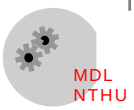
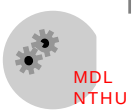
微機電系統簡介

方維倫 講座教授
國立清華大學 動機系/奈微所

fang@pme.nthu.edu.tw
http://mdl.pme.nthu.edu.tw



前言



About MEMS

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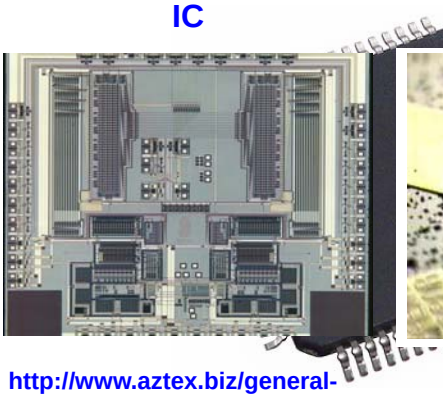
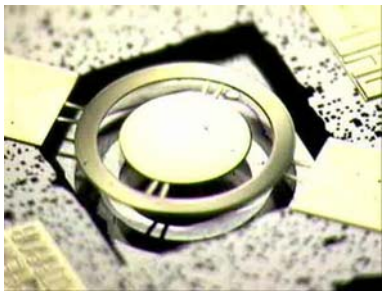
What's MEMS

IC



MEMS



http://www.aztex.biz/general-computer/integrated-circuit-work/

Texas Instruments Inc.

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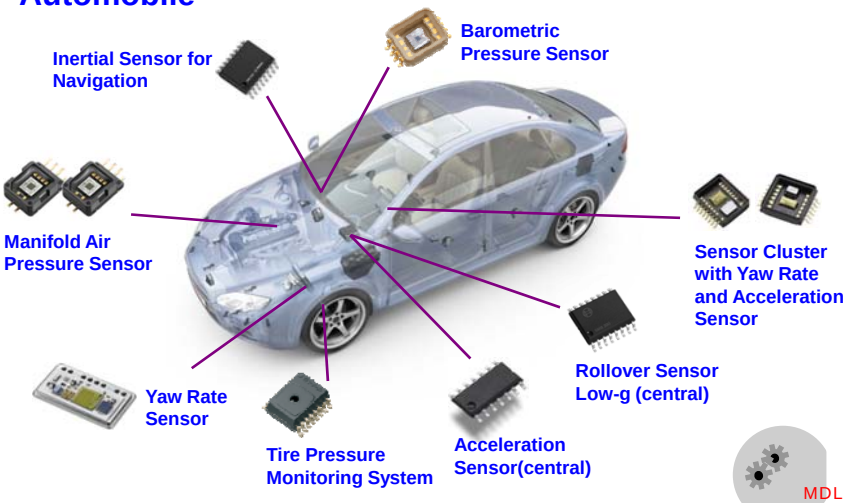
Where's MEMS

- **Automobile**

© Robert Bosch



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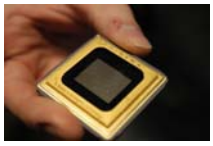
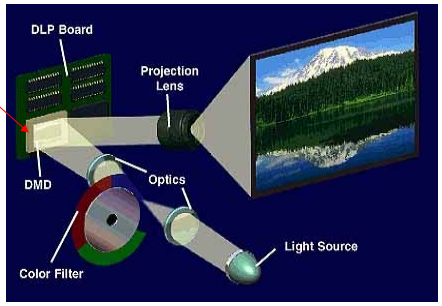
Where's MEMS

- Before 2000 – inkjet printer, projector





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Where's MEMS

- 2006~2013 – consumer electronics

Wii

Smart phone

Wearable

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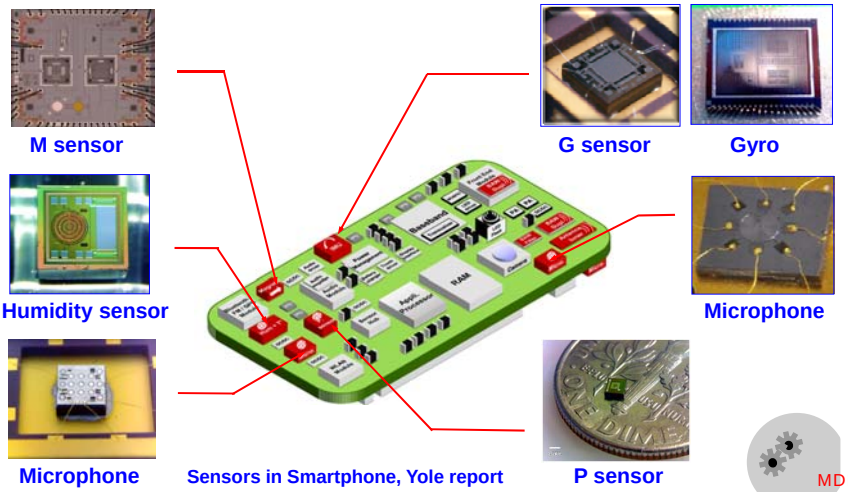
Where's MEMS

- MEMS Devices in volume in 2013 (from Yole)



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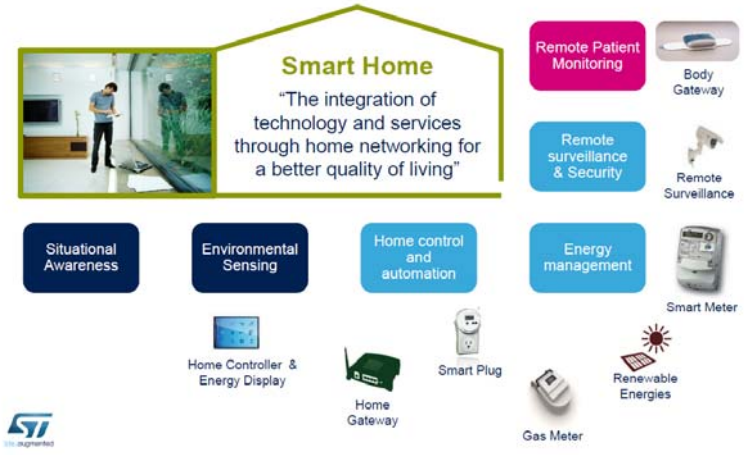
Where's MEMS

- Internet of Things (IoT)



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Corning - A Day Made of Glass

http://www.corning.com/index.aspx

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Corning - A Day Made of Glass

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Parrot - Drone

http://www.parrot.com/

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Parrot - Drone

http://www.parrot.com/

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Adidas – Smart Ball

http://micoach.adidas.com/

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Adidas - Smart Ball

http://micoach.adidas.com/

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Bragi – Smart Earphone

http://www.bragi.com/

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Bragi – Smart Earphone

http://www.bragi.com/

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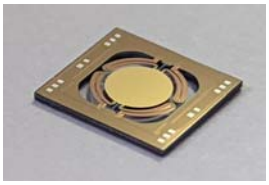
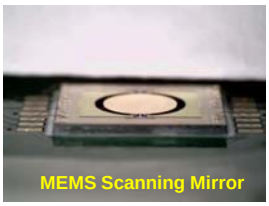
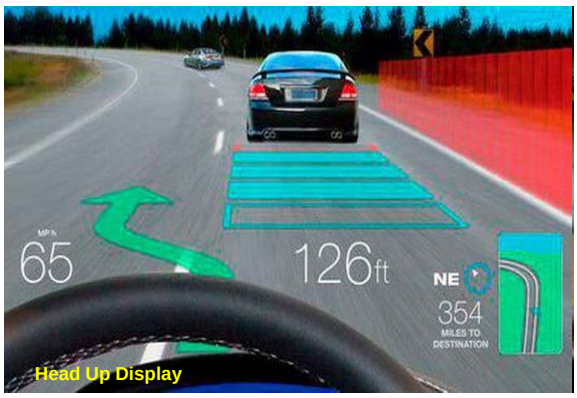
MEMS Scanning Mirror

- AR HUD, also for AR Glasses of Metaverse







Cheng, Liu and Fang, 2022

https://reurl.cc/EzozDv

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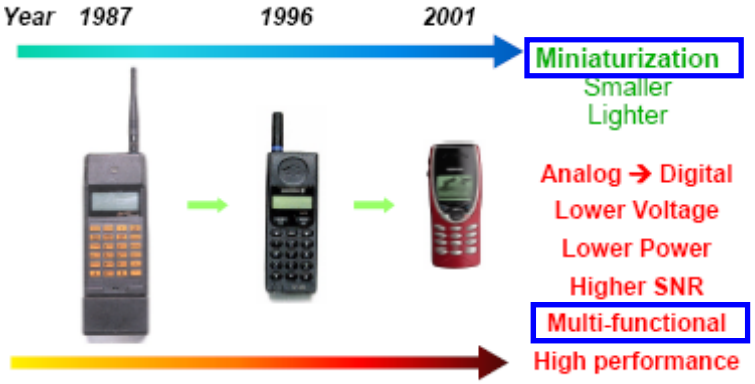
Why MEMS

- Small and Smart



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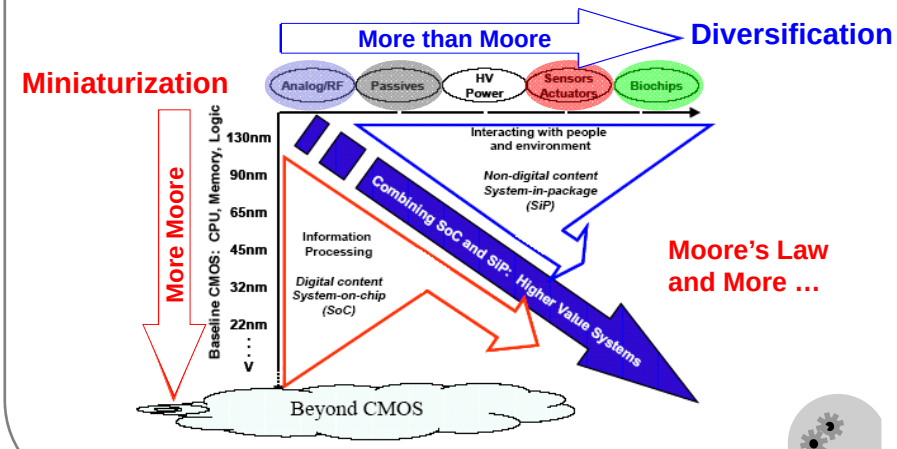
Why MEMS

- Small and Smart
- Add value to the existing CMOS tech



Source: ITRS Roadmap 2005, www.itrs.net

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平面加工技術

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Planar Technologies

- IC : TSMC, UMC, Vanguard, ...
- LED/VCSEL/Diode laser : Liteon, Epistar,…
- TFT-LCD : AUO, Chimei-Innolux, ...
- Magnetic recording head : Seagate, WD, ...
- MEMS : TSMC, UMC, APM, ...

