HKUST

MECH 1905 Buildings for Contemporary Living

Microsensor

Prof. Yi-Kuen Lee

Department of Mechanical and Aerospace Engineering

Hong Kong University of Science and Technology

Outline

- What is Microsystem technology?
- Why is it so popular? $$$
- History overview
- Current and future applications
- Micro pressure sensor, accerolerometer micro mirror arrays, inkjet printhead
- Microfabrication
- Microscience
- Summary and Conclusion

What's in a name?

- MicroSystem Technology (MST)
  popular in Europe
- Micro-Electro-Mechanical Systems (MEMS)
  widely used in United States
- Microengineering
  sometimes used in UK
- Micromachines, マイクロマシン
  used in Japan
- 微機電系統 in Chinese

MEMS definition

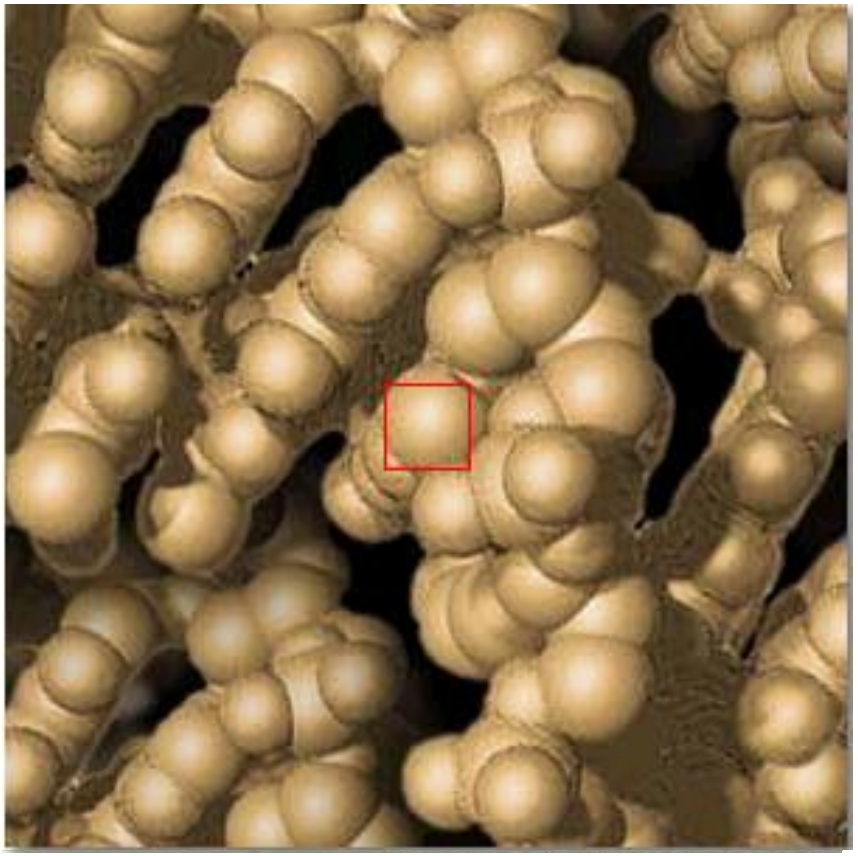
MEMS is a study of making machines in micro scale with the fabrication technique in Integrated circuit (IC) industry. The size ranges from micrometer to milimeter (10^{-6} ~ 10^{-3} m)

MEMS are the systems that integrate

- **sensing**
- **actuation**
- **computation**
- **control**
- **communication**
- **power**

