominate
- Materials costs negligible

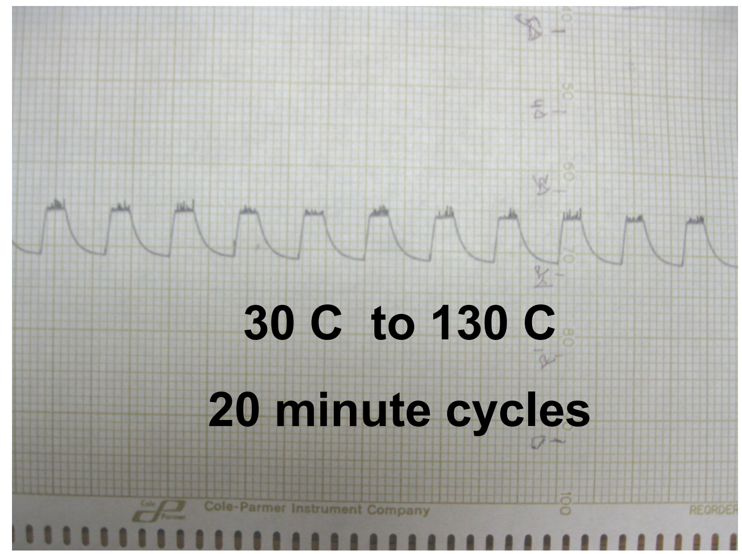
Thermal cycling tests



288 cycles/no failure



125 cycles/no failure

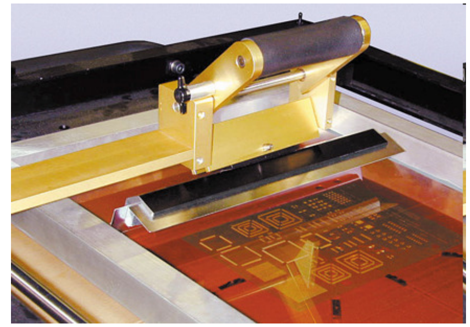


Chain resistance vs time

40 element Daisy Chains

Capital Equipment Required

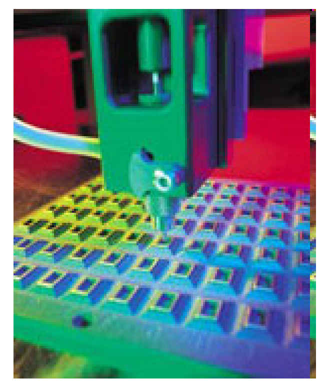
UV laser system



Paste fill & clean station

Encapsulation mold

Pick and Place



Epoxy Dispenser

Capital Equipment
NOT required

Resist exposure system

Etching/Plating tanks

Lamination Press

Resist stripper

It’s a work in progress, but....

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

More information and updates

www.potomacmeso.com

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