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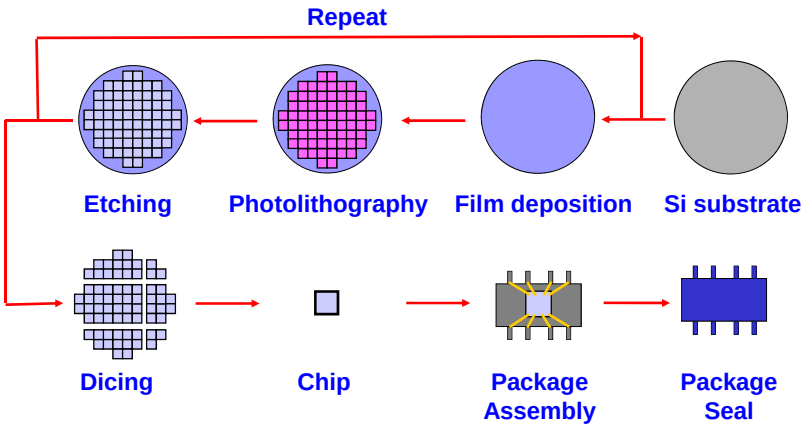
Semiconductor processes



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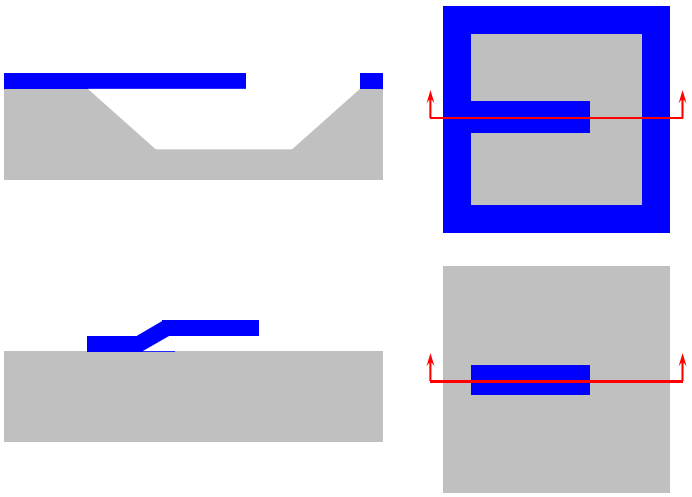
Suspended MEMS Structures



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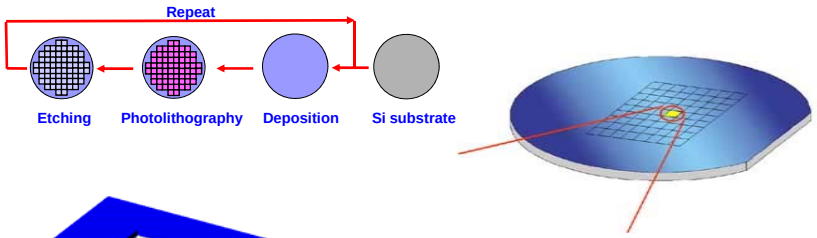
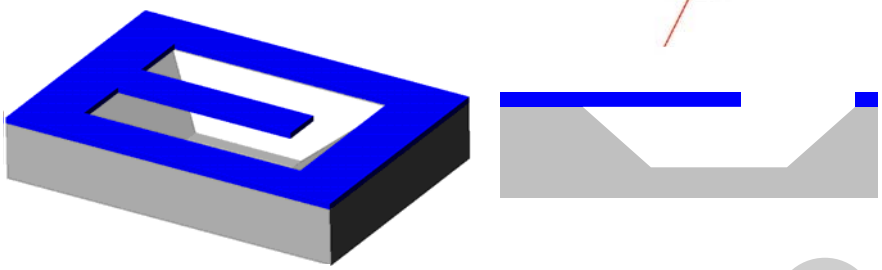
Bulk Micromachining





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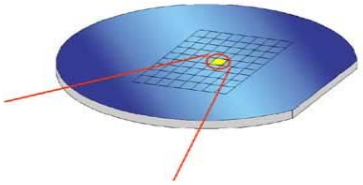
Thin film deposition

Photolithography

Thin film etching

Bulk Si etching



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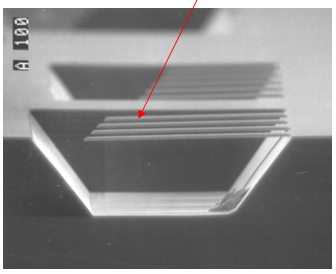
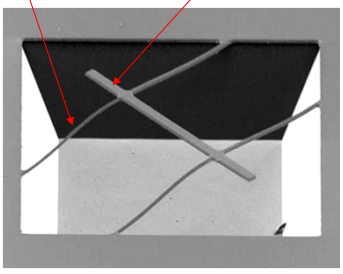
- **Bulk Micromachined Beams**



W. Fang, 1994



Yu and Fang, *JMM*, 2005

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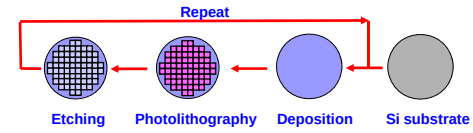
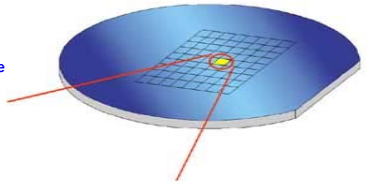
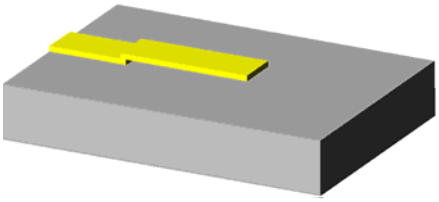
Surface Micromachining







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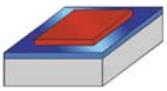
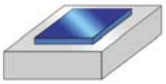
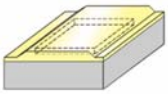
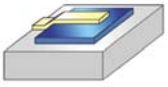
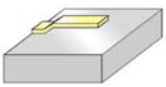
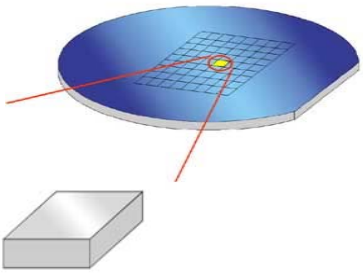




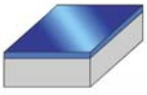








1st film deposition



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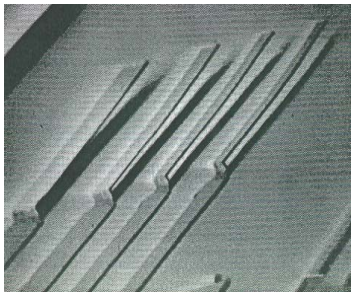
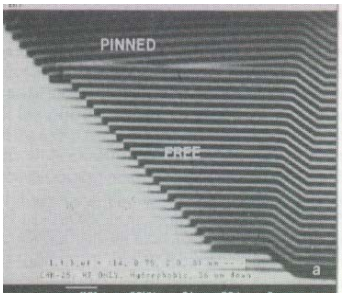
- **Surface Micromachined Beams**



Howe and Muller, 1983



Mastrangelo and Hsu, 1993

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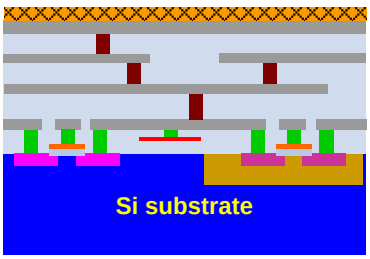
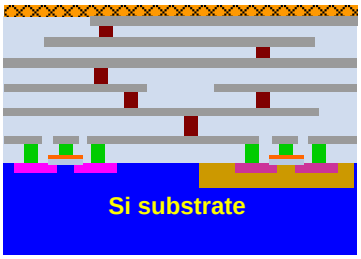
Semiconductor Devices

- **Examples: by CMOS processes at TSMC, UMC, etc…**

0.35μm 2P4M CMOS process



0.18μm 1P6M CMOS process



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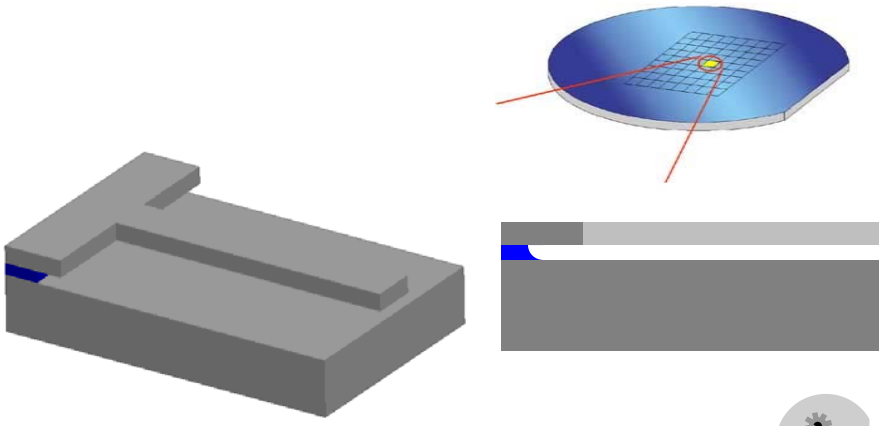
SOI Micromachining



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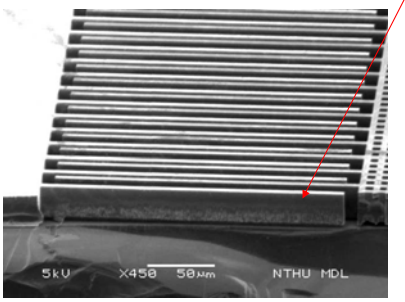
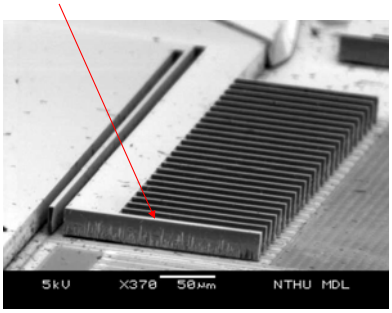
• SOI Micromachined Beams

30μm thick beam





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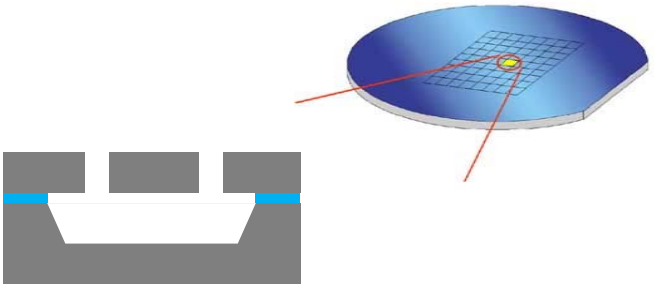
Cavity SOI Micromachining



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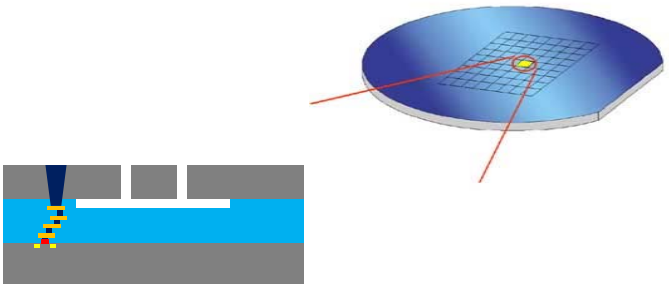
CMOS SOI Micromachining



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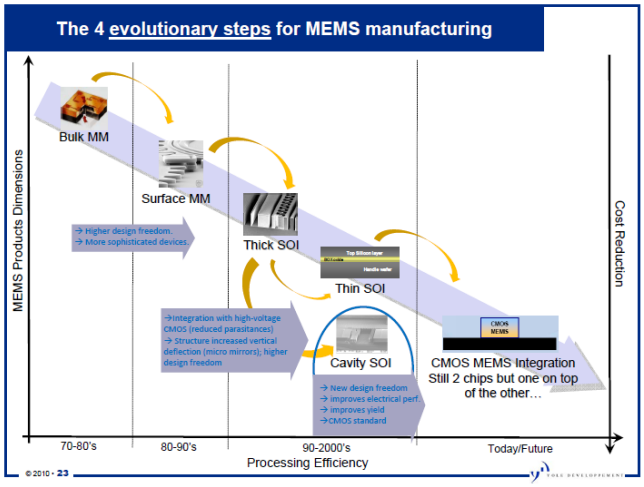

Yole's report, 2010

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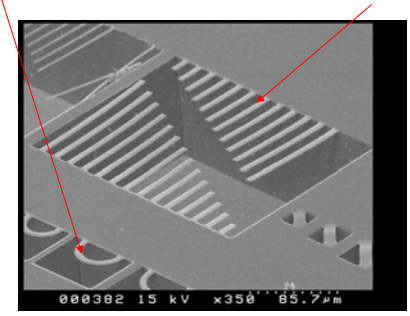
Passive component

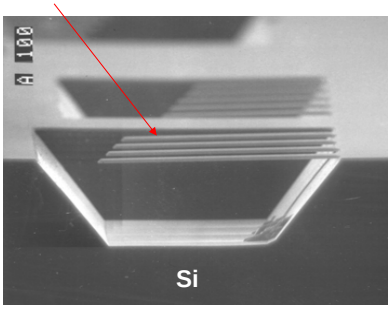
- Cantilever, suspension - springs

Semi-circular suspension

Cantilever



T. Tzou and W. Fang, 1999



W. Fang, 1994

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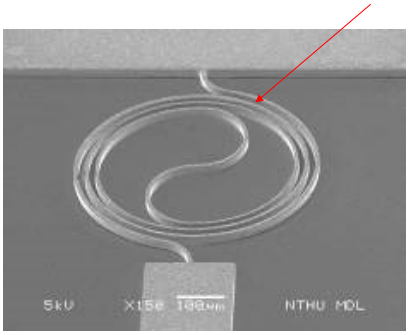
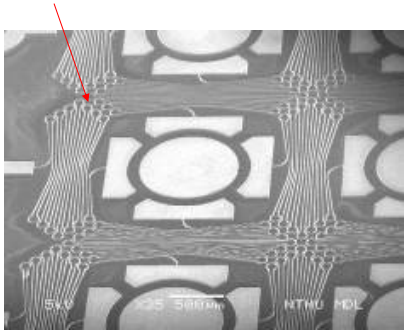
Passive component

