MEMS and BioMEMS in Laminates

IEEE Santa Clara Valley CPMT
IEEE SF Bay Area MEMS
Biltmore Hotel, Santa Clara, CA

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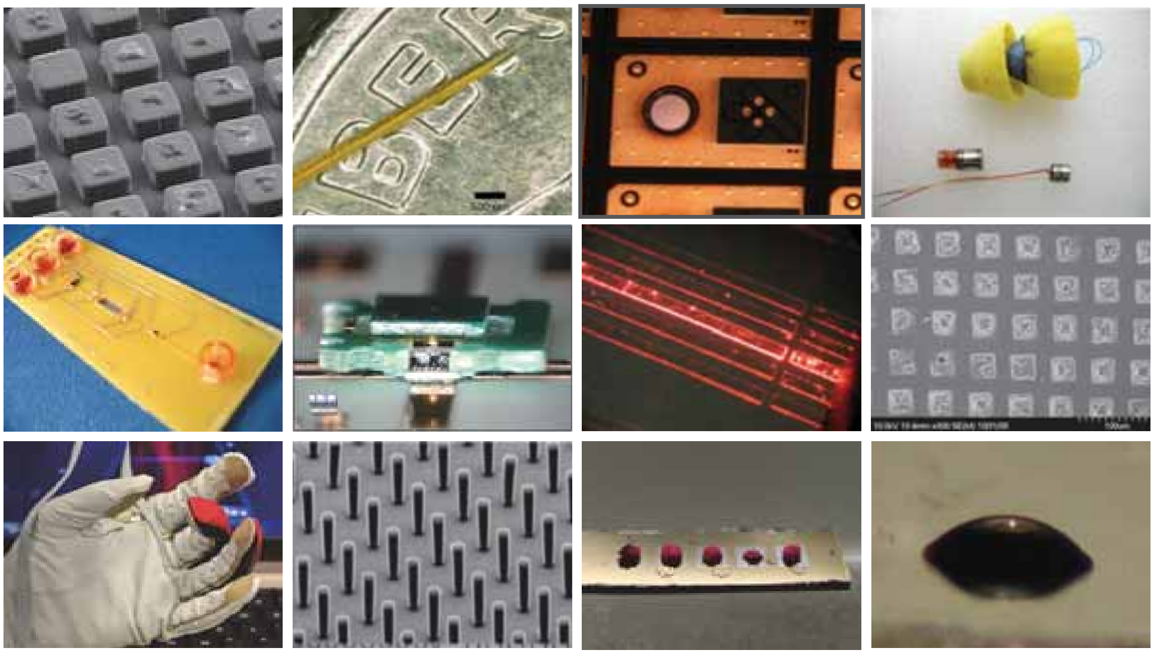
October 23, 2013

Engineering the Future at UCIrvine

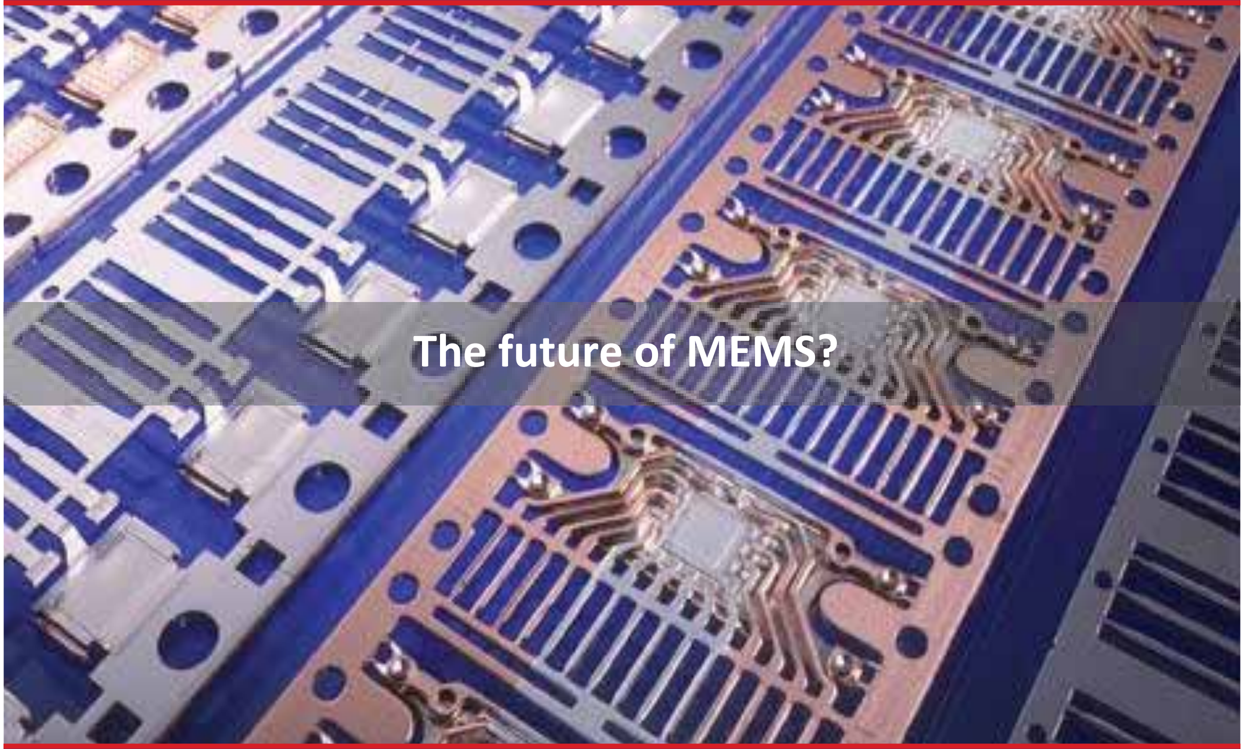
UCI Integrated Nanosystems Research Facility

All major fabrication tools for micro and nano fabrication down to 20 nm. Commitment to high quality education and research to produce next generation engineers and products.

Innovations in the MIDAS Lab

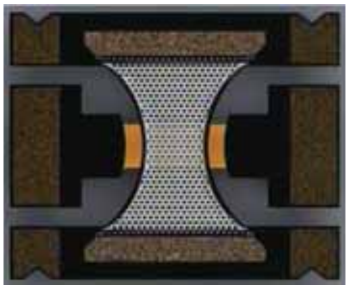


Bachman Lab: Microelectronic Integrated Devices And Systems

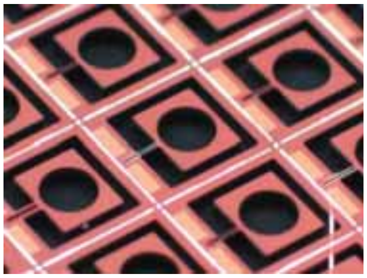


The future of MEMS?

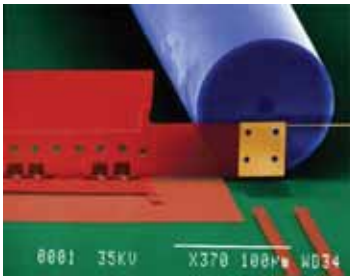
MEMS: Micro-Electrical-Mechanical Systems