HKUST

Size Does Matter



Science

Traditional Engineering

MEMS

Nanotechnology

10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}

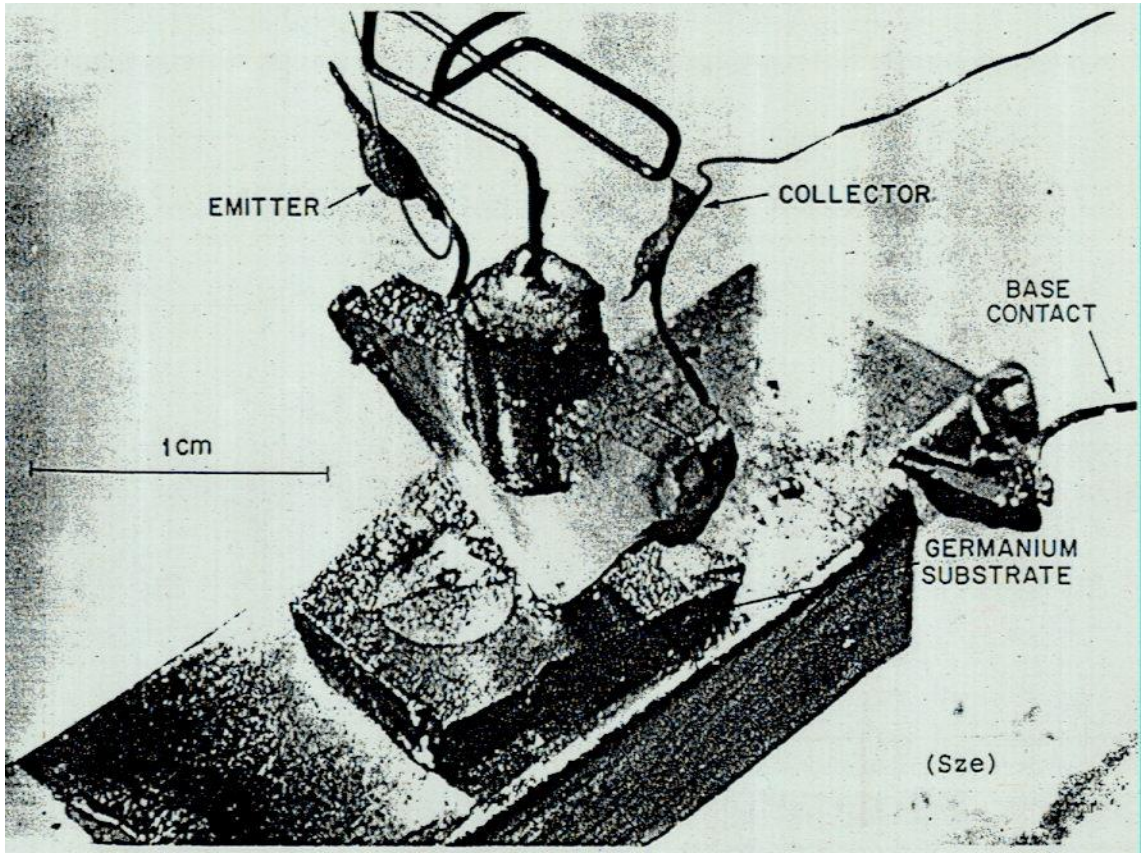
Biomedical

Unit : Meter

A brief history of MEMS

- 1947 invention of the transistor (made from germanium)
- 1958 silicon strain gauges commercialized; first integrated circuit (TI: Jack Kilby)
- 1961 first silicon pressure sensor demonstrated (Kulite)
- 1967 Invention of surface micromachining (Nathanson, Resonant Gate Transistor)
- 1970 first silicon accelerometer demonstrated (Kulite)
- 1977 first capacitive pressure sensor (Stanford) Prof James Angell
- 1979 first thermal inkjet printer (HP lab)
- 1980 Petersen, K.E., "Silicon Torsional Scanning Mirror"
- 1982 disposable blood pressure transducer (Foxboro/ICT, Honeywell, $40)
- 1984 First polysilicon MEMS device (Howe, Muller); HP ThinkJet
- 1988 Rotary electrostatic side drive motors (Fan, Tai, Muller)
- 1989 Lateral comb drive (Tang, Nguyen, Howe)
- 1990 BIACORE microfluidic chip
- 1991 polysilicon hinge (Pister, Judy, Burgett, Fearing)
- 1992 Grating light modulator (Solgaard, Sandejas, Bloom), DARPA USD$80M/yr
- 1993 First surface micromachined accelerometer sold (Analog Devices, ADXL50)
- 1996 Digital micro-mirrors array commercialized, DMD/DLP (Texas Instrument)
- 2001 Micro optical switch for internet backbone commercialized
- 2007 iPhone used micro accelerometer as tilt sensr (G-sensor)

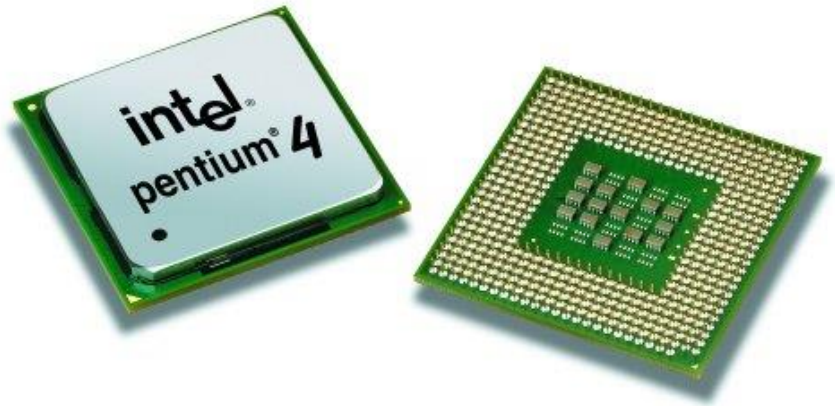
Early Semiconductor Fabrication



J. Bardeen, W.H. Brattain, "*The first transistor, a semiconductor triode*", Phys. Rev. **74**, p.230,1948

State-of-the-art Integrated Circuit Chip

Intel@ 3GHz
Northwood
Processor
55 million transistors
0.13 micron lithography
2003



90nm, transistor, Pentium M (0.144B) CPU in ’04

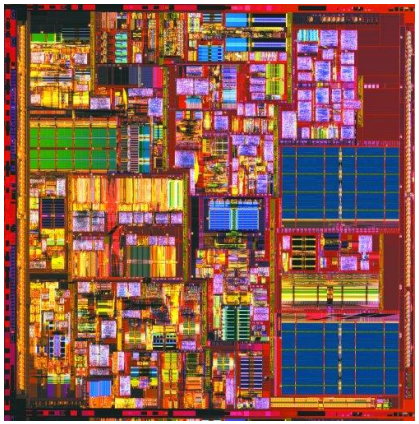
45 nm transistor, ’07

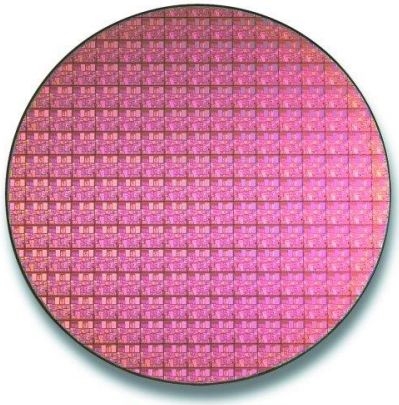
10nm transistor, Apple A11 (4.3B), ’17

Huawei Kirin 970 (5.5B)

