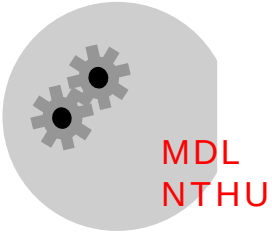
奈微米尺寸機器之製造及其應用

方維倫 教授

國立清華大學 動機系/微機電所

fang@pme.nthu.edu.tw

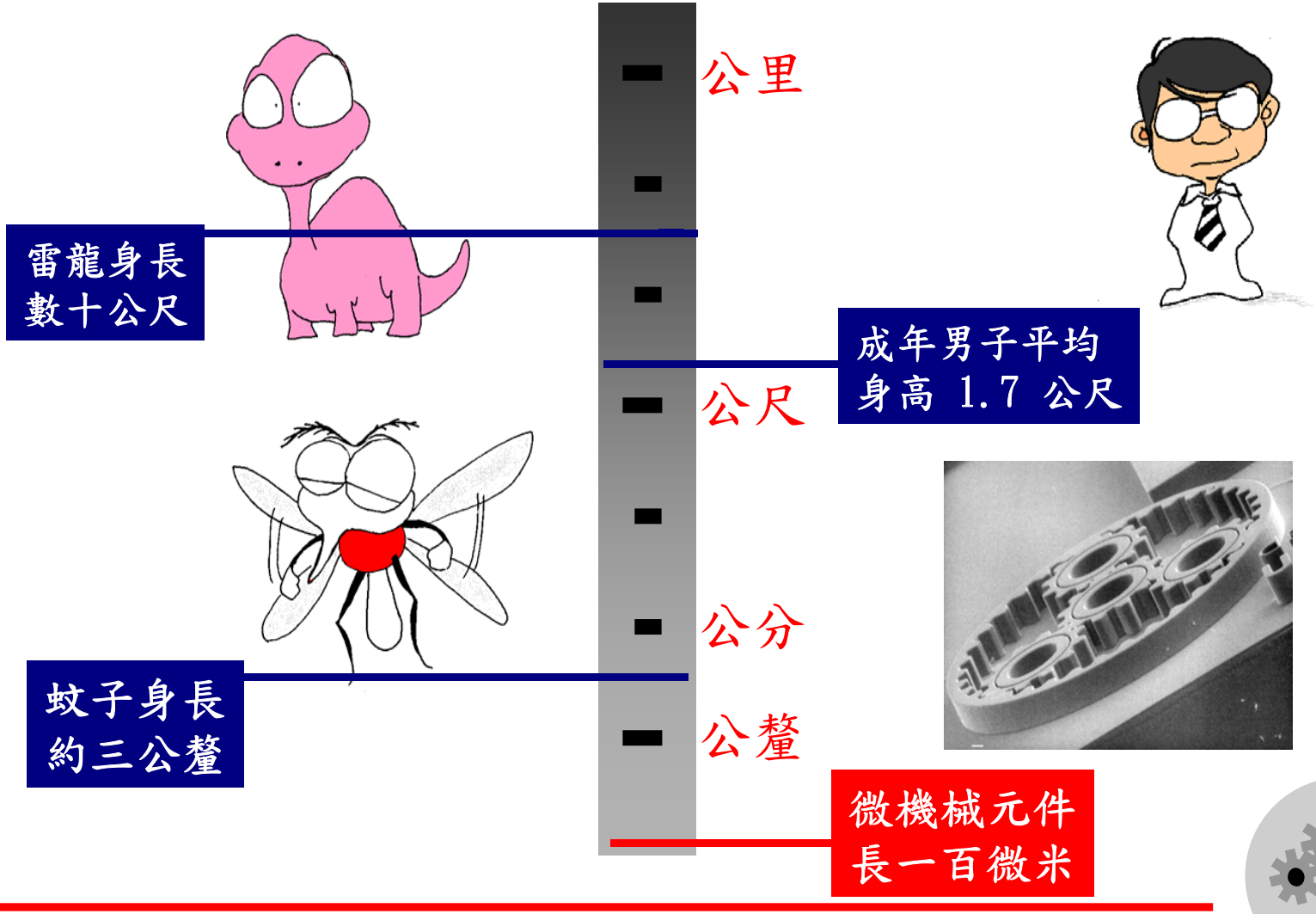
http://mdl.pme.nthu.edu.tw



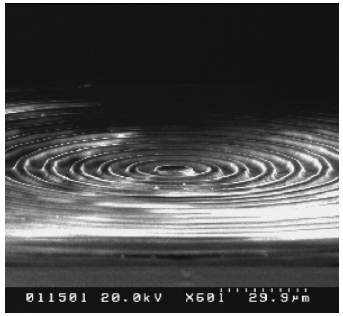
螞蟻與微結構

MDL
NTHU

MDL
NTHU



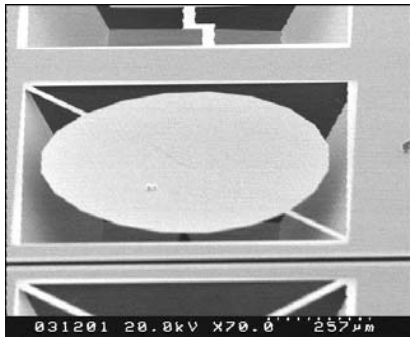
MDL
NTHU



公釐

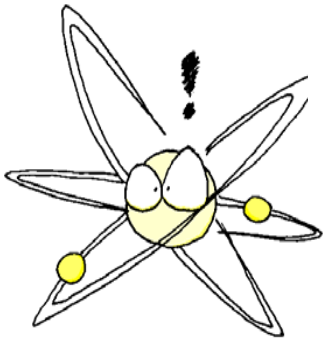
微機械元件
長一百微米

微光學元件
長數十微米



細菌約數微米

微米 = 百萬分之一公尺

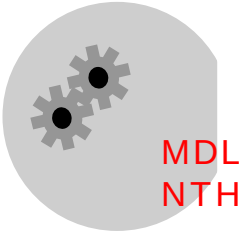


病毒約五十奈米

奈米 = 十億分之一公尺

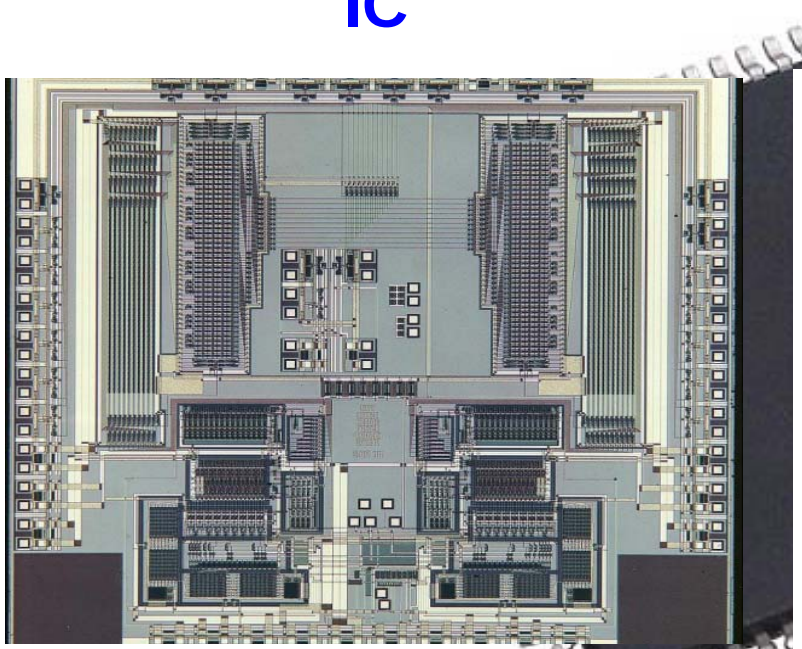
原子直徑
1-4埃

埃 = 百億分之一公尺



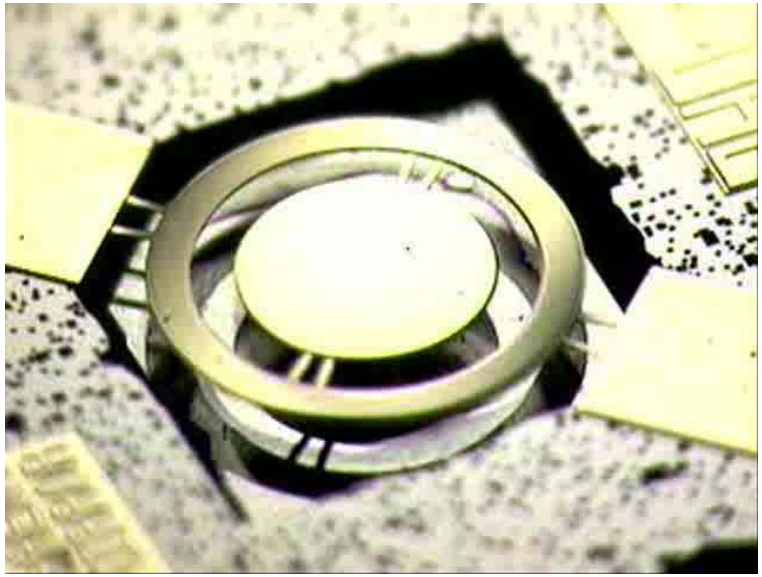
MDL
NTHU

IC



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

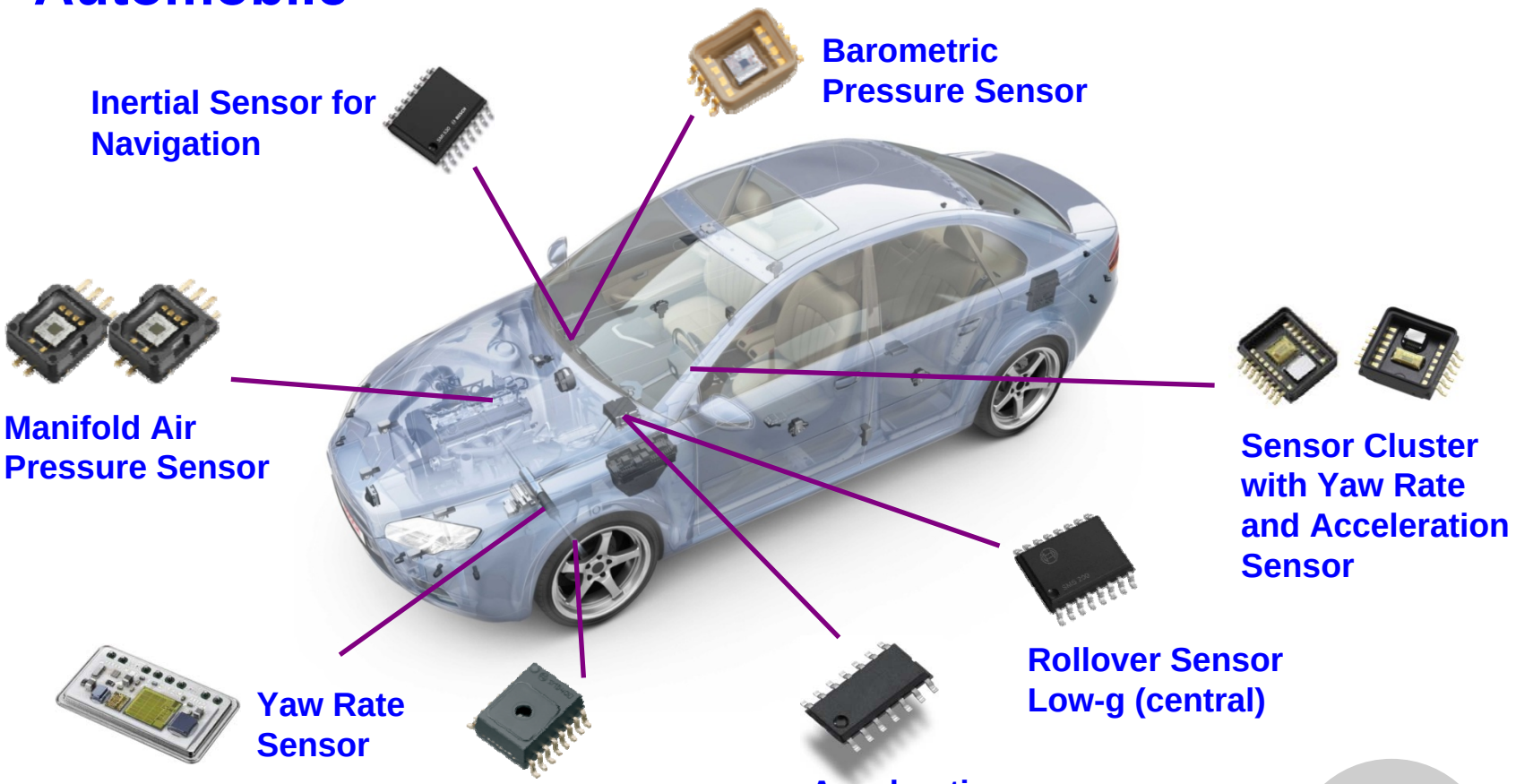
MEMS



MDL

Texas Instruments Inc.

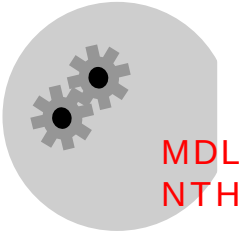
• Automobile



- **2006~present**

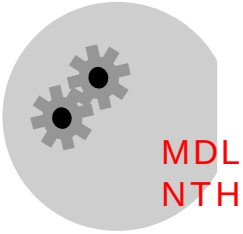
Camera 2006 iPad 2010

前言

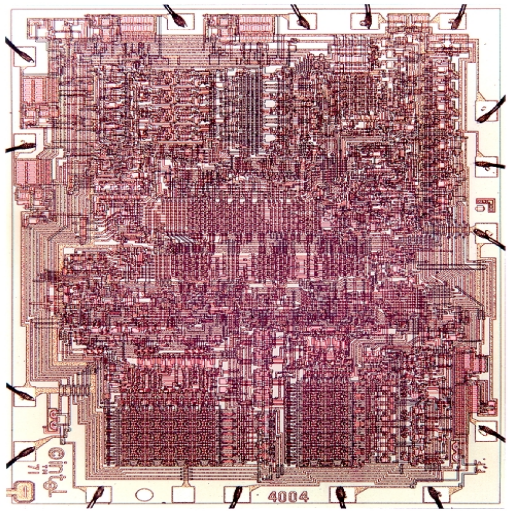


歷史背景

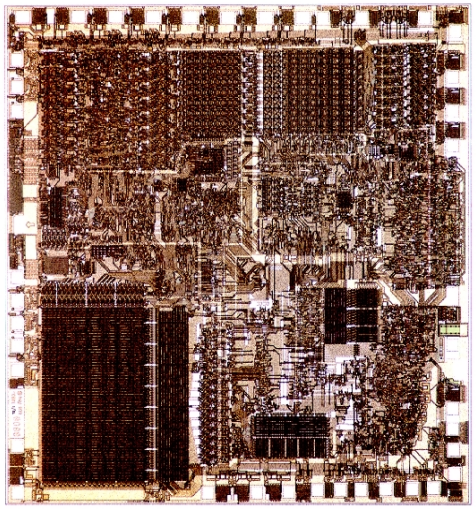
- **1947 : 1st Transistor (Bell lab)**
- **1958 : Planar technology (Fairchild)**
- **1959 : 1st IC (TI, Kilby)**
- **1969 : 1st commercial RAM (Intel, 256 bit)**
- **1971 : 1st Micro processor (Intel, 2300 transistors; 7.5M transistors for Pentium II at 1997)**



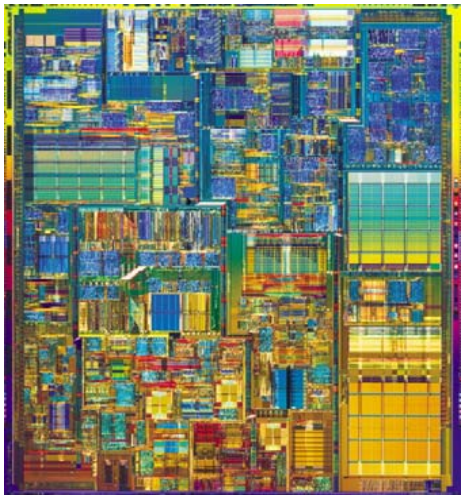
微處理器



The 4004 - 2,300 transistors, 1971



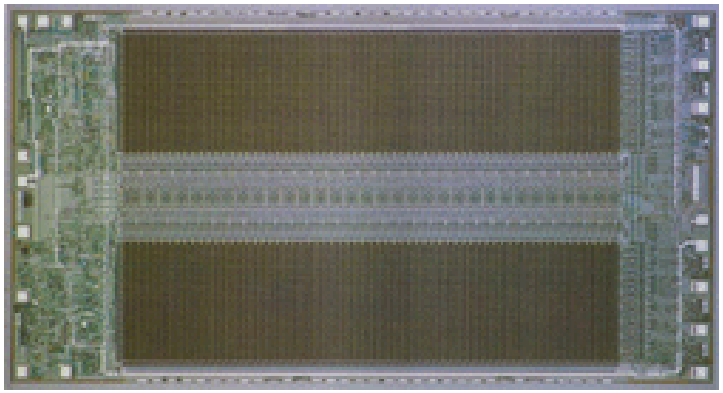
The 8088/8086 - 29,000 transistors, 1978



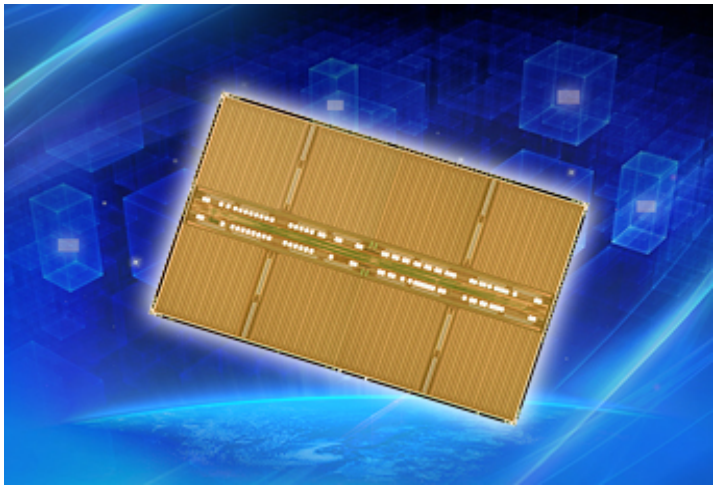
The Pentium IV - 42,000,000 transistors, 2000

MDL
NTHU

記憶體

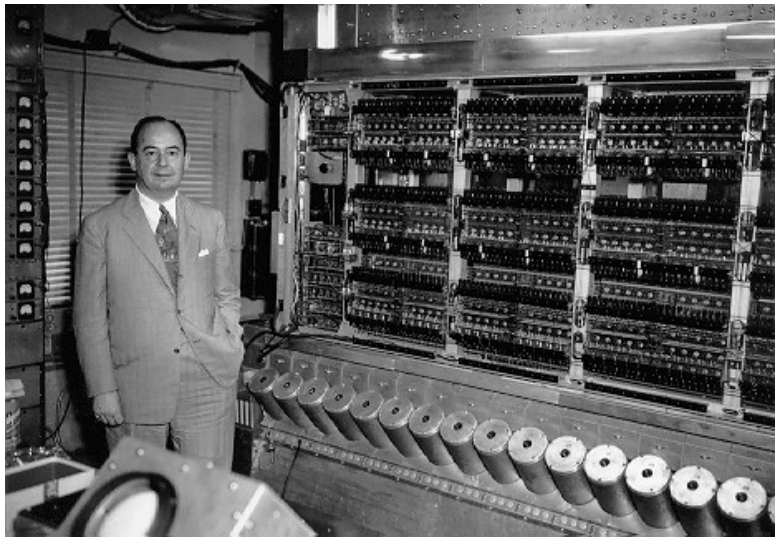


The 16kb DRAM, 1976

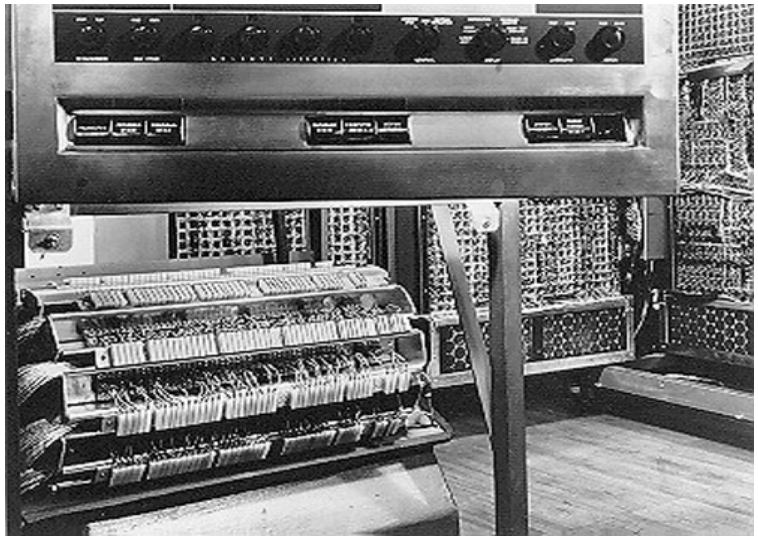


The 2Gb DRAM, 2011

電腦的演進 – I



von Neumann and his "computer", 1952

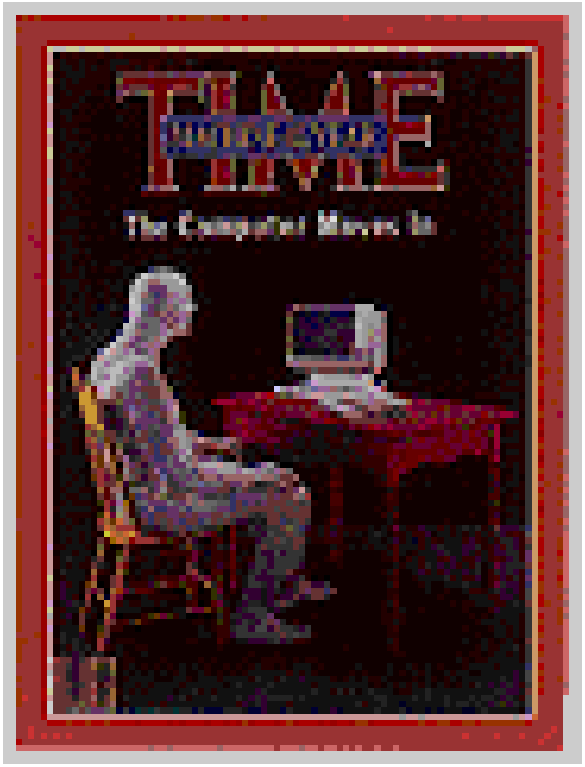


IBM 650, 1954

MDL
NTHU

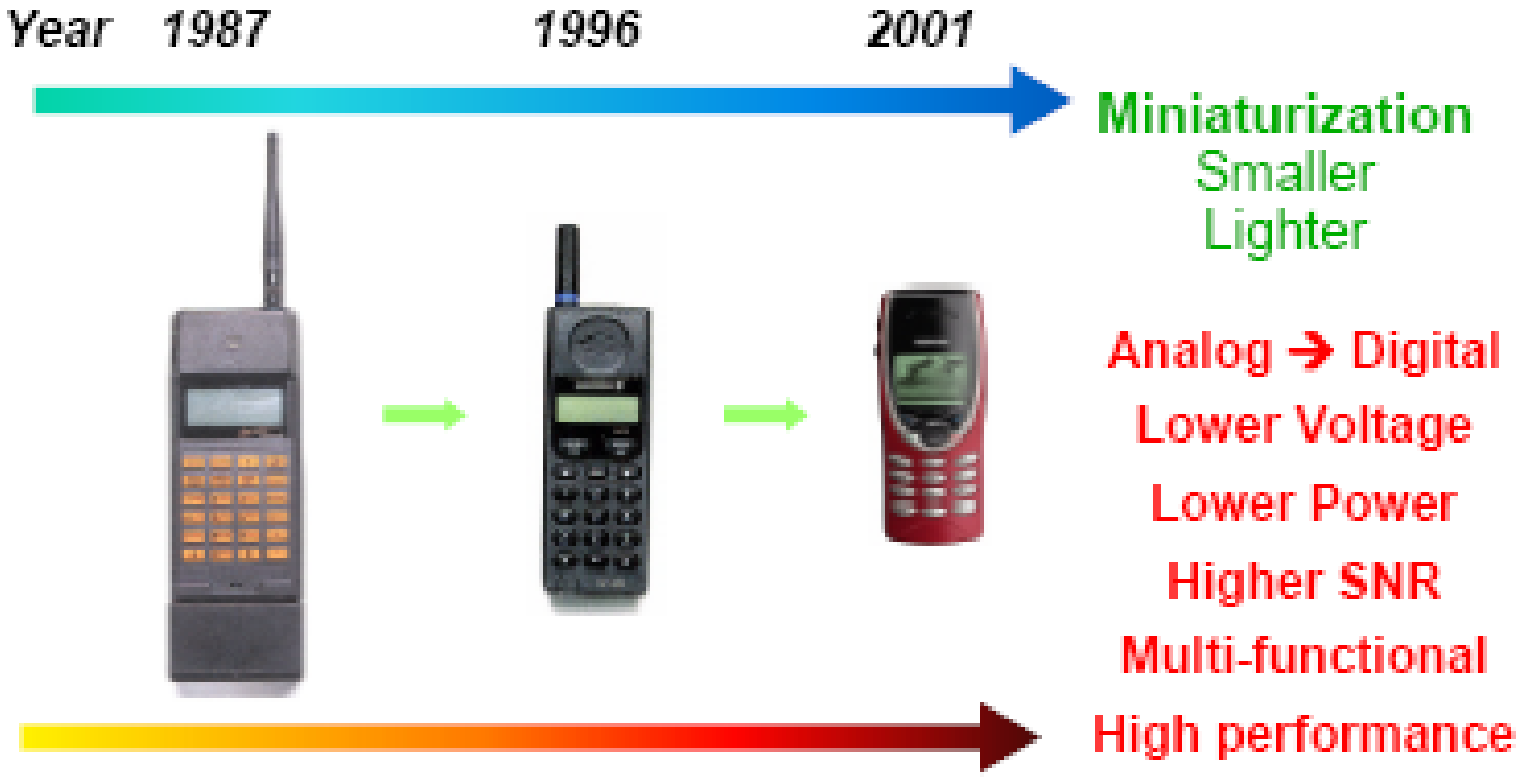
電腦的演進 – II

Jobs & Wozniak with Apple II - 1976



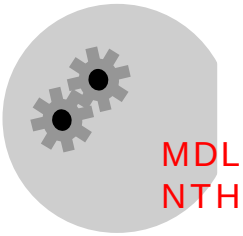
IBM PC – 1981/2

科技發展的趨勢


Year 1987
1996
2001
Miniaturization
Smaller
Lighter
Analog → Digital
Lower Voltage
Lower Power
Higher SNR
Multi-functional
High performance

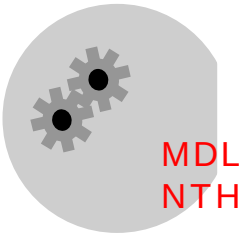
平面加工技術與高科技

- **IC： 台積電, 聯電, 華邦, ... (聯發科, 瑞昱, …)**
- **Magnetic recording head： Seagate, Hitachi, ...**
- **LED/VCSEL/Diode laser： 國聯, 光磊, 全磊, …**
- **TFT-LCD： 友達, 奇美, 廣輝, ...**
- **MEMS：探微, 亞太優勢, 台積電, ...**



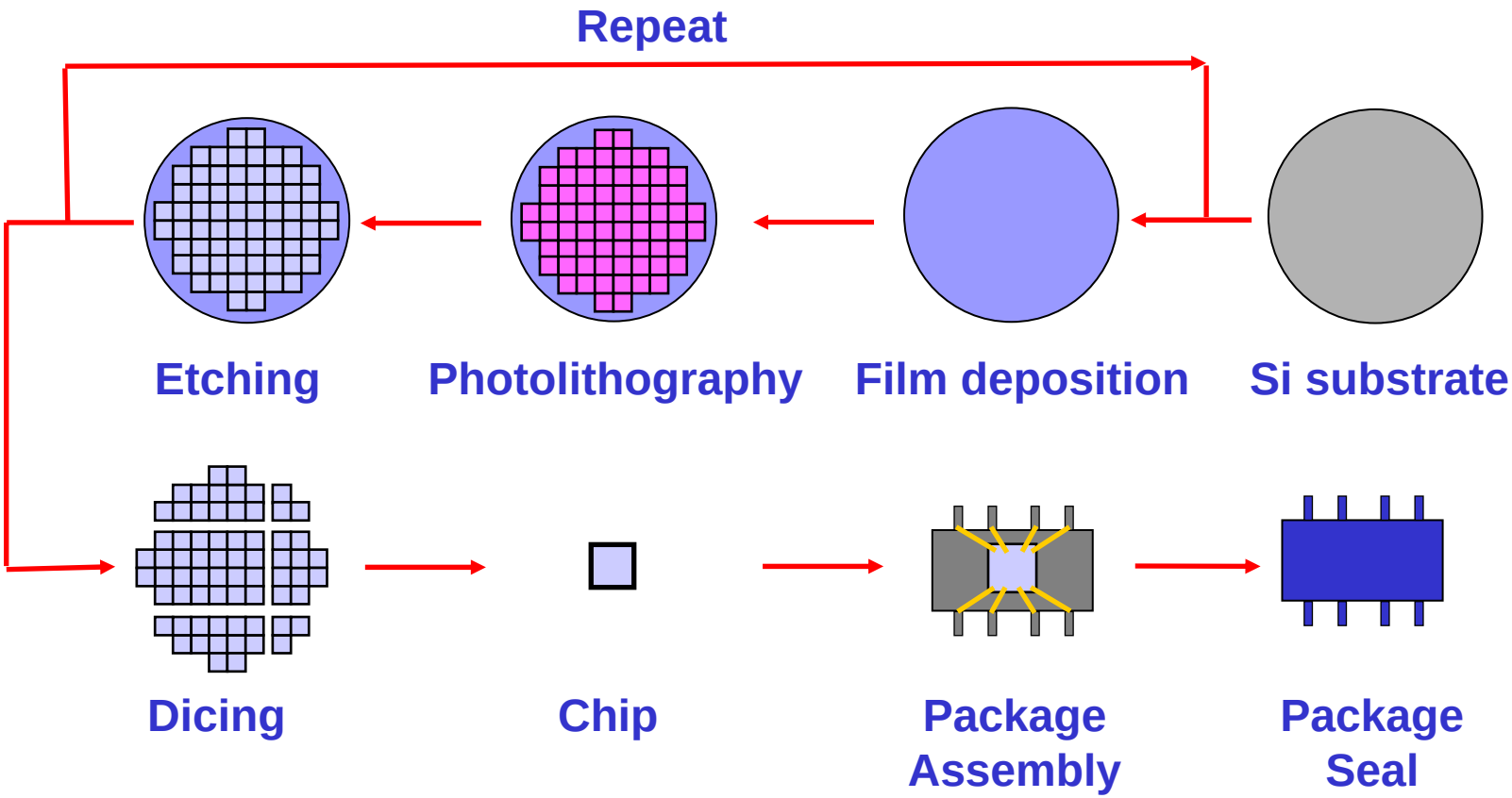
MDL
NTHU

平面加工技術



MDL
NTHU

Semiconductor processes



MDL
NTHU

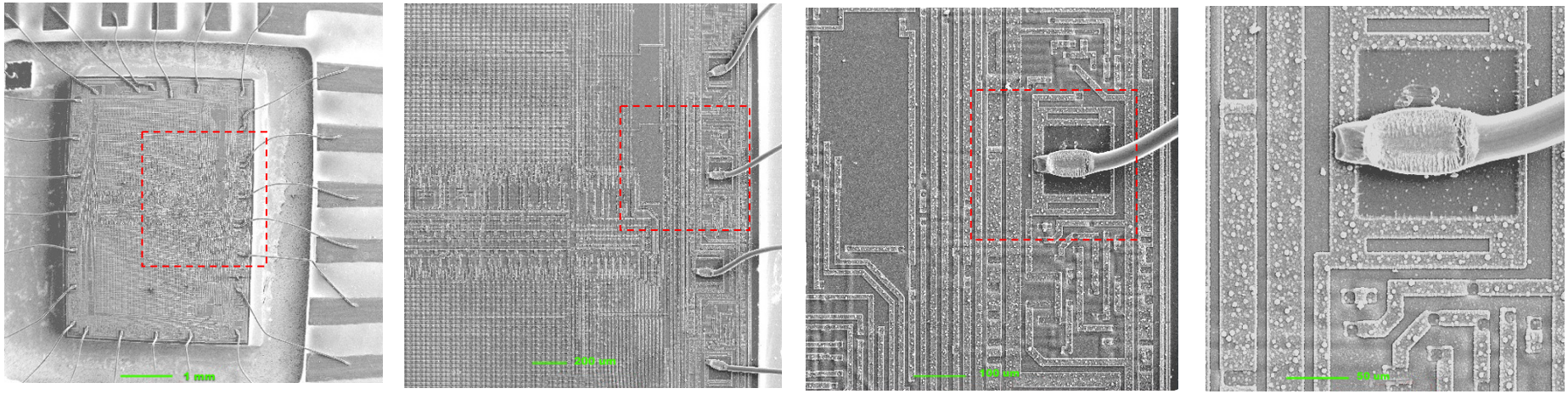
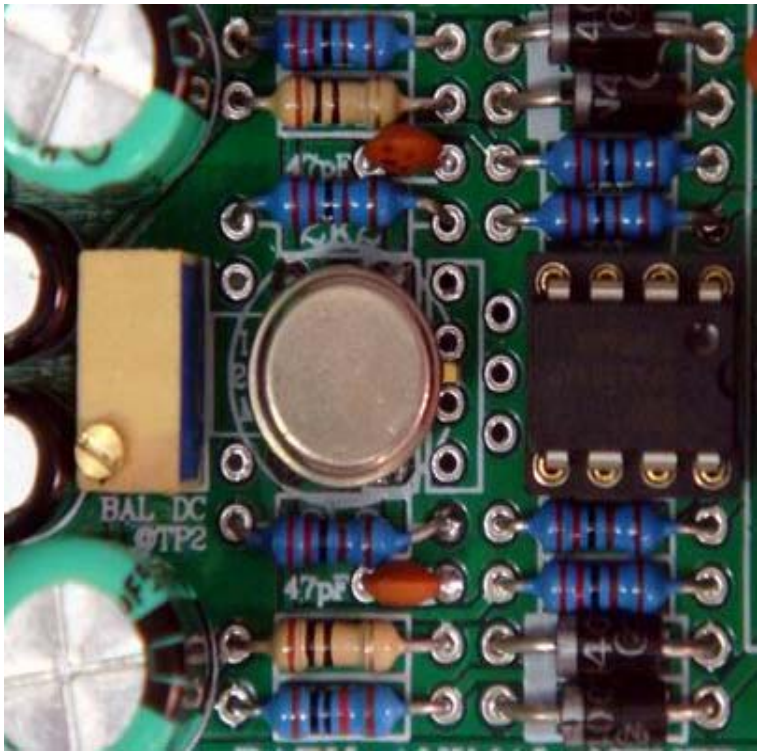


