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National Applied Research Laboratories

TSRI

The Implementation and Verification Platform for CMOS Sensing Technologies

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承諾·熱情·創新

Outline

- The IP Integration Platform for Intelligent Sensing System
- CMOS MEMS Design Platform
- System Integrating Examples
- Conclusions

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The Demand for AIoT

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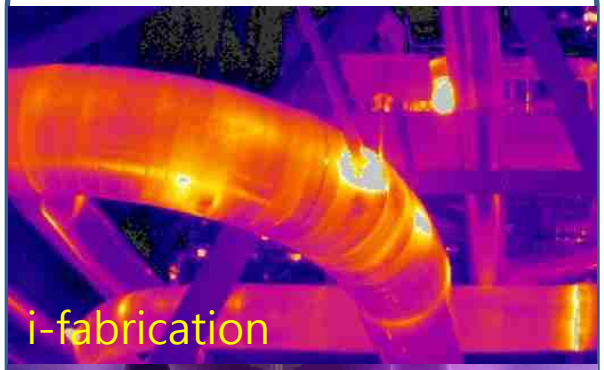
For future smart world there are trillion IoT devices!!

New Products

i-screw

i-EarPhone

New Component



i-fabrication

Helthcare

New Thinking

Smart city

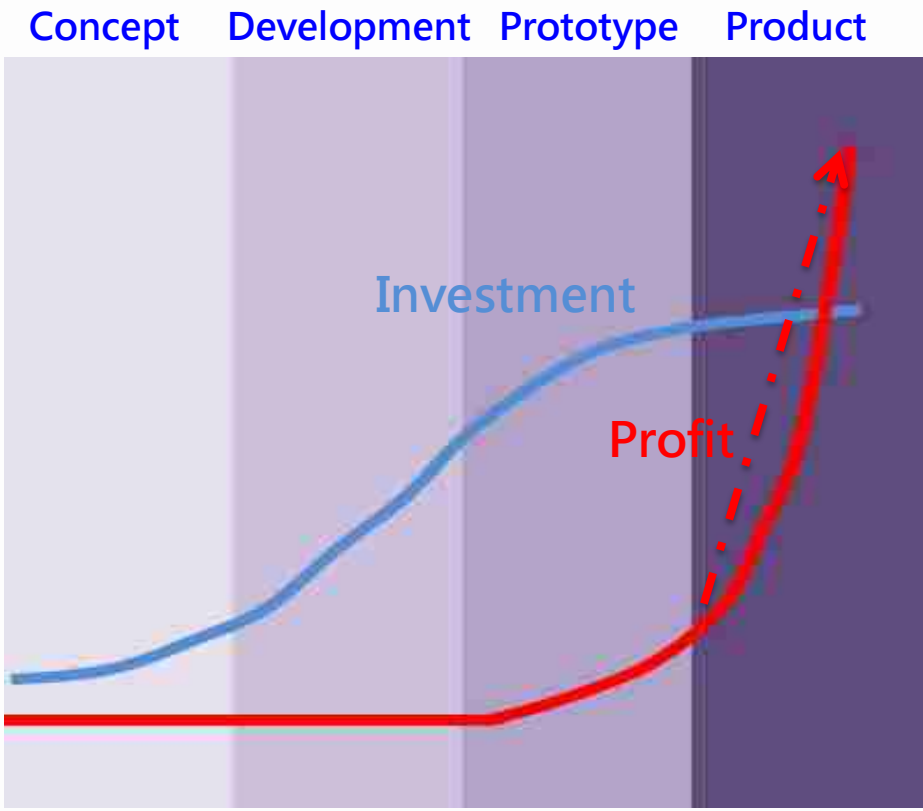
Wearable

Source: ITRI, TDK-Micronas , web

The Challenges of IP for AIoT

How to get useful IoT device in a short time?

- Include the optical, mechanical, chemical …. sensing elements
- The verification for flexible circuit and system IP integration
- Micro-module embedded multi-sensors
- Capability of wireless, energy harvest



TSRI Heterogeneous Integration Common Platform

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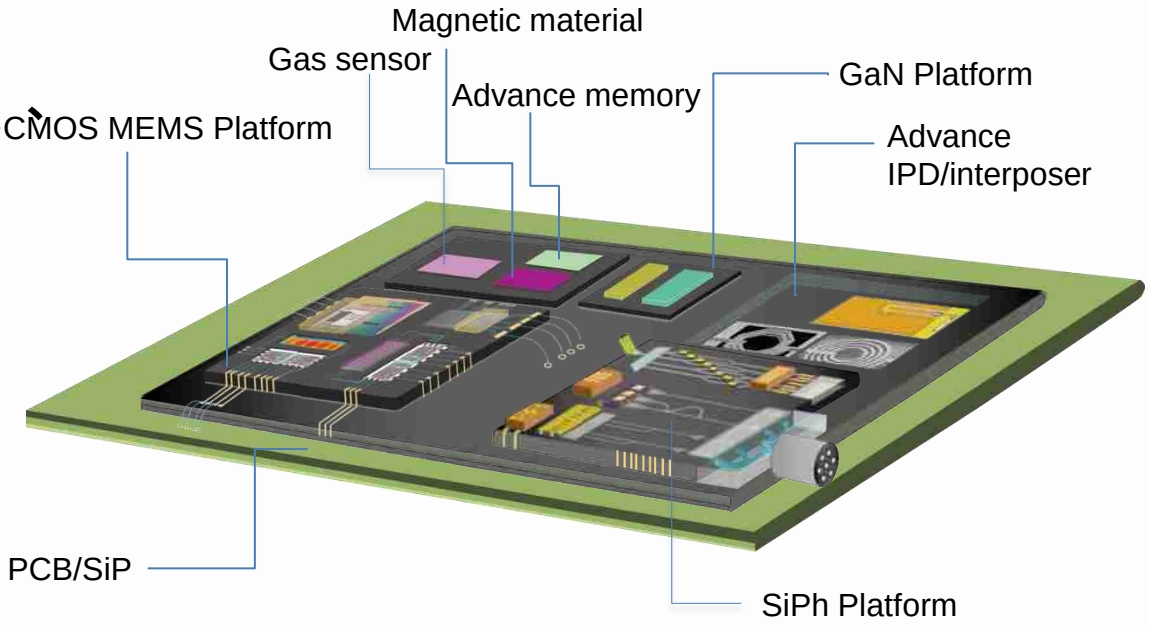
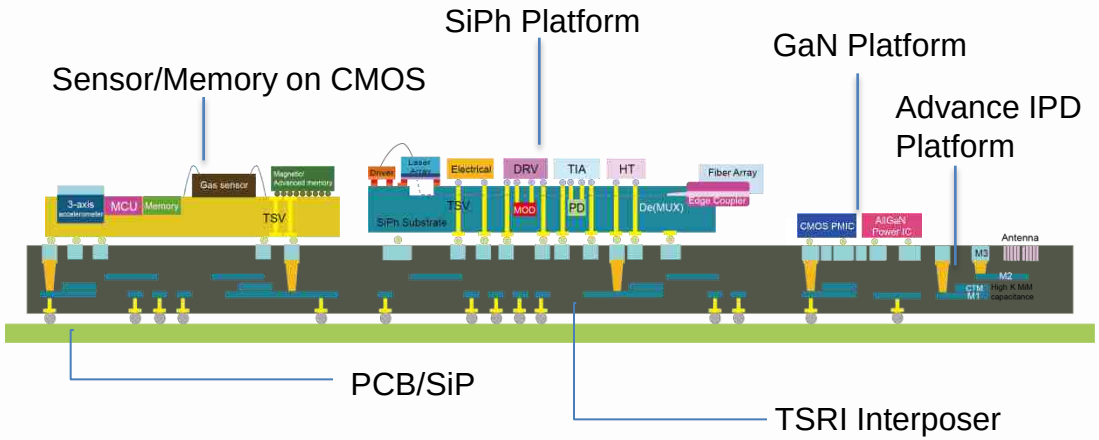
From 2018 to 2021

- **Special Material、Advanced Devices、IoT Devices**
- **EDA Design Environment**
- **High Performance Interface**





- **IPD/2.5D/TSV**
- **Sensor/Memory on CMOS**
- **SiPh w Optical Interposer**
- **All GaN Platform**

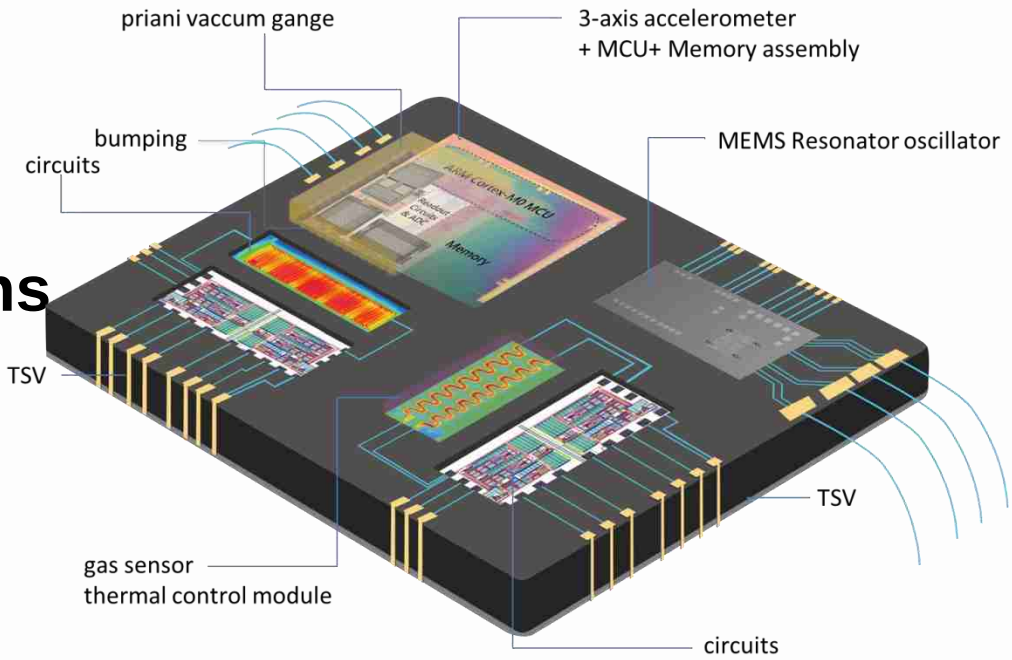
Sensor on CMOS Platform

Platform Considerations

- Integration with 8 inch CMOS-MEMS Platform、Multi-sensors with system circuit module
- Embedded gas、magnetic sensors
- Could be integrated with (Pt) thermal control unit 、2.5D interposer & TSV

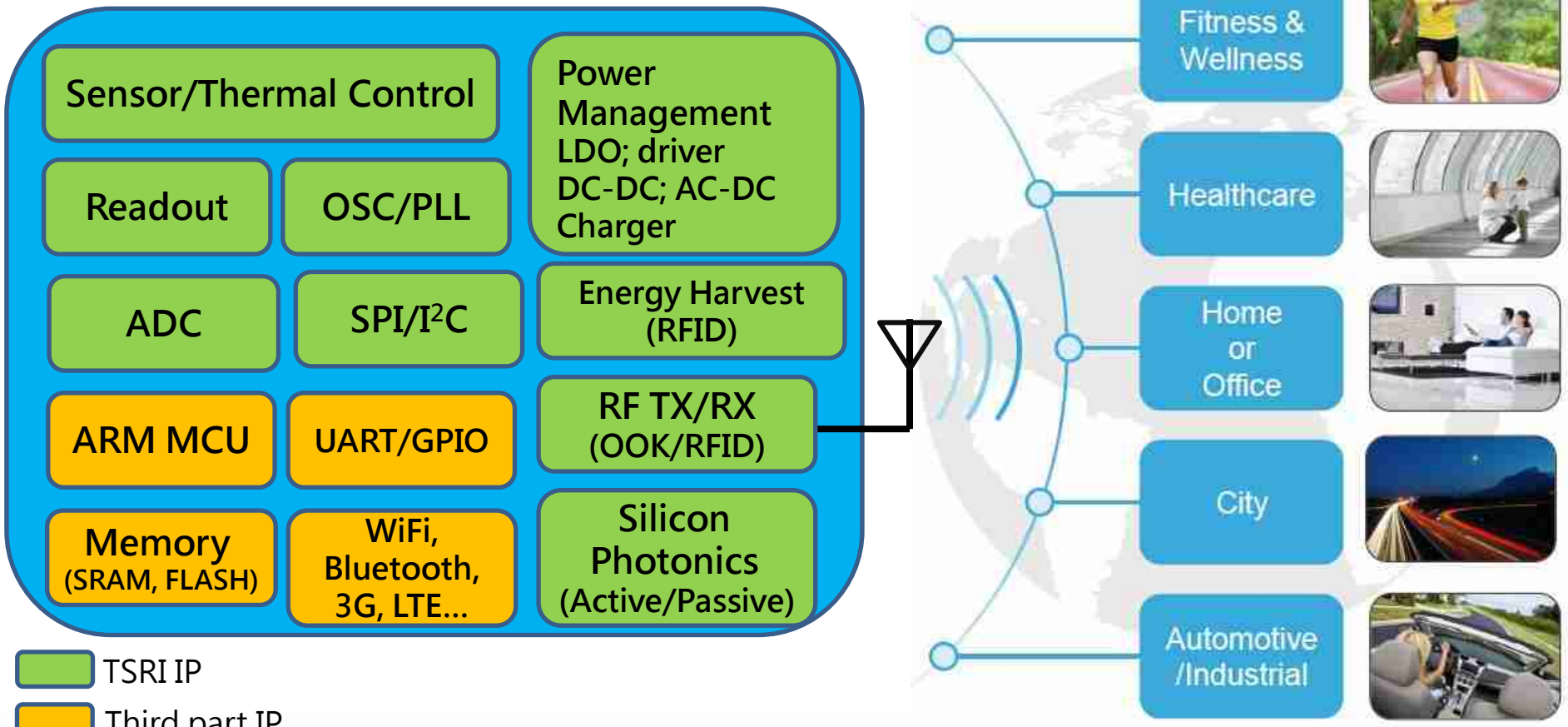
Application Considerations

- Customized sensors integration
- For IoT low power multi-sensors
- Application for intelligent machine