7nm transistor, Apple A12 (7B), ’18, made by TSMC

Huawei Kirin 990, 5G (10.3B) ’19 by TSMC

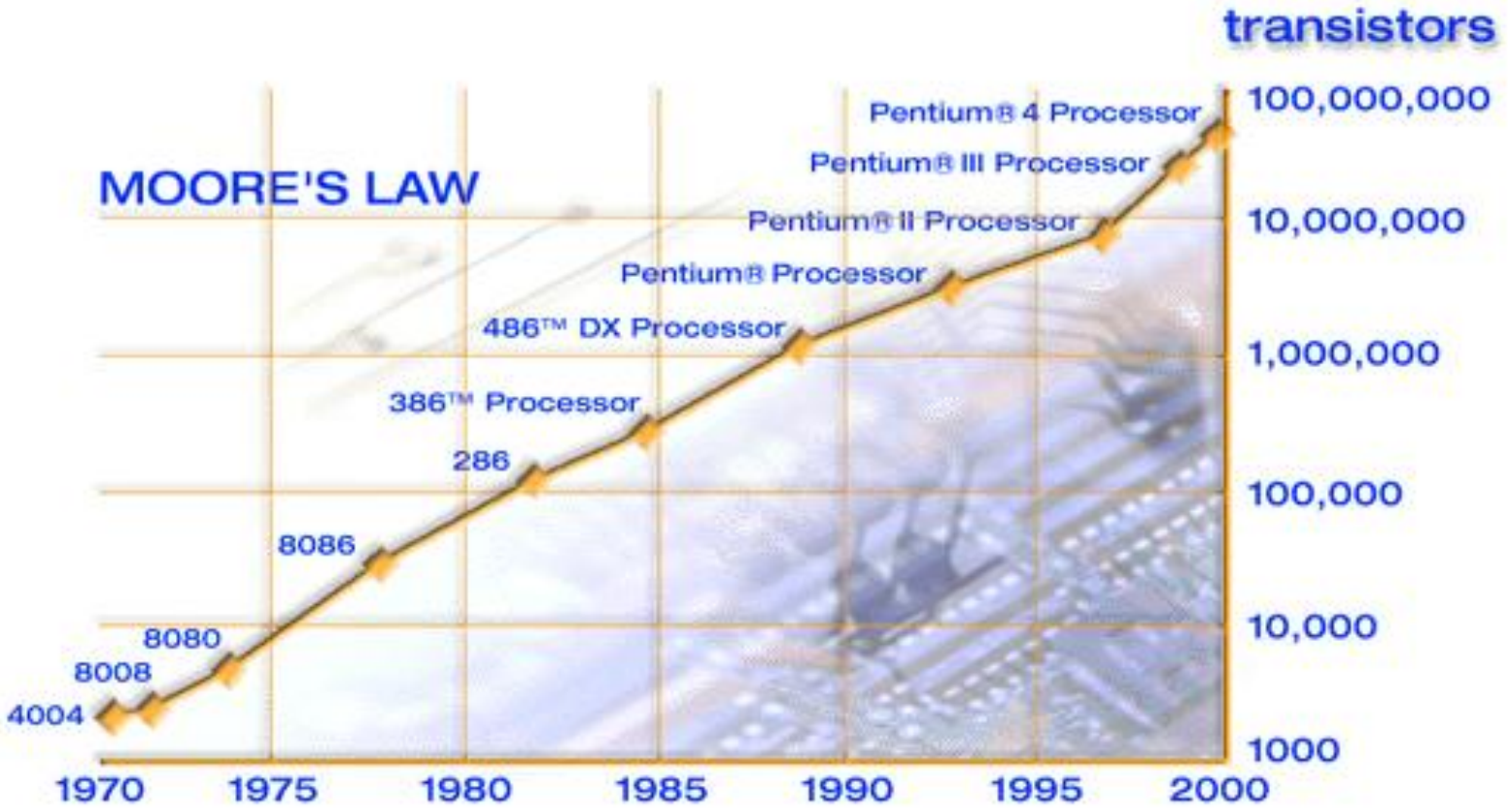




178 chips on 8” wafer

https://en.wikipedia.org/wiki/Apple_A12
https://www.engadget.com/2019/09/06/huawei-kirin-990-5g-ai/

Moore's Law for IC Chip

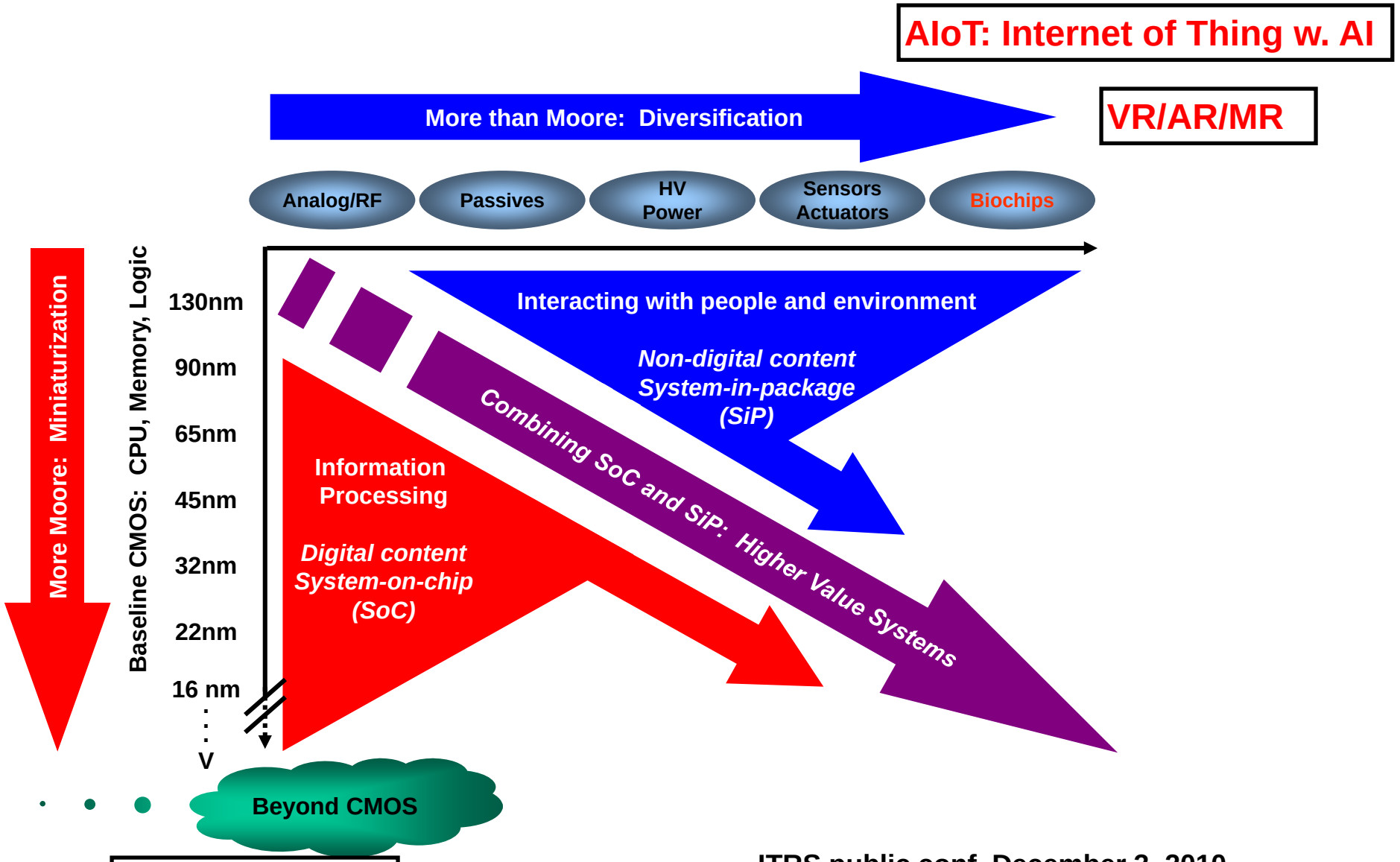


CPU power doubles every 18 months

How about MEMS?

