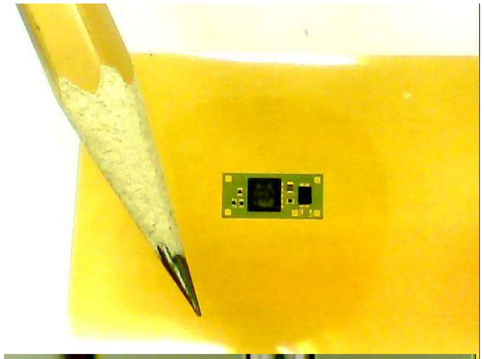
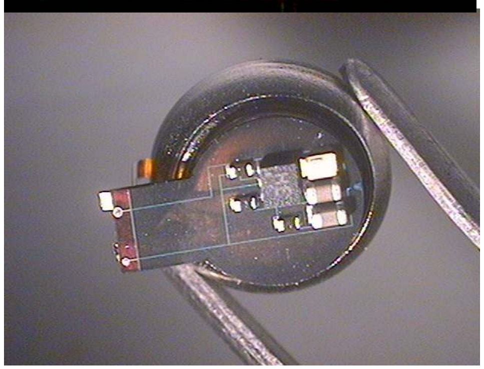
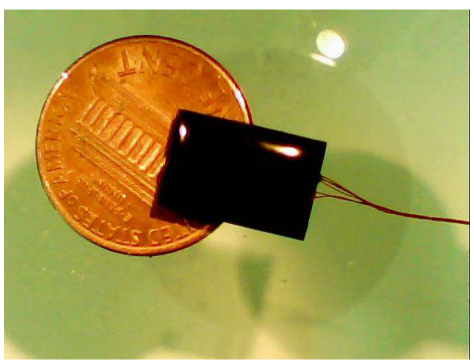






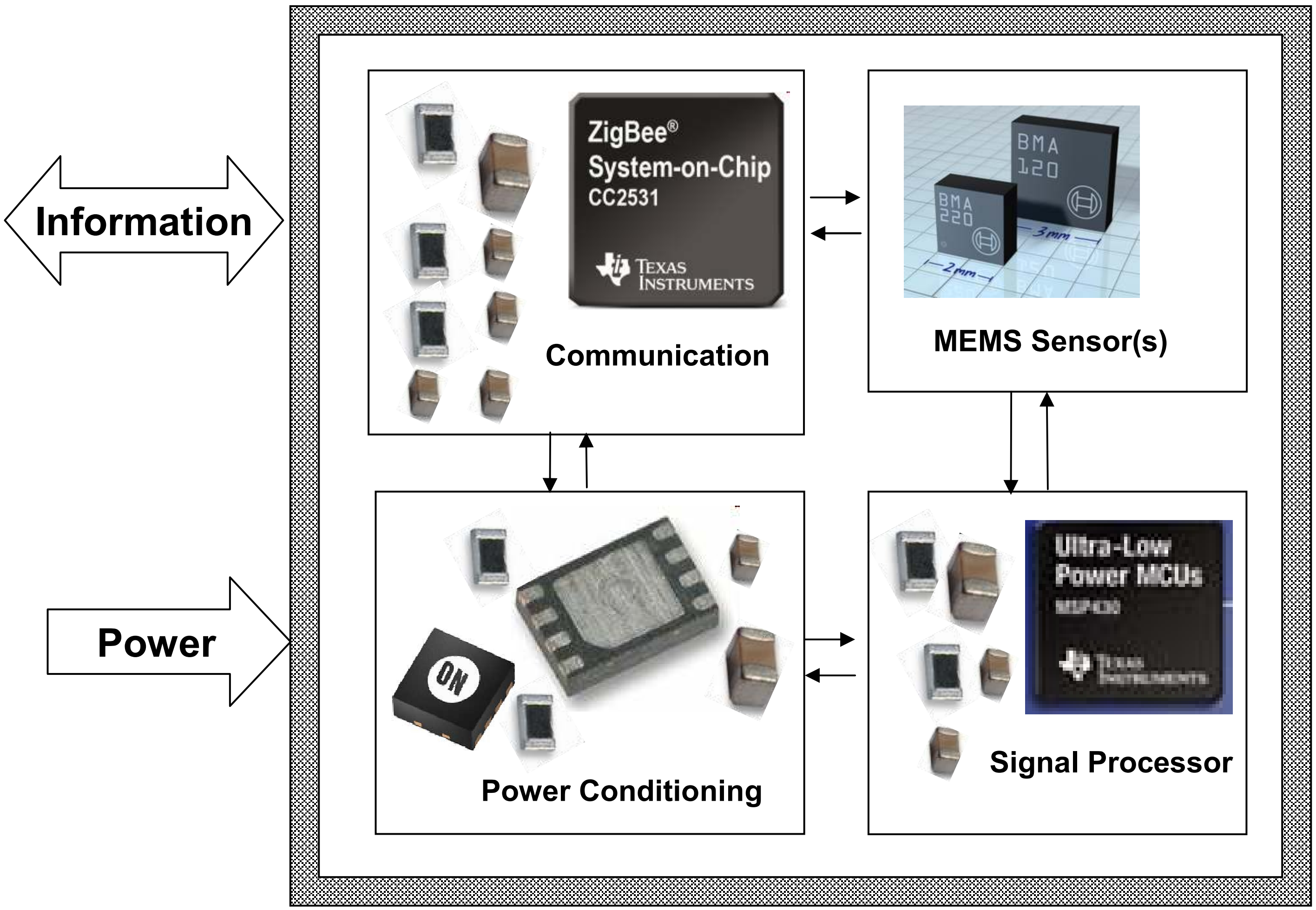
Miniature MEMS Interface Circuits Using Nanoparticle Conductors and Embedded Components

C. Paul Christensen

Potomac MesoSystems

231 Hidden Valley Road
Tracys Landing, MD 20779
240-375-7480

MEMS Sensor systems



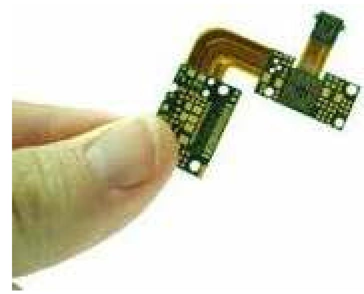
Enclosure

MEMS System Integration

A. MIniature size with flexible form factor
   i. Smallest component sizes
   ii. Fine-feature interconnect
   iii. 3D construction
B. Low-cost assembly
   i. Minimize capital/labor costs
   ii. Low materials costs
   iii. Minimal waste stream
C. Quick-turn with small/large batch compatibility
   i. Packaged components
   ii. CAD/CAM processes

POTOMAC
MesoSystems

Conventional PCB Technology

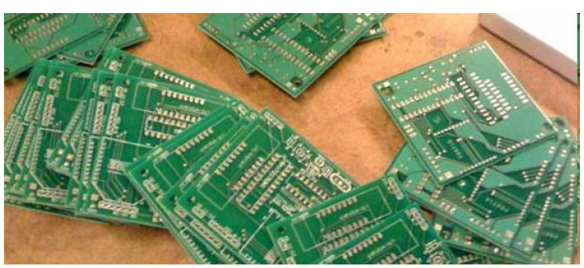


- Highly-Developed, proven technology
- Many competent vendors

But...

