微機電系統簡介

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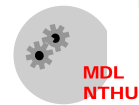
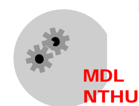
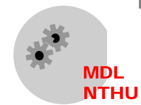


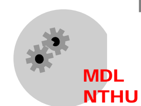
前言



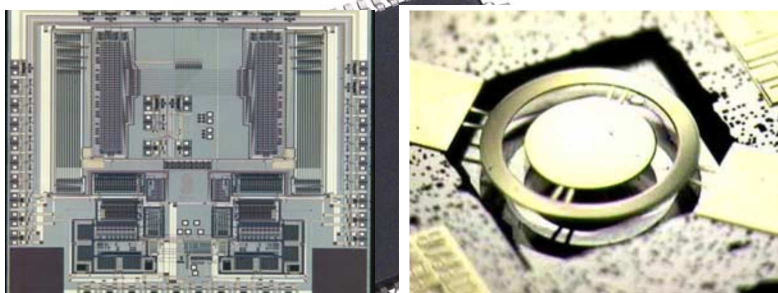
About MEMS

1 mm



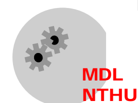


What's MEMS



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

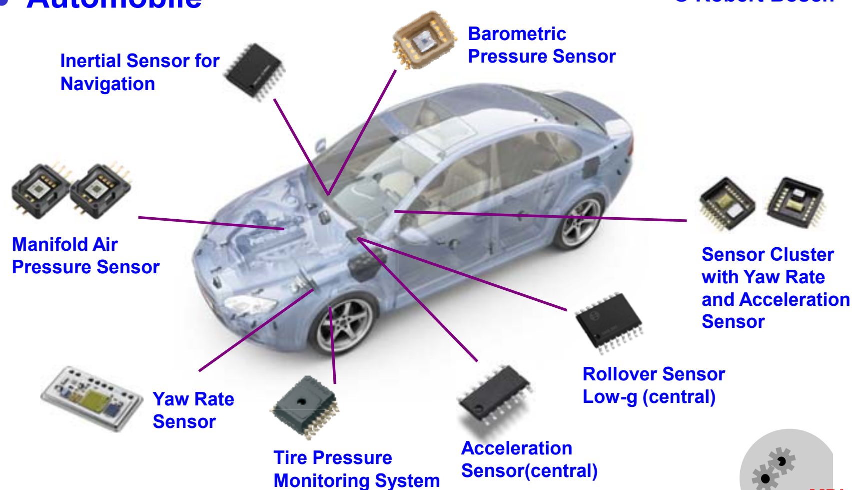
MDL

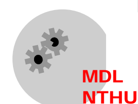


Where's MEMS

- **Automobile**

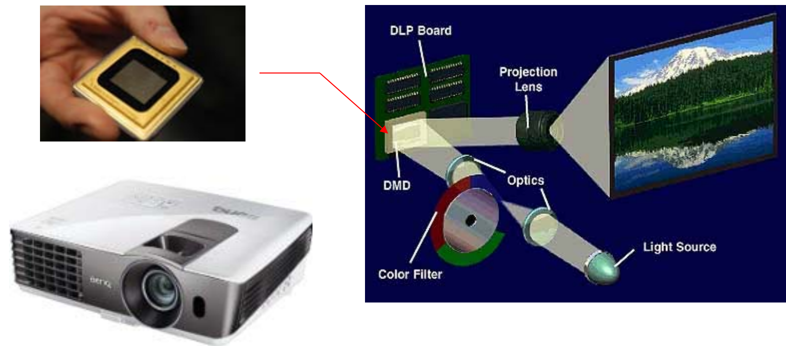
© Robert Bosch



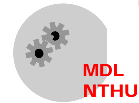


Where’s MEMS

- Before 2000 – inkjet printer, projector



Texas Instruments Inc.



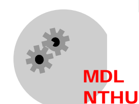
Where’s MEMS

- 2006~2013 – consumer electronics

Wii

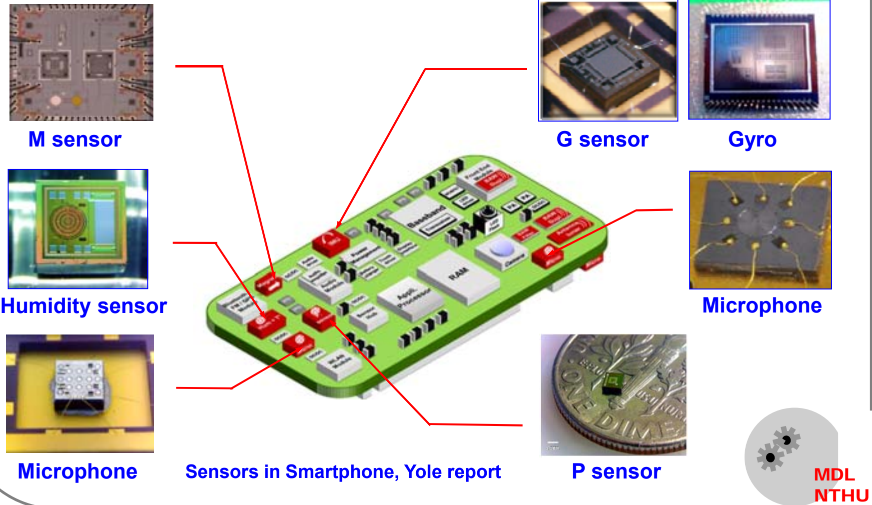
Smart phone

Wearable



Where's MEMS

- **MEMS Devices in volume in 2013 (from Yole)**



Sensors in Smartphone, Yole report

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Where's MEMS

- **Internet of Things (IoT)**

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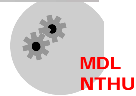
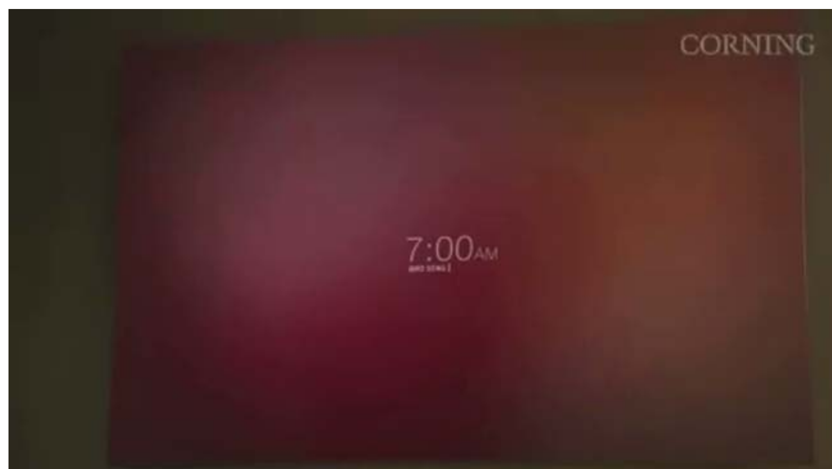
Corning - A Day Made of Glass

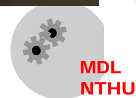
http://www.corning.com/index.aspx



Corning - A Day Made of Glass



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



Parrot - Drone

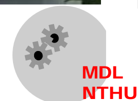
http://www.parrot.com/

Parrot - Drone

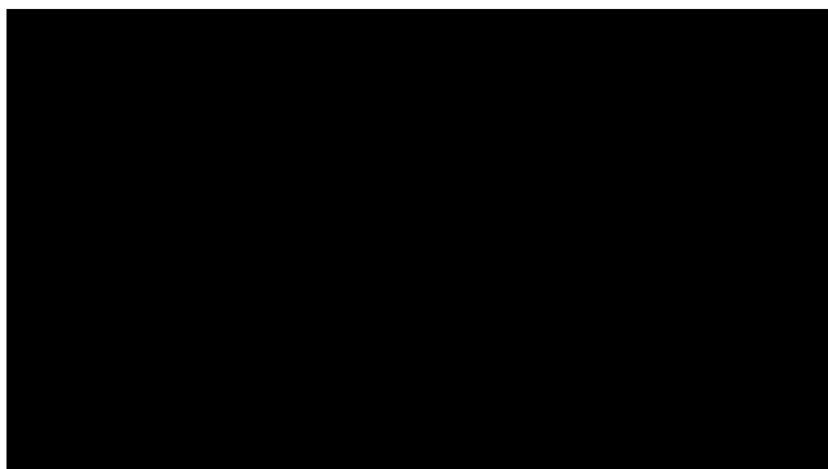
http://www.parrot.com/

Adidas – Smart Ball

http://micoach.adidas.com/



Adidas - Smart Ball

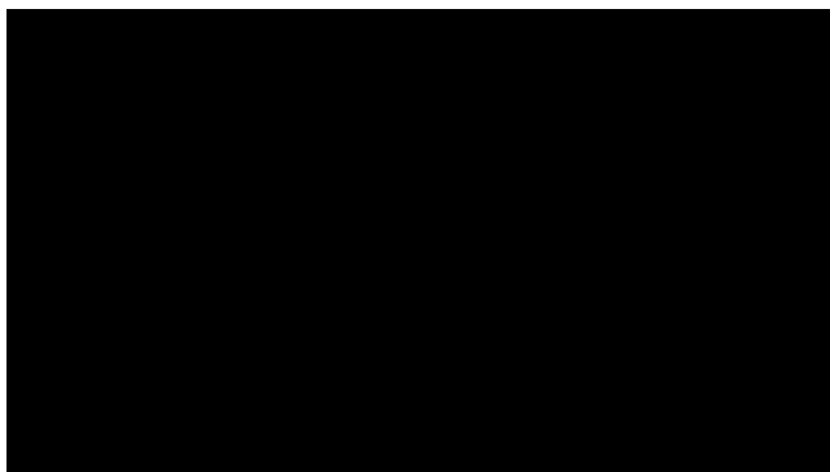


http://micoach.adidas.com/

Bragi – Smart Earphone

http://www.bragi.com/

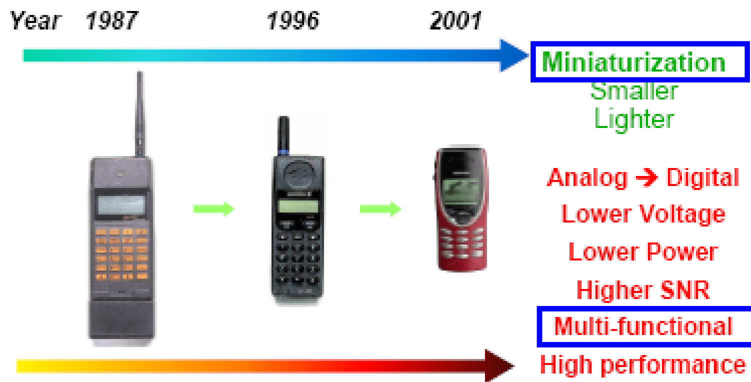
Bragi – Smart Earphone

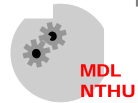


http://www.bragi.com/

Why MEMS

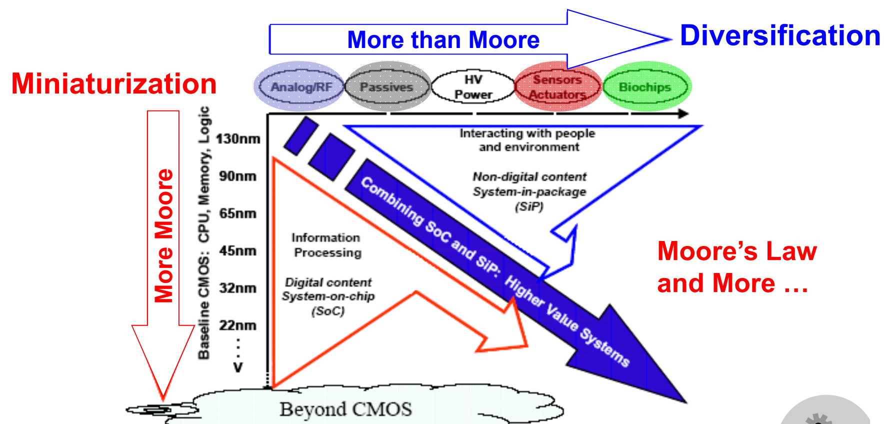
- Small and Smart



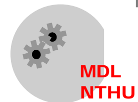


Why MEMS

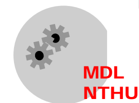
- Small and Smart
- Add value to the existing CMOS tech