HKUST

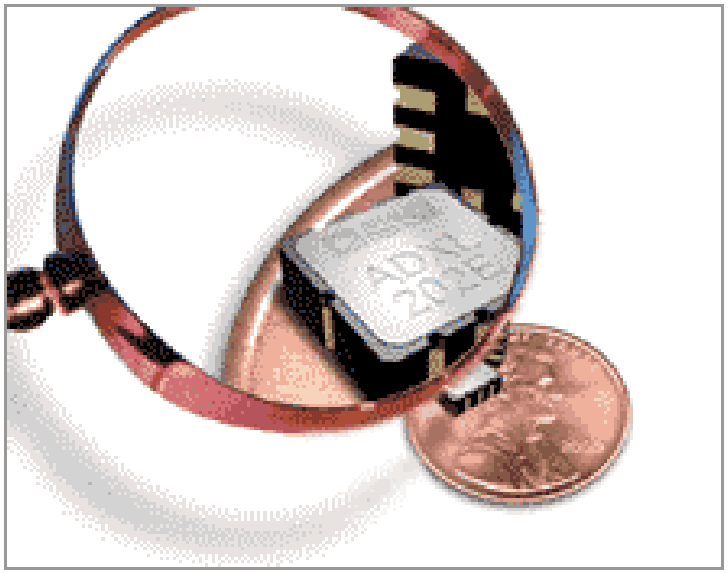
ITRS: Moore's Law & More than Moore (MtM)



ITRS public conf, December 3, 2010

Dr. Y.K. Lee

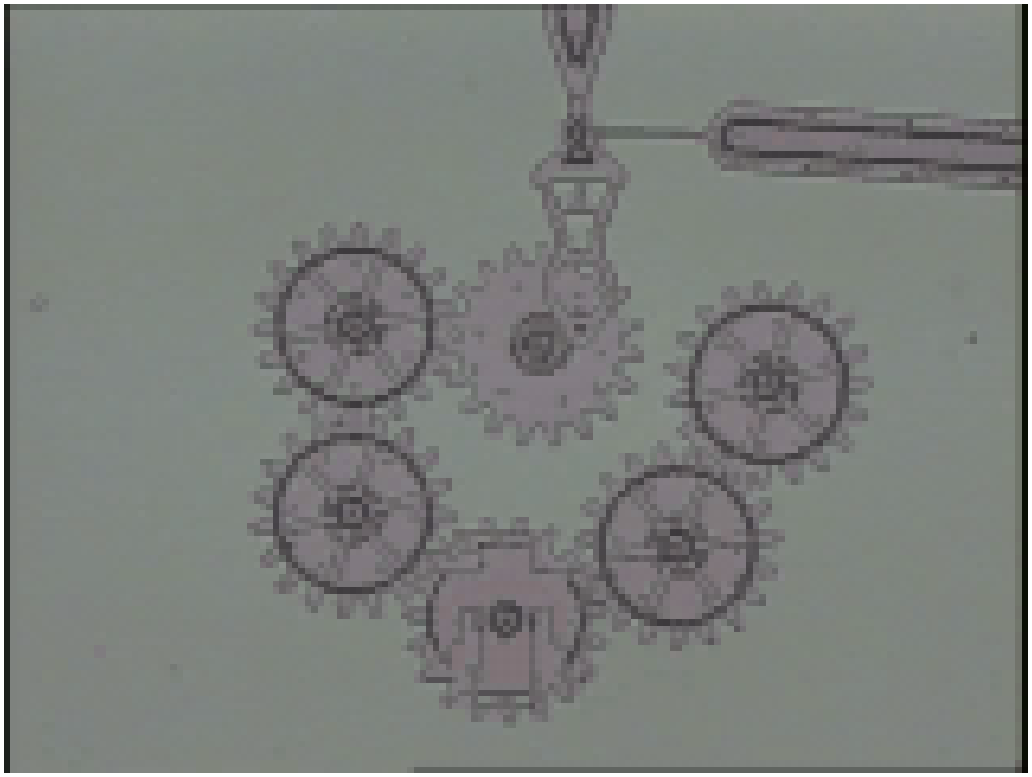
State-of-the-art MEMS Chips



Analog Devices
ADXL202
micro-accelerometer

Texas Instrument
Digital Light Processing
~ 1 million micro mirrors
http://www.dlp.com