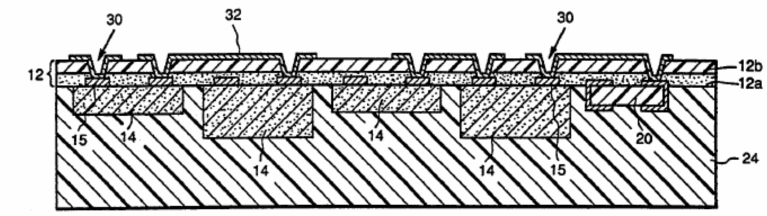
There's room for improvement

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



POTOMAC MesoSystems

Embedded 3D Fabrication

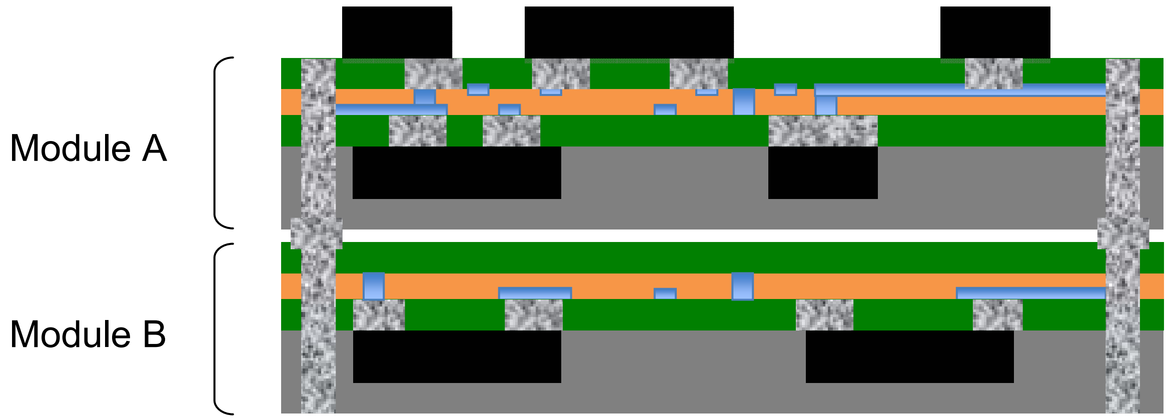


1994 Patent Drawing (U.S. 5353498)

- 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**

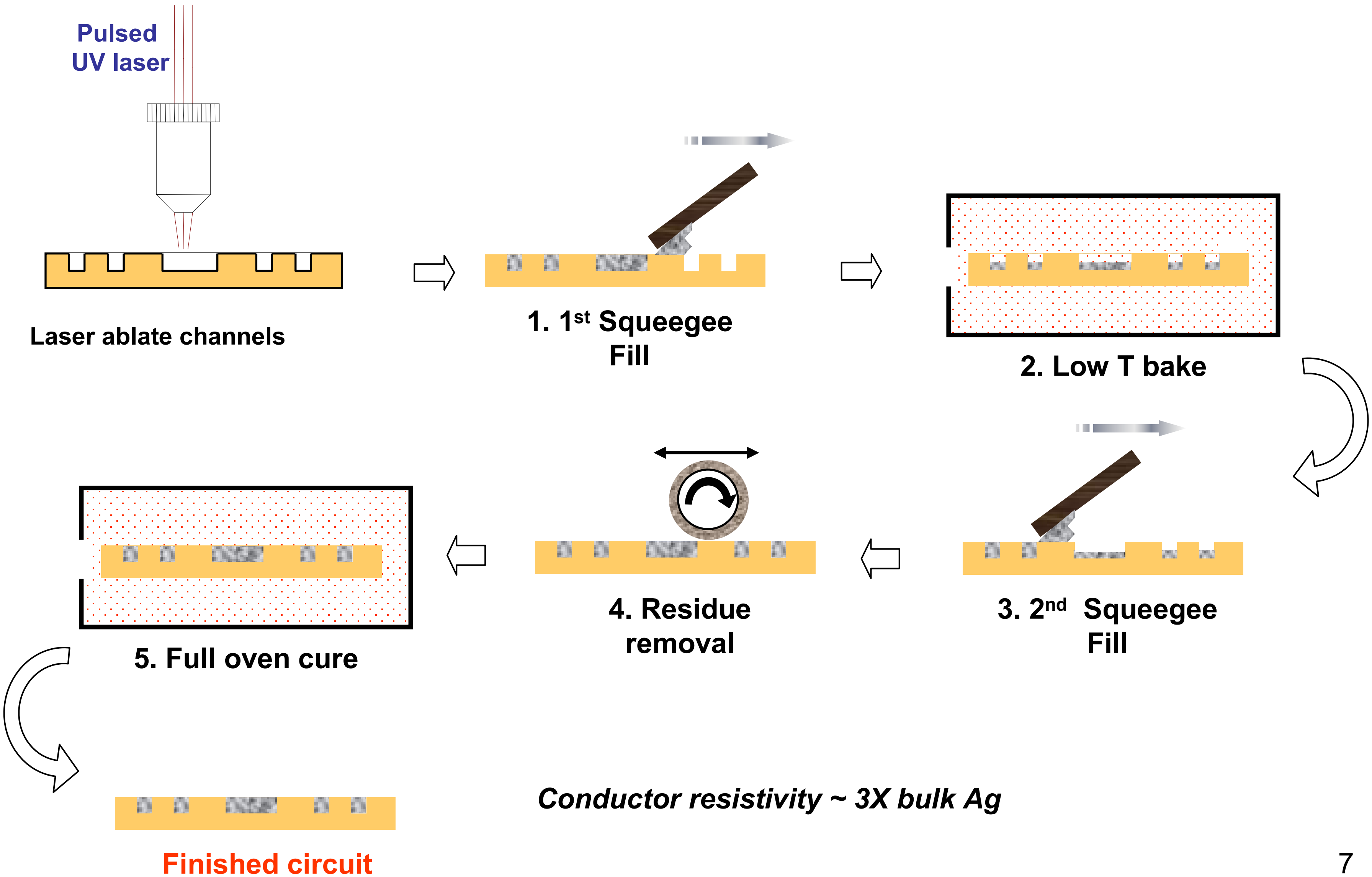
Approach

POTOMAC MesoSystems



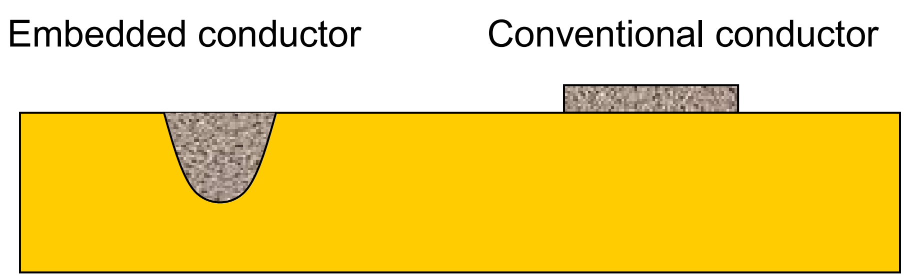
1. **Fabricate fine feature interconnects on thin substrates**
   - **Nanoparticale silver conductors**
   - **Laser direct-write processes**
2. **Attach packaged components**
3. **Encapsulate components**
4. **Stack modules**