Core IPs for Wireless Sensing System

NARLabs Provides the IP Integrated Platform Services for IoT Applications



Source: ST

Sensor and Circuit IPs in TSRI

	Category	Circuits
Sensor IP	Inertial Sensor	1-Axis, 2-Axis, 3-Axis Accelerometer
	Pressure Sensor	Cantilever Piezoresistive Sensor
	Environment Sensor	Temperature/Gas Sensor、 Cantilever Type Sensor (Pressure) Vibration Sensor (Gravity)
	Biomedical Sensor	Cantilever Sensor (Piezoresistive)、 PH ISFET Sensor ISFET Based Type Sensor
Actuator IP	Actuator	Resonator, Self Test (Inertial Sensor)
Circuit IP	Sensing Signal Readout	Capacitor to Voltage 、 Resistor to Voltage、 Current to Voltage Circuit
	Amplifier	Tunable Gain Amplifier
	Analog to Digital Converter	Successive Approximation ADC、 Sigma-Delta ADC
	Wireless Communication	OOK Transmitter、 OOK Receiver
	Energy Harvesting & Power Management	Wireless Charging Circuit、 DC Boost Circuit、Low-Dropout Regulator
	Digital Interface Circuit	SPI (Serial Peripheral Interface)、 I^2C(Inter-Integrated Circuit)
	Clock Circuit	Clock Circuit (MEMS Oscillator), PLL
	Calibration	Temperature Sensing Circuit

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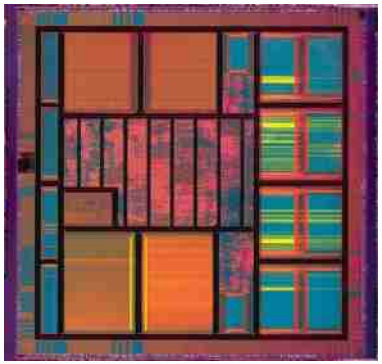
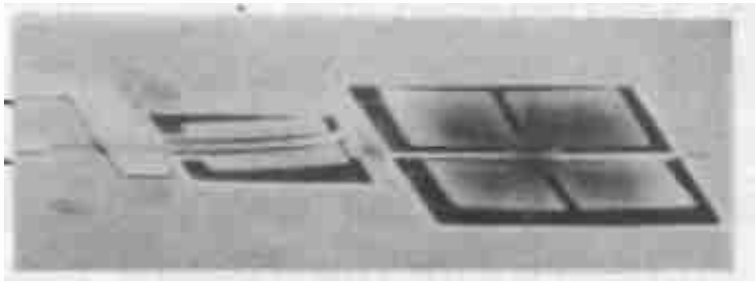
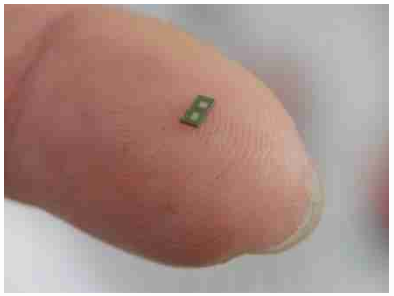
CMOS MEMS Sensor

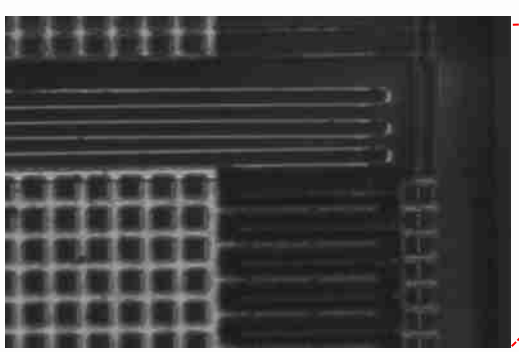


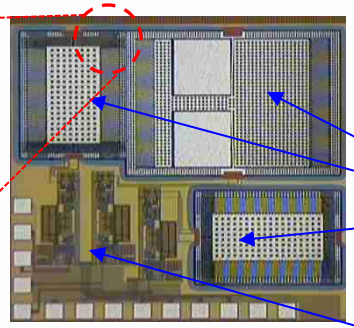
CMOS IC, from 1958



Silicon MEMS, from 1982







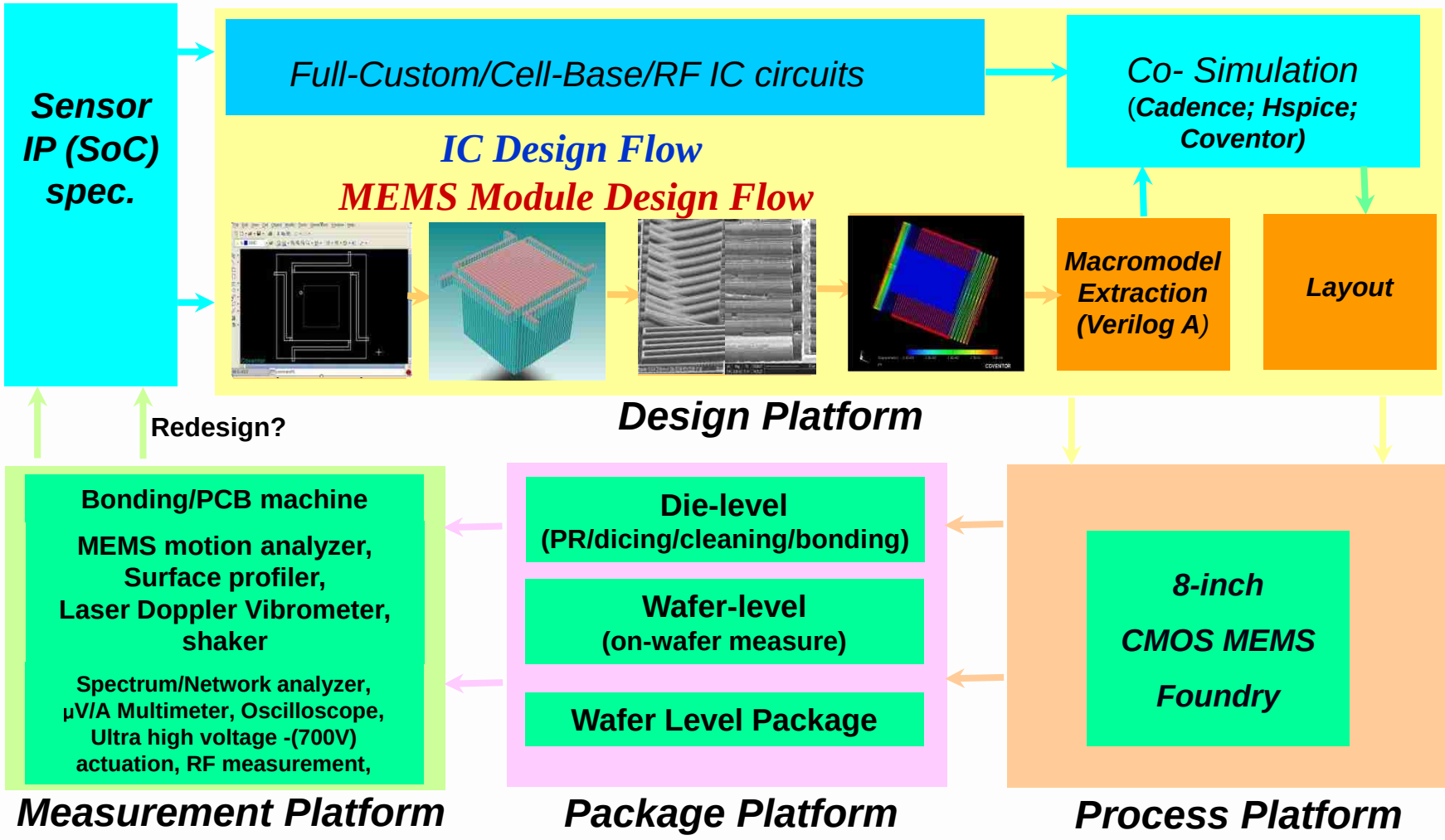
3-axis G sensor

Readout circuit

CMOS MEMS, 2000s

Source: web site, Proceedings of IEEE(1982)

CMOS MEMS Design Platform

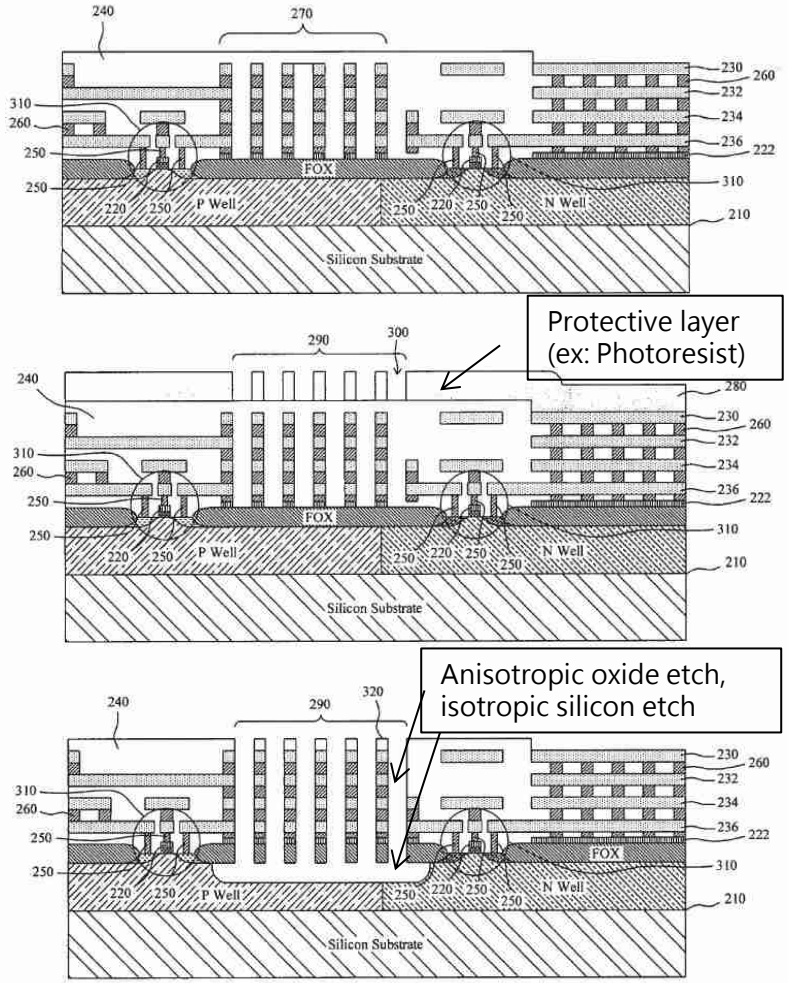


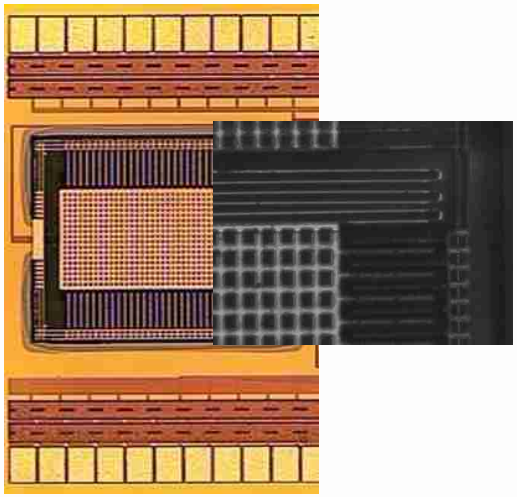
TSRI CMOS MEMS Platform

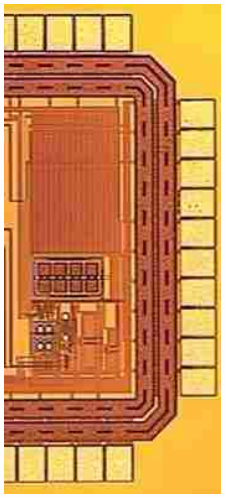
Since 2003

CMOS MEMS process (CIC) (0.35 μm)