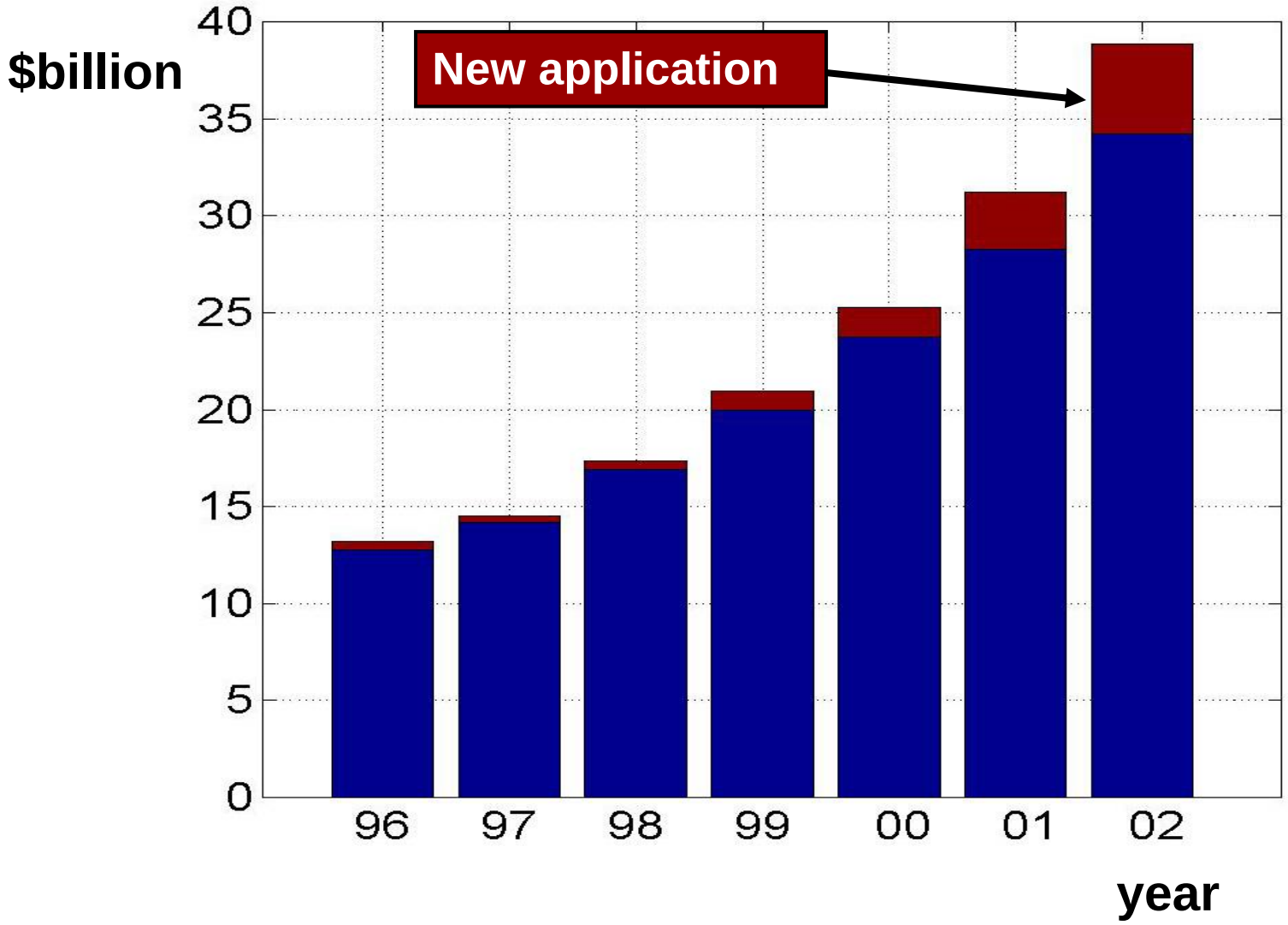
Microgears driven by a microengines



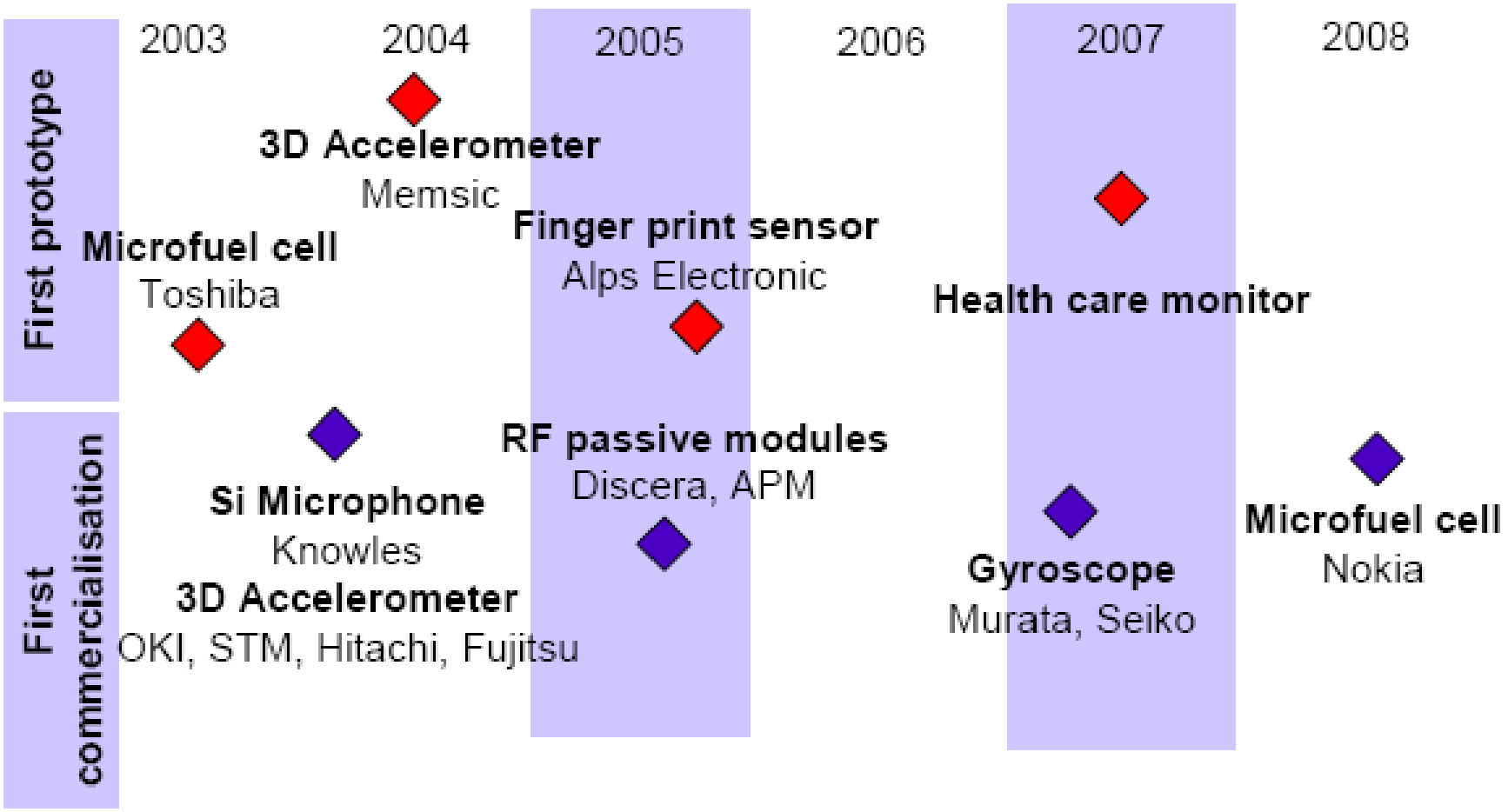
US Sandia National Lab MEMS project for nuclear weapon security