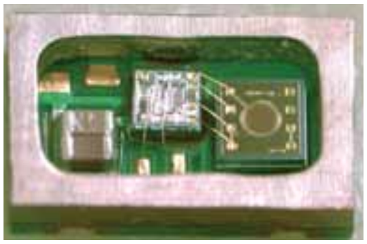
RF Switch from MEMtronics



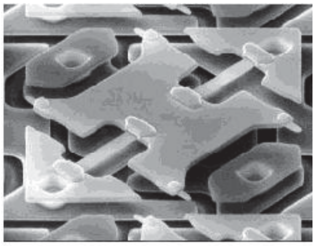
Energy harvester from Perpetuum



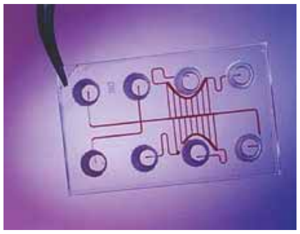
Optical Switch from Lucent



Microphone from Knowles



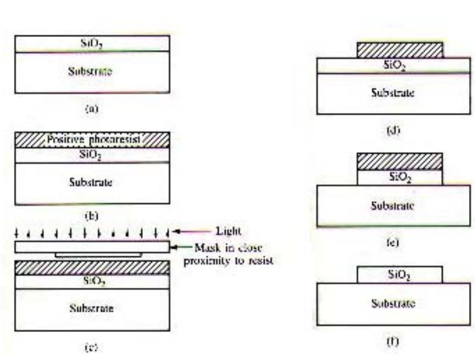
Digital Micromirrors from TI

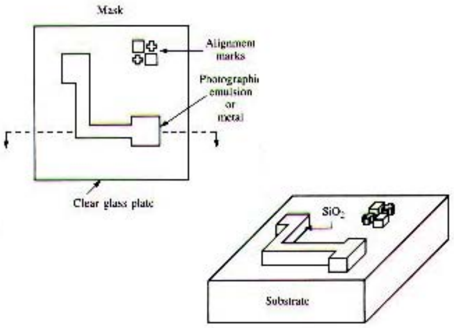


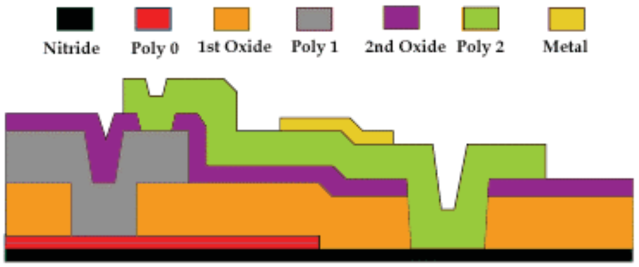
Lab-chips from Agilent

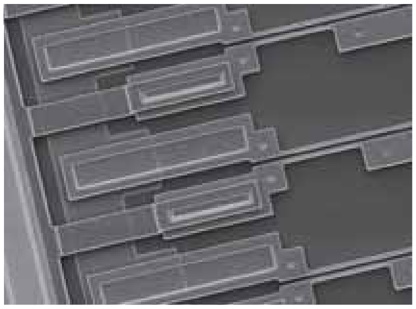
Products for mobile devices, automotive, aerospace, telecom.

A brief look at MEMS manufacturing (silicon)



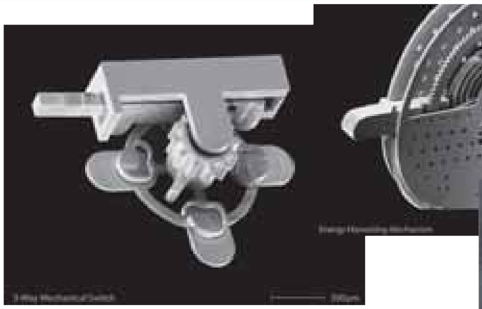




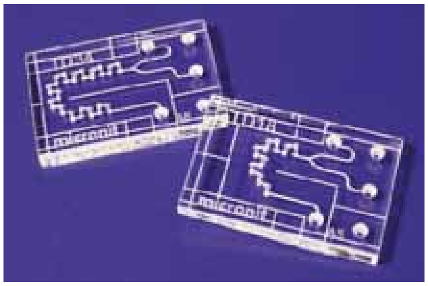


Process is primarily monolithic -- integration is difficult.

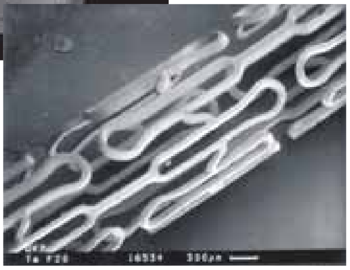
A brief look at MEMS manufacturing (specialty processes)



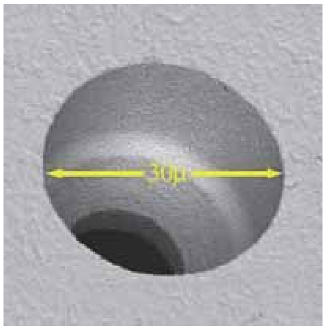
Electroforming using micromolds (Microfabrica)



Microfluidics by embossing or casting (Micronit Microfluidics)



Stent by laser micromachining(Laser Zentrum Hannover)



Inkjet nozzles by microEDM (Mikkros Technologies)

Suture pin by precision CNC(Micro-engineering solutions)

Processes are monolithic -- integration is difficult.

Brief look at MEMS manufacturing

Materials

Single crystal silicon
Poly Si, Nitride, Oxide
Polyimide, SU-8
Metals

Processes

Lithography
Vapor deposition
Etch

Comment:

Silicon-based micromachining is optimized for electronic devices. Other devices (mechanical, optical, fluidic, biological, etc.) pose significant challenges to manufacturing.

MEMS manufacturing summary

Advantages

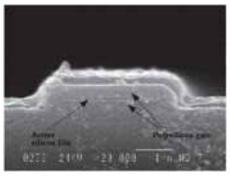
High precision lithography
Large infrastructure
Known processes
Well characterized material
Ability to add electronics

Disadvantages

Planar processes
Monolithic processes
Limited materials
Limited processes
Difficult integration
Difficult packaging

Comment:

Silicon-based micromachining is historically tied to the semiconductor industry. Electronic circuits essentially do NOT need to have true 3-D shapes.



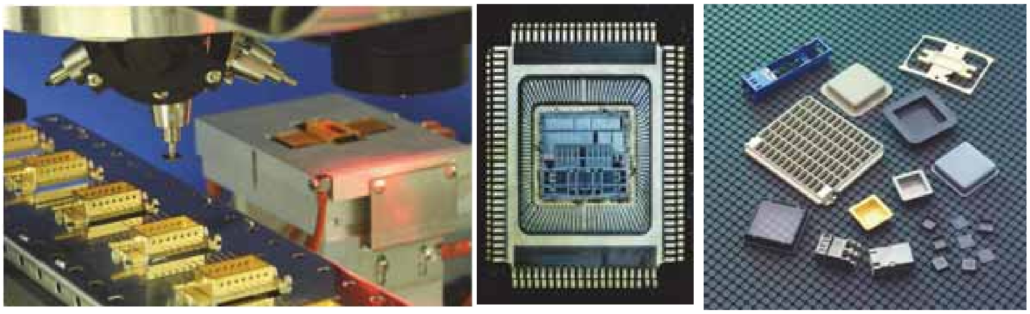
Silicon MEMS Observations

Characteristics of silicon	Characteristics of microdevices
Silicon devices are cheap ONLY when footprint is small and wafer is large.	Microdevices may have small feature sizes, but often have large footprints.
Silicon manufacturing (e.g., CMOS) is highly constrained using limited materials.	Microdevices often require specialty materials and processes (such as thick films, metals, etc.)
Silicon manufacturing is an additive process. Each layer multiplies the chance of yield loss, requiring highly optimized manufacturing.	Microdevices are NOT all the same. Each device design requires a custom fabrication development to go with it.
Microelectronic device packaging does not work well with MEMS devices.	Microdevices must be packaged. Packaging remains a significant challenge for the industry.

Post-semiconductor manufacturing

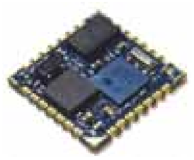
Microelectronic Packaging and Printed Circuit Boards

Global advanced packaging market is $42B, printed circuit boards is $50B.
Business model: service the semiconductor manufacturing industry.