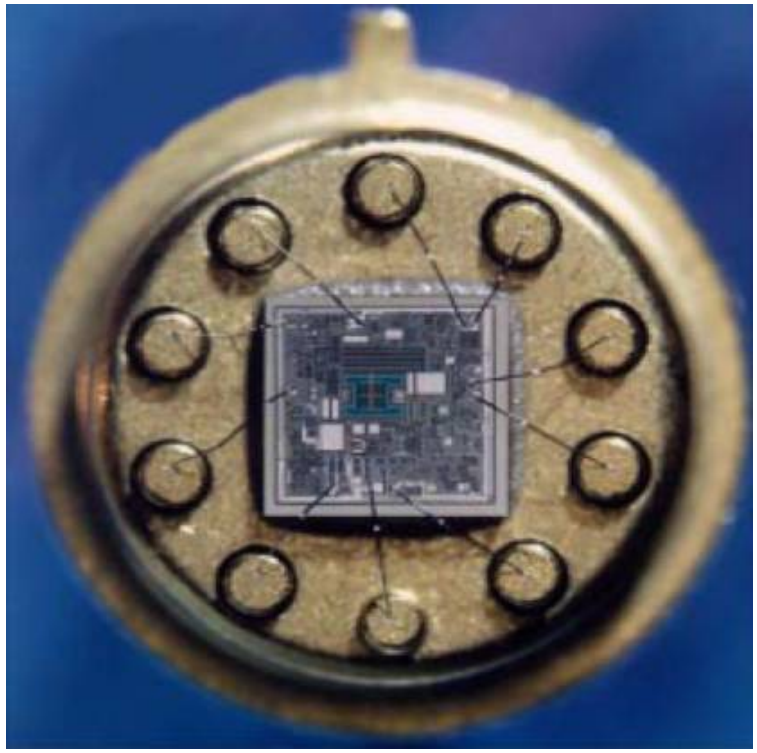
Photo source: Arizona State University

MDL
NTHU

- **Discrete vs Integrated electronics components**

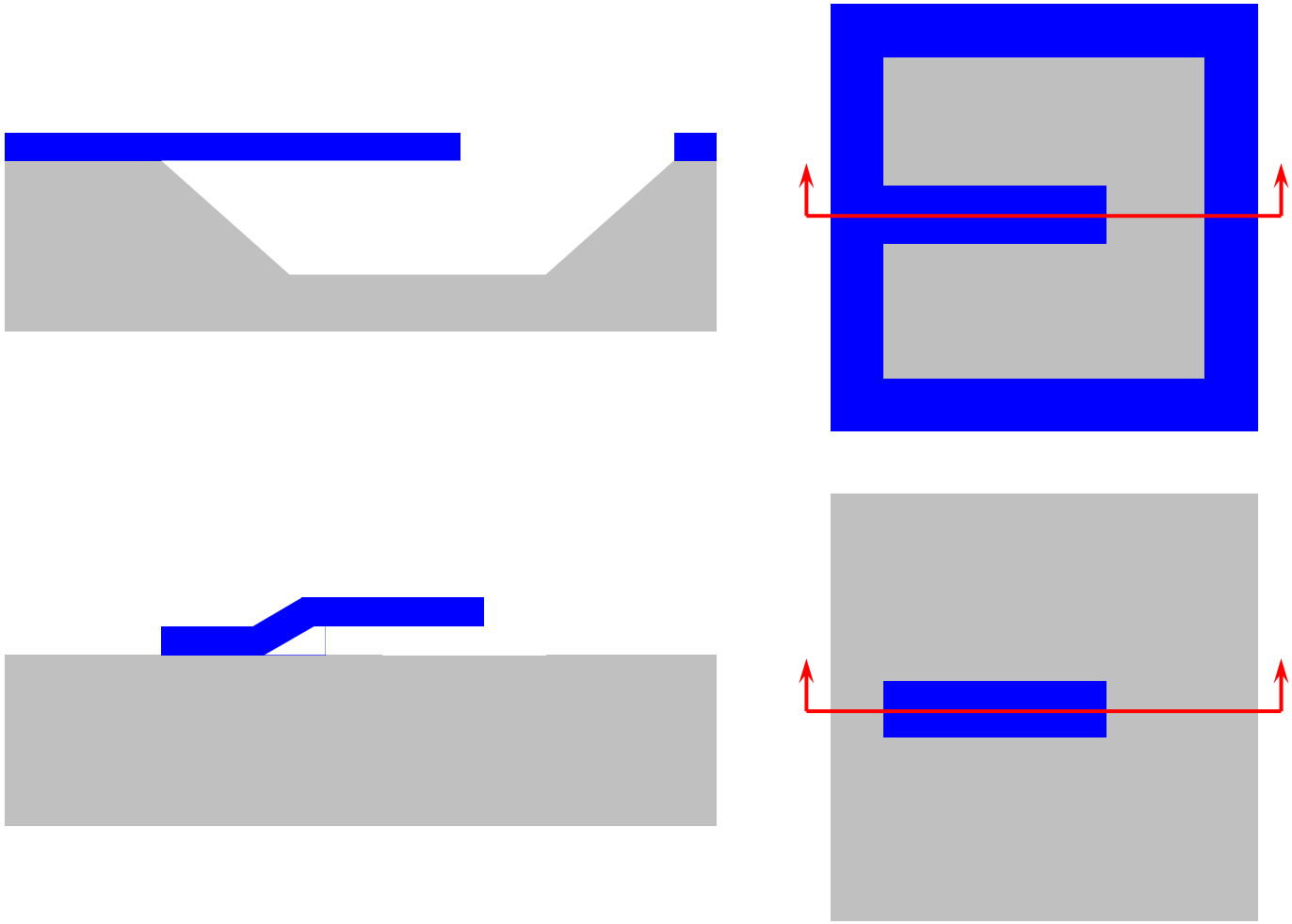


ATM Elektro, Czech Republic



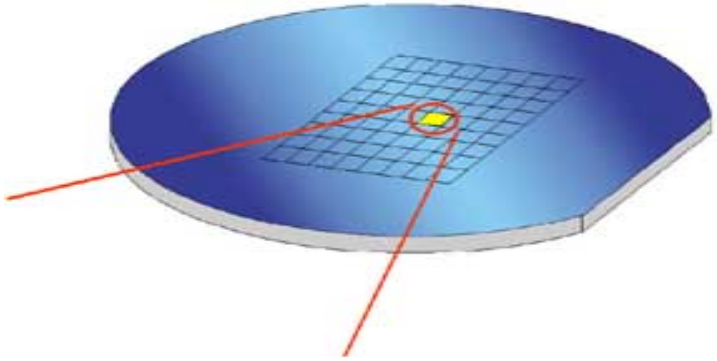
ADI, USA

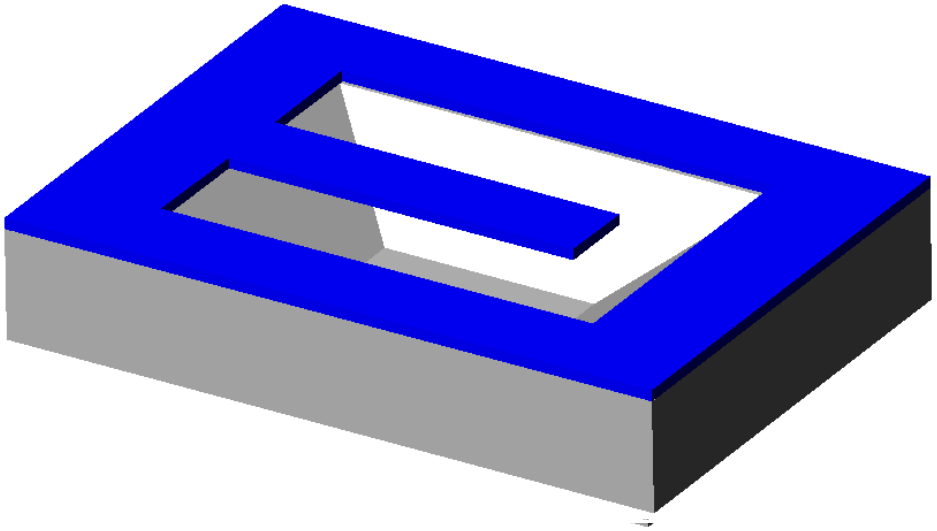
懸浮微機械結構

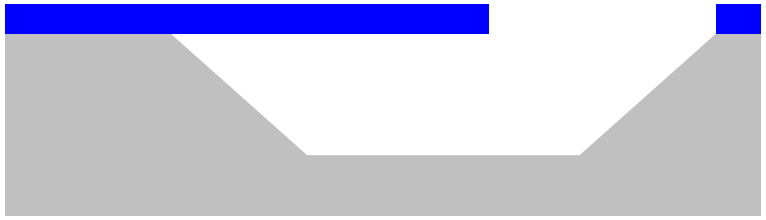


MDL
NTHU

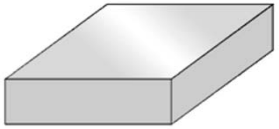
基本製程 I



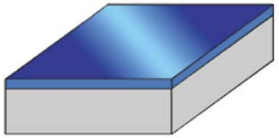




空白矽晶片

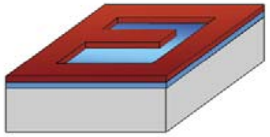


長膜



微影

留下光阻以保護下層薄膜

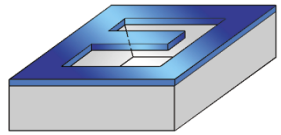


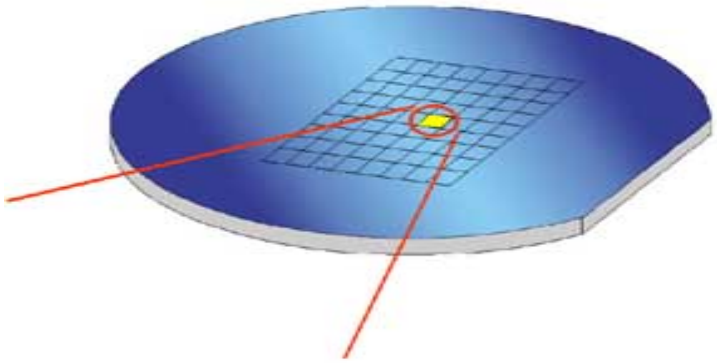
蝕刻薄膜、洗去光阻

此處的薄膜是結構層

蝕刻矽底材

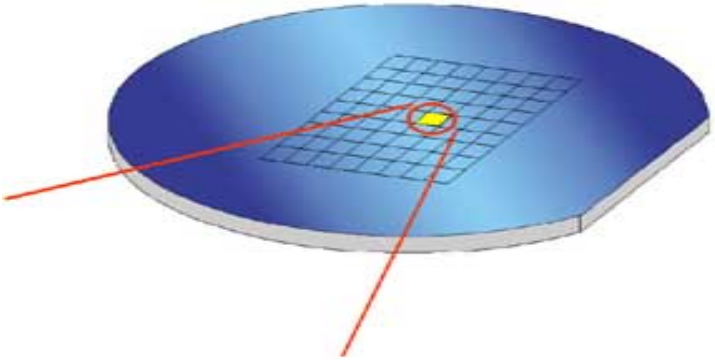
將結構懸浮

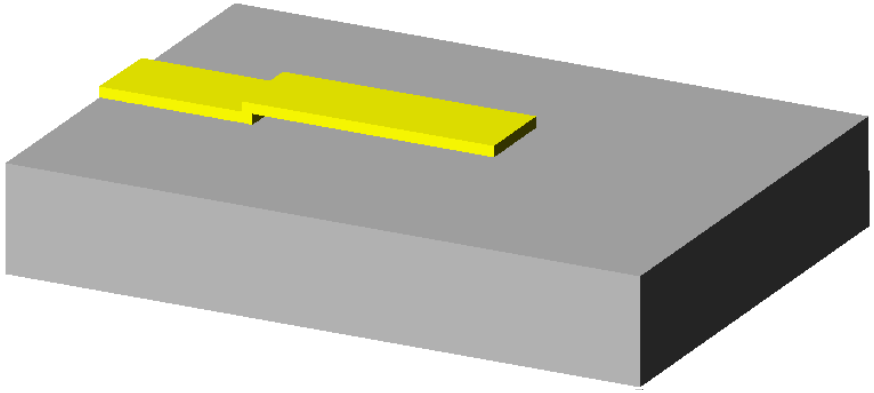




MDL
NTHU

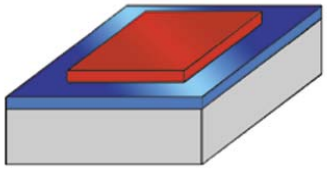
基本製程 II





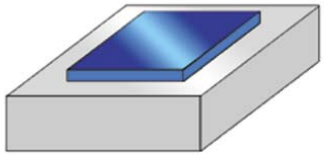
微影

留下光阻以保護下層薄膜



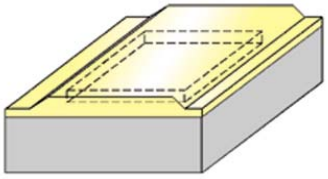
蝕刻薄膜、洗去光阻

此處的薄膜做爲犧牲層



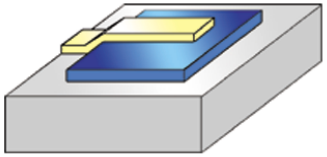
長第二層膜

作爲結構層



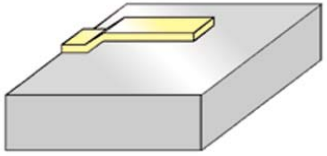
第二次微影、蝕刻

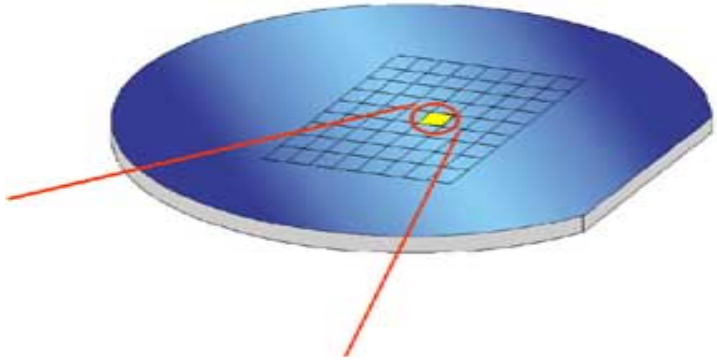
得到結構形狀



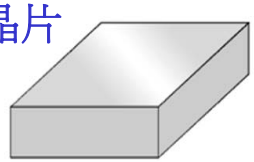
蝕刻犧牲層

得到懸浮結構

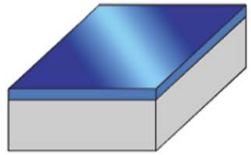




空白矽晶片

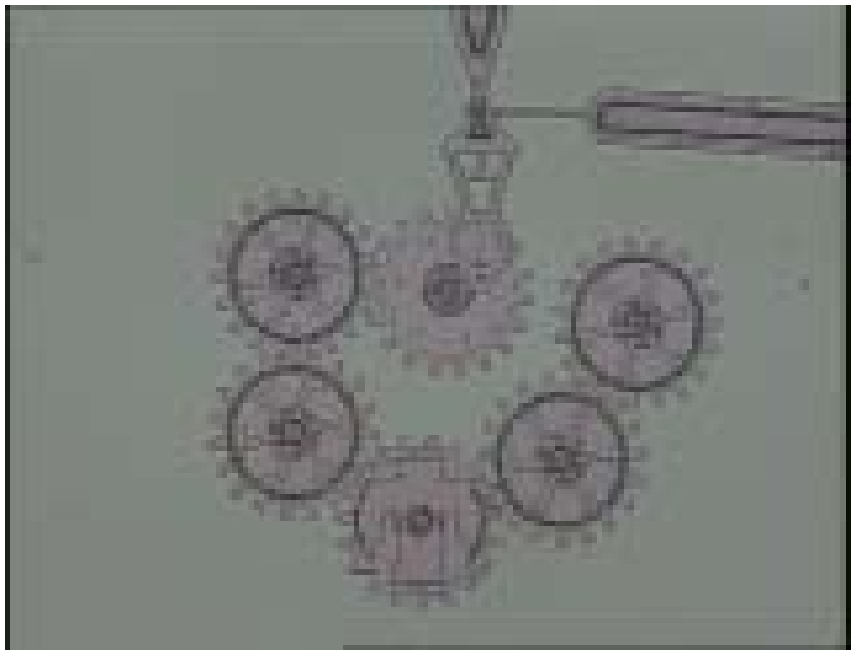


長膜



MDL
NTHU

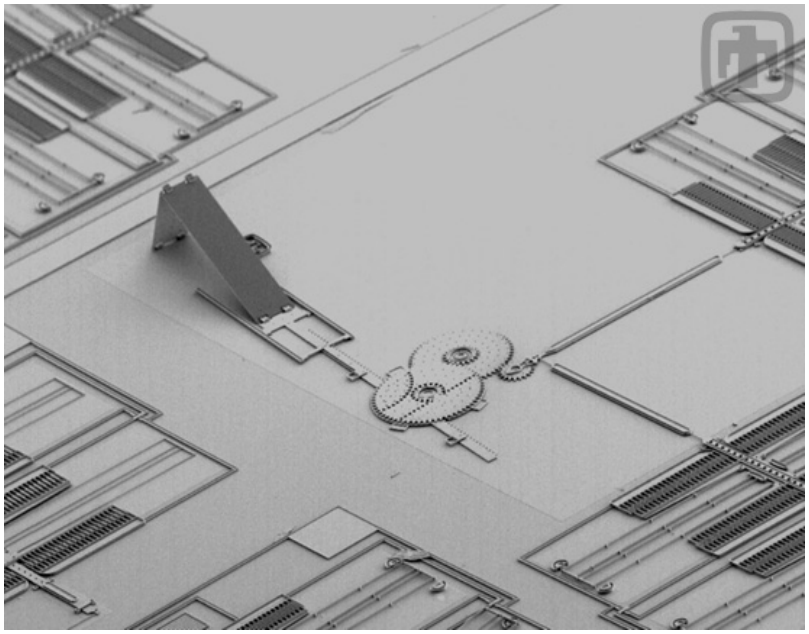
製程結果

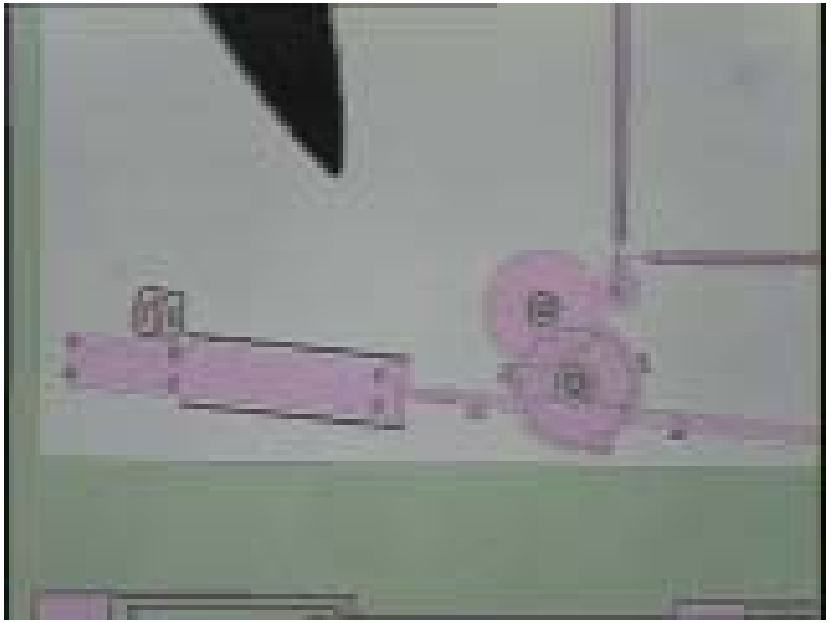


Sandia National lab., USA

MDL
NTHU

製程結果

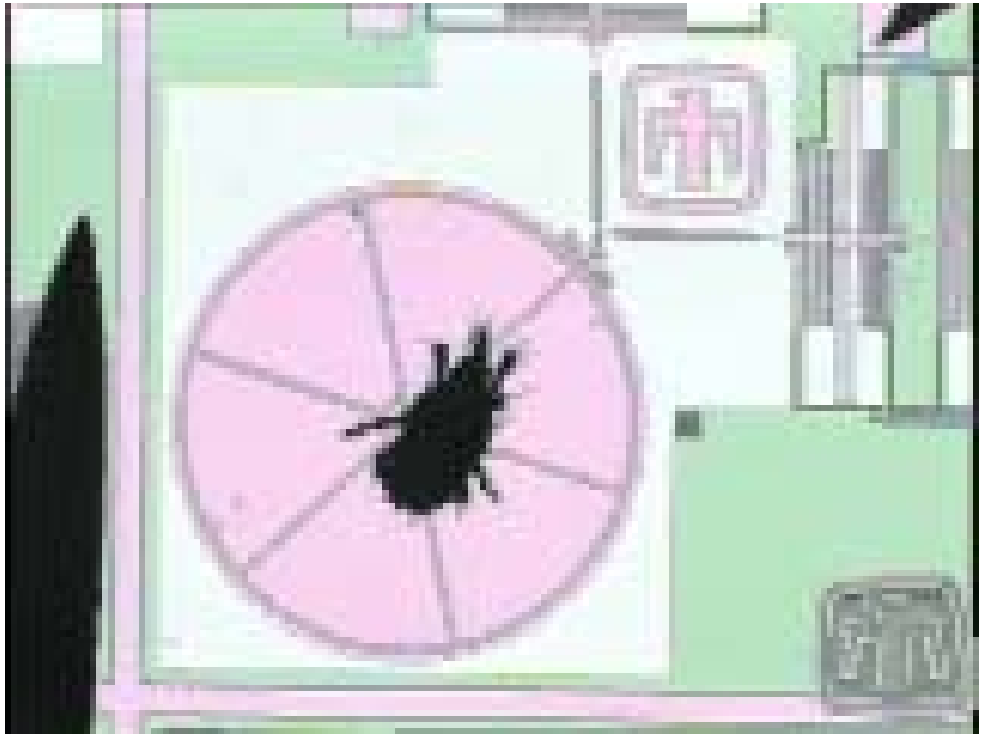




Sandia National lab., USA

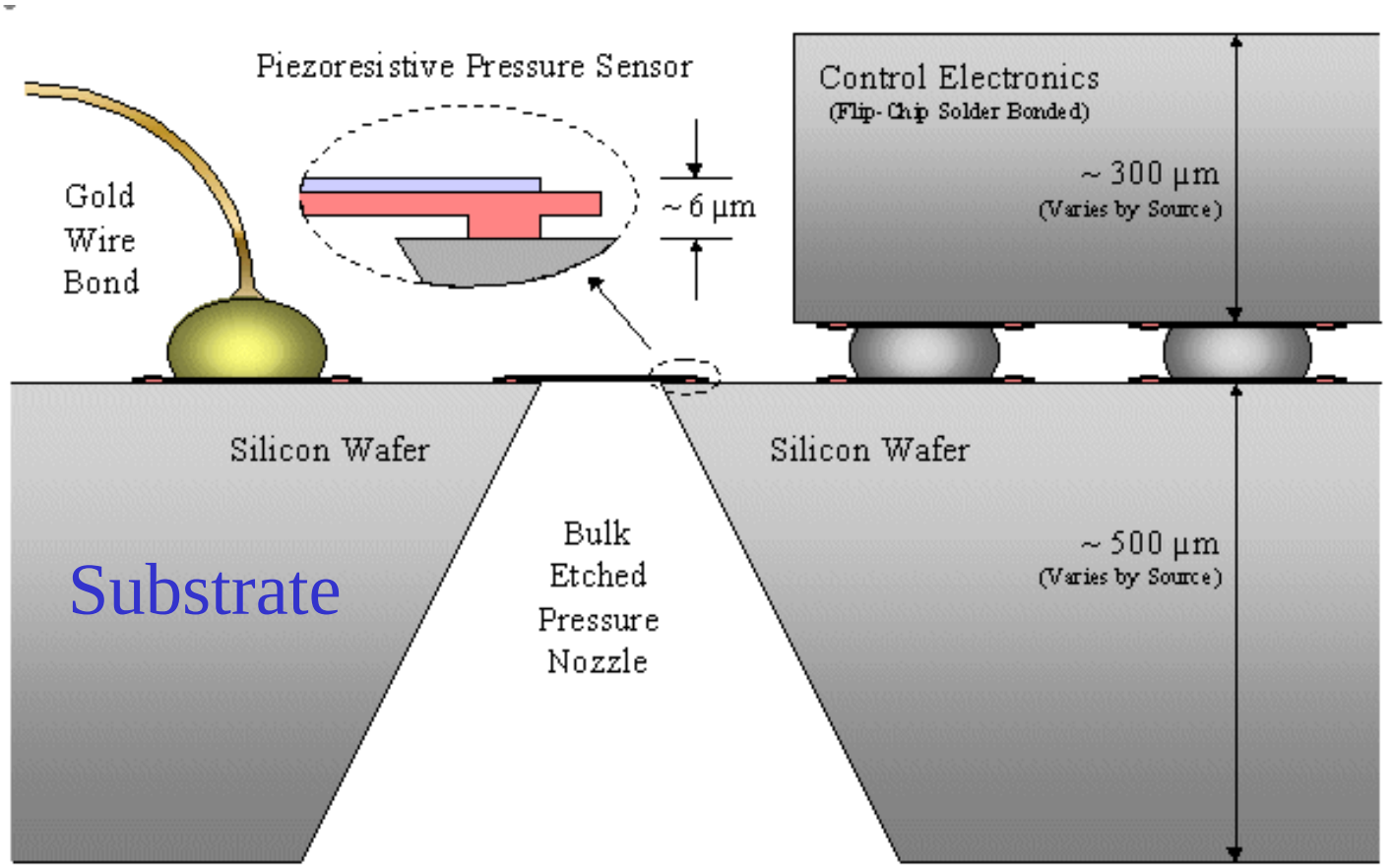
MDL
NTHU

製程結果



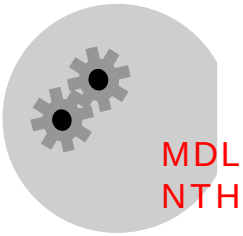
Sandia National Lab, USA

MDL
NTHU


Piezoresistive Pressure Sensor
Control Electronics
(Flip-Chip Solder Bonded)
~ 300 µm
(Varies by Source)
Gold
Wire
Bond
~ 6 µm
Silicon Wafer
Silicon Wafer
Substrate
Bulk
Etched
Pressure
Nozzle
~ 500 µm
(Varies by Source)