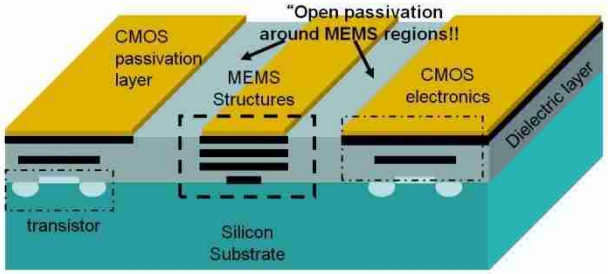
US7435612B2 (Patent), TW200633075 (Patent)



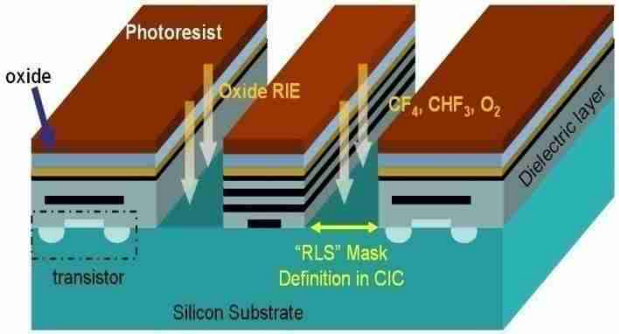




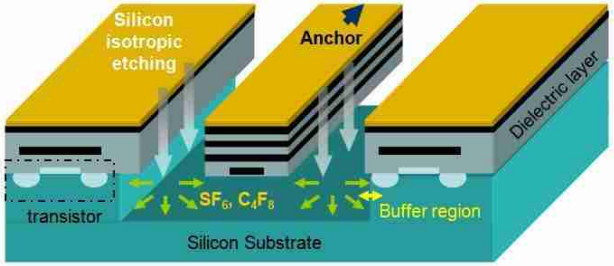
CMOS MEMS Process



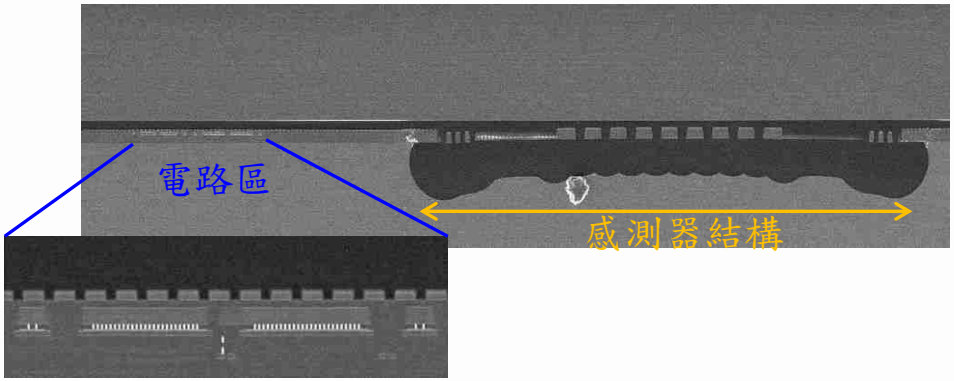
Standard CMOS wafer



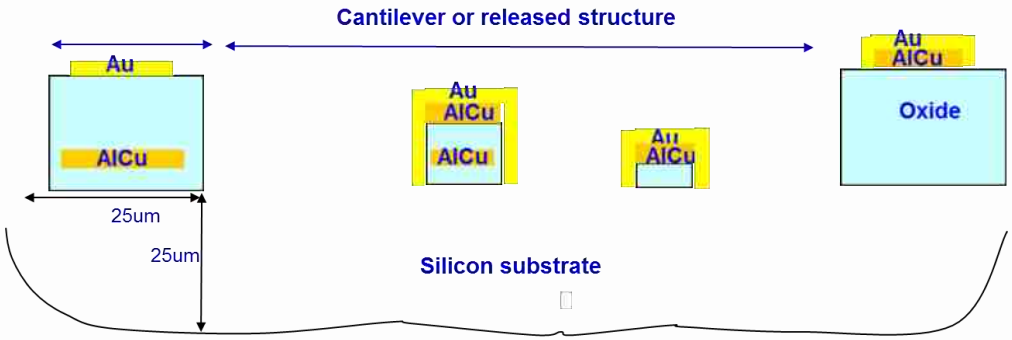
PR definition, anisotropic oxide etch



isotropic silicon etch, device releasing



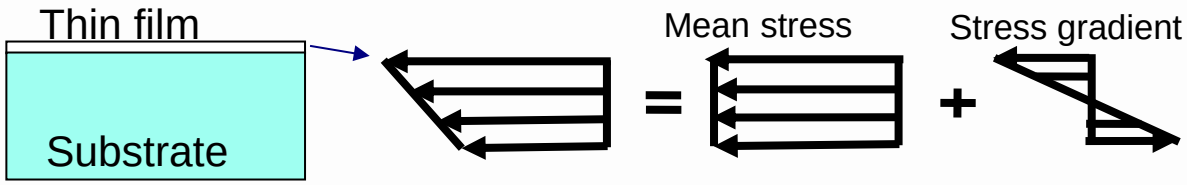
The circuit is not damage during the MEMS process

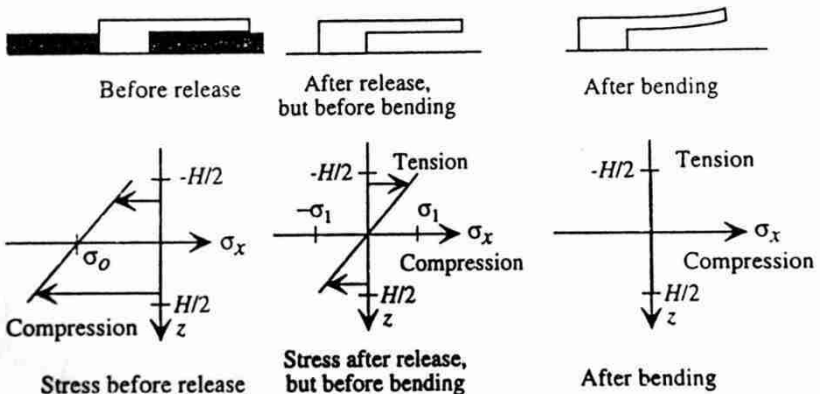


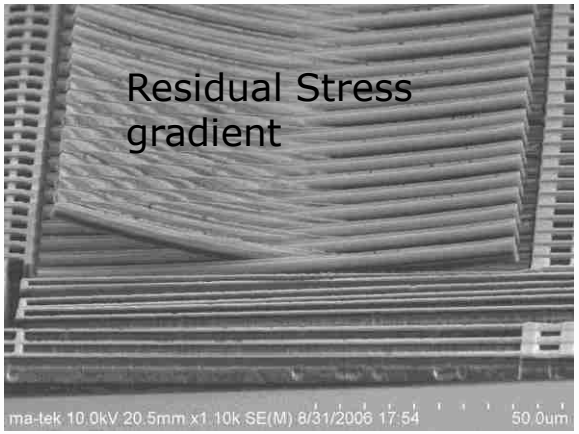
Gold and/or Platinum

The Modification for Stress/Stress Gradient

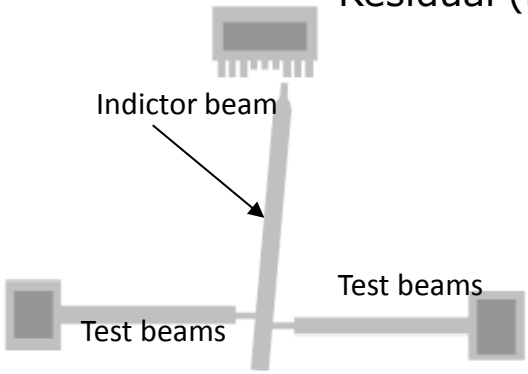
- Compression = $-\sigma_0$
- Tension = $+\sigma_0$
- Stress gradient = σ_1