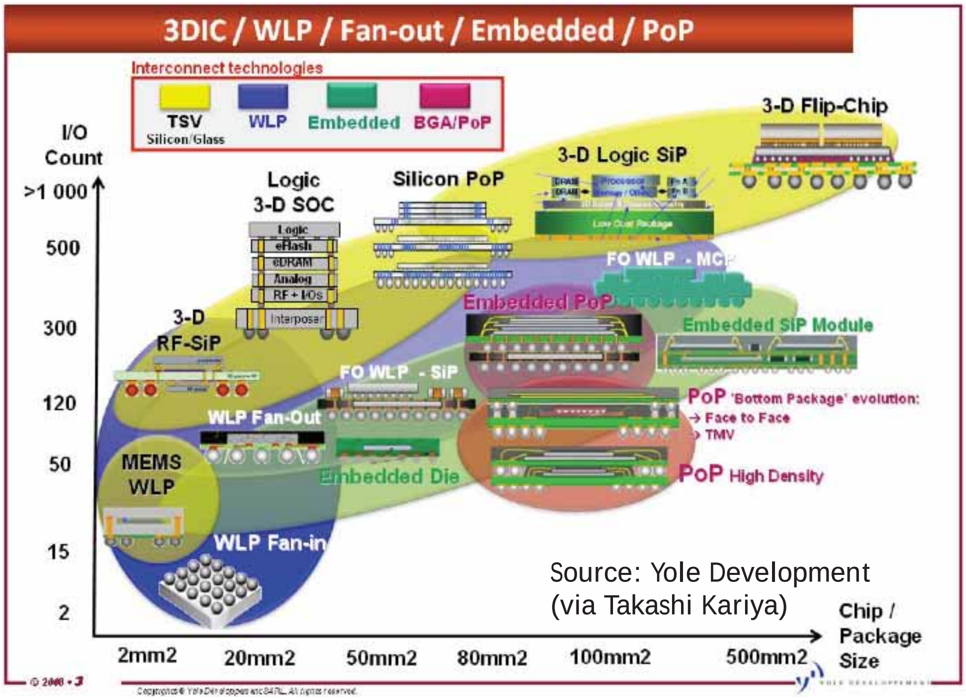


Food chain

Product design ➔ Module design ➔ Chip design ➔ Chip manufacture ➔ Chip packaging/testing ➔ Board assembly



PCB & Packaging precision/complexity



Source: Yole Development
(via Takashi Kariya)

PCB/packaging manufacturing

Materials

- Polymers
- Metals
- Ceramics
- Composites
- Laminates
- Adhesives
- Components

Processes

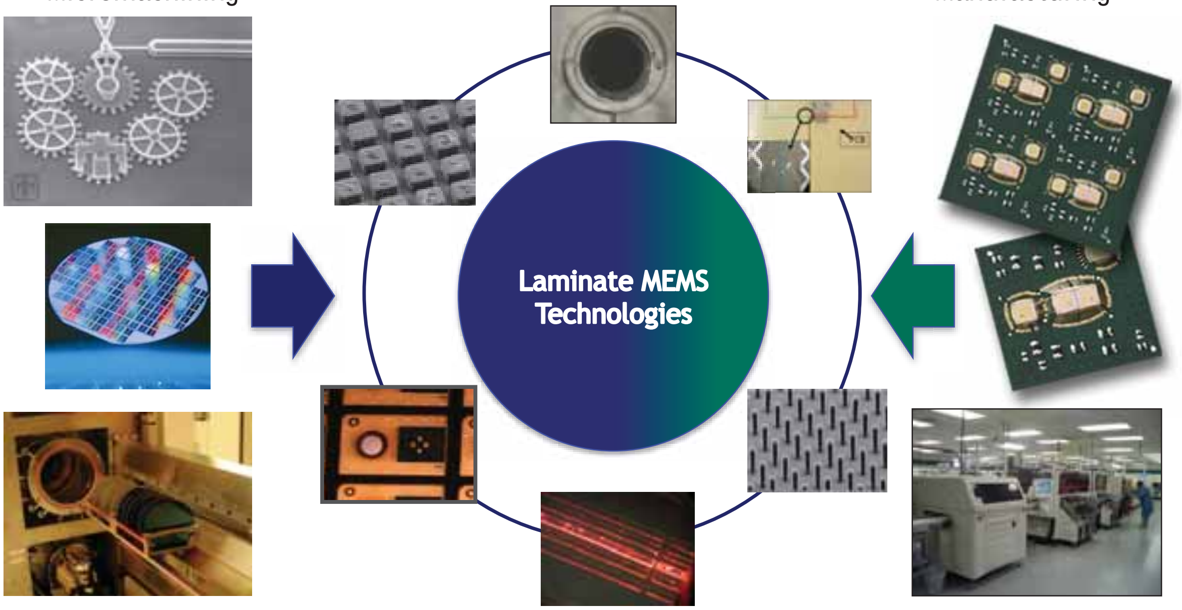
- Lithography
- Deposition
- Etch
- Electroplating
- Lamination
- Stenciling
- Assembly
- Machine cutting
- Laser machining
- Joining
- Bonding
- Molding
- Embossing

Laminate MEMS

Best of two worlds

Silicon-based Micromachining

PCB/Packaging Manufacturing



Laminate MEMS Technologies

Value proposition

New products

New types of products can be envisioned that can't be built using silicon, that feature high level of integration. Devices can be developed for emerging markets of energy, biomedical, and human interface.

New manufacturing

New manufacturing methods developed for these applications can be used to create unique capabilities. Manufacturing can produce 3D structures, integration of novel materials, and moving elements. Packaging is part of the manufacturing.

New business model

Packaging company can become device company. Sell finished products (or nearly finished products) to end customers. Higher margins, greater differentiation.

Laminate microfabrication strategy

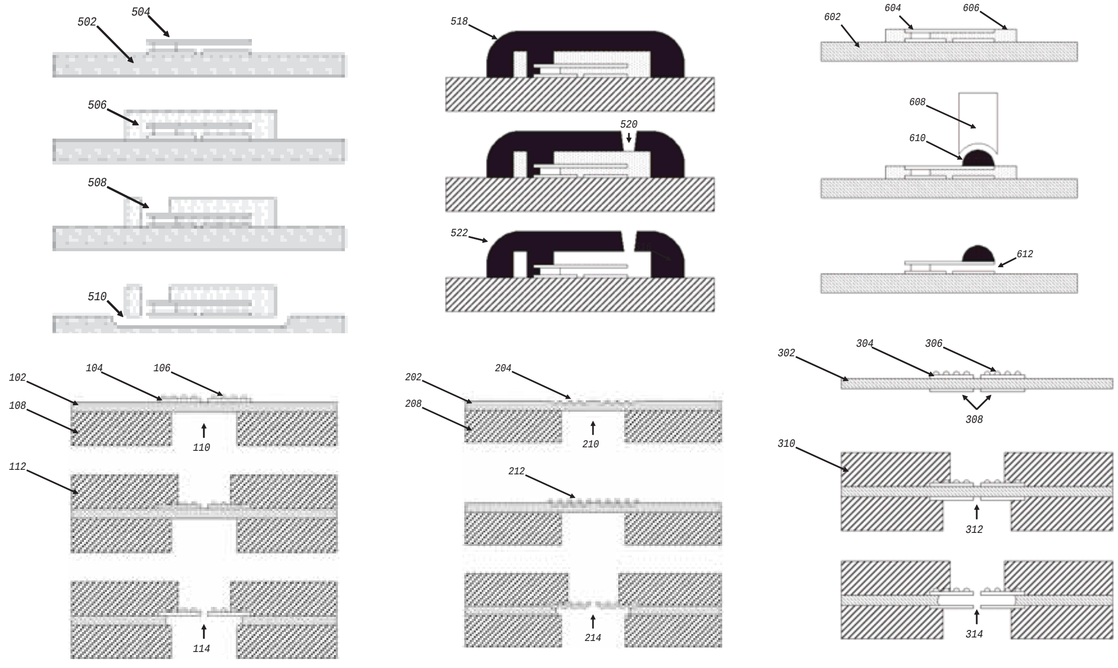
Need to develop new processes, modify existing processes

Low temperature processing
Non-planar processing
Micropatterning of non-etchable materials
Micro-assembly based manufacturing

Need new MEMS design thinking

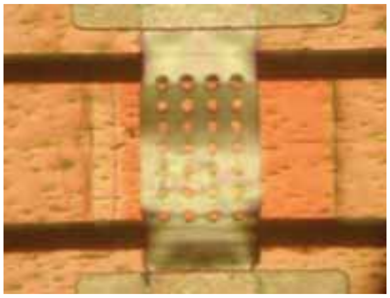
Think: integration!
Specialty materials available
Complex electronics and devices can be integrated
More footprint available
Packaging at fabrication level

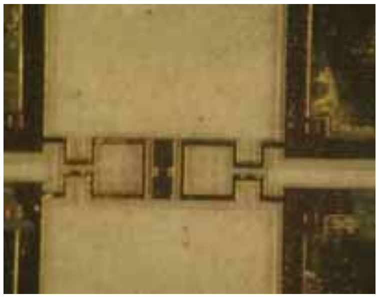
Laminate microdevices: Many ways to do it!