- Curved beam - spring

Curved beam





W.-L. Sung and W. Fang, 2014

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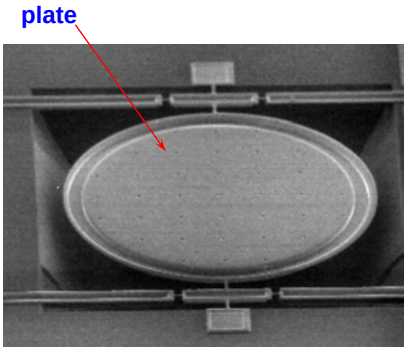
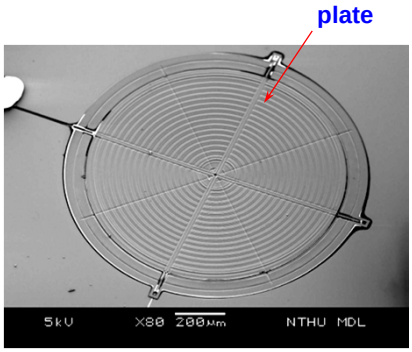
Passive component

- Plate – rigid mirror, flexible diaphragm (microphone)



H.-Y. Lin and W. Fang, 2000



C.-K. Chan and W. Fang, 2011

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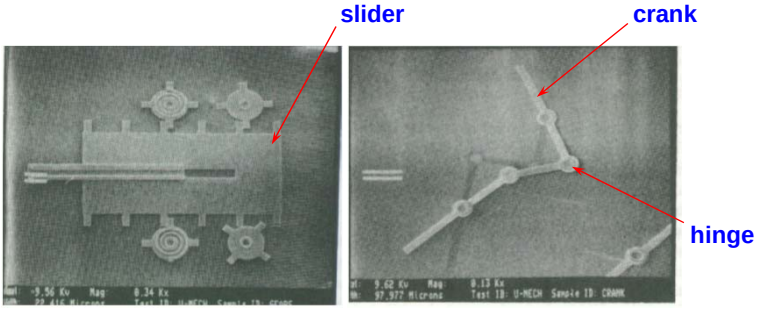
Passive component

- Slider, hinge, cranks



L.-S. Fan, et. al., IEEE Transaction on ED, 1988

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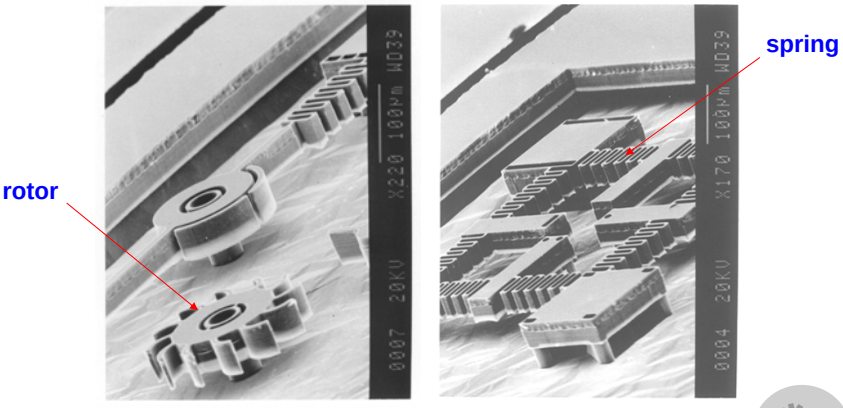
Passive component

- Gear, rotor, linkage



J. Hsieh and W. Fang, 2000

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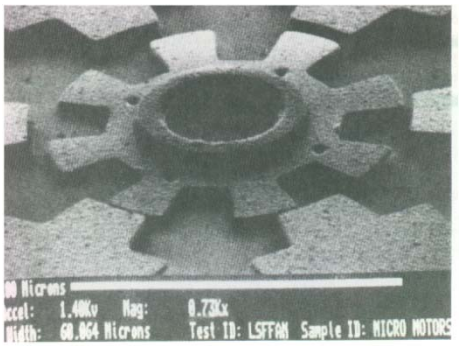
Active component

- Angular electrostatic actuator - motor



L.-S. Fan, et.al., Int. Electron Devices meeting, 1988

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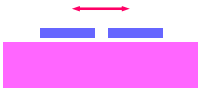
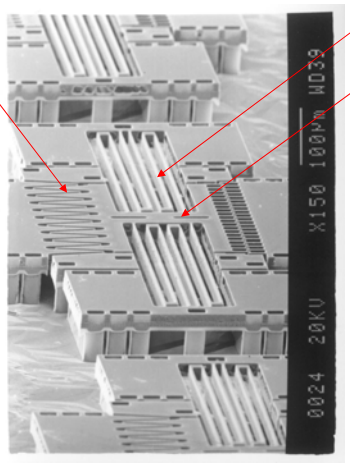
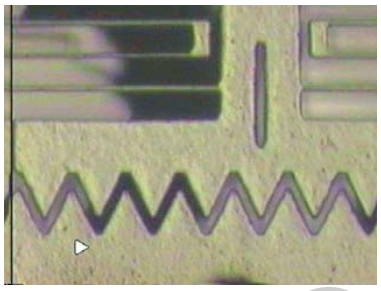
Active component

- Linear electrostatic actuator





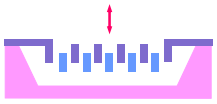


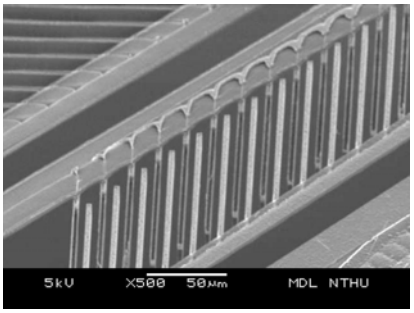
J. Hsieh and W. Fang, 2000

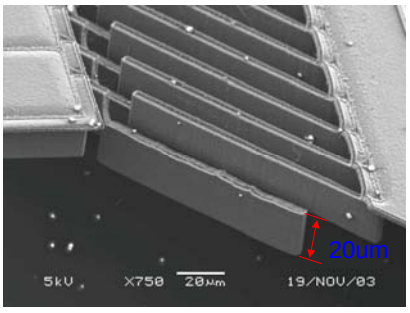
MDL
NTHU

Active component

- Linear electrostatic actuator







M. Wu and W. Fang, 2005

MDL
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Active component

- Angular electrostatic actuator

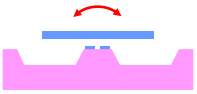
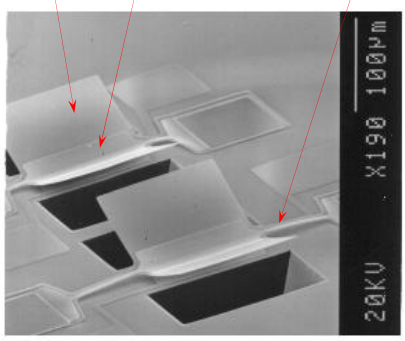
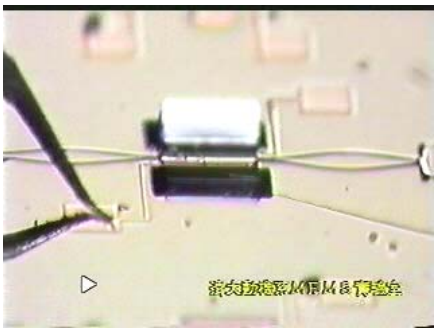


Plate Electrode Spring



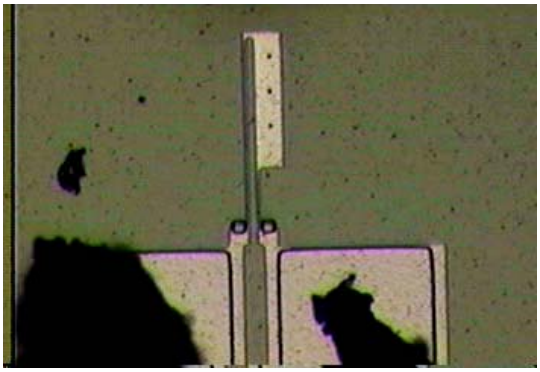


J. Hsieh and W. Fang, *Sensors and Actuators A*, 2000

MDL NTHU

Active component

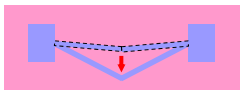
- Linear thermal actuator



MDL NTHU

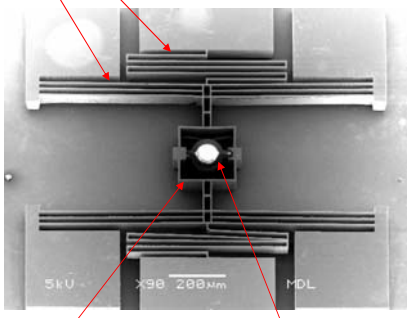
Active component

- Linear thermal actuator



Spring (passive)

V-beam actuator (active)



Supporting frame (passive)

Lens (passive)

C. Lai, J. Hsieh, and W. Fang, *IEEE Optical MEMS'04*, 2004

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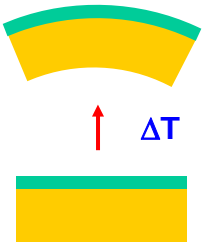
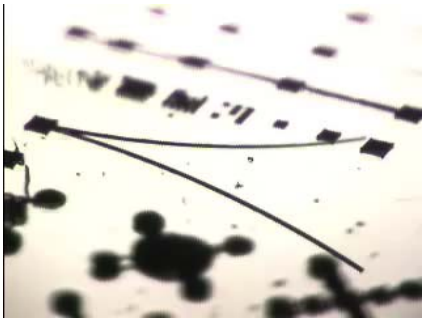
NTHU

Active component

- Linear thermal actuator





W.-K. Hsu, and W. Fang, *Nanotech*, 2008

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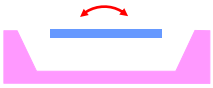
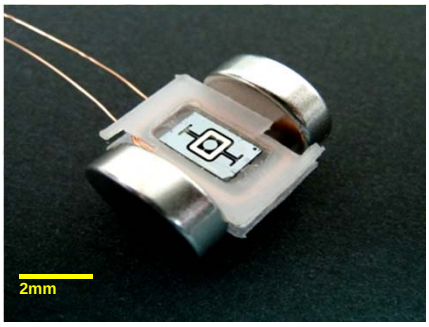
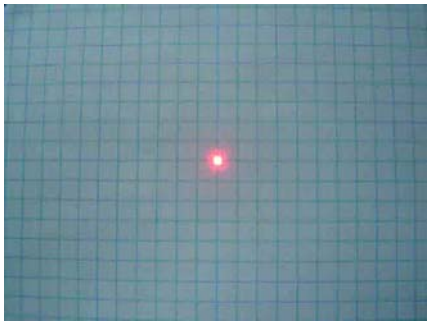
Active component

- **Angular magnetic actuator**







Yang, and Fang, *JMEMS*, 2007

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組裝與整合

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About Mechanical Device

https://www.patek.com/

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About Mechanical Device

https://www.patek.com/

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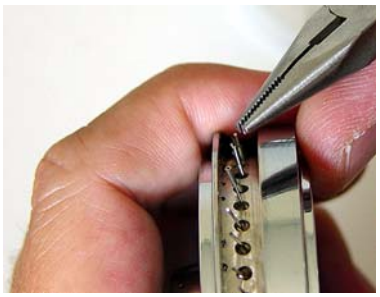
Assembly



www.precisionscalereplicas.com

www.kukausa.com

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Assembly

- Toyota and Foxconn assembly lines

www.youngertoyota.com

www.zaeke.com

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Assembly

- **Boeing 777 assembly lines**

www.ainonline.com

www.flightglobal.com

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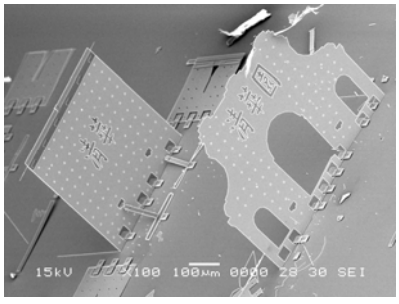
- **Manually assembled by probe**



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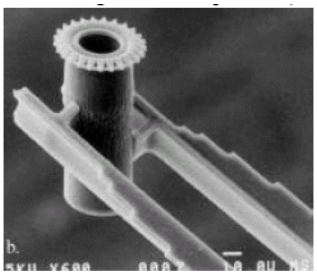
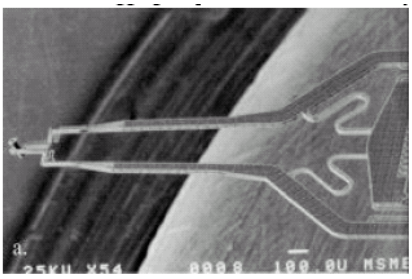
- **Manually assembled by micro gripper**





Keller, UC Berkeley, 1998

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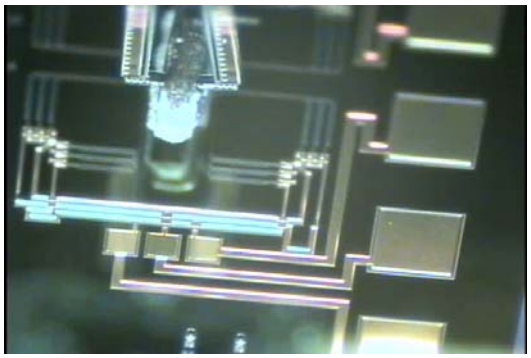
- **Automatically assembled by precision machine**



Zyvex Inc.

