Embedded Microdevices

An new way to build low cost, 3D, integrated microsystems in laminates

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UCIRVINE Calit2 INRF

INTEGRA DEVICES
SYSTEMS BEYOND SILICON

Times are changing

Today:
The Internet of People
Most data generated by/for **humans**

Tomorrow:
The Internet of Things
Most data generated by/for **things**

The Internet of Things—a connected world

What happens when everything is smart and connected?

- By 2020, the Internet of Everything expected to connect **50 Billion devices**.
- Triple digit growth: Energy, Transportation, Digital Cities, Healthcare, Financial Services, Retail (Verizon)
- "**…a $19 trillion opportunity**" (John Chambers, Cisco CEO)
- Big winners: semiconductor, network, remote sensor and big data.

50 Billion devices = 500,0000,0000 devices

IN FIVE YEARS

IoT is biggest market in recent tech history

$7 to $17 Trillion market opportunity

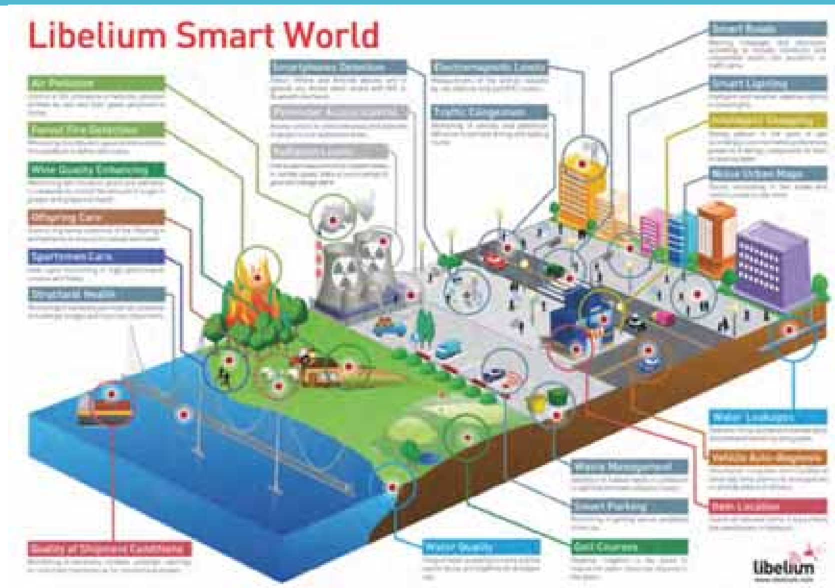
by 2020

$17 TRILLON = $17x10^{12}$

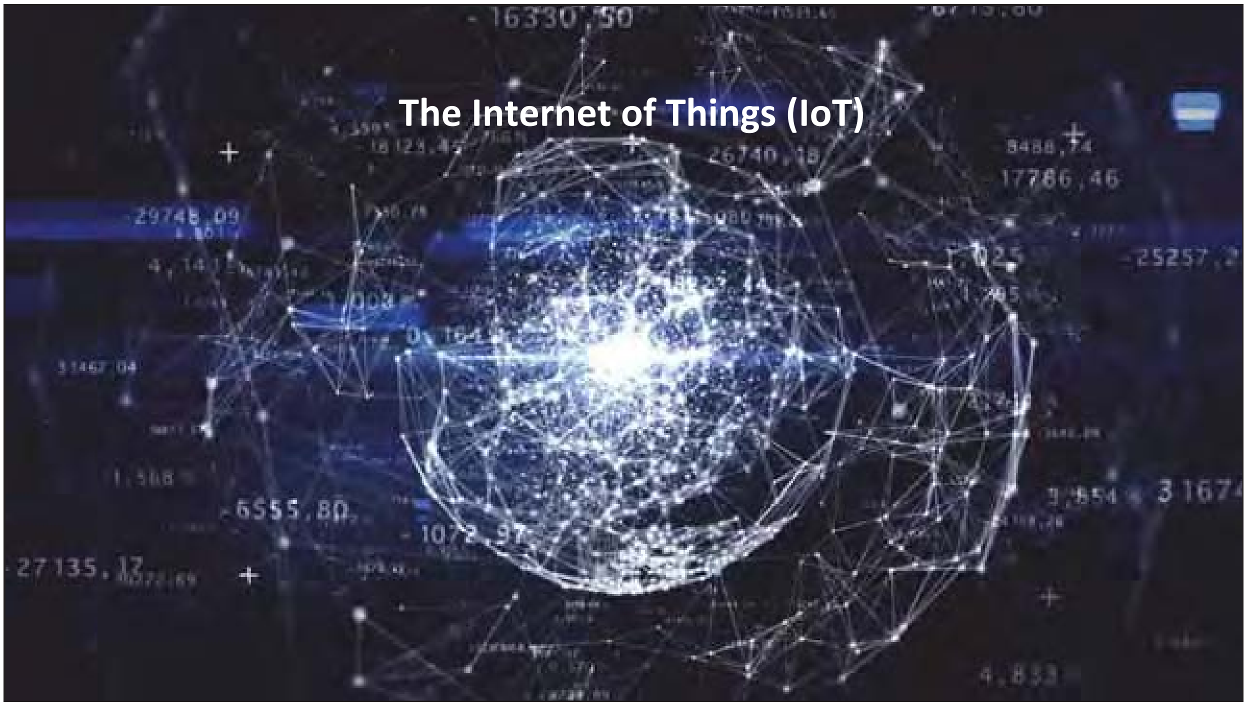
$17,000,000,000,000

"California GOLD RUSH"

Why the hype? A smart, connected world.