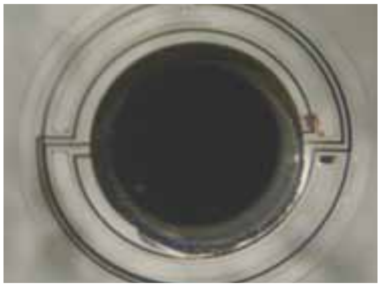


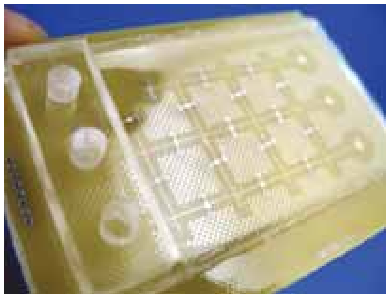
Drawings taken from USPTO 2006: Bachman, Li

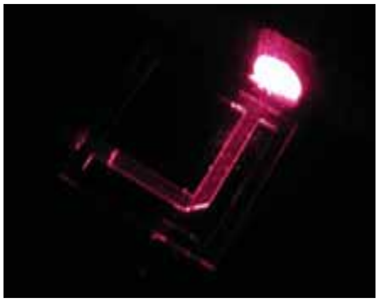
Example laminate MEMS devices

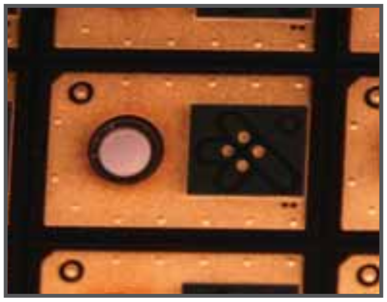

Bedri, Chang, DeFlaviis, Bachman, Li, 2003


Li/Bachman research 2009

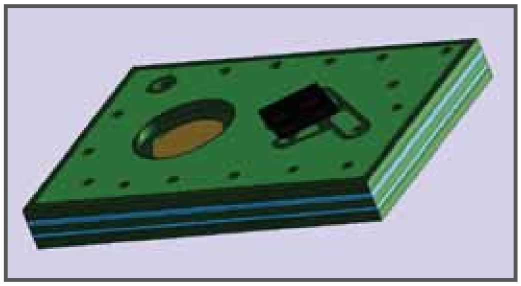

Li/Bachman research 2007


Li/Bachman research 2010


Li/Bachman research 2011


Li/Bachman research 2008

Example #1: Laminate MEMS microphone



Multi-layer design includes diaphragm, acoustic cavities, acoustic port, shielding layers, and solder pads for SMT.

Package/Element Dimensions
4.1 x 6.3 x 1.0mm (Initial, can be much smaller)

Diaphragm Dimension
2.3 mm x 2 um

ASIC Dimensions
1.0 x 1.0mm

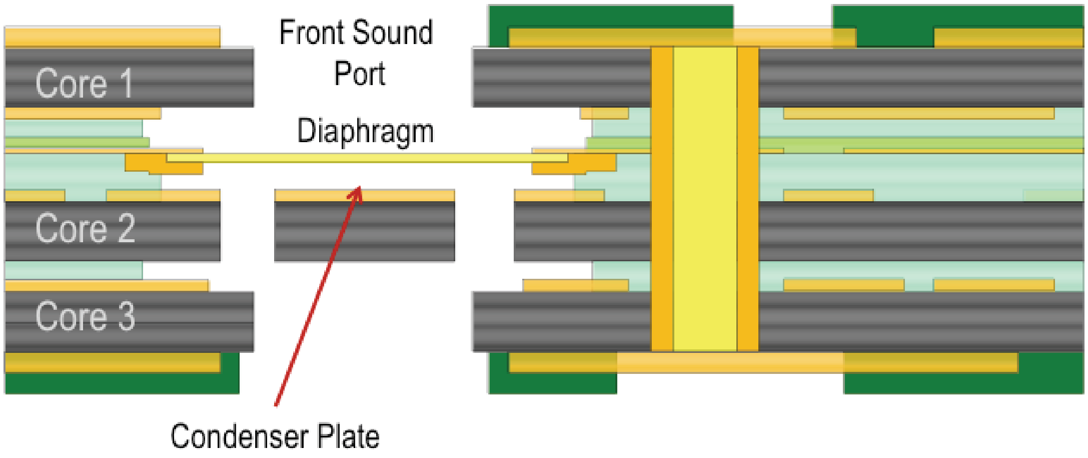
Diaphragm Material
Au, AuNi

Structural laminate material
Bismaleimide-Triazine (BT)

Condenser Plate Material
Cu

Condenser Plate Gap
40um (initial)

Example #1: Laminate MEMS microphone

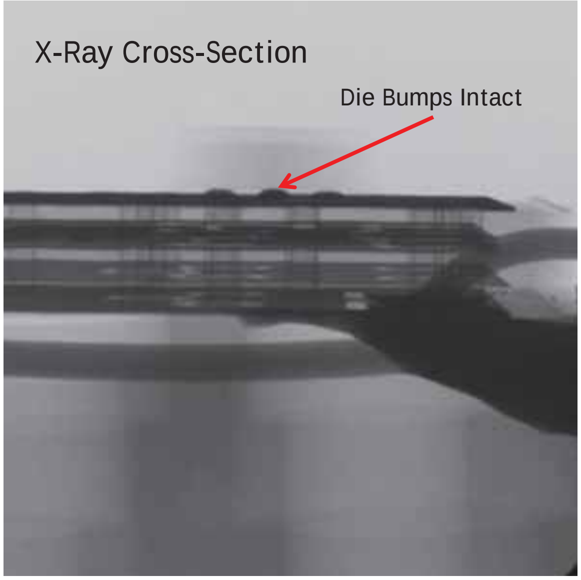


3 Core Layers
10 Mask Layers
Au Diaphragm Material

Non-Flow PrePreg gap material
2um Diaphragm Thickness
40um Condenser Plate Gap

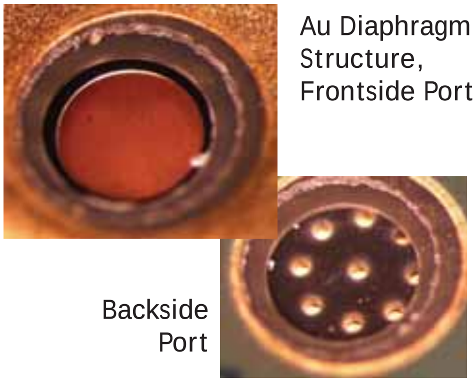
Credit: Dave Deroo and Mark Bachman

Laminate MEMS microphone



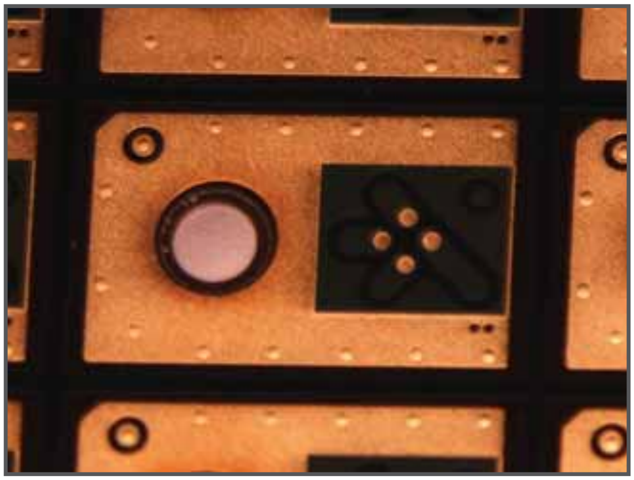
Device combines electrical circuitry, wiring, acoustic cavities, and mechanical membrane. All manufactured in PCB/Packaging shop (tw).