Nano-Ag conductor fabrication



Conductor resistivity ~ 3X bulk Ag

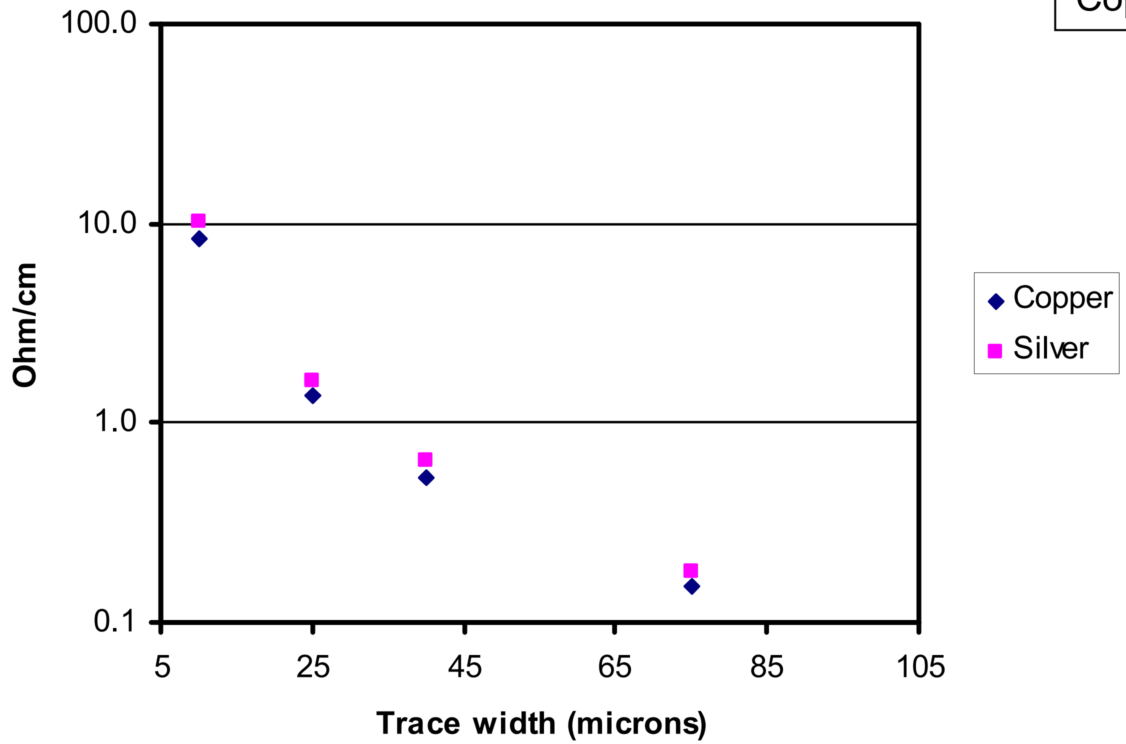
Embedded Nanoparticle Conductors



- 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

Trace resistivity

	Resistivity	Aspect ratio
Silver	3X bulk	1:1
Copper	1X bulk	5:1

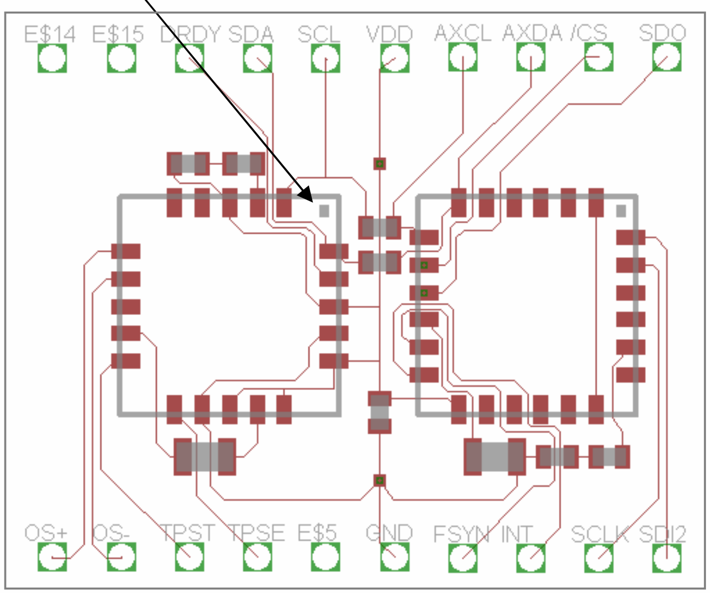


- **Silver aspect ratio compensates for higher resistivity**

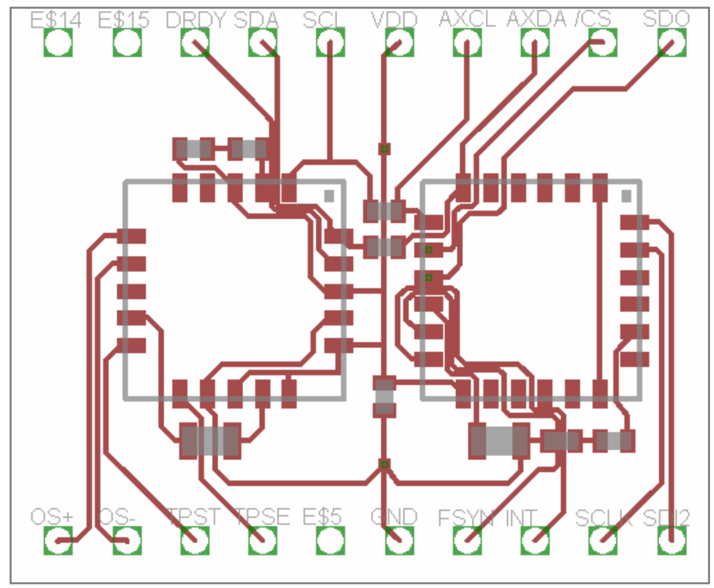
POTOMAC
MesoSystems

Narrow traces reduce layer count

4 mm x 4 mm
sensor



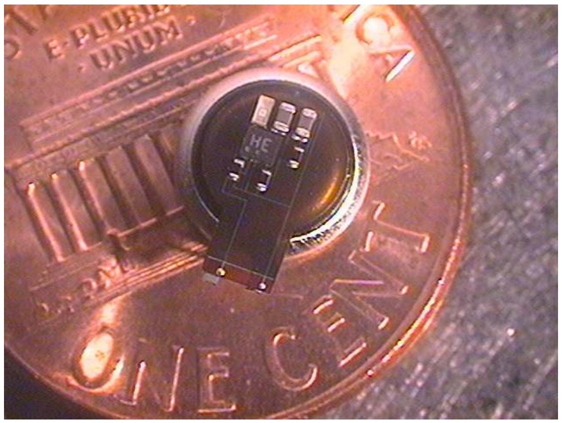
15 micron trace/space



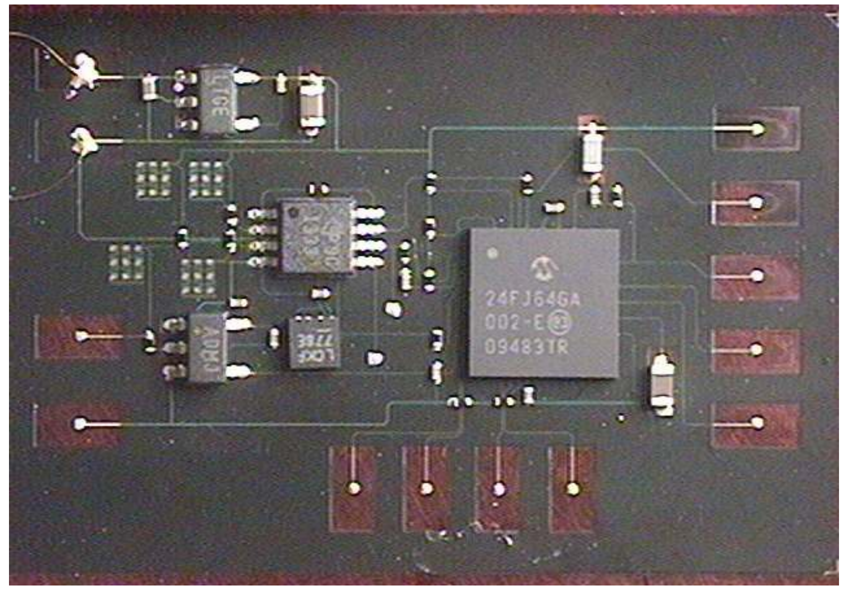
100 micron trace/space

Examples:

Polyimide substrate



Battery-powered LED flasher



23 mm

35 mm

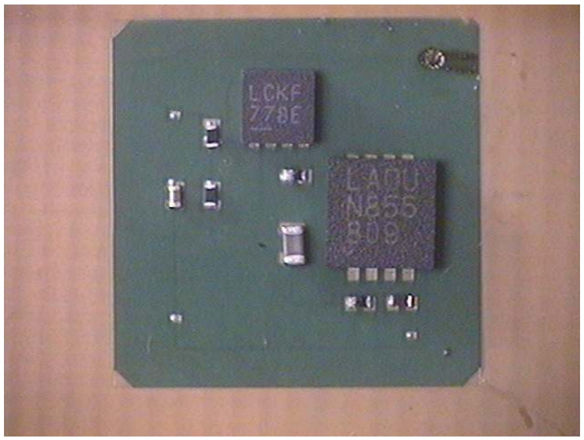
Strain gauge interface

Single Layer Circuits !

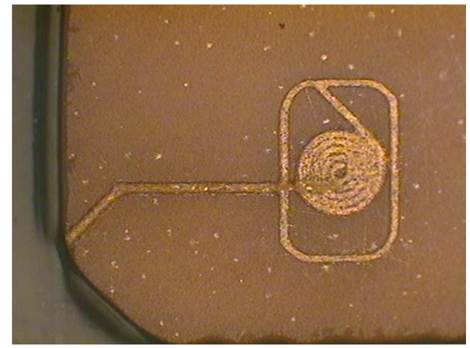
Examples:

Alternative Substrates

POTOMAC MesoSystems

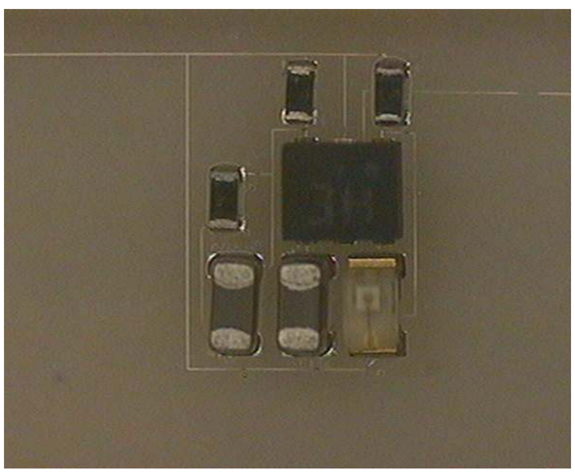


← **ABF** →

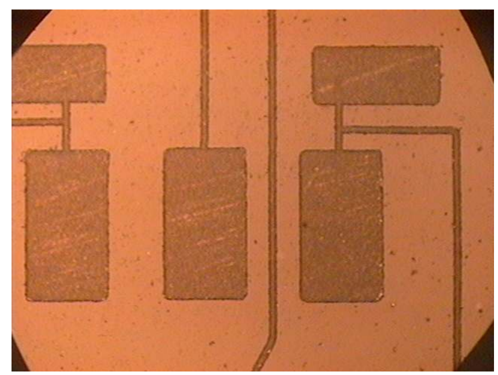


Working circuits

Pads and 15 micron traces

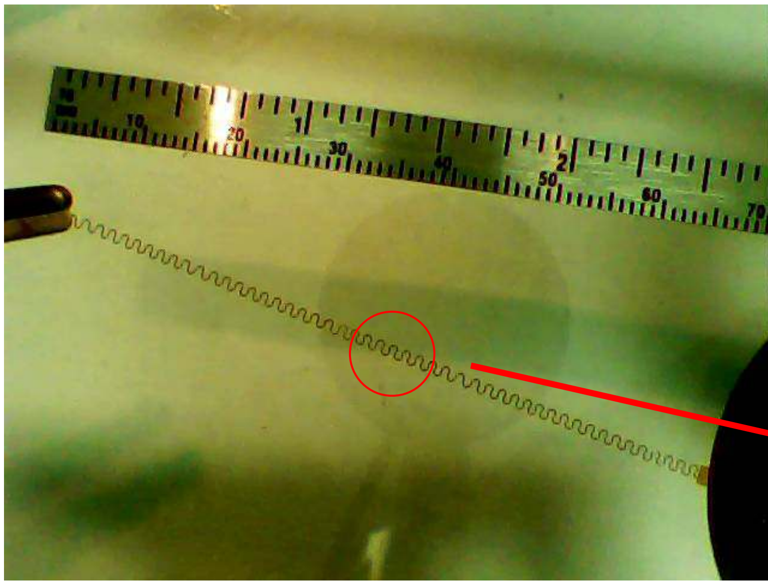


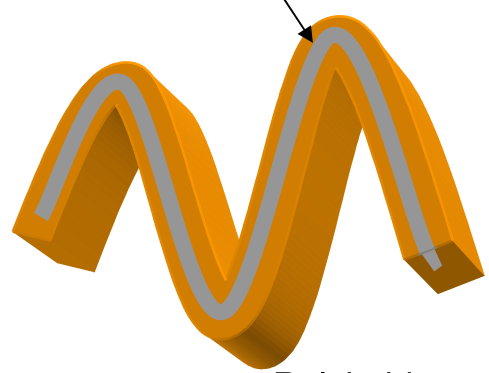
← **Alumina** →



POTOMAC MesoSystems

Stretchable Interconnects

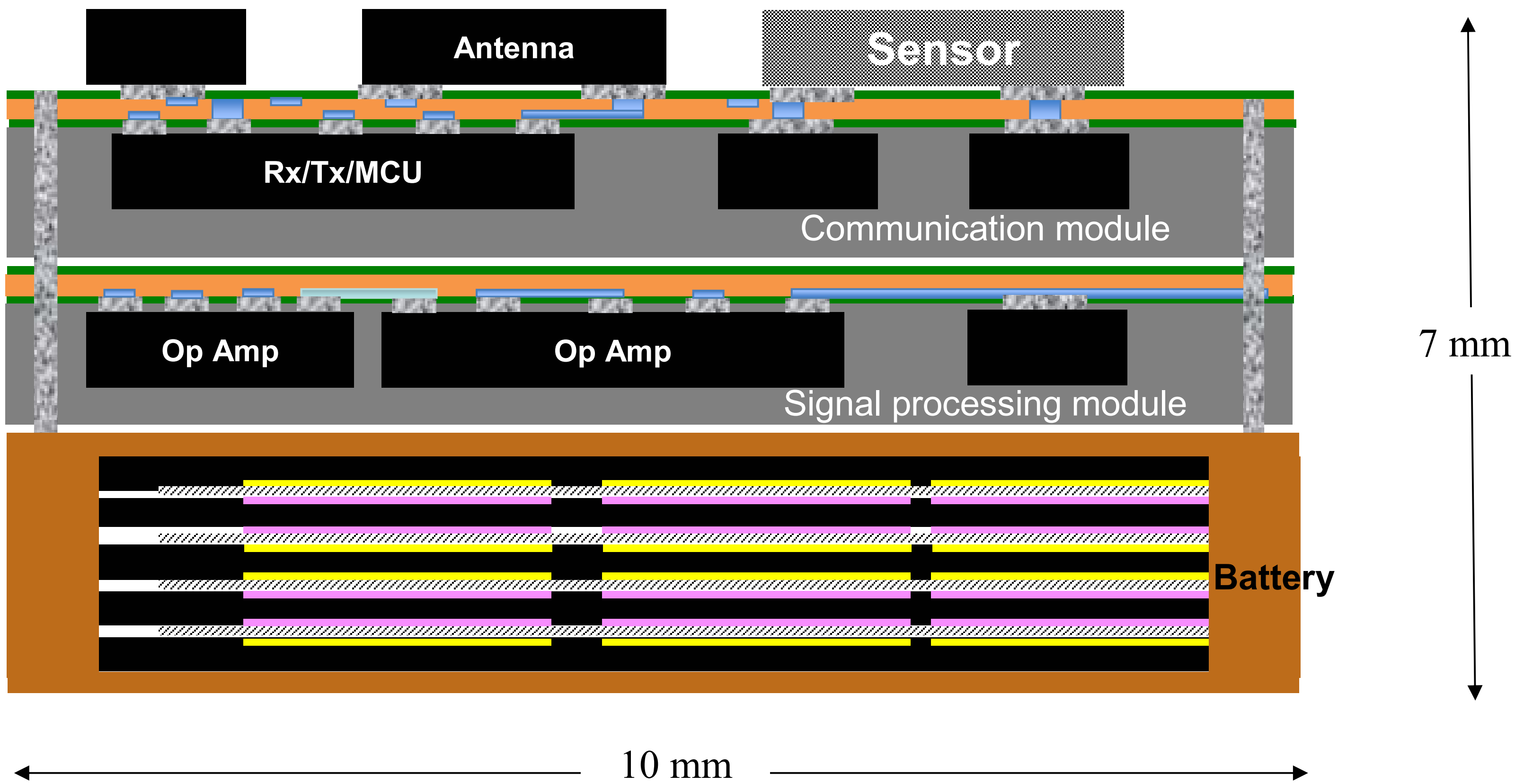




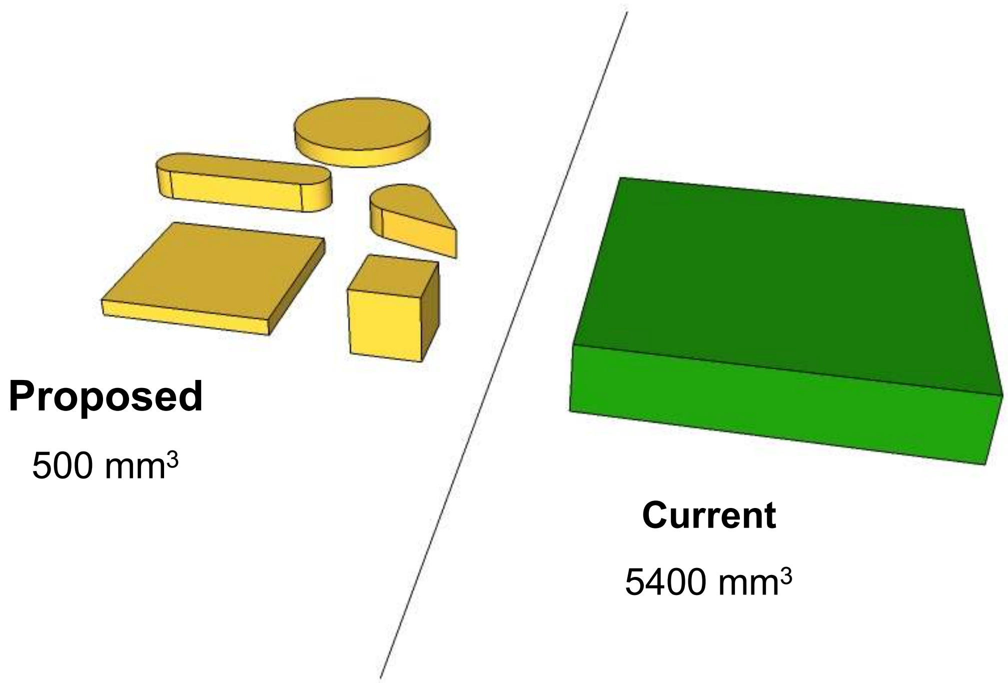
System example:

NSF Wireless sensor platform mockup

POTOMAC MesoSystems



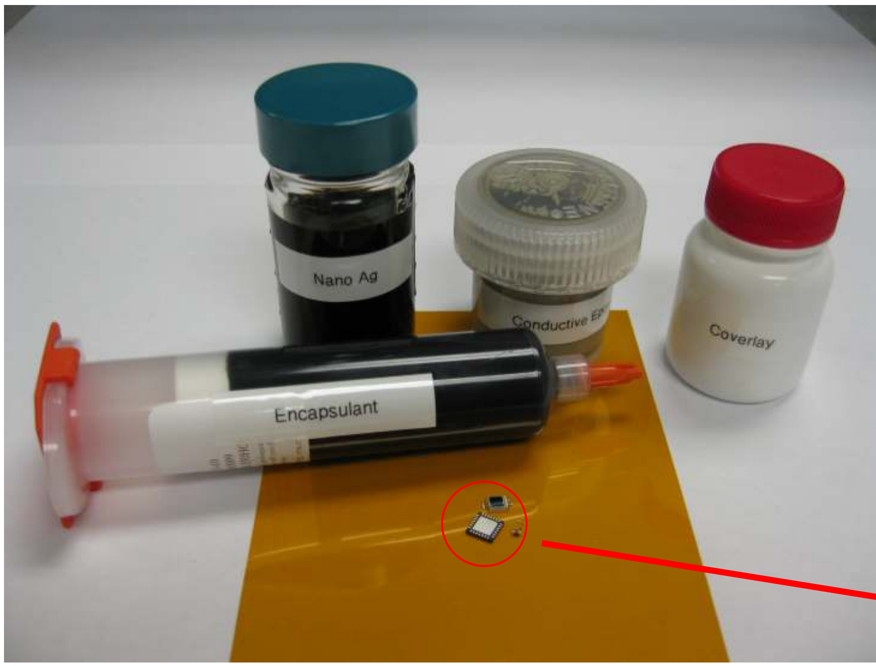
Size Reduction + Freedom of Form Factor

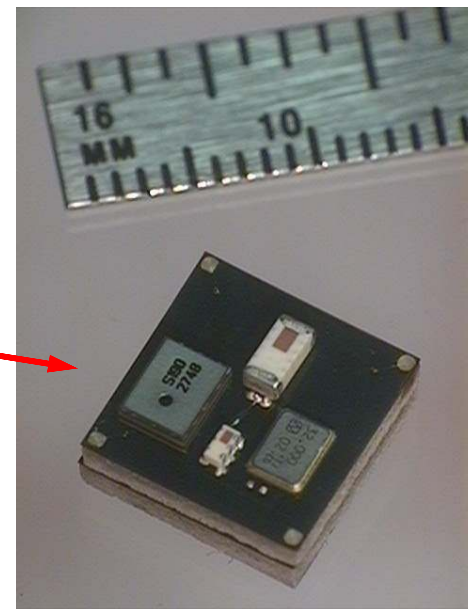


- Volume reduction through high density packaging and fine line interconnects.
- Laser based CAD/CAM process allow wide range of shapes

Miniature systems based on additive processes

POTOMAC MesoSystems

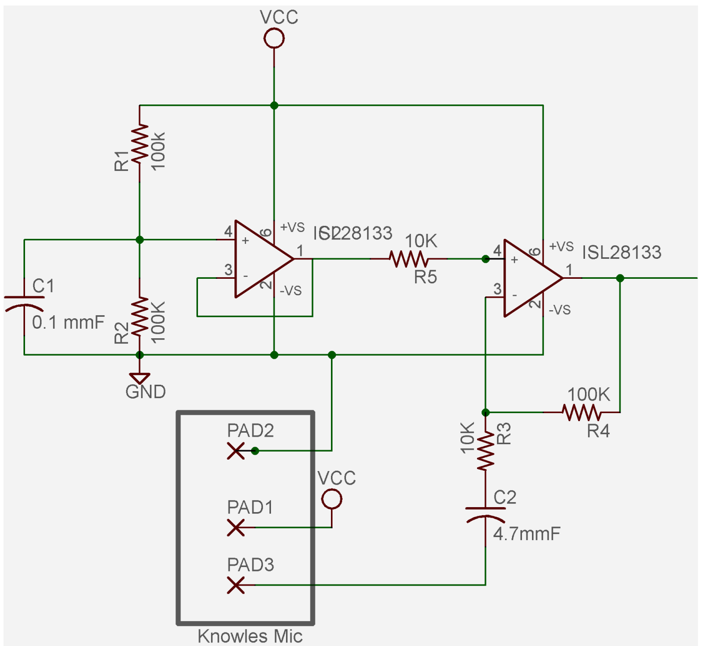




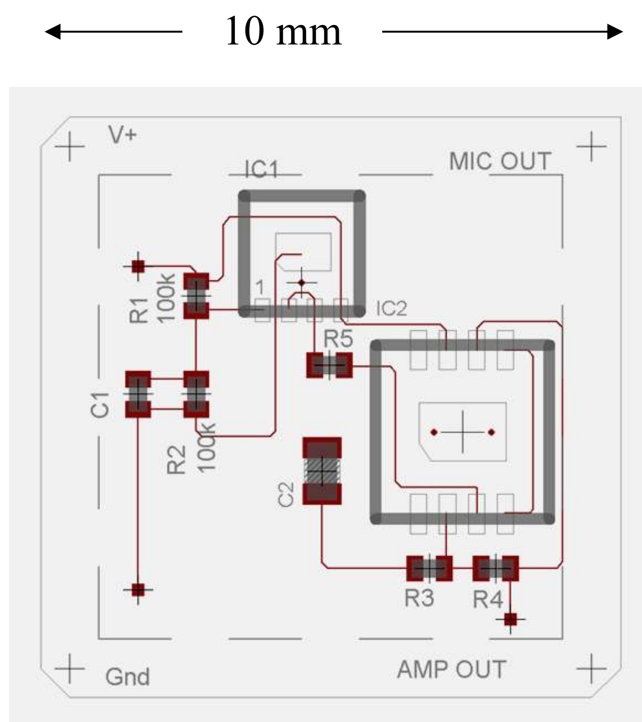
- Process temperatures < 200 C
- Negligible waste stream

POTOMAC MesoSystems

Layout



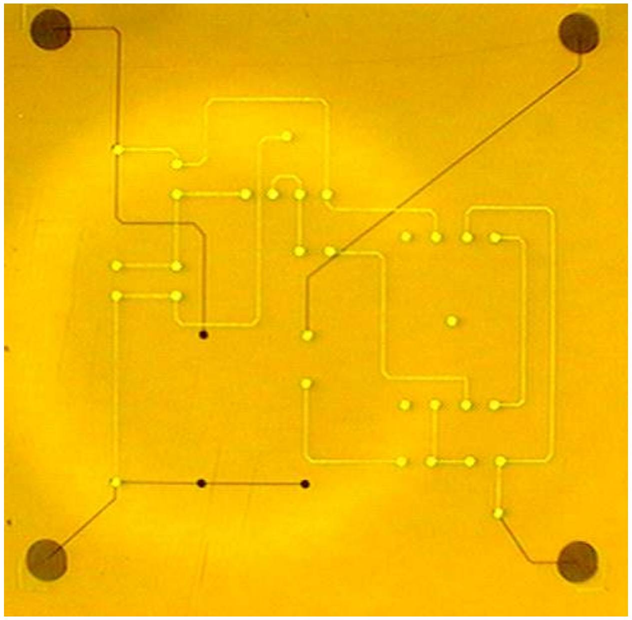
Schematic



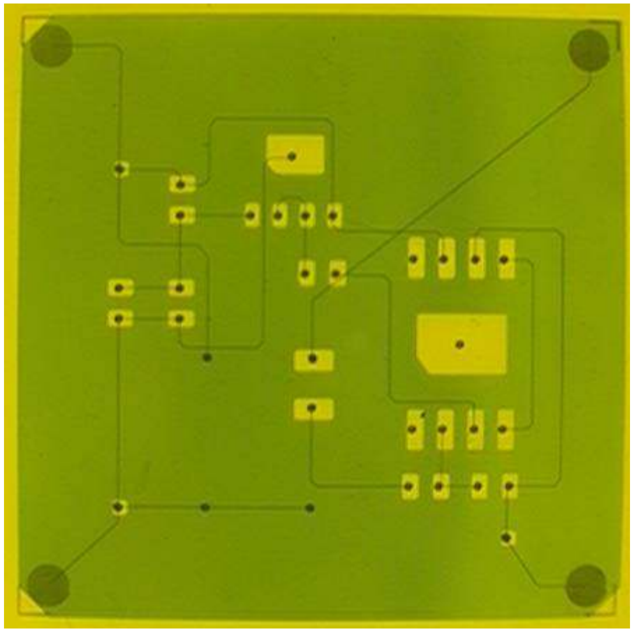
All CAD/CAM processes are driven by layout