Source: ITRS Roadmap 2005, www.itrs.net

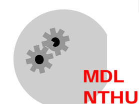


平面加工技術

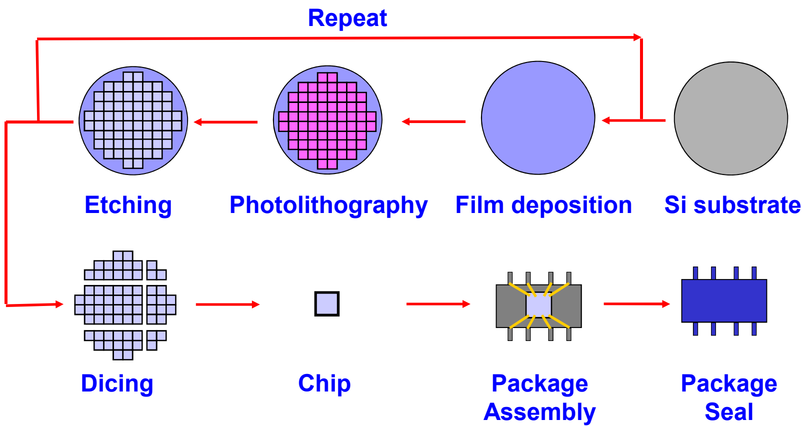


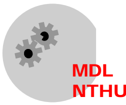
Planar Technologies

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

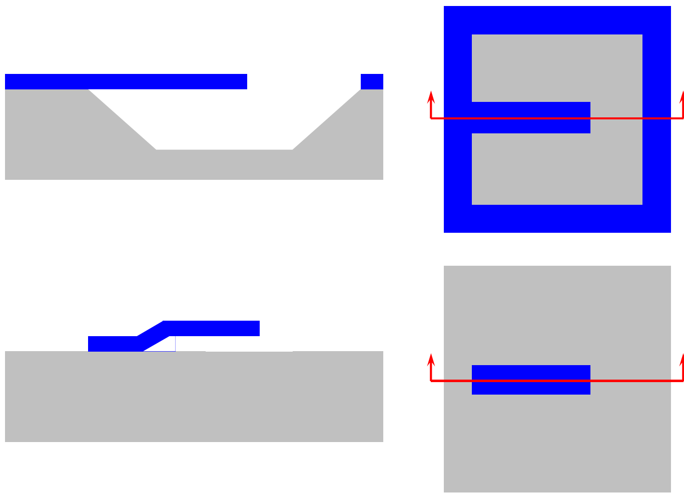


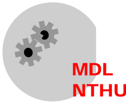
Semiconductor processes



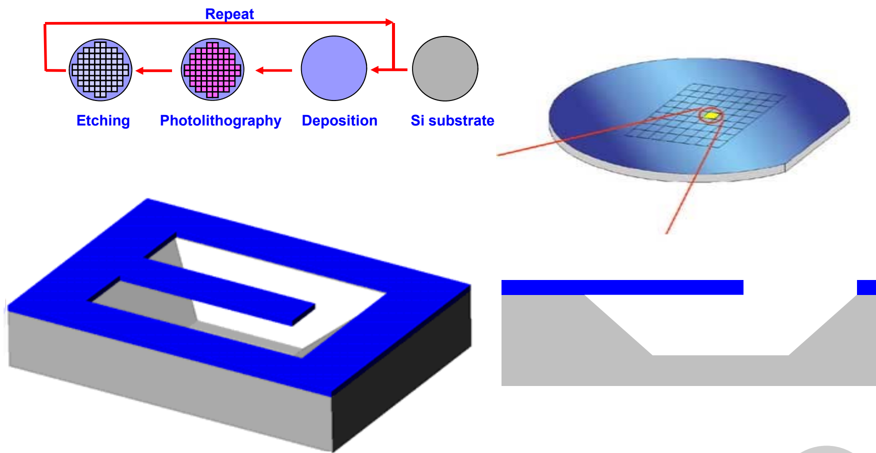


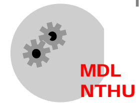
Suspended MEMS Structures

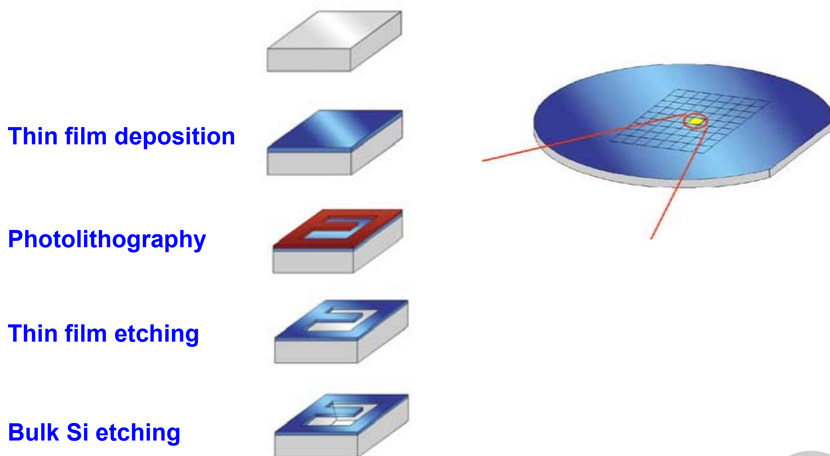


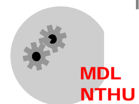


Bulk Micromachining



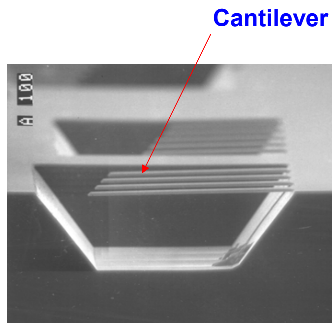






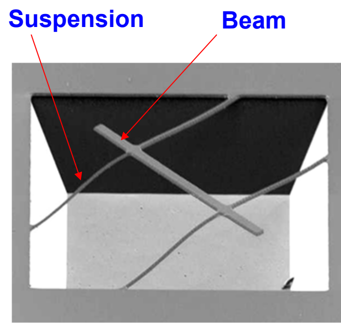
- **Bulk Micromachined Beams**

Cantilever

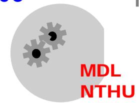


W. Fang, 1994

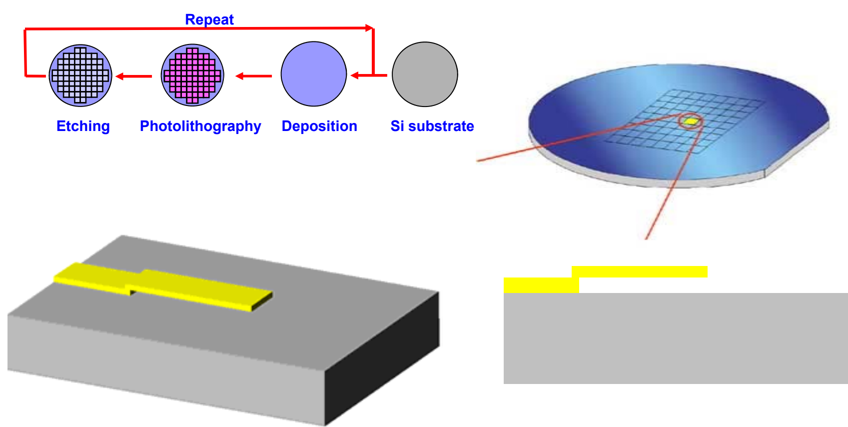
Suspension Beam



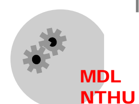
Yu and Fang, *JMM*, 2005

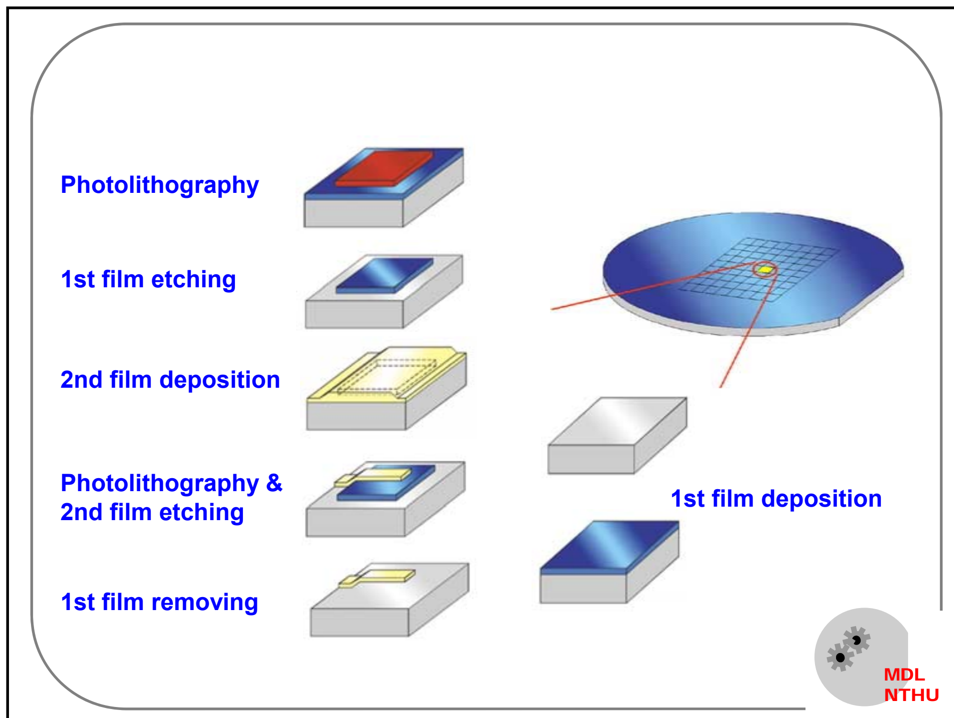


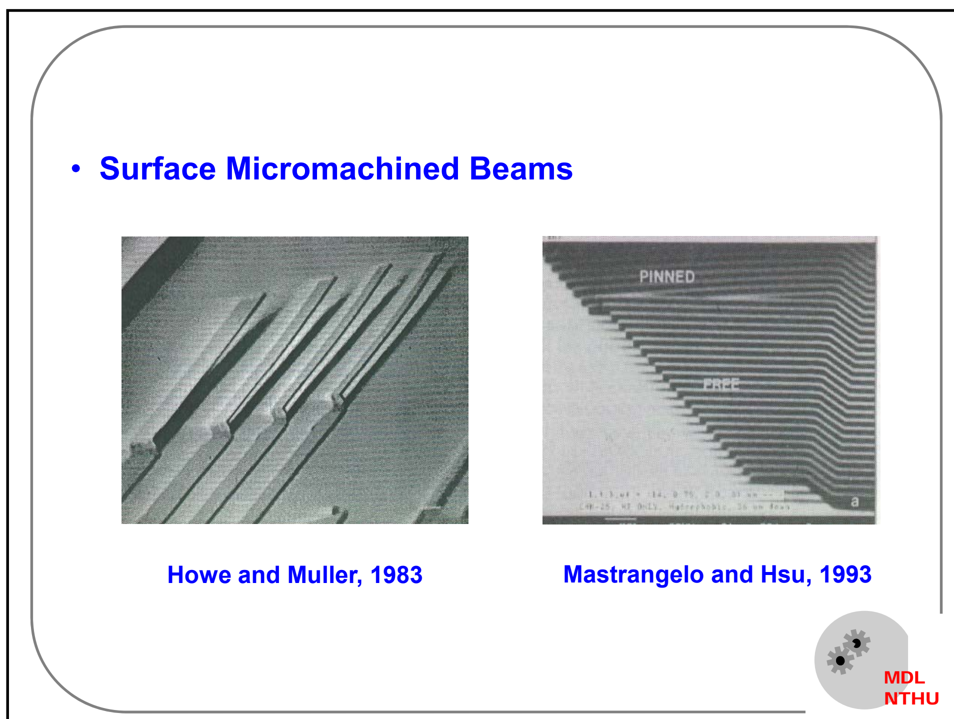
Surface Micromachining



Lith[illegible]hing



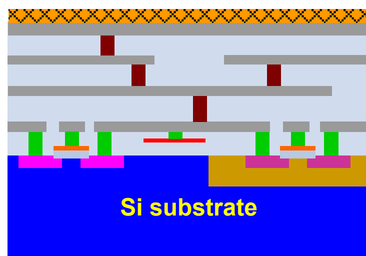

Photolithography
1st film etching
2nd film deposition
Photolithography &
2nd film etching
1st film removing
1st film deposition
MDL
NTHU


• Surface Micromachined Beams
PINNED
FREE
Howe and Muller, 1983
Mastrangelo and Hsu, 1993
MDL
NTHU

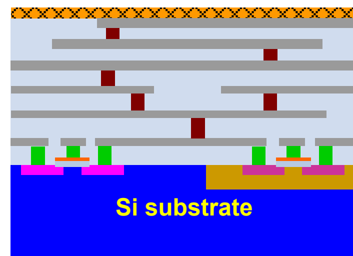
Semiconductor Devices

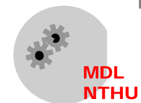
- Examples: by CMOS processes at TSMC, UMC, etc…