Laminate MEMS microphone



Au Diaphragm
Structure,
Frontside Port

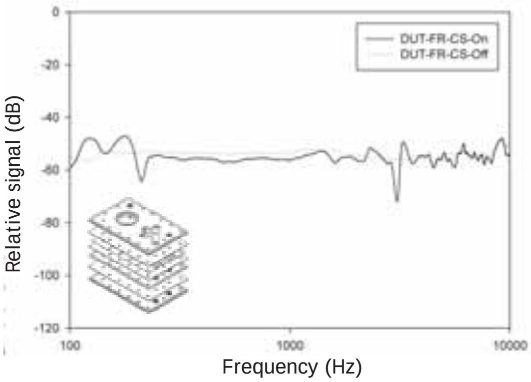
Backside
Port



Panel-level fabrication in commercial PCB fabrication shop (TW).
Excellent quality of work.

Laminate MEMS microphone

Frequency response of laminate
MEMS microphone

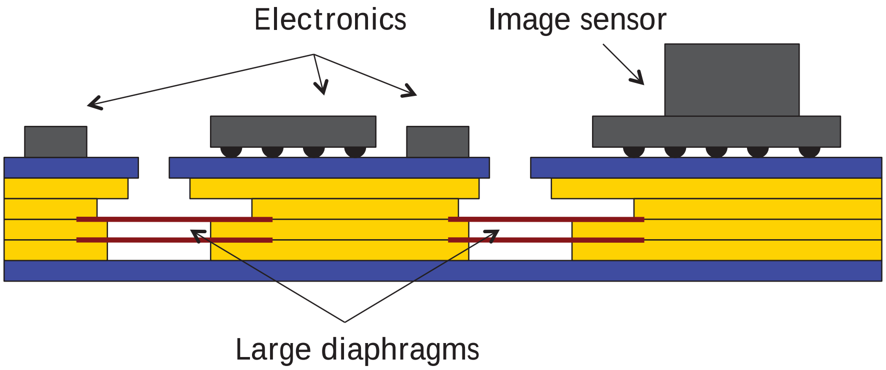


Good
- Very thin device (400 um)
- PCB compatible fabrication
- Panel level batch fab
- Performance is good
- Can handle reflow temperature

Bad
- Sensitivity not as high as hoped (too much parasitic capacitance—design flaw)

Likely to be useful as direct replacement for MEMS microphones or ECMs in applications that require thin microphones or need acoustically sensitive substrates. Also useful for microphone arrays.

Next step: Acoustic substrate (smart substrate)



Electronics

Image sensor

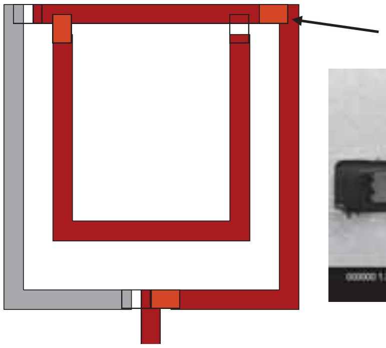
Large diaphragms

Benefits for embedded MEMS in Substrate

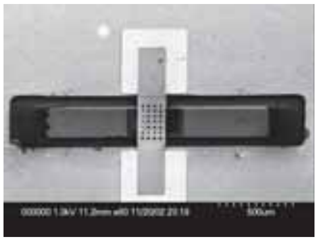
- **Multiple sensors (e.g., array) without increase in footprint**
- **Space saving, leave room for electronics**
- **Larger sensing area possible**
- **Thinner profile**
- **More integration**

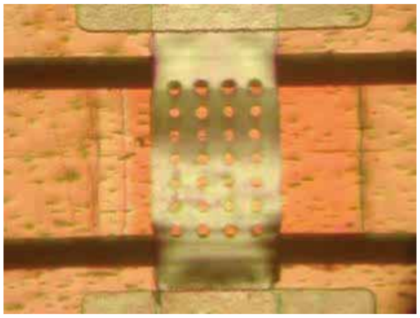
Example #2: Latching magnetic MEMS switch