IoT application: Industry 4.0



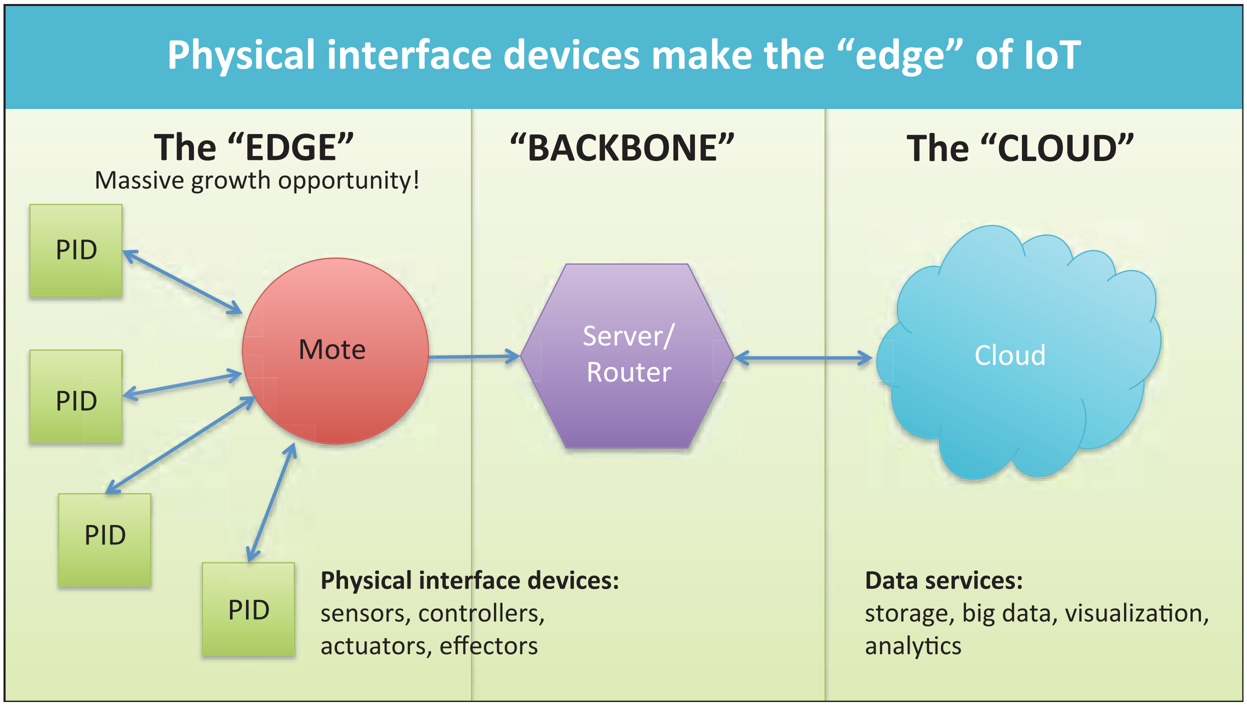
The Internet of Things (IoT)

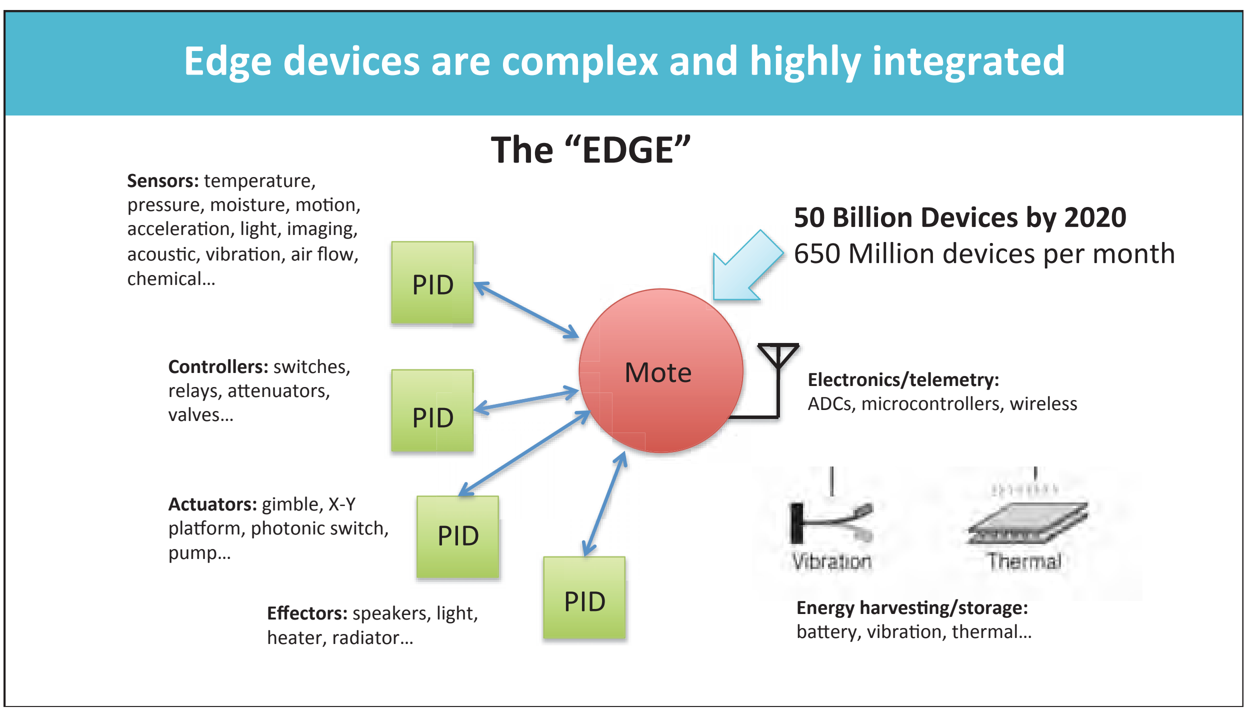
The Internet of Things (IoT) is expected to be a **$17 Trillion dollar** opportunity by 2020.

More than **50 Billion devices** will be connected to the internet by 2020. Expectations are up to **1 Trillion sensors** by 2020.