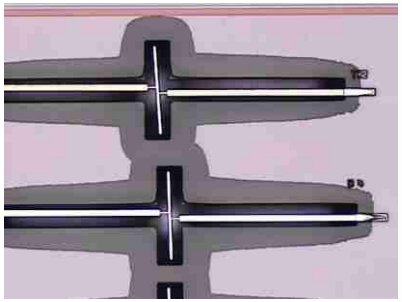






Residual (in-plane) Stress

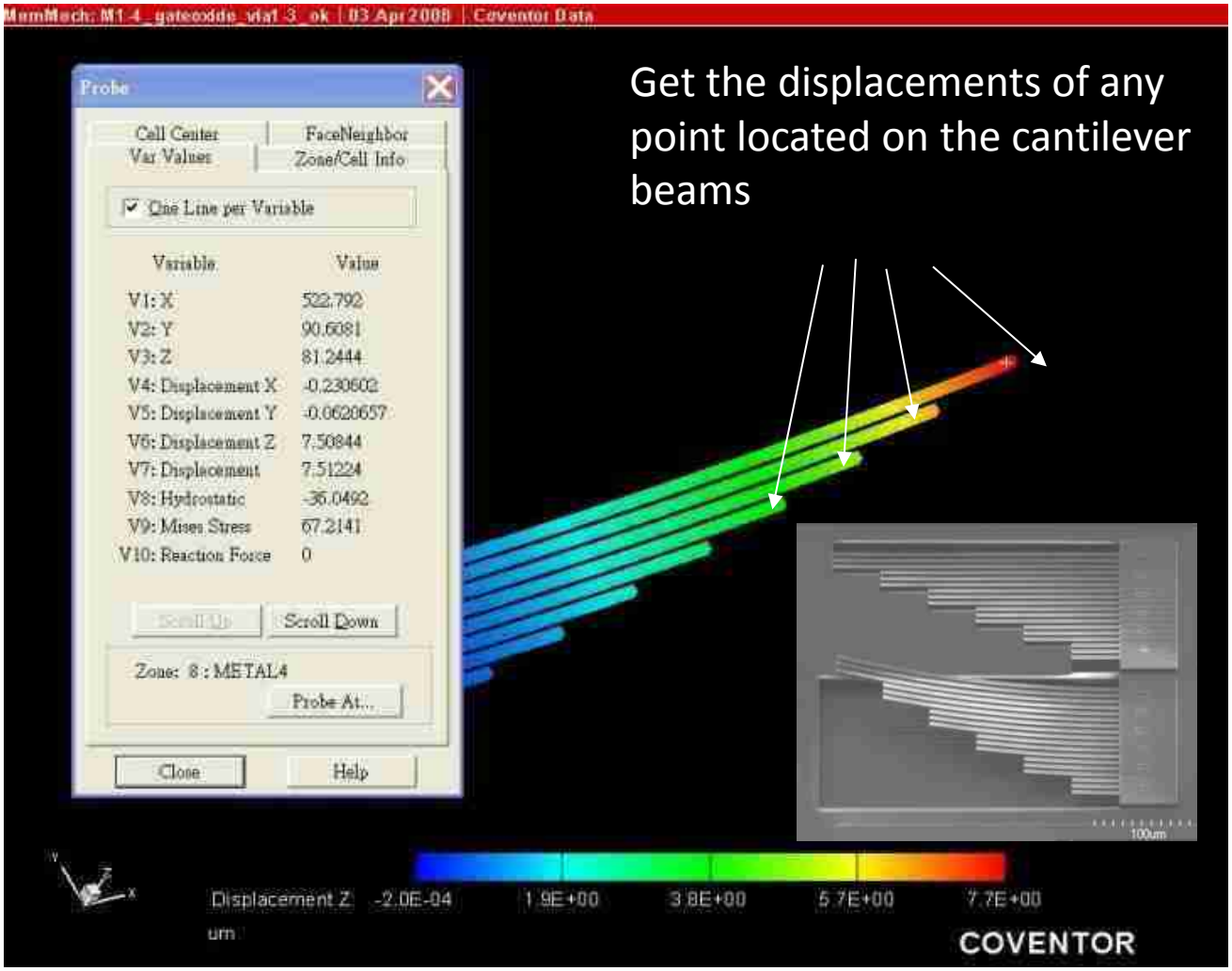


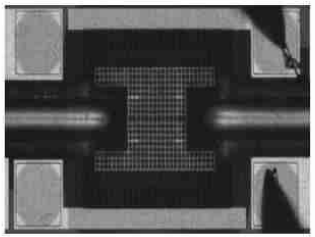


- Stress Gradient
- Stress
- Young's Modulus

For accurate simulation, and better performance in MEMS design

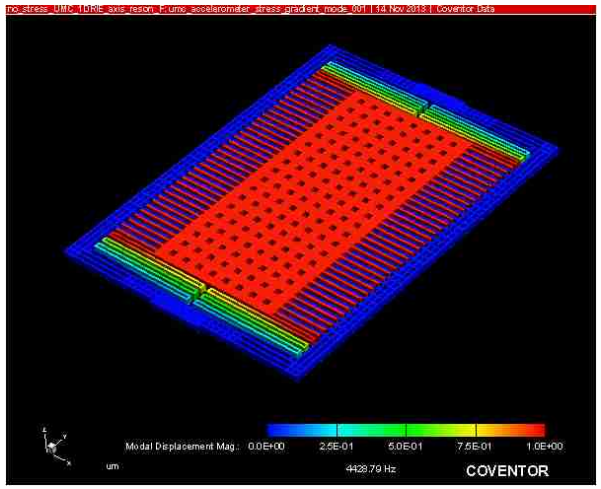
Predictable of Structural Behavior



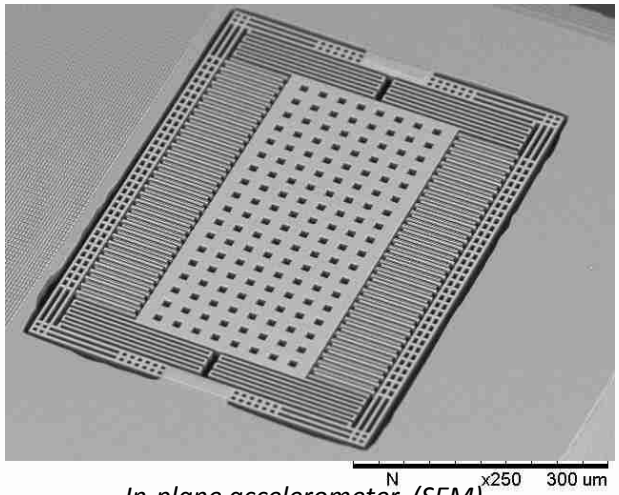


	1st mode
Simulation with default value (Coventorware)	29.7 kHz
Simulation with CIC extraction value	23.6 kHz
Measurement value	23.3 kHz

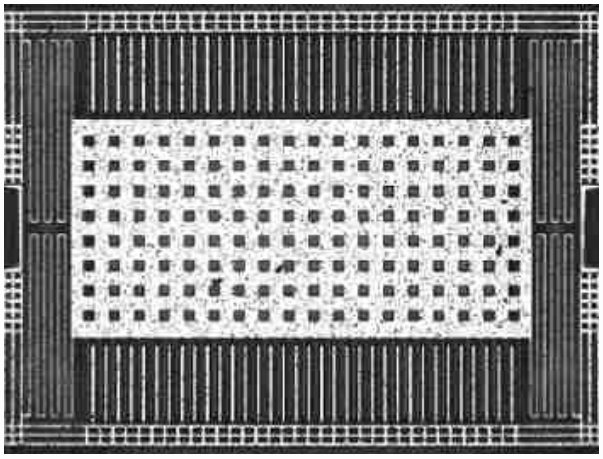
CMOS-MEMS Inertial Sensors



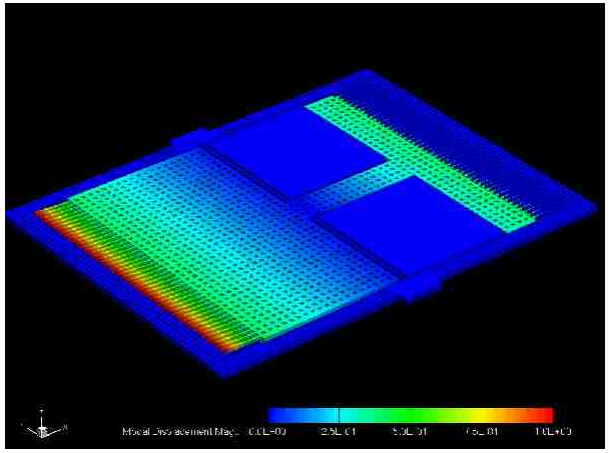
In-plane accelerometer (Simulation)



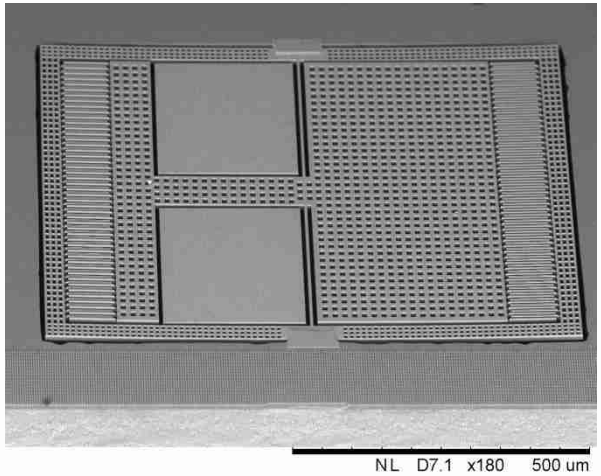
In-plane accelerometer (SEM)
(J. Micromech. and Microeng.2012, IEEE J. Sensors 2014)



In-plane vibration measurement



Out-of-plane accelerometer (Simulation)



Out-of-plane accelerometer (SEM)
(J. Microelectronic Engineering 2014)

Out-of-plane vibration measurement

Structure Considerations-Motion Sensor IP

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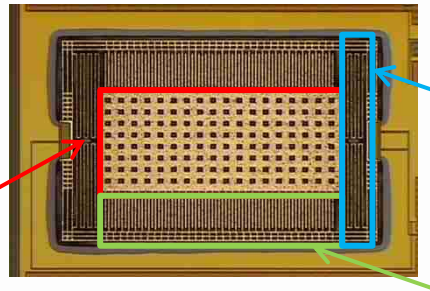
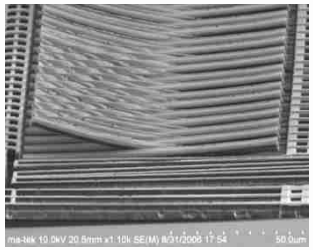
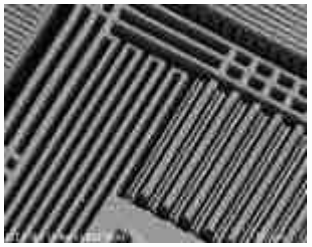
- Parts of G sensor structures : Proof mass, spring, and comb
- The choice of metal/oxide combination is important



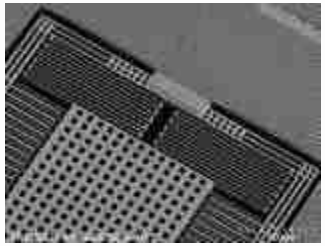
	G sensor A	G sensor B	G sensor C
Process	0.35um	0.18um	0.18um
Proof Mass	structure 1	structure 4	structure 4
Spring	structure 2	structure 5	structure 7
Comb	structure 3	structure 6	structure 6
Resonant frequency	5.9 KHz	4.7 KHz	3.2 KHz



metal/oxide組成造成comb結構翹曲很嚴重

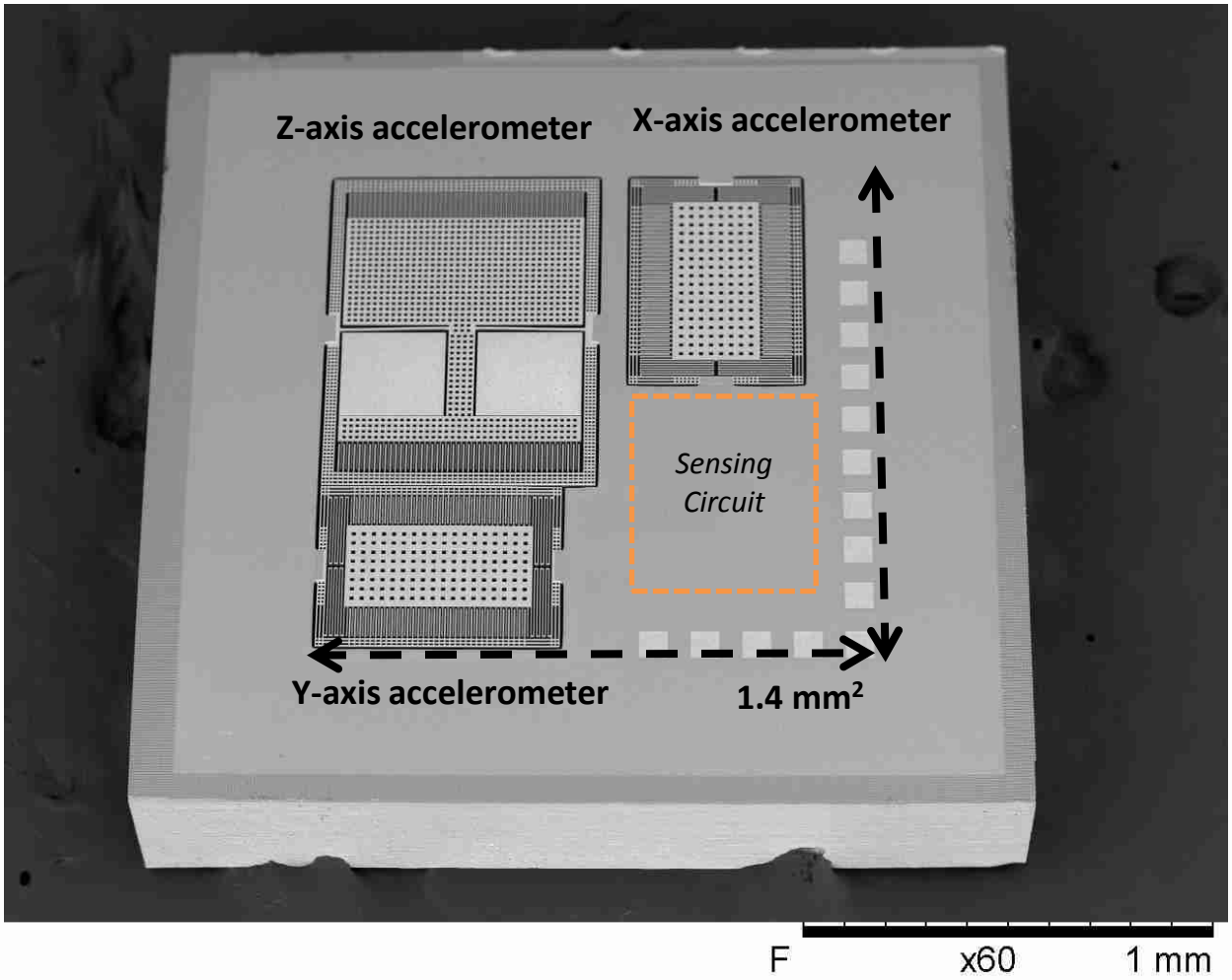


結構幾乎無翹曲，1~6G驗證成功



結構幾乎無翹曲，元件靈敏度最大，1~6G驗證成功

3-Axis CMOS MEMS Accelerometer

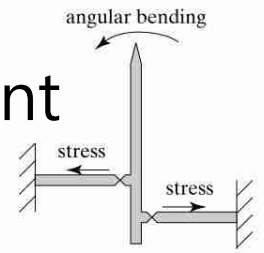


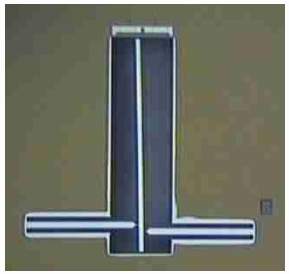
G Sensor Performance Comparison

	ST (LIS331DLH)	ADI (ADXL313)	TSRI
Process	Thick Epi-Poly+ CMOS (hybrid)	Poly silicon+ ASIC (hybrid)	0.18µm CMOS MEMS
Range	± 8	± 4	± 6
Sensitivity(mV/g)	206	300	250
Power (mW)	0.62	0.34	0.22
Cross Axis (%)	N/A	1	3
Noise floor (mG/rtHz)	0.22	0.15	0.1
Offset (mg)	20	X/Y: 50 Z: 75	< 50
FOM (uW-g/Hz^{½})	0.13	0.05	0.041