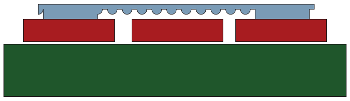
Polarization diversity

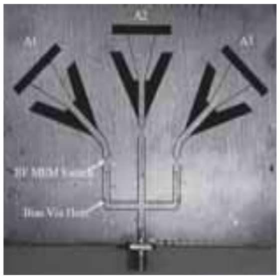


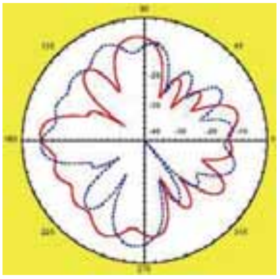
Microswitches





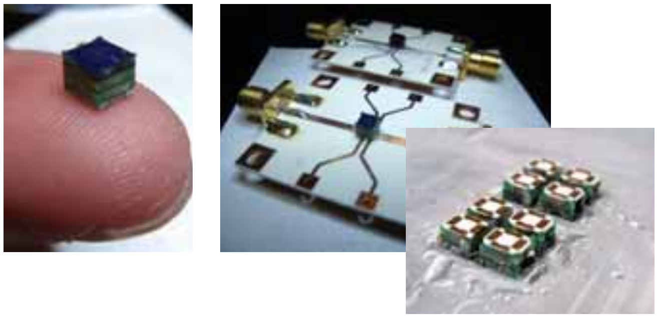


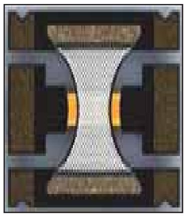




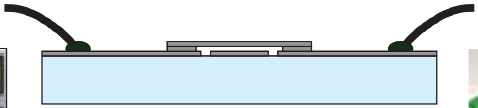
RF micro-switch
on PCB

High power applications

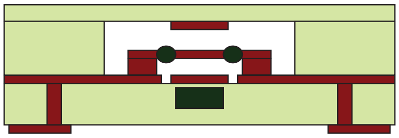




MEMtronic switch



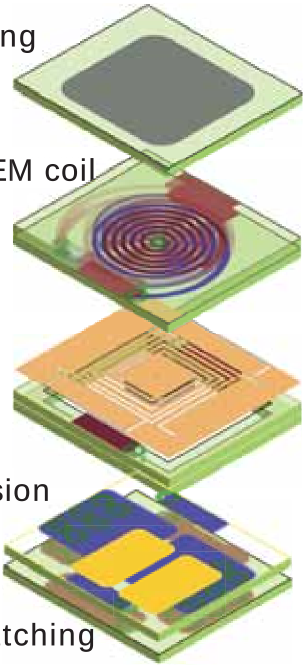
Conventional device



Laminate device

UCI switch

Latching magnetic MEMS switch



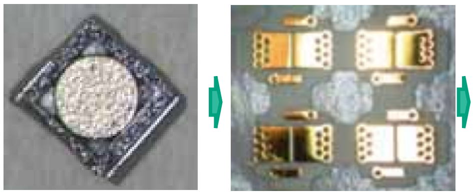
Top latching

12 layer EM coil

Magnet
Spring
Spacer

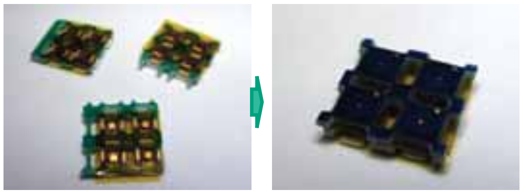
Transmission
Line

Bottom latching



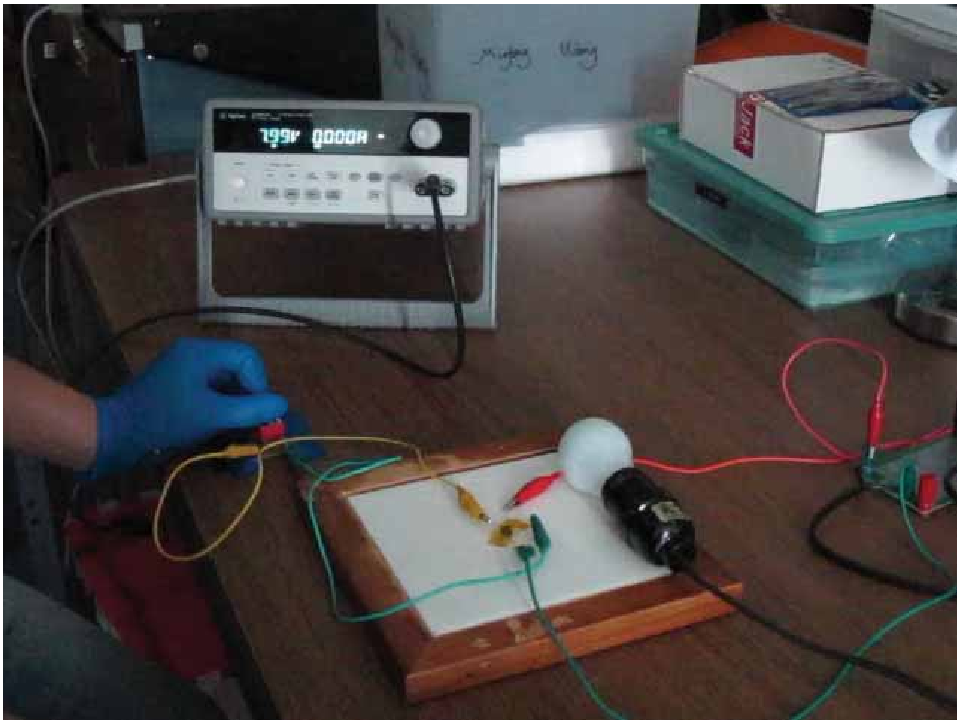
Magnet +
Silicon header

Polished
Transmission
line



Spring/pad assembly EM coil add on

MEMS switch handles high power and voltage

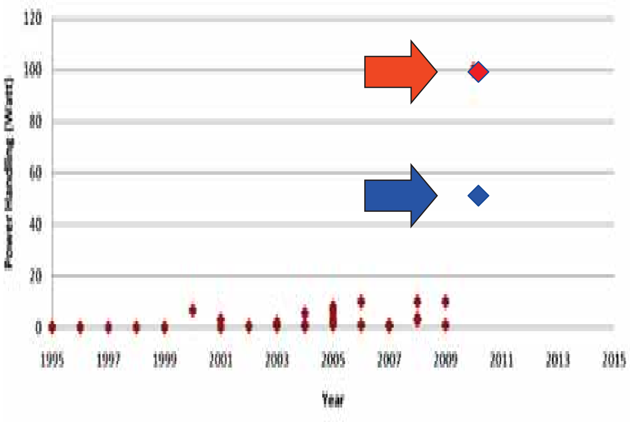


MEMS switch handles high power and voltage

World Record!

Our MEMS DC switch 3x3 mm (packaged) can handle more than 50 watts of power. Instantaneous power is 100 W. That is more than 20 times the best silicon device.

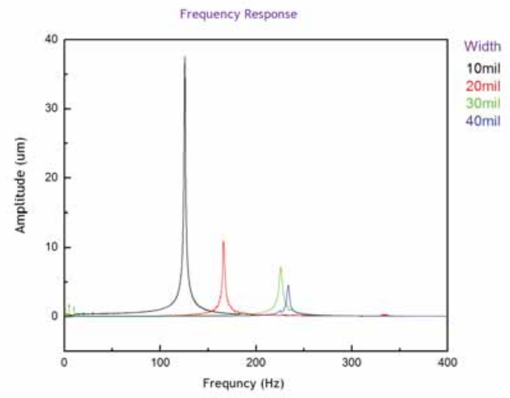
This is the ONLY low voltage, high power latching MEMS switch.

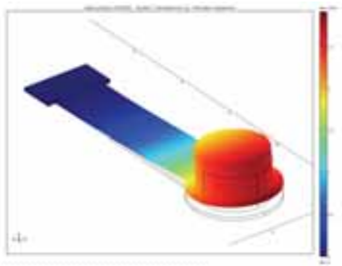


UCI switch (momentary)

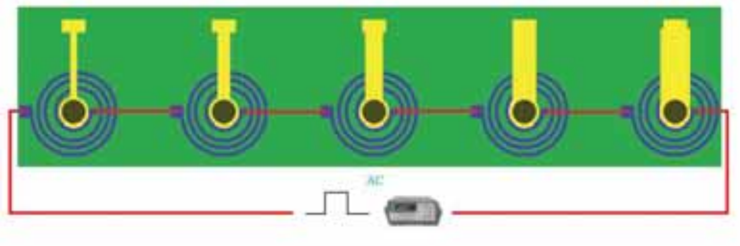
UCI switch (continuous)

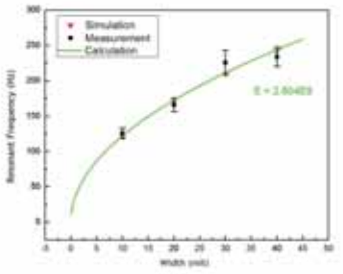
Resonant frequency switching



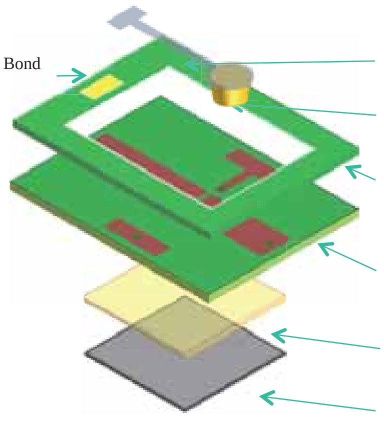


$$f_0 = \frac{1}{4\pi}\sqrt{\frac{Ebh^3}{L^3 M}}$$





Frequency addressable latched microswitch



Bond

Polymer Cantilever

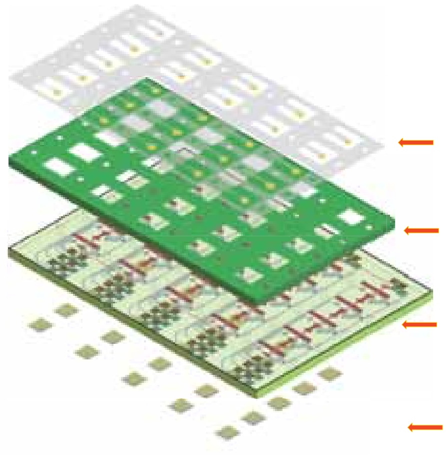
Mini Magnet

Pre-routed Polyimide Spacer

Double Layer PCB RF Transmission Line & Electromagnetic Coils

Isolation Adhesive

Nickel Latching Plate



Top Cantilever Structure Layer
With Mini Magnet Mounted

Middle Polyimide Spacer Layer

Bottom Electrode
& Electromagnetic Coils Layer
(Double Layer PCB Board)