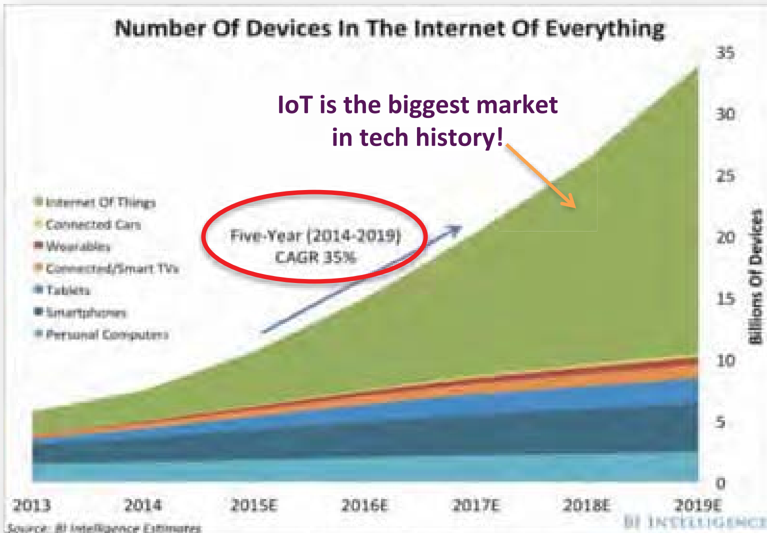
Requires a build rate **of 650+ Million (6,5000,0000) DEVICES PER MONTH** for the next five years.

Large opportunities for **hardware, software, services, and applications** in the **largest market in recent tech history**.

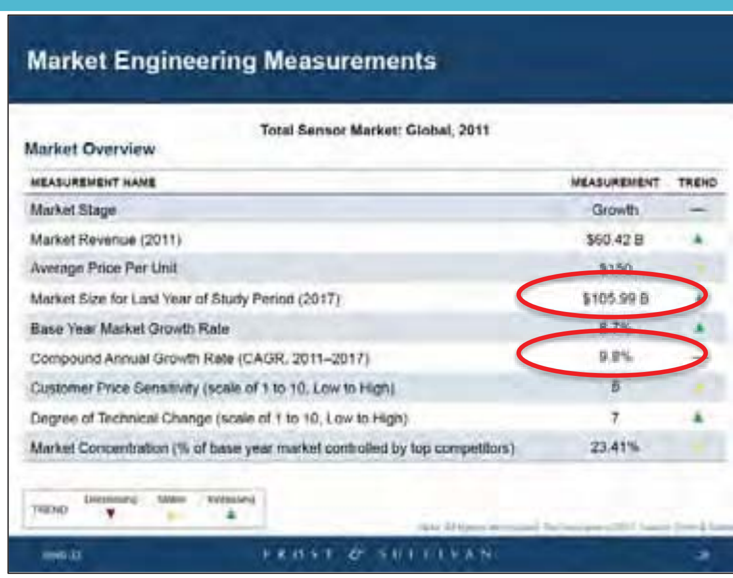

Physical interface devices make the "edge" of IoT
The "EDGE"
Massive growth opportunity!
"BACKBONE"
The "CLOUD"
PID
PID
PID
PID
Mote
Server/ Router
Cloud
Physical interface devices: sensors, controllers, actuators, effectors
Data services: storage, big data, visualization, analytics


Edge devices are complex and highly integrated
The "EDGE"
Sensors: temperature, pressure, moisture, motion, acceleration, light, imaging, acoustic, vibration, air flow, chemical…
Controllers: switches, relays, attenuators, valves…
Actuators: gimble, X-Y platform, photonic switch, pump…
Effectors: speakers, light, heater, radiator…
PID
PID
PID
PID
Mote
50 Billion Devices by 2020
650 Million devices per month
Electronics/telemetry: ADCs, microcontrollers, wireless
Vibration
Thermal
Energy harvesting/storage: battery, vibration, thermal…

Billions of Things, Trillions of Dollars



$106 Billion market for edge devices



Market Engineering Measurements

Total Sensor Market: Global, 2011

Market Overview

MEASUREMENT NAME	MEASUREMENT	TREND
Market Stage	Growth	—
Market Revenue (2011)	$60.42 B	▲
Average Price Per Unit	$150	
Market Size for Last Year of Study Period (2017)	$105.99 B	
Base Year Market Growth Rate	8.7%	▲
Compound Annual Growth Rate (CAGR, 2011–2017)	9.8%	—
Customer Price Sensitivity (scale of 1 to 10, Low to High)	5	
Degree of Technical Change (scale of 1 to 10, Low to High)	7	▲
Market Concentration (% of base year market controlled by top competitors)	23.41%	

TREND: Decreasing ▼ Stable Increasing ▲

FROST & SULLIVAN

Frost and Sullivan, "Insight into Sensors: Current Markets and Forecasts" July 2013