TSRI CMOS/MEMS Design Kits

- Design kits of EDA tools (Synopsys, Cadence, Mentor, Coventor)
  - Technology files (with CMOS) (Cadence, Synopsys)
  - Design Rule Check files (Calibre)
  - Design Handbook
  - Process design files for 3D model (Coventor)
  - Effective Young's module, stress, stress gradient database (sign NDA with TSRI)
  - EDA cloud environment
  - Training courses (in Taiwan)





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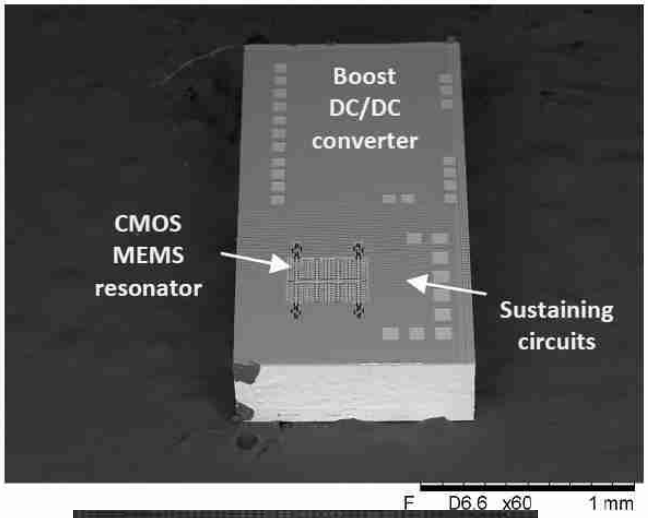
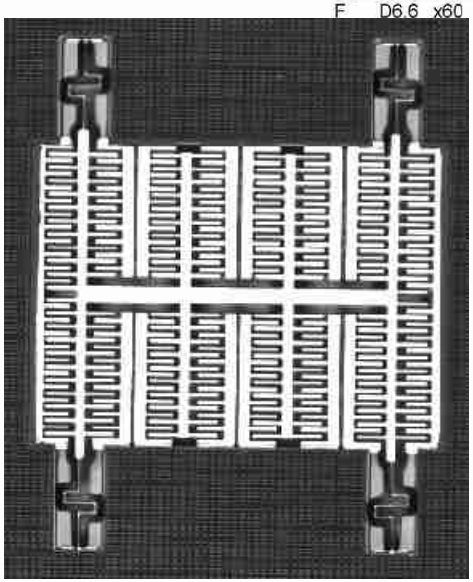
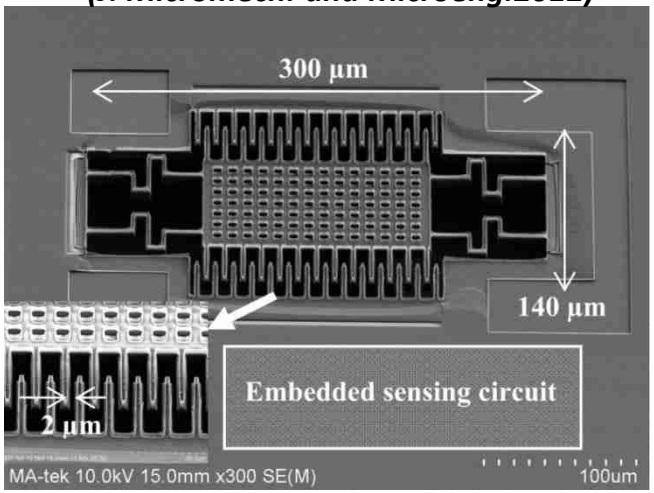
CMOS-MEMS Resonator Oscillator

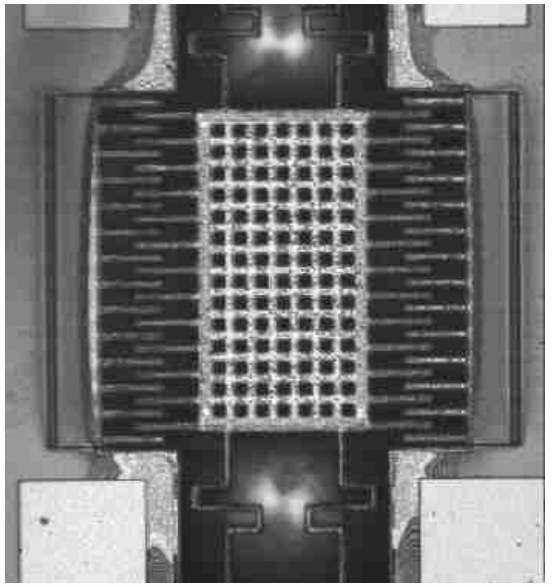
BCD MEMS resonator oscillator (IEEE Transducers 2015)



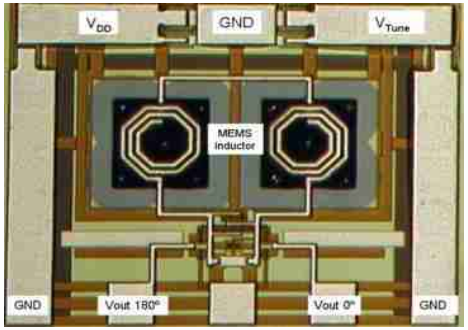


MEMS resonator oscillator with PLL circuits (J. Micromech. and Microeng.2012)



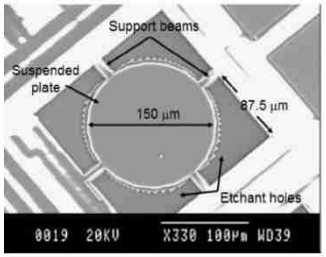


Other Verified CMOS MEMS Designs



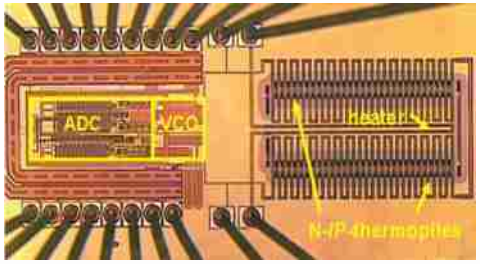
MEMS VCO

(*Sensors & Actuators, '07*)



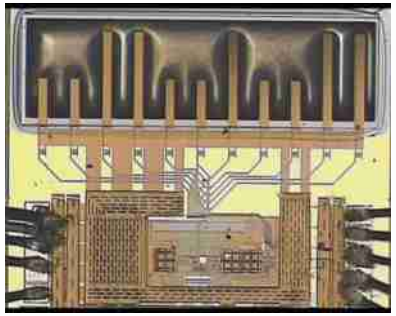
Tactile Sensor w/i ckt

(*IEEE J. Microelectromechanical* Systems '06)



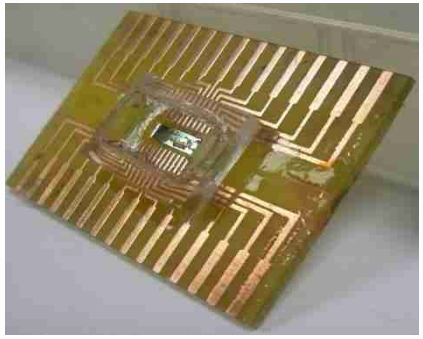
Thermal Sensor w/i ckt

(*IEEE sensor '08*)



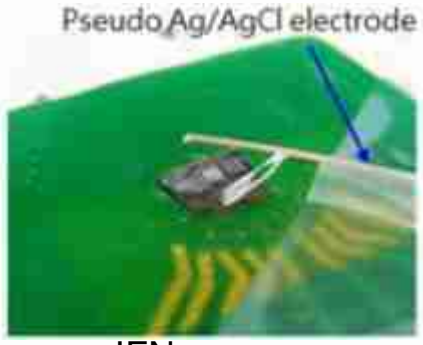
Breath/Flow sensor

(IEEE sensor Journal, 2010)



Immunoassay sensor

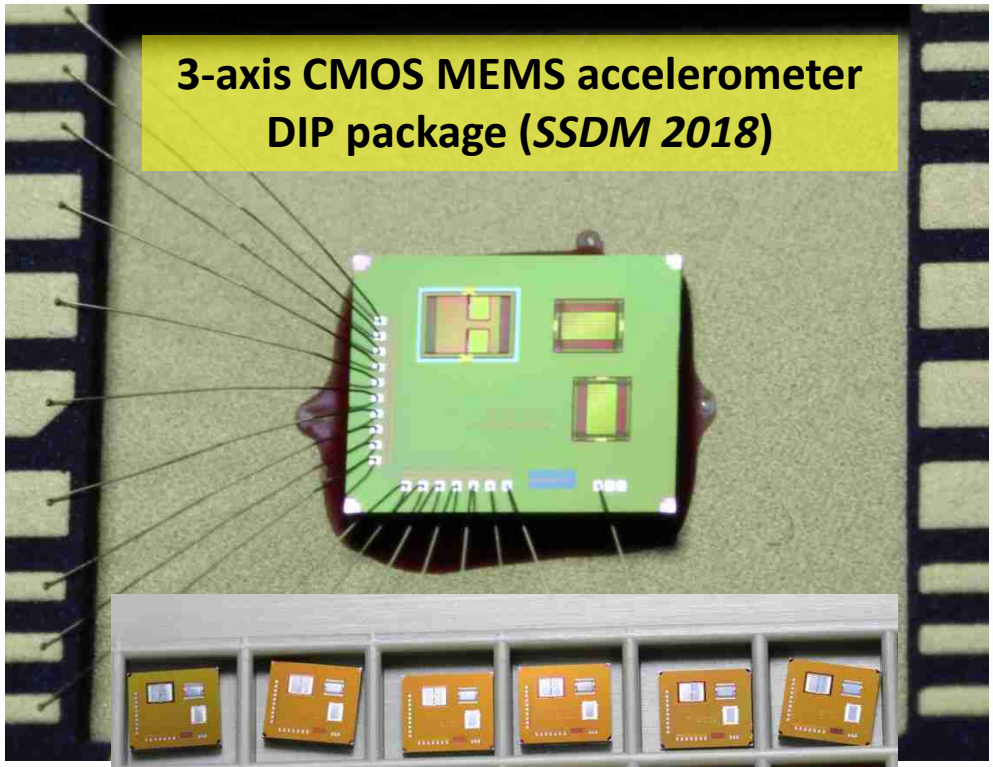
(Sensor & Actuators B, 2010)



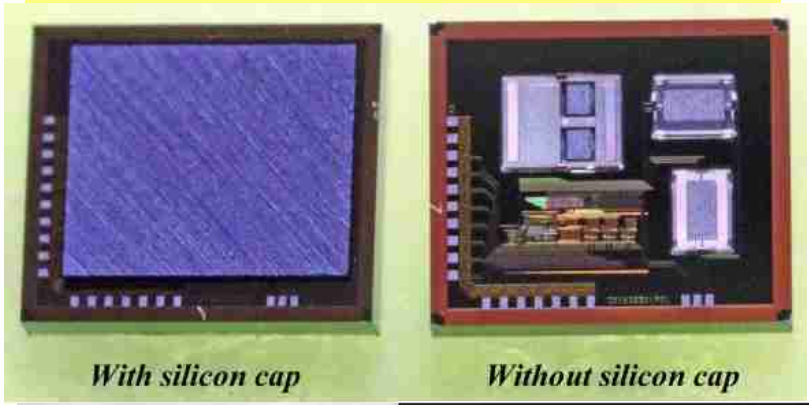
IFN-γ sensor

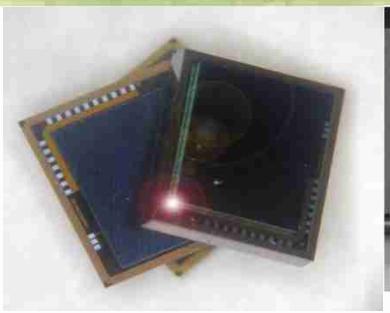
(SEMBA, 2014)

