CMOS MEMS: a Platform Technology for Microsystems

Speaker: Prof. Weileun Fang (方維倫)

Micro Devices Laboratory (MDL)
Power Mech. Eng. Dept/NEMS Inst.
National Tsing Hua University, Taiwan

fang@pme.nthu.edu.tw

MDL
NTHU

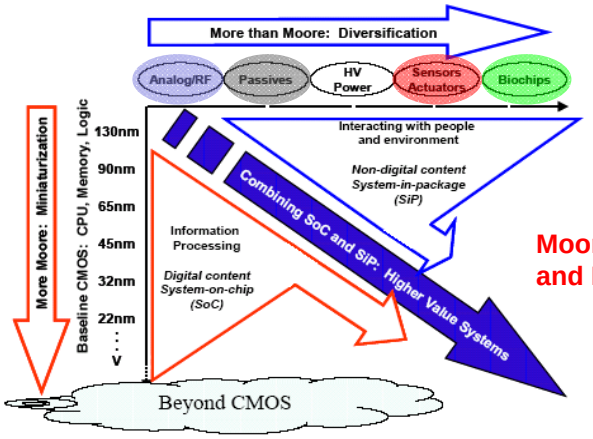
Outline

- **Introduction**
- **CMOS MEMS Fabrication Platform**
- **Application: CMOS MEMS Sensors**
- **Extension of CMOS MEMS Technology**
- **CMOS MEMS in Taiwan**
- **Outlook and Concluding Remarks**

MDL
NTHU

Moore's Law and More

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



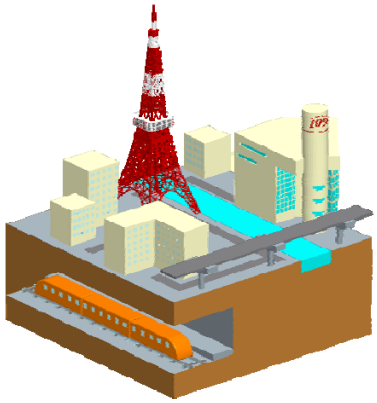
Moore's Law and More …

Source: ITRS Roadmap 2005, www.itrs.net

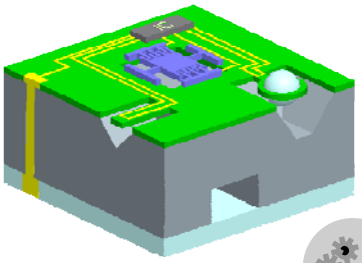
MDL NTHU

MEMS vs IC

- From *Planar Technology* to *3D Architecture* on Chip



m ~ km



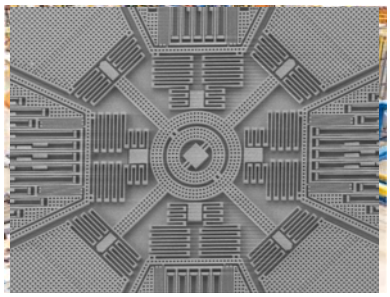
μm ~ mm

MDL NTHU

MEMS vs ME

- From *Parts Assembly* to *Process Integration*

www.precisionmicroreplicas.com



Sensonor Dynamic Gyro

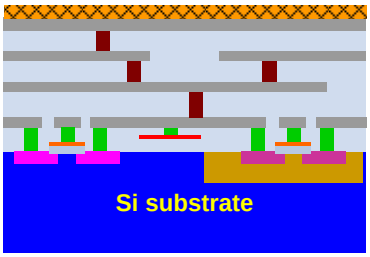
Outline

- Introduction
- CMOS MEMS Fabrication Platform
- Application: CMOS MEMS Sensors
- Extension of CMOS MEMS Technology
- CMOS MEMS in Taiwan
- Outlook and Concluding Remarks

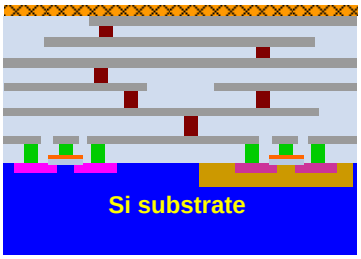
CMOS Fabrication Platform

- Mature CMOS processes: 2P4M, 1P6M, etc…
- Available CMOS foundries: TSMC, UMC, etc…

0.35μm 2P4M CMOS process



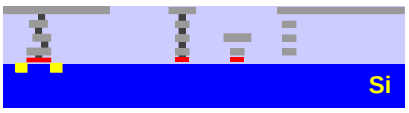
0.18μm 1P6M CMOS process



MDL
NTHU

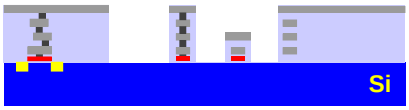
IC vs MEMS

CMOS process

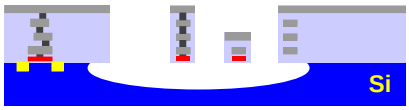


IC

Thin film etching



Bulk Si etching

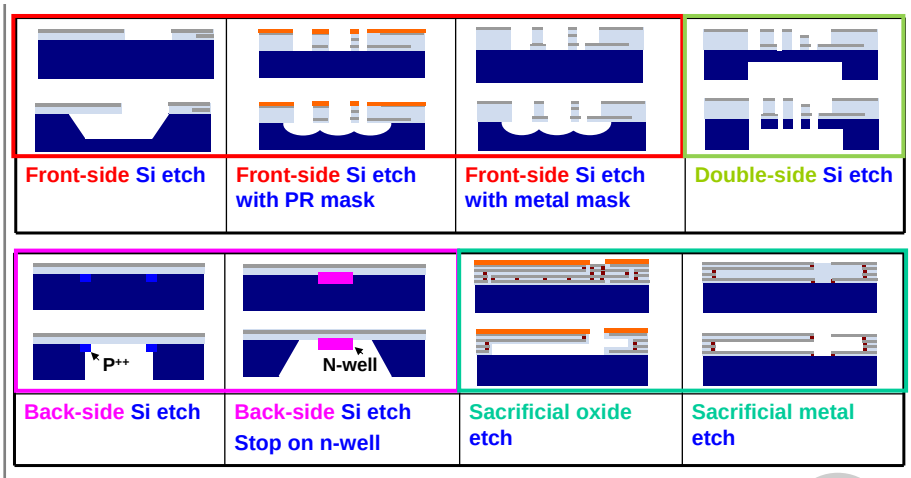


IC + MEMS

TSMC 2P4M process

MDL
NTHU

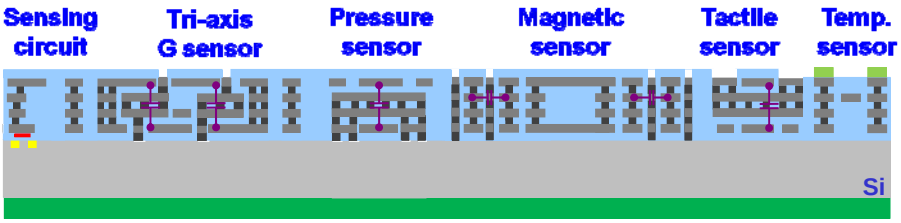
CMOS post process – for MEMS



G.K Fedder, *IEEE Sensors*, 2005

MDL NTHU

CMOS-MEMS Sensors Platform



CMOS-based sensors platform

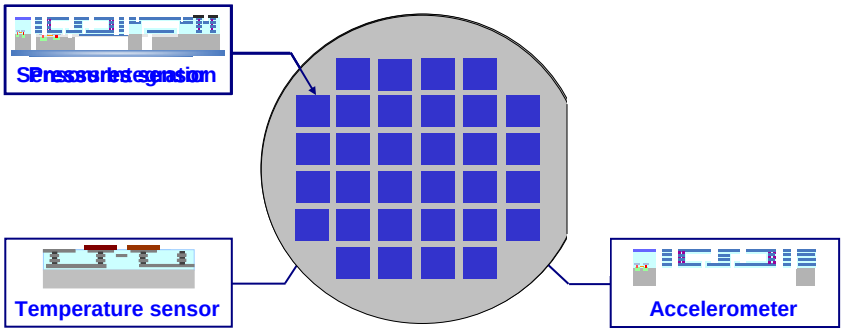
Si | Poly-Si | W-via | Metal

Polymer | SiO_2 | Pt

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

MDL NTHU

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



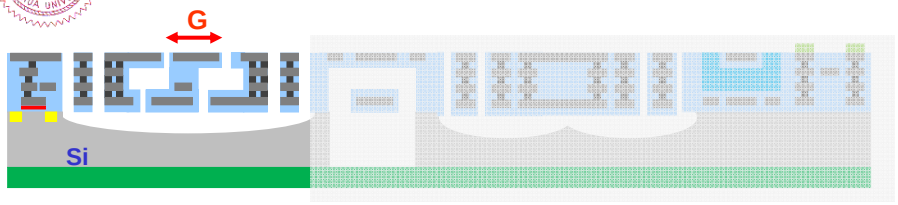
MDL
NTHU

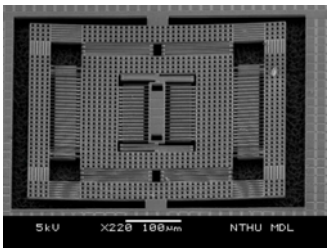
Outline

- Introduction
- CMOS MEMS Fabrication Platform
- Applications: CMOS MEMS Sensors
- Extension of CMOS MEMS Technology
- CMOS MEMS in Taiwan
- Outlook and Concluding Remarks