0.35µm 2P4M CMOS process

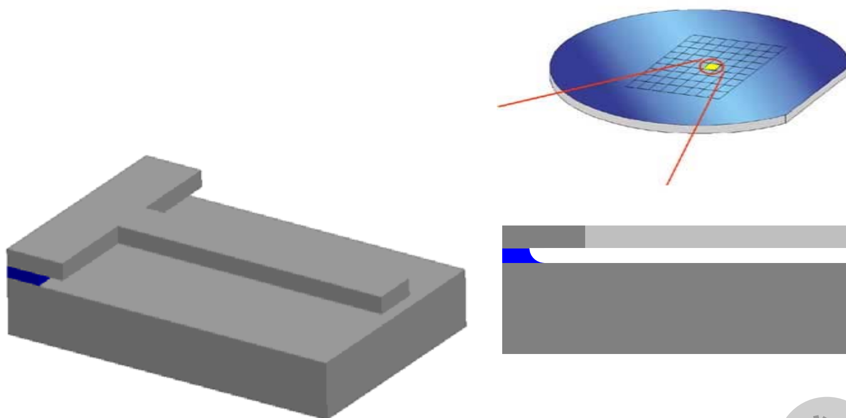


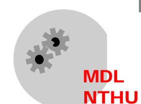
0.18µm 1P6M CMOS process



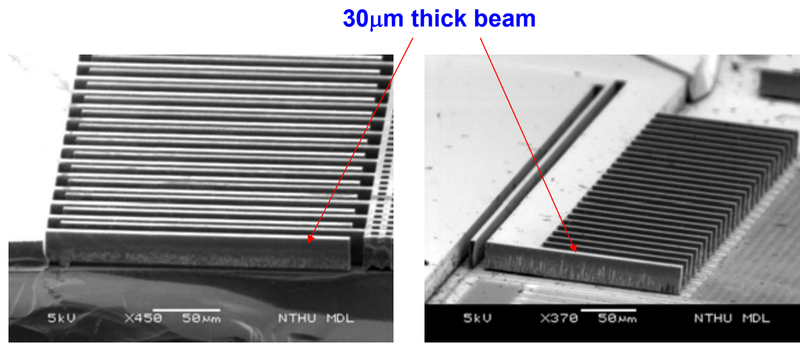


SOI Micromachining

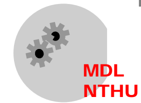




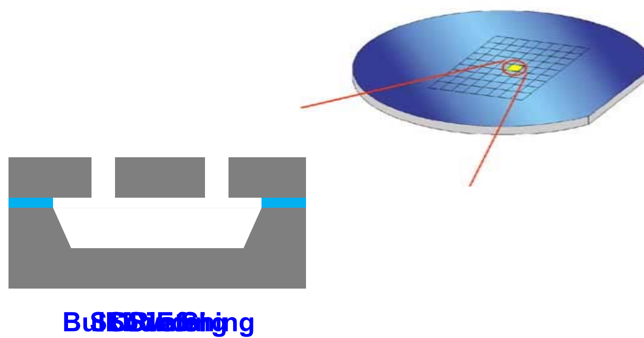
- **SOI Micromachined Beams**

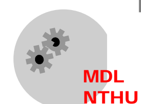


MDL

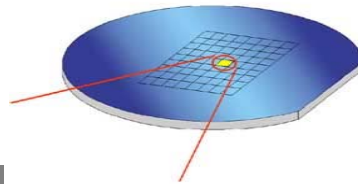


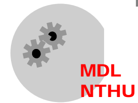
Cavity SOI Micromachining



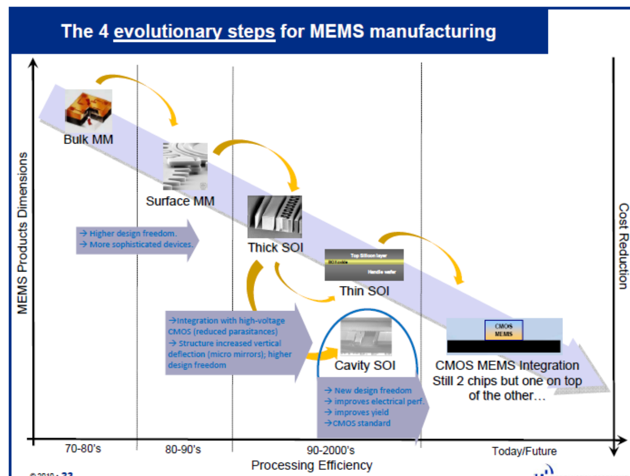


CMOS SOI Micromachining

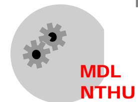




MDL
NTHU

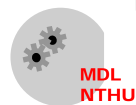


Yole's report, 2010



MDL
NTHU

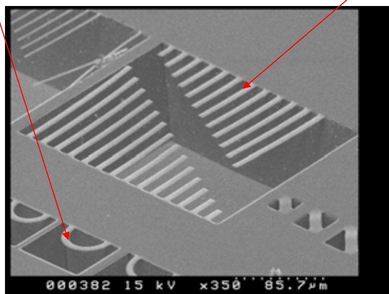
關鍵元件



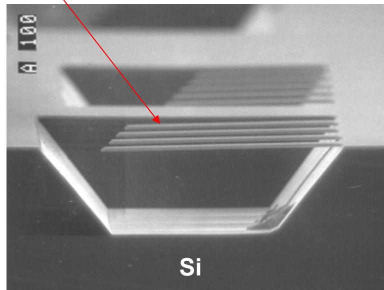
Passive component

- Cantilever, suspension - springs

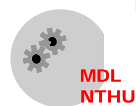
Semi-circular suspension   Cantilever



T. Tzou and W. Fang, 1999

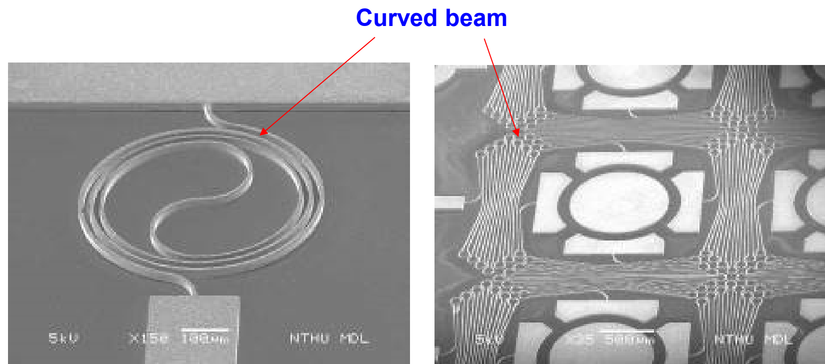


W. Fang, 1994

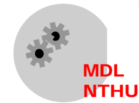


Passive component

- **Curved beam - spring**

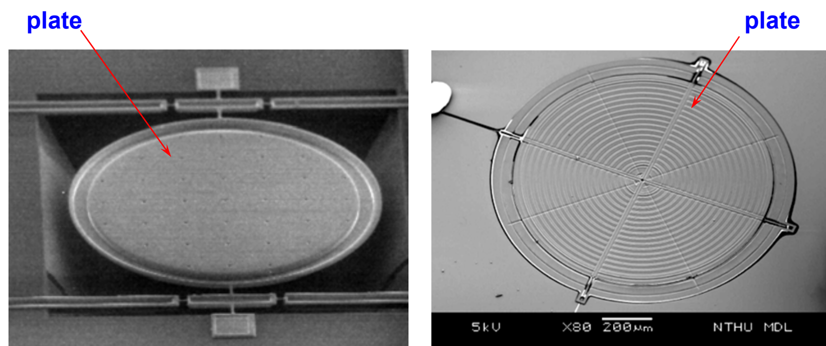


W.-L. Sung and W. Fang, 2014



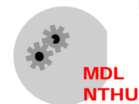
Passive component

- **Plate – rigid mirror, flexible diaphragm (microphone)**



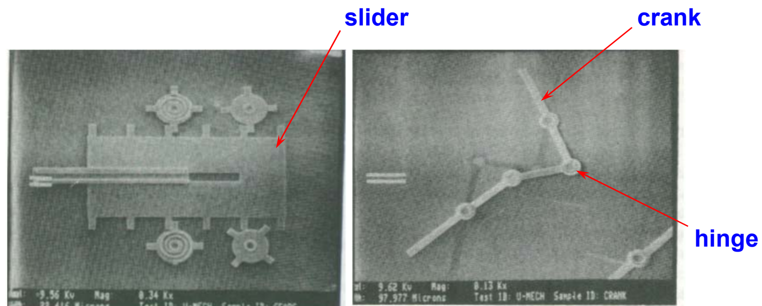
H.-Y. Lin and W. Fang, 2000

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

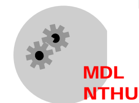


Passive component

- Slider, hinge, cranks

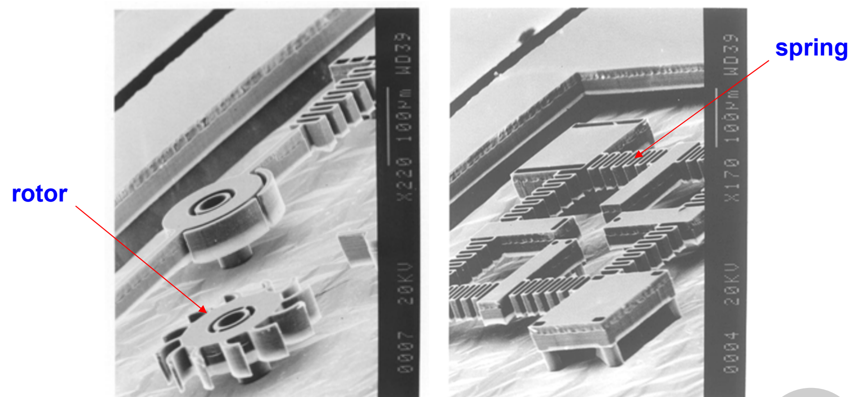


L.-S. Fan, et. al., IEEE Transaction on ED, 1988

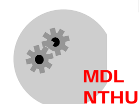


Passive component

- Gear, rotor, linkage

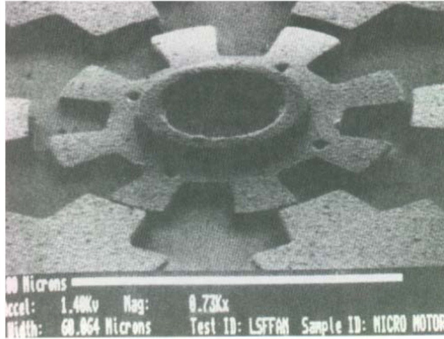


J. Hsieh and W. Fang, 2000

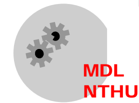


Active component

- Angular electrostatic actuator - motor

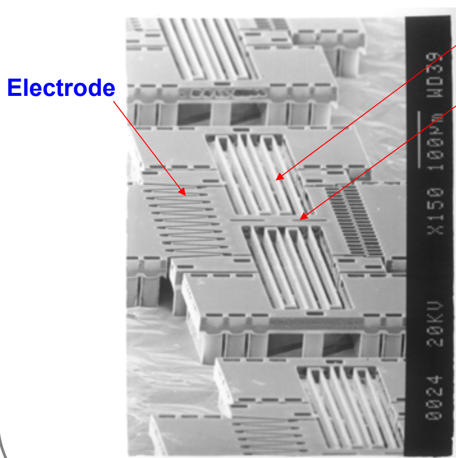


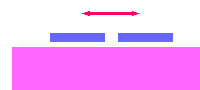
L.-S. Fan, et.al., Int. Electron Devices meeting, 1988

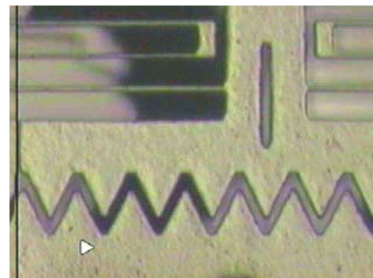


Active component

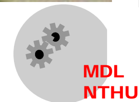
- Linear electrostatic actuator





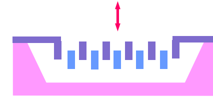


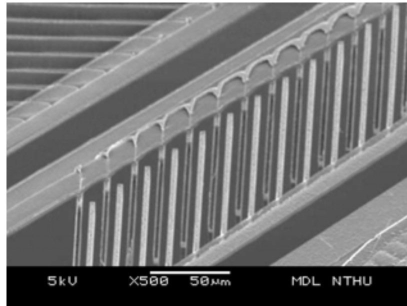
J. Hsieh and W. Fang, 2000

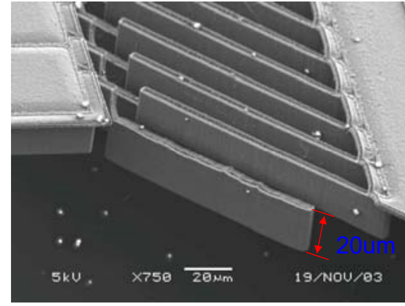


Active component

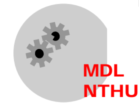
- Linear electrostatic actuator





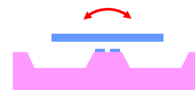


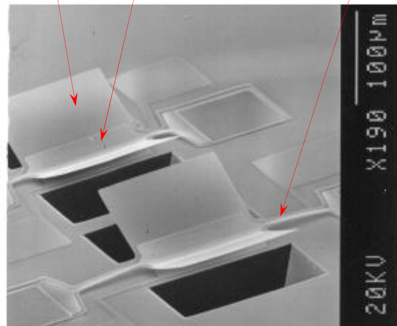
M. Wu and W. Fang, 2005

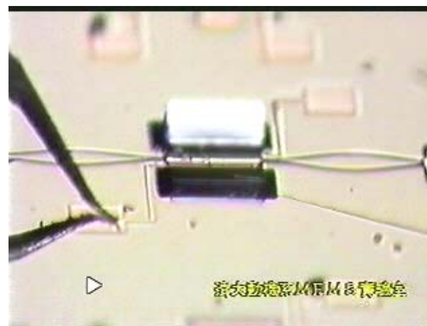


Active component

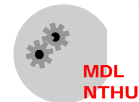
- Angular electrostatic actuator





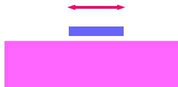


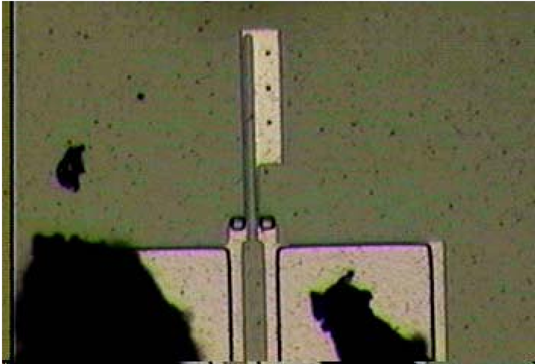
J. Hsieh and W. Fang, *Sensors and Actuators A*, 2000

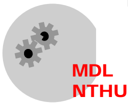


Active component

- Linear thermal actuator

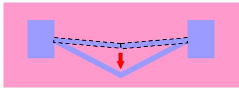






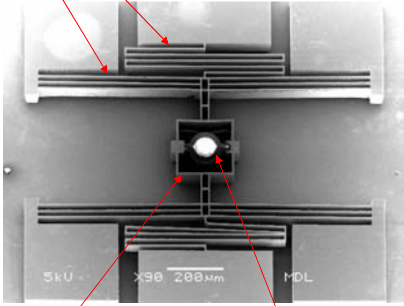
Active component

- Linear thermal actuator



Spring (passive)

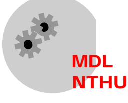
V-beam actuator (active)



Supporting frame (passive)

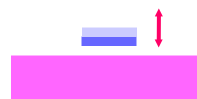
Lens (passive)

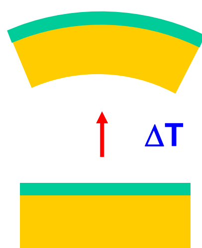
C. Lai, J. Hsieh, and W. Fang, *IEEE Optical MEMS'04*, 2004

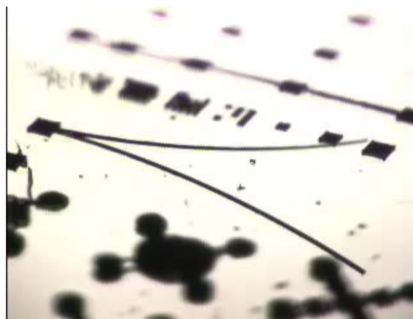


Active component

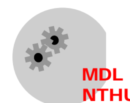
- Linear thermal actuator





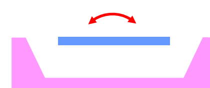


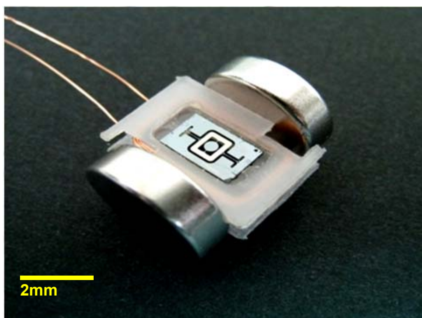
W.-K. Hsu, and W. Fang, *Nanotech*, 2008

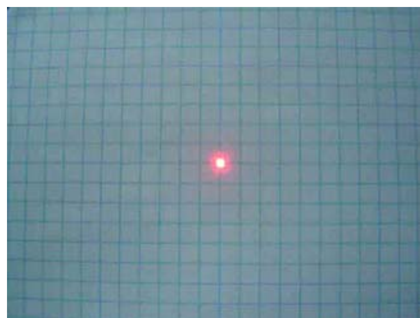


Active component

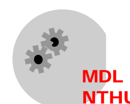
- Angular magnetic actuator



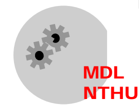




Yang, and Fang, *JMEMS*, 2007

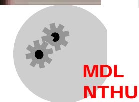


組裝與整合



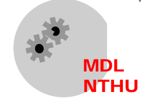
About Mechanical Device

https://www.patek.com/



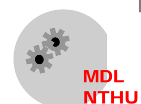
About Mechanical Device

https://www.patek.com/



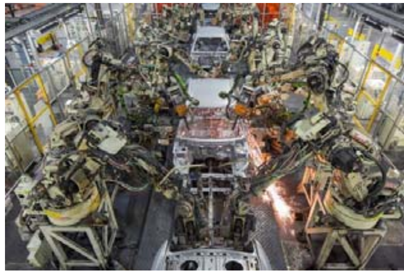
Assembly

www.precisionscalereplicas.com www.kukausa.com



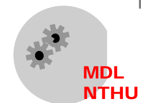
Assembly

- **Toyota and Foxconn assembly lines**



www.youngertoyota.com

www.zaeke.com

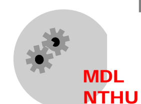


Assembly

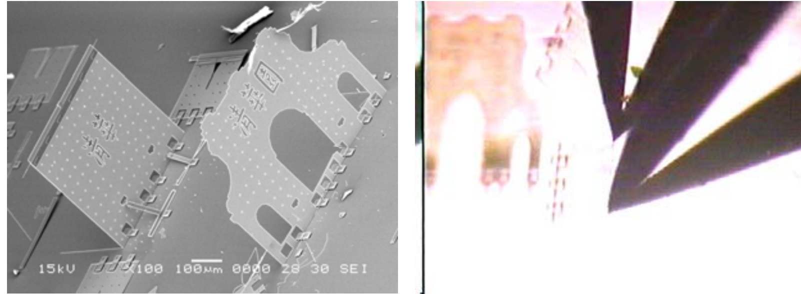
- **Boeing 777 assembly lines**

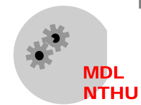
www.ainonline.com

www.flightglobal.com

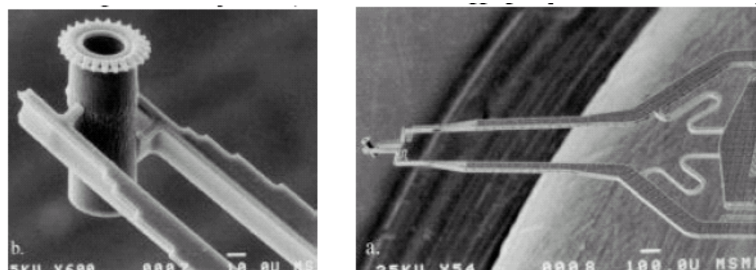


- **Manually assembled by probe**

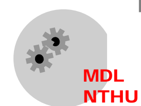




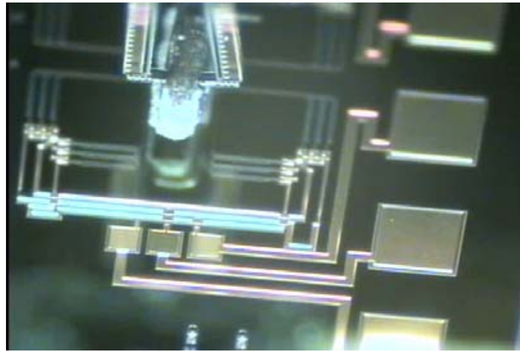
- **Manually assembled by micro gripper**