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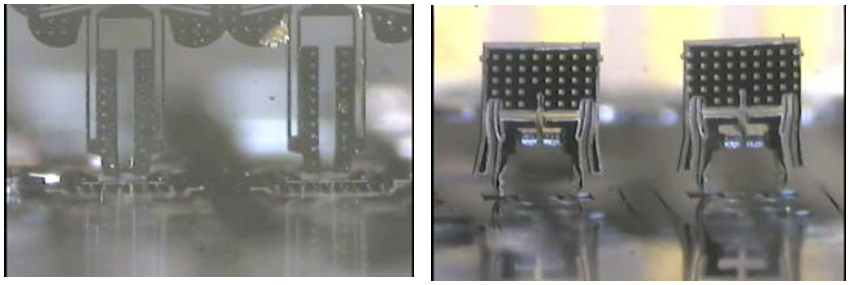
NTHU

- **Automatically assembled by precision machine**



Zyvex Inc.

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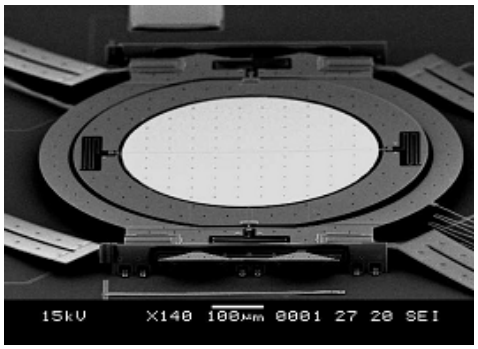
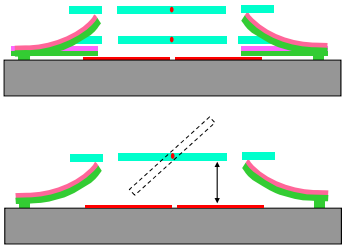
NTHU

- **Self assembly by residual stress deformed beam**





Y.-P. Ho, M. Wu, H. Lin, and W. Fang, *IEEE Optical MEMS '02*, 2002

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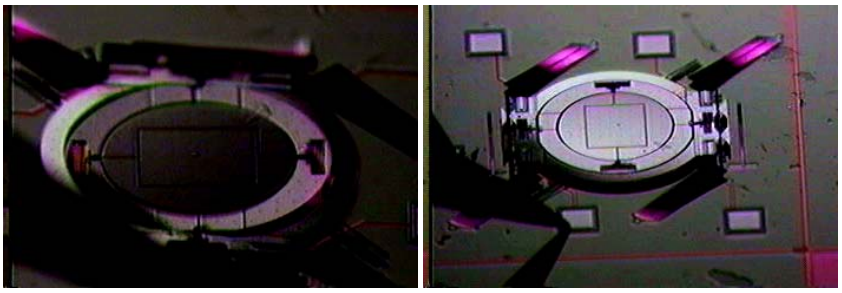

Y.-P. Ho, M. Wu, H. Lin, and W. Fang, *IEEE Optical MEMS '02*, 2002

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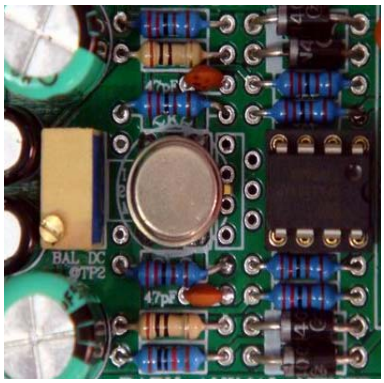
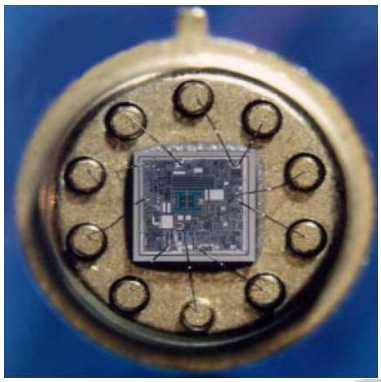
Process Integration

- **Discrete vs Integrated electronics components**



ATM Elektro, Czech Republic



ADI, USA

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NTHU

- **Assembly by process integration (一體成形)**

Brigham Young Univ., USA

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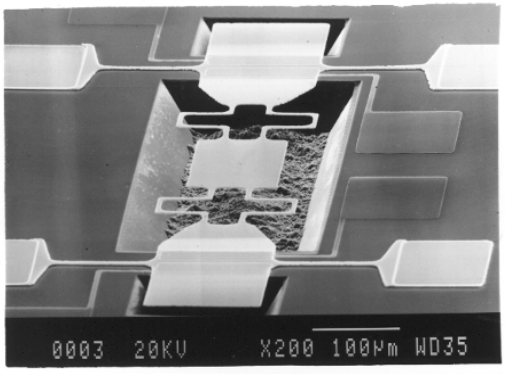
- **Assembly by process integration**



J. Hsieh and W. Fang, *Transducer'99*, 1999

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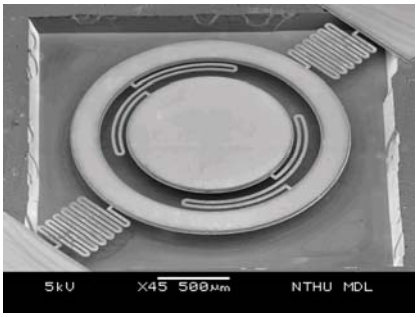
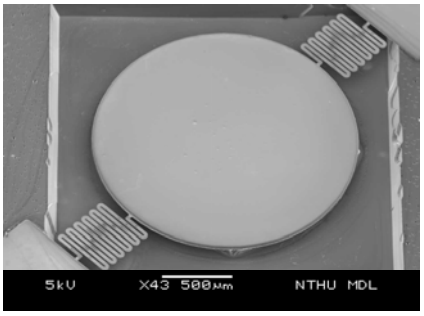
- **Assembly by process integration**





H. Yang, and W. Fang, *IEEE MEMS'06*, Istanbul, Turkey, 2006

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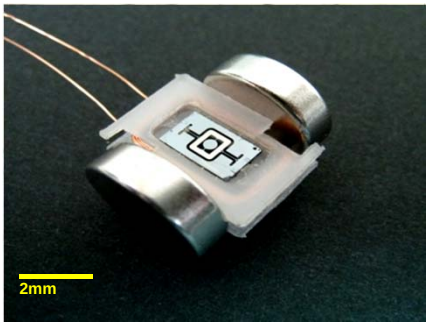
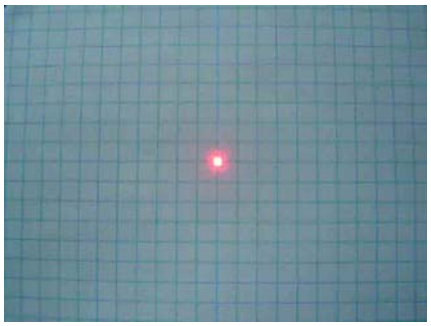
- **Scanning images**





Yang, and Fang, *JMEMS*, 2007

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製程平台 – 標準製程

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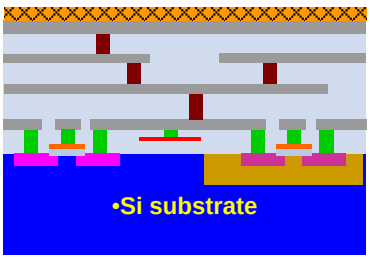
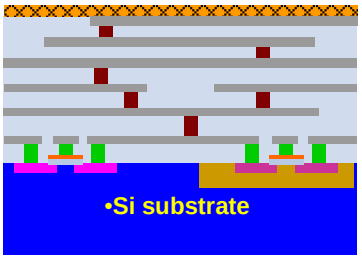
Standard CMOS Processes

- **Available in CMOS foundries: TSMC, UMC, etc…**

0.35μm 2P4M CMOS process



0.18μm 1P6M CMOS process



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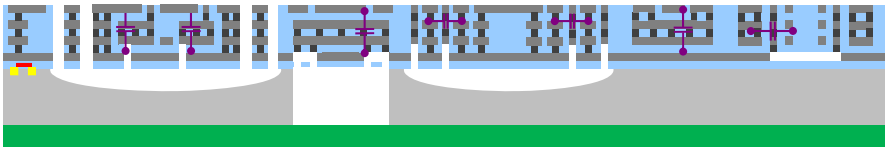
CMOS-MEMS Platform

Sensing circuit | Tri-axis G sensor | Pressure sensor | Magnetic sensor | Tactile sensor | RF resonator



Si | Poly-Si | W-via

Metal | Polymer | SiO_2

- Standard TSMC 0.35μm 2P4M CMOS process
- Post-CMOS processes developed by Prof. Fang's group

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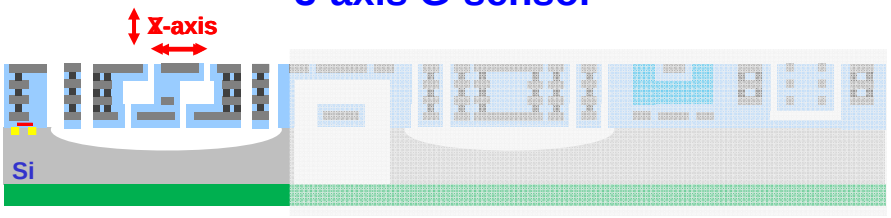
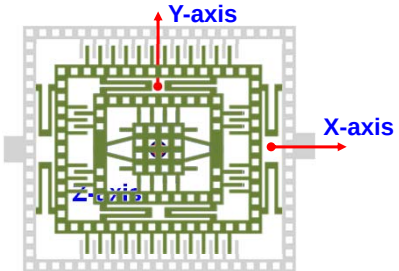
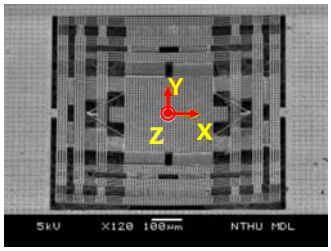
3-axis G-sensor







Single proof mass 4 springs

Sun, and Fang, *IEEE MEMS*, 2009
Sun, and Fang, *IEEE Trans. on ED*, 2010

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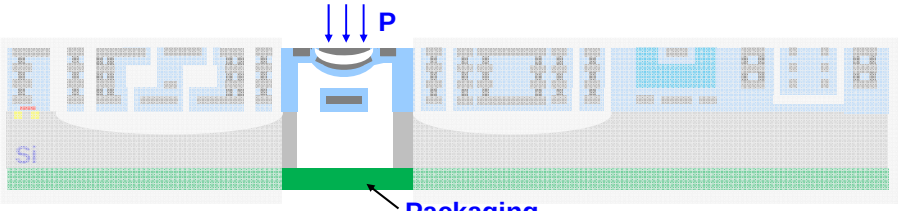
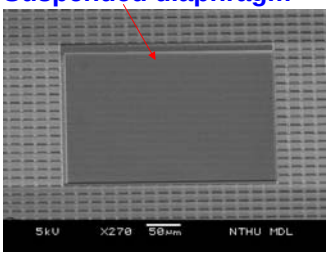
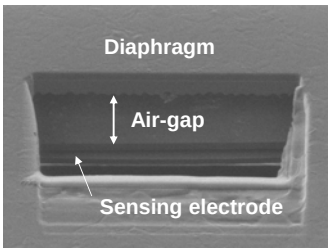
Pressure Sensors