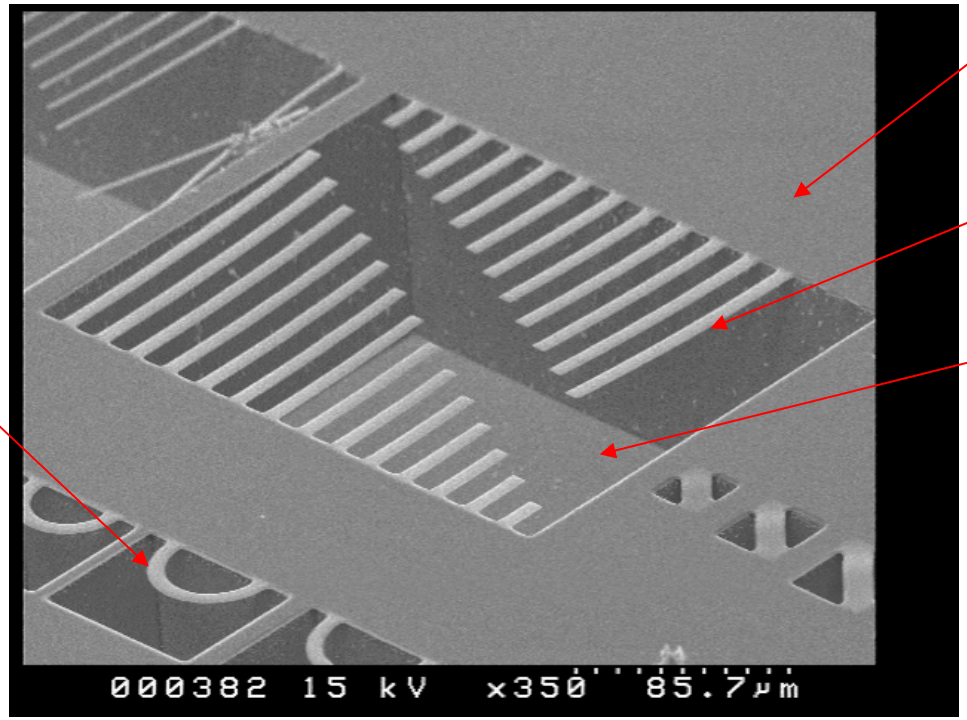
MDL
NTHU

關鍵元件 – 被動元件



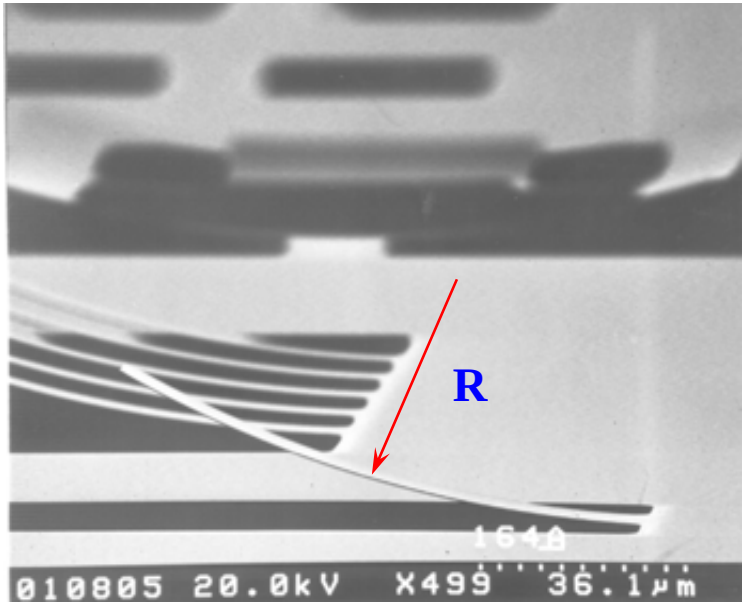
被動元件 – 樑

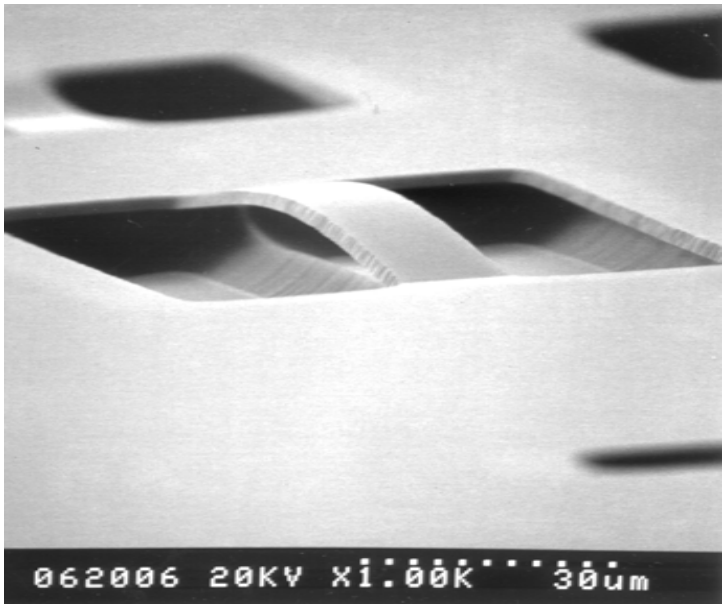
- 微機械結構 – 樑、浮板



T. Tzou and W. Fang, 1999

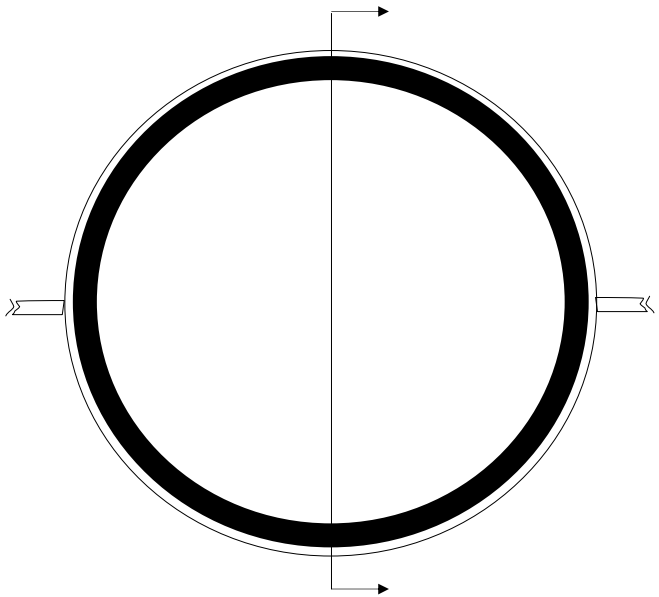
- 結構厚度與剛性



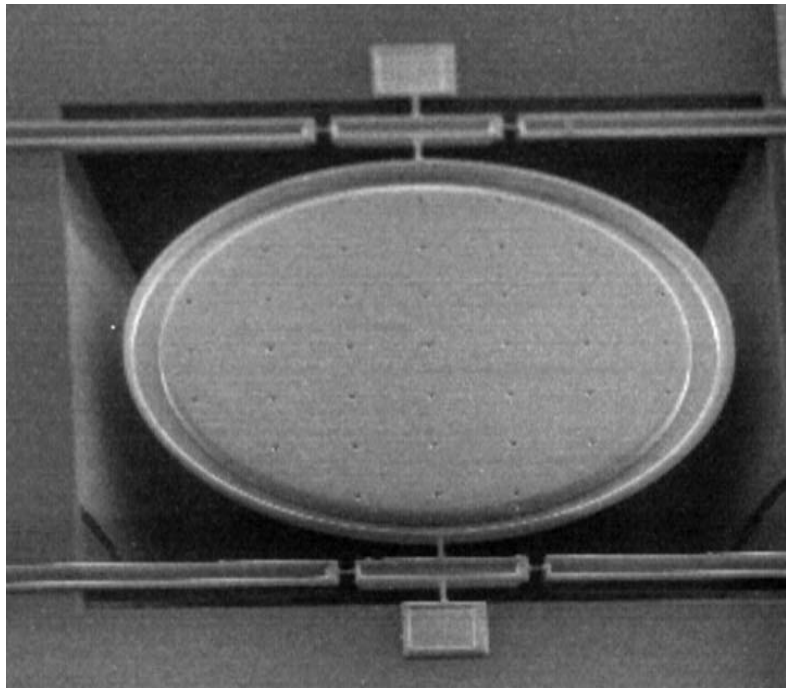


W. Fang, 1995

被動元件 – 平板



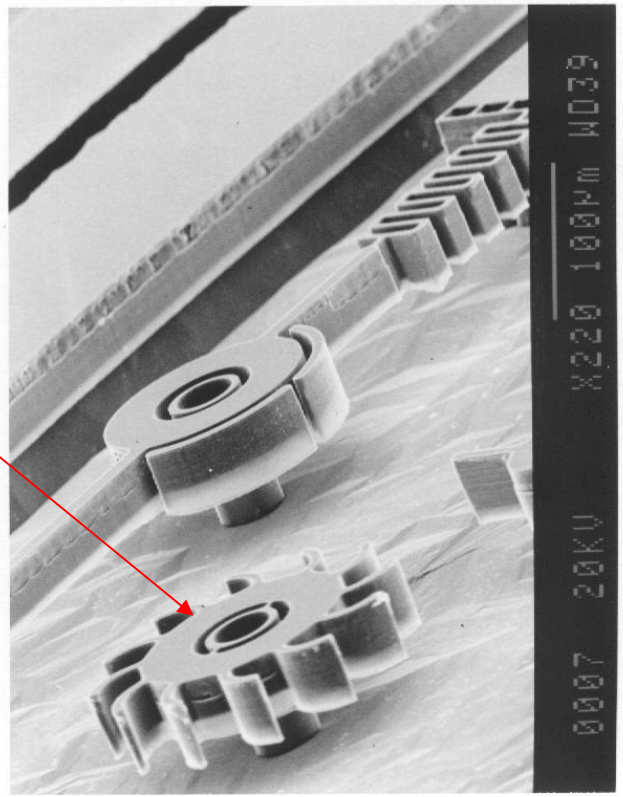
Reinforced folded frame



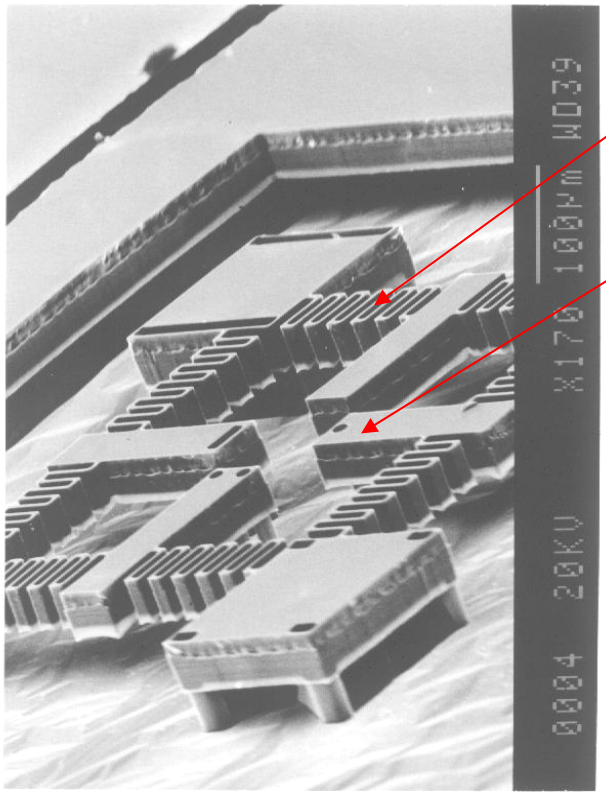
H.-Y. Lin and W. Fang, the *ASME IMECE*, Orlando, FL, 2000

MDL
NTHU

被動元件 – 齒輪、彈簧



轉子

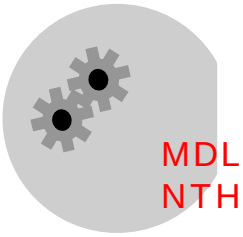


彈簧

樑

MDL
NTHU

關鍵元件 – 致動元件



傳統主動元件

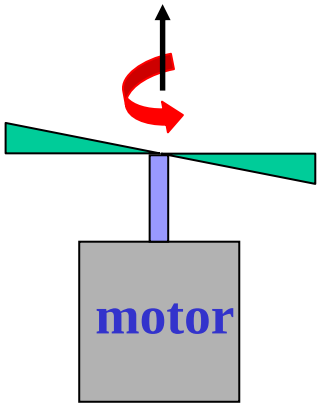
Motor

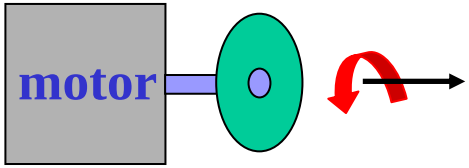
www.classictesla.com/photos/
tesla/motor.jpg

Engine

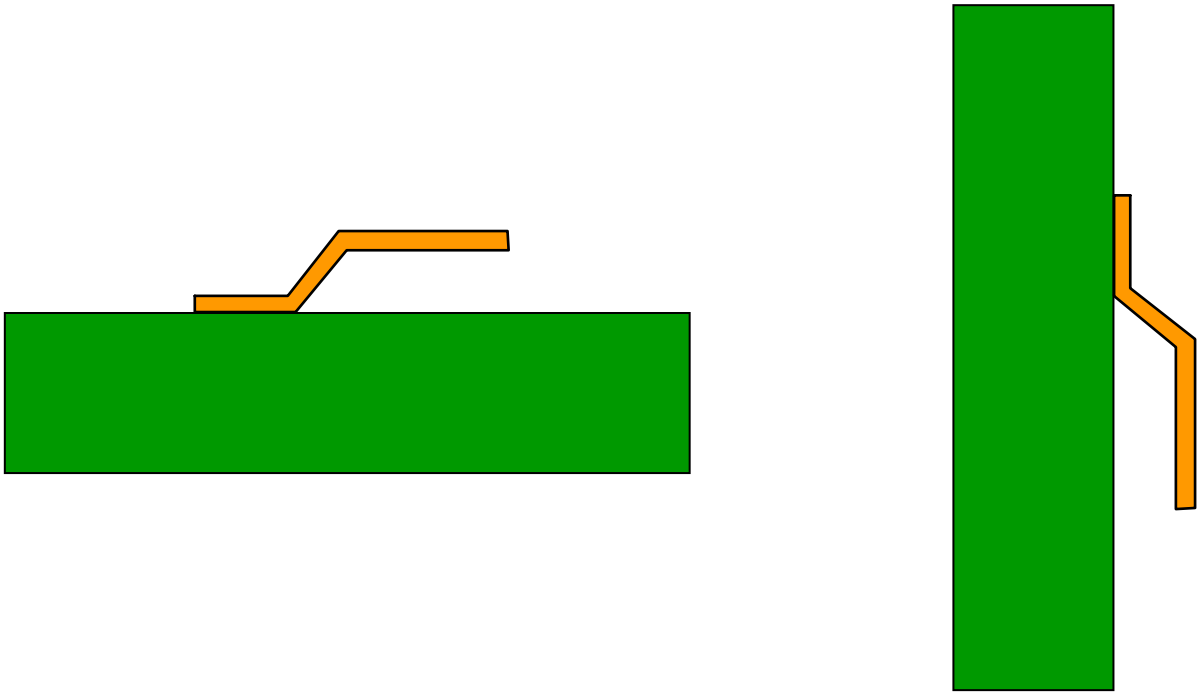
www.sportruck.com/feature/
tangerine/engine.jpg

- 傳統致動元件之輸出 – 可由組裝調整

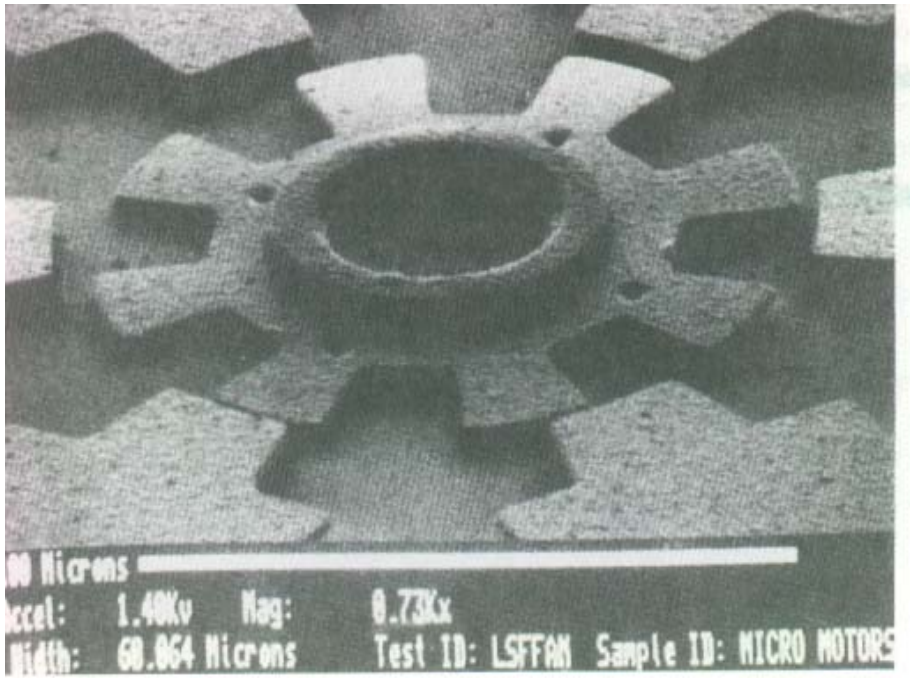


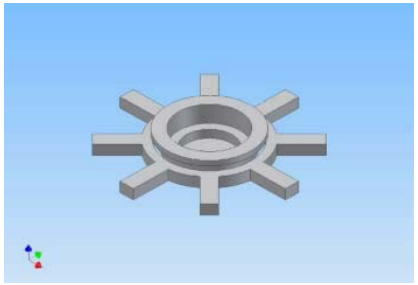


- 微致動元件附著於矽晶片 – 輸出無法由組裝調整

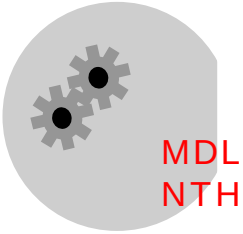


主動元件 – 轉動式靜電致動器

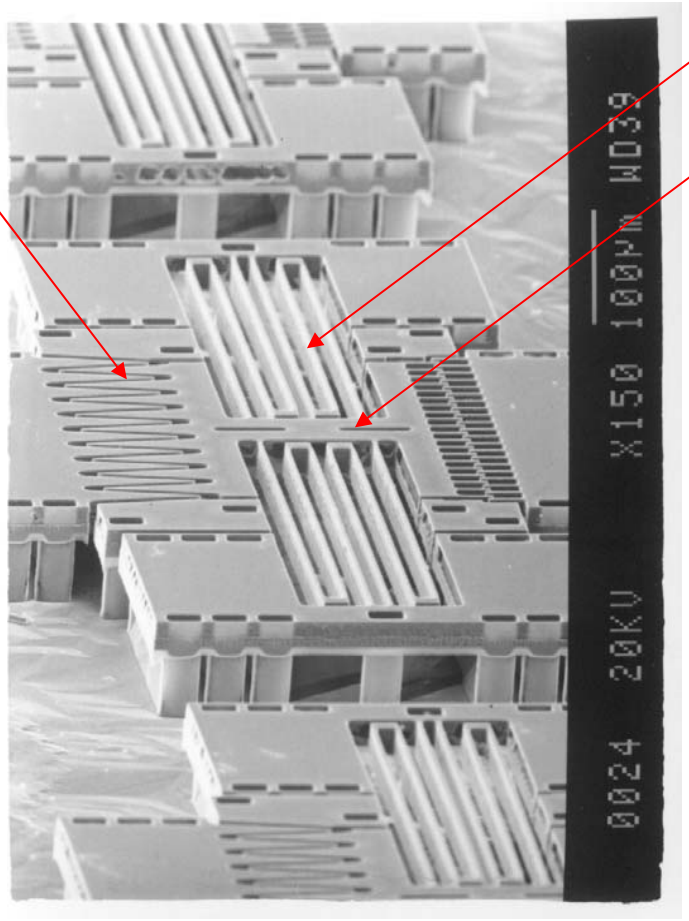


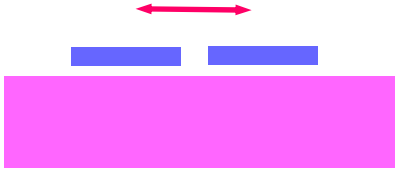


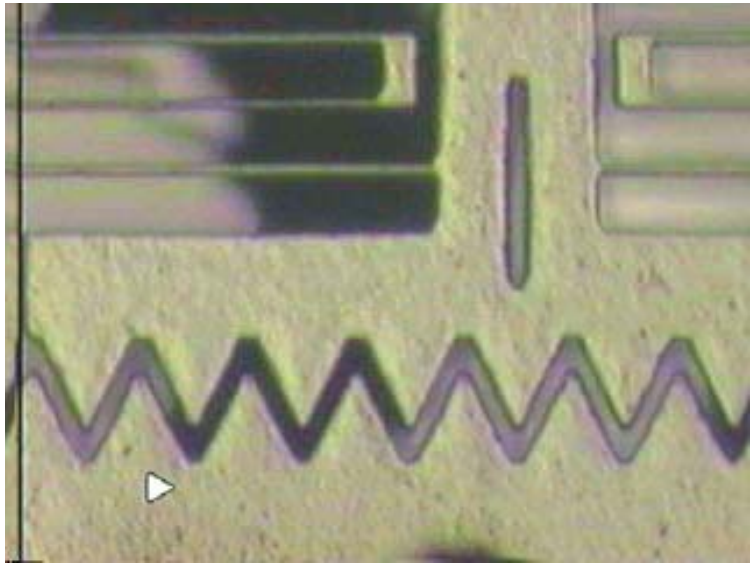
L.-S. Fan, Y.-C. Tai, and R.S. Muller, Int. Electron Devices meeting, 1988.



主動元件 – 線性運動靜電致動器

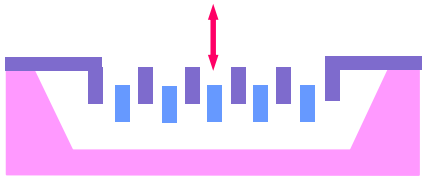


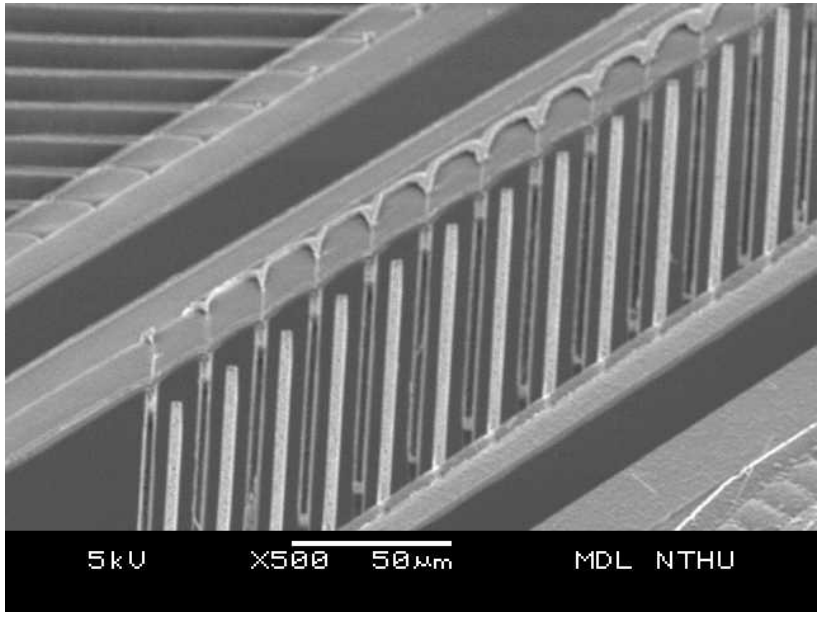


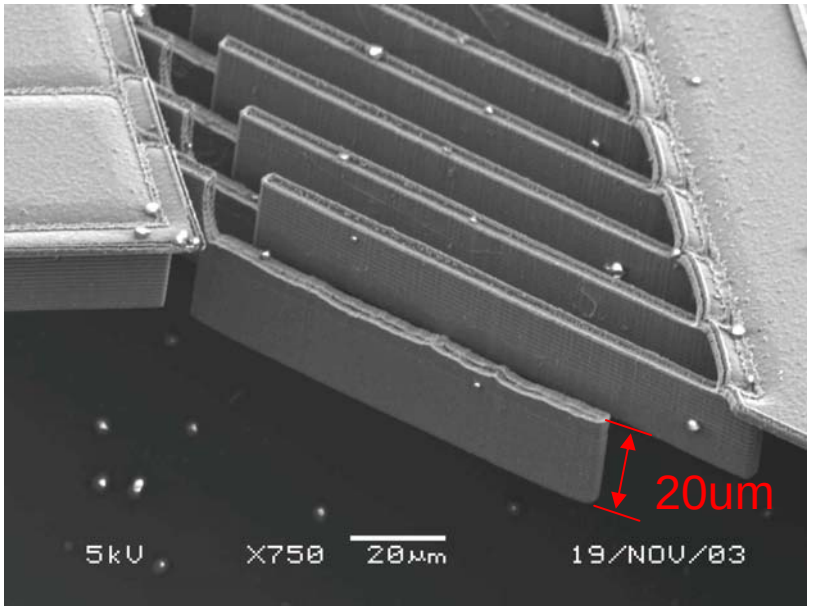


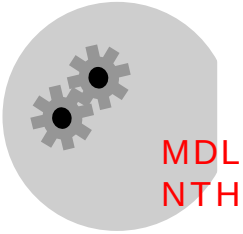
主動元件 – 靜電驅動致動器

- **Vertical comb electrodes**
  - + Comb thickness ~20um
  - + Travel stoke ~20um



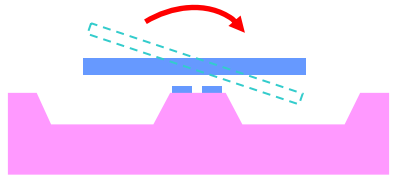




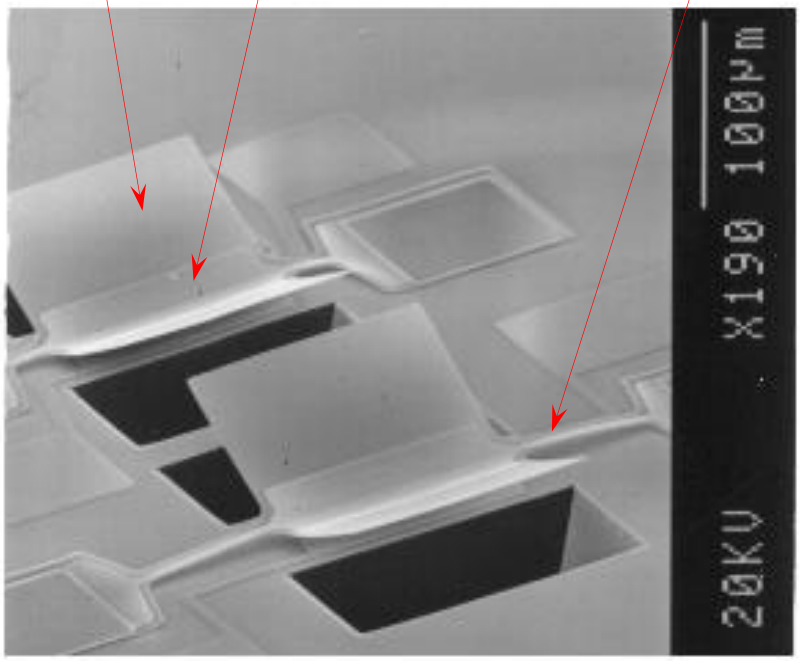


MDL
NTHU

主動元件 – 扭轉式靜電致動器



平板　　驅動電極　　扭轉彈簧

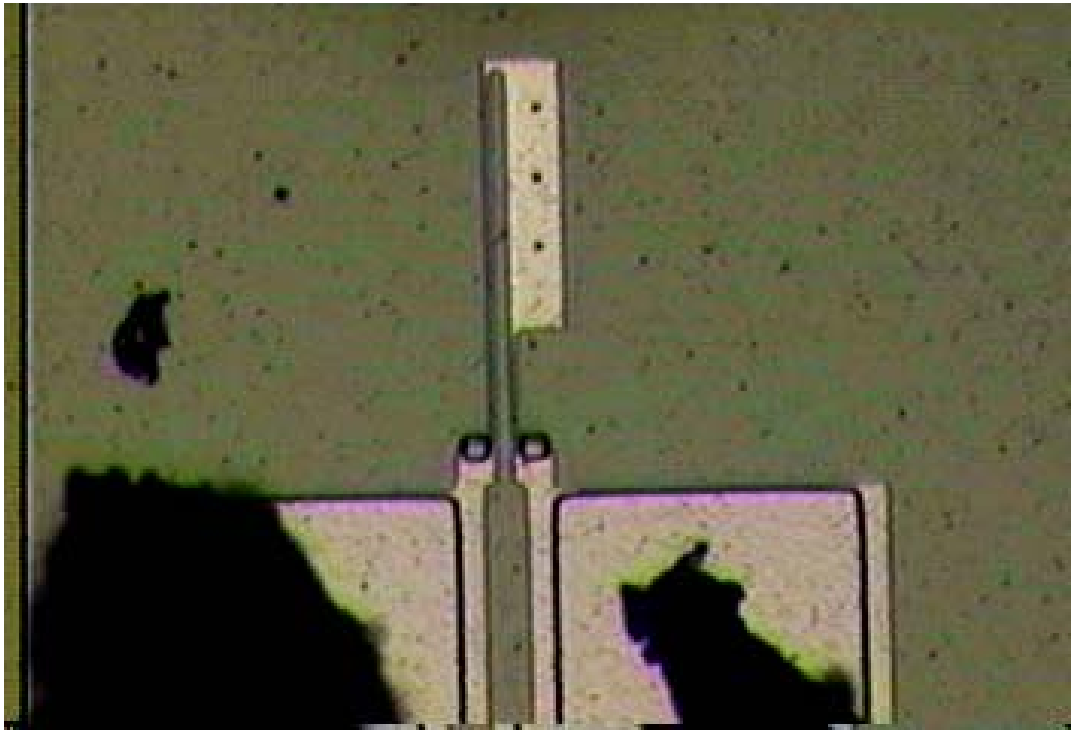


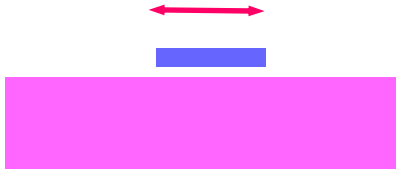
J. Hsieh and W. Fang, *Transducers'99*, Sendai Japan, 1999

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

MDL
NTHU

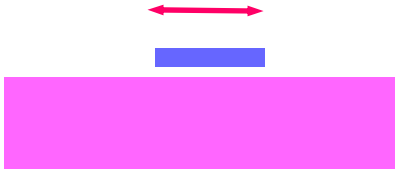
主動元件 – 線性運動電熱致動器





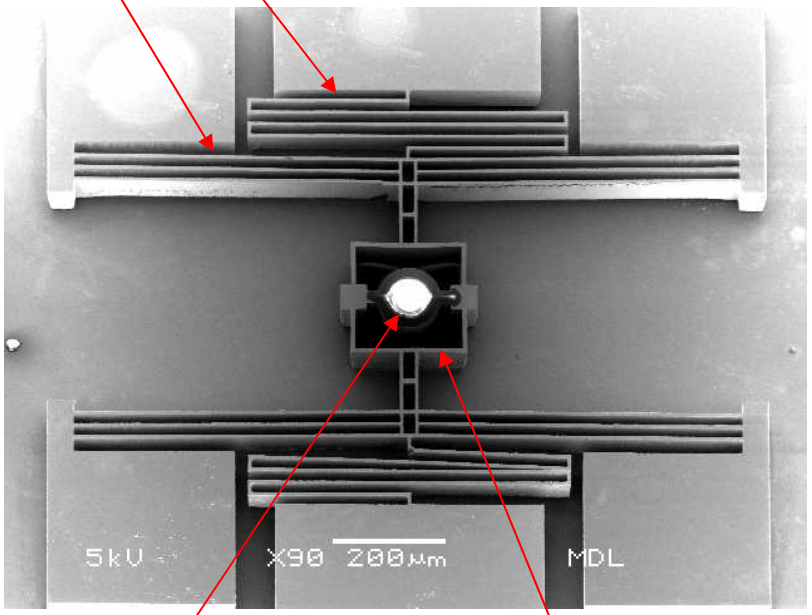
主動元件 – 線性運動電熱致動器

- 晶片表面之同平面運動



Spring (passive)

V-beam actuator (active)



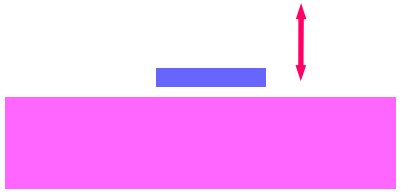
Supporting frame (passive)