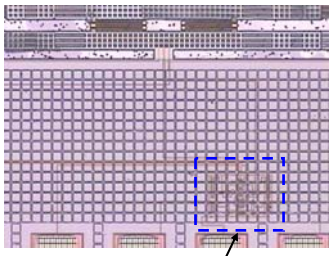
MDL
NTHU

1-axis G-sensor





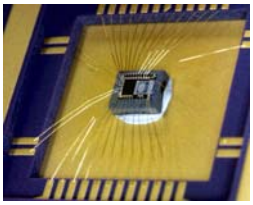
MEMS structure

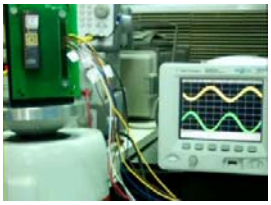


CMOS IC

MDL
NTHU

1-axis G-sensor



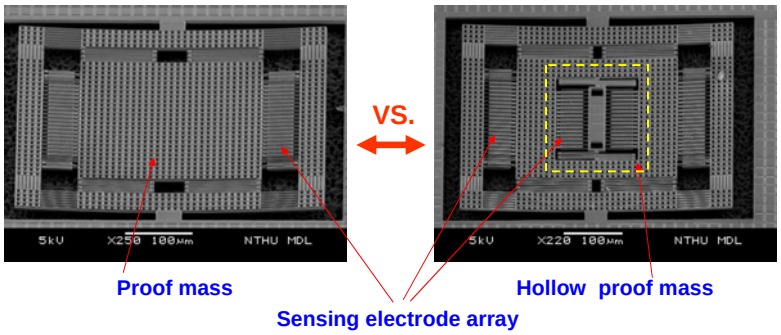


	Hollow proof-mass
Measurement Range (G)	0.3~10
Sensitivity (mV/G)	3.95
Resonant Freq. (kHz)	5.83
Nonlinearity (%)	2.75
Cross-axis sensitivity_Y (%)	1.05
Cross-axis sensitivity_Z (%)	< 1

Sun, and Fang, *IEEE Sensors*, 2006
Sun, and Fang, *Sens. Actuators A*, 2008

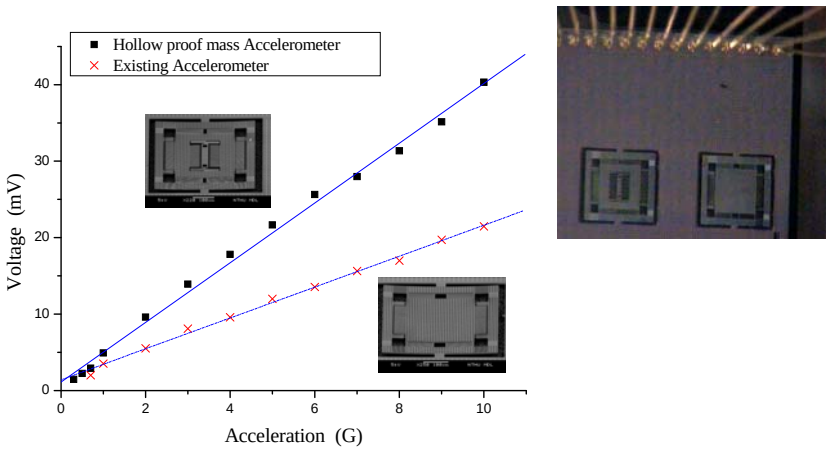
MDL
NTHU

- **Hollow proof mass Accel. – sensitivity improvement**



Sun, Wang, Tsai, and Fang, *Sensors and Actuators A*, 2008

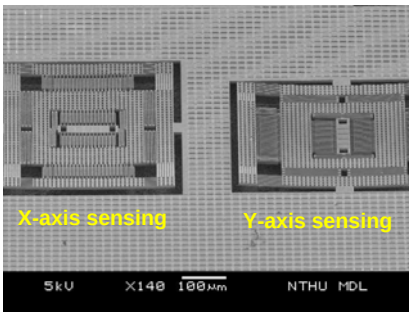
MDL
NTHU

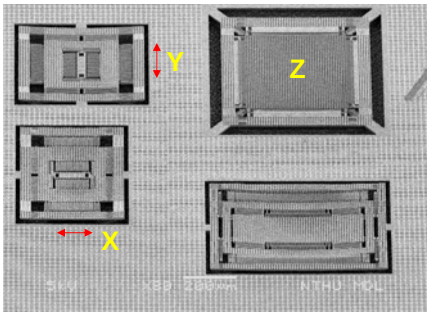


Sensitivity improved from 2.1mV/G to 3.95mV/G

MDL
NTHU

- **Multi-axes Accel. by integrating of multi 1-axis Accel.**

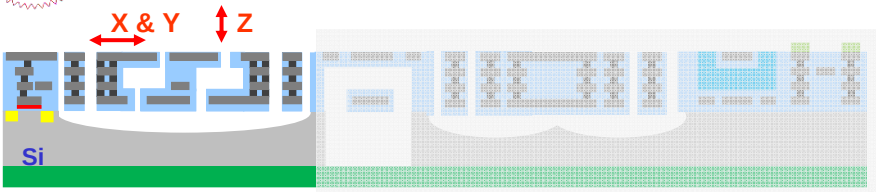


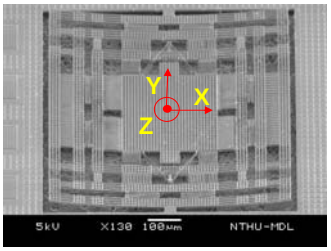


Tsai, Wang, Sun, and Fang, *IEEE NEMS'08 (best paper finalist)*, SanYa, China, 2008

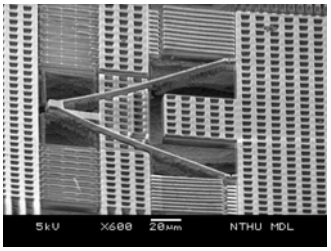
MDL
NTHU

3-axis G-sensor



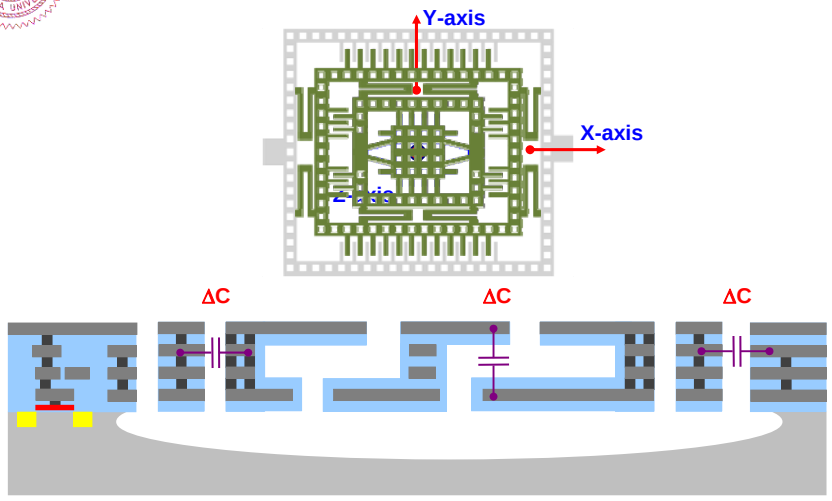


Single proof-mass



Z-spring

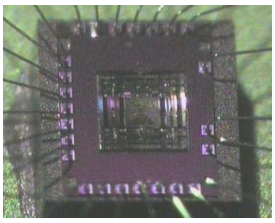
MDL
NTHU



X-axis sensing unit

MDL
NTHU

3-axis G-sensor

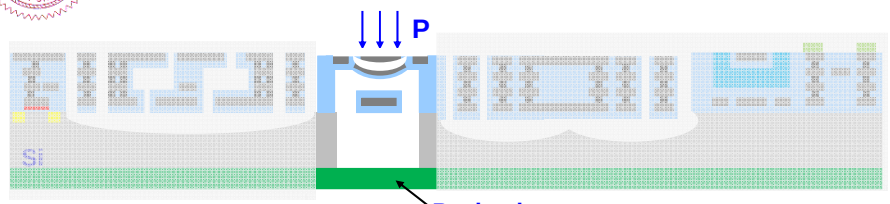


	X-axis	*Y-axis*	*Z-axis*
Sensitivity (mV/G)	0.53	0.28	0.20
Non-linearity (%)	2.64	3.15	3.36
Noise floor (mG/rtHz)	120	271	357
Cross-axis sensitivity _X(%)		< 7.46	< 2.88
Cross-axis sensitivity _Y(%)	< 1		< 8.05
Cross-axis sensitivity _Z (%)	< 1	< 8.33	

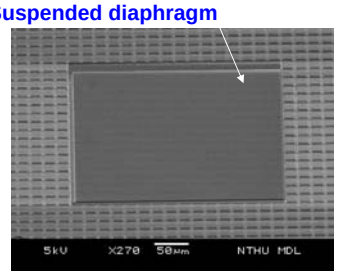
Sun, and Fang, *IEEE MEMS*, 2009
Sun, and Fang, *IEEE Trans. on ED*, 2010

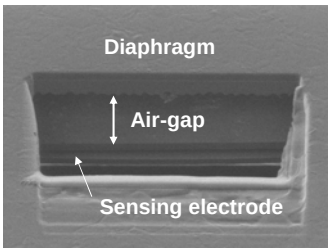
MDL
NTHU

Pressure Sensors



Suspended diaphragm



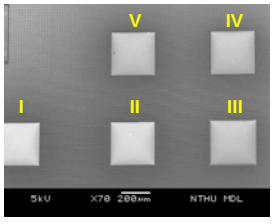


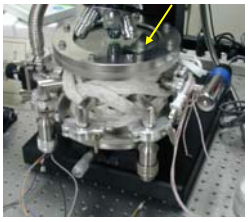
FIB sectioning

MDL
NTHU

Pressure Sensors

Pressure load chamber

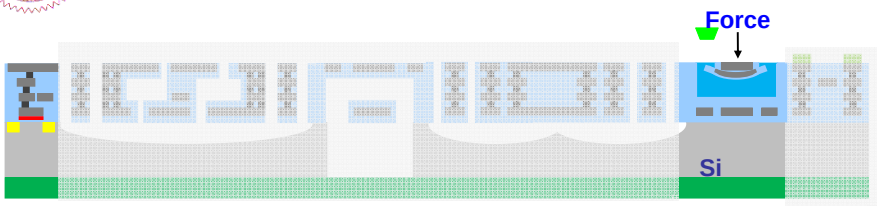




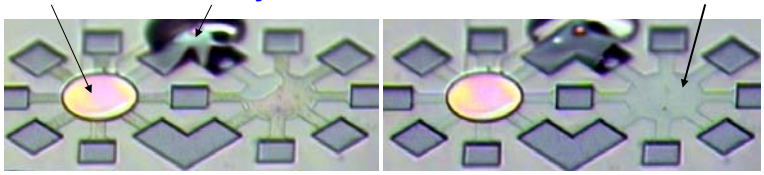
	I	II	III	IV	V
Diaphragm Thickness	1.925 μm	3.56 μm	3.56 μm	1.64 μm	1.925 μm
Sensitivity	0.04 fF/KPa	0.02 fF/KPa	0.042 fF/KPa	0.36 fF/KPa	0.23 fF/KPa
Sensing Range	0~500 KPa	90~500 KPa	100~500 KPa	0~60 KPa	0 ~ 90 KPa