Suspended diaphragm





FIB sectioning

Sun, and Fang, *Transducers*, 2009
Sun, and Fang, *JMM*, 2009

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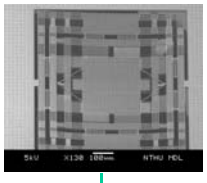
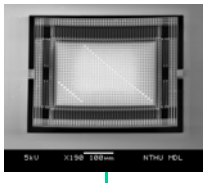
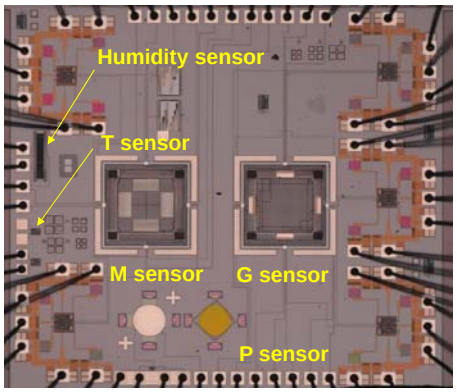
3-axis G Sensor

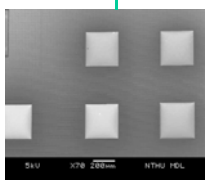


M Sensor

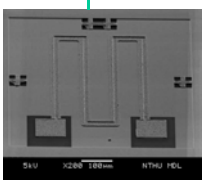




P Sensor Array



T Sensor



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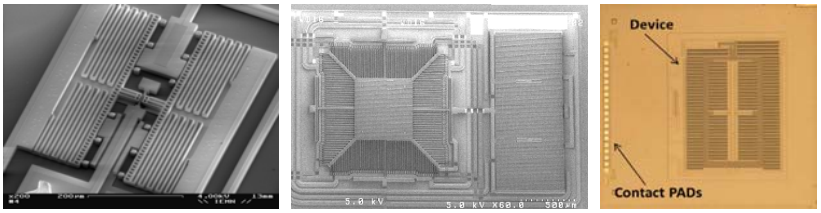
STM THELMA Platform

- Thick Epi-poly Layer for Microactuators and Accelerometers

Poly-Si SiO_2 Epi-Poly-Si



http://www.st.com/

G. Langfelder et al., *IEEE Trans. on IE*, 2012

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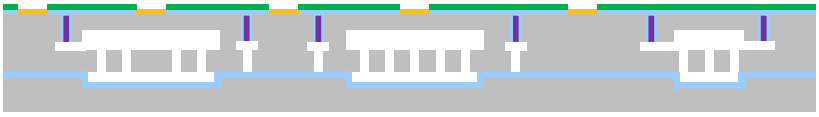
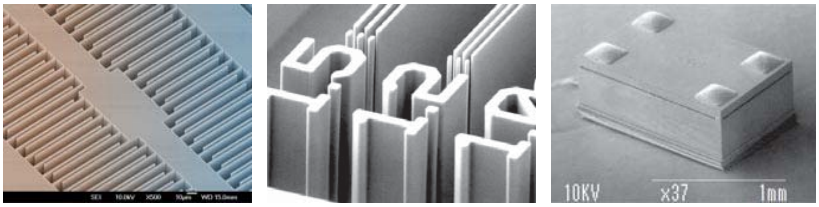
Teledyne DALSA MIDIS Platform

- MEMS Integrated Design for Inertial Sensors

Accelerometer Gyroscope Resonator



Si SiO_2 ISDP Polymer AlCu



http://www.teledynedalsa.com/

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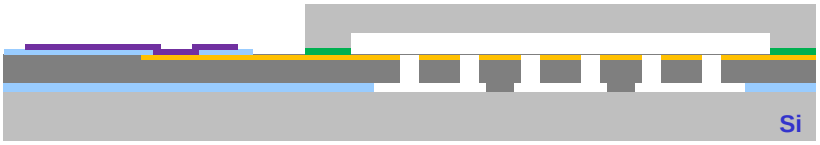
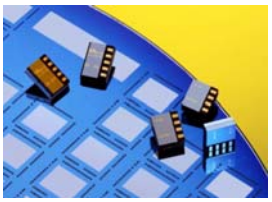
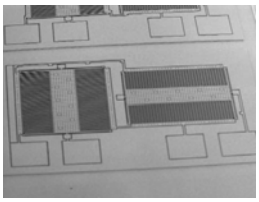
Tronics Platform

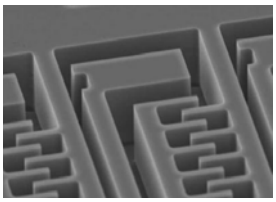
- Epi-SOI technology



Epi-Si SiO_2 Implant Metal Polymer







http://www.tronicsgroup.com/

S. Renard, *JMM*, 2000

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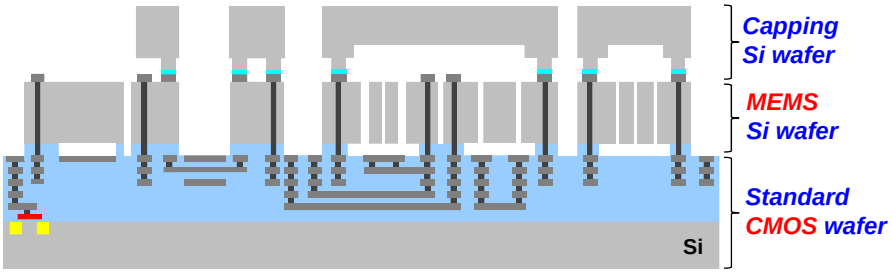
TSMC MEMS Platform

- Si-MEMS above CMOS

Other sensors Motion sensors



SiO_2 Poly-Si W-via Metal

Source : TSMC

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台灣現況簡介

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NTHU

MEMS Eco-system at Taiwan

~300 km

Taiwan
Area: ~36,000 km²
Population: ~23.4 M

Switzerland
Area: ~41,300 km²
Population: ~8 M

The Neatherland
Area: ~41,500 km²
Population: ~17 M

CIC
NSC
TSMC
UMC
ITRC
MOSIS
VIS
ITRI
TSMC
CIC
TSMC
NDL
UMC
ITRI

NTU (NML)
ASE-CL
Xintec
NTHU (CML)
NCTU (NFC)
NYEC
PTI
Sigurd
Lingsen
SPIL
NCKU (SML)
ASE
TICP

apm
TSMC
UMC
VIS
…

National Fab / CMOS Fab
Research Inst / MEMS Fab
Packaging House / Univ MEMS Fab

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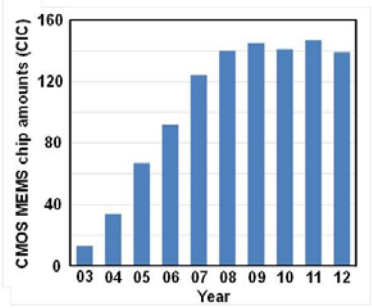
National Lab – CIC (TSRI)

- CIC: Chip Implementation Center, since 1993
- CMOS MEMS Processes
  + 0.35μm 2-Poly 4-Metal TSMC process (from 2002, 4 runs/year)
  + 0.18μm 1-Poly 6-Metal TSMC process (from 2006, 4 runs/year)
  + 0.18μm 1-Poly 7-Metal UMC process (from 2013, 2 runs/year)
- APM post-CMOS Process to release MEMS designs



Source : CIC

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National Lab – NDL (TSRI)

- NDL: Nano Device Laboratories, since 1988
- NDL has been dedicated to:
  + Support academic research
    (More than 70 equipments are opened to students)
  + Frontier IC/MEMS technology development
  + Bridging the academic and industry

Clean room areas (m^2)

Class 10	370
Class 1,000	250
Class 10,000	1525
Facilities area	1420

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Nonprofit Research Org - ITRI

- ITRI: Industrial Tech. Research Inst., since 1973
- Manpower: ~6,000
  + ~200 MEMS engineers/researchers
- Microsystems Tech Center: MEMS total solution
- Pilot-run MEMS Fab: MEMS/post-CMOS processes

MEMS clean room areas (m^2)

Class 10	N/A
Class 1,000	260
Class 10,000	390
Facilities area	360

Source：ITRI Southern Region Campus

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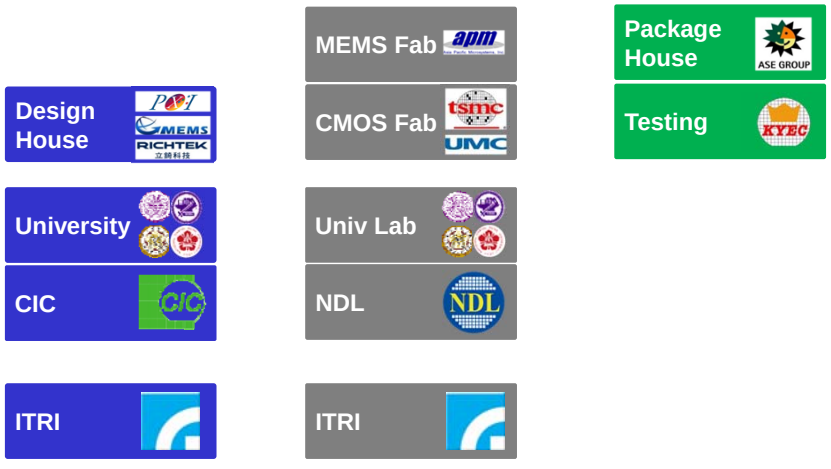
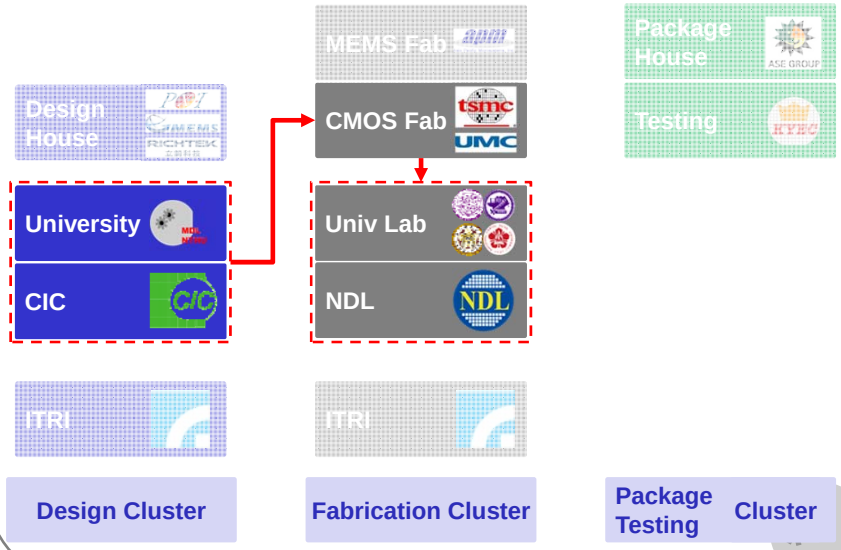
MEMS Networks at Taiwan



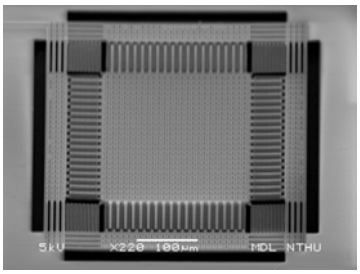
MDL NTHU

MEMS Networks at Taiwan

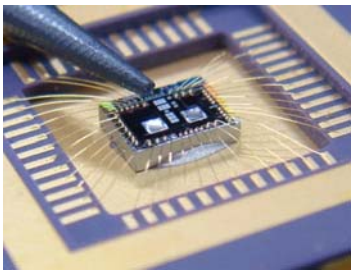


MDL NTHU

0.18um 1P6M TSMC CMOS Process



3-axis accelerometer



Sensor after bonding

Sensing-axis	*X-axis*	*Y-axis*	*Z-axis*
Measurement Range (G)	0.01~1	0.01~1	0.01~1
Sensitivity (mV/G)	14.2	14.6	8.0
Non-linearity (%)	3.0%	1.5%	1.8%
Noise (mG/sqrtHz)	1.9	2.9	3.4

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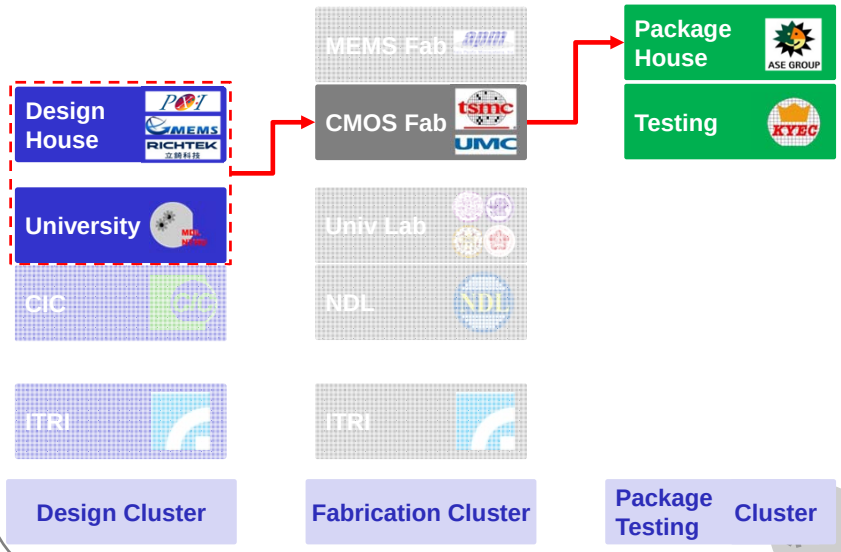
MEMS Networks at Taiwan