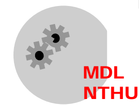
Keller, UC Berkeley, 1998



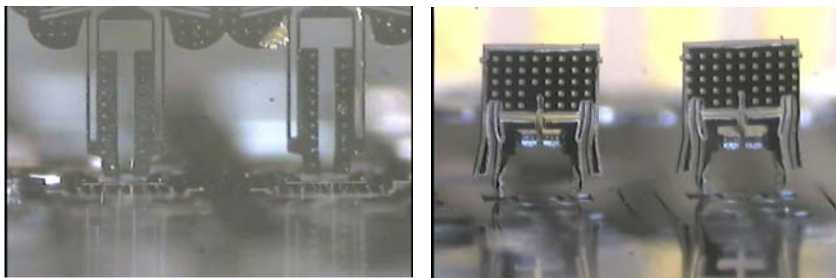
- **Automatically assembled by precision machine**



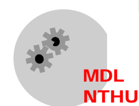
Zyvex Inc.



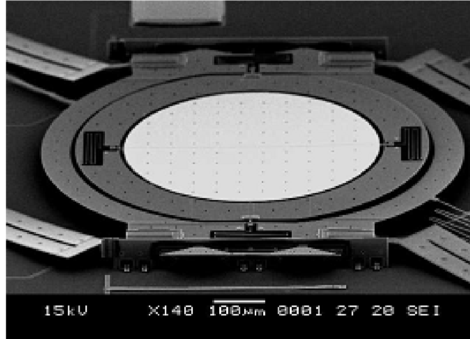
- **Automatically assembled by precision machine**

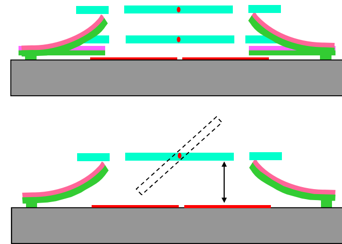


Zyvex Inc.

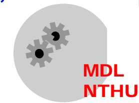


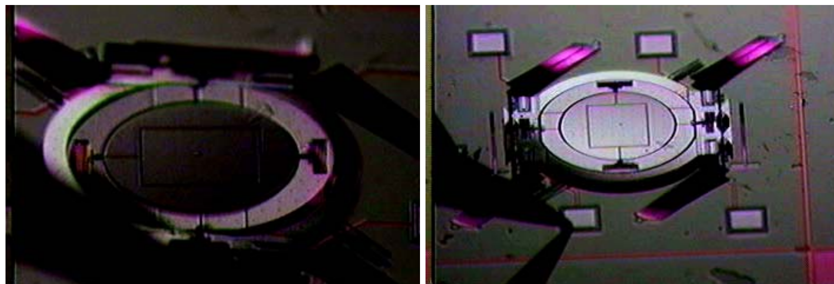
- **Self assembly by residual stress deformed beam**



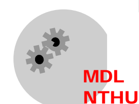


Y.-P. Ho, M. Wu, H. Lin, and W. Fang, *IEEE Optical MEMS '02*, 2002



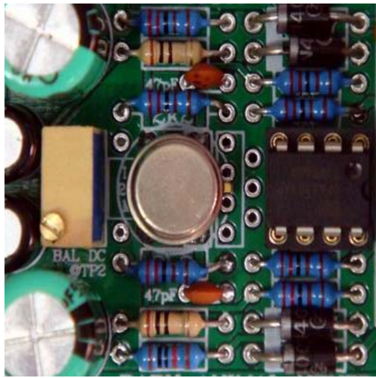


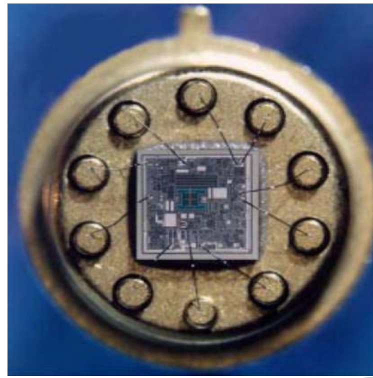
Y.-P. Ho, M. Wu, H. Lin, and W. Fang, *IEEE Optical MEMS '02*, 2002



Process Integration

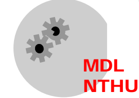
- Discrete vs Integrated electronics components





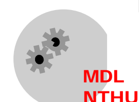
ATM Elektro, Czech Republic

ADI, USA

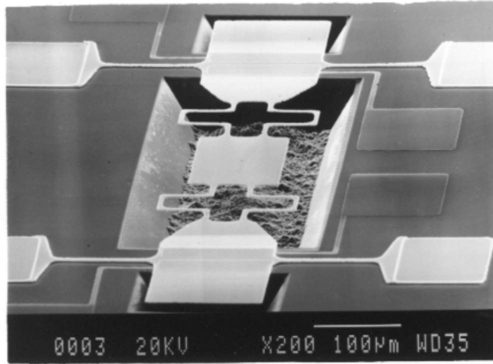


- Assembly by process integration (一體成形)

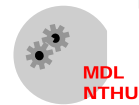
Brigham Young Univ., USA



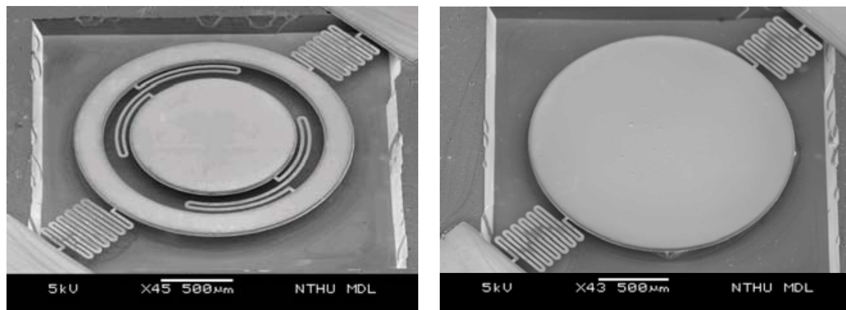
- **Assembly by process integration**



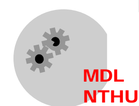
J. Hsieh and W. Fang, *Transducer'99*, 1999



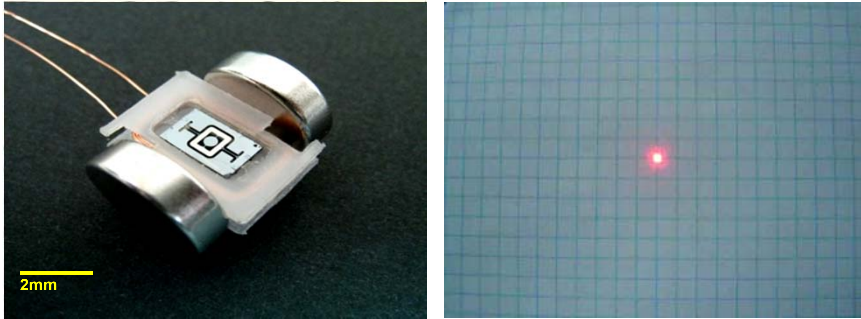
- **Assembly by process integration**



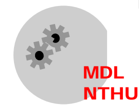
H. Yang, and W. Fang, *IEEE MEMS'06*, Istanbul, Turkey, 2006



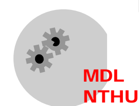
• Scanning images



Yang, and Fang, *JMEMS*, 2007



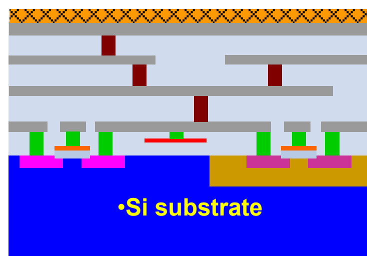
製程平台 – 標準製程



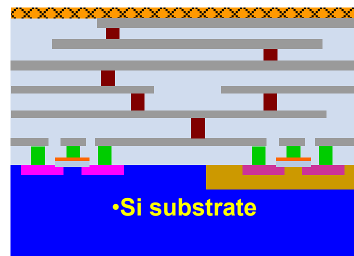
Standard CMOS Processes

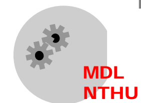
- Available in CMOS foundries: TSMC, UMC, etc…

0.35μm 2P4M CMOS process



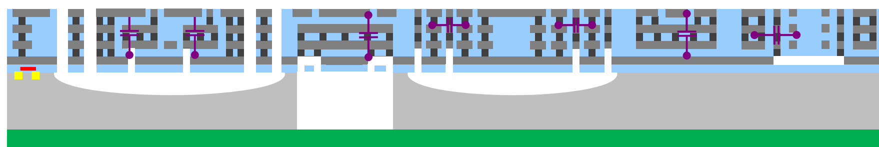
0.18μm 1P6M CMOS process





CMOS-MEMS Platform

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



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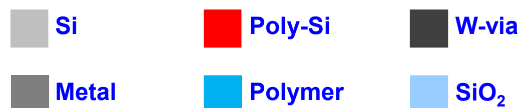
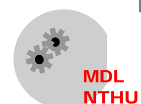


- Standard TSMC 0.35μm 2P4M CMOS process
- Post-CMOS processes developed by Prof. Fang's group



3-axis G-sensor

Z-axis

X-axis

Si

Y-axis

X-axis

Z-axis

Y

Z

X

5kU X120 100μm NTHU MDL

Single proof mass

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

MDL
NTHU

Pressure Sensors

P

Si

Packaging

Suspended diaphragm

5kU X270 50μm NTHU MDL

Diaphragm

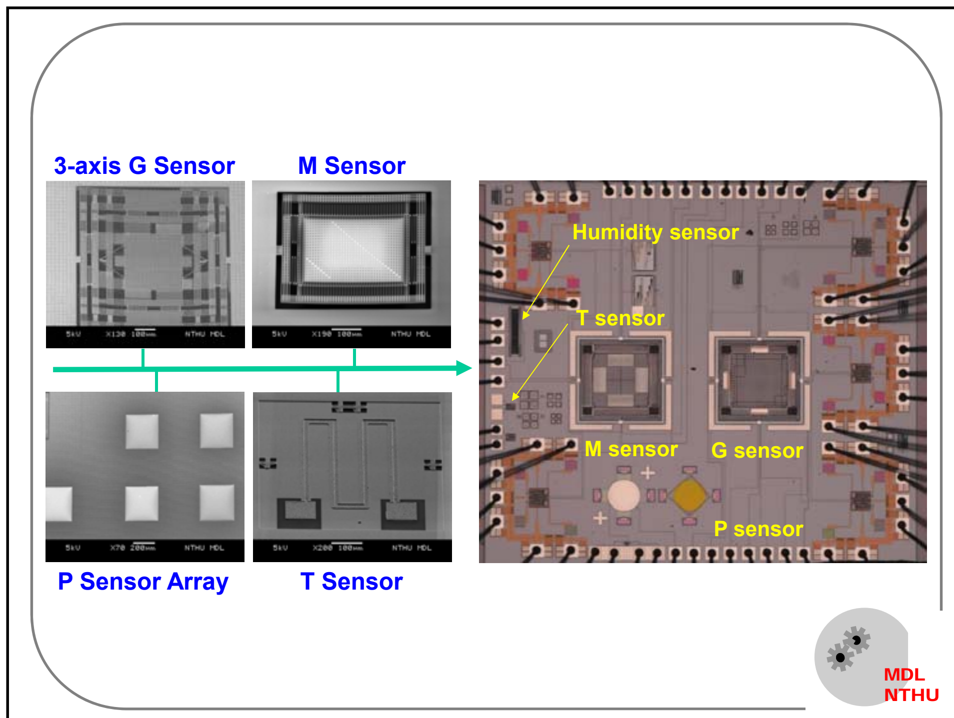
Air-gap

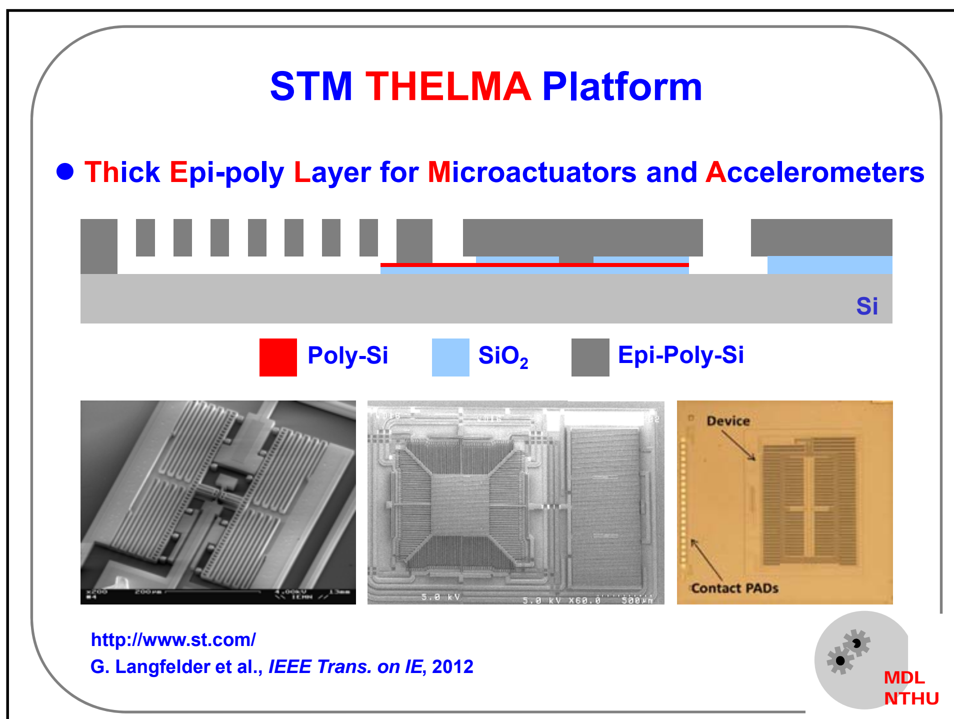
Sensing electrode

FIB sectioning

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

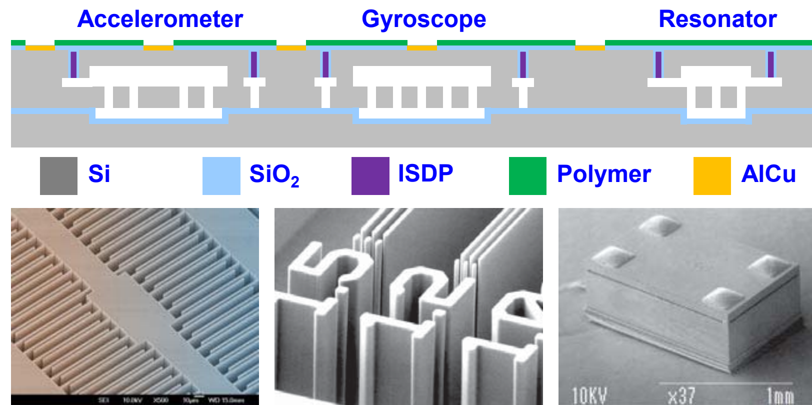
MDL
NTHU


3-axis G Sensor
M Sensor
P Sensor Array
T Sensor
Humidity sensor
T sensor
M sensor
G sensor
P sensor
MDL
NTHU