MDL
NTHU

Tactile Sensor w Polymer Fill-in



Tactile sensor Polymer inlet hole Monitor testkey

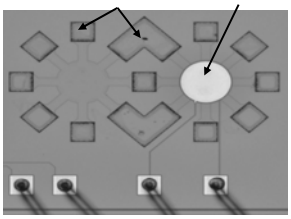


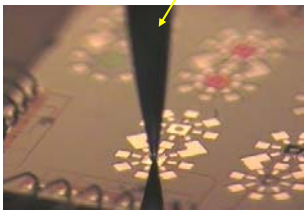
Polymer fill-in to modulate sensitivity and sensing range

MDL
NTHU

Tactile Sensor w Polymer Fill-in

PDMS Tactile sensor Loading probe



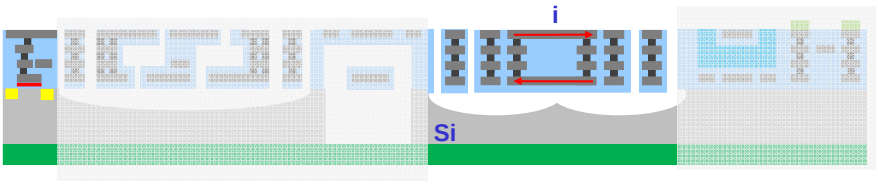


Gap material	Air	PDMS (1:1)	PDMS (1:5)	PDMS (1:10)
Initial capacitance, C_0 (fF)	99	299	287	284
Sensitivity (mV/mN)	31.29	63.36	39.03	18.38
Sensing range (mN)	0.1~0.5	0.3~0.7	0.3~1.0	0.5~1.8
Non-linearity (%)	1.6	5.6	3.5	3.5

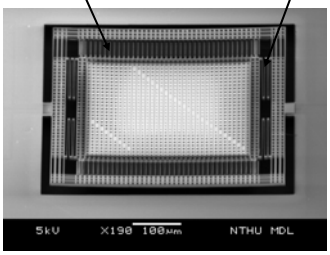
Liu, and Fang, *IEEE Transducers'09*, 2009
Liu, and Fang, *IEEE JMEMS*, 2011

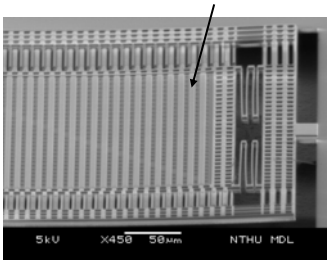
MDL
NTHU

Magnetic Sensors



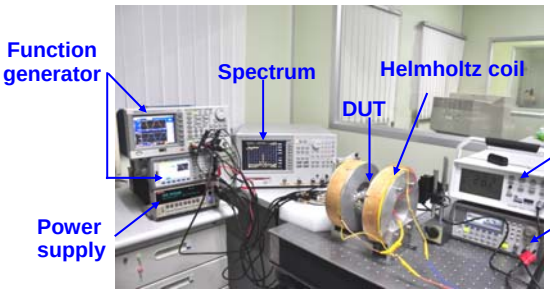
Fingers Spring Coil





MDL
NTHU

Magnetic Sensors

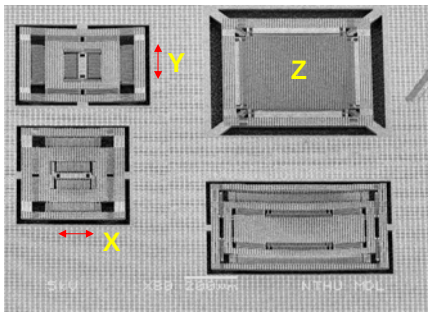


Magnetic Field	X	Y	Z
Current (mA)	4.18	4.02	4.02
Sensitivity (mV/mT)	0.13	0.14	1.51
Resolution (nT/rtHz)	319.9	296.5	121.6
Nonlinearity (%)	2.27	3.27	2.24
Pressure	1atm		

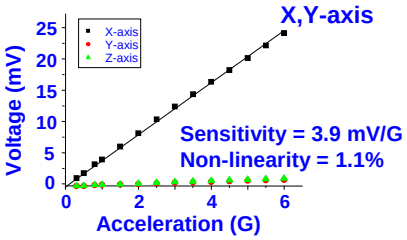
Chang, and Fang, *IEEE MEMS*, 2013

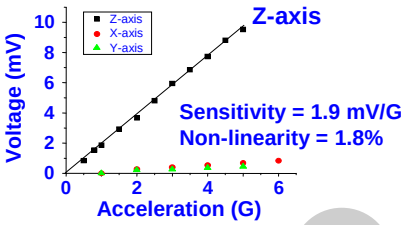
MDL
NTHU

Sensor Integration: G/G/G Sensors



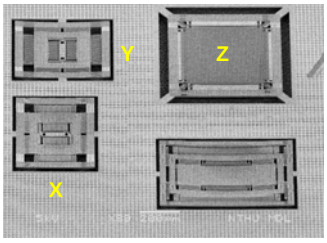
0.35μm CMOS process integration



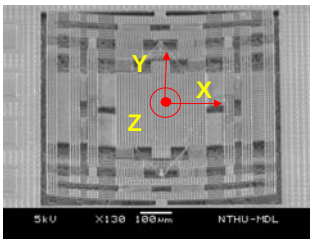


MDL
NTHU

- **Note: ~50% chip footprint reduction by single unit**



Three 1-axis units

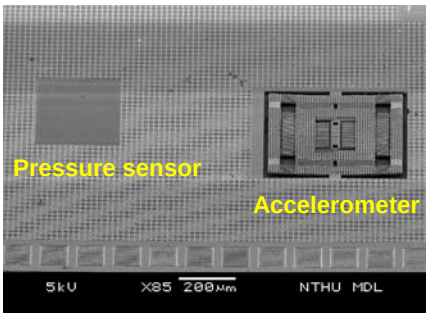


One 3-axis unit

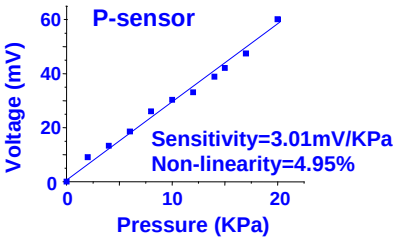
Sun, Tsai, and Fang, *IEEE MEMS*, 2009
Sun, Tsai, and Fang, *IEEE Trans on ED*, 2010

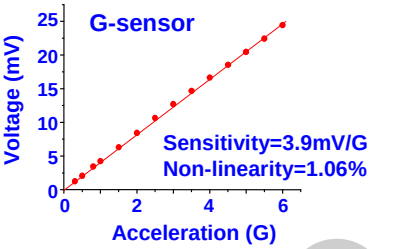
MDL
NTHU

Sensor Integration: G/P Sensors



0.35μm CMOS process integration

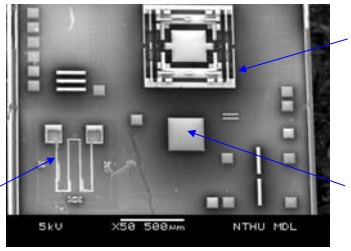




Sun, and Fang, *IEEE MEMS*, 2008
Sun, and Fang, *IEEE Transducers*, 2009

MDL
NTHU

Sensor Integration: G/P/T Sensors

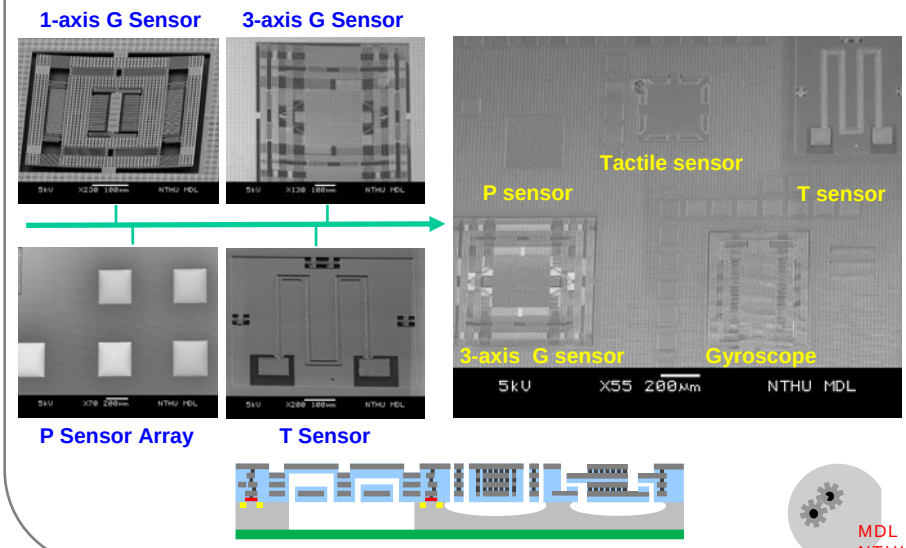


	Monolithic sensors integration		
Sensor	*3-axis G-sensor*	*P-sensor*	*T-sensor*
Sensitivity	0.54 / 0.32 /0.19 X/Y/Z (mV/G)	2.7 mV/KPa	1.74 mV/^{0}C
Non-linearity	< 5%	4.58 %	4.29 %
Sensing range	0.8~5 G	0~20 KPa	25~150 ^{0}C