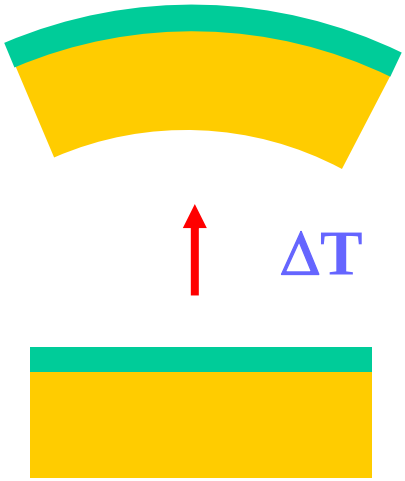
Lens (passive)

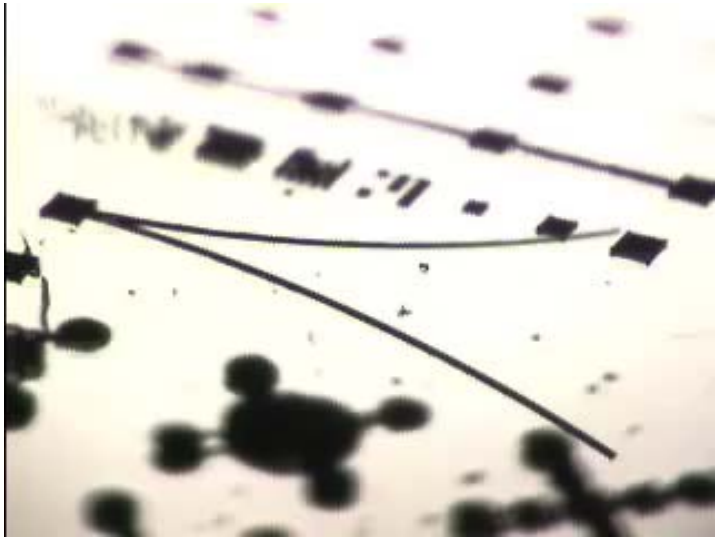
C. Lai, J. Hsieh, and W. Fang, *IEEE Optical MEMS'04*, 2004

主動元件 – 線性運動電熱致動器

- 晶片表面之出平面運動

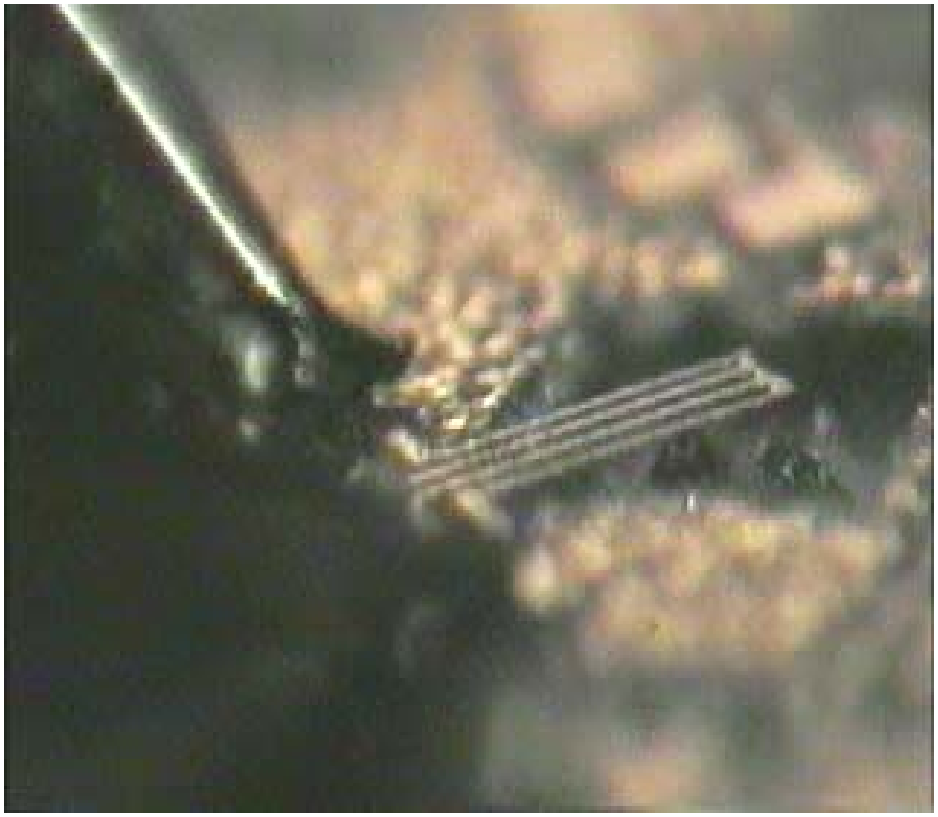


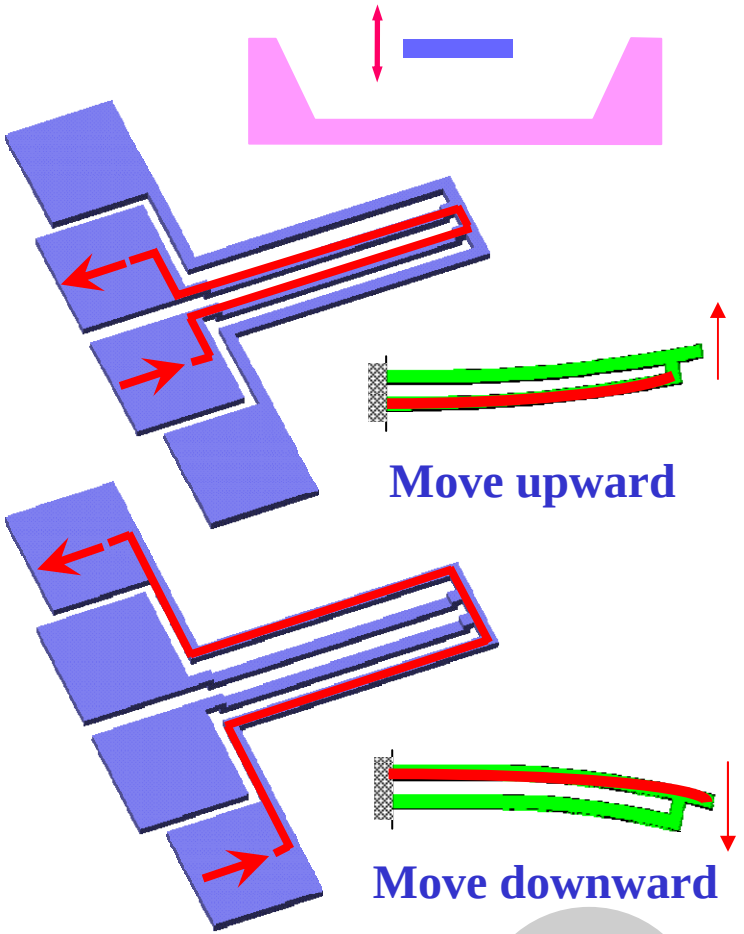




主動元件 – 線性運動電熱致動器

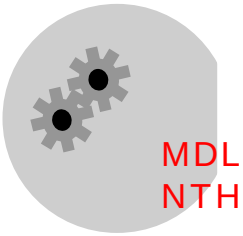
- 晶片表面之出平面運動





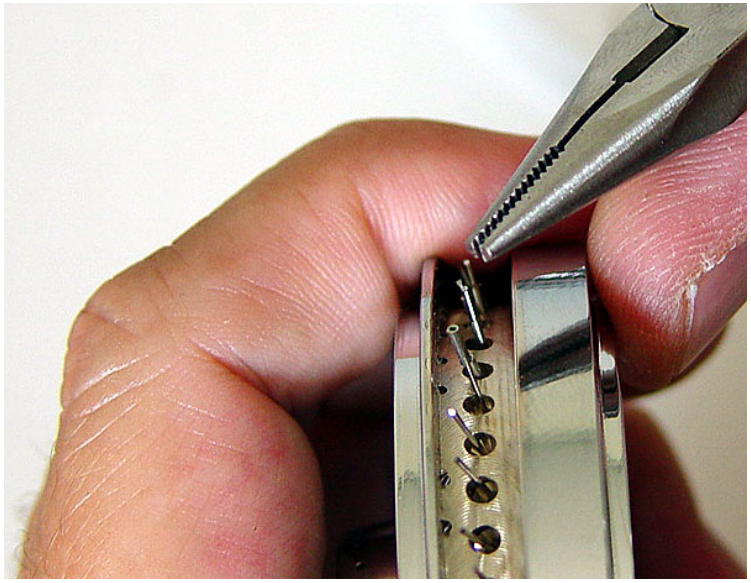
W.-C. Chen, J. Hsieh, and W. Fang, *IEEE MEMS'02*, Las Vegas, NV, 2002

組裝與整合



MDL
NTHU

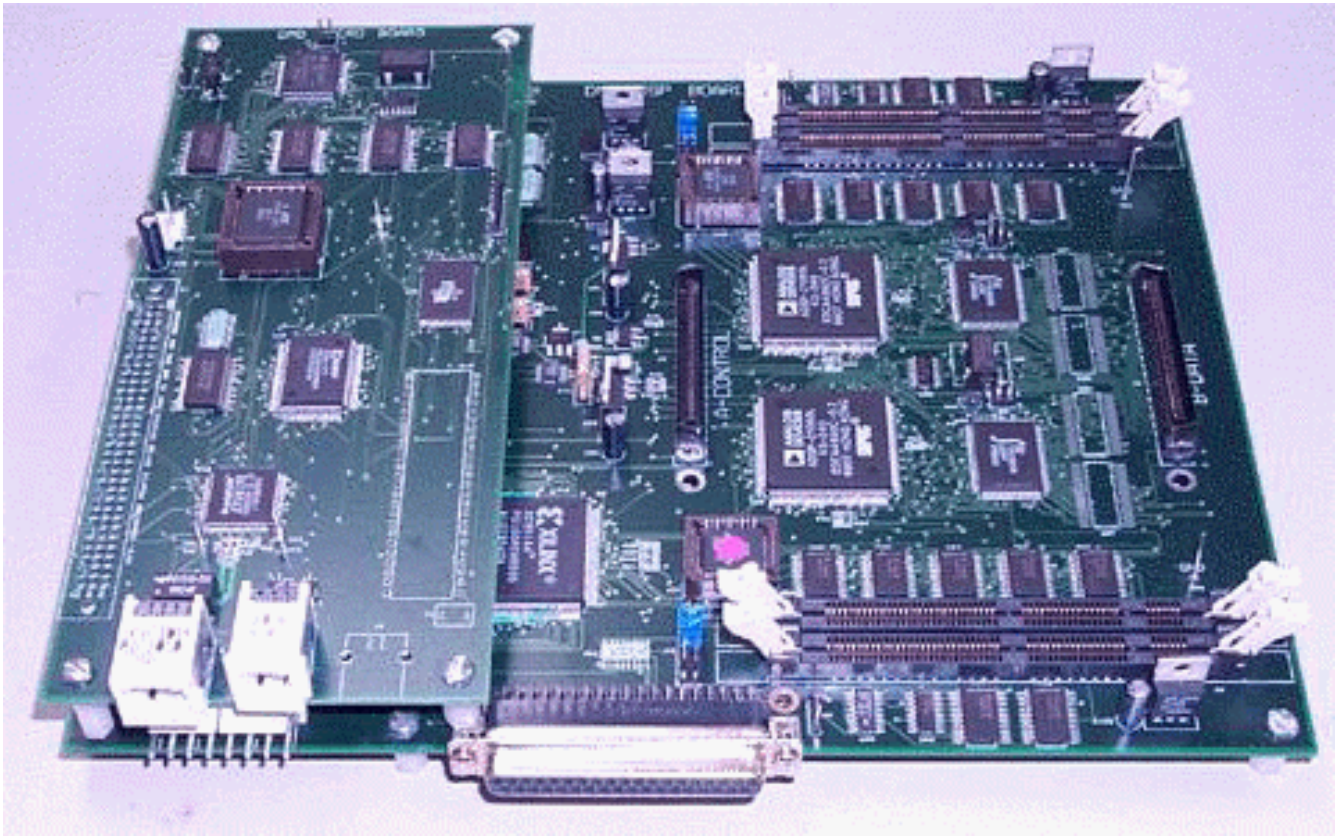
元件組裝



www.precisionscalereplicas.com

www.kukausa.com

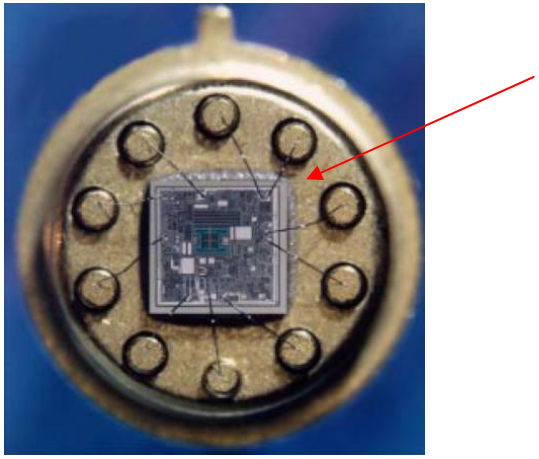
元件組裝

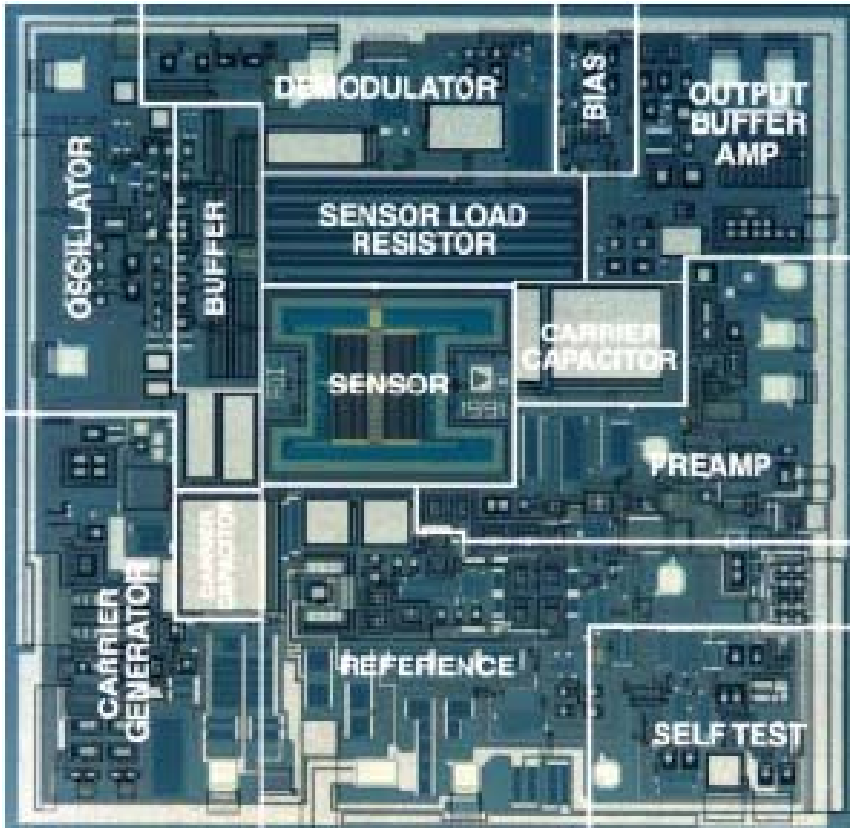


電腦主機板

MDL
NTHU

製程整合



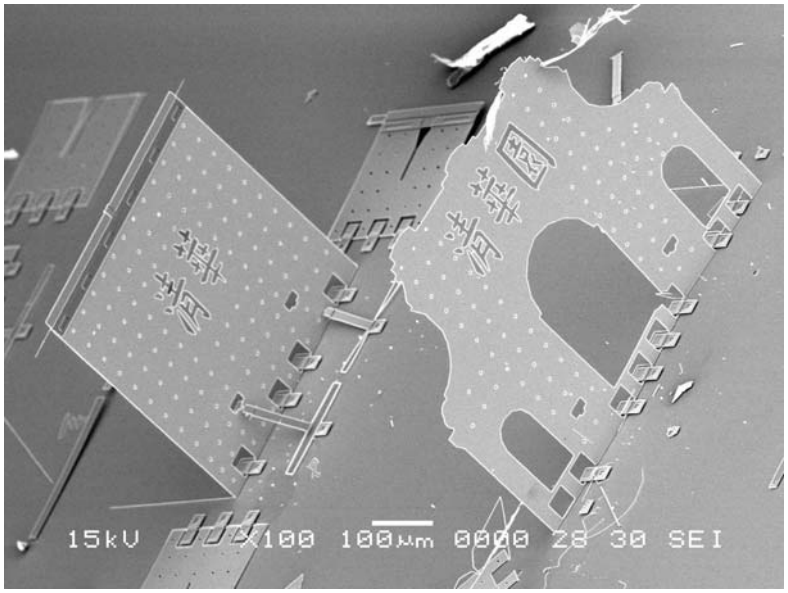


啟動汽車安全氣囊之加速度計 IC (ADI Inc.)

MDL
NTHU

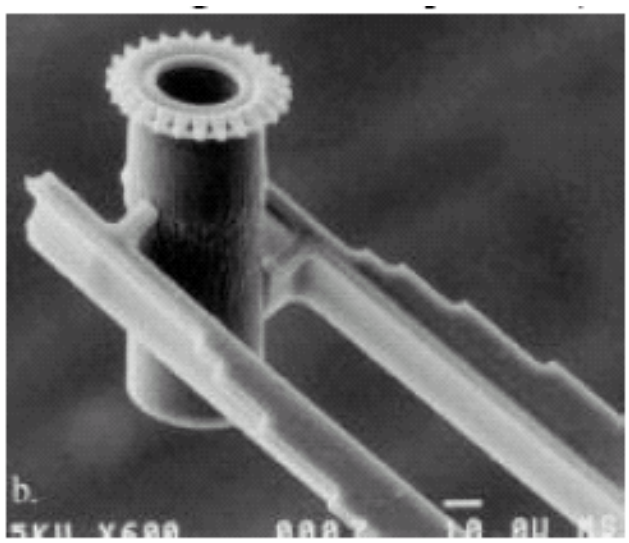
組裝－手工式

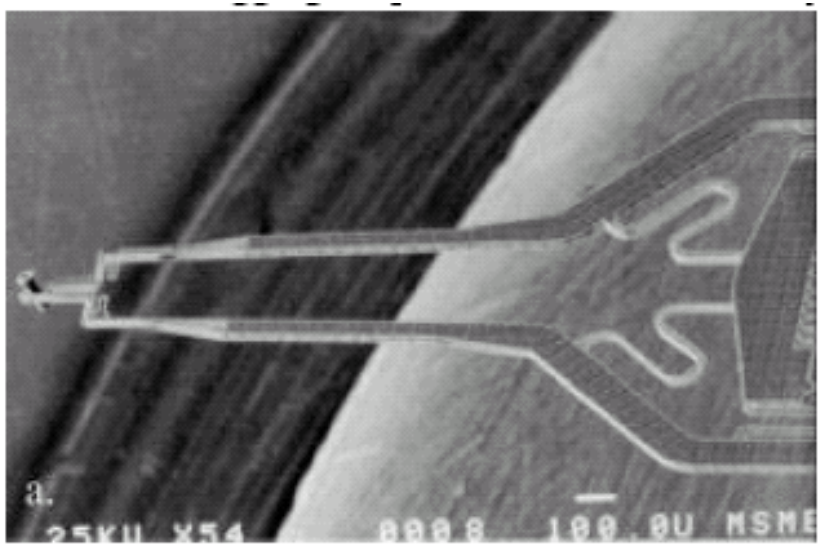
- 平面元件與直立元件



組裝－精密機械式

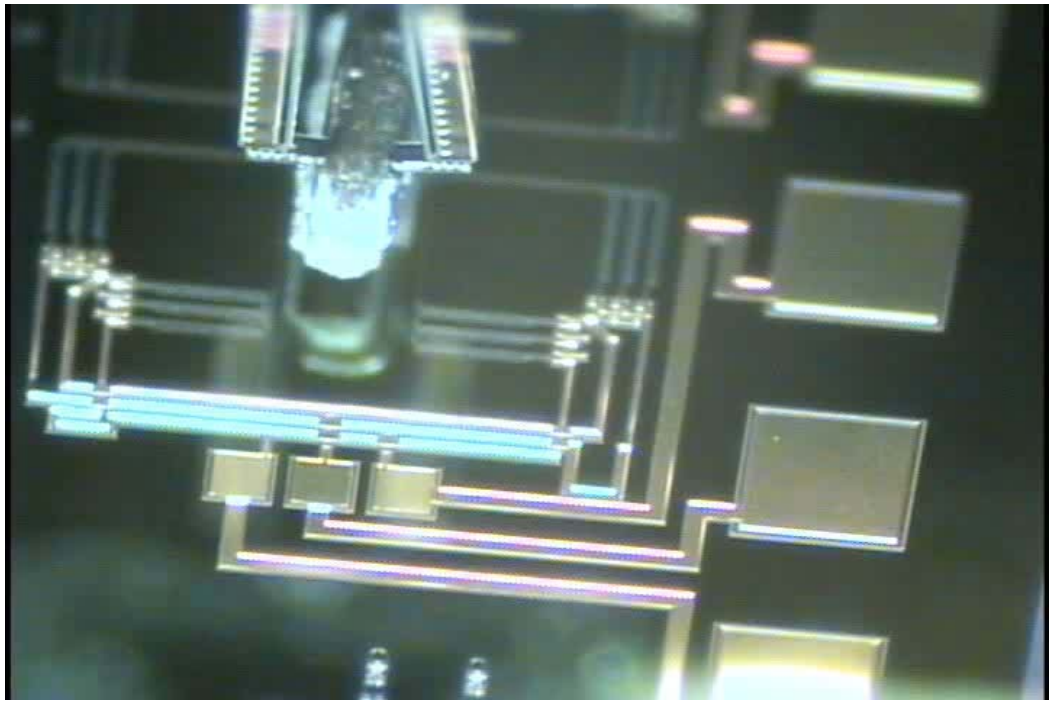
- **Manually - Micro probe/gripper**





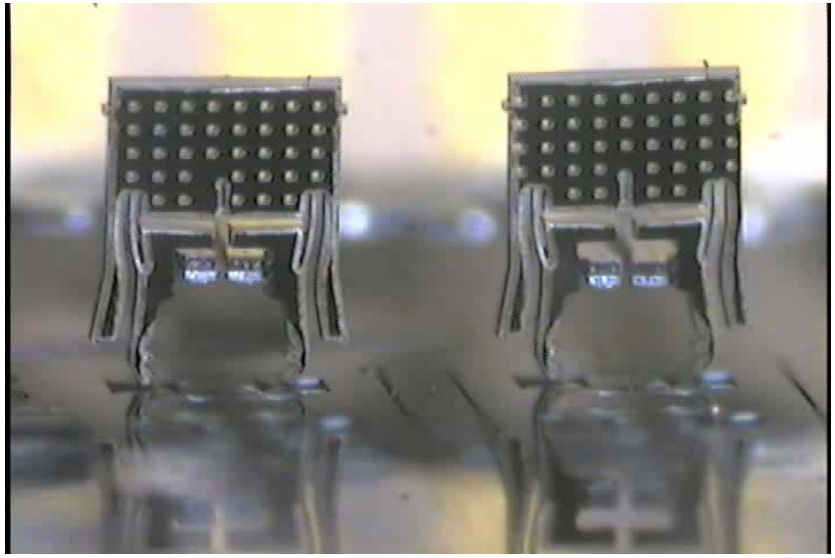
Keller, UC Berkeley, 1998

組裝－精密機械式



Zyvex Inc.

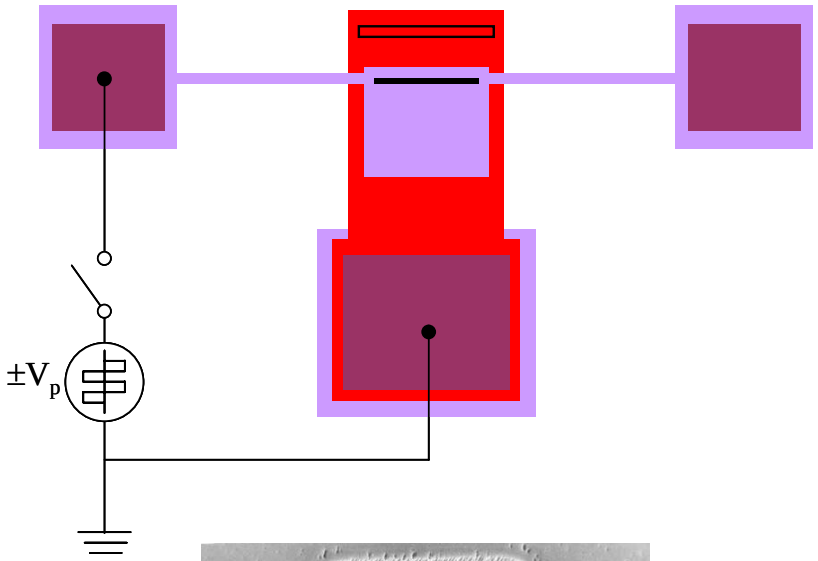
組裝－精密機械式

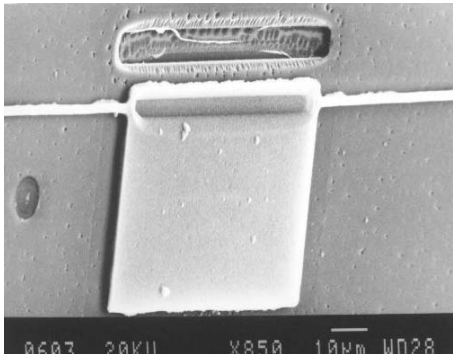


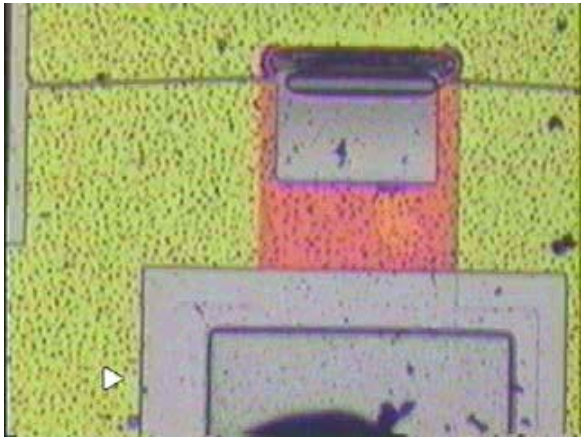
Zyvex Inc.