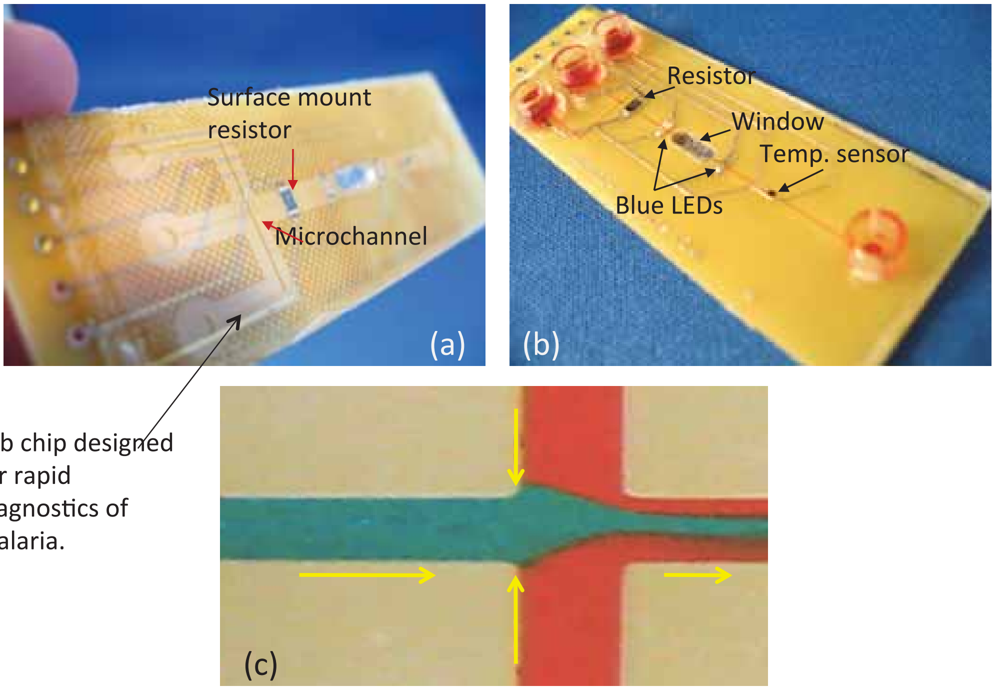
Latching Component Layer

Small resonant switches embedded in PCB

Video of individual addressing

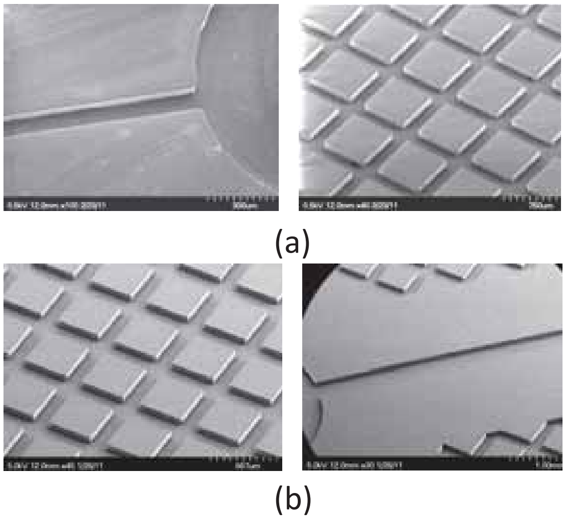
Example #3: Microfluidics (“Lab on a Chip”)

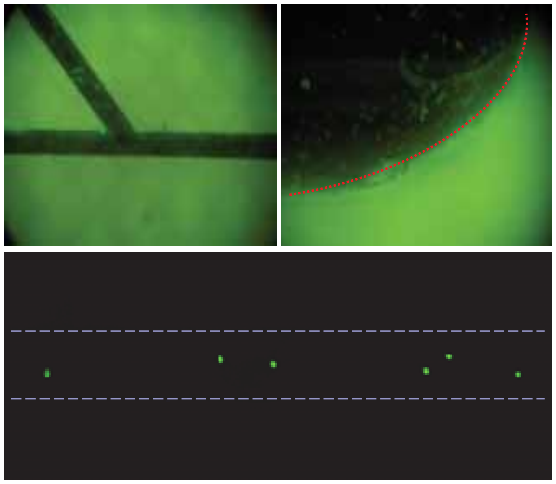
Laminate PCB/electronic units



Lab chip designed for rapid diagnostics of malaria.

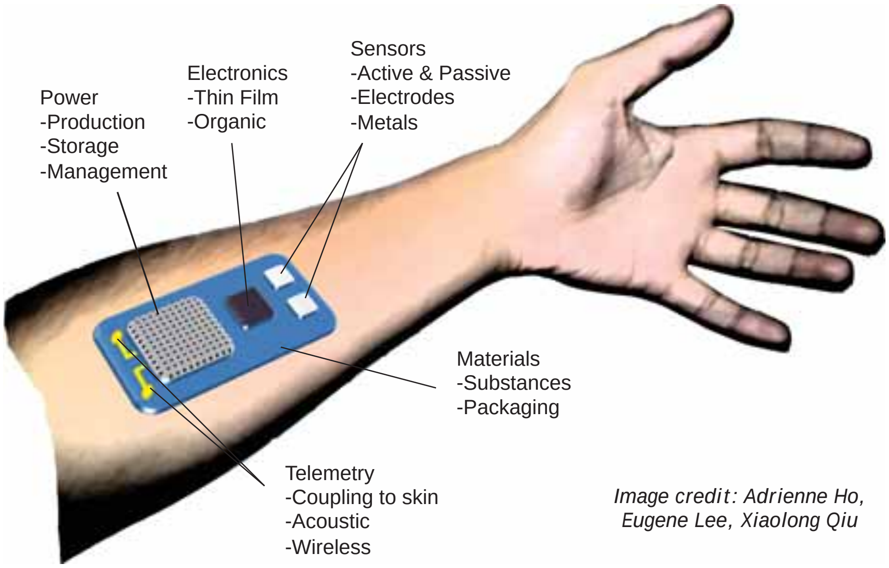
Good quality microfluidics on PCB laminate





Very fine features (<25 μm) are readily embossed over SMT and traces
Autofluorescence of FR4 requires blocking layer

Ongoing work: Integrated bioflexible devices


Power
-Production
-Storage
-Management

Electronics
-Thin Film
-Organic

Sensors
-Active & Passive
-Electrodes
-Metals

Materials
-Substances
-Packaging

Telemetry
-Coupling to skin
-Acoustic
-Wireless

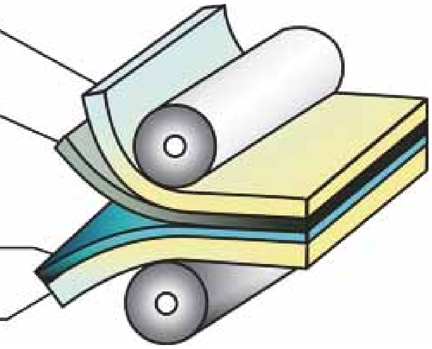
Image credit: Adrienne Ho, Eugene Lee, Xiaolong Qiu

Many technologies, many materials on same substrate

Can we make this manufacturable, scalable, affordable?

Flexible microfluidic circuit films

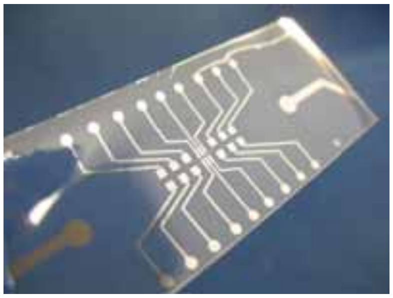

Low cost metallized polyester films (sputtered metal)


Interface layer

Microfluidics layer Ethylene-vinyl acetate (EVA)

Electronics layer

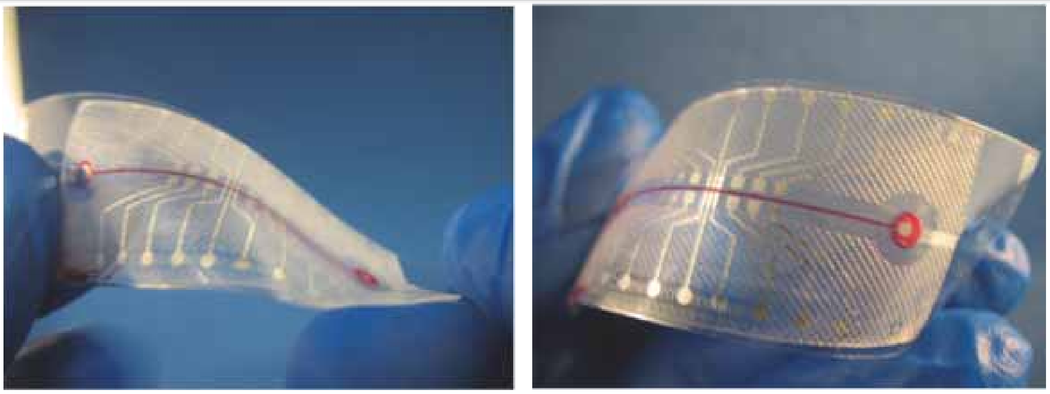
Polyester layer w/metal traces



Subtractive process

1. Coat with photoresist
2. Expose through mask
3. Develop resist pattern
4. Etch metal layer
5. Strip resist
6. Clean

Flexible microfluidic circuit films



- **Flexible integrated microfluidics**
  Can combine multiple technologies, functions, materials on same chip
- **Low cost, scalable**
  Devices can be manufactured cheaply in mass quantities using standard manufacturing infrastructure.
- **Subtractive patterning process (etch)**
  Unfortunately, requires coating of resist, etch, strip.