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

MDL
NTHU

CMOS-MEMS Sensors Integration



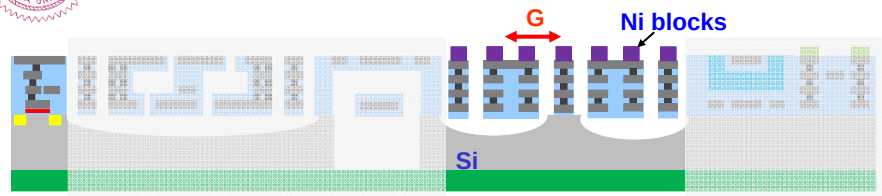
MDL
NTHU

Outline

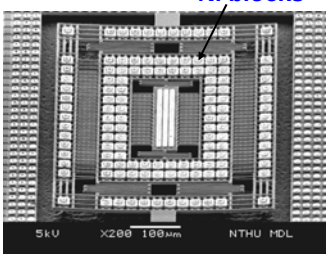
- Introduction
- CMOS MEMS Fabrication Platform
- Applications: CMOS MEMS Sensors
- Extension of CMOS MEMS Technology
- CMOS MEMS in Taiwan
- Outlook and Concluding Remarks

MDL
NTHU

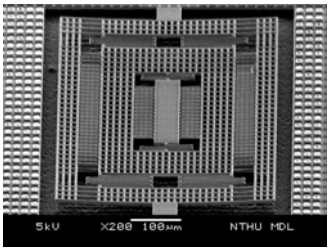
G-sensor w Electroplating-Ni



Ni blocks



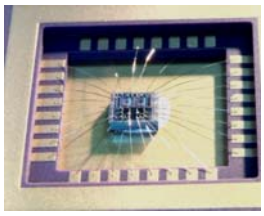
With electroplating

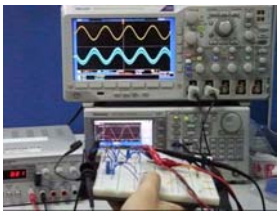


Without electroplating

MDL
NTHU

G-sensor w Electroplating-Ni



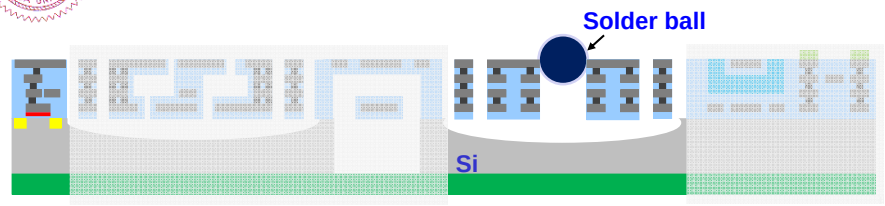


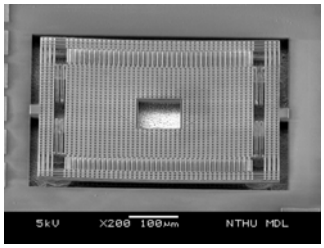
	Without Ni	With Ni
Frequency (kHz)	6.97	4.71
Sensitivity (mV/G)	1.08	2.68
Nonlinearity (%)	2.64	2.81
Noise floor (mG/rt Hz)	8.15	3.28
Resolution (G)	1	0.2

Liu, and Fang, *IEEE Transducers*, 2011
Liu, and Fang, *JMM*, 2011

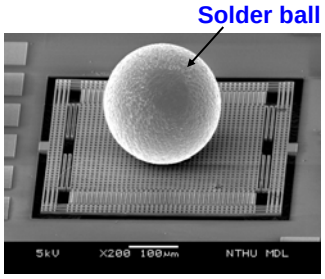
MDL
NTHU

Tilt Sensor w Pick-place Mass





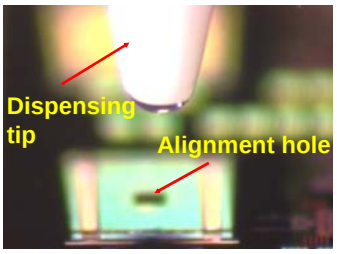
W/O solder ball

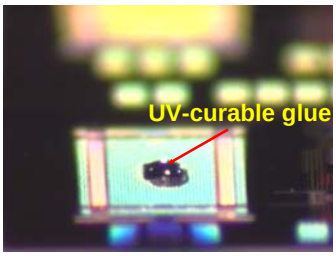


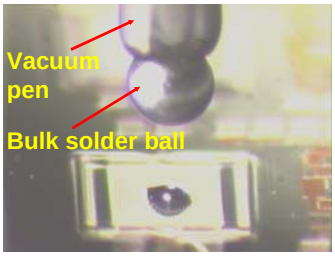
W solder ball

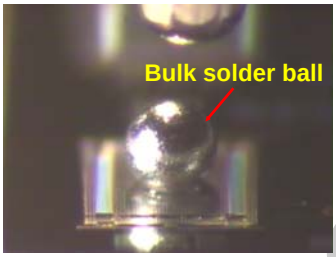
MDL
NTHU

Tilt Sensor w Pick-place Mass



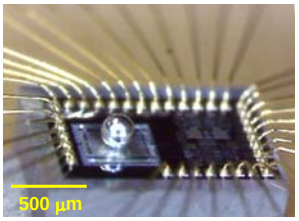


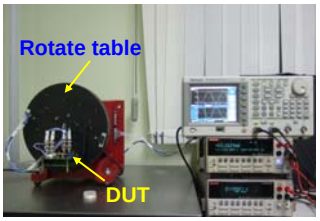




MDL
NTHU

Tilt Sensor w Pick-place Mass



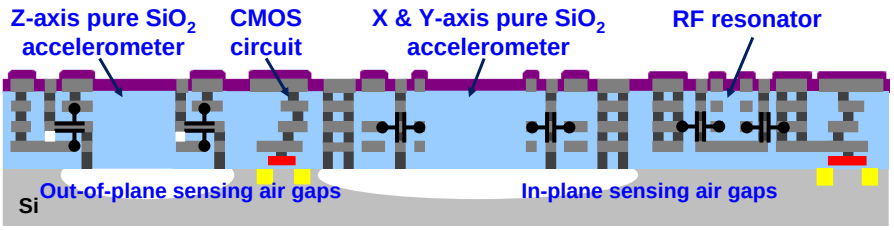


Specifications	W/O bulk ball	With bulk ball
Proof mass (ng)	1.72	62.14
Linear range (°)	0 ~ 45	0 ~ 45
Sensitivity (mV/°)	0.41	1.41
Resolution (°)	1	0.1
Non-linearity (%)	7.6	2.3

Chang, and Fang, *IEEE Transducers*, 2011

MDL
NTHU

Pure oxide-based CMOS-MEMS platform



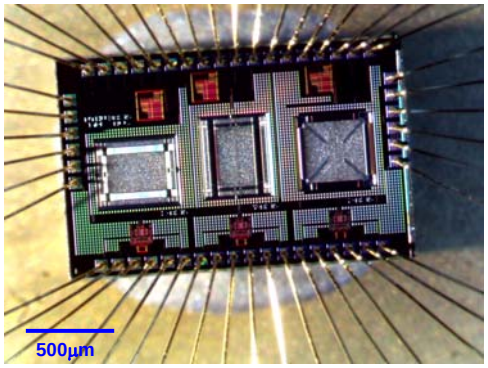
XeF_2 release structure

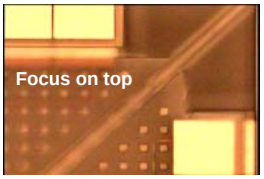
Poly SiO_2 Via Al Passivation

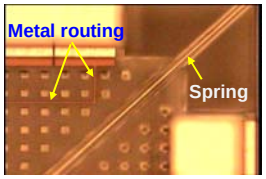
MDL
NTHU

3-axis pure oxide G-sensor

- G-sensor: Transparent Oxide proof-mass with embeded wires





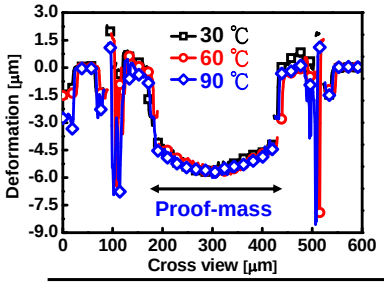


Liu, and Fang, *IEEE MEMS*, 2012

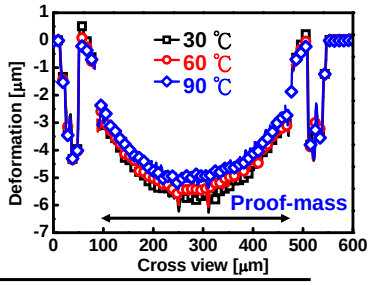
MDL NTHU

3-axis pure oxide G-sensor

◆ In-plane



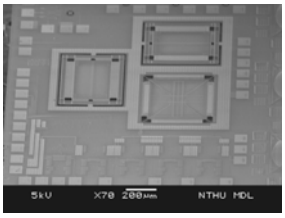
◆ Out-of-plane

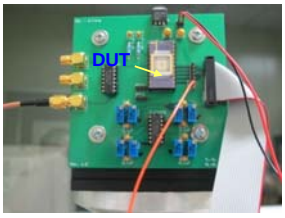


	X-axis	Y-axis	Z-axis
Temperature [℃]	ROC [mm]	ROC [mm]	ROC [mm]
30	9.43	9.55	6.07
60	9.82	9.76	6.51
90	10.35	10.31	6.96
ROC change with temperature (%/°C)	0.16	0.13	0.24

MDL NTHU

Pure oxide CMOS device



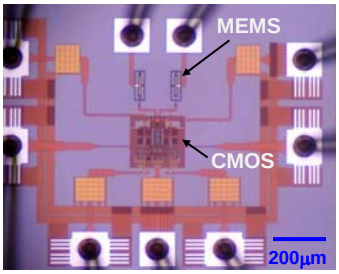


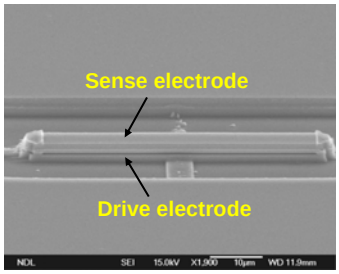
Sensing-axis	*X-axis*	*Y-axis*	*Z-axis*
Measurement Range (G)		±2	
Sensitivity (mV/G)	105.2	127.4	57.7
Non-linearity (%)	1.01	0.52	2.43
Noise (mG/sqrtHz)	0.4	0.21	0.94
Cross-axis sensitivity _X(%)		1.57	6.41
Cross-axis sensitivity _Y(%)	1.05		6.07
Cross-axis sensitivity _Z (%)	2.86	1.65	