http://mems.sandia.gov/scripts/images.asp

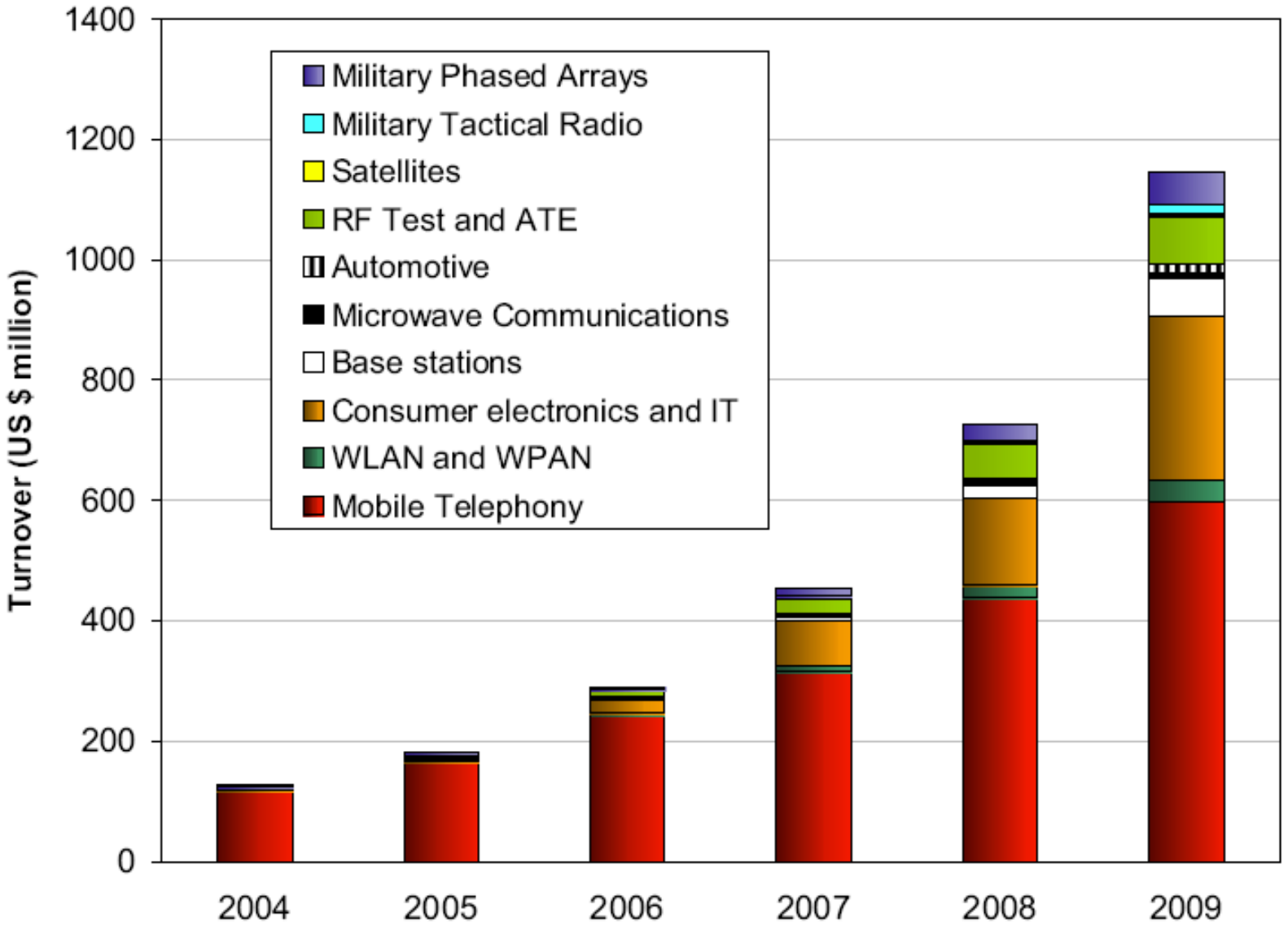
MEMS market analysis by NEXUS



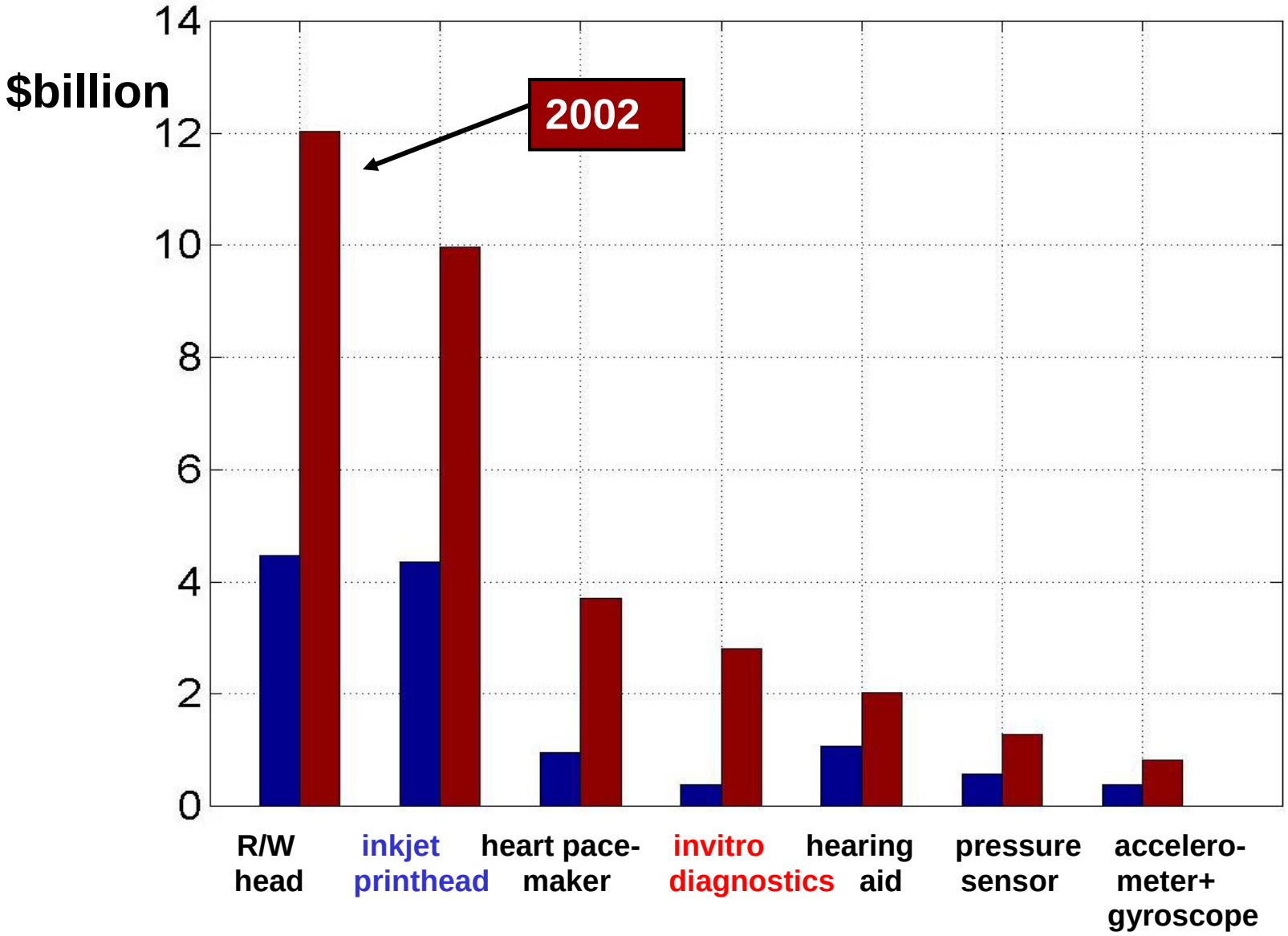
2004-2008 MEMS market for mobile phone



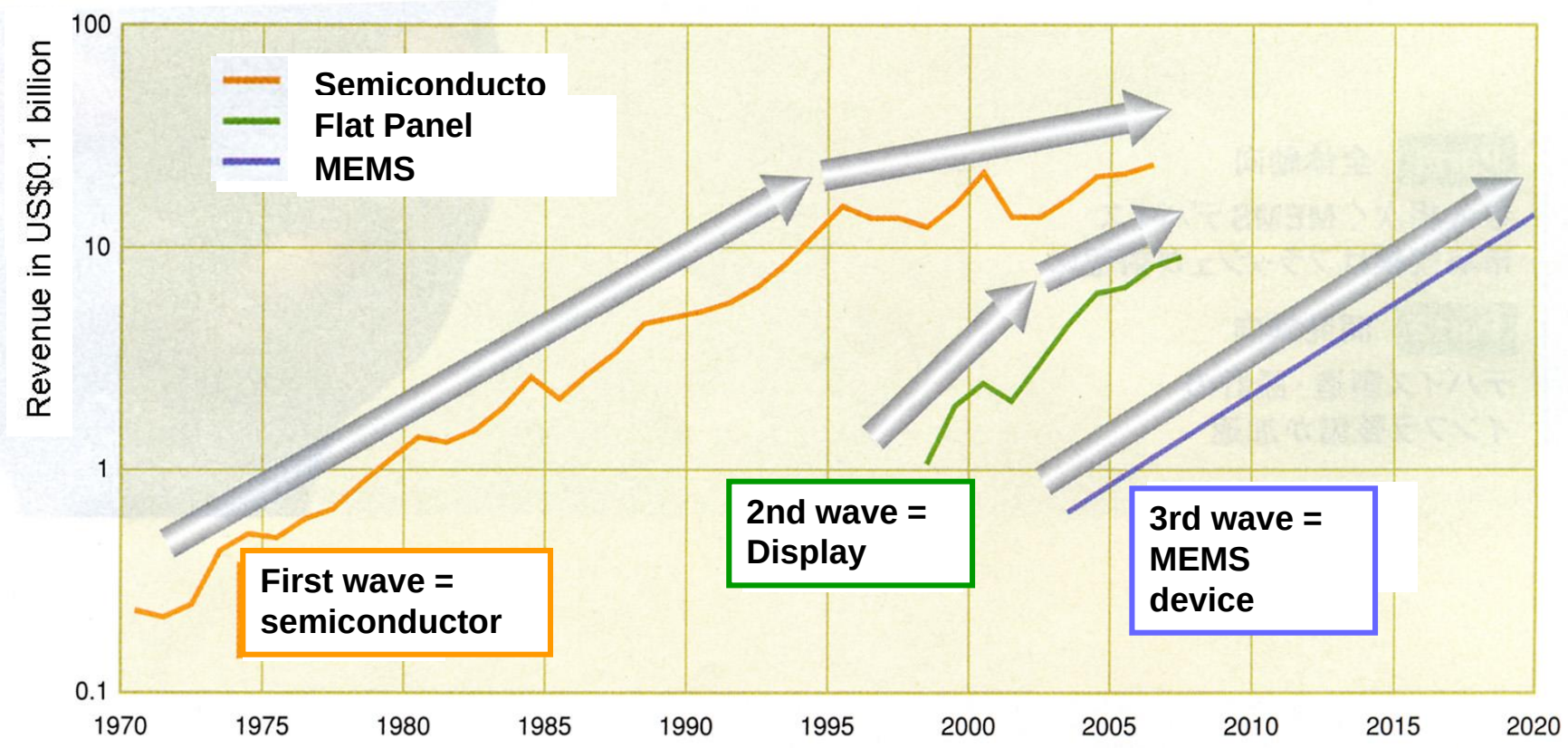
RF MEMS Market Forcast 2004-2009



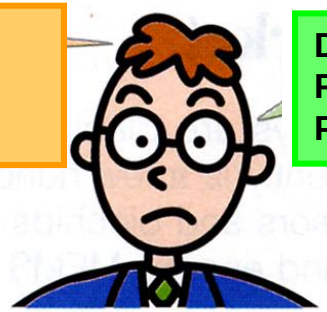
MEMS market volumes in 1996 & 2002



Market Research, Nikkei Microdevice (Dec 2004, Tokyo)



Semiconductor
Brain=Logic, memory



Display
Face=LCD, PDP

MEMS device
Ear & Eye = sensor
Hand & Leg = Actuator

Current MEMS applications

- **Pressure sensors, disposable blood pressure**