POTOMAC MesoSystems

Conductors and Coverlay



Laser pattern and fill frontside and backside conductors

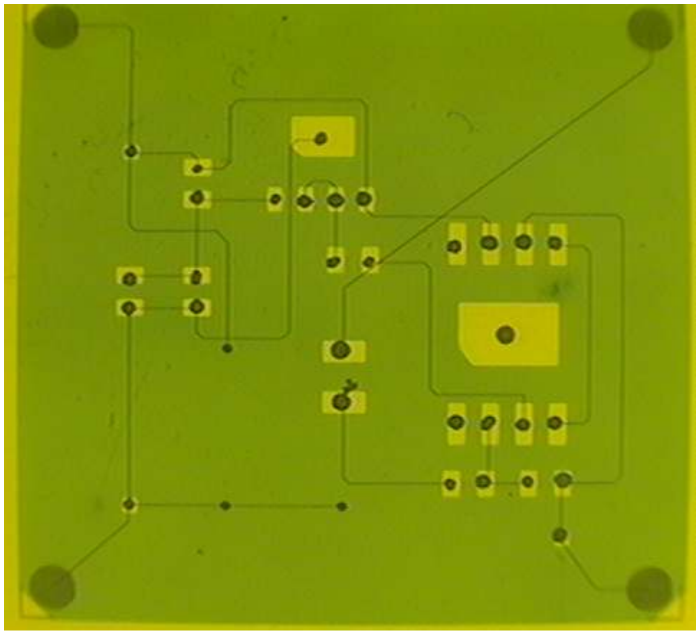


Apply, laser image and develop (aqueous) frontside coverlay

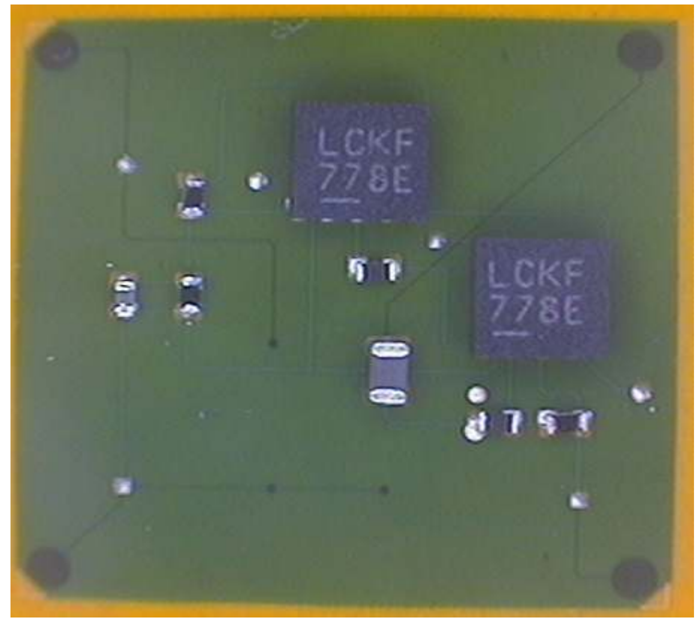
Example: Amplifier module fabrication

POTOMAC MesoSystems

Dispense adhesive and populate



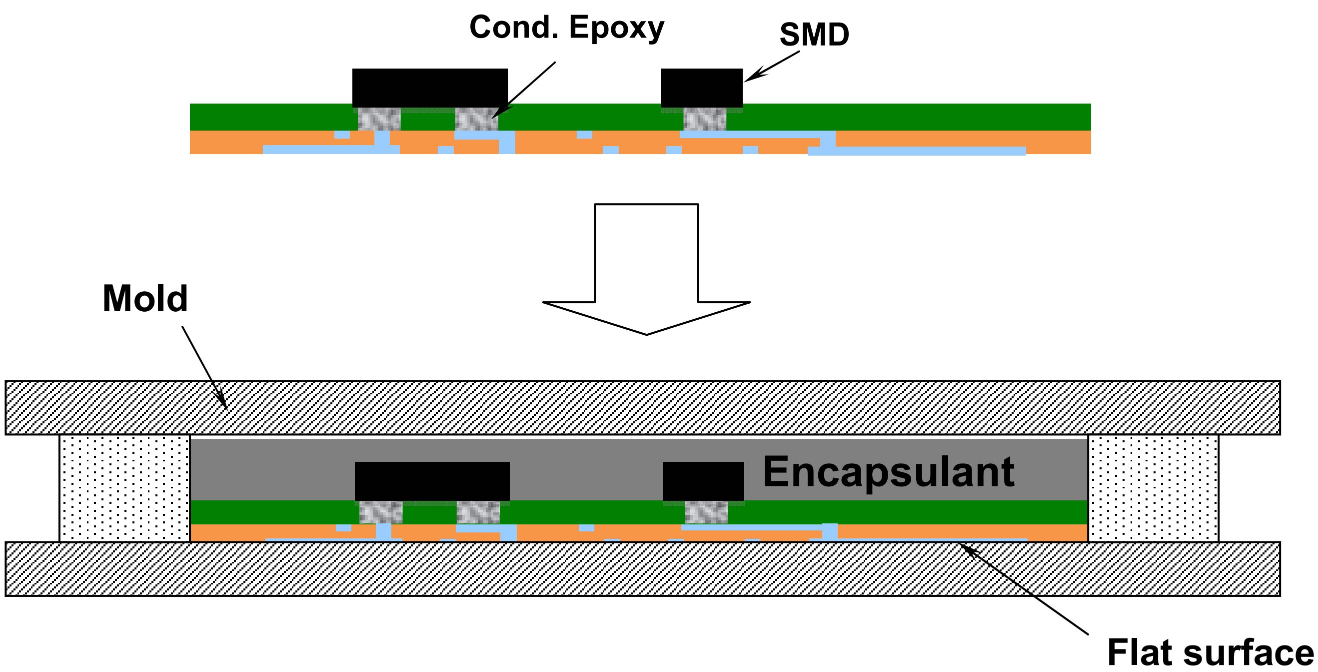
Dispense epoxy using locations derived from layout



Pick and place components using locations derived from layout

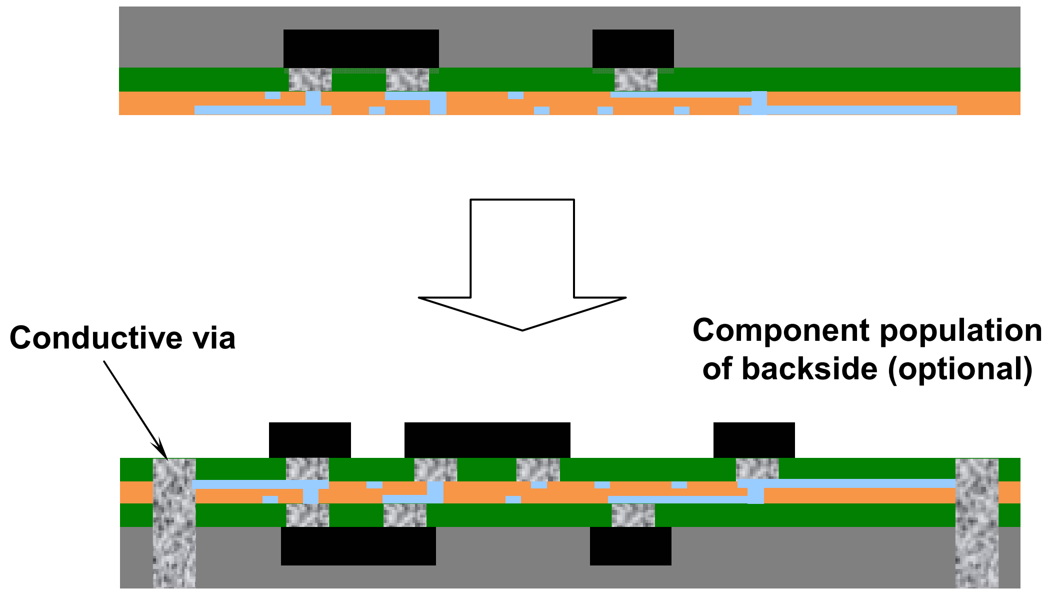
Must have high accuracy and repeatability