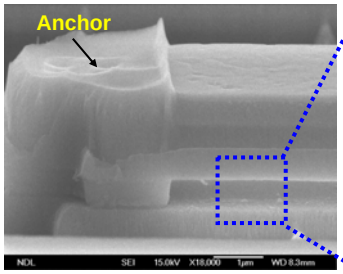
Liu, and Fang, *IEEE MEMS*, 2012

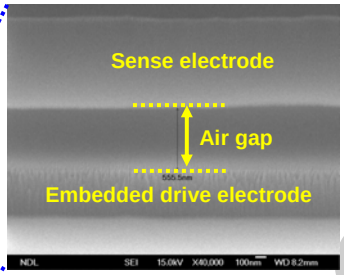
MDL
NTHU

Pure oxide resonator



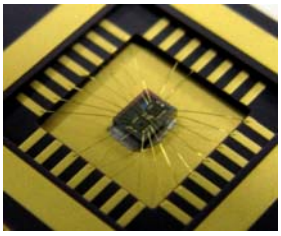


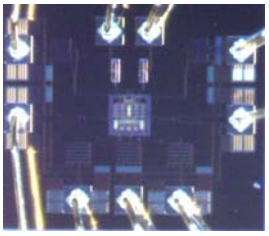




MDL
NTHU

Pure oxide resonator



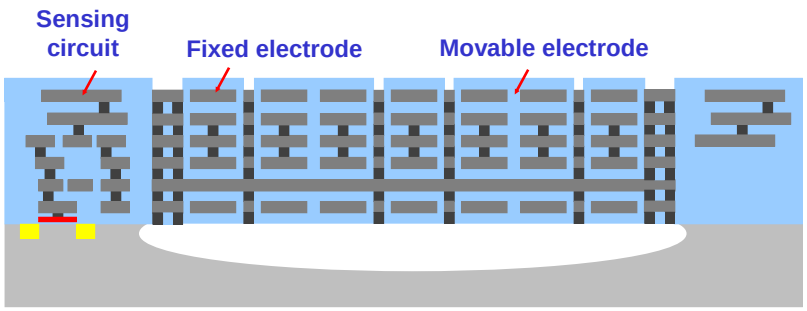


Mode Type	Out-of-plane CC-beam
Temp. Frequency Change	30,000ppm (-40~80℃)
Frequency, f_o	3.01MHz
DC-Bias Voltage, V_P	170V
Quality Factor, Q	4,400
$f_o \times Q$ Product	1.37×10^{10}
Stopband Rejection, *SB rej.*	80dB
Insertion Loss, *IL*	11.81dB

Liu, and Fang, *IEEE Transducers*, 2011

MDL
NTHU

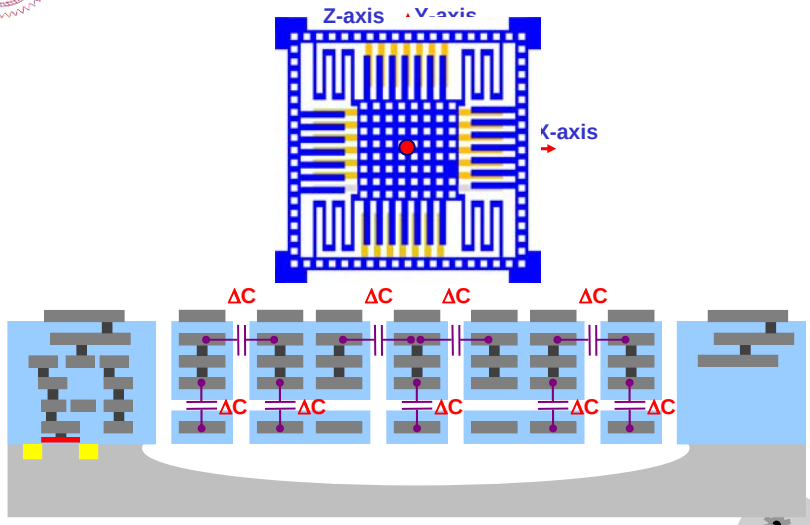
0.18μm 1P6M Process



XeF_2 release structure

MDL
NTHU

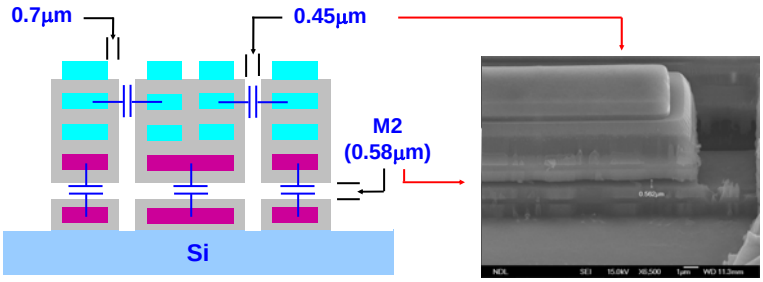
3-axis G-sensor



MDL
NTHU

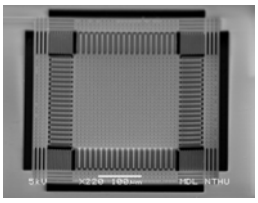
3-axis G-sensor

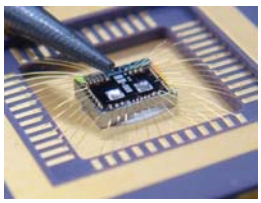
- **Sub-micron sensing gap by 0.18um process**



MDL
NTHU

3-axis G-sensor





Single proof-mass 3-axis G-sensor .18μm CMOS process (0.4mm×0.4mm)

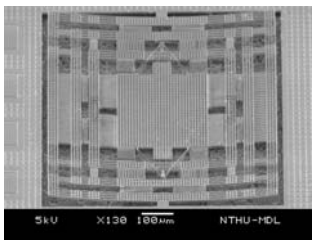
Sensing-axis	*X-axis*	*Y-axis*	*Z-axis*
Measurement Range (G)	0.01~1	0.01~1	0.01~1
Sensitivity (mV/G)	14.2	14.6	8.0
Non-linearity (%)	3.0	1.5	1.8
Noise (mG/sqrtHz)	1.9	2.9	3.4
Cross-axis sensitivity _X(%)		8.1	2.3
Cross-axis sensitivity _Y(%)	7.4		8.0
Cross-axis sensitivity _Z (%)	5.7	6.4	

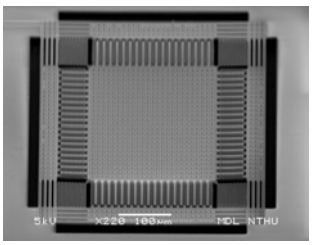
Tsai, and Fang, *IEEE Transducers, 2011*

MDL
NTHU

3-axis G-sensor

- **Note: ~3-fold footprint reduction by 0.18μm process**





0.35μm process
Footprint: 0.7mm ×0.7mm
Sensitivity (mV/G): 0.5, 0.3, 0.2

0.18μm process
Footprint: 0.4mm ×0.4mm
Sensitivity (mV/G): 14.2, 14.6, 8.0

Tsai, and Fang, *IEEE JMEMS, 2012*

MDL
NTHU

Outline

- Introduction
- CMOS MEMS Fabrication Platform
- Applications: CMOS MEMS Sensors
- Extension of CMOS MEMS Technology
- CMOS MEMS in Taiwan
- Outlook and Concluding Remarks

MDL
NTHU

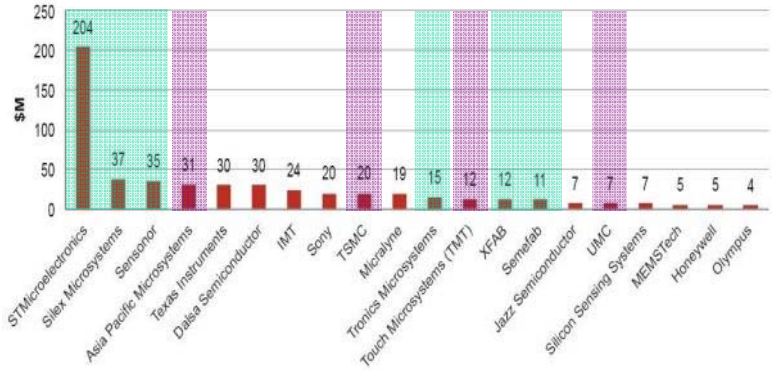
CMOS MEMS Eco-system at Taiwan

TSMC tMt Xintech
CIC NTHU (CML)
UMC apm ASE
ITRC NCTU (NFC)
MXIC ...
NDL Amkor
Siguard
SRRC Meicer
ITRI
Lingsen
SPIL
CIC NCKU (SML)
NDL
ASE
ITRI

MDL
NTHU

World Top-20 MEMS Foundry

apm, #4 tsmc, #9 tmt, #12 UMC, #16



MEMS Fab in Taiwan

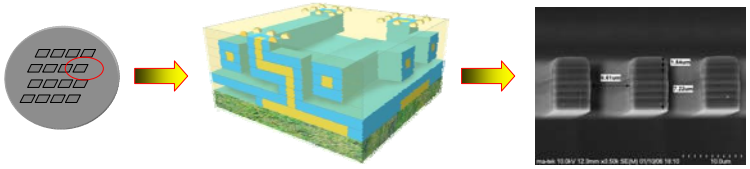
MEMS Fab in Europe

Yole Report, 2011

MDL
NTHU

CIC Service for Academia

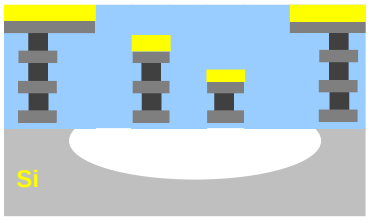
- CIC: Chip Implementation Center, founded by Gov.
- TSMC CMOS Process (for MEMS)
  + 0.35μm 2-Poly 4-Metal CMOS process (from 2002, 5 runs/year)
  + 0.18μm 1-Poly 6-Metal CMOS process (from 2006, 3 runs/year)
- APM Post-CMOS Process to release MEMS designs