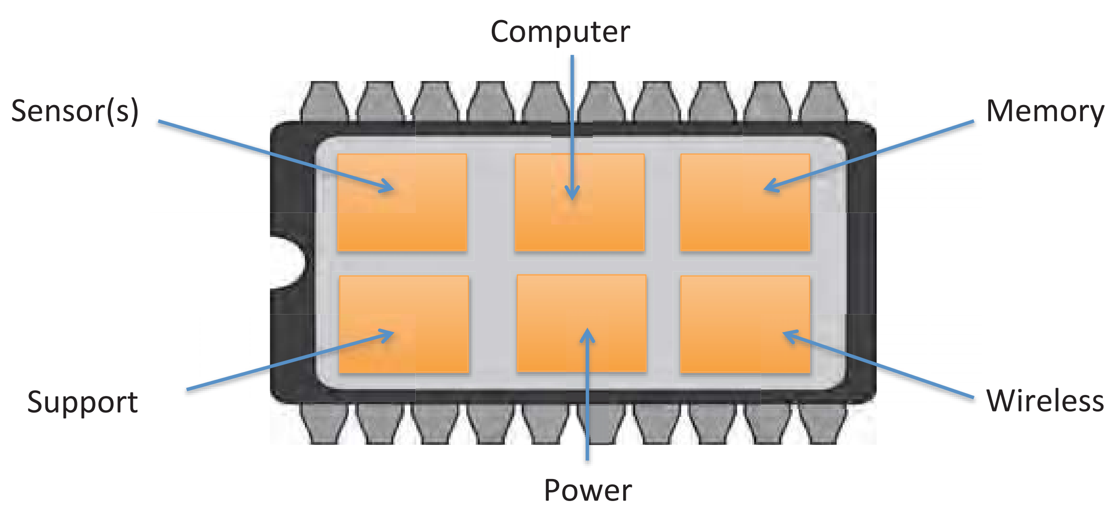

Some example edge products…


"Edge" products represent a big opportunity for IoT
But, there is a problem…

Small, low cost, integrated devices are hard to make

1. **Sensor(s)**
   Interface to world
2. **Computer**
   Smart
3. **Memory**
   Allows telelemtry
4. **Wireless / telemetry**
   Communications
5. **Power**
   Power management
6. **Support electronics**
   Amplification, filtering

Anatomy of an ideal IoT device ("chip")

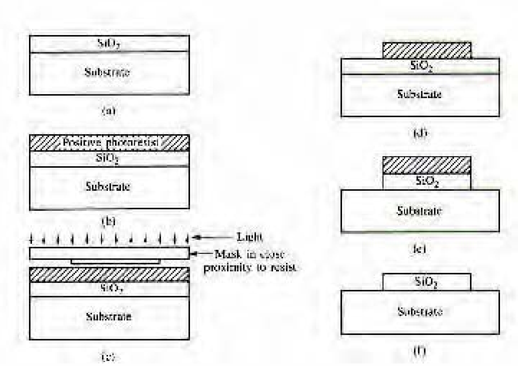


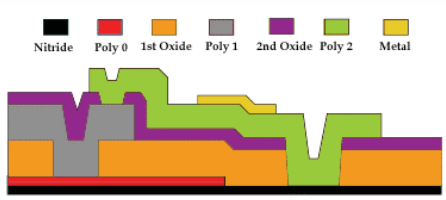
The Internet of Things (IoT) will require 50 billion devices connected by 2020.

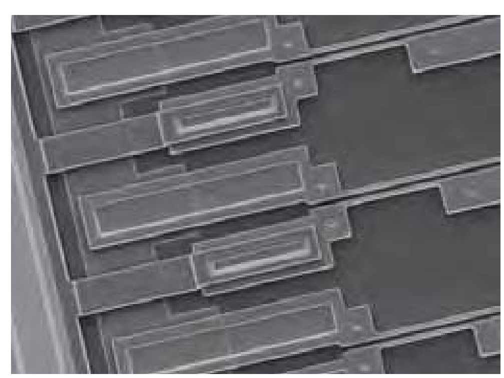
The future of IoT devices: System in Package

SIP: Everything in one small package.
Including the microdevice?

A brief look at MEMS manufacturing (silicon)







Process is primarily 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

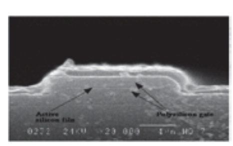
High precision lithography
Large infrastructure
Known processes
Well characterized material
Ability to add electronics

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.

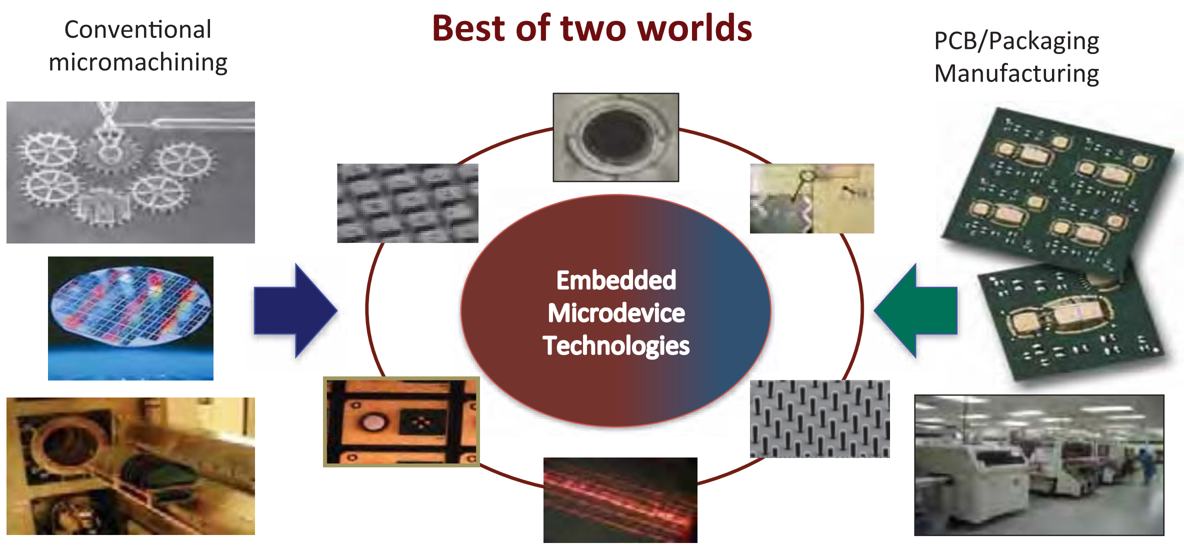


MEMS in SIP?