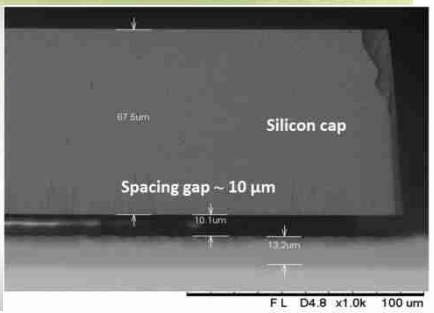
Chip Dicing, Packaging



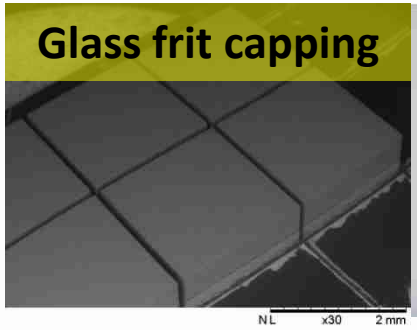
Eutectic bonding (*Eurosensors 2017*)

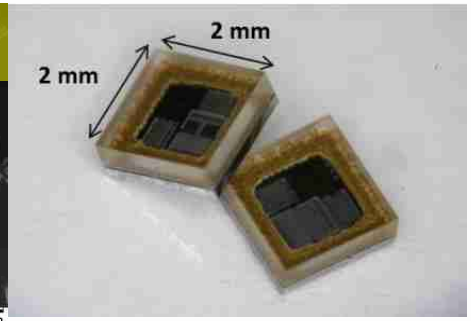






Glass frit capping





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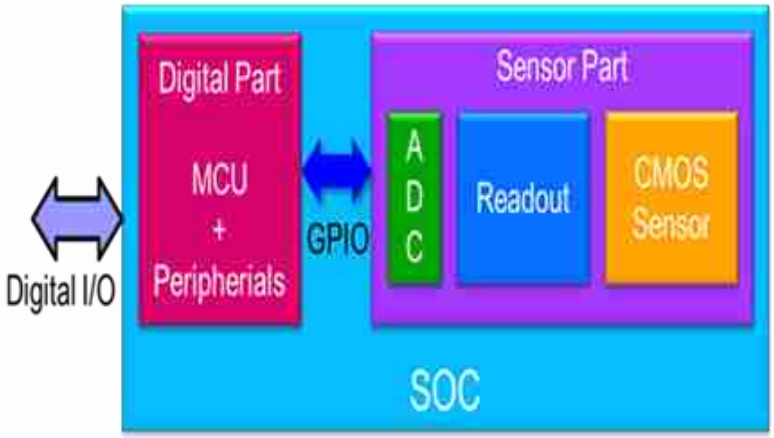
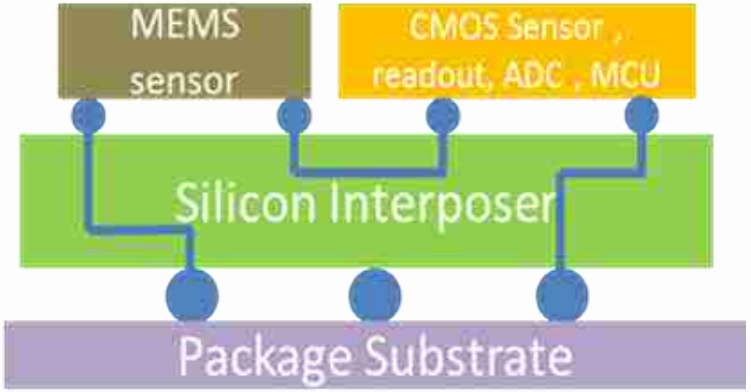
Outline

- The IP Integration Platform for Intelligent Sensing System
- CMOS MEMS Design Platform
- System Integrating Examples
- Conclusions

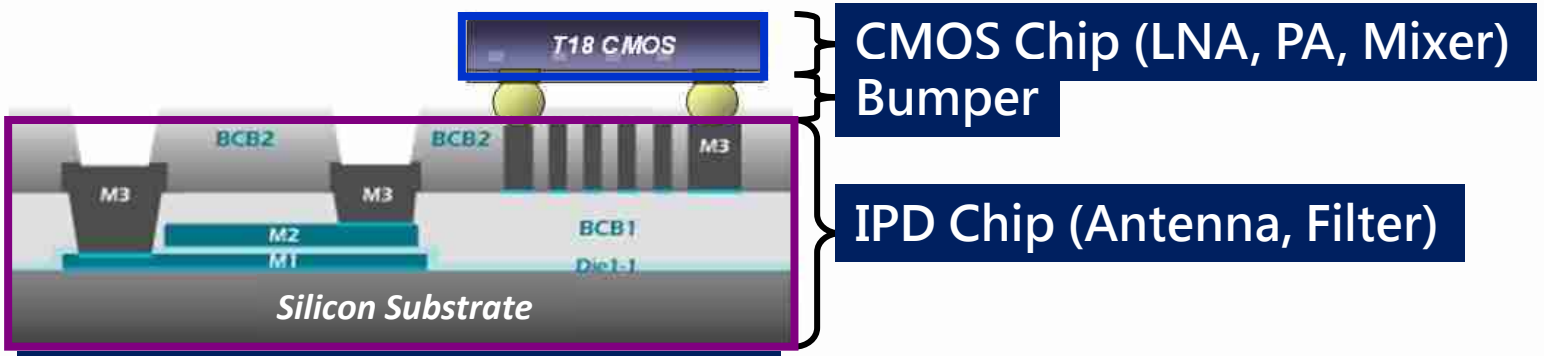
The Reference Design on TSRI Platform

- Realize a micro batteryless wireless sensing module (<2cm x 2 cm) including
  - Multi sensors
  - Analog readout, ADC, and MCU
  - Energy harvest circuit
  - Antenna (the largest element)





CMOS-IPD Integrated Service



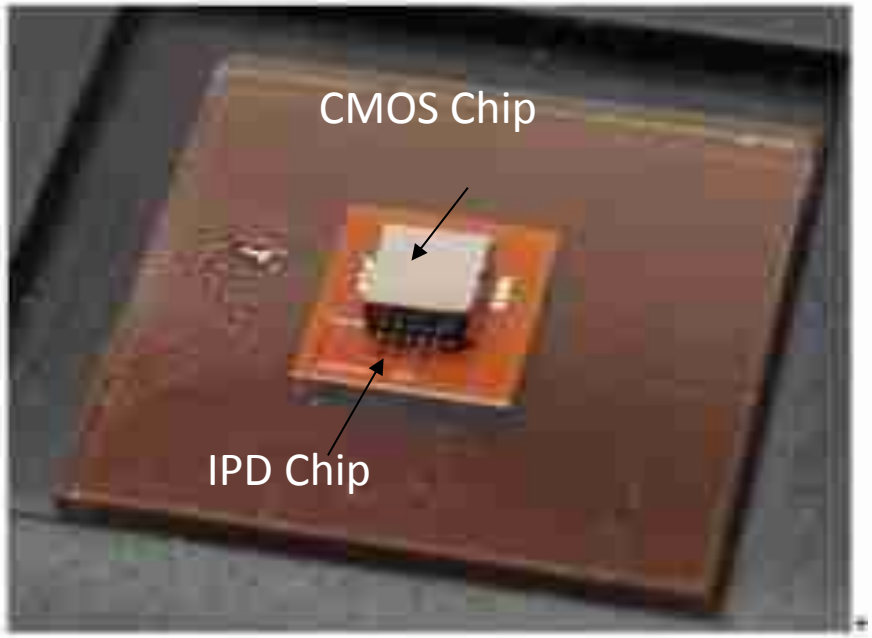
CMOS Chip (LNA, PA, Mixer)

Bumper

IPD Chip (Antenna, Filter)

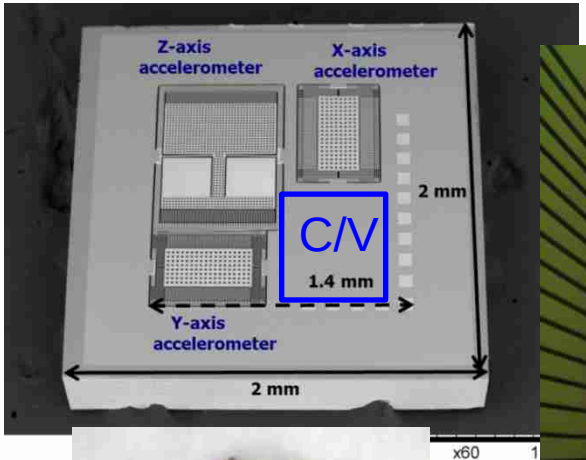
Integrated Passive Device (IPD)

- Integrated Passive Device (IPD) includes integrated resistor, capacitor, and thick-metal-layer.
- Flip Chip package and solder bump are used to integrated CMOS and IPD Chips

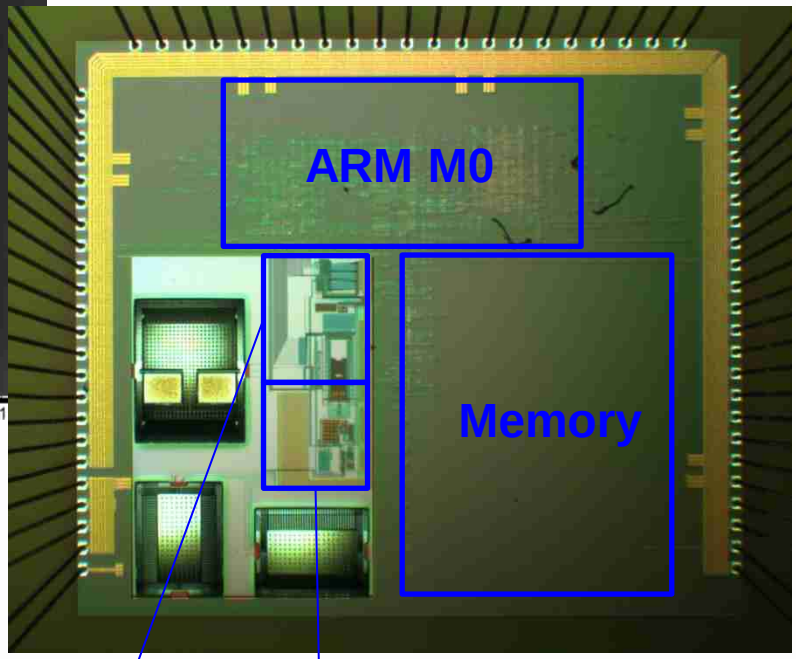


Sensor & Actuator SoC

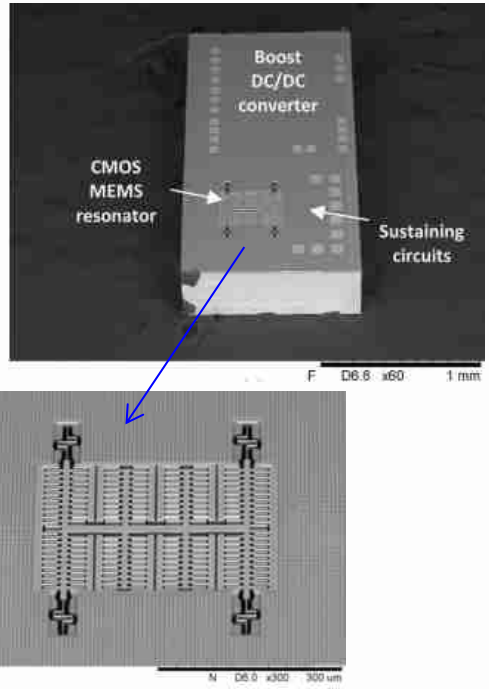
- **Integrations of**
  - **3-axis accelerometer, C/V readout, ADC, and MCU**
  - **resonator and high-voltage driver**