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

Connection to and between modules

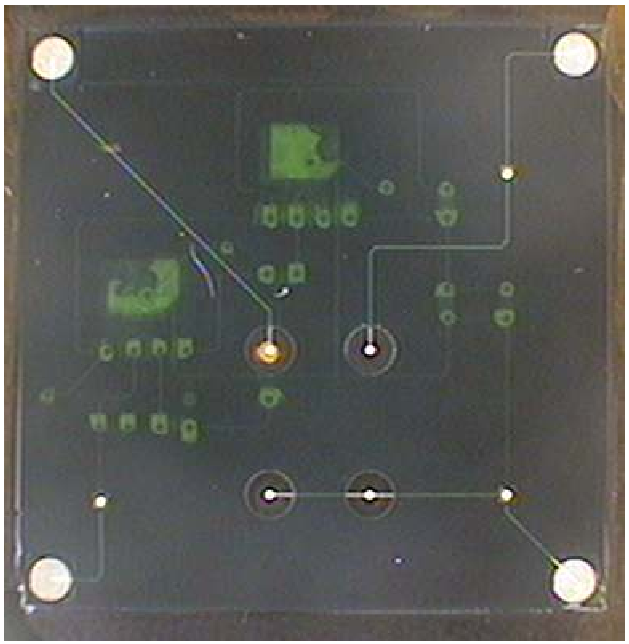


- Conductive vias for interconnection of modules
  - Laser drilled
  - Epoxy filled
  - Many other options

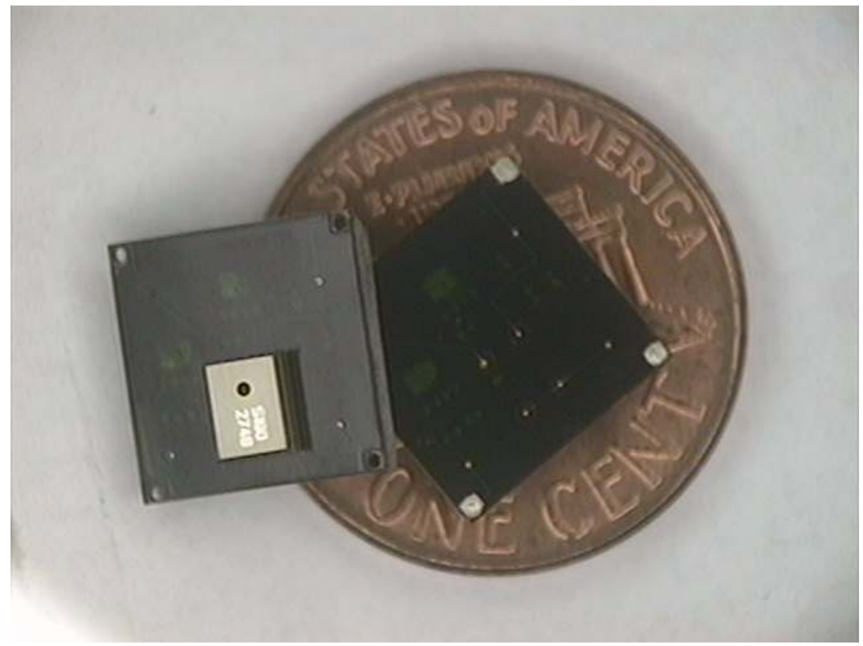
Example: Amplifier module fabrication

POTOMAC MesoSystems

Encapsulation, Vertical Vias, Backside Components



Encapsulated circuit with patterned backside coverlay

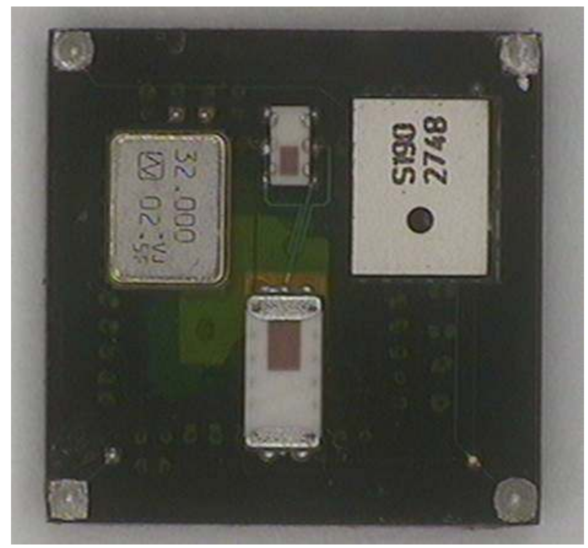


Completed modules

POTOMAC
MESOSYSTEMS

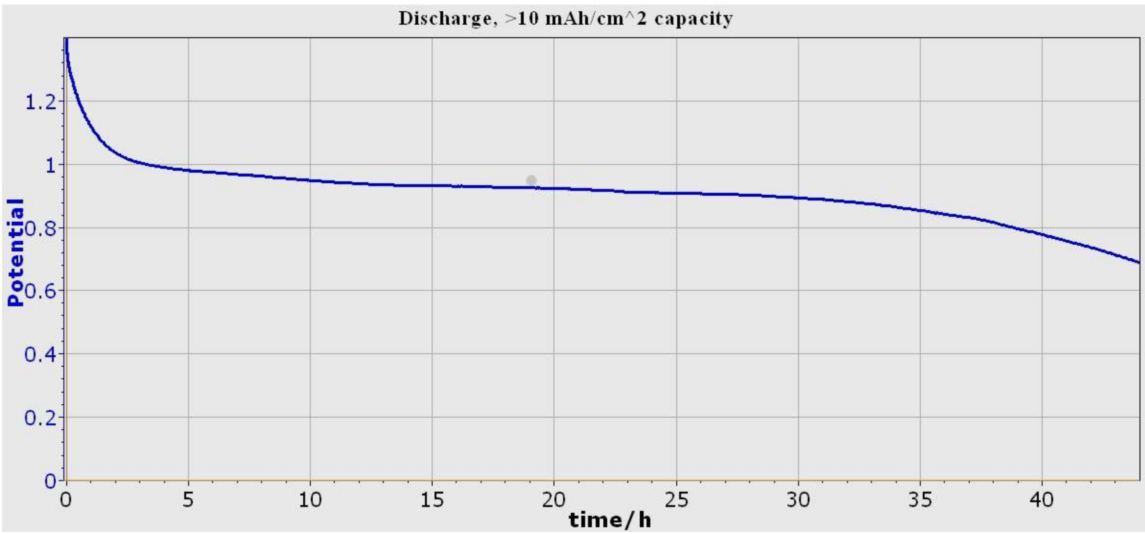
Communication Module

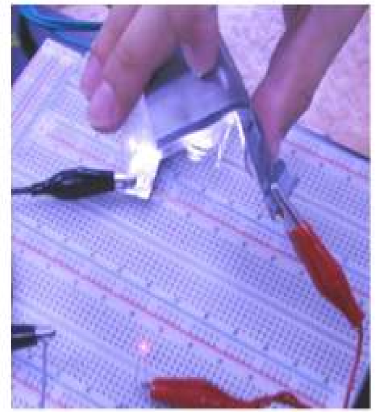
Wireless SoC with passives



Encapsulated module with exposed chip antenna and MEMS microphone

FlexEl, LLC
Advanced Thin Film Battery

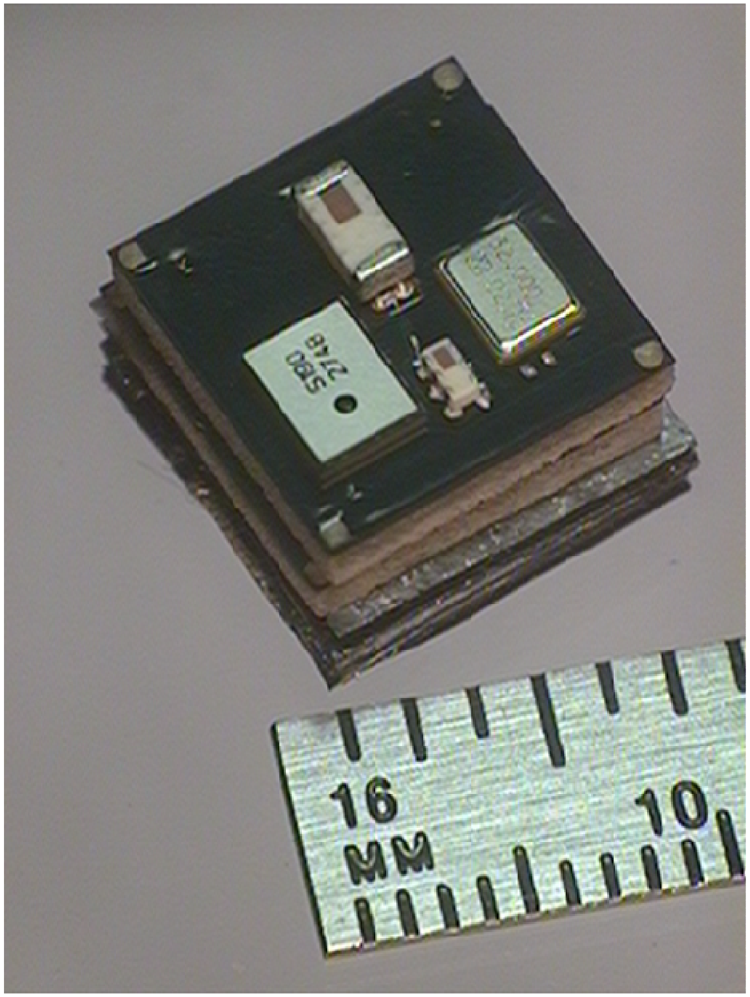




- New RuOx chemistry gives >10 mA-hr/cm2
- < 0.3 mm thickness
- 10 x 10 mm^2 footprint