Source：CIC

MDL
NTHU

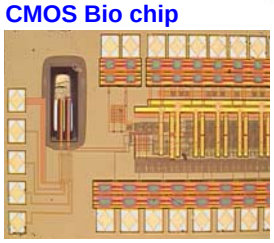
CMOS Bio-MEMS



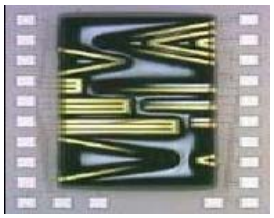
XeF_2 releasing

W-via Metal SiO_2 Au

- CMOS Bio chip



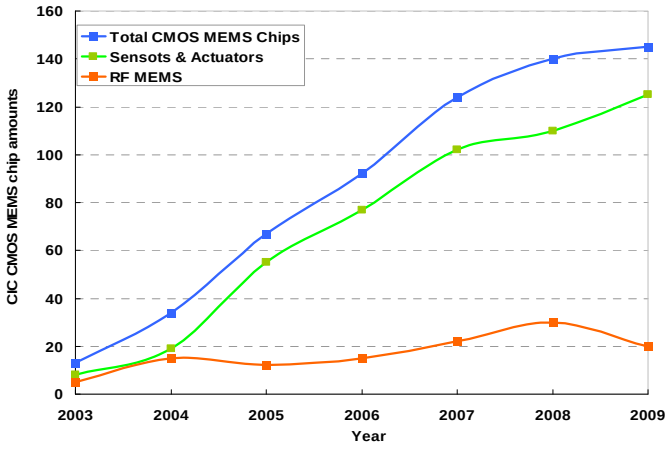
- Au cantilever beam



Source：CIC

MDL
NTHU

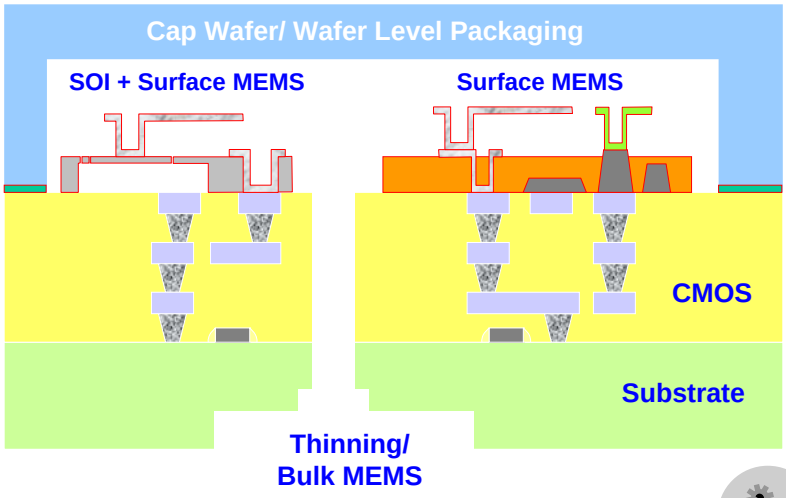
CMOS MEMS Design via CIC



Source：CIC

MDL
NTHU

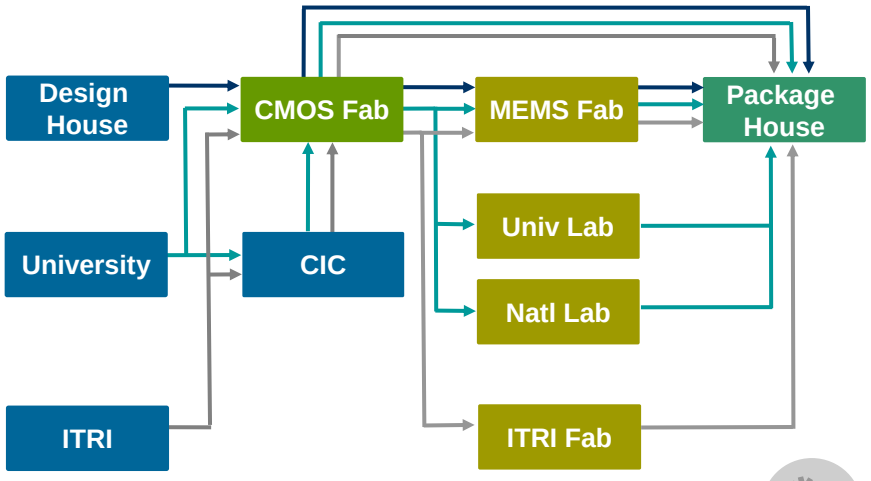
TSMC MEMS Process Capability



Source：TSMC, 2008

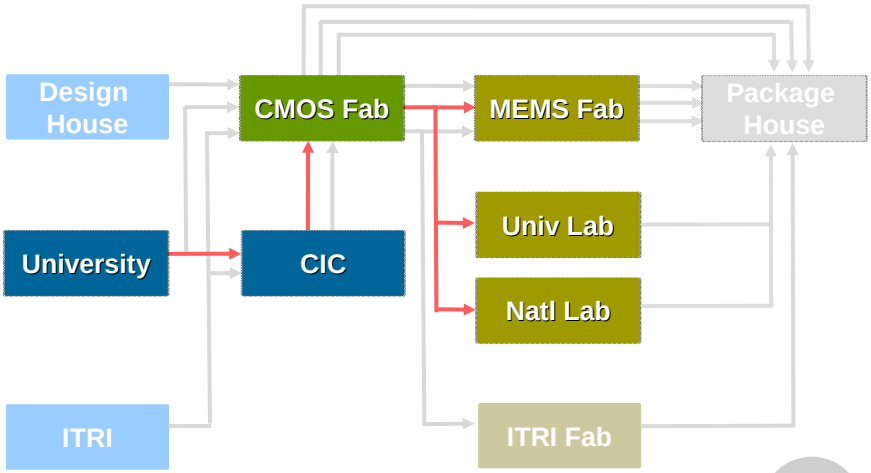
MDL
NTHU

CMOS MEMS Networks at Taiwan



MDL
NTHU

CMOS MEMS Networks at Taiwan



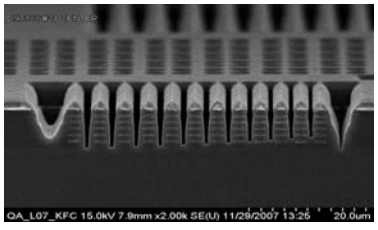
MDL NTHU

CMOS Films Mech. Properties - TSMC

Test cantilever for TSMC Process

Mechanical properties extraction:

- Density
- Young's Modulus
- Residual stresses
- Residual stress gradient



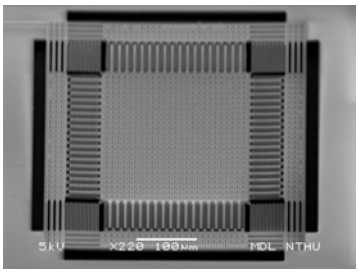
Test key for loading effect

Properties	Value
Al film Density	2600~2800 kg/m^3
SiO_2 Young's Modulus	55~60 GPa
SiO_2 Residual stress	240~250 MPa
Poly Residual stress	180~190 MPa
SiO_2 Stress gradient	40~50 MPa