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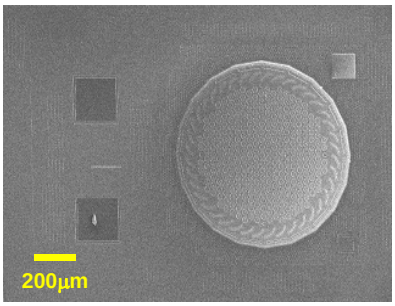
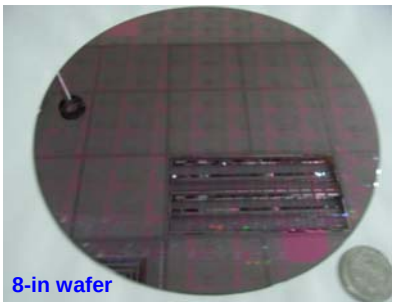
MEMS Sensor – Design Houses

- UMC CMOS processes: 8-inch 0.18um 1P6M process



Microphone by M design house



G-sensor by P design house

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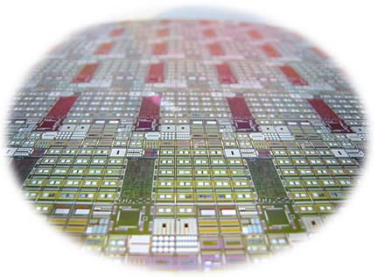
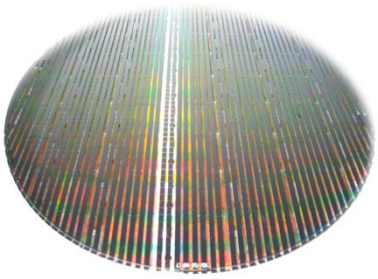
MEMS Sensors - Ecosystems

- CMOS MEMS sensors on 8-inch wafer
- Eco-systems: ITE/Univ - UMC - SPIL - KYEC



CMOS MEMS on 8" Wafer



Capped CMOS MEMS Sensors

ITE TECH.INC. UMC — *Design* *Foundry*

SPIL KYEC — *Packaging* *Testing*

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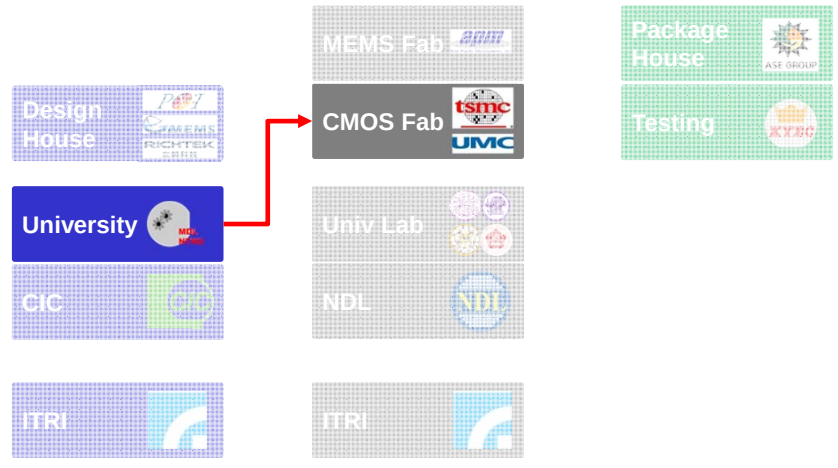
MEMS Networks at Taiwan



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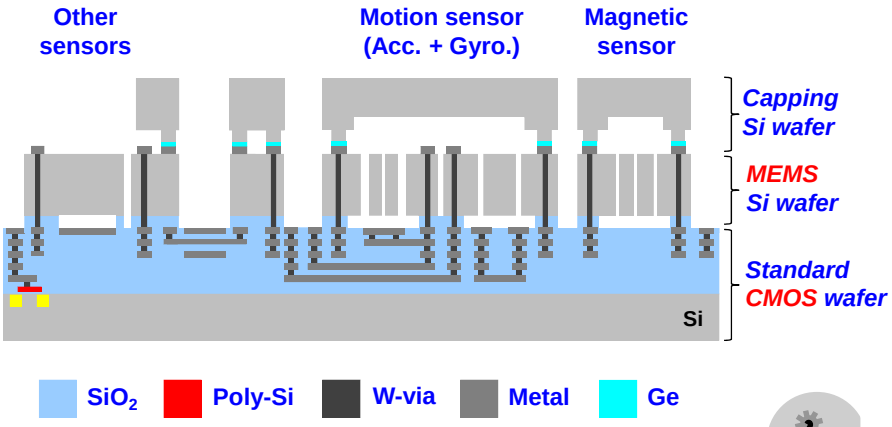
TSMC MEMS Platform

- **Si-MEMS above CMOS**



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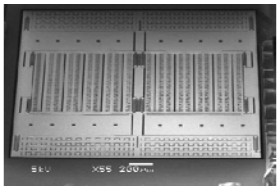
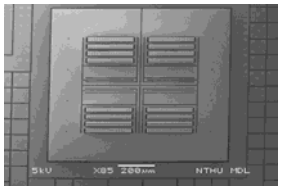
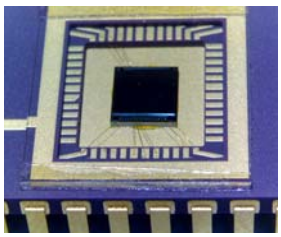
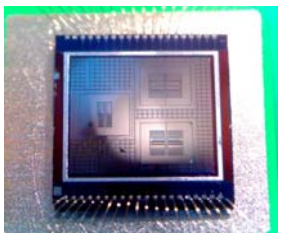
TSMC MEMS Platform

- **Gyroscope and Magnetic Sensor**









Lee and Fang, *IEEE MEMS*, 2016

Sung and Fang, *IEEE MEMS*, 2016

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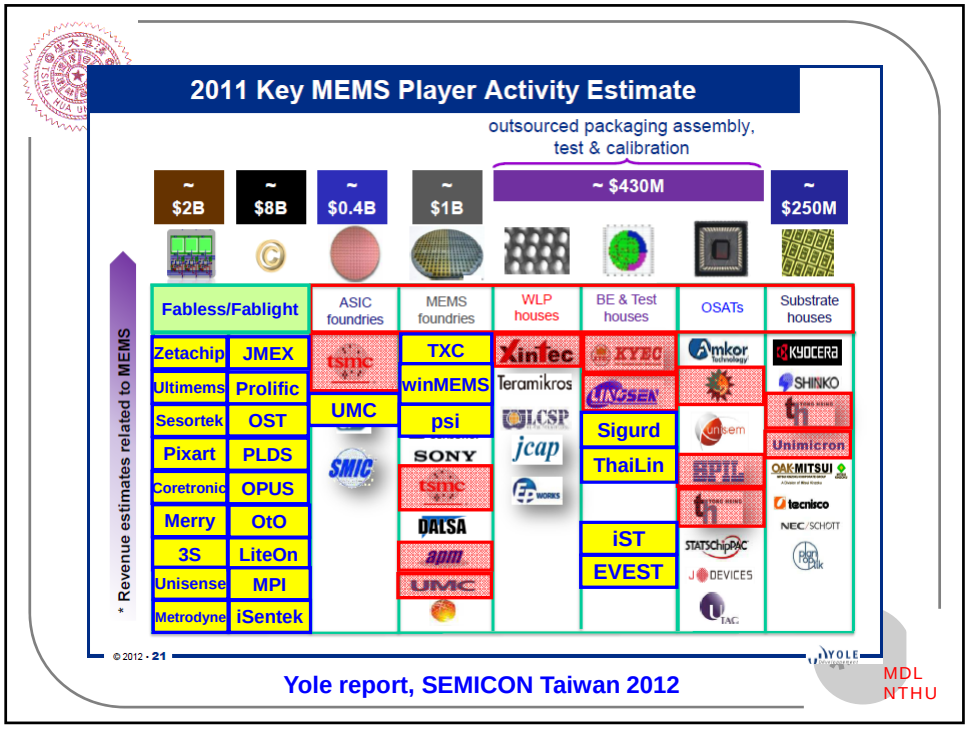

Yole report, SEMICON Taiwan 2012

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結論

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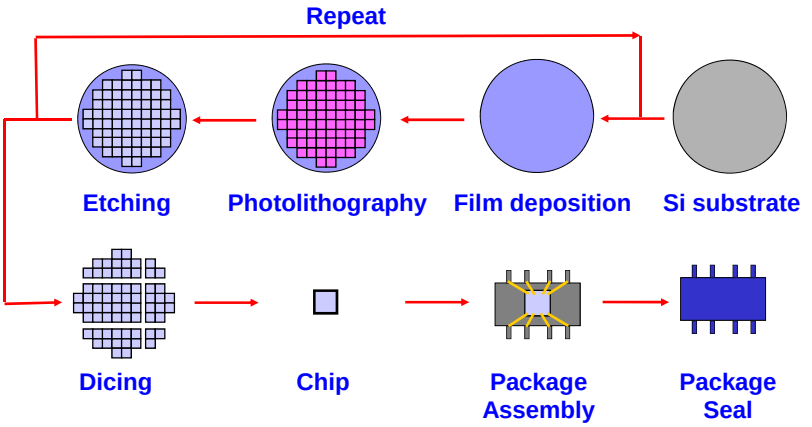
Semiconductor processes



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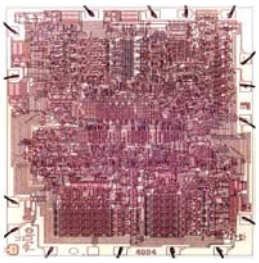
Microprocessor



The 4004 – 2.3k transistors, 1971

8088/8086 - 29k transistors, 1978

Pentium IV – 42M transistors, 2000

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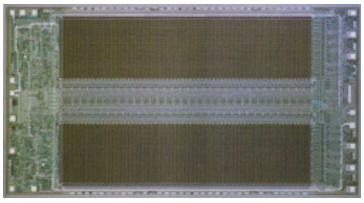
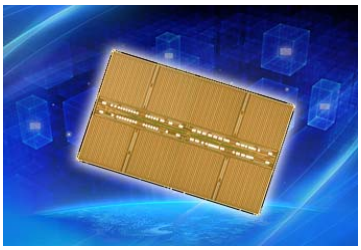
Memory



The 16kb DRAM, 1976



The 2Gb DRAM, 2011

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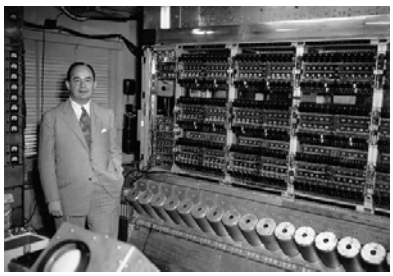
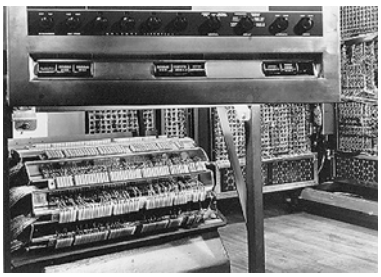
Computer



von Neumann and his "computer", 1952



IBM 650, 1954

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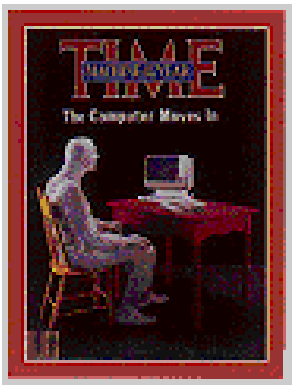
Computer

Jobs & Wozniak with Apple II - 1976



IBM PC – 1981/2

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Computer

ENIAC (Vacuum tube)

Mainframes (LSI)

Notebook

Tablet

1946 1960 1965 1975 1992 2004 2010

First Mainframes
(Transistor)

Person computer
(VLSI)