3-axis accelerometer with silicon cap

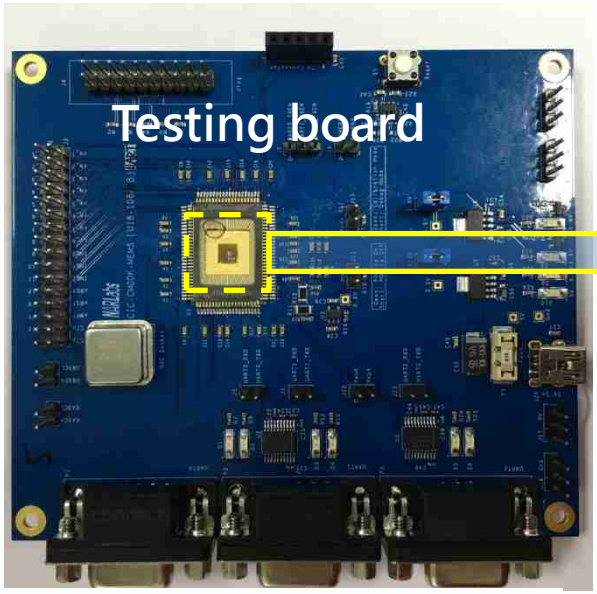


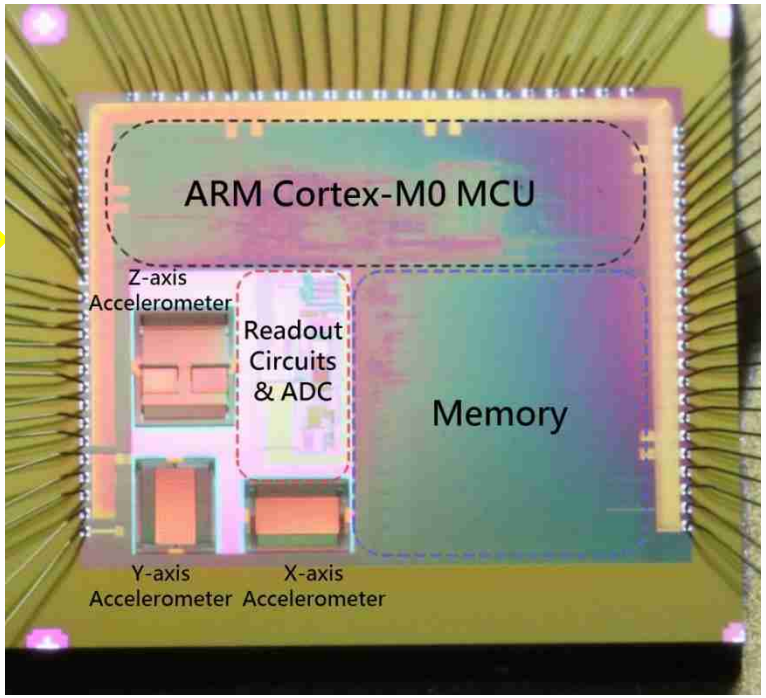
SAR ADC C/V

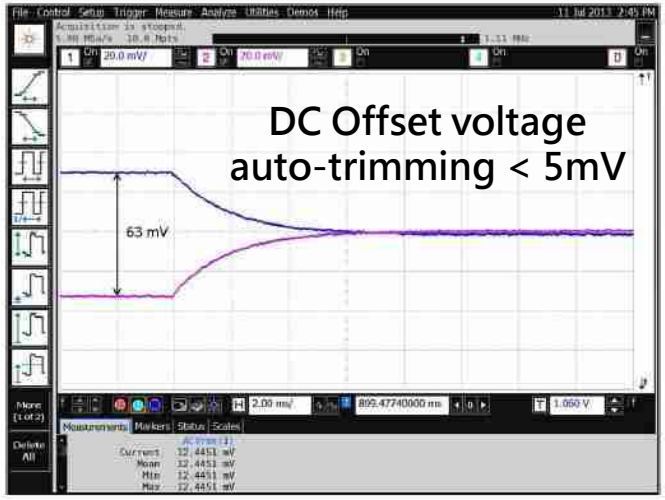


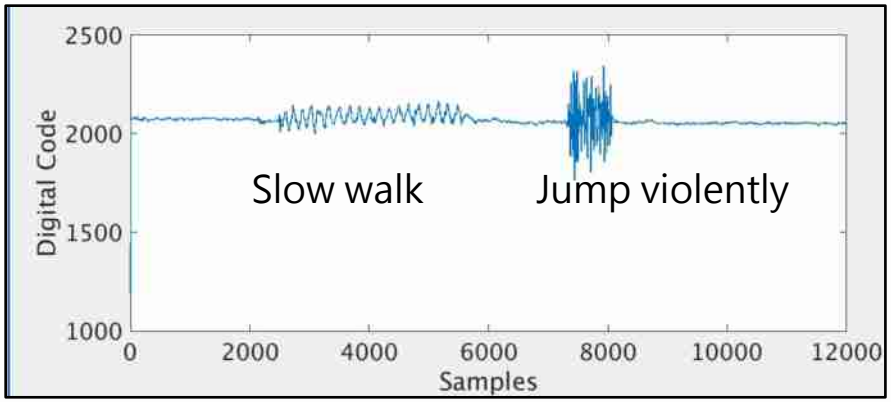
32.76 KHz resonator with boost DC/DC converter

CMOS MEMS Sensors with Integrated MCU



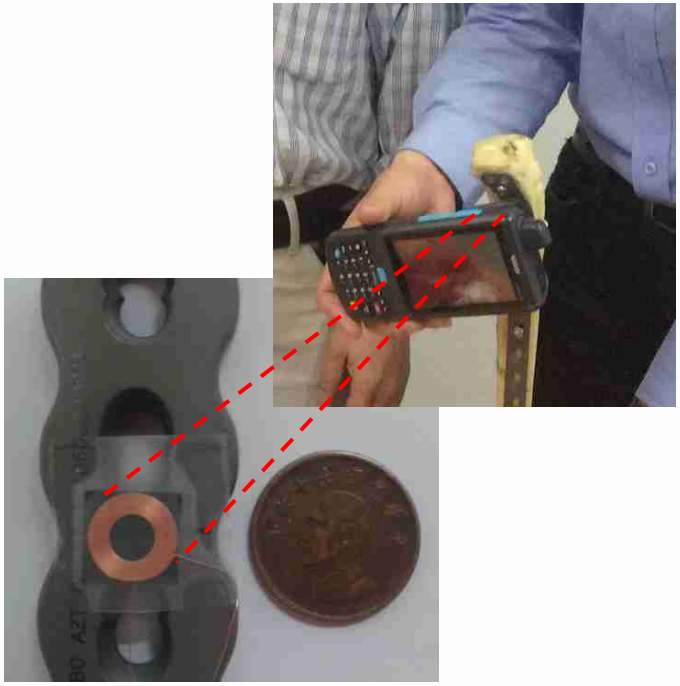




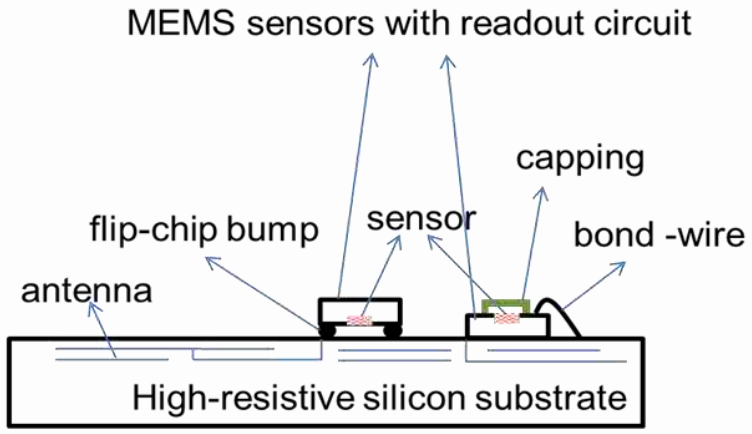


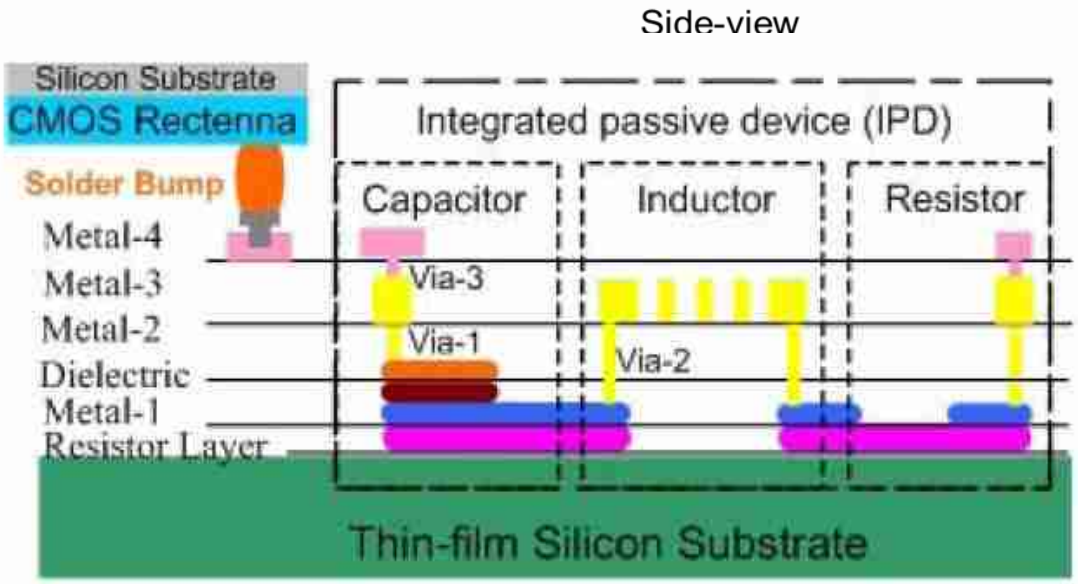
Multi-Sensors Module Using IPD

- **Antenna : core → IPD**
- **Rectifier and antenna integration**



Bone Plate

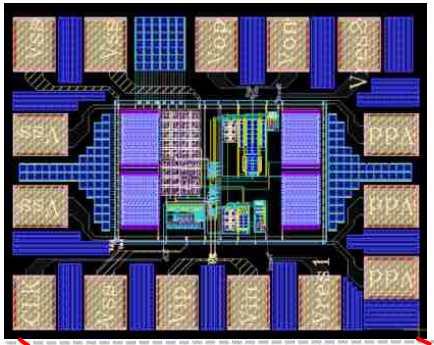


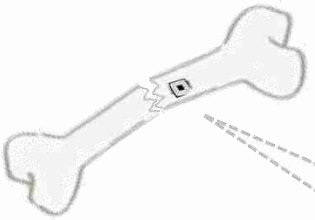


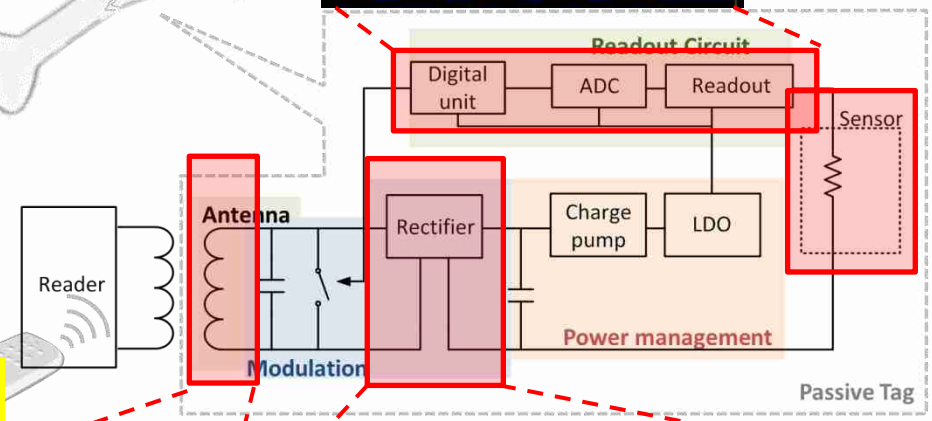
The Batteryless Stress Sensing Module

Readout circuit

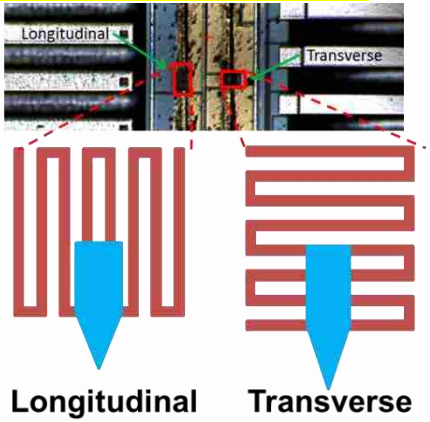
- 讀取電路將感測器形變信號轉換成電壓信號
- 創新之多感測器通用電路架構具有專利與學術價值
- 低功耗電路設計可降低線圈感應之尺寸