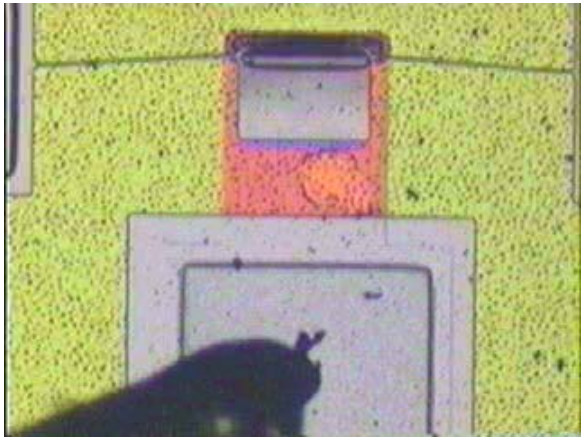
MDL
NTHU

組裝 – 微致動器輔助式



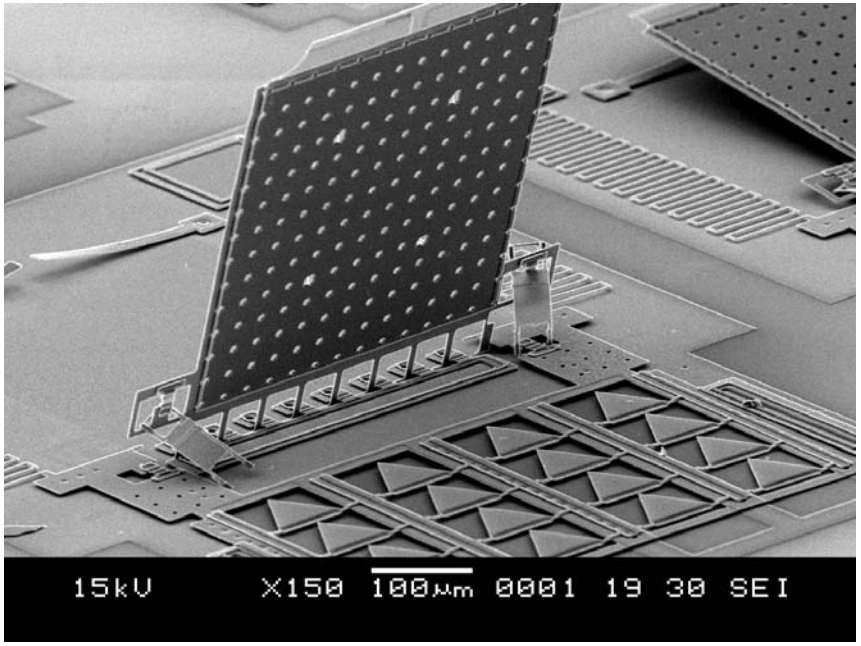


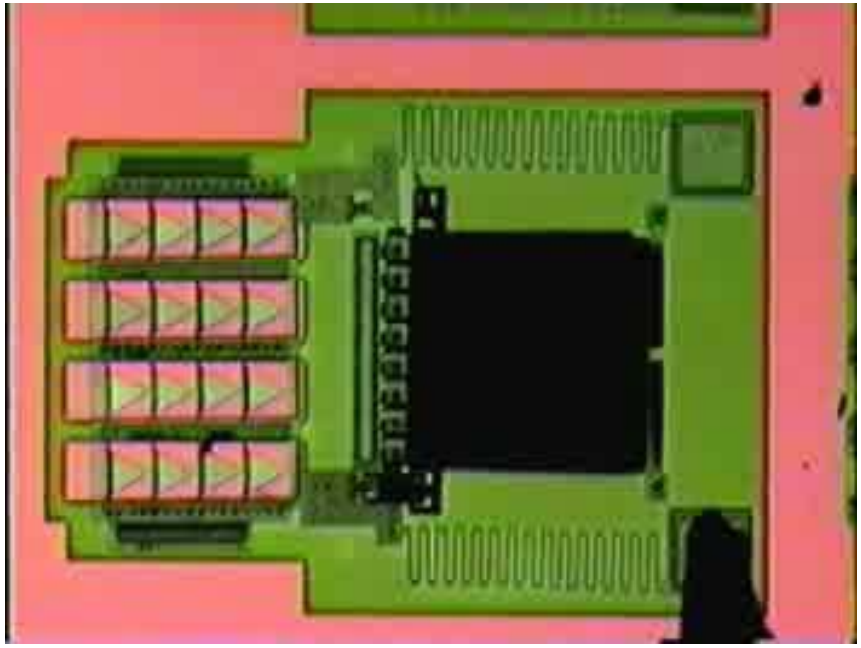




MDL
NTHU

組裝－微致動器輔助式

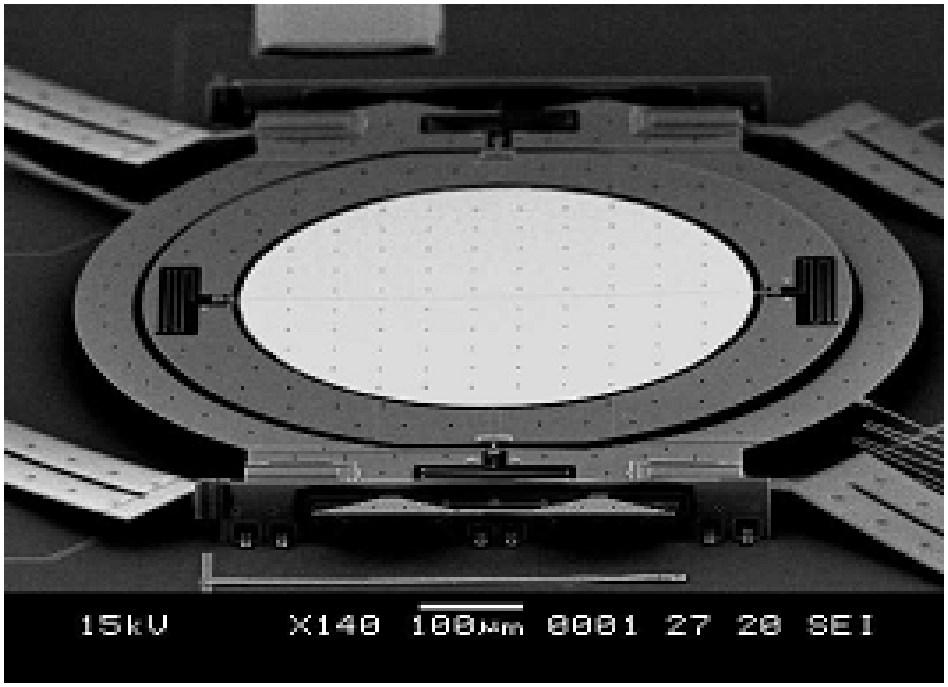


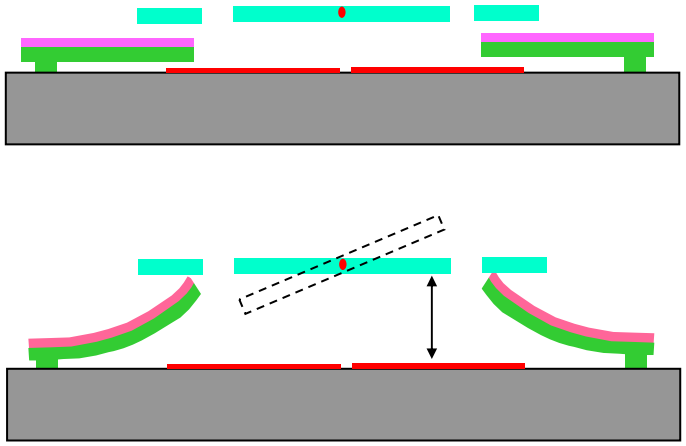


C.-Y. Wu, and W. Fang, 2002

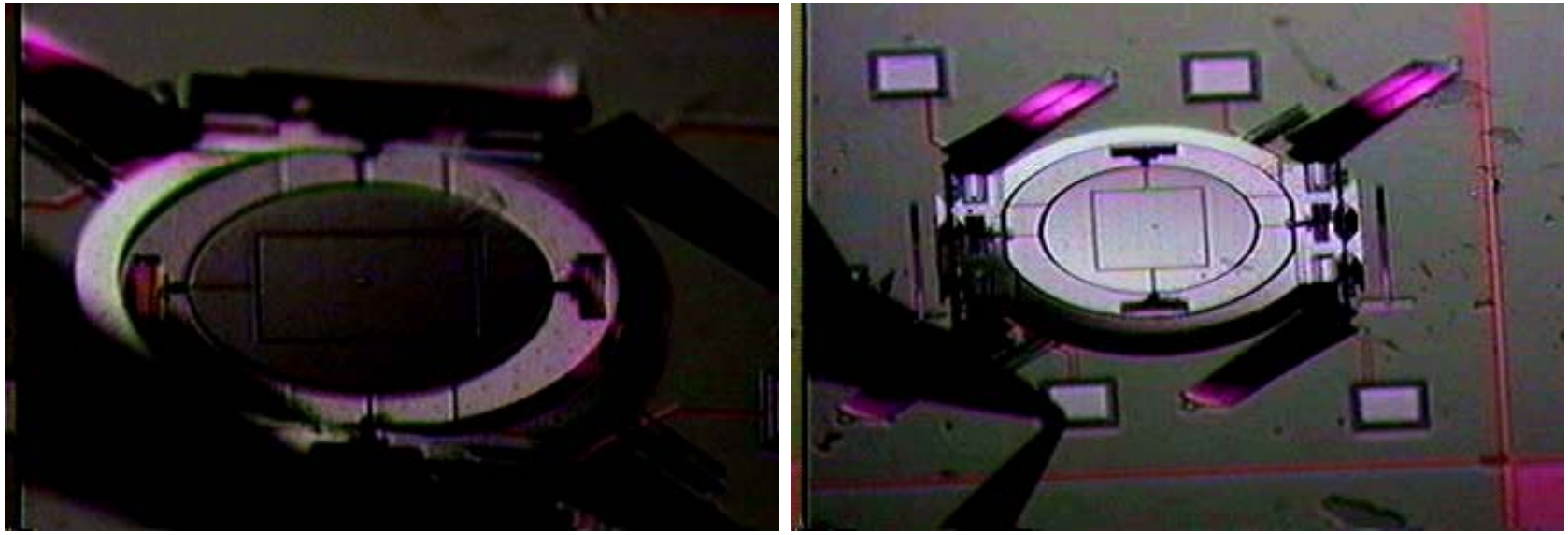
MDL
NTHU

應力自組裝成形





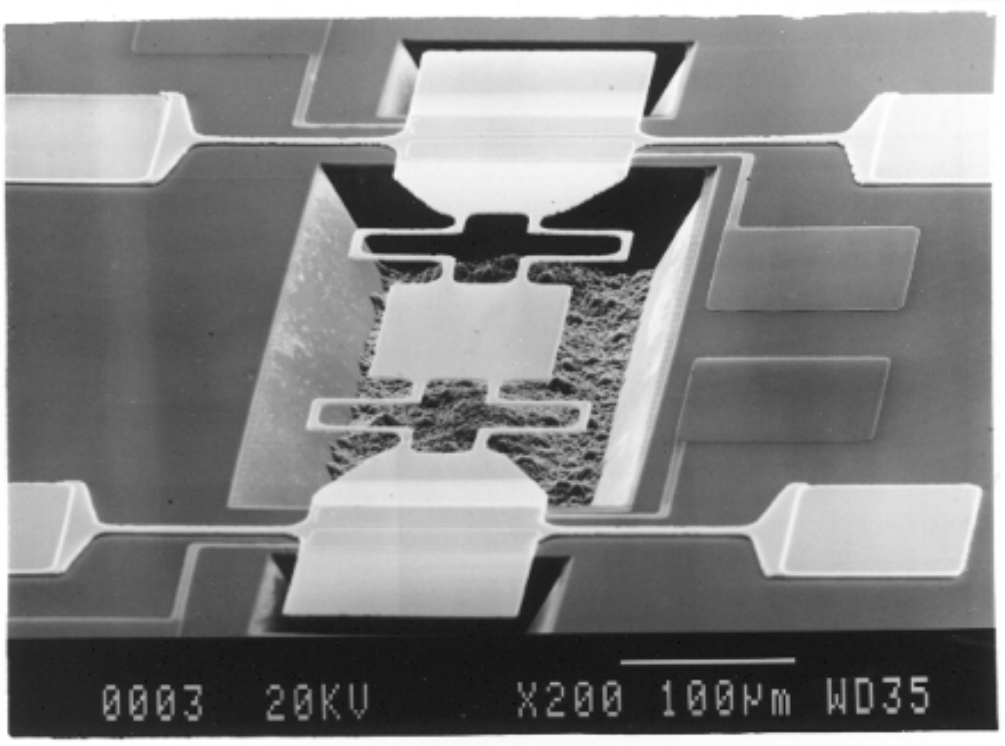
Y.-P. Ho, M. Wu, H.-Y. Lin and W. Fang, *IEEE Optical MEMS '02*, 2002