Notebook

Ref: Wiki

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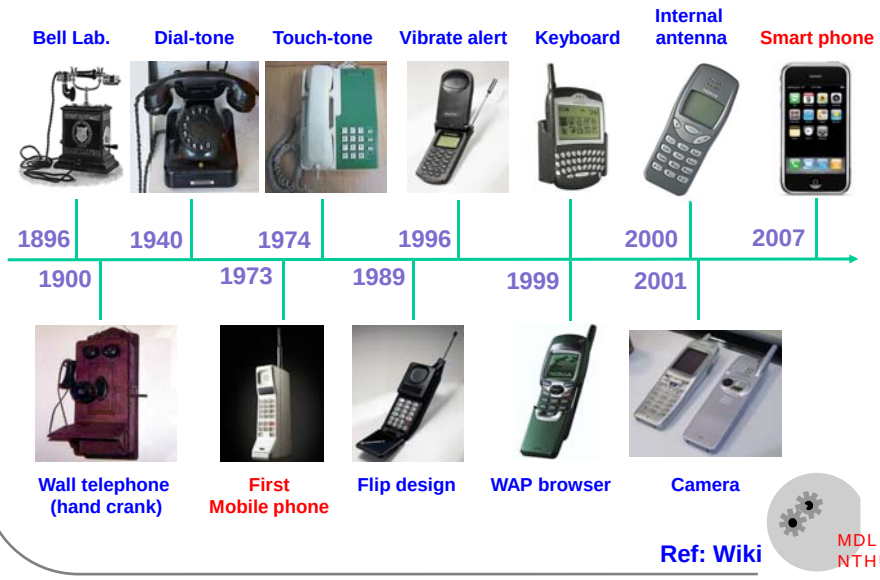
Telephone



Ref: Wiki

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Ecosystems for IoT

STMicroelectronics

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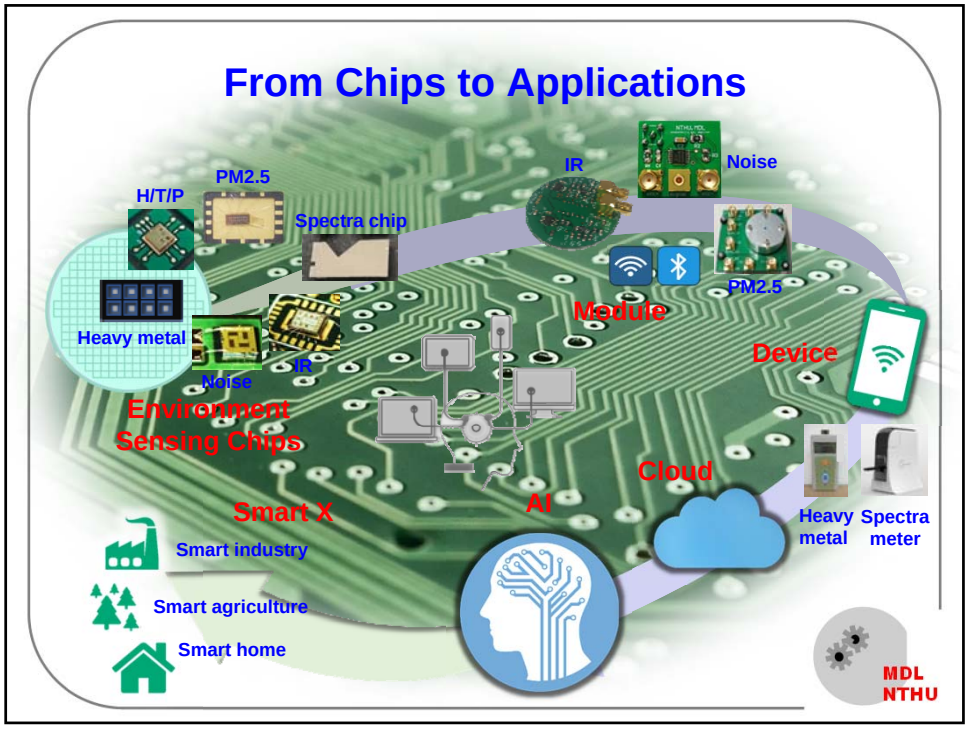
From Chips to Applications
PM2.5
H/T/P
Spectra chip
IR
Noise
PM2.5
Module
Heavy metal
Noise
IR
Device
Environment
Sensing Chips
Cloud
AI
Smart X
Heavy metal
Spectra meter
Smart industry
Smart agriculture
Smart home
MDL
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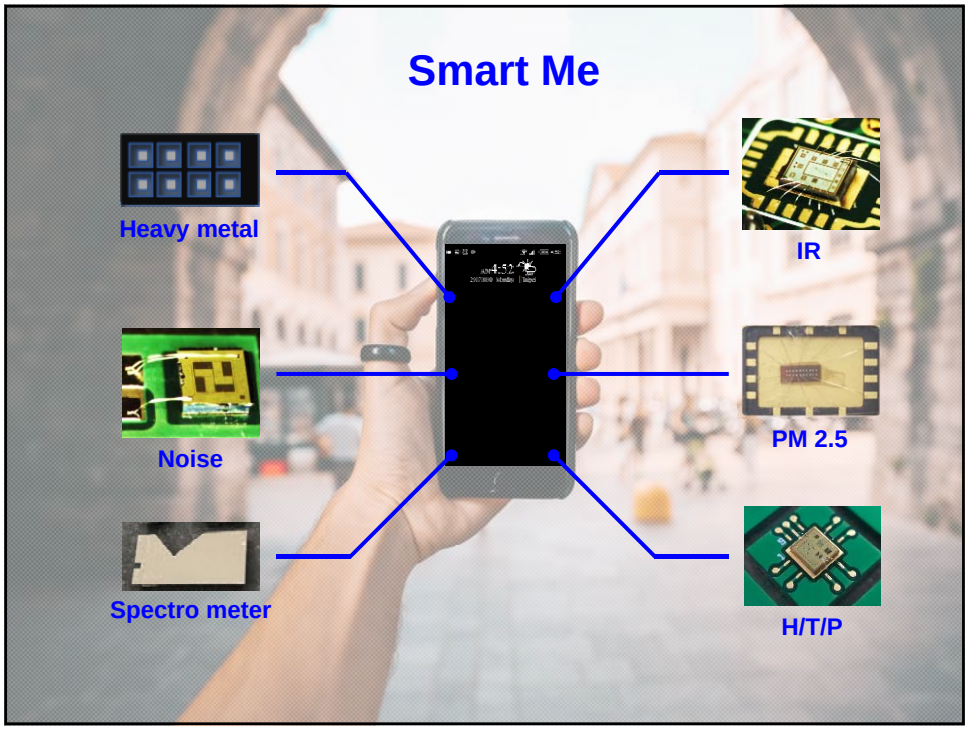
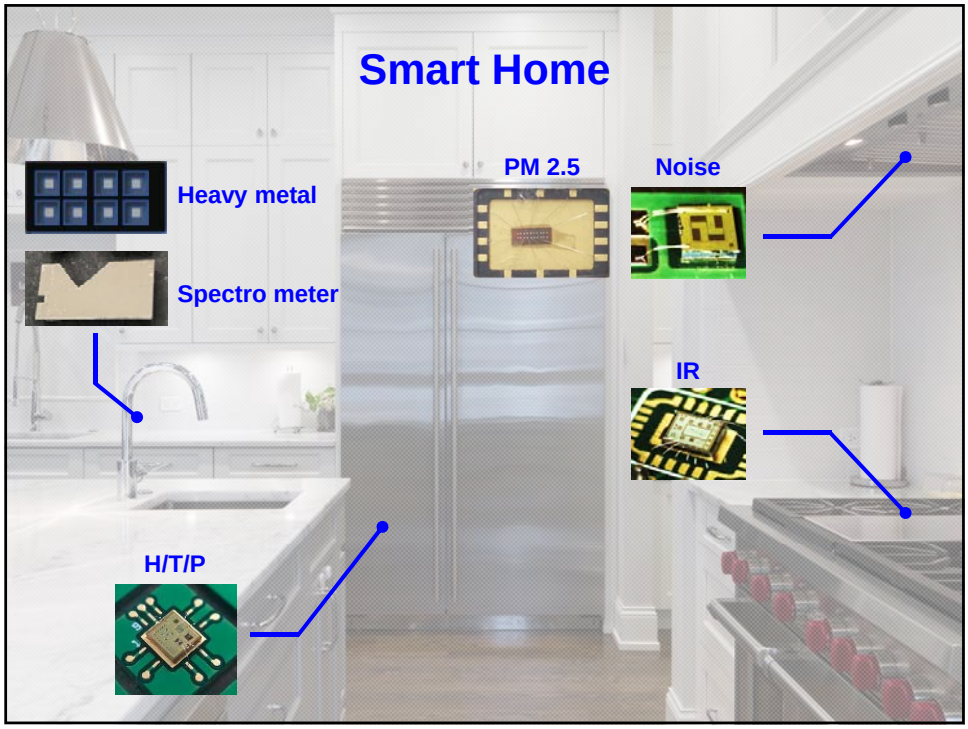
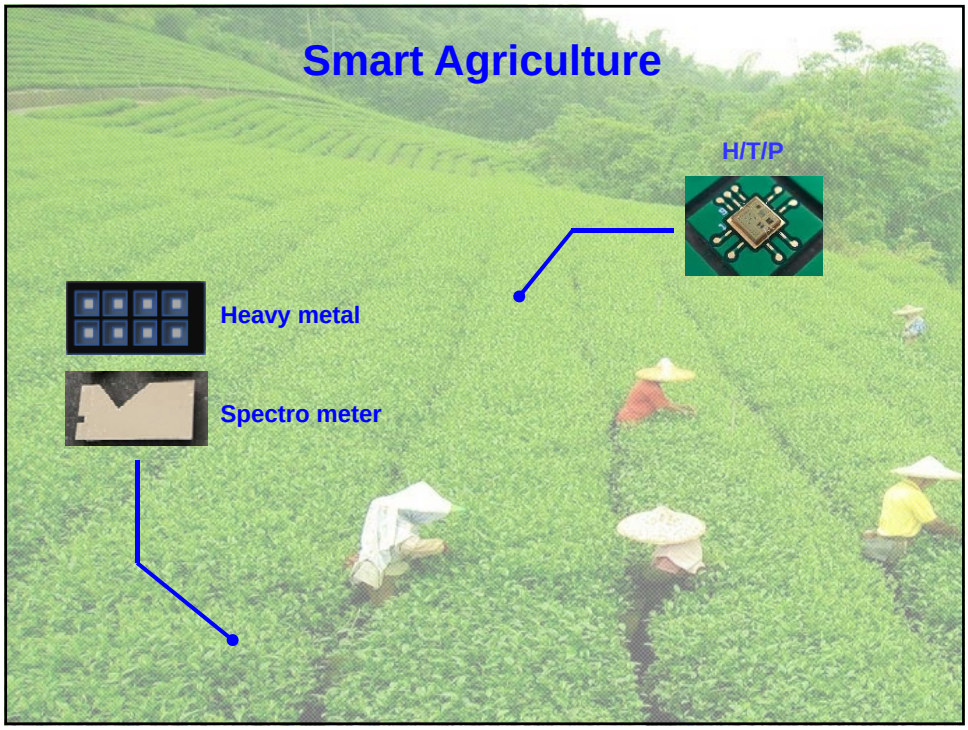
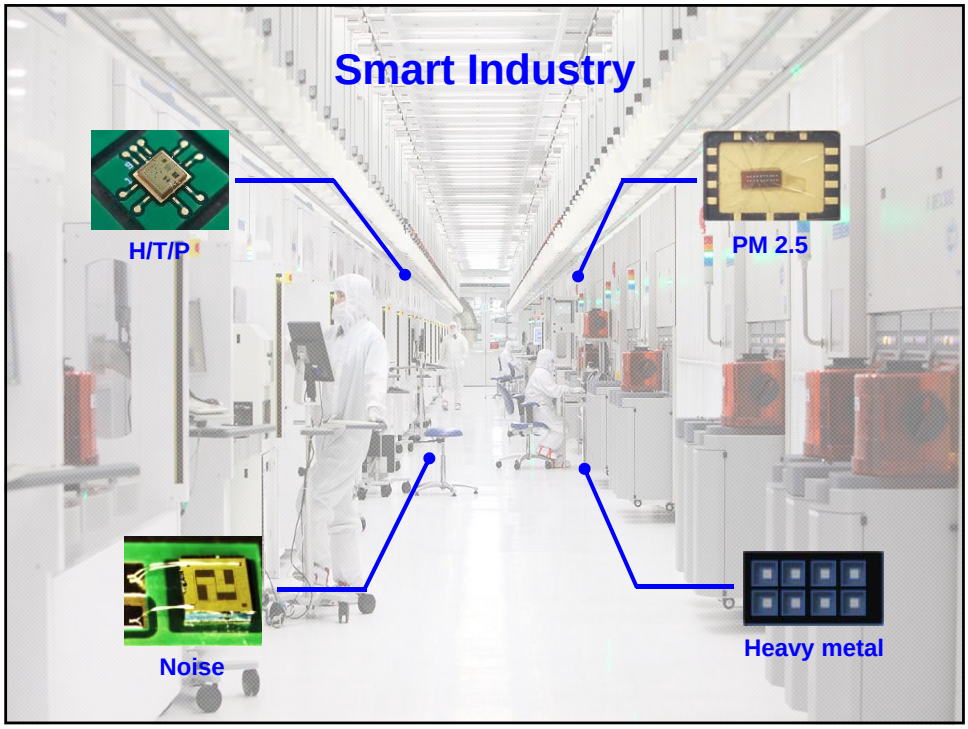
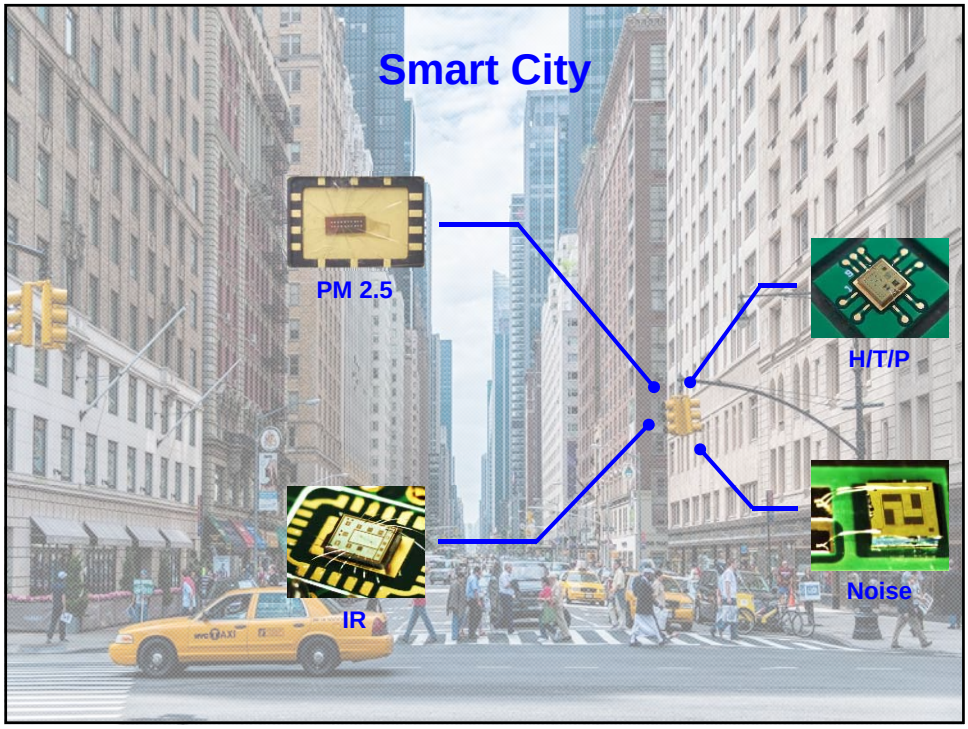