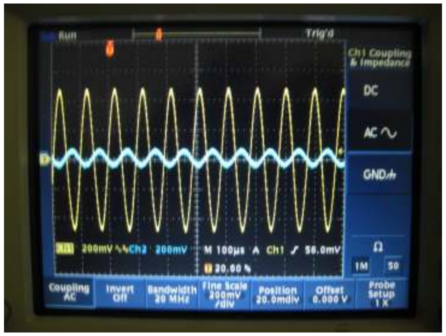
POTOMAC MesoSystems

Complete wireless sensor



POTOMAC
MESOSYSTEMS

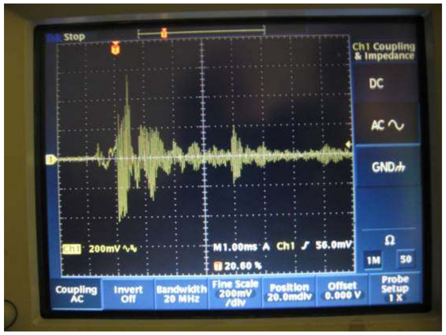
Electrical Test



10X Amp Gain
(after component attach)

Several intermediate testing opportunities during module production

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



Amplified microphone output
(after module completion)

Capital Equipment Required

POTOMAC MesoSystems

Integrated Laser/PnP/Dispense

Paste fill & clean station

Encapsulation mold

Capital Equipment NOT required

POTOMAC MesoSystems

Resist exposure system

Etching/Plating tanks

Lamination Press

Resist stripper

Scaling to higher volume

POTOMAC MesoSystems

UV laser system

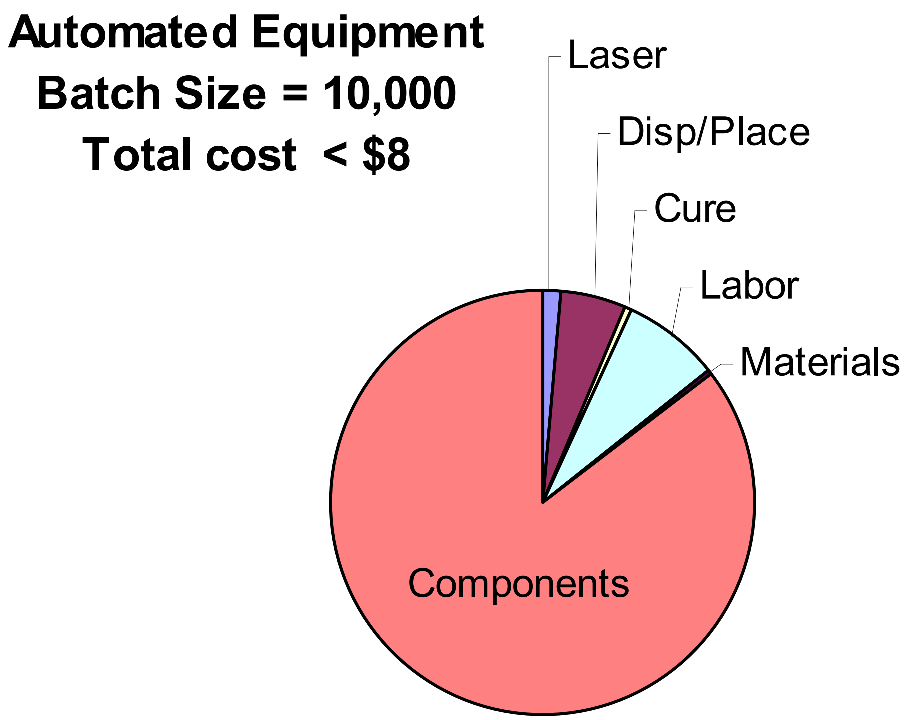
Encapsulation mold

Epoxy Dispenser

Pick and Place

Paste fill & clean station

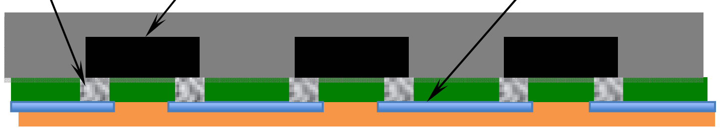
Module cost estimate



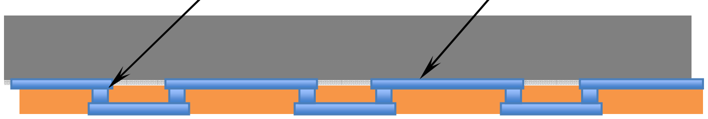
- Component costs dominate
- Materials costs negligible

Thermal cycling tests

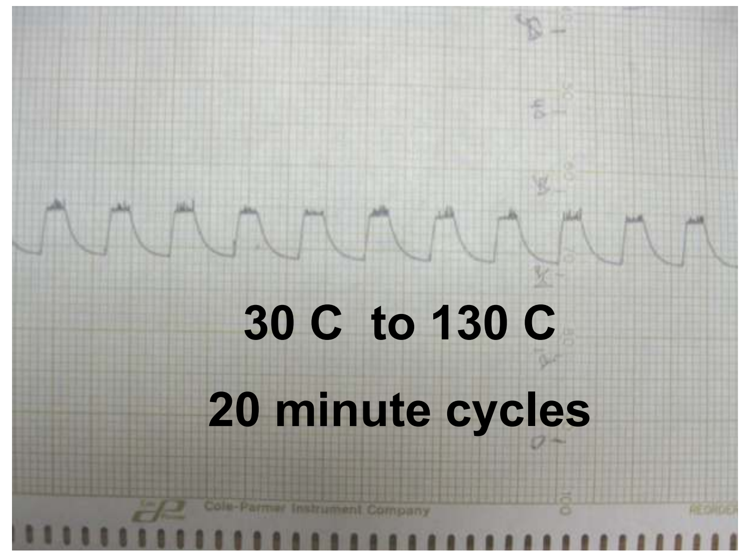
POTOMAC MESOSYSTEMS



288 cycles/no failure



125 cycles/no failure



Chain resistance vs time

40 element Daisy Chains

POTOMAC MesoSystems

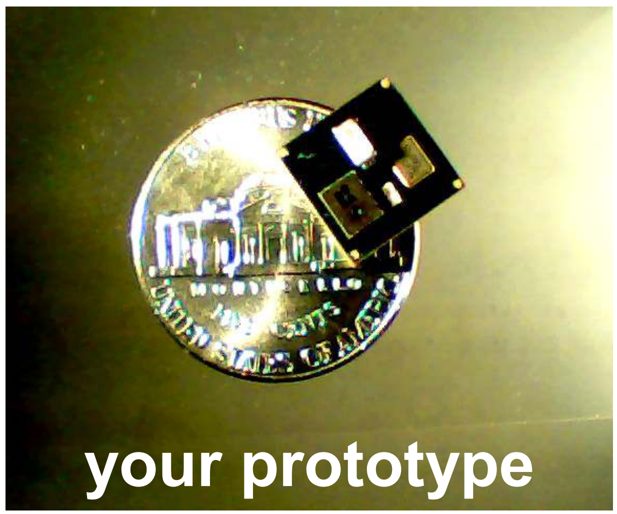
It's a work in progress, but....

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

POTOMAC
MesoSystems

Collaboration and evaluation

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



Let us build your prototype on our nickel!

www.potomacmeso.com **www.potomac-laser.com**