- Non-standard manufacturing
  Many sensors not standard solid state, often with specialty materials
- Special packaging requirements
  May require environmental access, hermetic seals, low temperature, expensive!...
- Fragile components
  Often have free-standing, delicate components
- Batch (wafer-level) testing difficult
  Many sensors are not active until after singulation

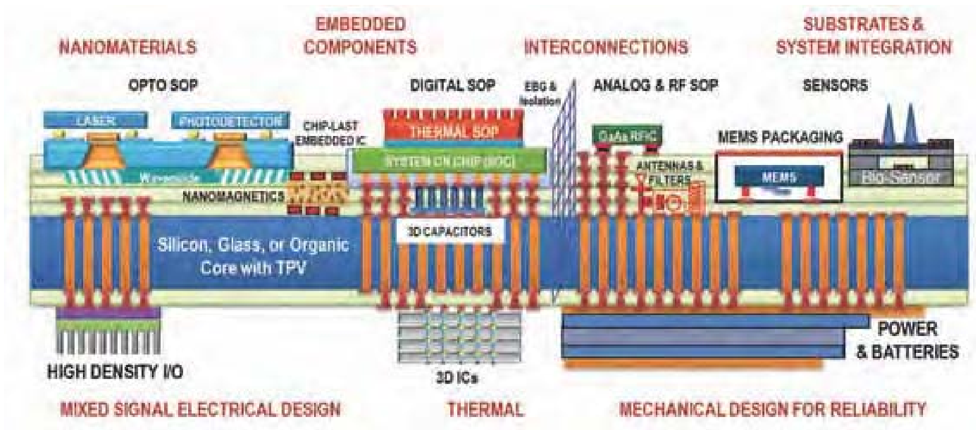
Hard to integrate MEMS in SIP module. Difficult to achieve low manufacturing cost.

Embedded devices in laminates / 3D heterogeneous integration



Post-semiconductor manufacturing ➔ System In Package

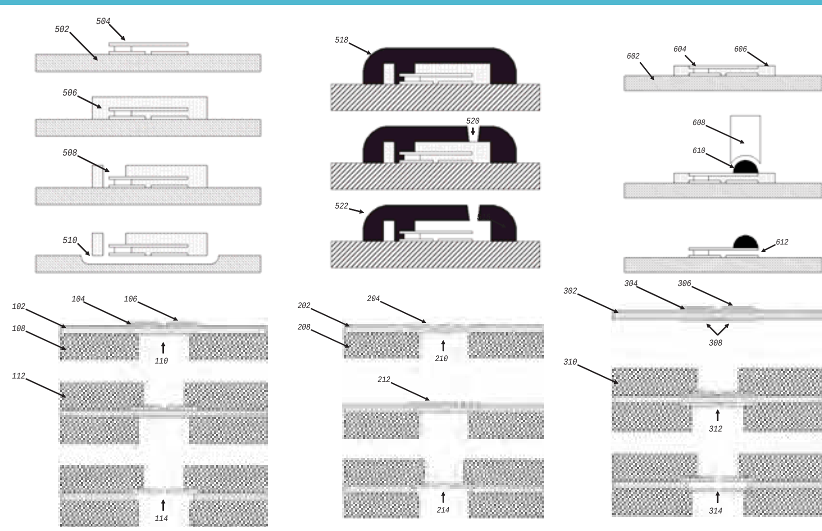
System in Package requires: 3D Heterogeneous Integration



Precision manufacturing, multiple materials, multiple technologies

Integrated embedded microdevices in laminates

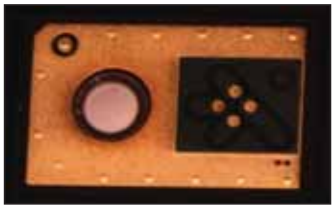
Conventional MEMS strategies can be adapted to laminate/ packaging manufacturing.



Bachman and Li, "Methods of manufacturing microdevices in laminates, lead frames, packages, and printed circuit boards ," US 8,877,074 A1 (2014).

Examples of integrated embedded microdevices

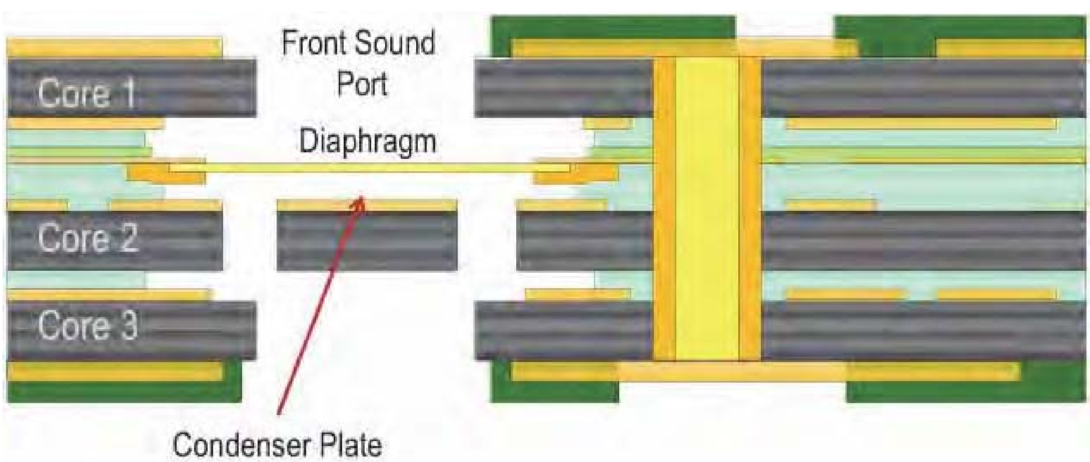
Microphones



Microfluidic systems

Microrelays

Integrated embedded microdevices: microphones



3 Core Layers
10 Mask Layers
Au Diaphragm Material

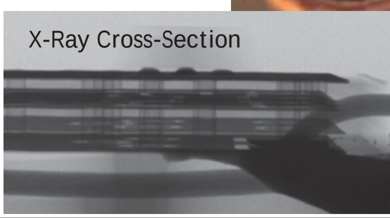
Non-Flow PrePreg gap material
2um Diaphragm Thickness
40um Condenser Plate Gap