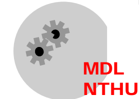

STM THELMA Platform
Thick Epi-poly Layer for Microactuators and Accelerometers
Si
Poly-Si
SiO2
Epi-Poly-Si
Device
Contact PADs
http://www.st.com/
G. Langfelder et al., IEEE Trans. on IE, 2012
MDL
NTHU

Teledyne DALSA MIDIS Platform

- MEMS Integrated Design for Inertial Sensors

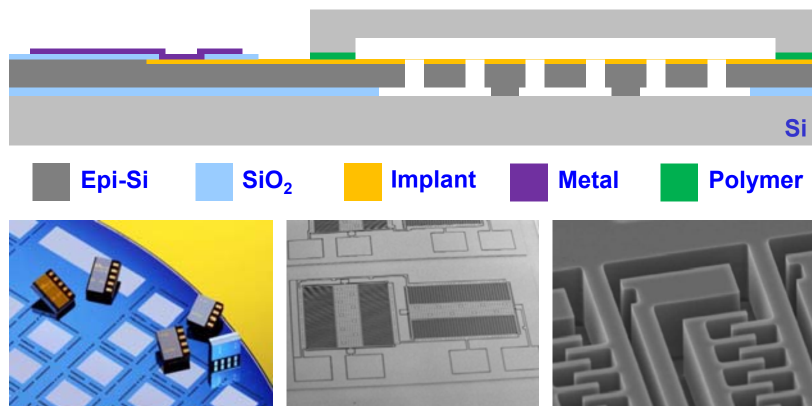


http://www.teledynedalsa.com/



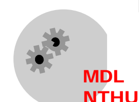
Tronics Platform

- Epi-SOI technology



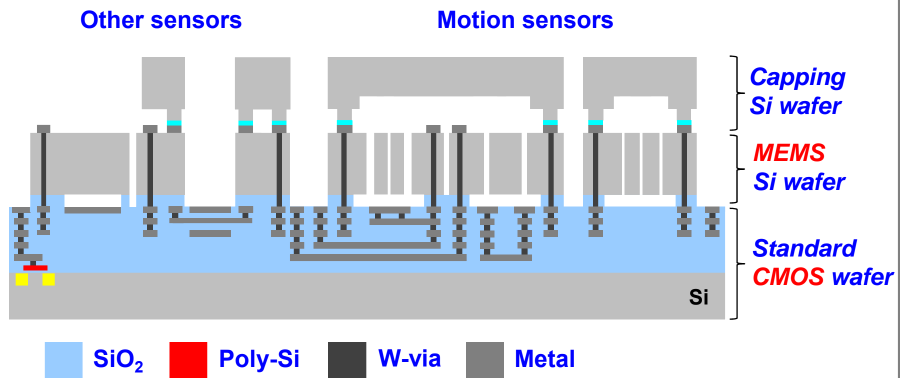
http://www.tronicsgroup.com/

S. Renard, *JMM*, 2000

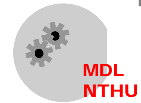


TSMC MEMS Platform

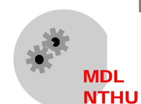
- Si-MEMS above CMOS



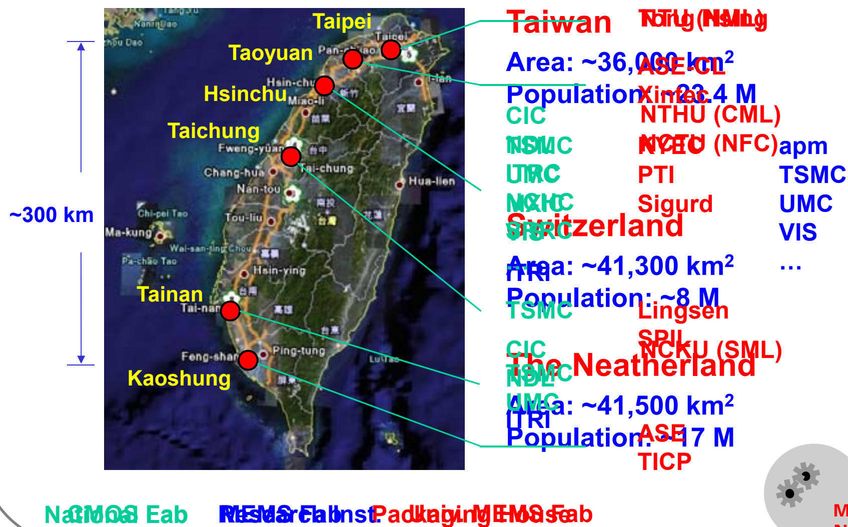
Source：TSMC



台灣現況簡介



MEMS Eco-system at Taiwan

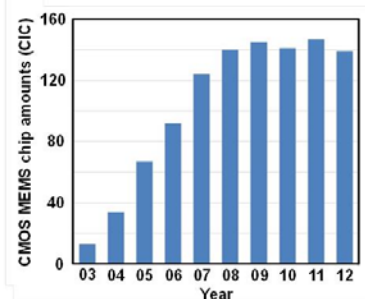


MDL
NTHU

National Lab – CIC (TSRI)

CIC

- 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

MDL
NTHU

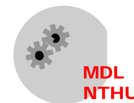
National Lab – NDL (TSRI)

- 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



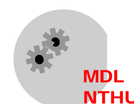
Nonprofit Research Org - ITRI

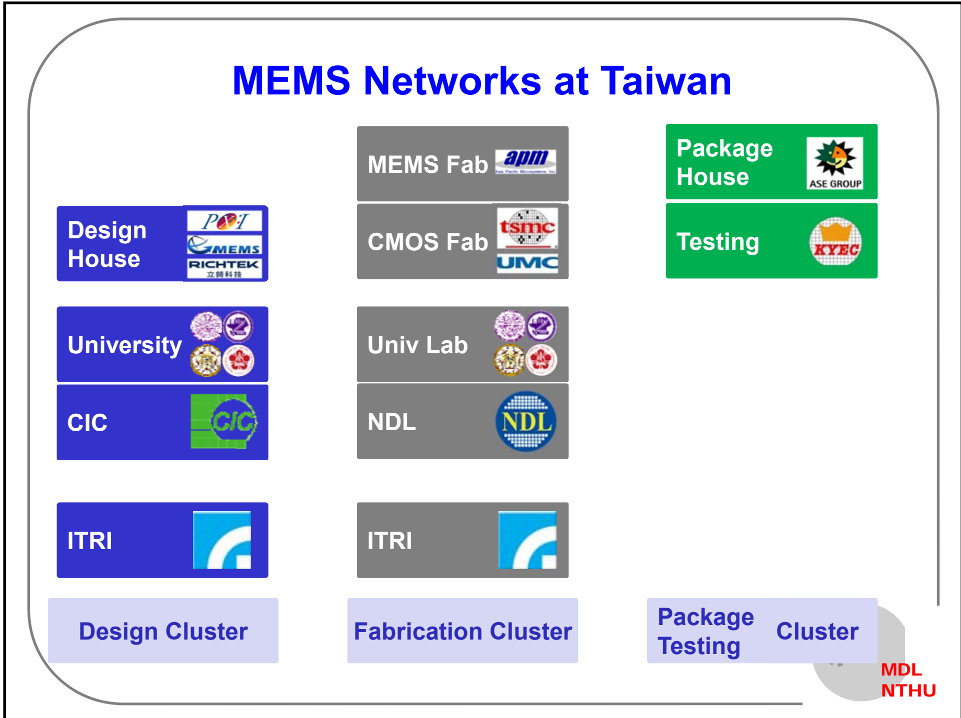
- ITRI: Industrial Tech. Research Inst., since 1973
- Manpower: ~6,000
  + ~200 MEMS engineers/researchers
- Microsystems Tech Center: MEMS total solution
- Pilot-run MEMS Fab: MEMS/post-CMOS processes

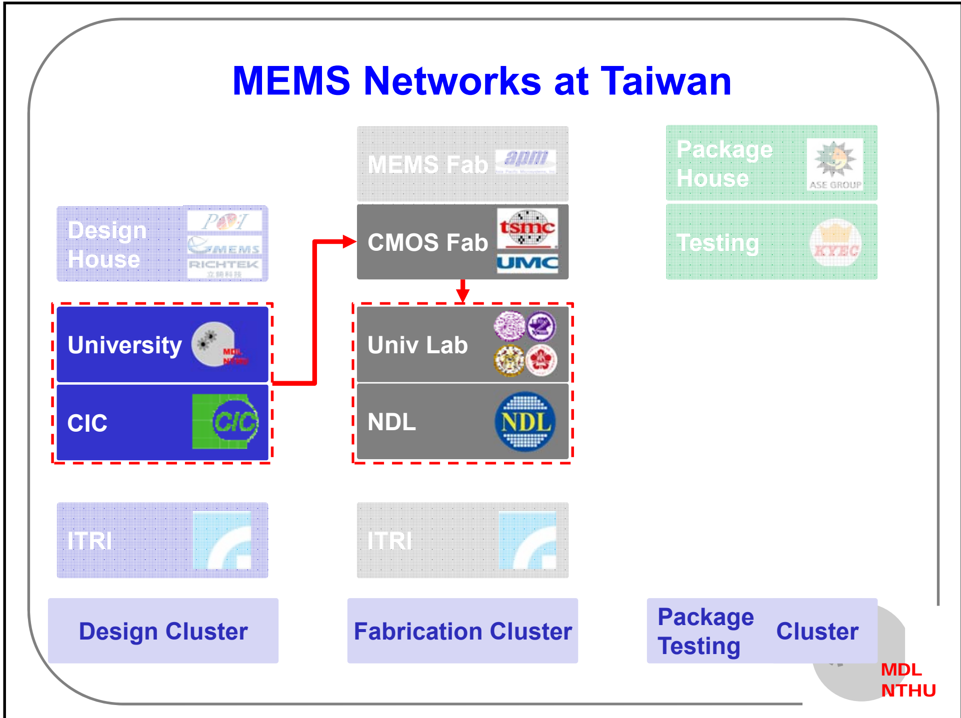
MEMS clean room areas (m^2)

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

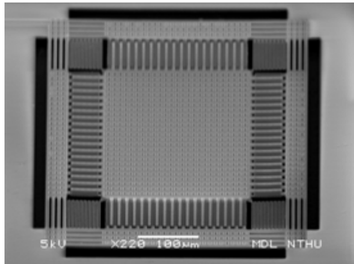
Source：ITRI Southern Region Campus

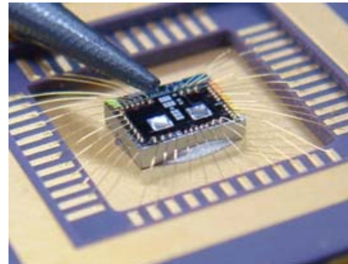



MEMS Networks at Taiwan
MEMS Fab
Package House
Testing
Design House
CMOS Fab
University
Univ Lab
CIC
NDL
ITRI
ITRI
Design Cluster
Fabrication Cluster
Package Testing Cluster
MDL NTHU

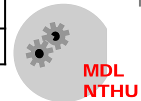

MEMS Networks at Taiwan
MEMS Fab
Package House
Testing
Design House
CMOS Fab
University
Univ Lab
CIC
NDL
ITRI
ITRI
Design Cluster
Fabrication Cluster
Package Testing Cluster
MDL NTHU

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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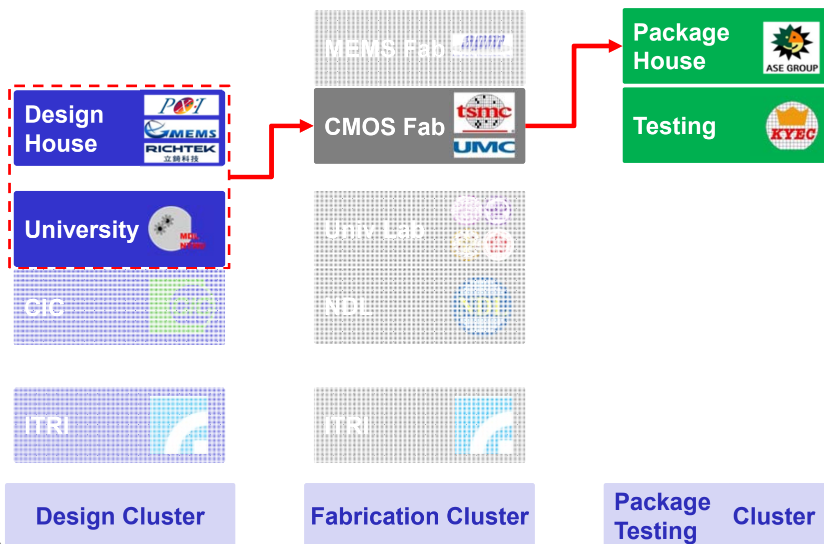
NTHU