Smart Me
Heavy metal
IR
Noise
PM 2.5
Spectro meter
H/T/P


Smart Home
Heavy metal
Spectro meter
PM 2.5
Noise
IR
H/T/P


Smart Agriculture
H/T/P
Heavy metal
Spectro meter


Smart Industry
H/T/P
PM 2.5
Noise
Heavy metal


Smart City
PM 2.5
H/T/P
IR
Noise

IoT – the Next Big Things

- **The next big things**
  - + Highlight by Dr. Morris Chang of TSMC in 2014
  - + Major players: Google, Apple, Cisco, Alibaba, Huawei, etc.
  - + Semiconductor remain the key enabling tech.

www.appledaily.com.tw

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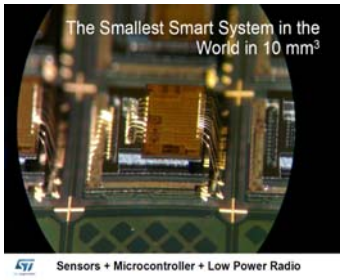
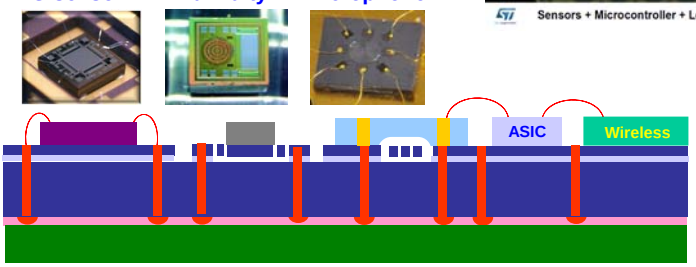
Semiconductor: Key Tech for *IoT*

- **Key Techs for IoT**
  - + MEMS and Sensors
  - + Advanced packaging
  - + Ultra low power



G sensor Humidity Microphone



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課程安排

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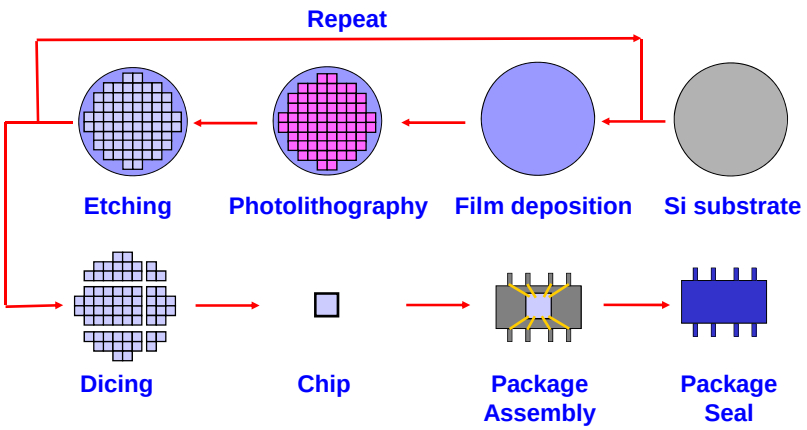
Semiconductor processes



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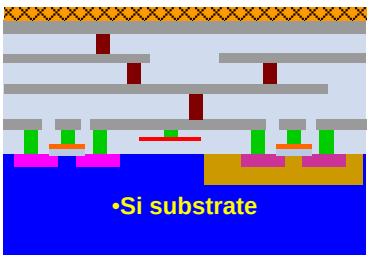
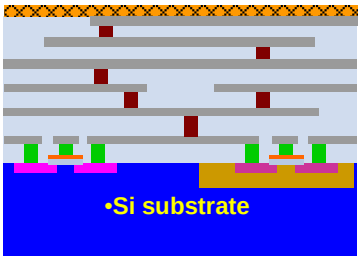
Standard CMOS Processes

- Available in CMOS foundries: TSMC, UMC, etc…

0.35μm 2P4M CMOS process



0.18μm 1P6M CMOS process



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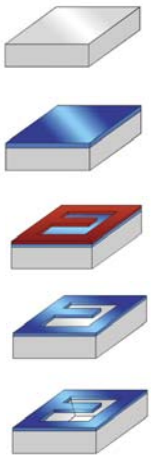
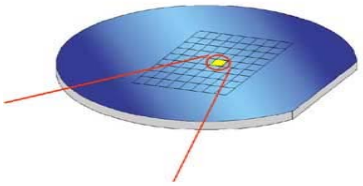
Thin film deposition

Photolithography

Thin film etching

Bulk Si etching





MDL
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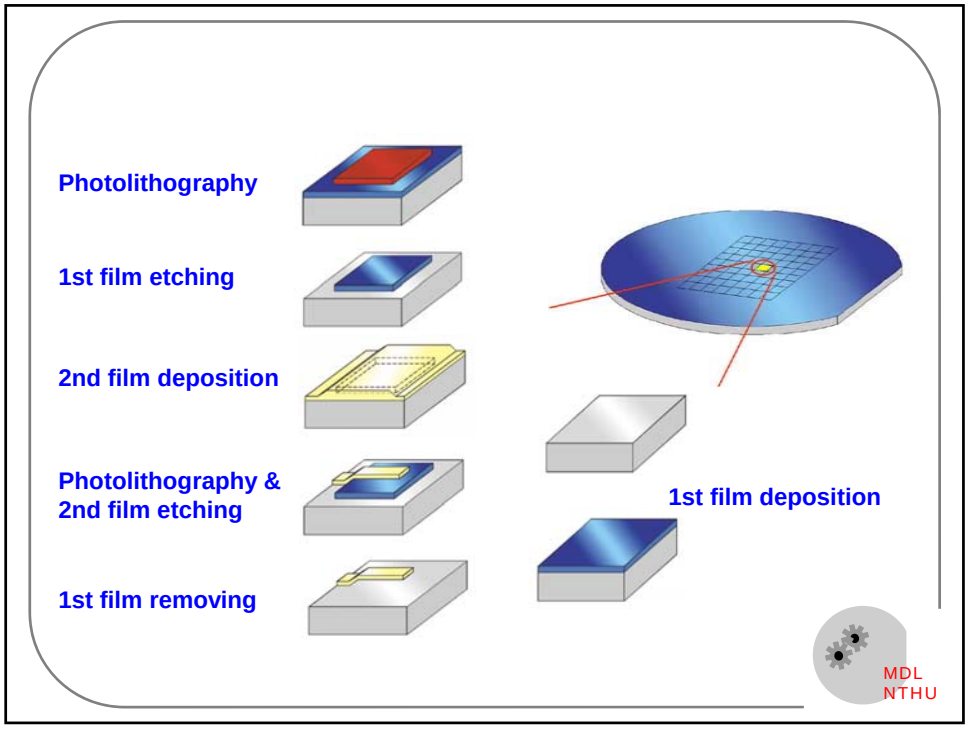
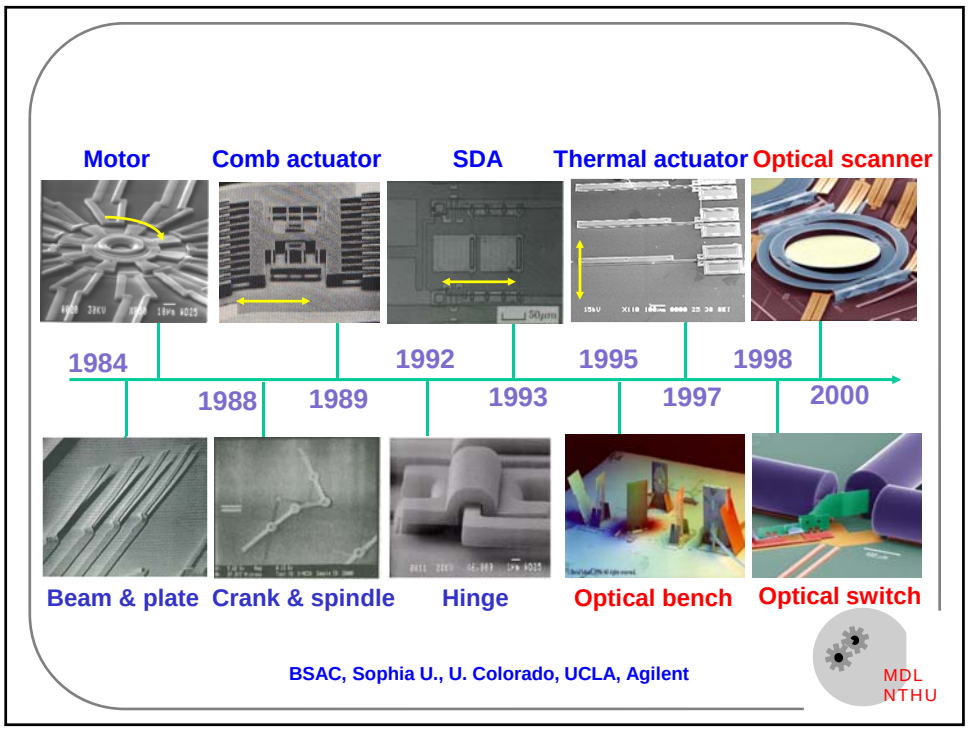

Photolithography
1st film etching
2nd film deposition
Photolithography &
2nd film etching
1st film removing
1st film deposition
MDL
NTHU


Motor
Comb actuator
SDA
Thermal actuator
Optical scanner
1984
1988
1989
1992
1993
1995
1997
1998
2000
Beam & plate
Crank & spindle
Hinge
Optical bench
Optical switch
BSAC, Sophia U., U. Colorado, UCLA, Agilent
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NTHU