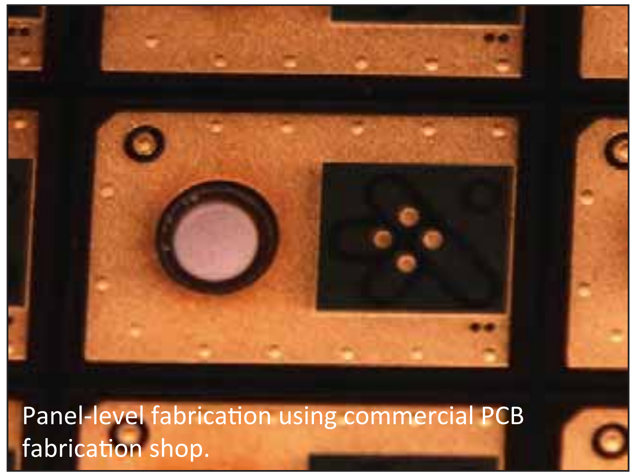
David Deroo, Meso Integrated and Conexant Systems, 2006

Integrated embedded microdevices: microphones

Frontside Port showing 1 um Au diaphragm structure

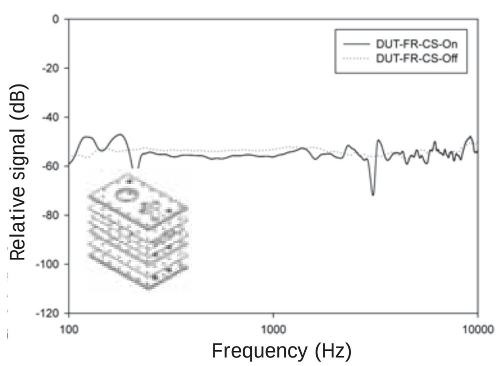
Backside port acoustic holes



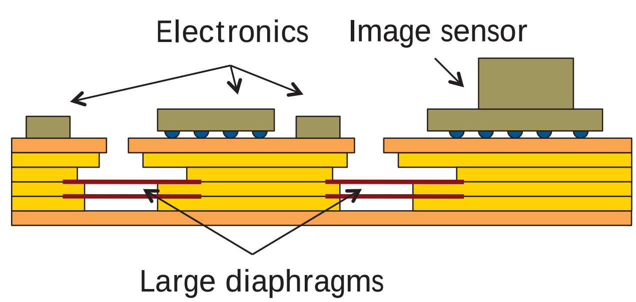


David Deroo, Meso Integrated, Mark Bachman, and Conexant Systems, 2006

Integrated embedded microdevices: microphone arrays



Device performance comparable to ECM microphones.



- Multiple sensors (e.g., array) small footprint
- Space saving, leave room for electronics
- Larger sensing area possible
- Thinner profile
- More integration

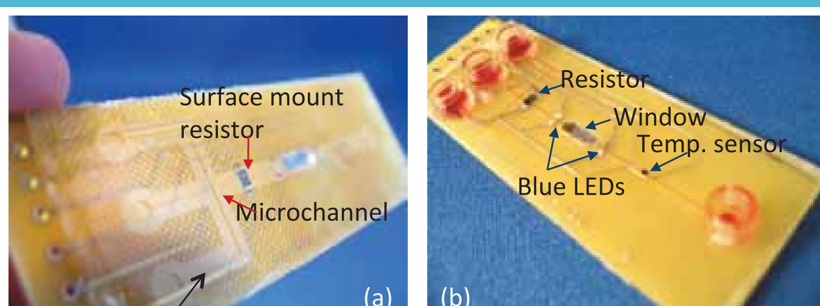
Examples of integrated embedded microdevices

Microphones

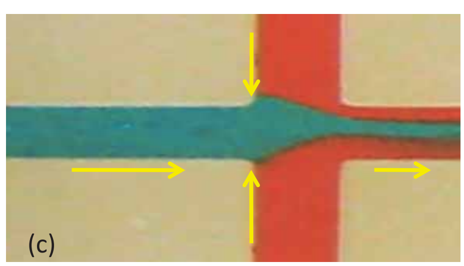
Microfluidic systems

Microrelays

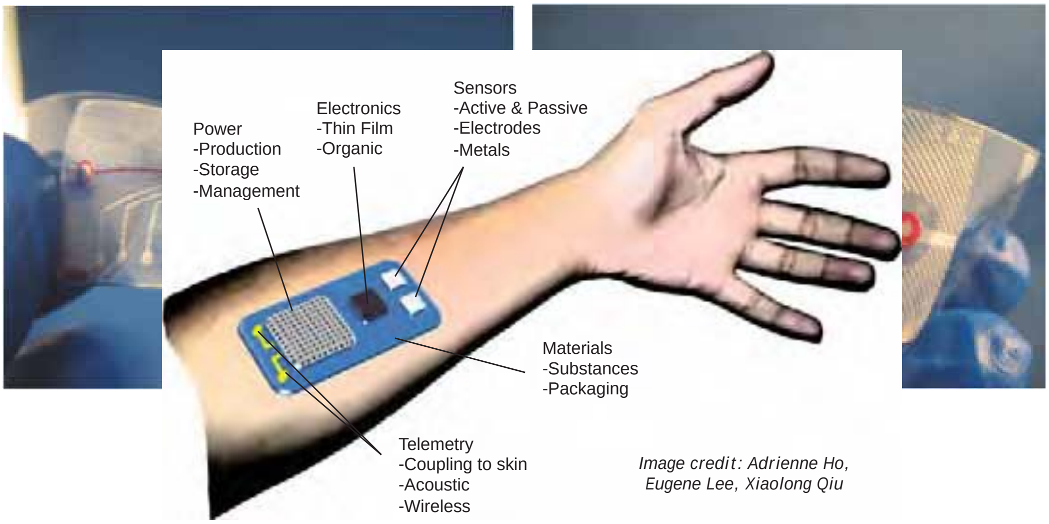
Microfluidic systems on PCBs



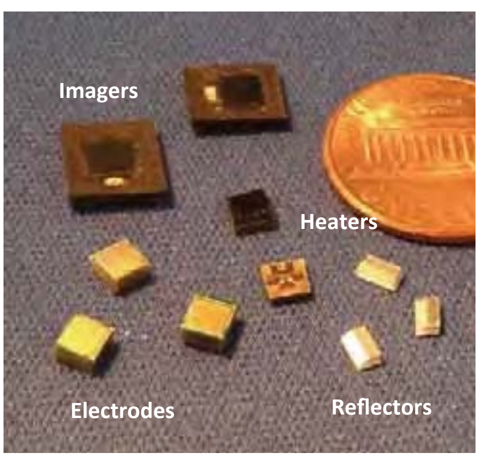
Lab chip designed for rapid diagnostics of malaria.