MEMS Networks at Taiwan



Design Cluster

Fabrication Cluster

Package Testing Cluster

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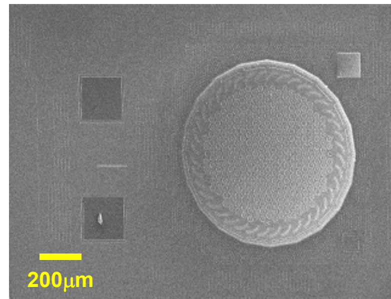
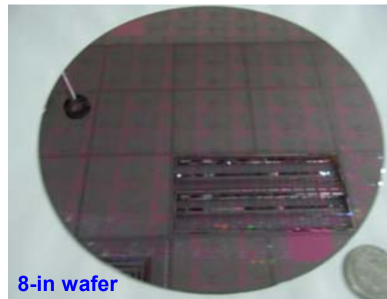
MEMS Sensor – Design Houses

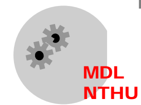
- UMC CMOS processes: 8-inch 0.18um 1P6M process



Microphone by M design house

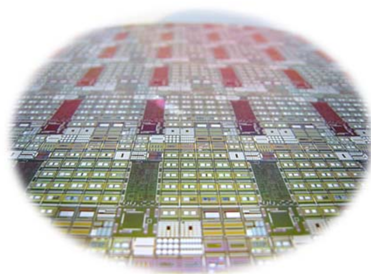


G-sensor by P design house



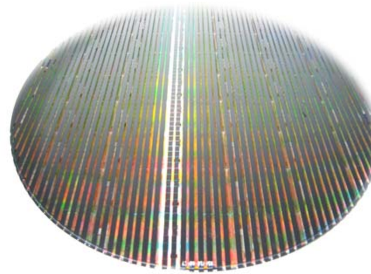
MEMS Sensors - Ecosystems

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



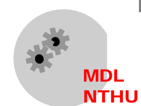
CMOS MEMS on 8" Wafer

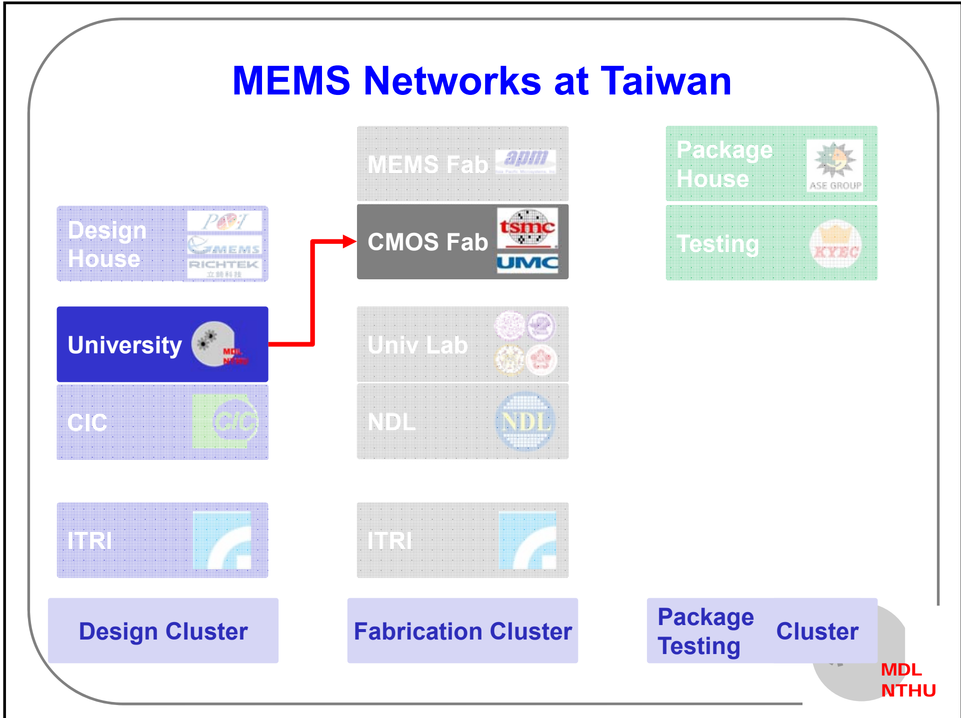
Design Foundry

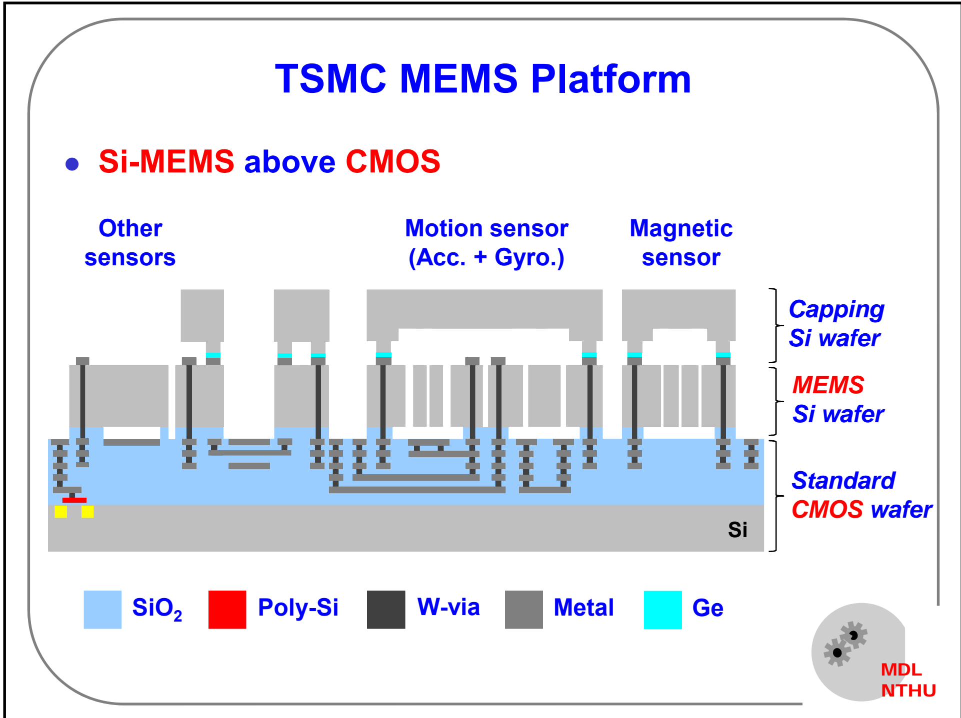


Capped CMOS MEMS Sensors

Packaging Testing

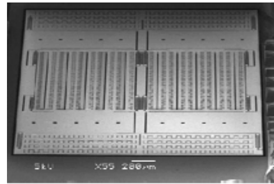
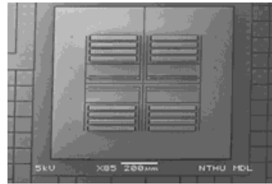
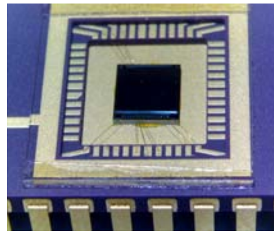
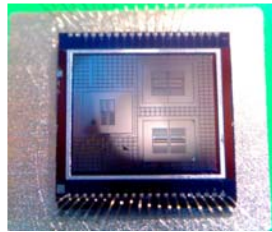



MEMS Networks at Taiwan
MEMS Fab
Package House
Design House
CMOS Fab
Testing
University
Univ Lab
CIC
NDL
ITRI
ITRI
Design Cluster
Fabrication Cluster
Package Testing Cluster
MDL NTHU

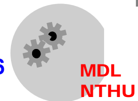

TSMC MEMS Platform
• Si-MEMS above CMOS
Other sensors
Motion sensor (Acc. + Gyro.)
Magnetic sensor
Capping Si wafer
MEMS Si wafer
Standard CMOS wafer
Si
SiO2
Poly-Si
W-via
Metal
Ge
MDL NTHU

TSMC MEMS Platform

- Gyroscope and Magnetic Sensor

Lee and Fang, *IEEE MEMS*, 2016 Sung and Fang, *IEEE MEMS*, 2016



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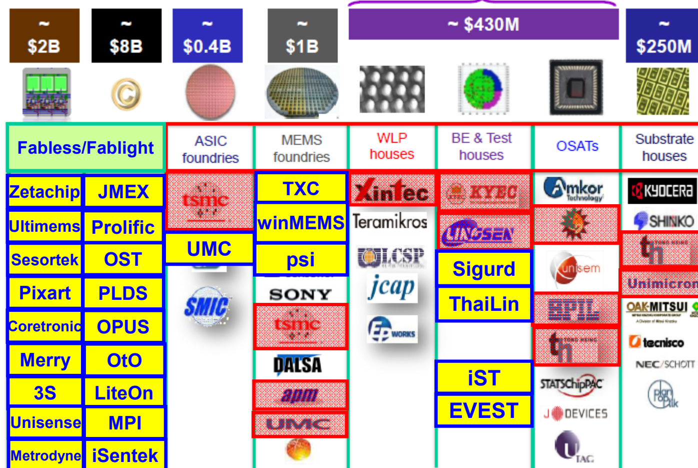

Yole report, SEMICON Taiwan 2012

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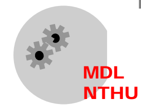
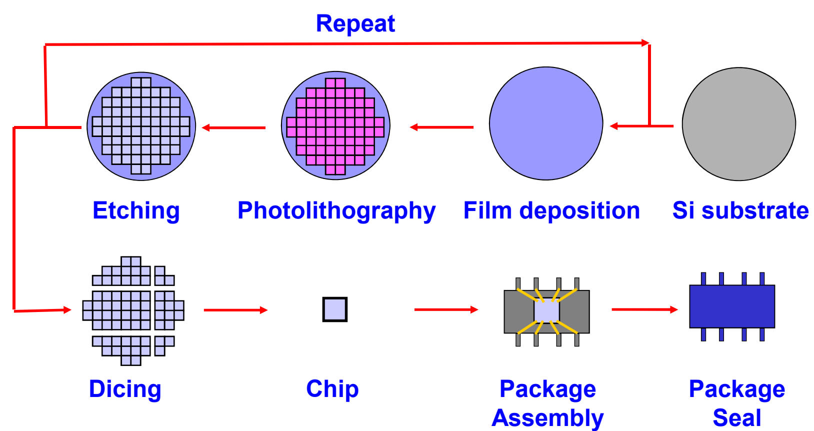
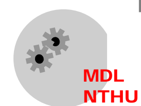
結論