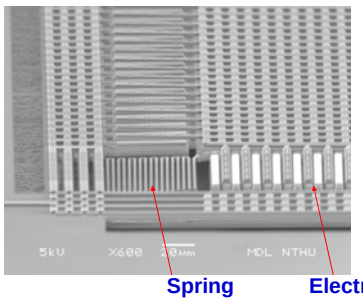
Preliminary results

MDL NTHU

0.18um 1P6M CMOS Process - TSMC



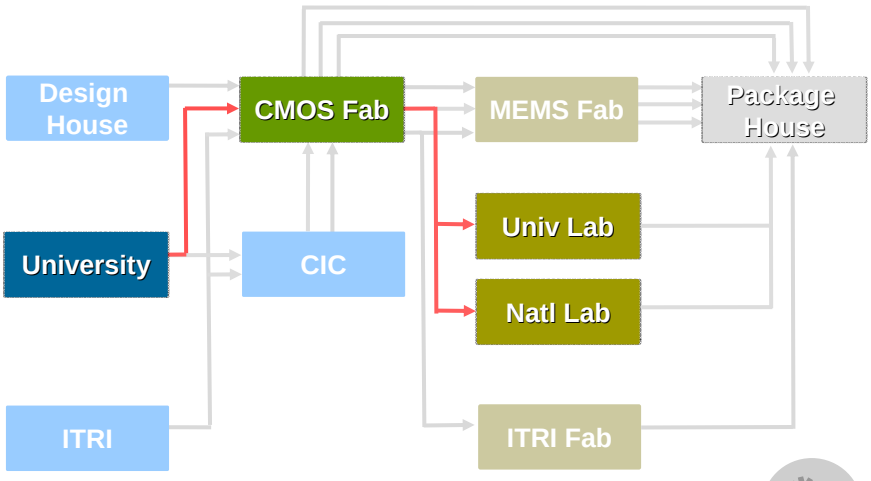
3-axis accelerometer



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

MDL
NTHU

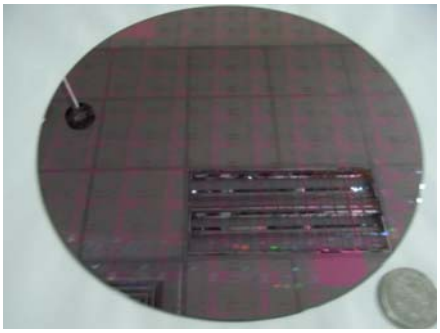
CMOS MEMS Networks at Taiwan



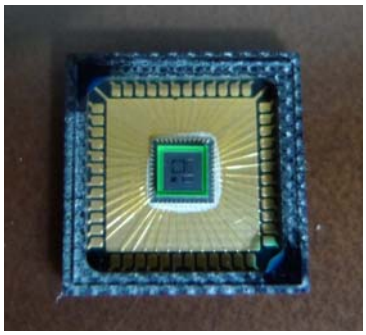
MDL
NTHU

CMOS MEMS Sensors – X Design House

- 8-in 0.18um processes other than TSMC



CMOS MEMS on 8" Wafer

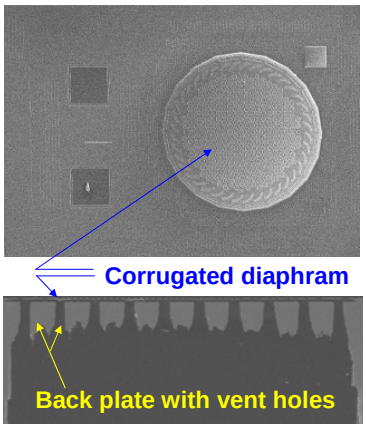


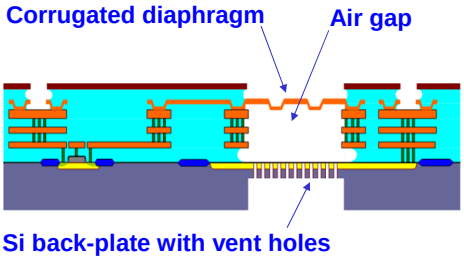
CMOS MEMS Sensors after bonding

MDL
NTHU

CMOS MEMS Sensors – Y Design House

- **Microphone:** 8-in 0.18um UMC CMOS processes

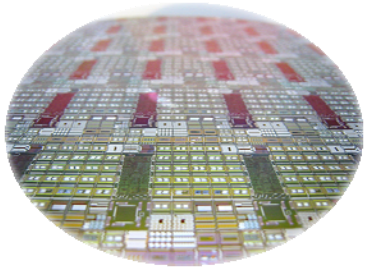




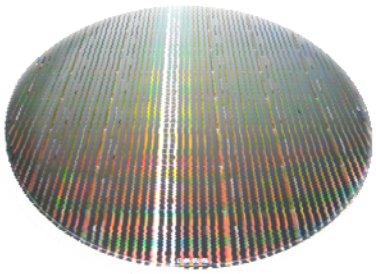
MDL
NTHU

CMOS MEMS Sensors

- 8-in 0.18um UMC processes
- ITE/Univ. - UMC - SPIL - KYEC



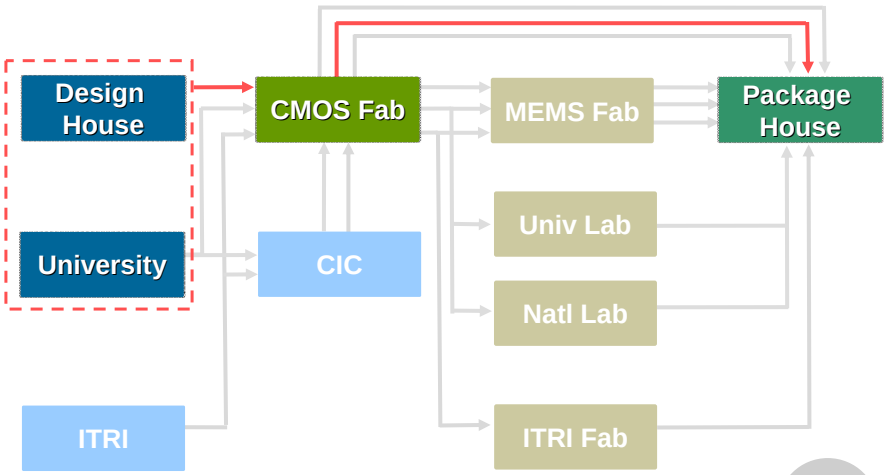
CMOS MEMS on 8" Wafer - UMC



Capped CMOS MEMS Sensors - SPIL

MDL
NTHU

CMOS MEMS Networks at Taiwan



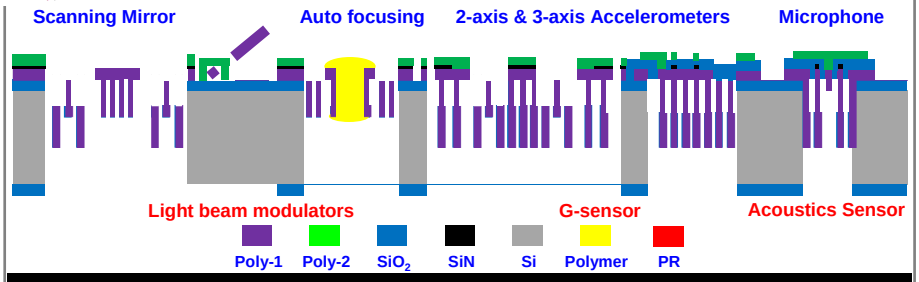
MDL
NTHU

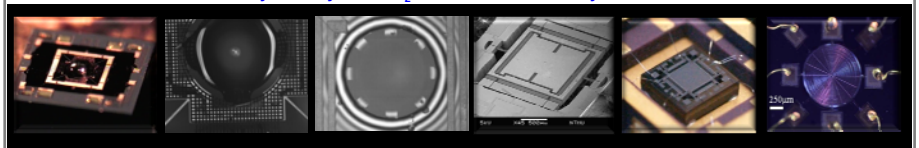
Outline

- Introduction
- CMOS MEMS Fabrication Platform
- Applications: CMOS MEMS Sensors
- Extension of CMOS MEMS Technology
- CMOS MEMS in Taiwan
- Outlook and Concluding Remarks

MDL
NTHU

Poly-Silicon Platform



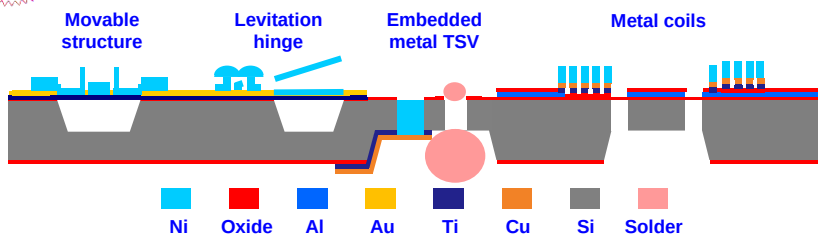


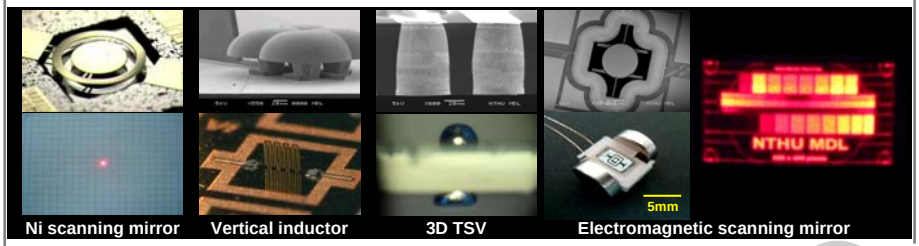
Light beam modulator – tracking/focusing | 2-Axis Accelerometer | 3-Axis Accelerometer | Microphone

Wu, and Fang, *J. Micromech. Microeng., 2005*
Wu, and Fang, *J. Micromech. Microeng., 2006*
Wu, and Fang, *J. Opt. A.*, 2006
Wu, and Fang, *IEEE Photonics Technol. Lett.*, 2006
Wu, and Fang, *IEEE Photo. Tech. Lett.*, 2007
Chan, and Fang, *Transducers*, Denver, 2009
Chan, and Fang, *MEMS*, Hong Kong, 2010
Chan, and Fang, *IEEE Sens. J.*, 2011

MDL
NTHU

Metal-MEMS Platform

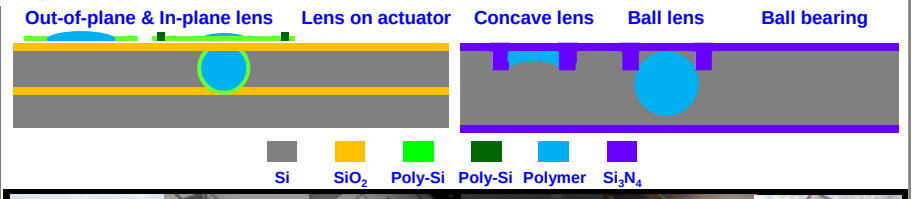


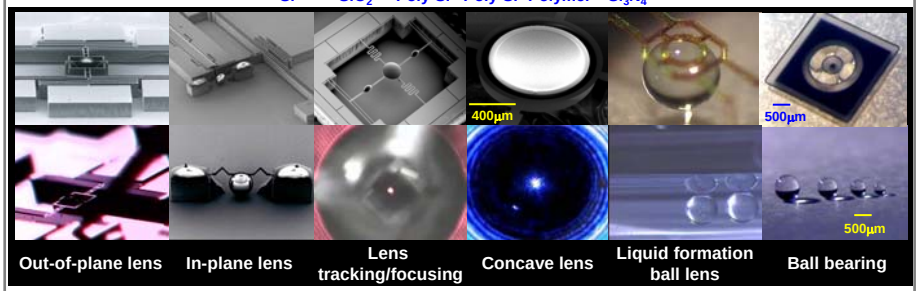


Yang, and Fang, *IEEE MEMS*, Istanbul, 2005
Yang, and Fang, *JMM*, 2006
Yang, and Fang, *JMEMS* , 2007
Su, and Fang, *IEEE MEMS*, Sorrento, 2009
Huang, and W. Fang, *JMMM*, 2010
Tang, and Fang, *JMM*, 2010
Tang, and Fang, *IEEE MEMS*, Cancun, 2011
Tang, and Fang, *JMM*, 2011

MDL
NTHU

Polymer-MEMS Platform



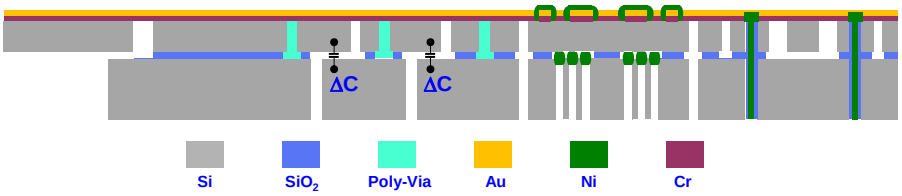


Hsieh, and Fang, *JMM*, 2007
Tung, and Fang, *IEEE MEMS*, Kobe, Japan, 2007
Lee, and Fang, *Transducers*, Leon, France, 2007
Hsiao, and Fang, *IEEE MEMS*, Tucson, USA, 2008
Lee, and Fang, *IEEE MEMS*, Sorrento, Italy, 2009
Lee, and Fang, *Transducers*, Denver, USA, 2009
Lee, and Fang, *IEEE MEMS*, Hong Kong, 2010
Lee, and Fang, *IEEE MEMS*, Cancun, Mexico, 2011