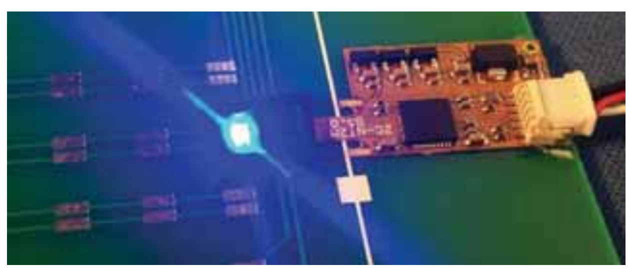


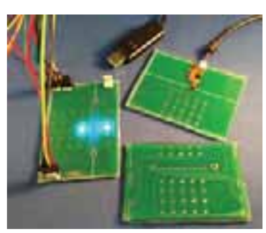
Microfluidic systems on flexible PCBs

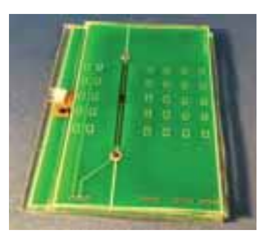


µFLEMs: Surface mountable fluid optical electrical components







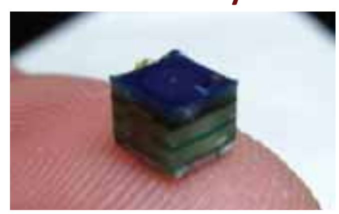


Examples of integrated embedded microdevices

Microphones

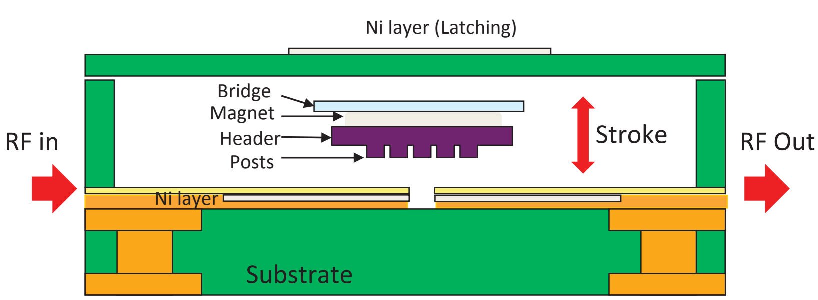
Microfluidic systems

Microrelays

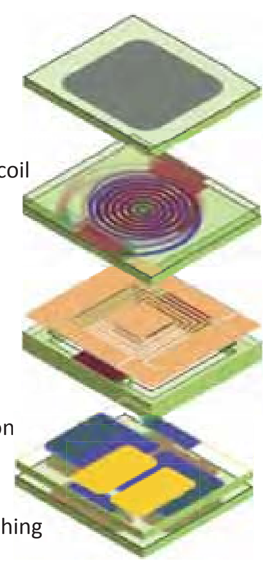


Embedded magnetic micro-relay (dual latch)

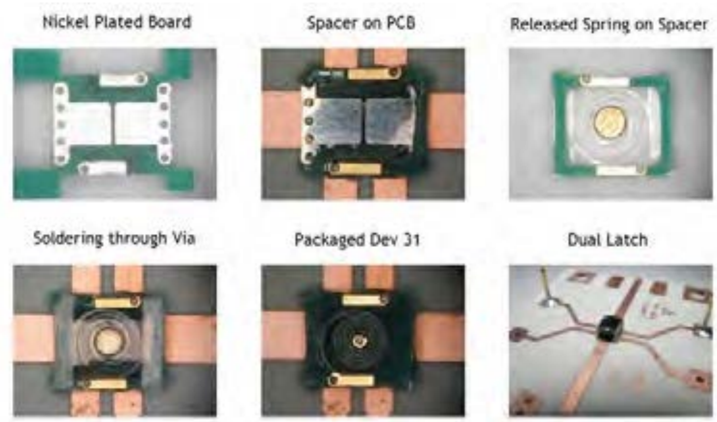
1. Separated RF transmission line from MEMS components
2. Optimized for high power RF transmission
3. Bi-directional latched switching design
4. Contact surface control by specialized headers



RF transmission line/MEMS Design side view

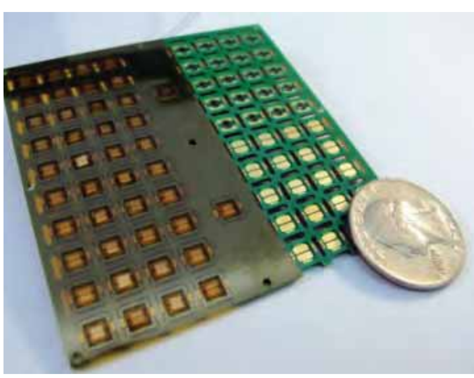


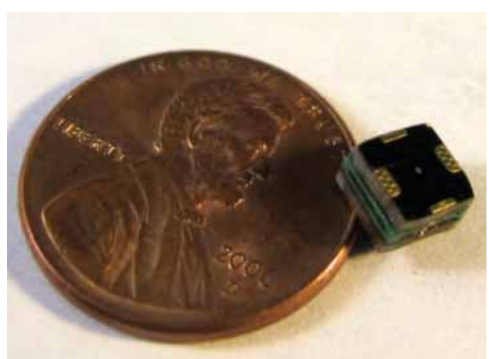
Embedded micro-relay construction



Images showing original laminate magnetically actuated MEMS RF switch at different stages of its manufacture. The unit utilizes a microcoil and miniature magnet to move a plate into contact against a transmission line.