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

製程整合－一體成形

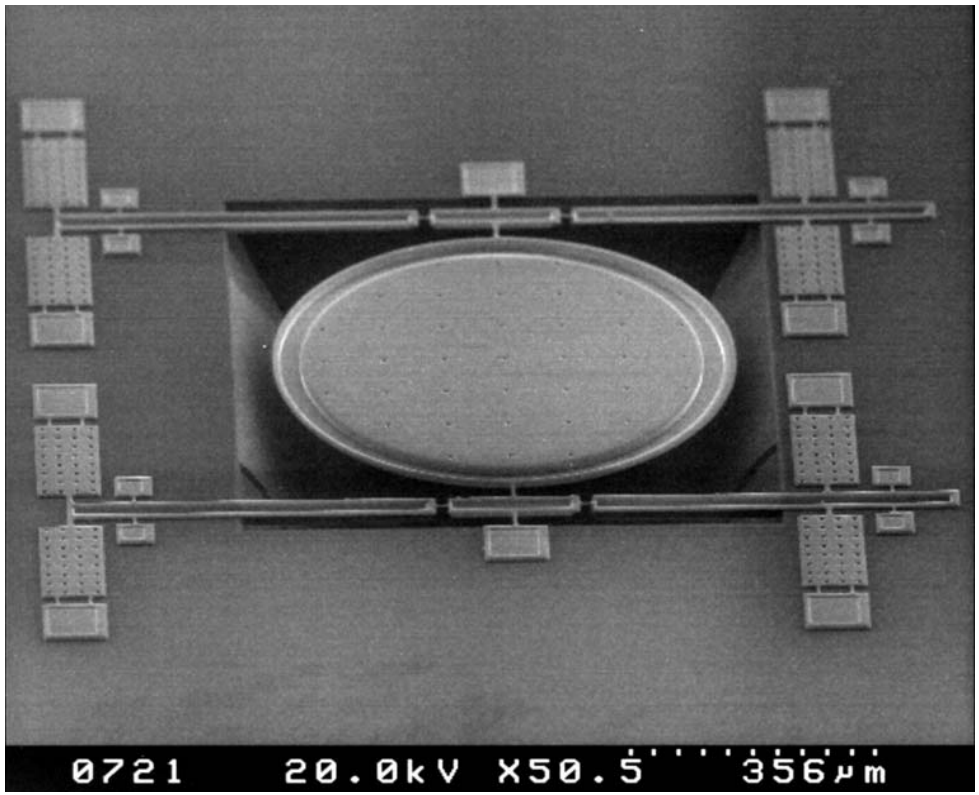
- 微定位平台



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

製程整合－一體成形

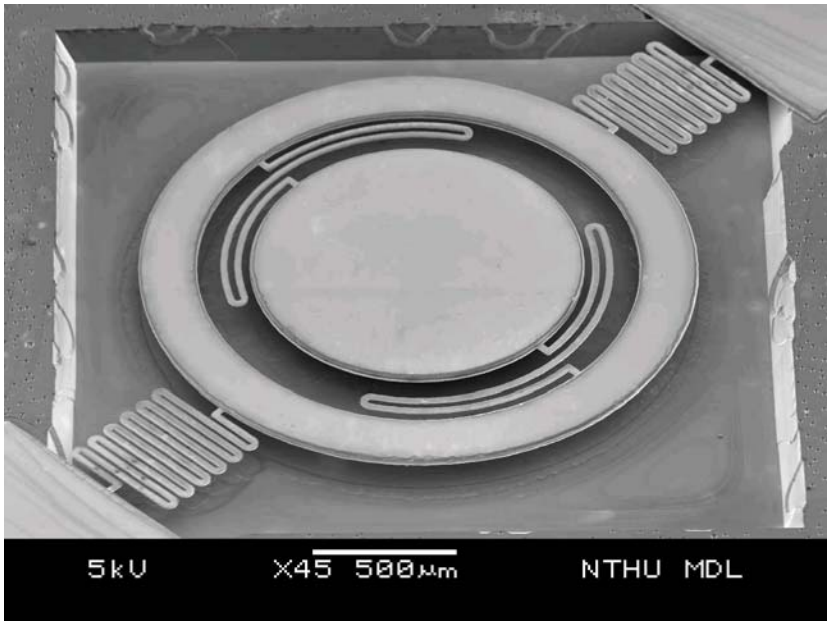
- 微一維掃瞄器

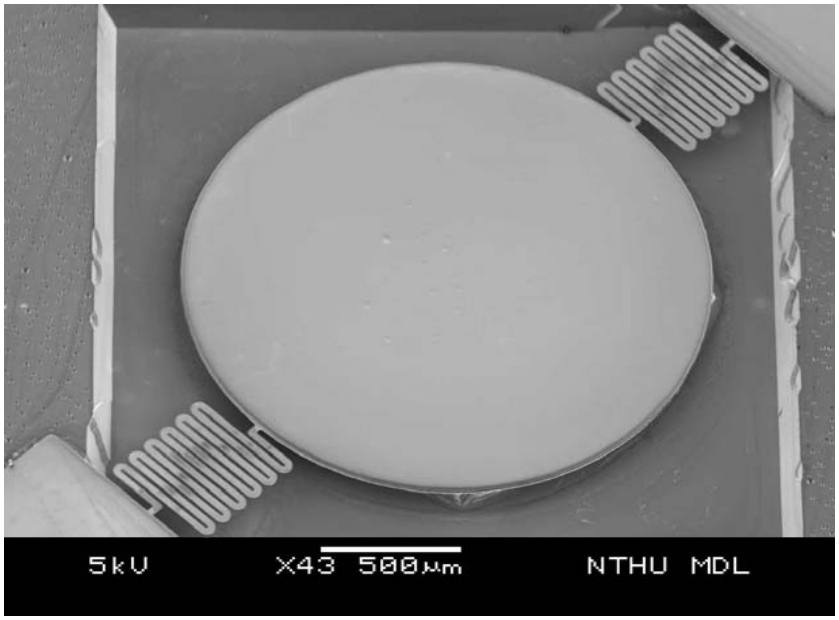


H.-Y. Lin and W. Fang, *IEEE Optical MEMS*, USA, 2000

製程整合－一體成形

- 微掃瞄器

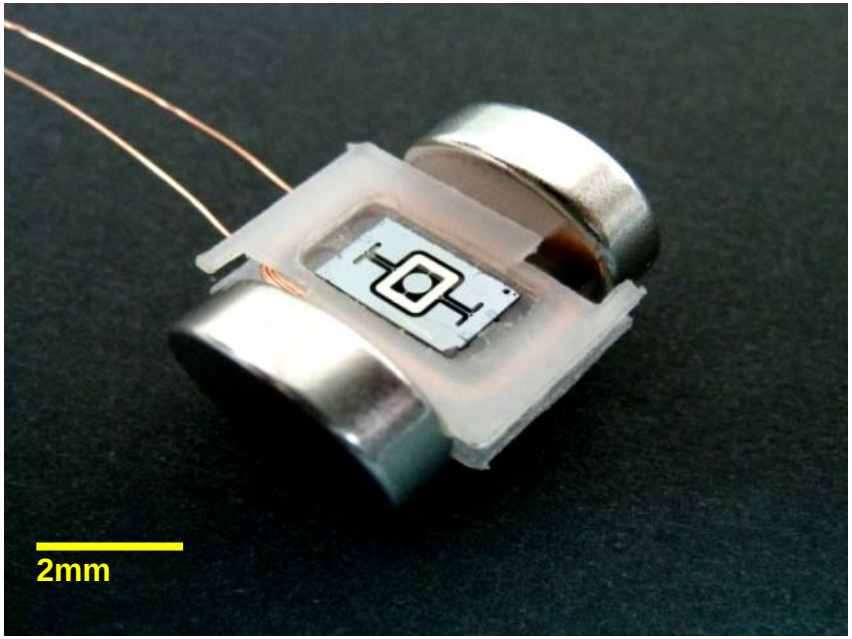


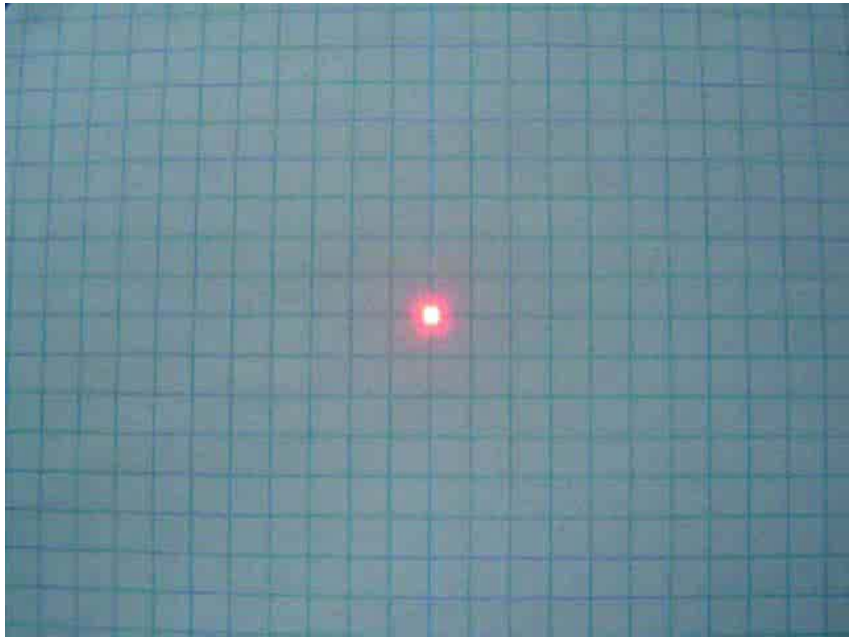


H. Yang, and W. Fang, *IEEE MEMS'06*, Istanbul, Turkey, 2006

MDL
NTHU

- **Scanning images**

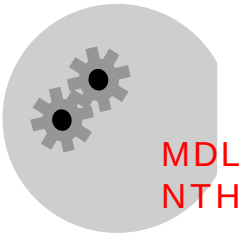




Yang, and Fang, *JMEMS*, 2007

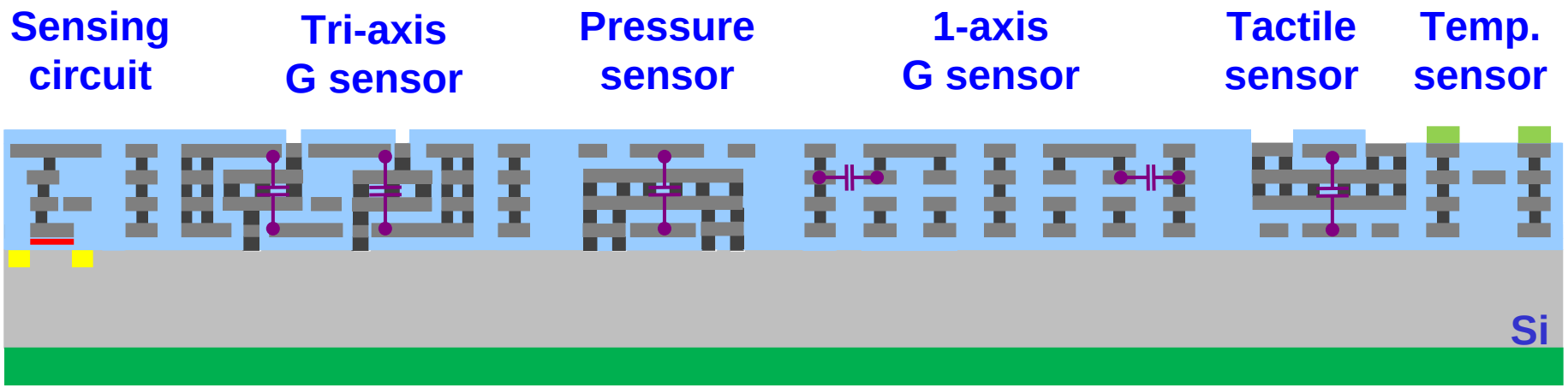
MDL
NTHU

製程平台 – 標準製程



MDL
NTHU

製程平台 I



CMOS-based sensors platform

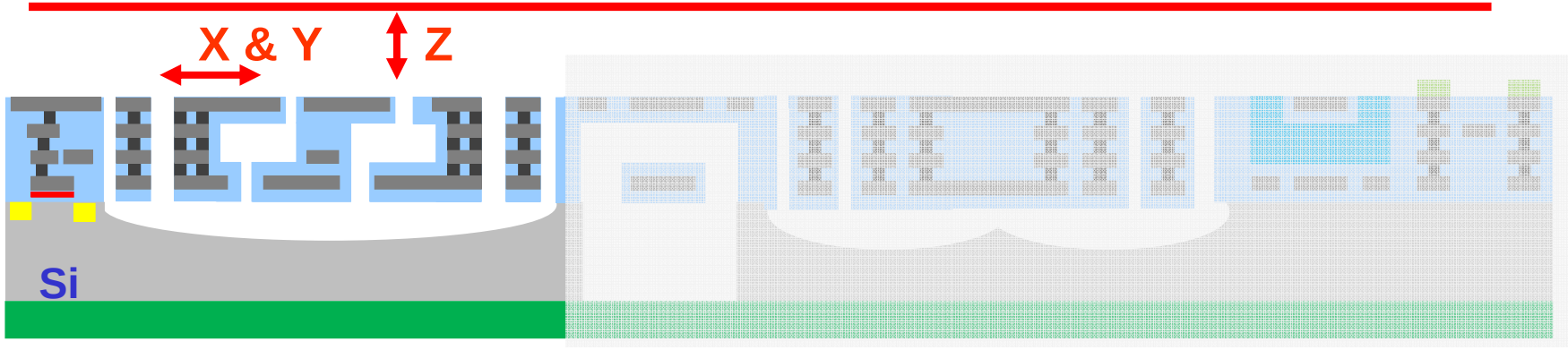
Si　Poly-Si　W-via　Metal

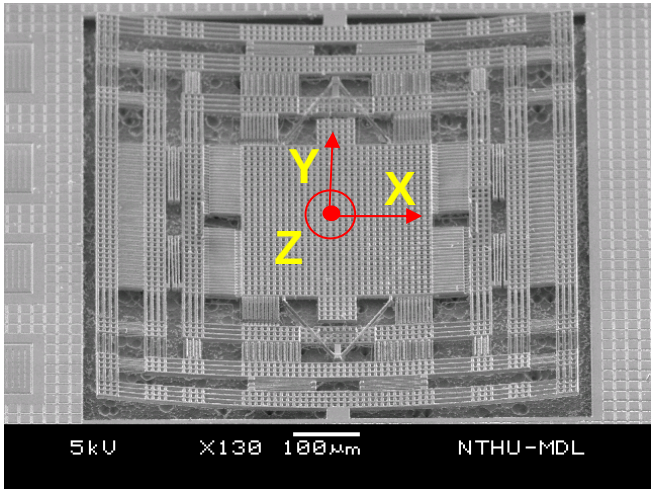
Polymer　SiO_2　Pt

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

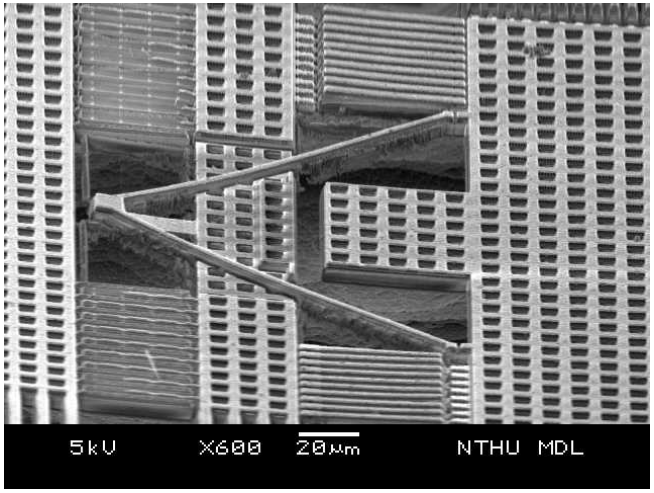
MDL
NTHU

3-axis G-sensor





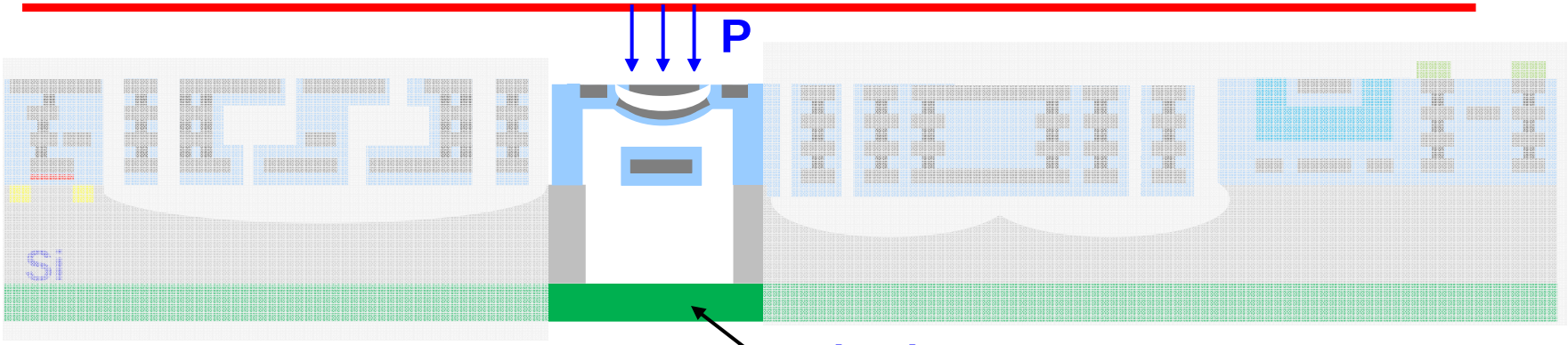
Single proof-mass



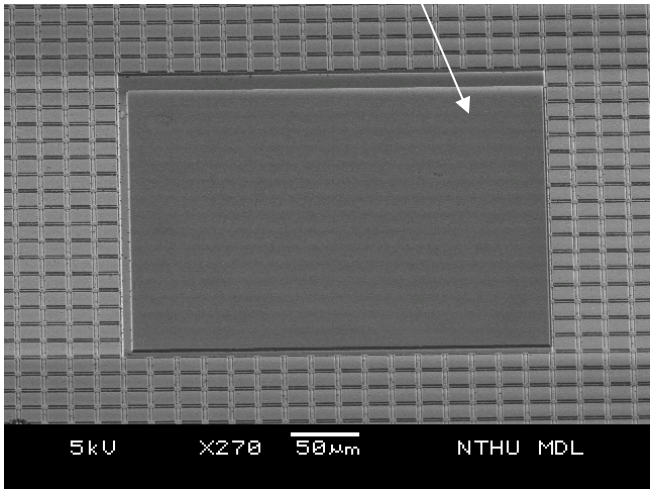
Z-spring

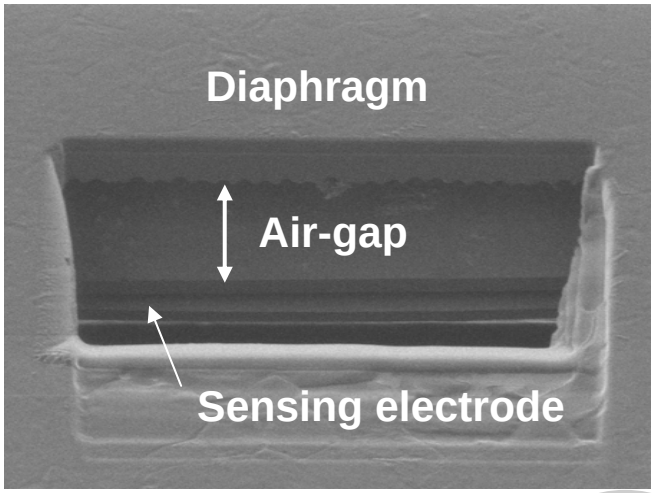
MDL
NTHU

Pressure Sensors



Suspended diaphragm

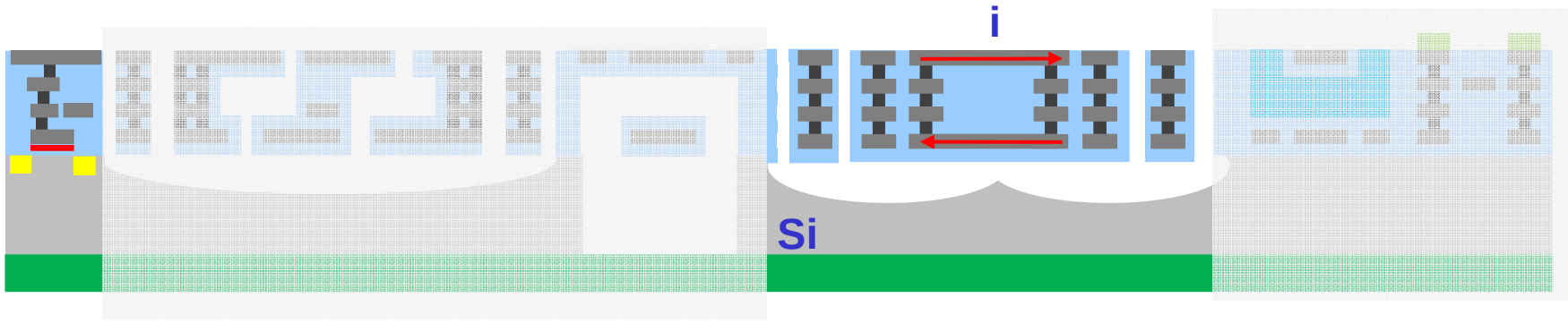




FIB sectioning

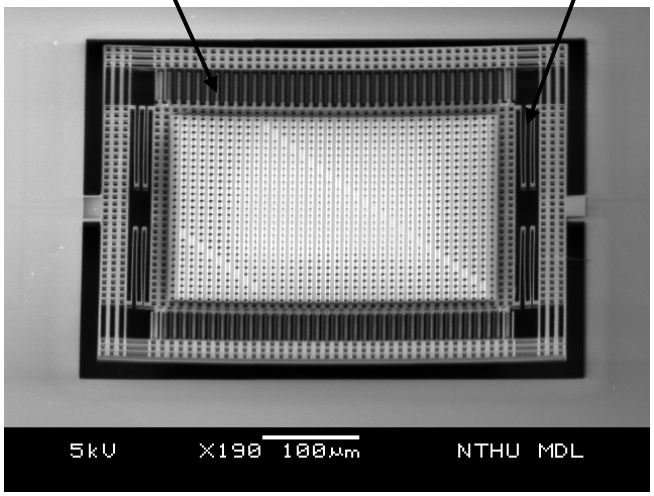
MDL
NTHU

Magnetic Sensors

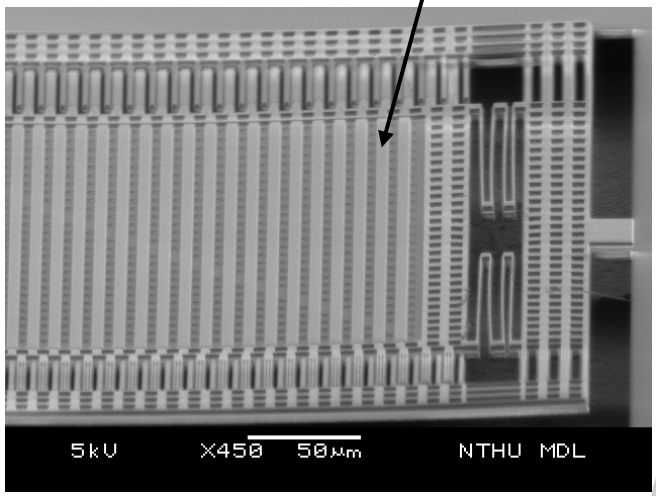


Fingers

Spring

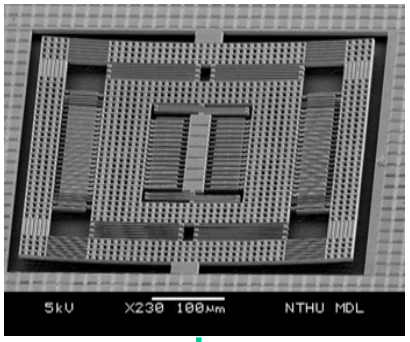


Coil

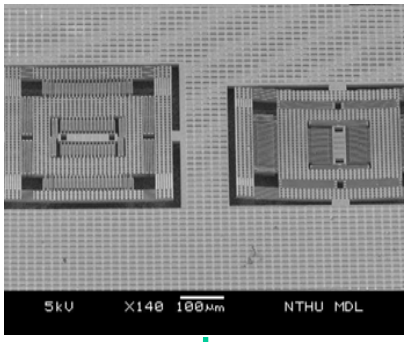


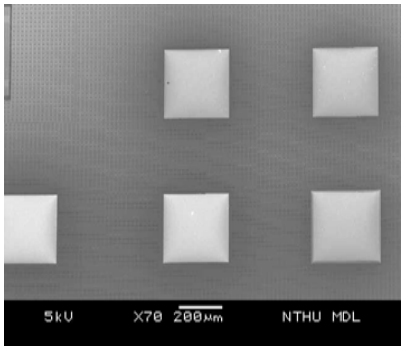
MDL
NTHU

1-axis G Sensor

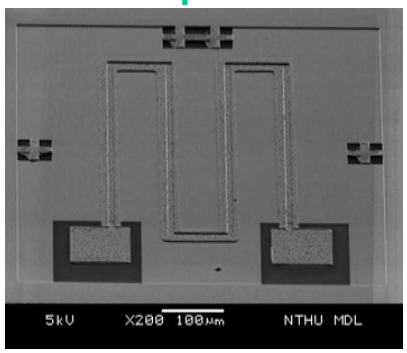


2-axis G Sensor

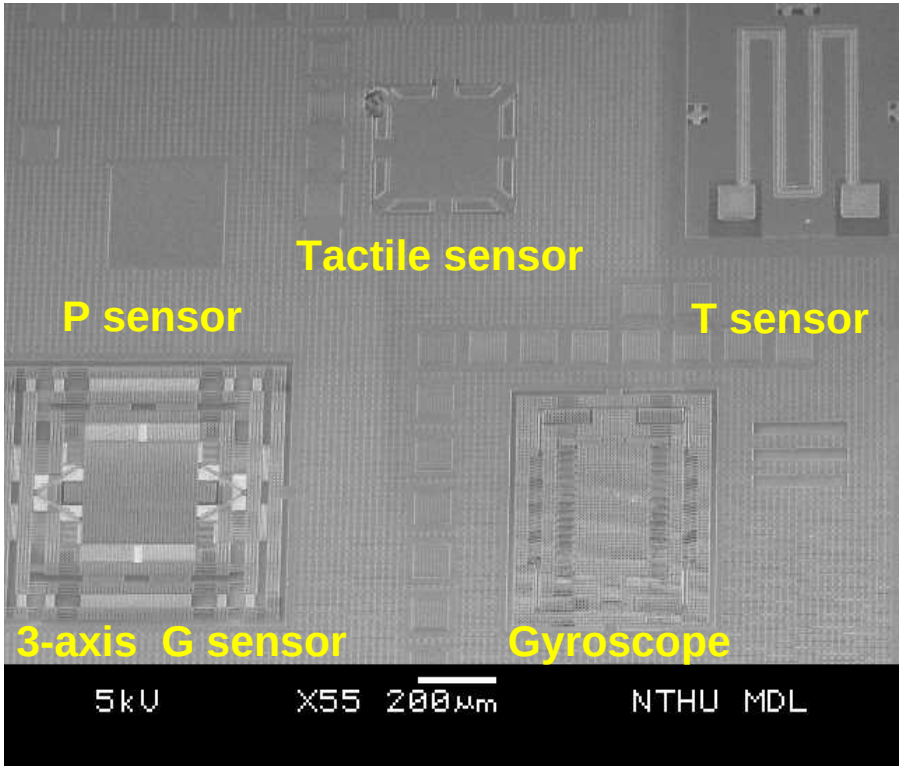




P Sensor Array

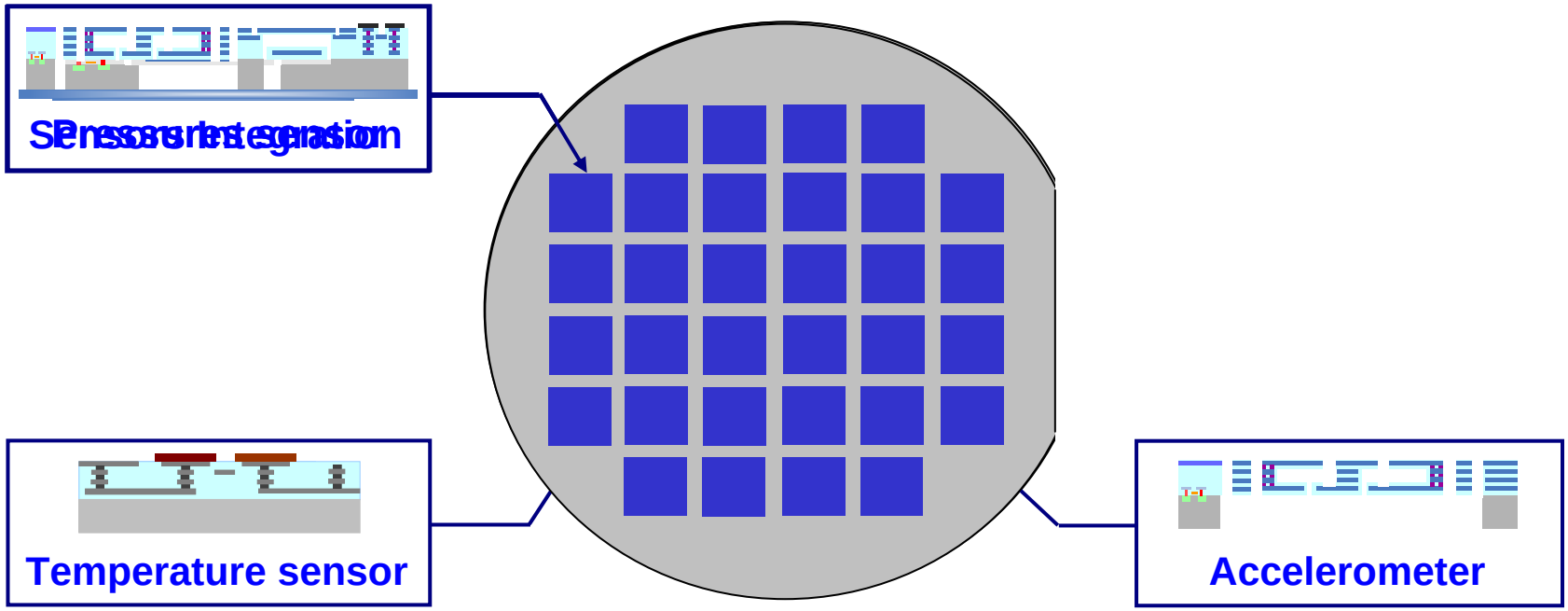


T Sensor

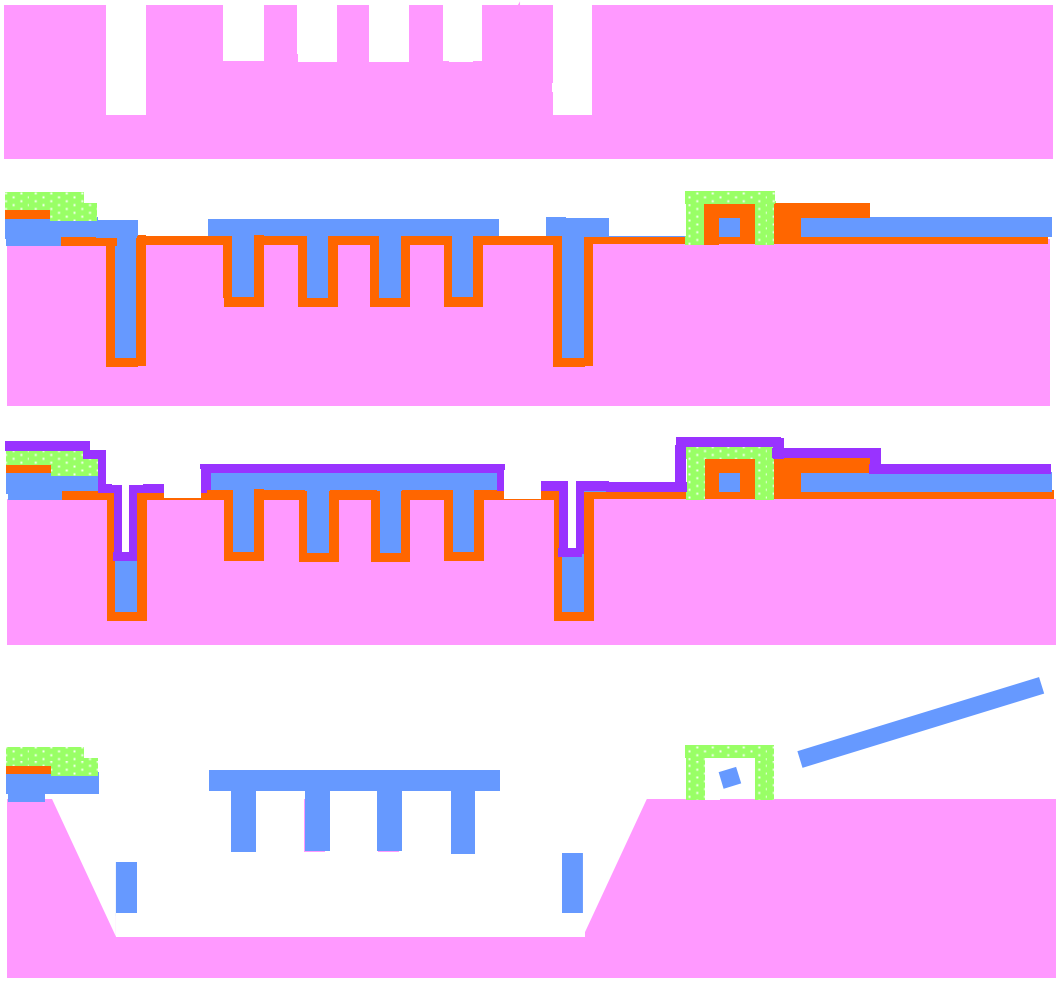


MDL
NTHU

- **Batch of Sensor, Multi Sensors, and Sensors Integration**



製程平台 II



DRIE

MUMPs process

DRIE trimming
SixNy passivation

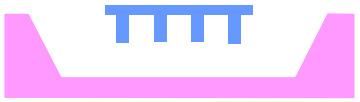
Bulk etching
Remove passivation

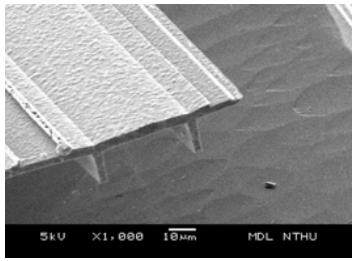
M. Wu, C. Lai, and W. Fang, *IEEE MEMS'04*, the Netherlands, 2004

MDL
NTHU

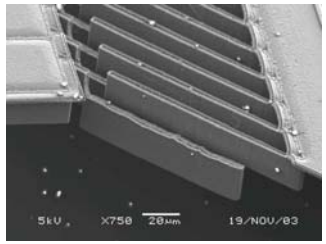
單軸式微光掃瞄器

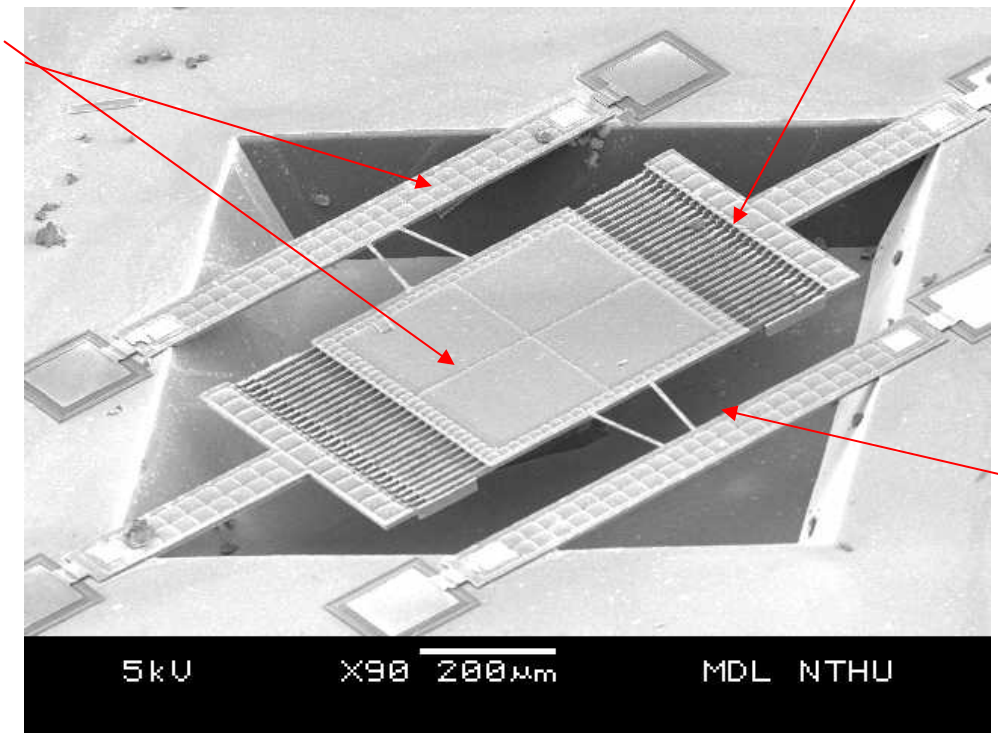
Rib-reinforced mirror and frame





Vertical comb actuator





Torsional spring

M. Wu, and W. Fang, IEEE MEMS, Masstricht, the Netherlands, 2004

MDL
NTHU

條碼器

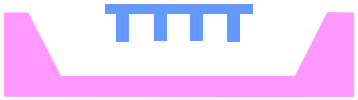
Flic

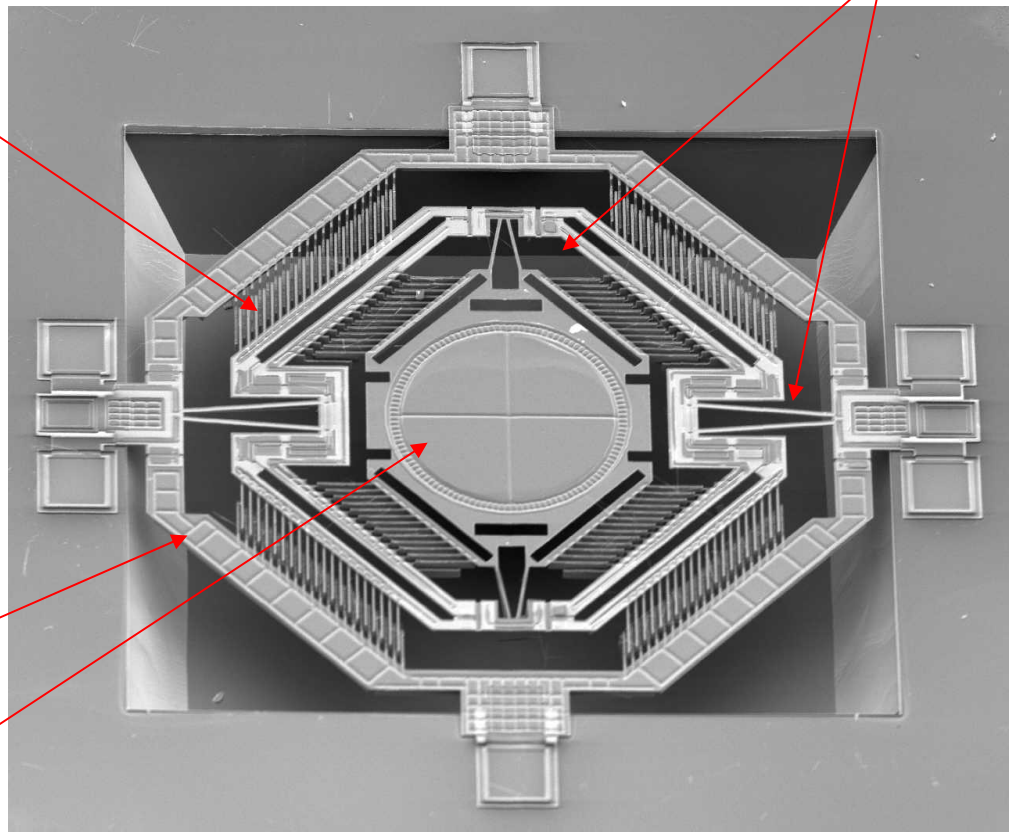
MDL
NTHU

雙軸式微光掃瞄器

Springs (passive)

Driving electrodes (active)





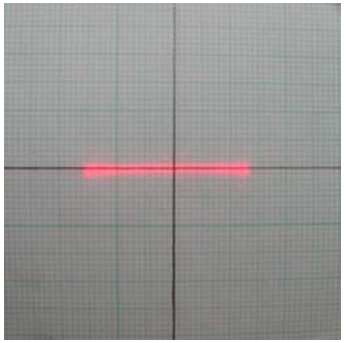
Supporting frame (passive)

Mirror (passive)

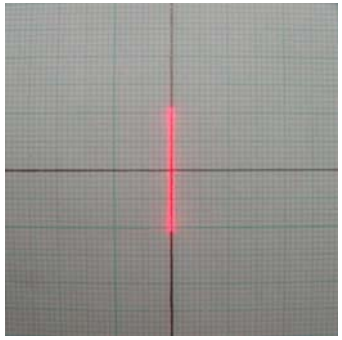
M. Wu, C. Lai, and W. Fang, *IEEE MEMS'04*, the Netherlands, 2004