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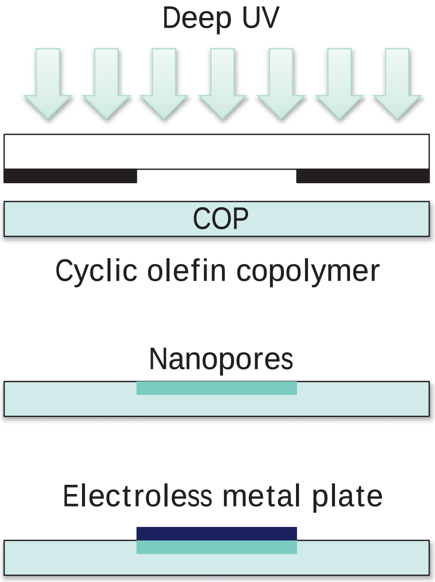
Additive process – UV patterned electroless plating



Deep UV

COP

Cyclic olefin copolymer

Nanopores

Electroless metal plate

No resist required. No etch required. No physical vapor deposition. Metallization occurs in solution at pre-patterned sites.

Credit: Prof. Hideo Honma,
Kanto Gakuin University, Japan

Simple two-step low cost metallization process.

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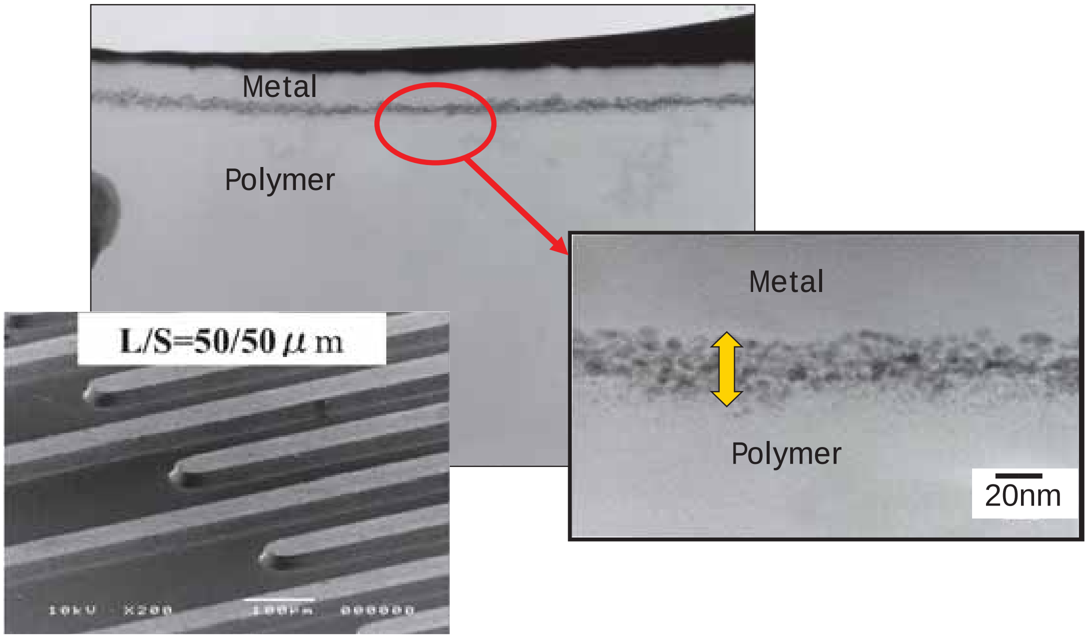
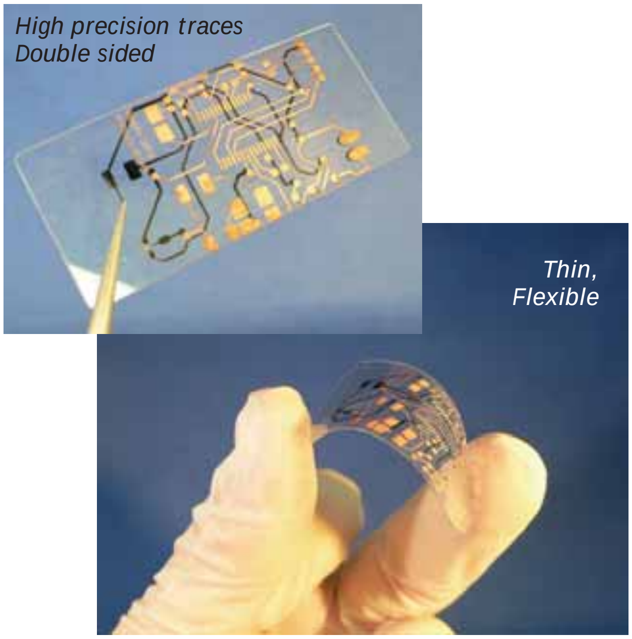
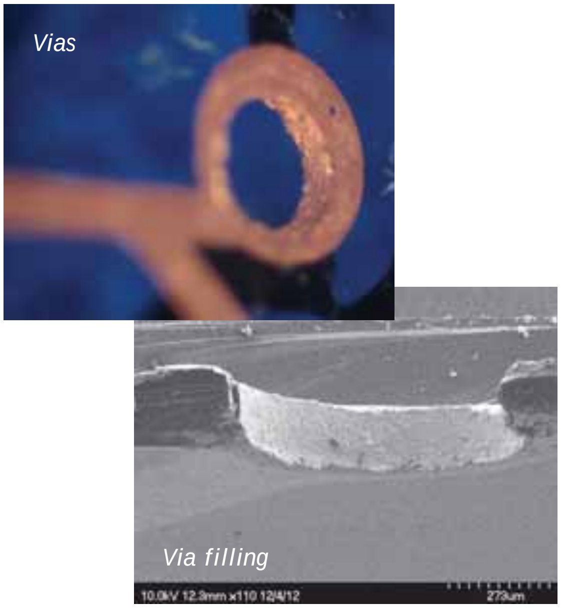
No surface roughening needed



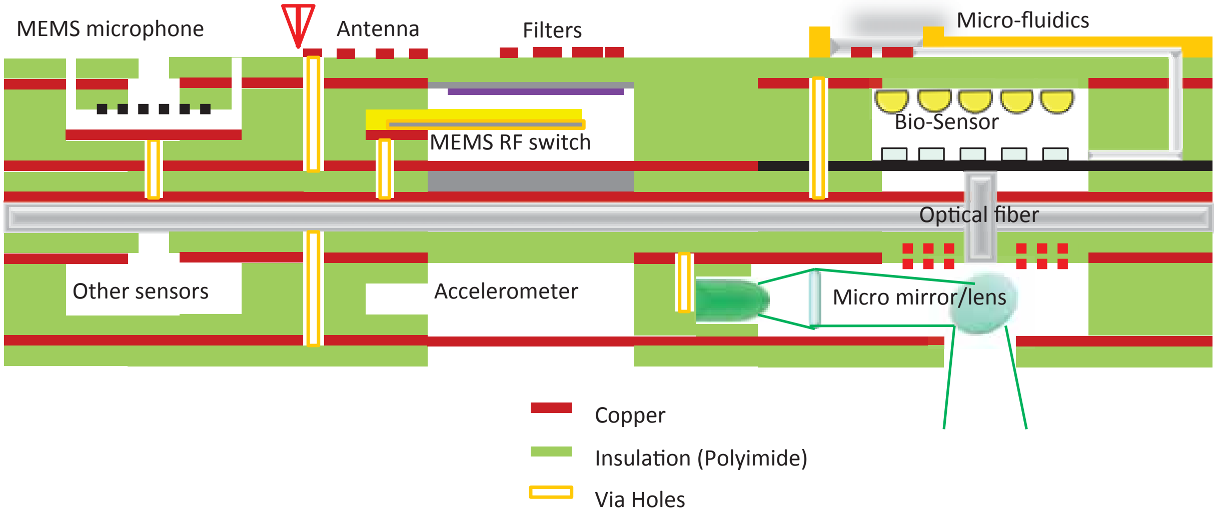
Flexible microfluidic circuit films 2





All features needed for transparent printed circuits

The vision: Fully integrated packages and PCB



Sensors and actuators fabricated on PCB and laminates

At UCI, we have fabricated many types of microdevices on laminates and PCB, including

1. acoustic devices
2. microfluidic devices
3. thermal sensors
4. micro switches
5. switch arrays

This work demonstrates that important, useful microdevices can be fabricated using standard manufacturing methods common to the PCB and packaging industry.

Research sponsors

Thanks to our research sponsors and partners

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Li/Bachman 2010

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Thank You

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