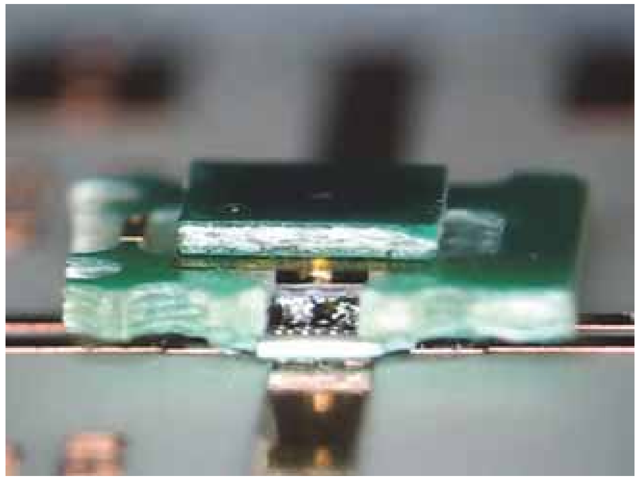
Panel-level construction and packaged dies





Images showing panels used for manufacturing RF microrelays and a completed, packaged RF microrelay.

Embedded micro-relay actuation



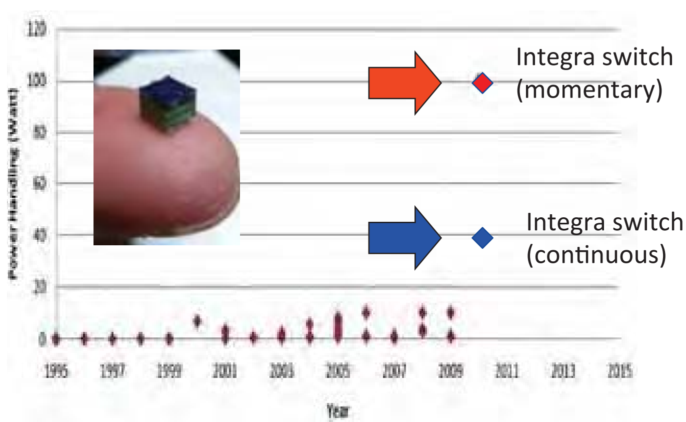
Video showing actuation of partially packaged RF microrelay.

Power performance of embedded micro-relay

Integra's MEMS DC switch 3x3 mm can handle over 40 watts of power.

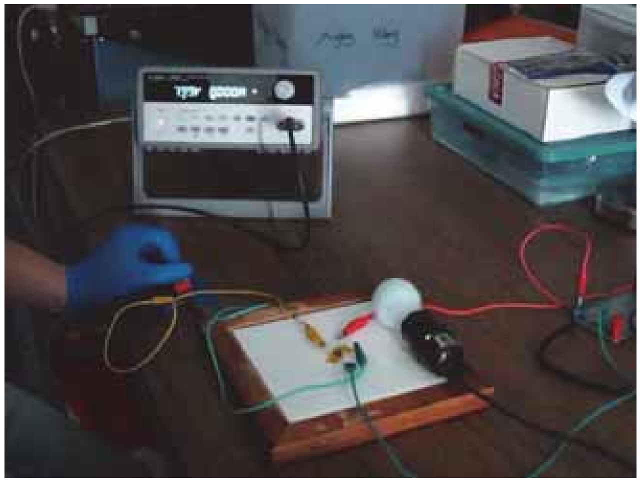
Instantaneous power is 100 W. That is more than 20 times the best conventional silicon device.

Low voltage actuation, high power latching MEMS switch.



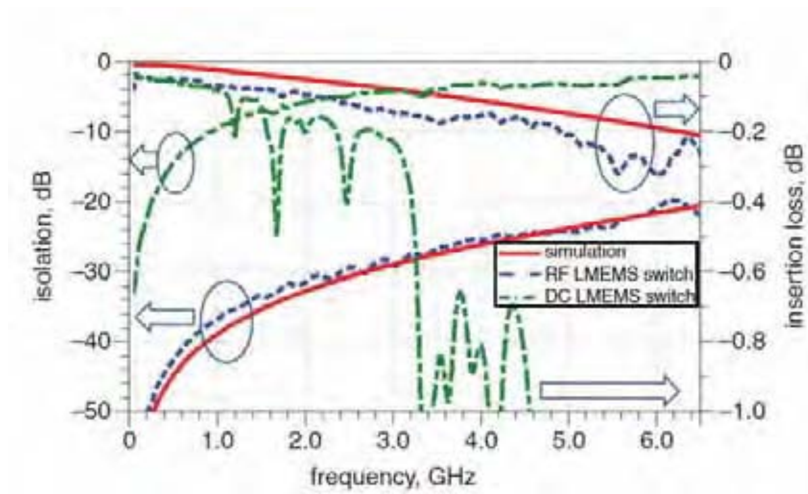
Power handling of microrelay.

Demonstration of high power microrelay



Video showing switching of 110 VAC at 40 W.

Performance of RF microrelay



Frequency response of RF microrelay.

Integrated embedded microdevices 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.

Integrated embedded microdevices?

New advancements in sensor packaging and 3D heterogeneous integration will be needed to bring the cost of IoT sensor systems down.

New methods of manufacturing sensors and actuators can be explored to produce smaller, less expensive sensor components that are **integrated in package**.

3D heterogeneous integration and packaging technology is a viable manufacturing technology for building sensors and actuators. **Packaging manufacturers could become device manufacturers.**

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SYSTEMS BEYOND SILICON

Calit2

Thank You

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