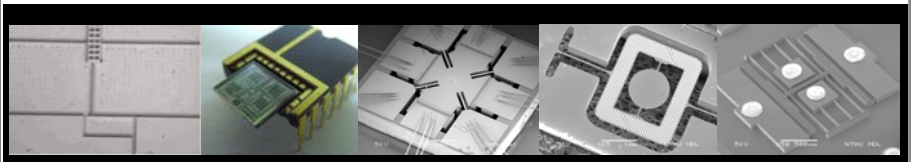
MDL
NTHU

SOI-MEMS Platform

Micro bending-test instrument | 3-axis accelerometer | Magnetostatic actuator | Wafer-level packaging metal TSV



Si | SiO_2 | Poly-Via | Au | Ni | Cr



Chip-scale micro instrument | 3-axis accelerometer | Electromagnetic actuator | SOI actuator with 3D-TSV

Lin, and Fang, *Transducers*, 2007
Lin, and Fang, *JMM*, 2007
Lau, and Fang, *MRS Fall Meeting*, 2007
Hsu, and Fang, *Transducers*, 2009
Tang, and Fang, *Transducers*, 2009
Hsu, and Fang, *JMM*, 2009
Tang, and Fang, *JMM*, 2010
Hsu, and Fang, *IEEE Sensors*, 2010

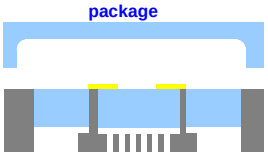
MDL NTHU

Glass-MEMS Platform

Neural probe integrated with Si-via

Medical application

SOG device with Si-via package

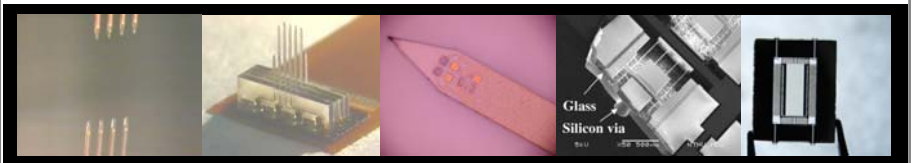


Package application

Fully-differential glass accelerometer

Physical sensor application

Glass | Parylene | Metal | Si

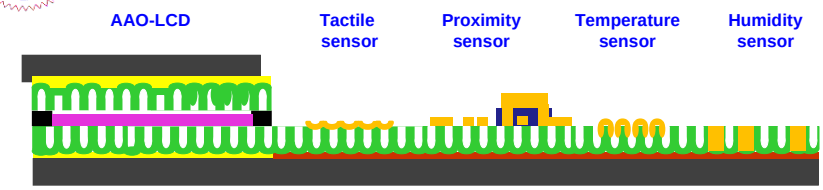


Neural probe | 3D neural probe | Si electrode neural probe | SOG device with Si-via package | Glass accelerator

Lin, and Fang, *J. Micromech. Microeng.*, 2008
Lin, and Fang, *IEEE MEMS*, Sorrento, 2009
Lin, and Fang, *Biosens. Bioelec.*, 2009
Lee, and Fang, *Transducers*, Denver, 2009
Lee, and Fang, *Biosens. Bioelec.*, 2009
Lee, and Fang, *J. Micromech. Microeng*, 2010
Hsu, and Fang, *IEEE MEMS*, Hong Kong, 2010
Lee, and Fang, *IEEE MEMS*, Cancun, 2011

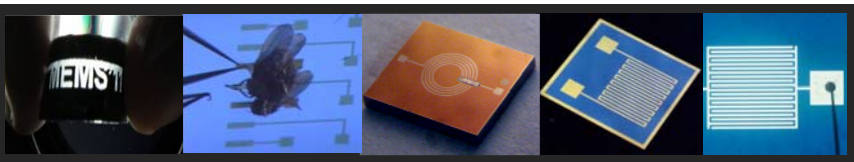
MDL NTHU

AAO-MEMS Platform



AAO Devices | AAO Physical sensor | AAO Environment Sensor

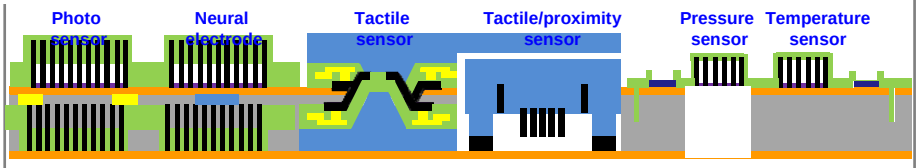
Ti | AAO | PET | Metal | ITO | SiO_2 | Si | LC



Hong, and Fang, *IEEE MEMS*, Italy, 2009
Hong, and Fang, *SID*, USA, 2010
Hong, and Fang, *Nanotechnology*, 2010
Hong, and Fang, *IEEE MEMS*, Mexico, 2011
Hong, and Fang, *IEEE Sensor J.*, 2011
Yeh, and Fang, *IEEE SENSORS*, Ireland, 2011
Lo, and Fang, *Transducers*, Beijing, 2011
Hong, and Fang, *Molecular & Liquid Crystals*, 2011

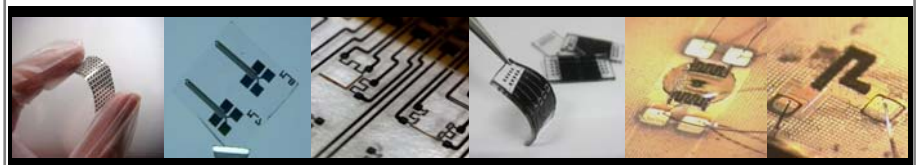
MDL NTHU

CNTs-MEMS Platform



Flexible CNTs-parylene sensor | Flexible CNTs-PDMS sensor | CNTs-parylene on Si structure

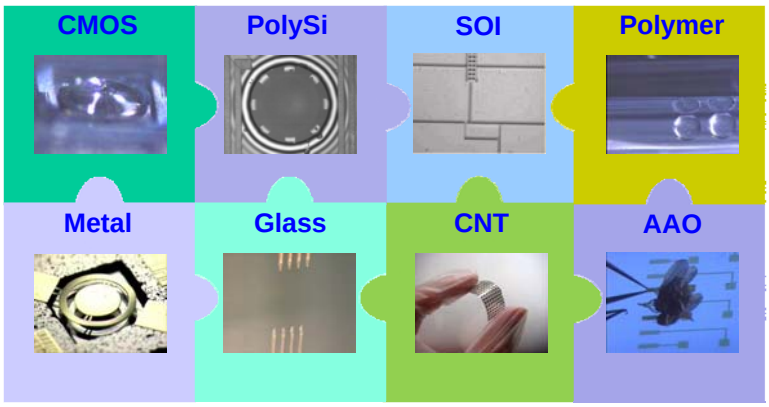
CNTs | Parylene | PDMS | Metal | Poly-Si | SiO_2 | Si | Fe



Fang, and Chu, *Adv. Materials*, 2006
Chu, and Fang, *Transducers*, Lyon, 2007
Lin, and Fang, *Biosens. Bioelec.*, 2009
Lin, and Fang, *Nanotechnology*, 2009
Lin, and Fang, *IEEE MEMS*, Hong Kong, 2010
Wang, and Fang, *IEEE MEMS*, Cancun, 2011
Hu, and Fang, *Transducers*, Beijing, 2011
Hu, and Fang, *J. Micromech. Microeng.*, 2011

MDL NTHU

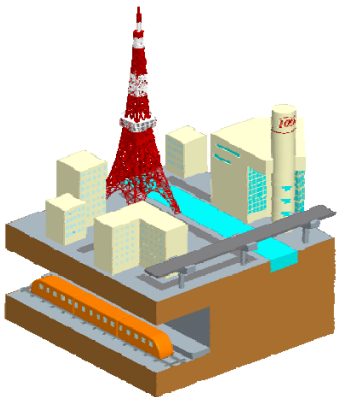
Platforms as Building Blocks



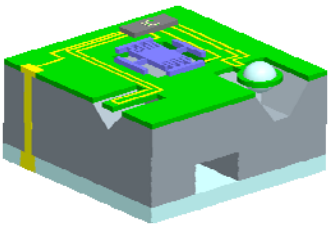
MDL
NTHU

3D Architecture on Chip

- MEMS technology enables “3D” structures on chip



m ~ km

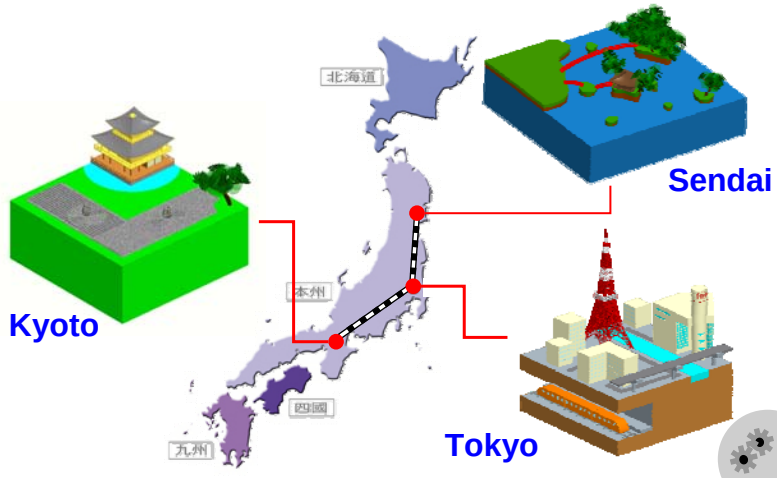


μm ~ mm

MDL
NTHU

Fabrication Platform as Building Blocks

- Towards the Era of "More than Moore": SoC/SiP/3D-IC



MDL
NTHU

A Small World on Chip

- "*It's a small world*," … and…
  build up your own "*Magic Kingdom*" on chip

Source: www.youtube.com

MDL
NTHU

Acknowledgements

- National Science Council (NSC), Taiwan
- TSMC, APM, tMt, PixArt, Sitronix, Delta, ASE Domintech, Sensirion
- National Labs, Taiwan – CIC, NDL
- Fabrication Common Labs – NTHU, NCTU, NTU
- My graduate students

MDL
NTHU

Thank you for your attention

MDL
NTHU