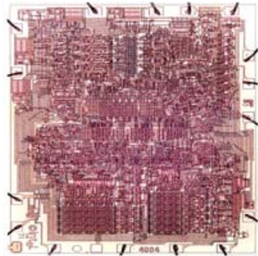


Semiconductor processes

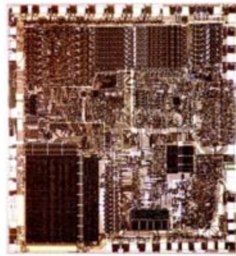




Microprocessor

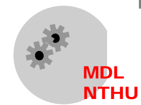


The 4004 – 2.3k transistors, 1971

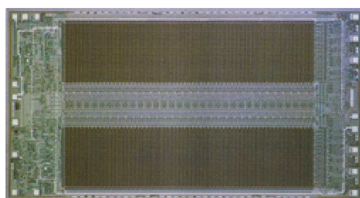


8088/8086 - 29k transistors, 1978

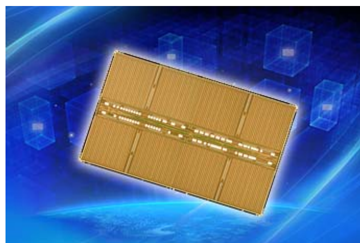
Pentium IV – 42M transistors, 2000



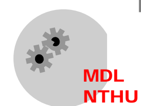
Memory



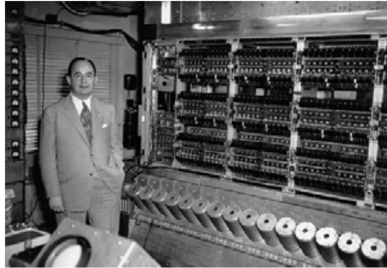
The 16kb DRAM, 1976



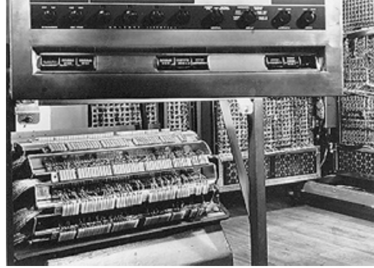
The 2Gb DRAM, 2011



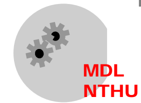
Computer



von Neumann and his
“computer”, 1952

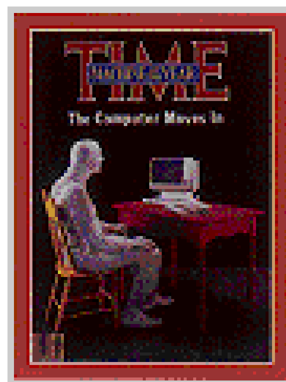


IBM 650, 1954

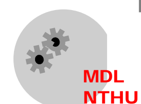


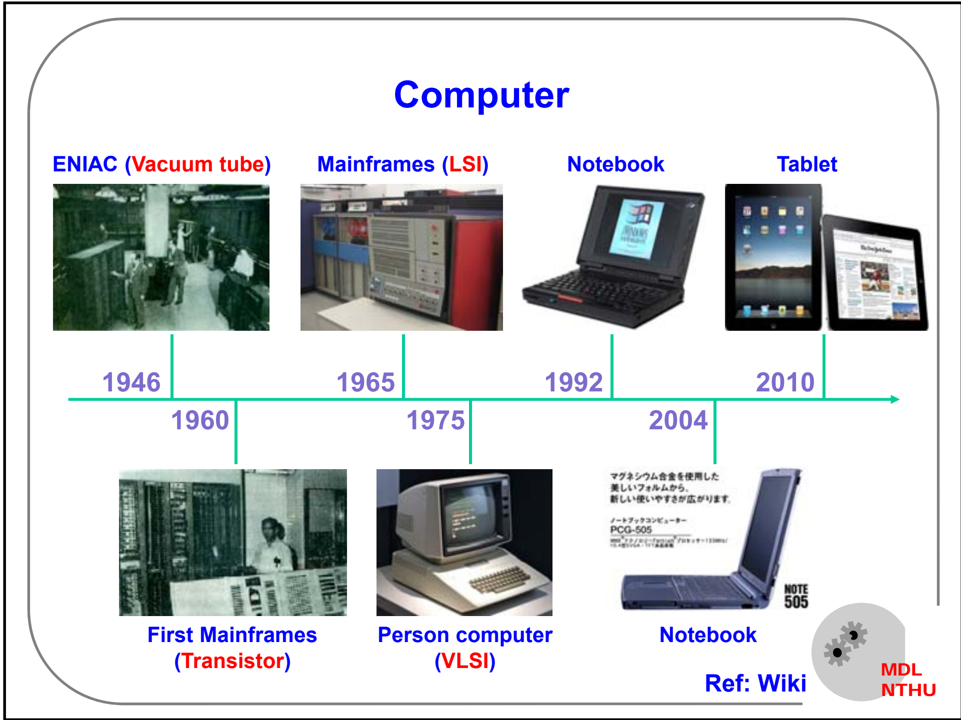
Computer

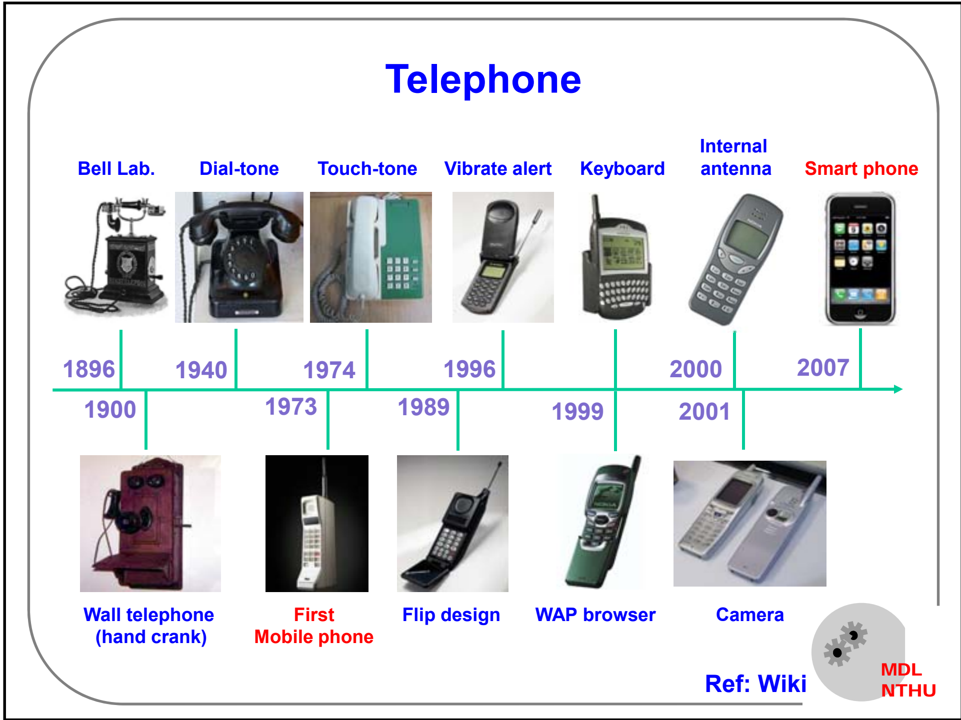
Jobs & Wozniak with Apple II - 1976

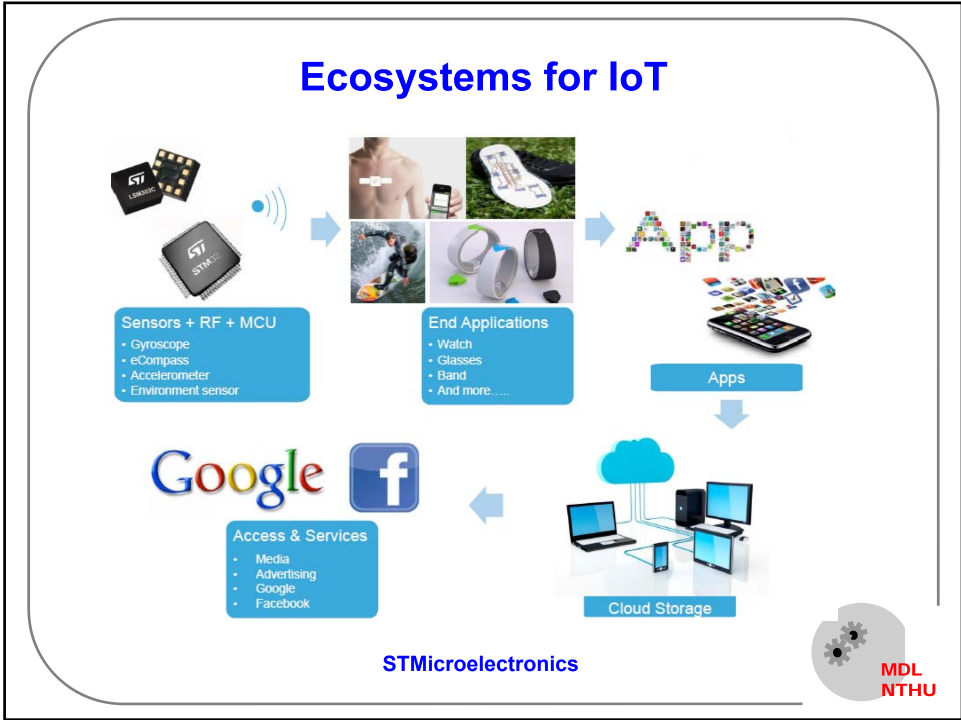


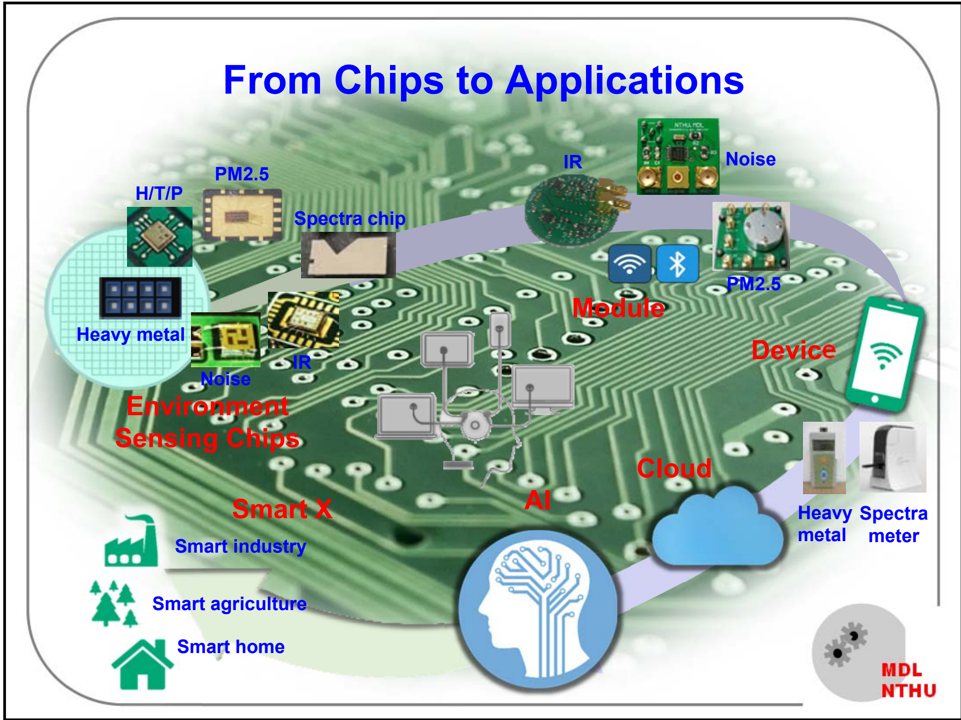
IBM PC – 1981/2

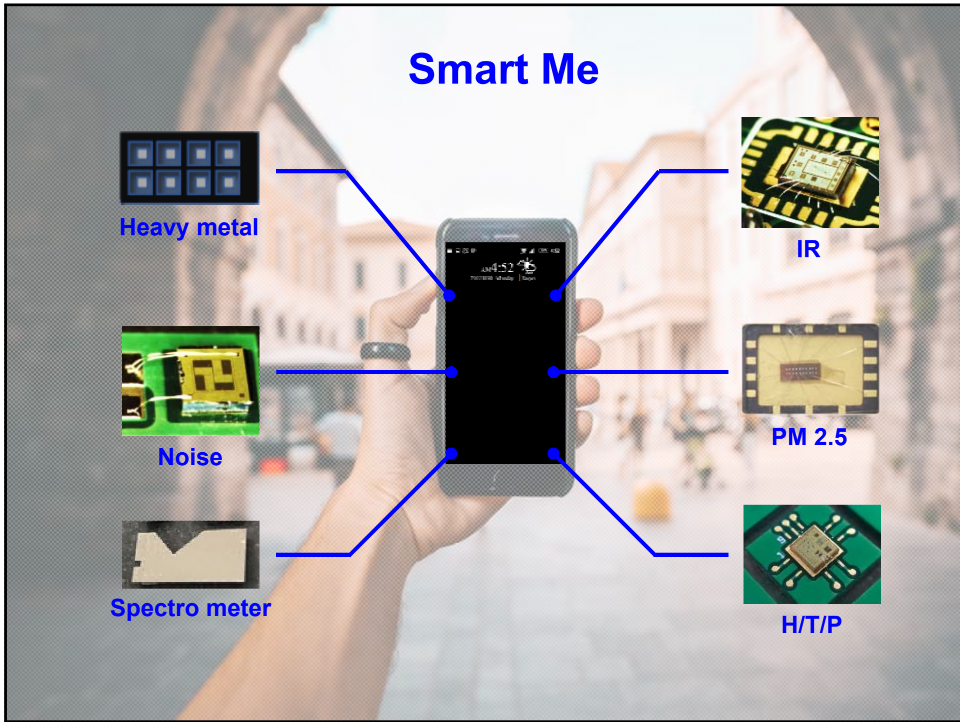


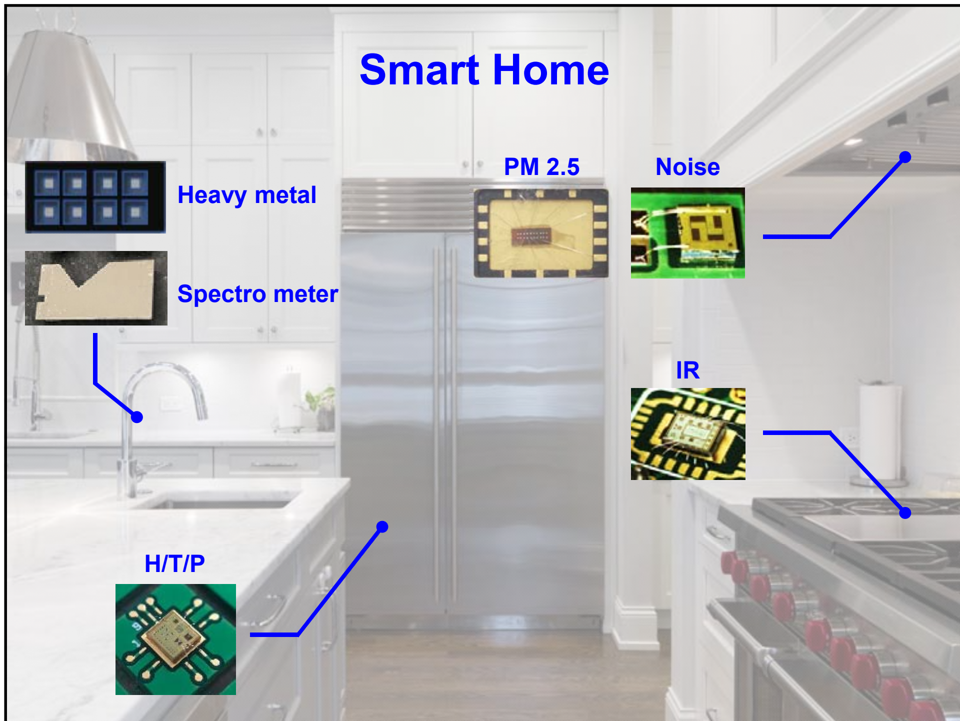

Computer
ENIAC (Vacuum tube)
Mainframes (LSI)
Notebook
Tablet
1946
1965
1992
2010
1960
1975
2004
NOTE 505
First Mainframes
(Transistor)
Person computer
(VLSI)
Notebook
Ref: Wiki
MDL
NTHU

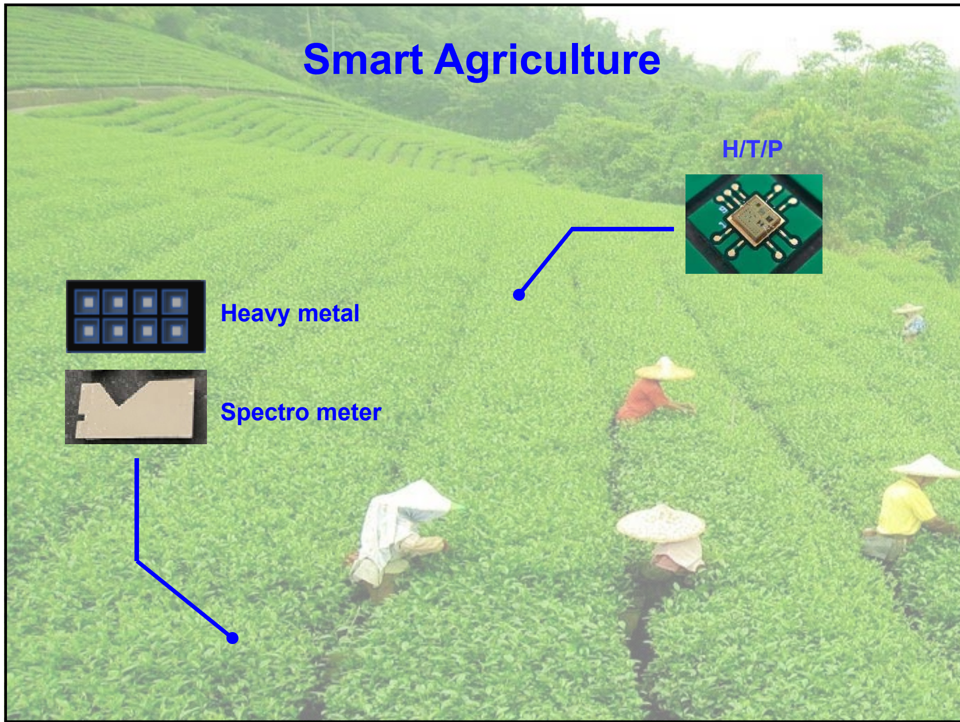

Telephone
Bell Lab.
Dial-tone
Touch-tone
Vibrate alert
Keyboard
Internal antenna
Smart phone
1896
1940
1974
1996
2000
2007
1900
1973
1989
1999
2001
Wall telephone
(hand crank)
First
Mobile phone
Flip design
WAP browser
Camera
Ref: Wiki
MDL
NTHU