CMOS stress sensor

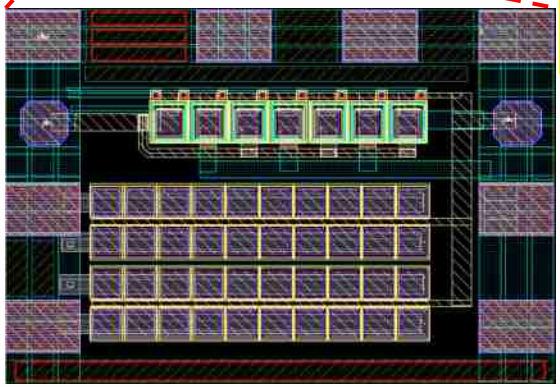


-已完成可與IC晶片結合之壓阻式Shear型應變感測器初步驗證，在50mN的力下，產生約0.2%-0.5%變化率

Power picking coil

- 1x1cm^{2}線圈可輸出>2V電壓供電路使用
- 亦將嘗試利用新穎之IPD (整合被動元件)技術來將感應線圈與晶片整合

1x1cm^2

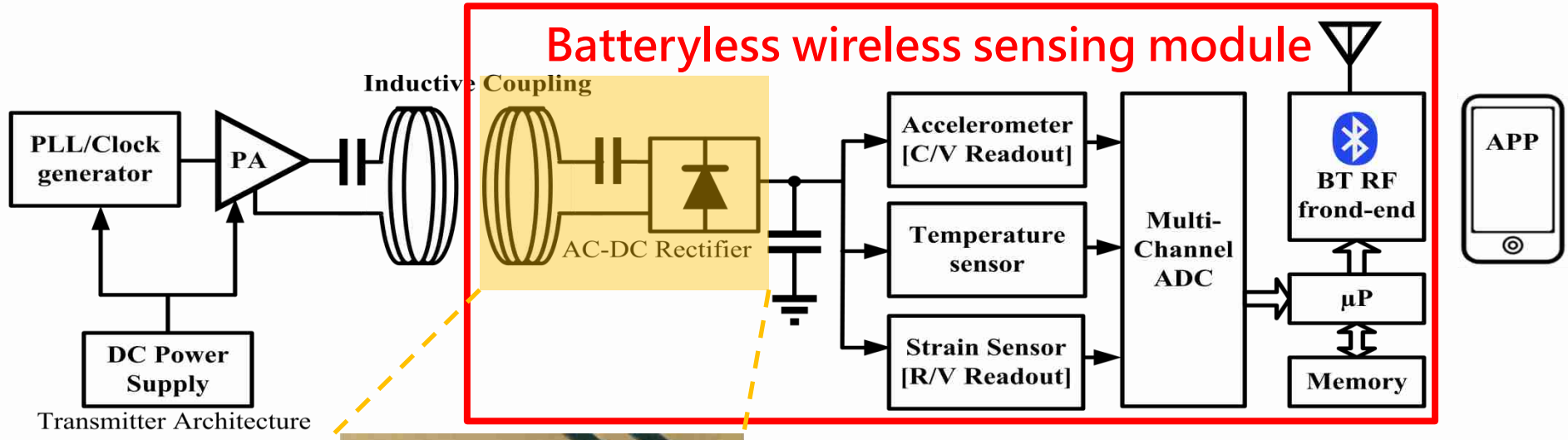


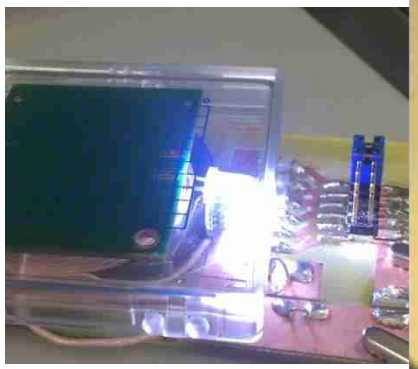
Rectifier IP

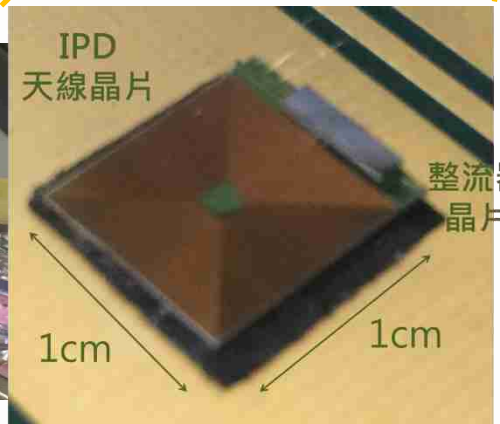
- 整流電路將線圈感應之交流信號轉換成電源供應
- 單晶片設計可提升轉換效率與降低封裝面積
- 高轉換效率可降低線圈感應之尺寸

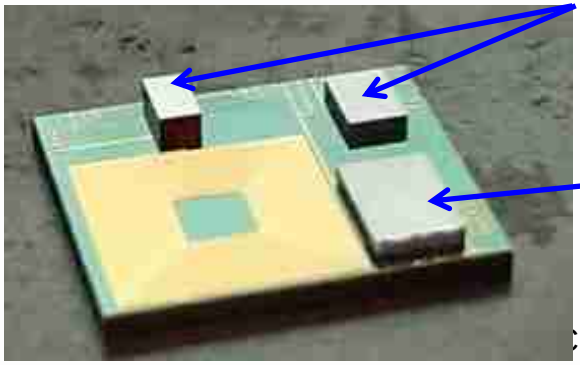
Multi-Sensors Integration Using IPD

- Rectifier、micro antenna、energy harvest included
- Embedded multi-sensing chips on IPD ~ 0.9x1 cm^2

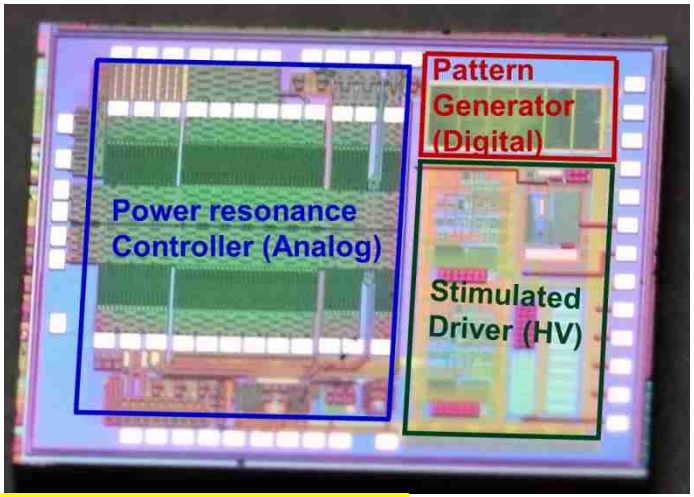




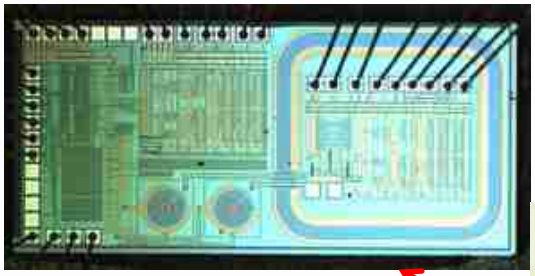




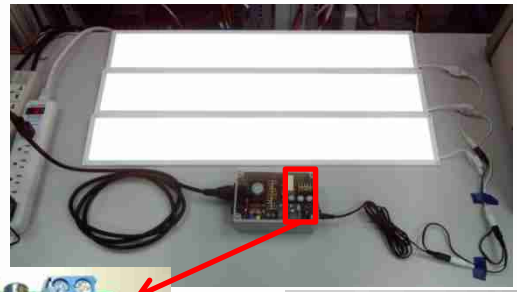
High-voltage/Mixed-signal SoC

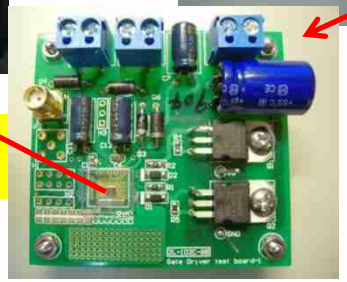


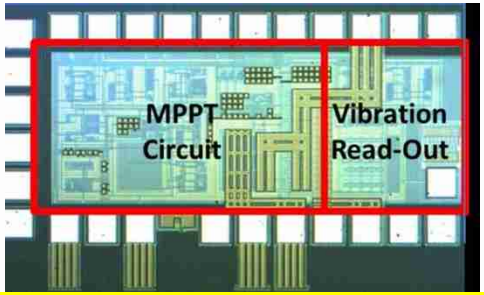
Spinal Cord Stimulator (SCS)



UVH Gate Driver IC



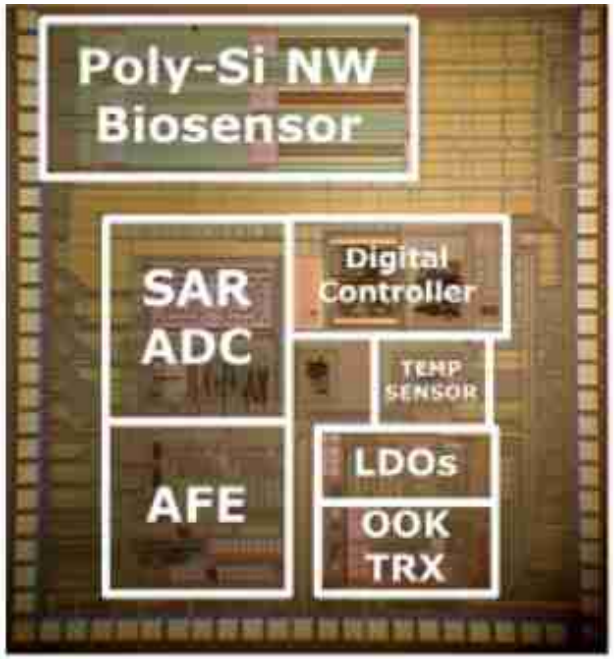




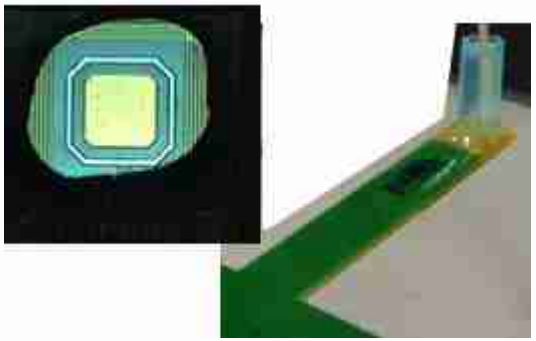
Charger
(1 mA ~ 100 mA input)

Biomedical Sensor SoC

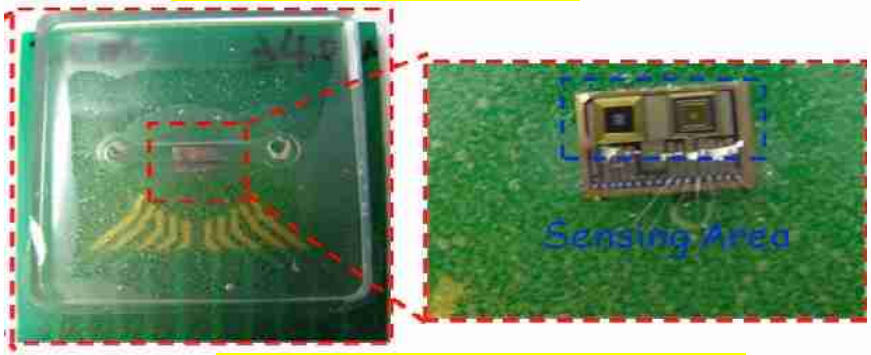
- **Integration of biosensor, temperature sensor readout circuit, ADC, and Tx/Rx**
- **Isolation and microfluidics integration**



Poly nanowire sensor SoC for HBV (Hepatitis B virus) DNA detection (collaborated with NTU)



Isolation by epoxy



Microfluidics integration

Conclusions

- TSRI provides service of UMC 0.18um CMOS MEMS and 0.35um multi-option MEMS process
- The environmental, biomedical, and motion sensors are realized by TSRI CMOS MEMS technology
- The wireless sensing system with multi sensors has been verified in our platform
- The Common Platform for Intelligent Sensing System is the future focus and will be powerful for AIoT

Thanks for your attention!

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Welcome to TSRI