MDL
NTHU

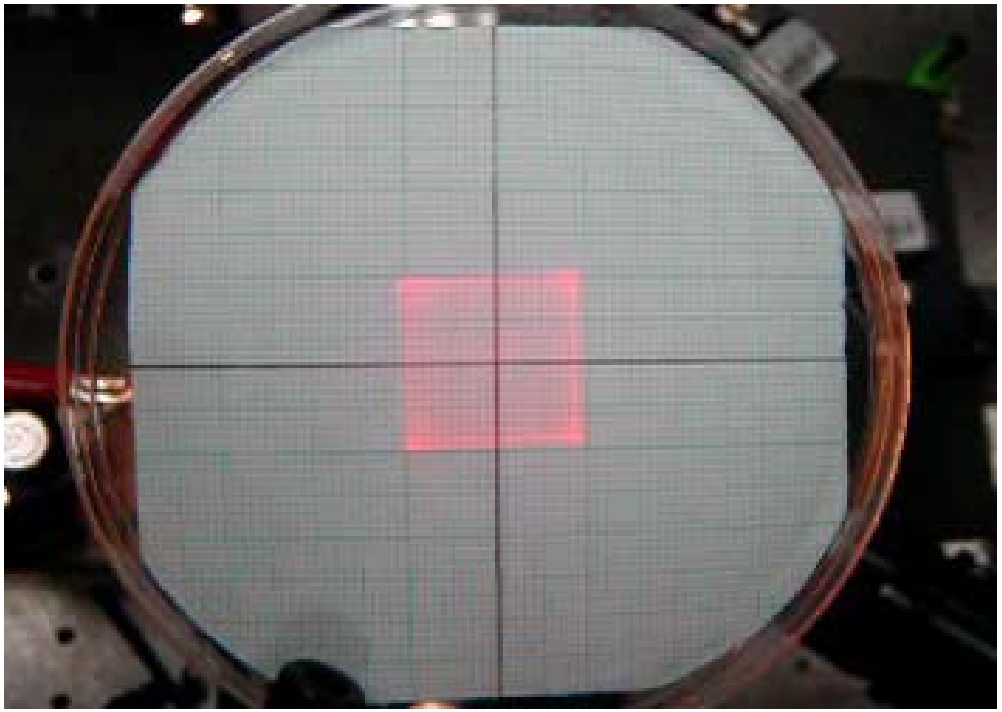
- **Scanning images**



Inner axis: 4.1kHz

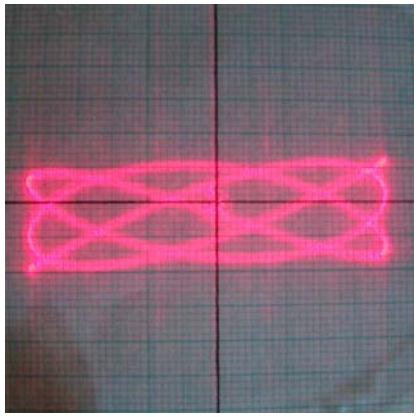


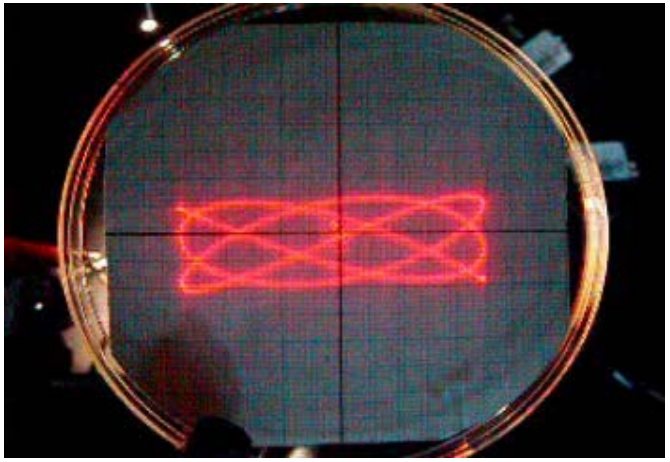
Outer axis: 7.1kHz

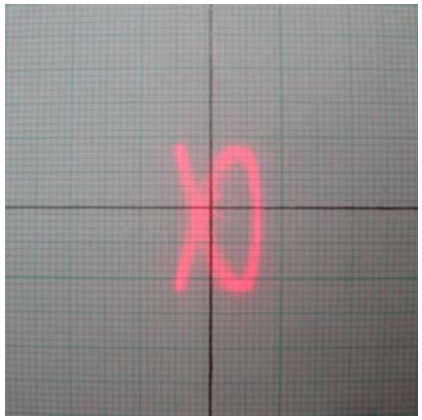


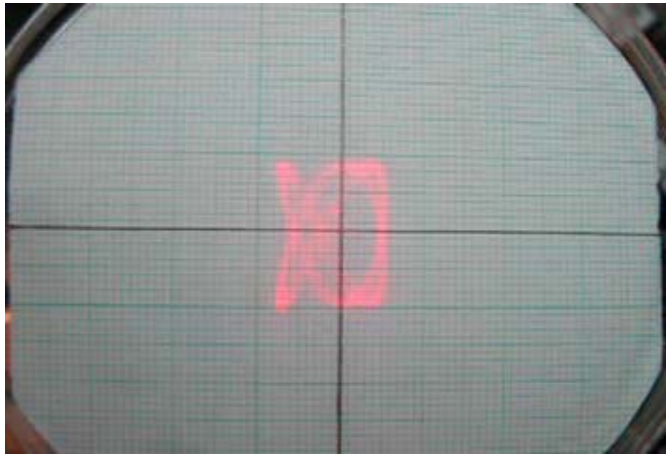
MDL
NTHU

- **Scanning images**



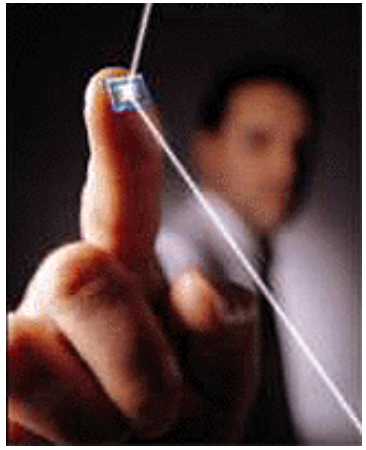






MDL
NTHU

掃描式投影機



Microvision Inc. 2000

MDL
NTHU

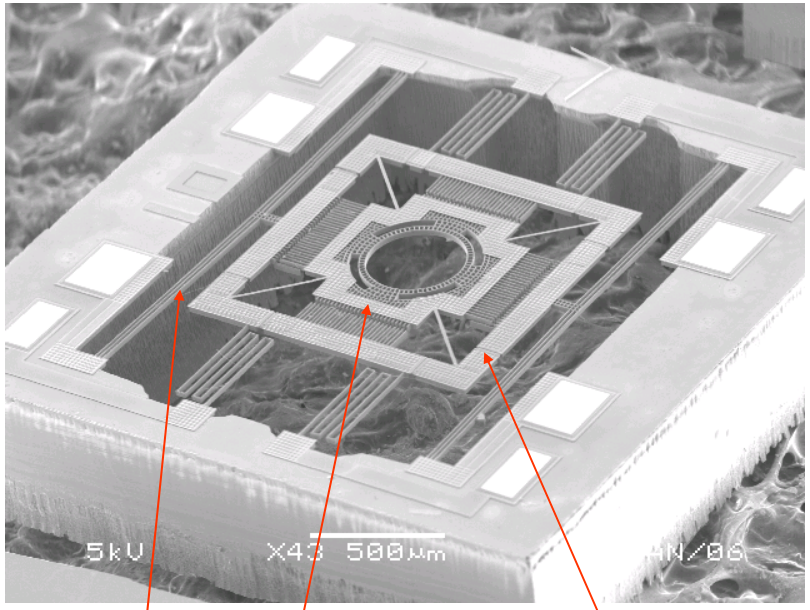
頭戴式顯示器

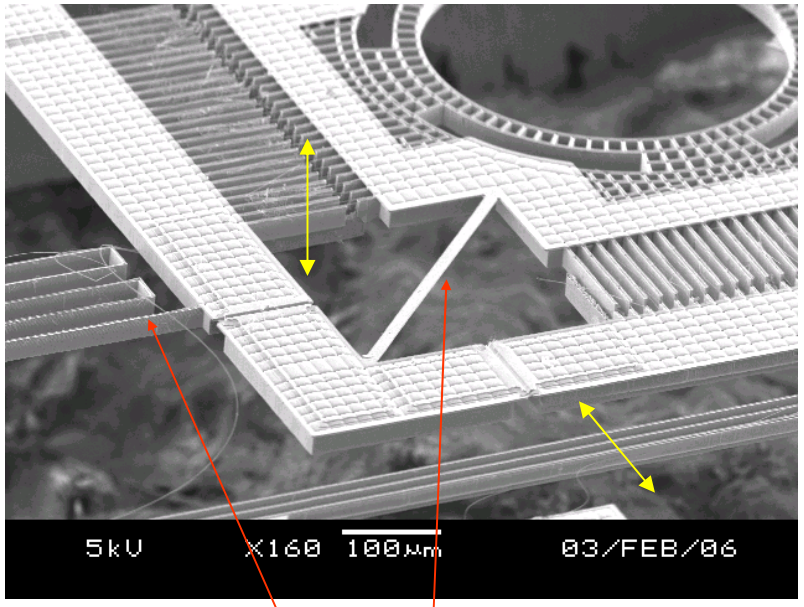
Olympus

Micro Optical

HP

微光聚焦定位器





In-plane and out-of-plane actuators

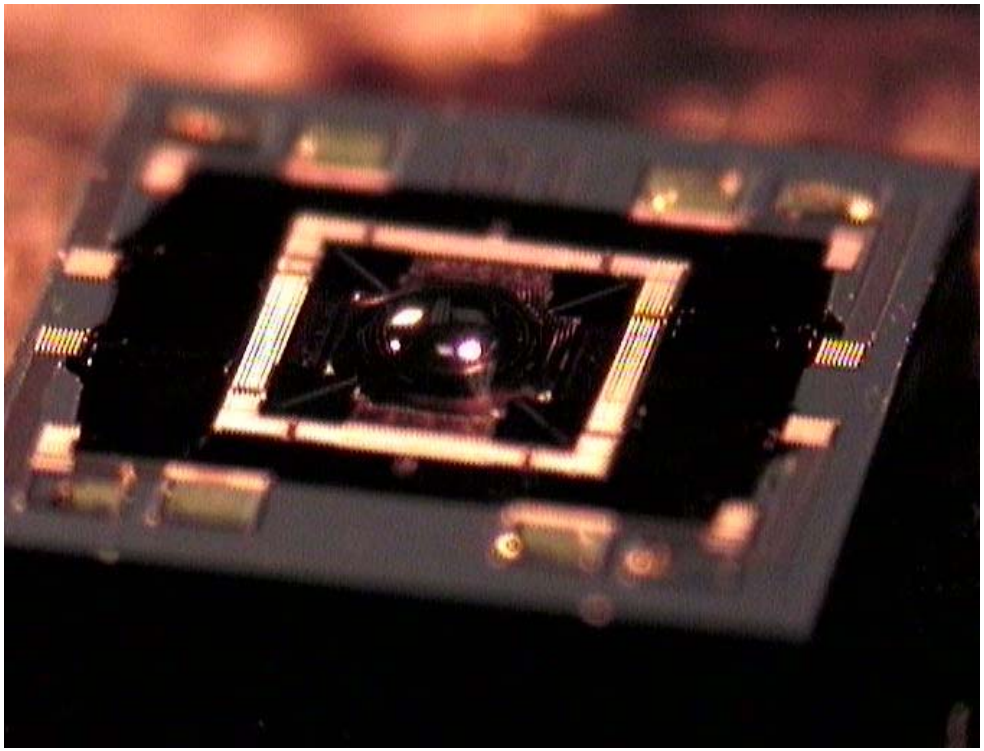
Stiff supporting frame

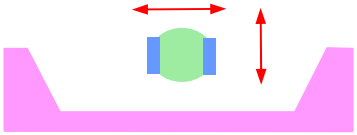
In-plane and out-of-plane springs

M. Wu, and W. Fang, *JMM, 2006*

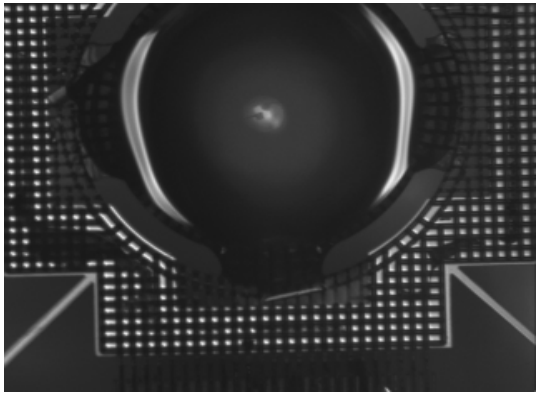
MDL
NTHU

- **Polymer lens and Driving test**

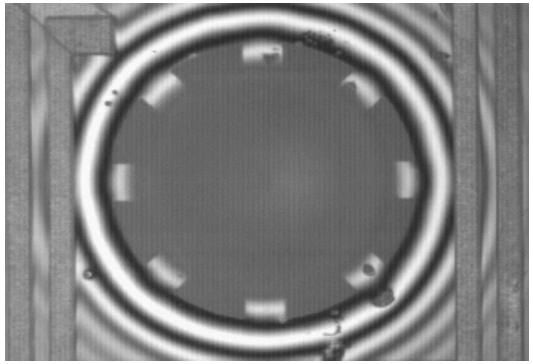




Tracking



Focusing

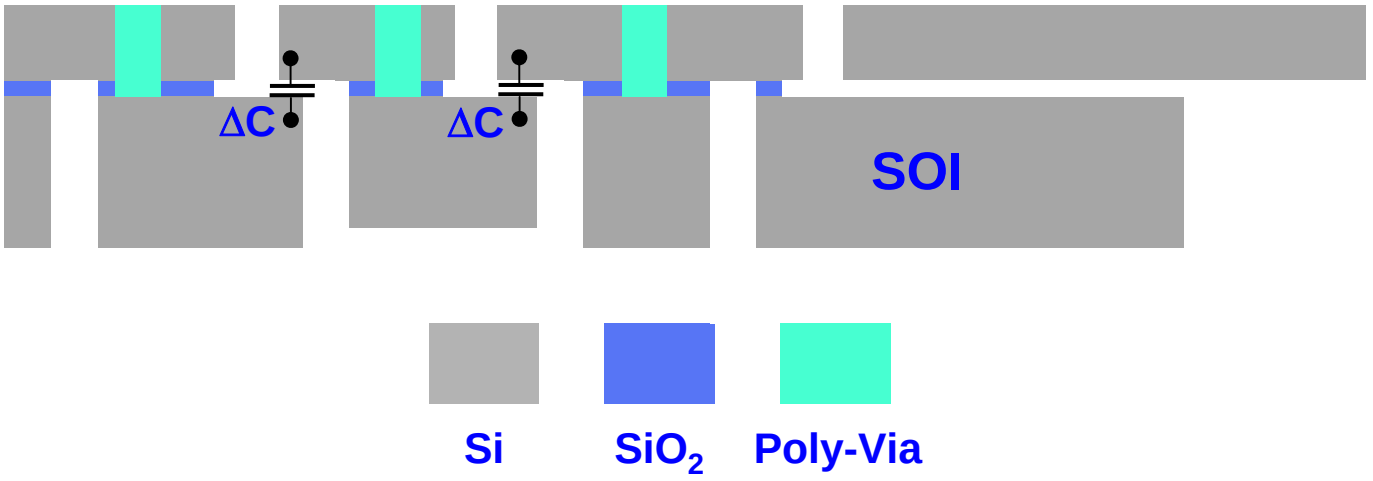


MDL
NTHU

製程平台 III

3-axis accelerometer

Chip-scale micro-instrument

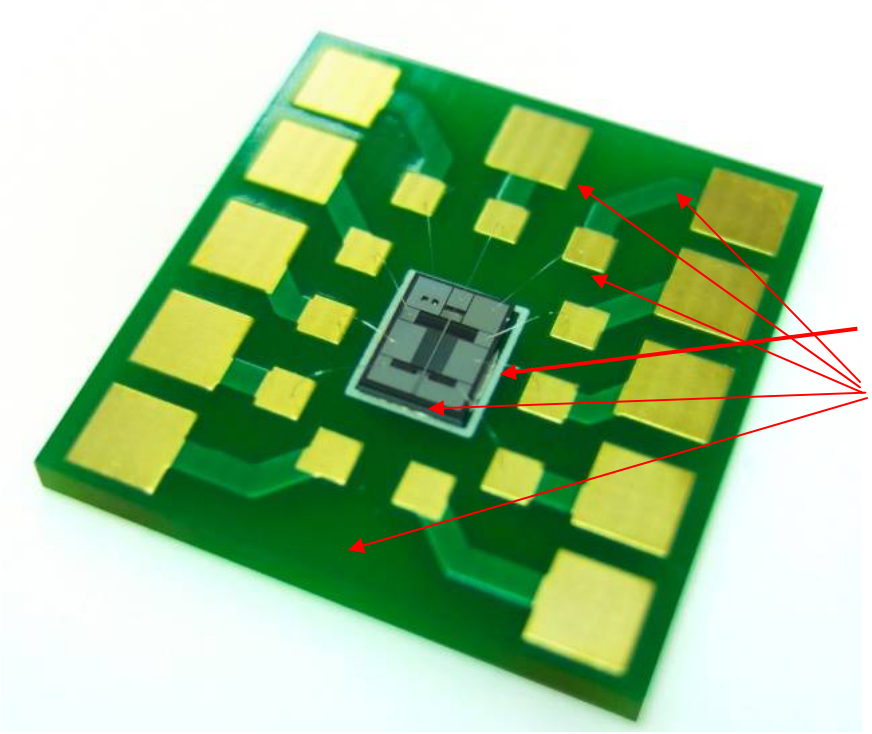


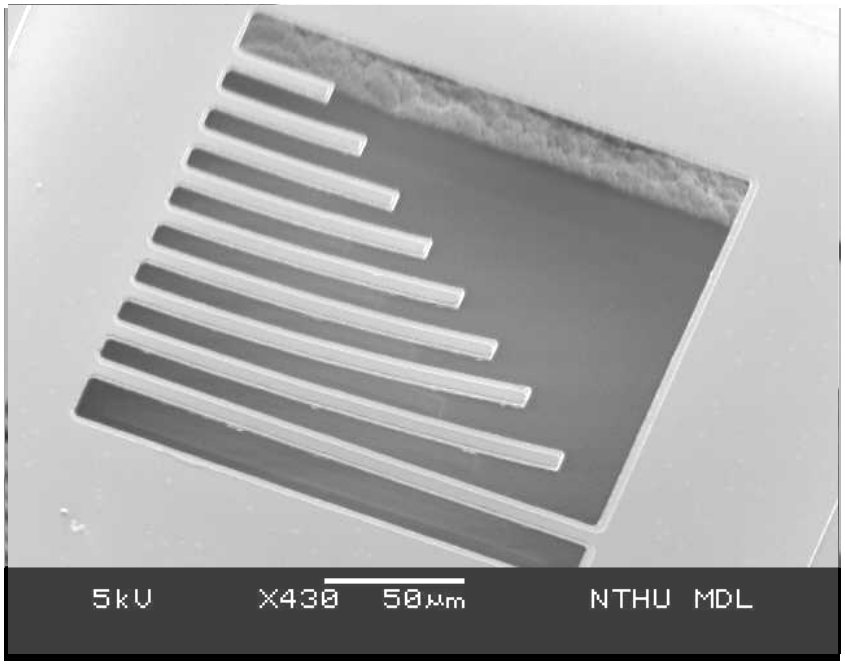
Hsu, and Fang, *Transducers*, Denver, USA, 2009

Hsu, and Fang, *JMM*, 2009

MDL
NTHU

- **Process integration - Micro test chip (SOI process)**

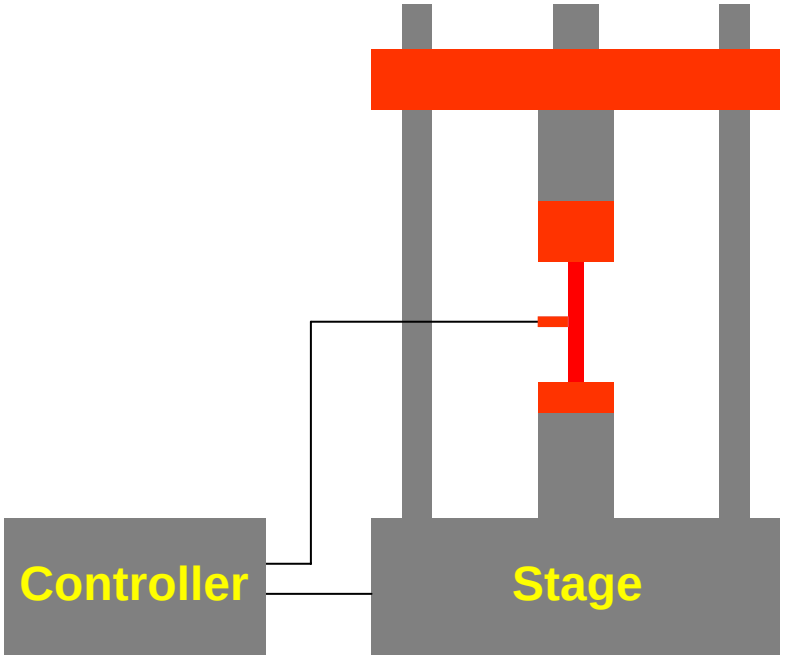




MDL
NTHU

- **Existing mechanical property tester – by assembly**

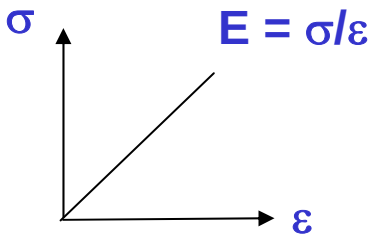
  + EX: Tensile test



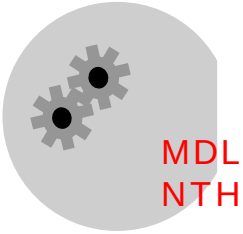
Load/displacement applying

Load/displacement detection

Sample preparation

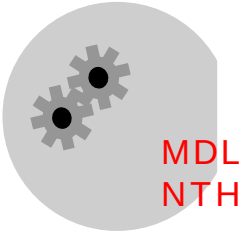


奈微系統的特色與應用

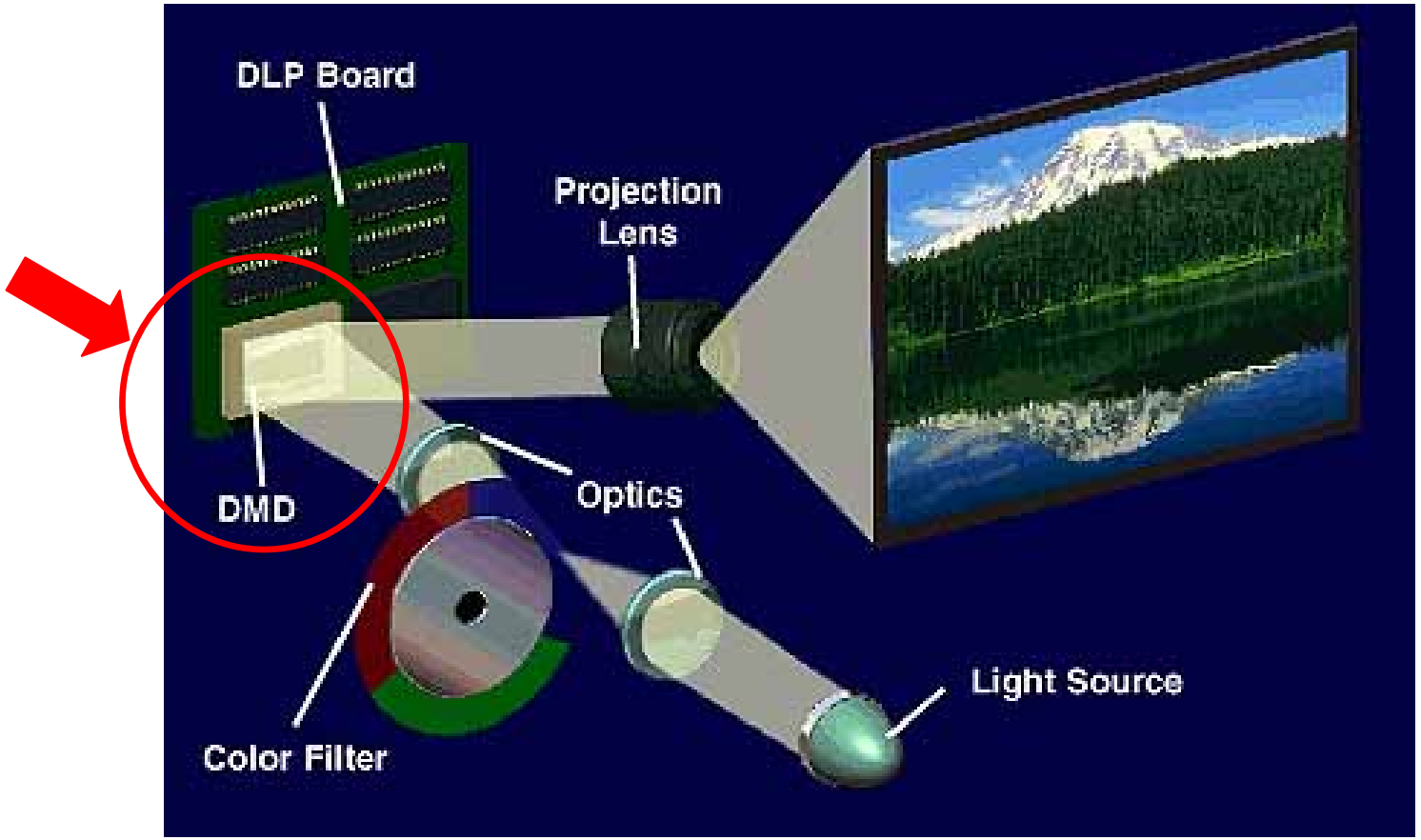


MDL
NTHU

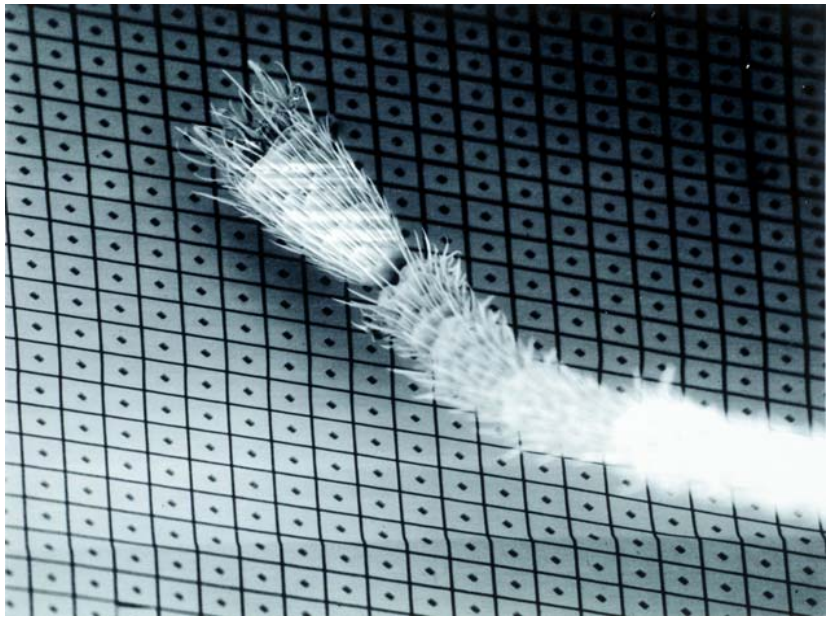
- **Miniaturization (縮小) - length scale**
- **Distribution (分布) - array, multi function**
- **Integration (整合) - mechanical and electrical**
- **Motion (運動) - moving parts and media**