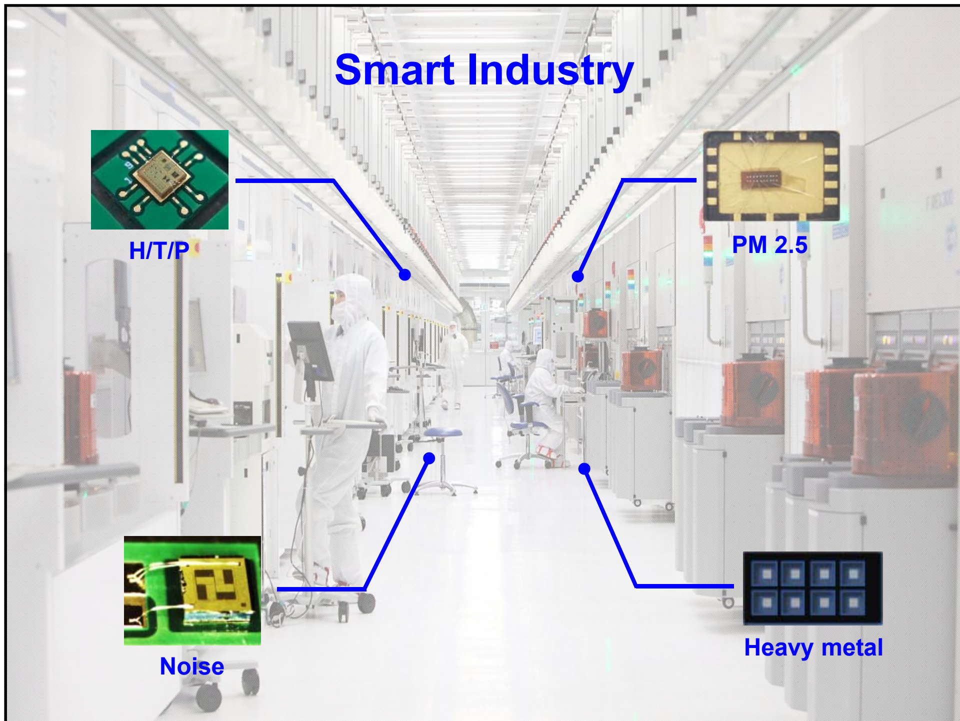

Ecosystems for IoT
Sensors + RF + MCU
• Gyroscope
• eCompass
• Accelerometer
• Environment sensor
End Applications
• Watch
• Glasses
• Band
• And more.....
App
Apps
Cloud Storage
Google
Access & Services
Media
Advertising
Google
Facebook
STMicroelectronics
MDL
NTHU

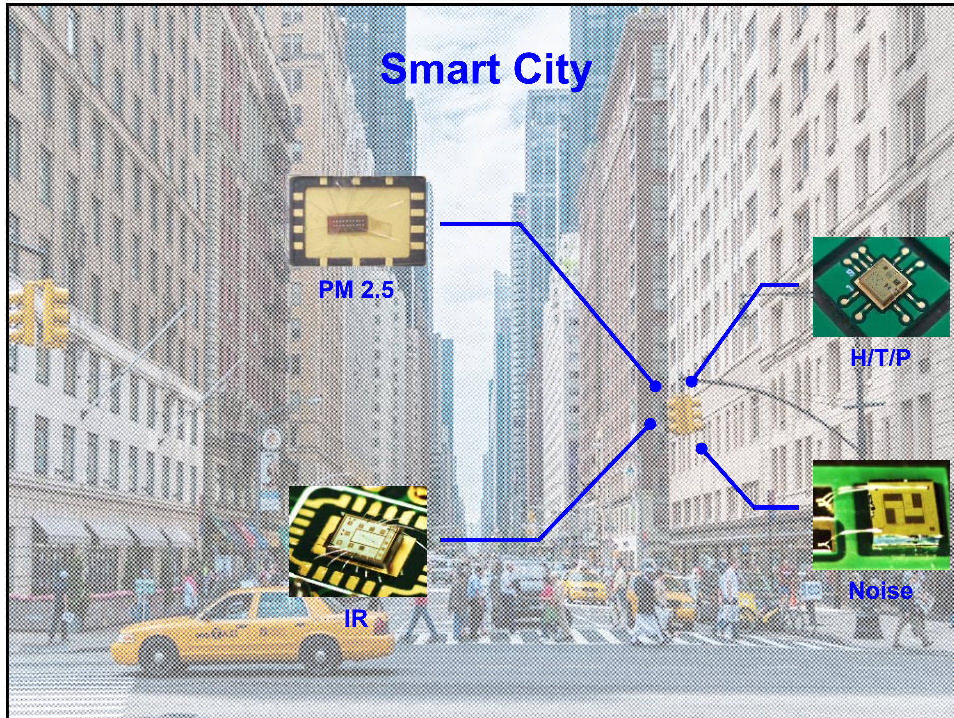

From Chips to Applications
H/T/P
PM2.5
Spectra chip
Heavy metal
Noise
IR
Environment
Sensing Chips
IR
Noise
PM2.5
Module
Device
Cloud
AI
Smart X
Smart industry
Smart agriculture
Smart home
Heavy metal
Spectra meter
MDL
NTHU


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


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


Smart Agriculture
H/T/P
Heavy metal
Spectro meter

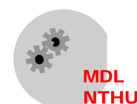

Smart Industry
H/T/P
PM 2.5
Noise
Heavy metal



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.

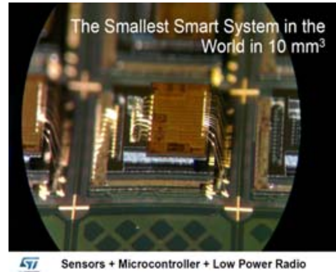
www.appledaily.com.tw



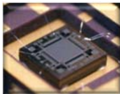
MDL
NTHU

Semiconductor: Key Tech for *IoT*

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

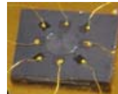


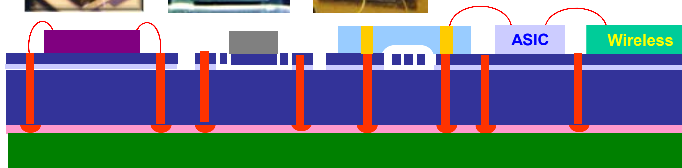
G sensor

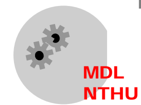


Humidity

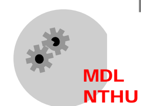
Microphone



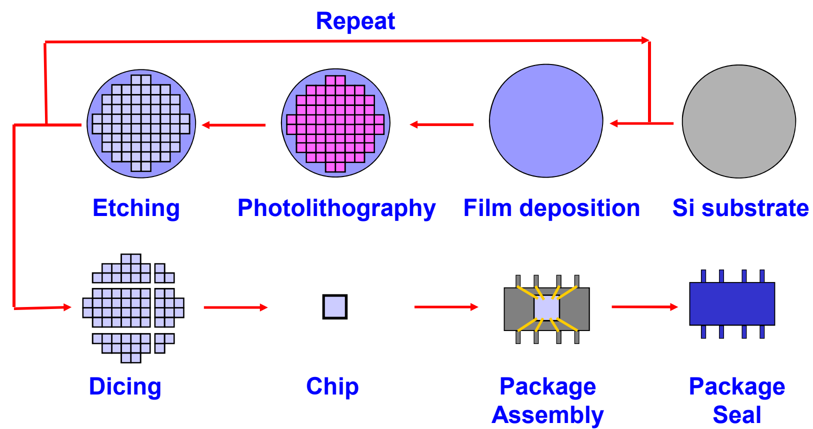


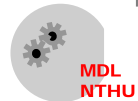


課程安排



Semiconductor processes

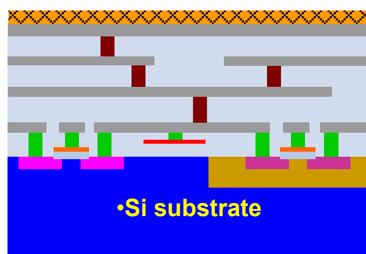




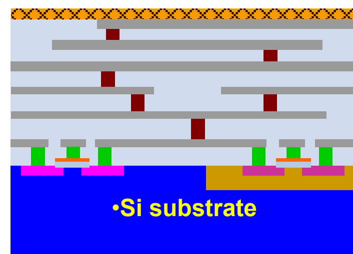
Standard CMOS Processes

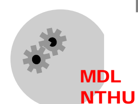
- Available in CMOS foundries: TSMC, UMC, etc…

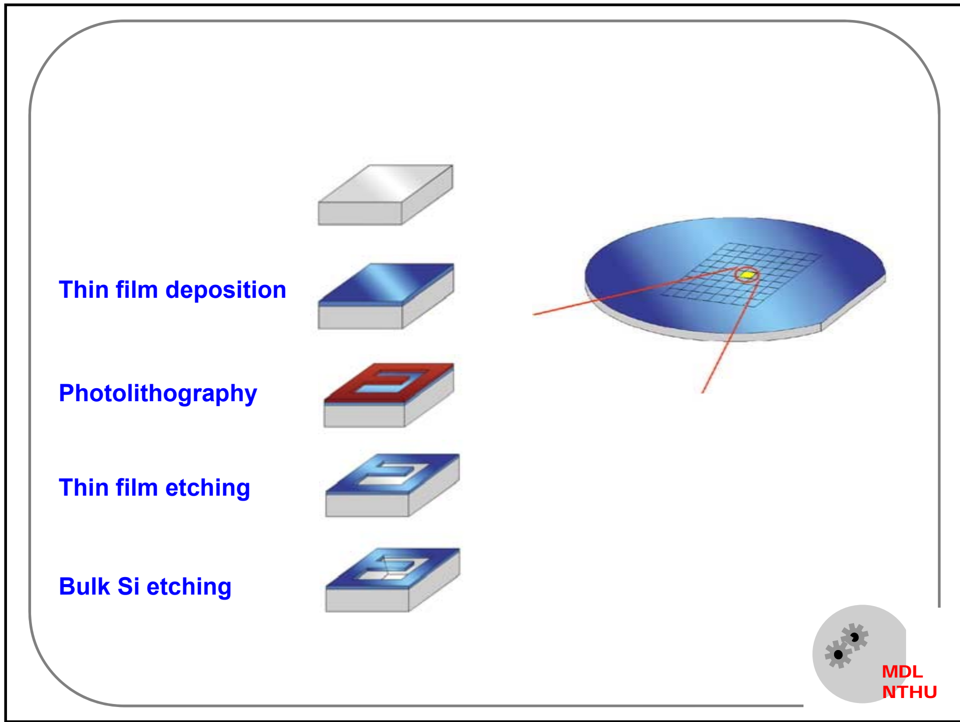
0.35μm 2P4M CMOS process

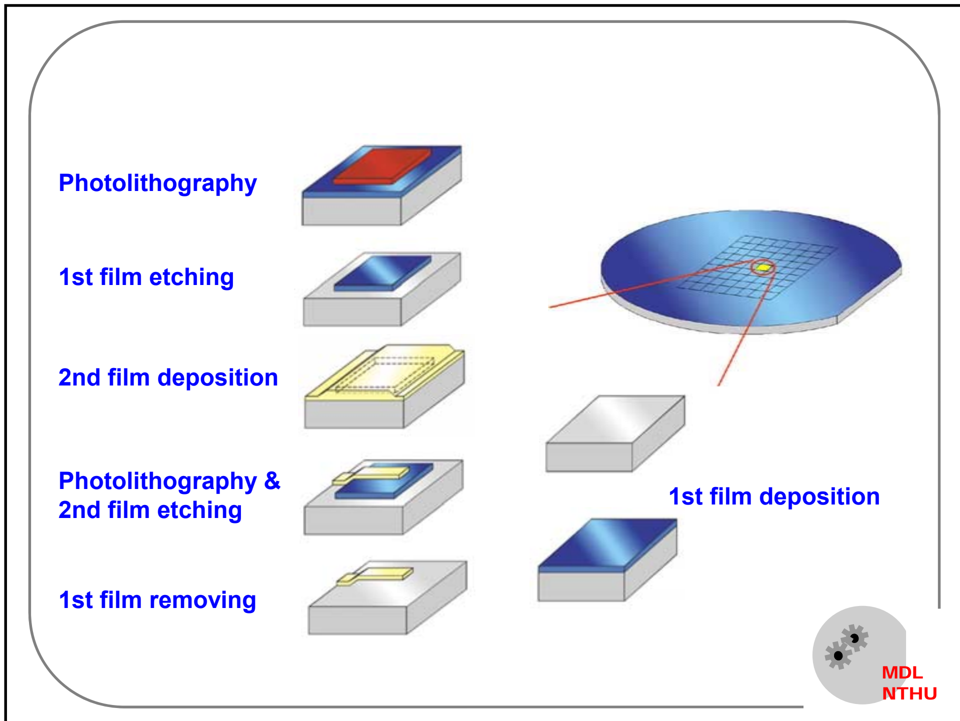


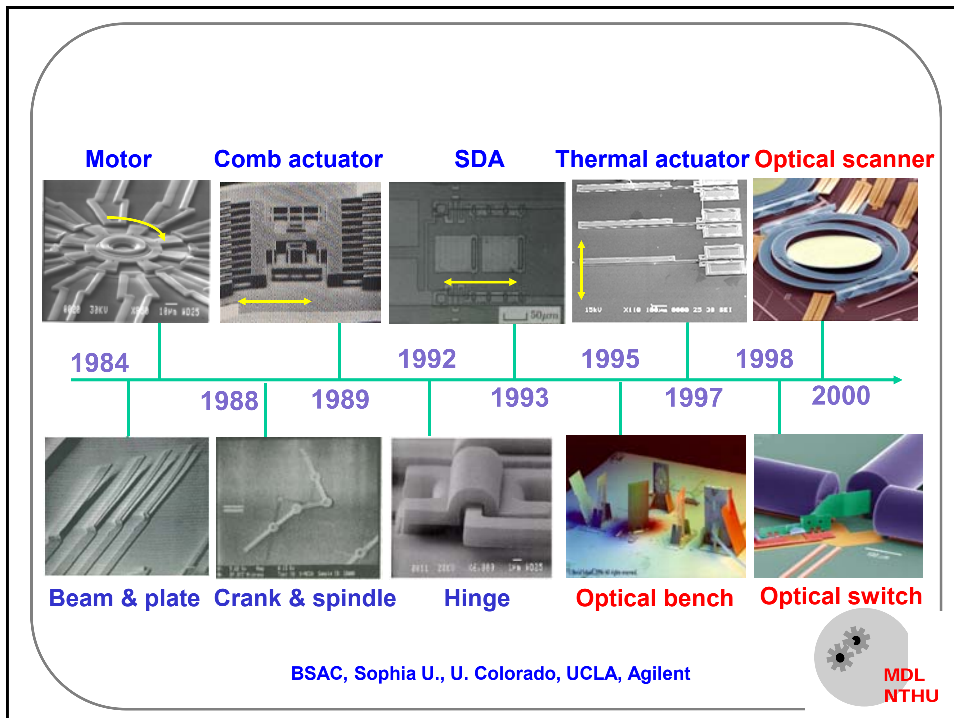
0.18μm 1P6M CMOS process






Thin film deposition
Photolithography
Thin film etching
Bulk Si etching
MDL
NTHU


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
MDL
NTHU