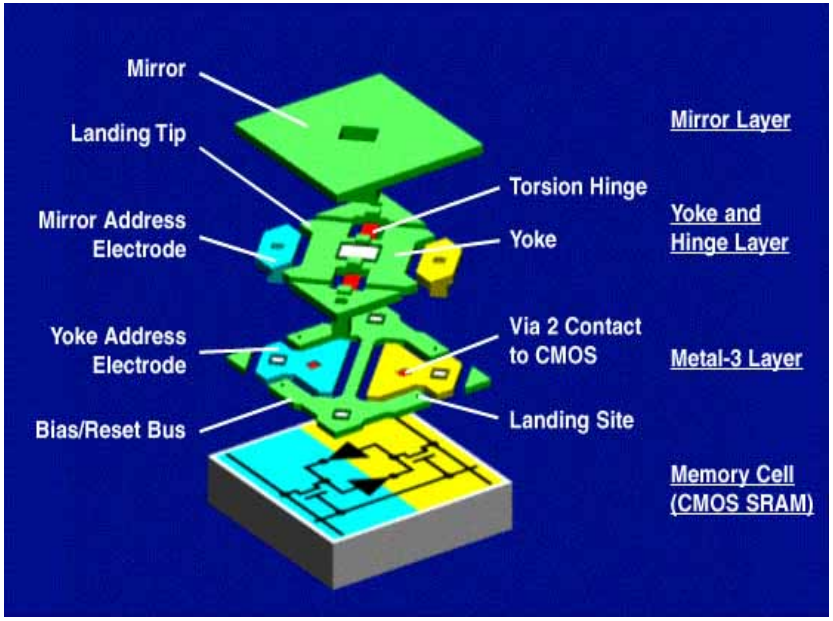
實例 – DLP Projector, TI

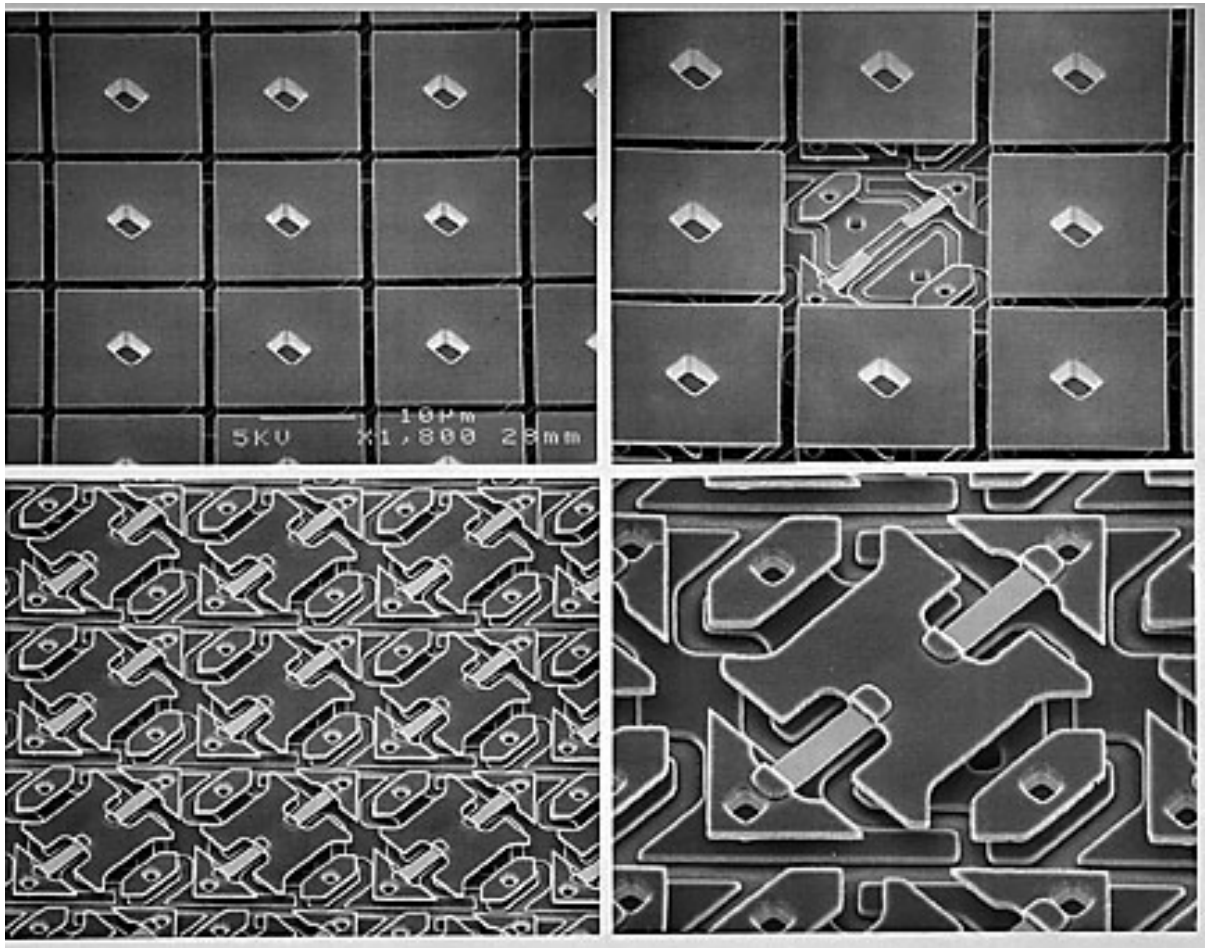


- 縮小/分布/整合/運動

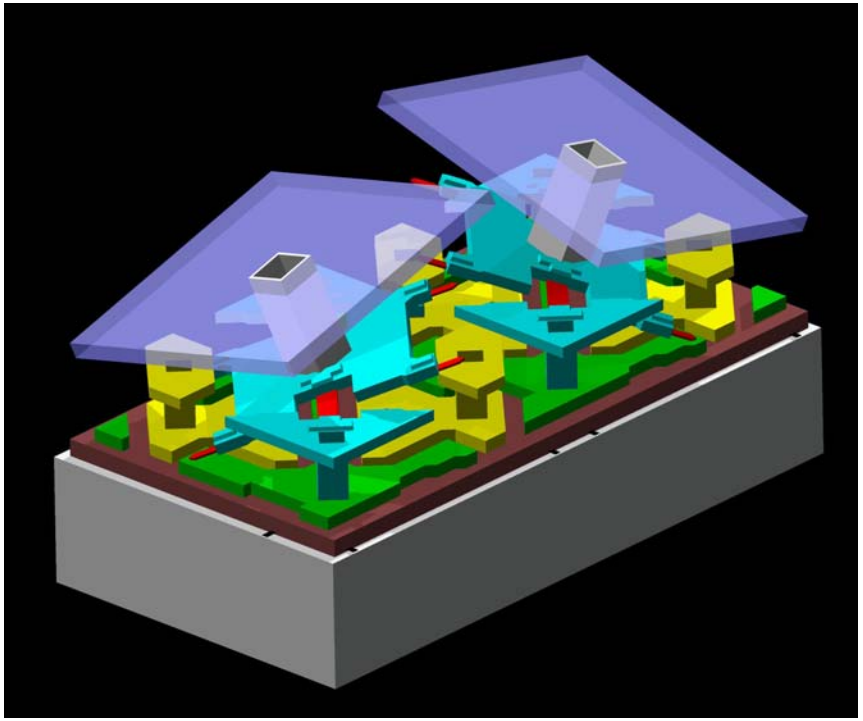


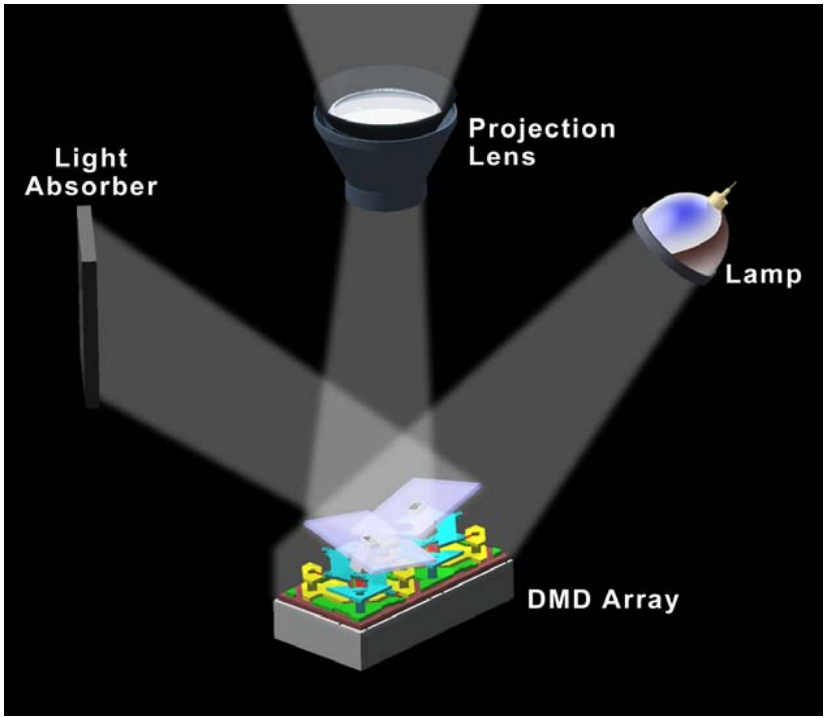
~15 μm





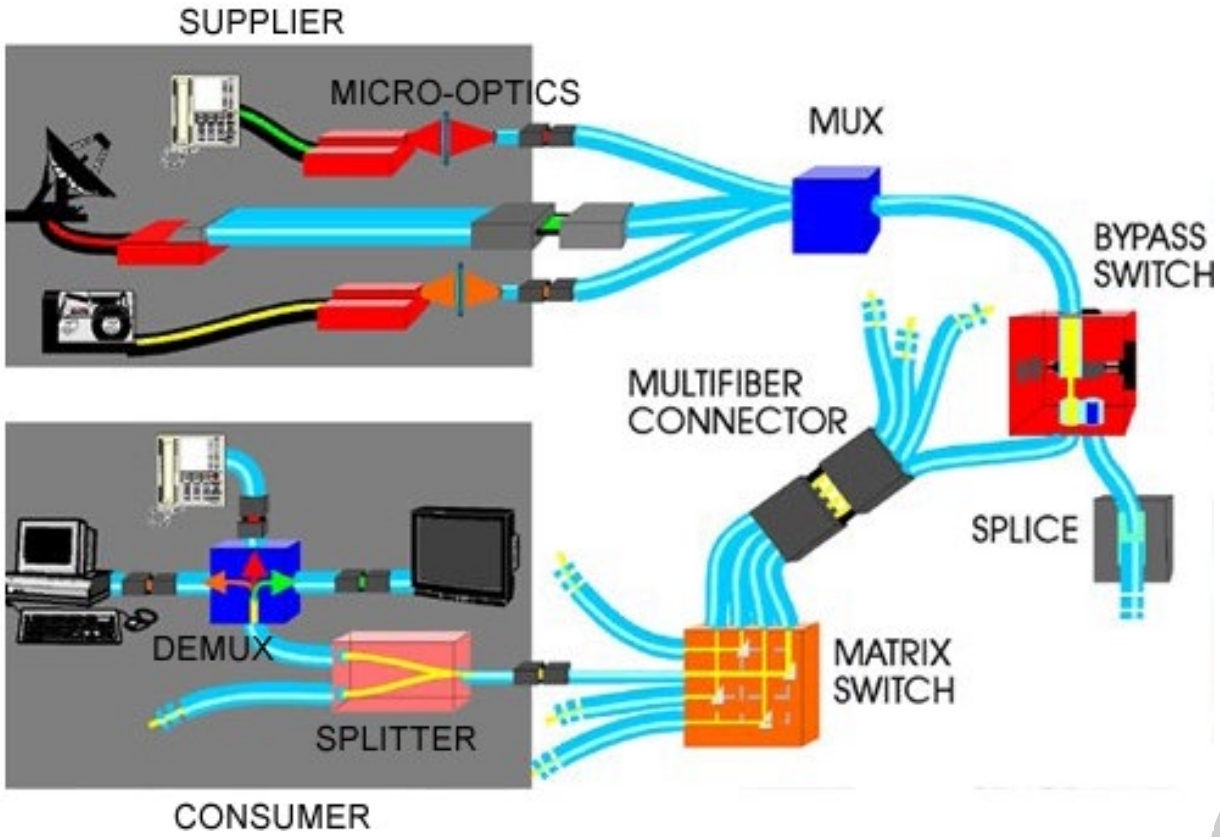
MDL
NTHU




Light
Absorber
Projection
Lens
Lamp
DMD Array

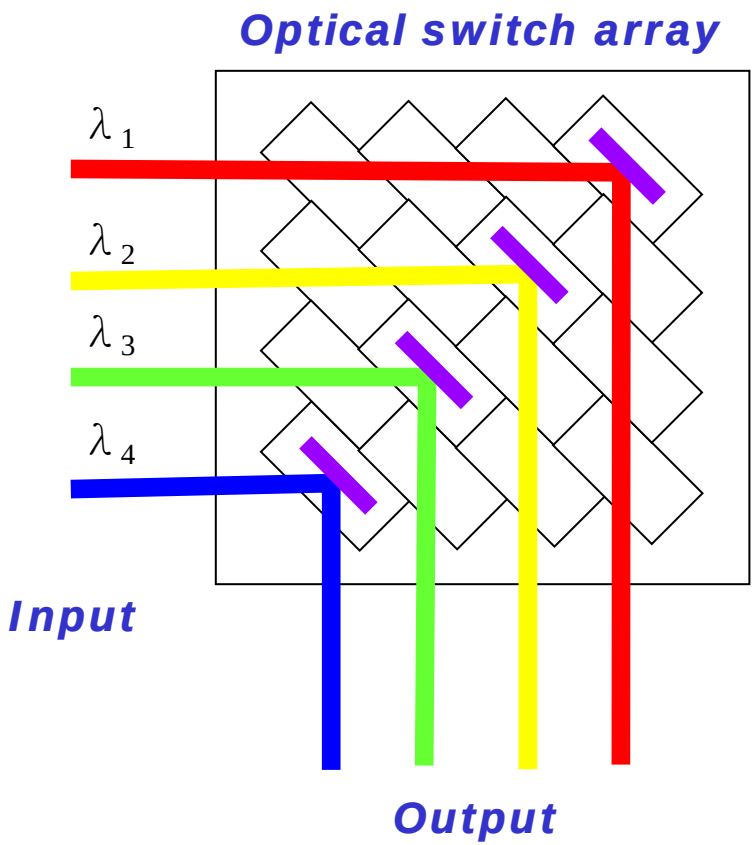
光纖通訊

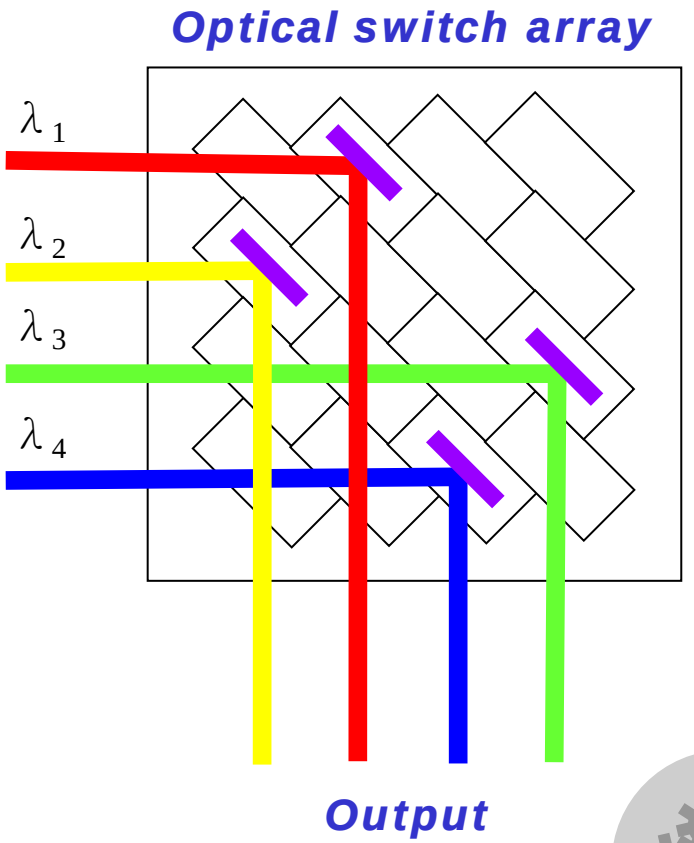
Optical fiber communication



光纖通訊

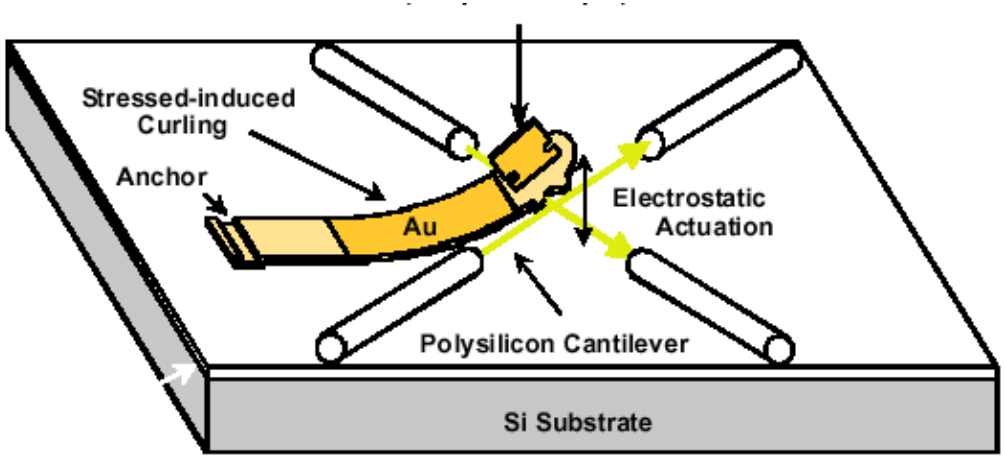
- 微光開關原理

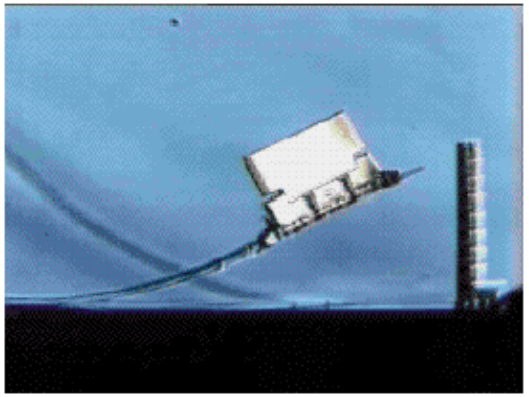

Optical switch array
λ 1
λ 2
λ 3
λ 4
Input
Output


Optical switch array
λ 1
λ 2
λ 3
λ 4
Output

光纖通訊

- 微光開關原理

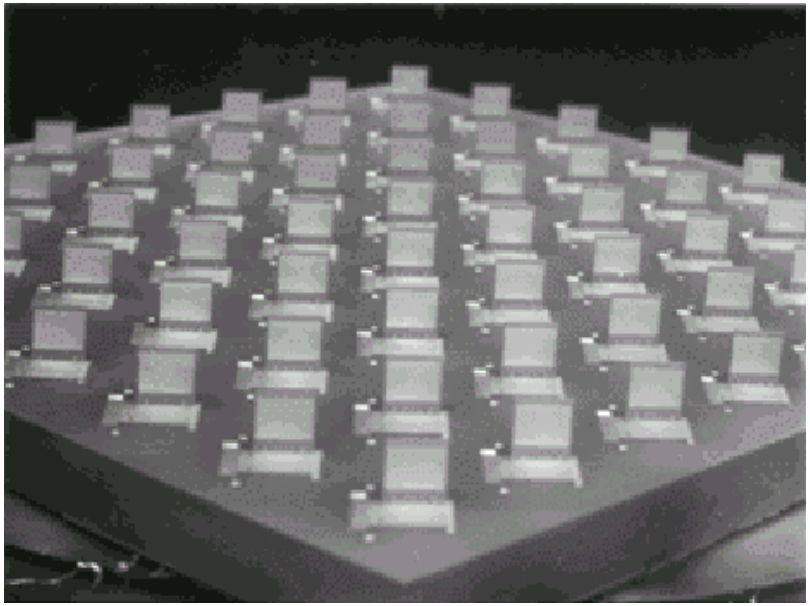


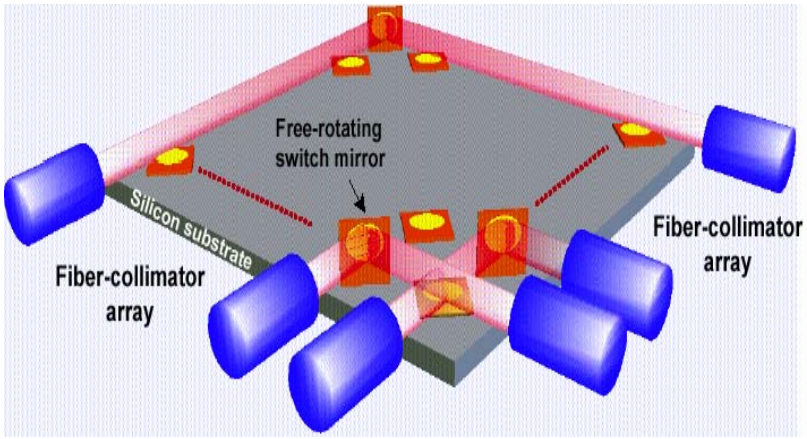


R. Chen, H. Nguyen, M.C. Wu, *IEEE MEMS Conference*, 1999

光纖通訊

- 微光開關陣列





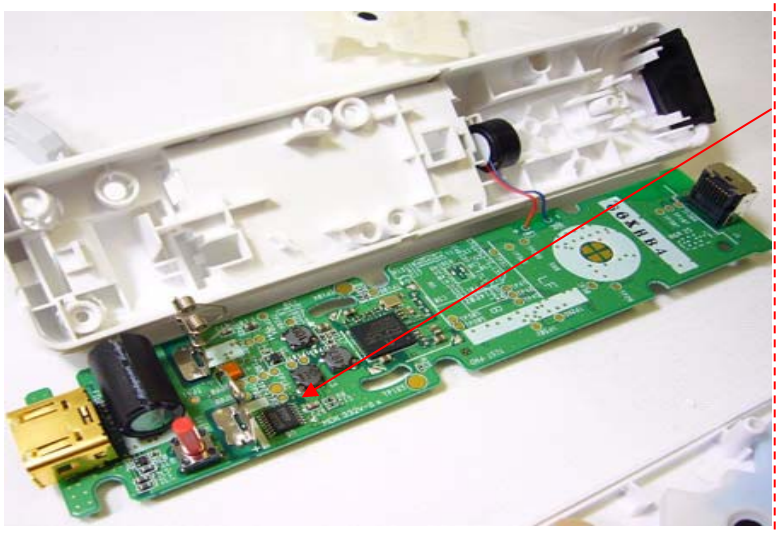
OMM

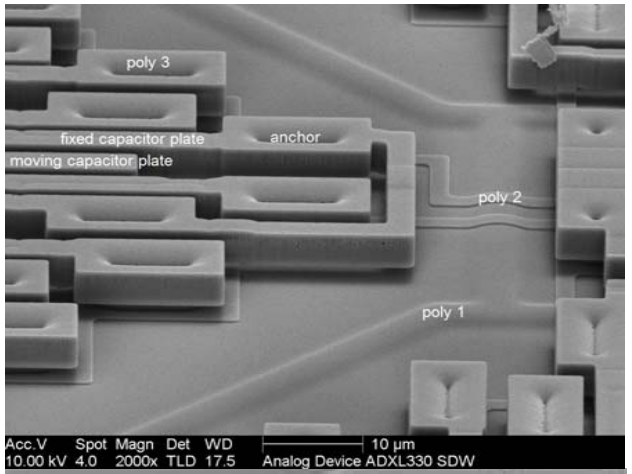
車用電子 - (TPMS)

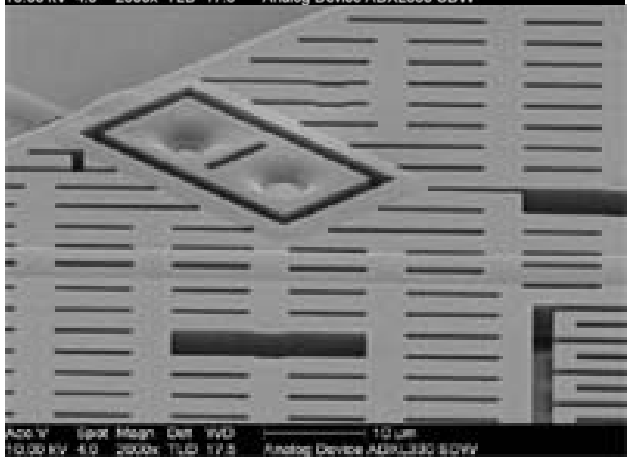
- Pressure sensor
- X-,Z-Accelerometer
- Temperature sensor
- RF transmitter

Driving Real-Time Detection

消費性電子 – Wii



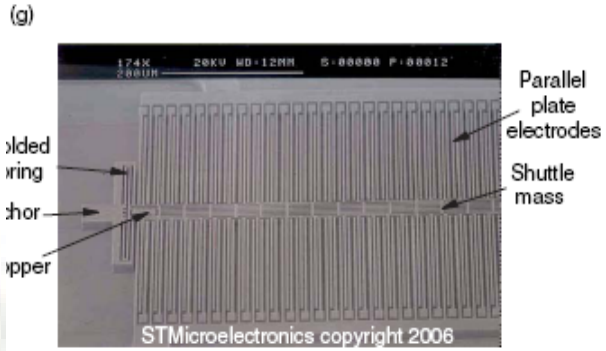




Wii-Remote **MEMS accelerometer**

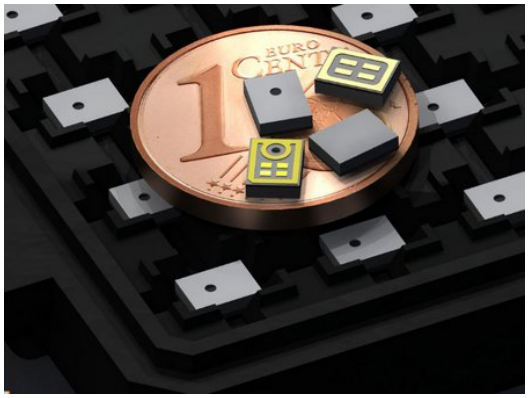
MDL
NTHU

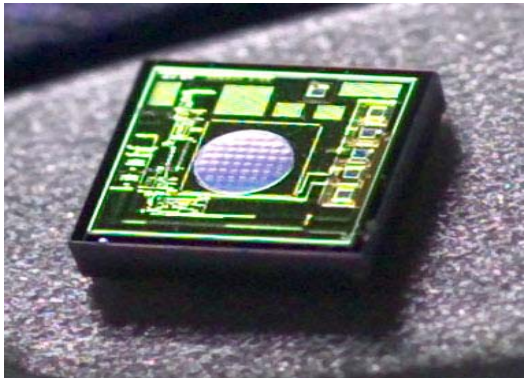
消費性電子 – IPod Touch

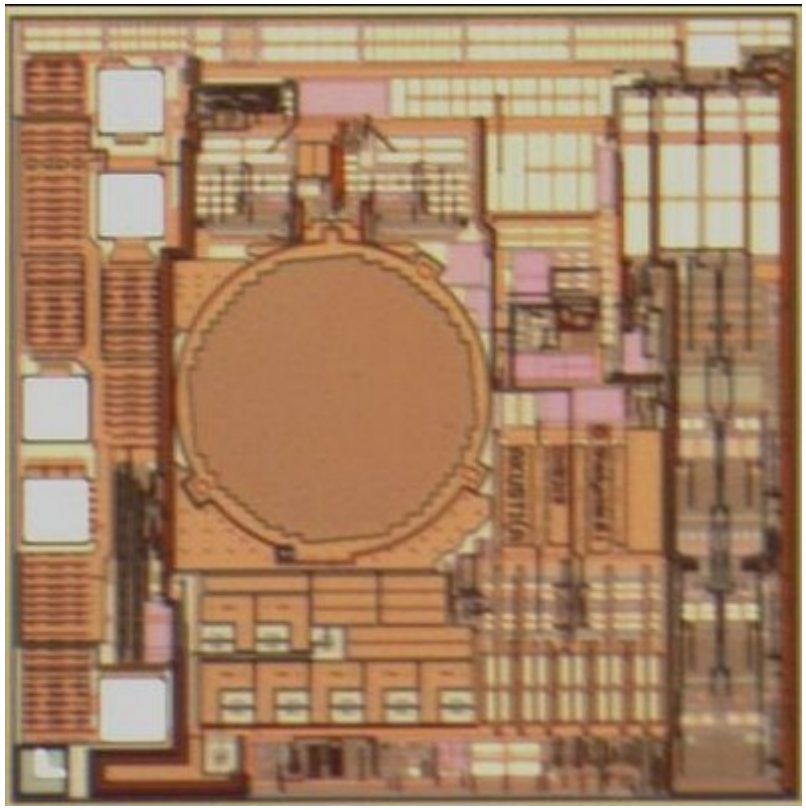


Movements control the action using MEMS accelerometer

消費性電子 – Microphone







“Small ”, “ Easy integration”, MEMS Microphone

MDL
NTHU

生醫電子 – Fitbit tracker

A 3-axis accelerometer to sense user movement for Health Care application

MDL
NTHU

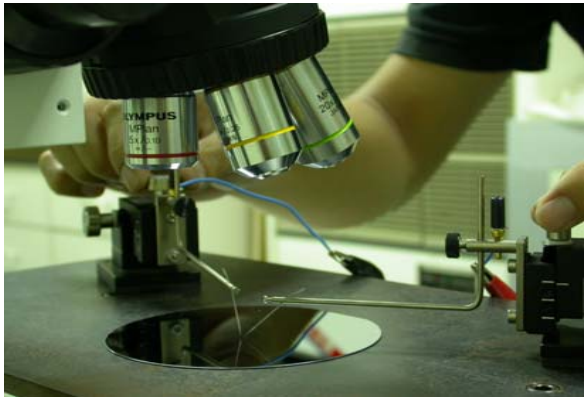
生醫電子 – Blood pressure sensor

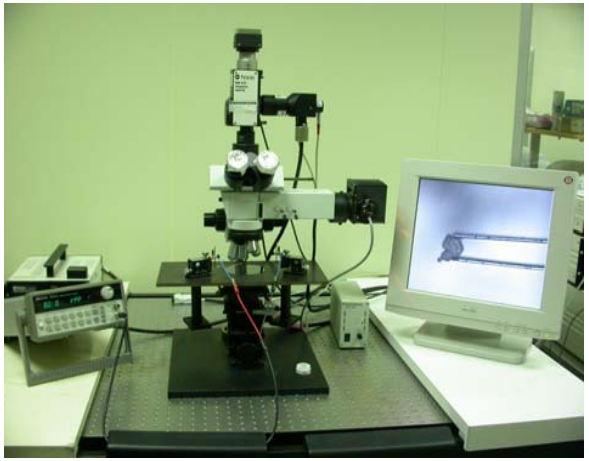
Pressure sensor for Health Care

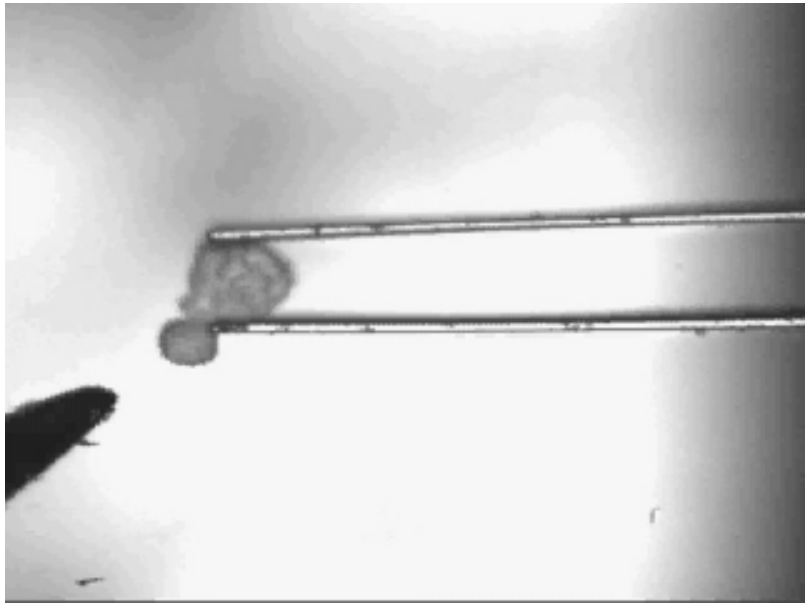
MDL
NTHU

巨觀與奈米世界的介面

- **Macro world (m/cm) → MEMS (mm/μm)**
  → Micro/Nano world (μm/nm)

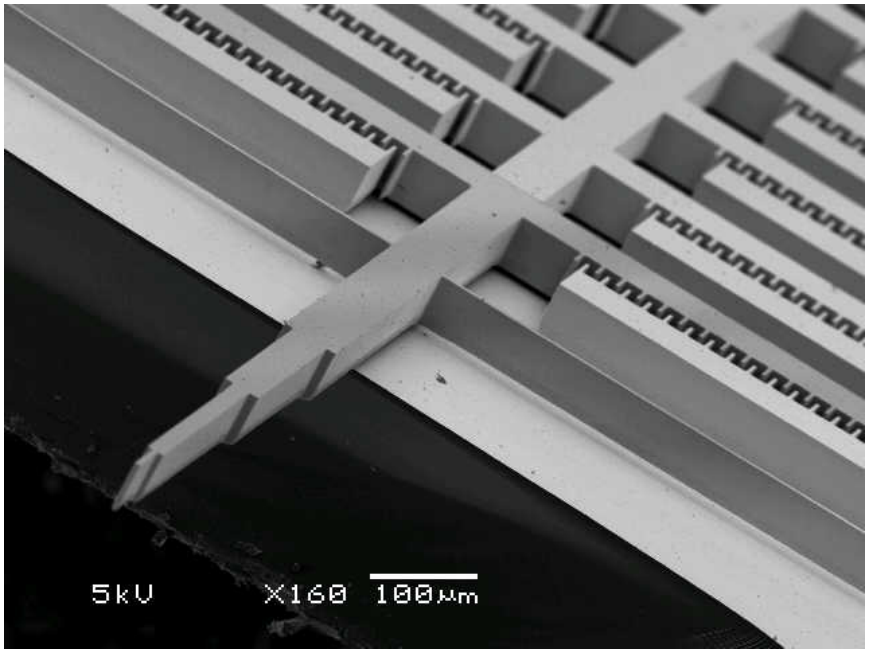


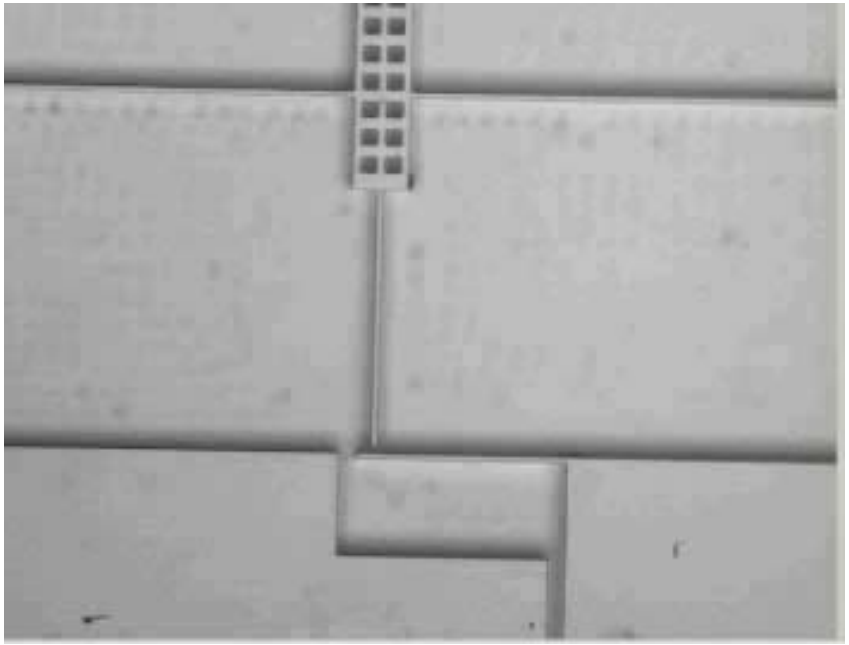




巨觀與奈米世界的介面

- 微奈米結構測試

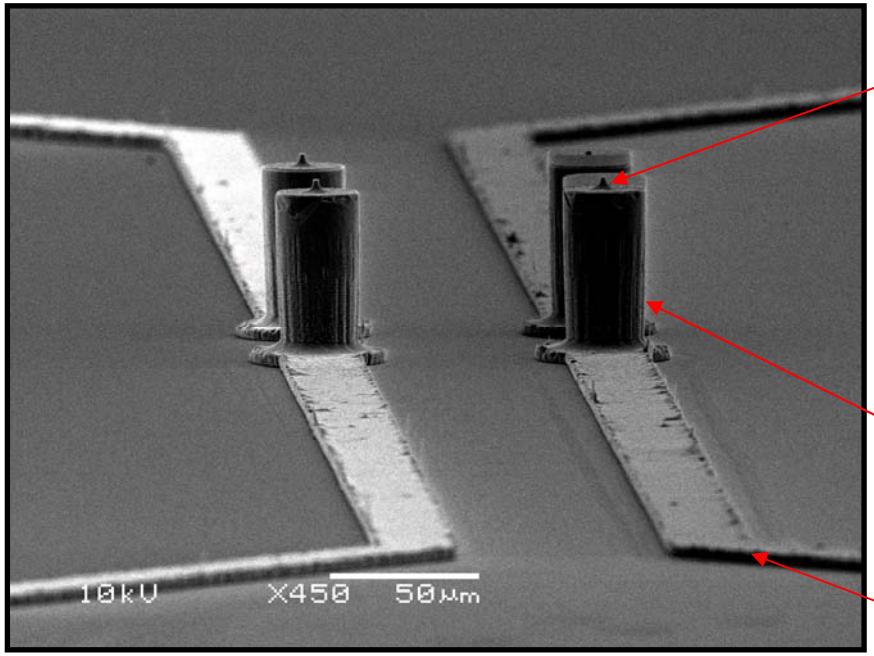


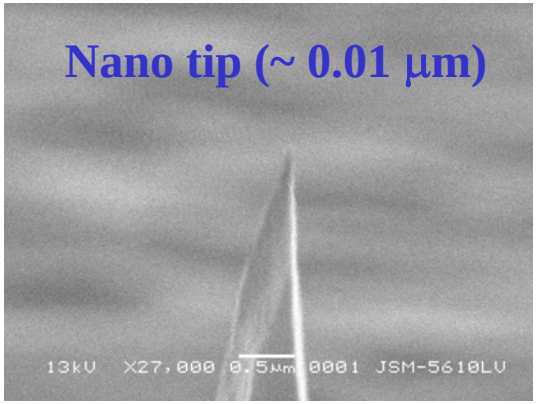


C. Chang, H.-Y. Chu, and W. Fang, 2004

巨觀與奈米世界的介面

- 腦神經探針





Nano tip (~ 0.01 µm)

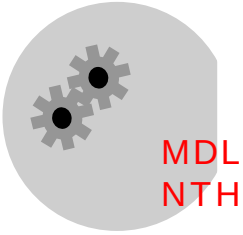
Micro needle (~ 10 µm)

Conducting wire (~ 1 µm)

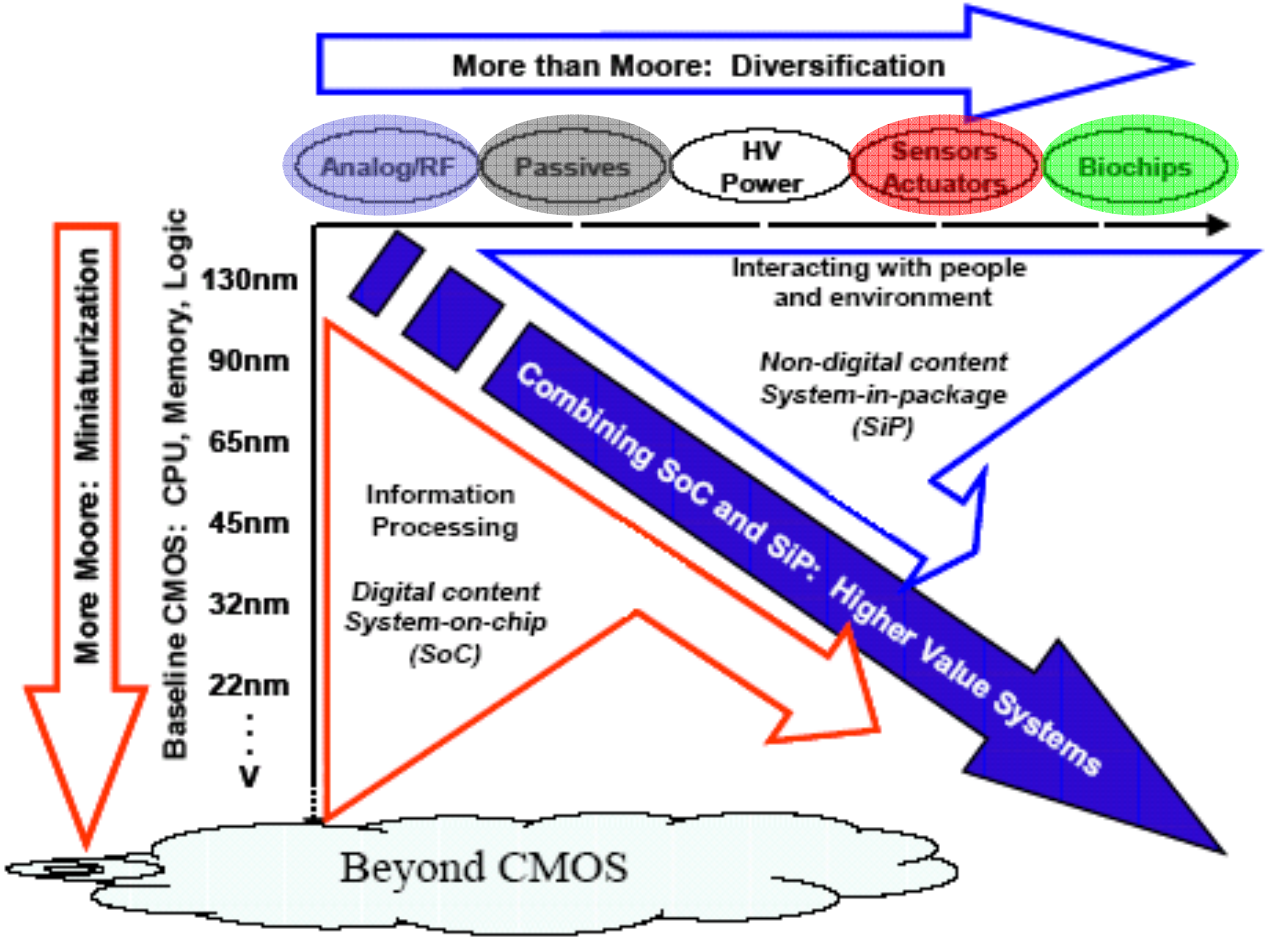
T.-Y. Kuo, H.-Y. Chu, B. Chang, and W. Fang, *APCOT'04*, Japan, 2004

MDL
NTHU

結論



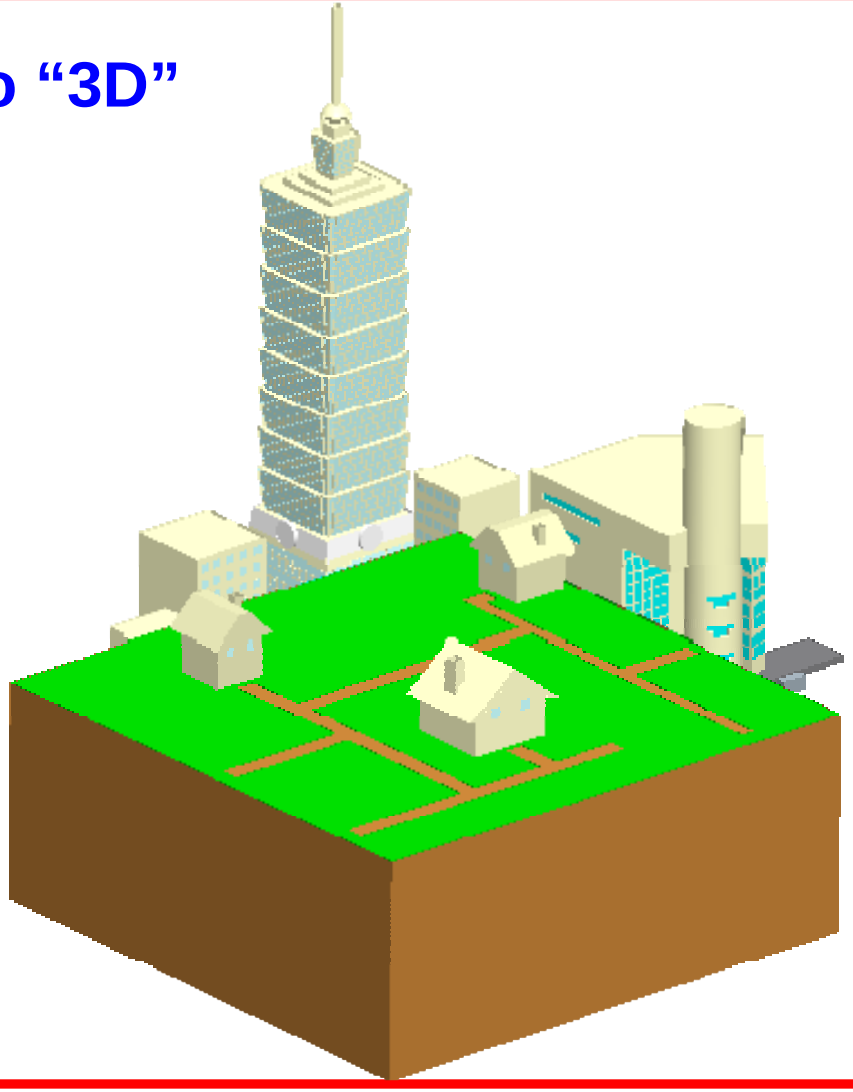
Moore's Law and More than Moore



ITRS Roadmap 2005, www.itrs.net

Architectures in the city

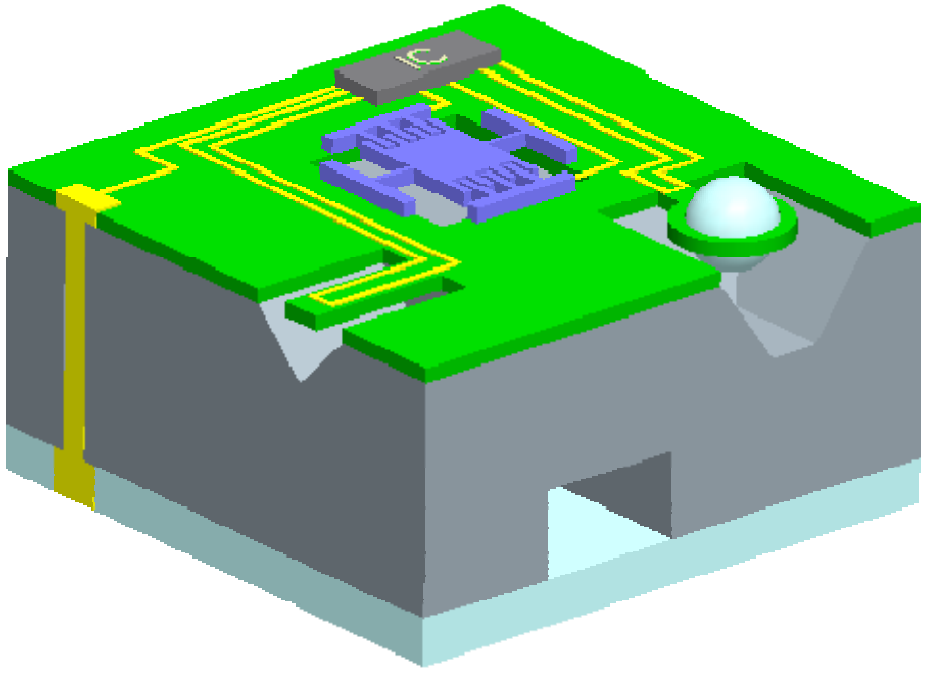
- From “2D” to “3D”



MDL
NTHU

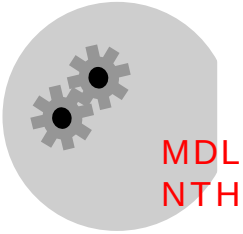
Architectures on the chip

- From “2D” to “3D”



MDL
NTHU

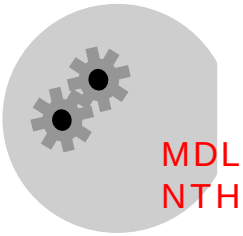
What’s the primary applications for IC at 1960’



MDL
NTHU

Hearing aid !!

- **1956 Nobel prize : Shockley, Brandon, and Bardin**



- **2000 Nobel prize : Kilby**

  透過 **IC** 的發明為 **Information technology** 奠立基礎

- **Vacuum tube to Transistor to IC …to N/MEMS…**

  這不只是一種技術演進的過程，更重要的是，
  它，改變了一個文明