- **Accelerometers: air-bag deployment, (Wii, Nintendo), portable electronics (iPhone)**
- **Ink-jet printer heads**
- **Digital micromirrors (DLP) for computer projectors & TV**
- **Portable clinical analyzers**
- **DNA microarray**

More applications

- Inertial guidance microdevices: microgyroscope
- Active magnetic head for ultra high density hard-drive
- Optical switches for internet backbone system
- Flow control, drag reduction
- Bio-chemical lab-on-a-chip

  bio/biochemical micro sensors for food safety,

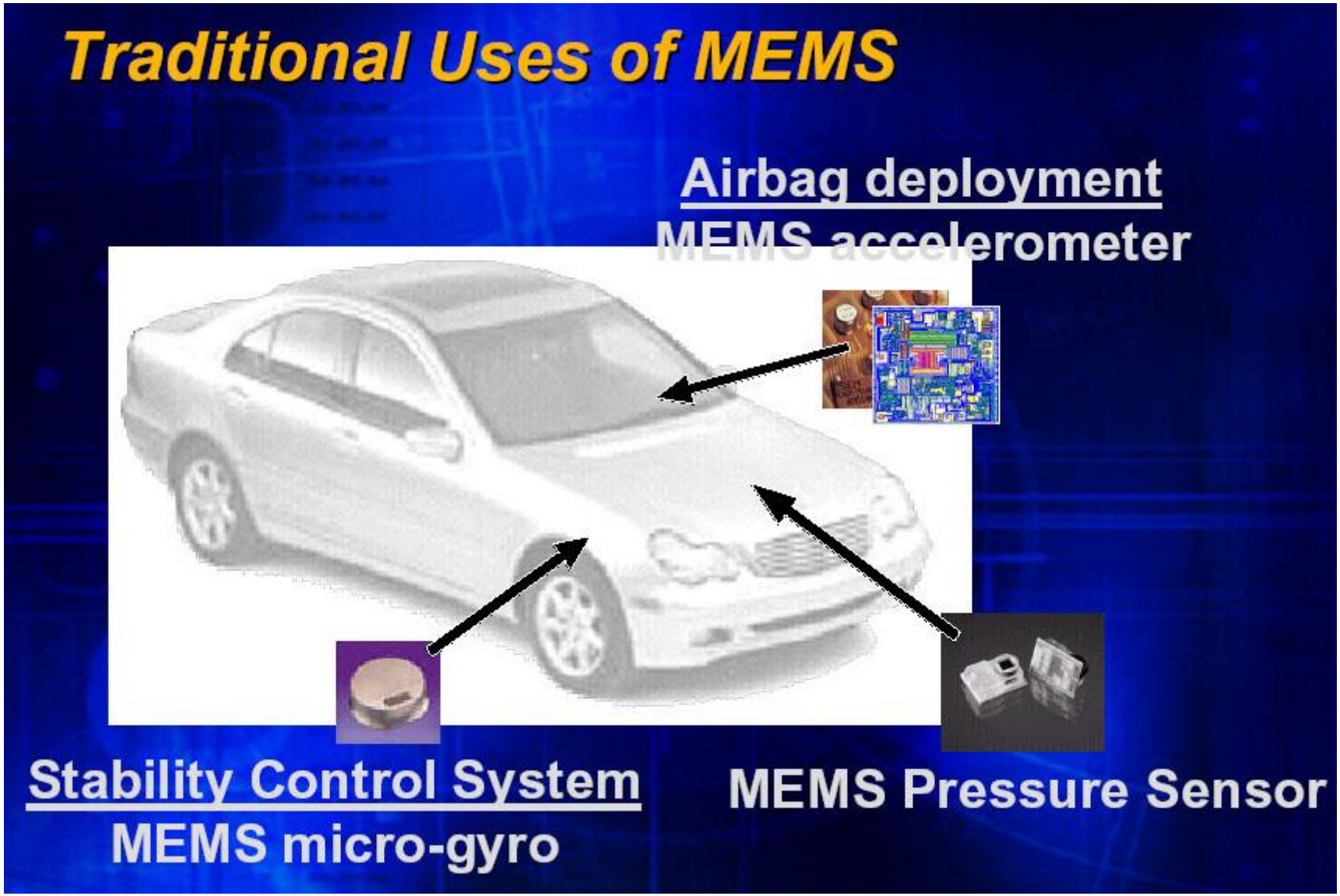
  agricultral products
- Communication components & mobile phones:

  micromech. filters, RF-switches & relays, SMT microphone
- Power MEMS:

  microfuel cells, micro generators
- Military MEMS:

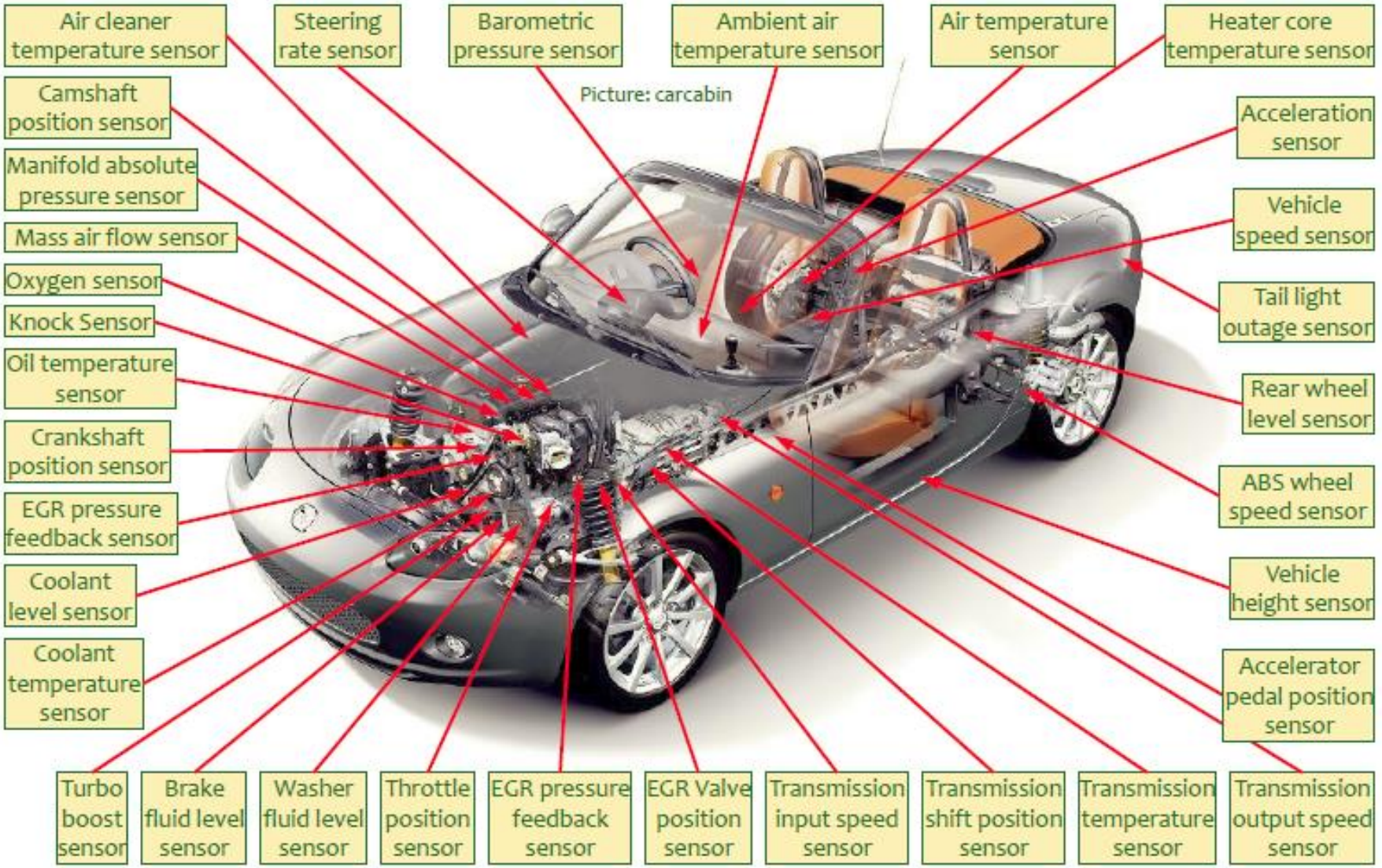
  micro NBC (nuclear, baterial and chemical) detectors

Traditional Uses of MEMS



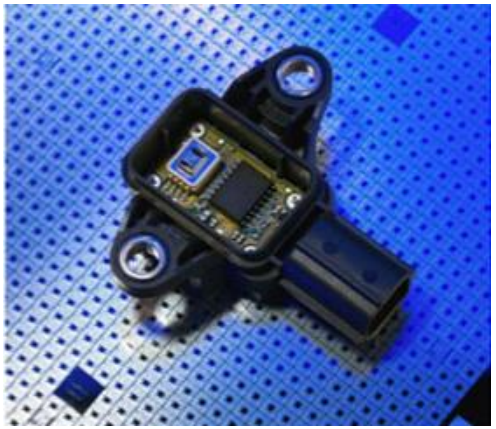
HKUST

New Car will have >50 sensors



HKUST

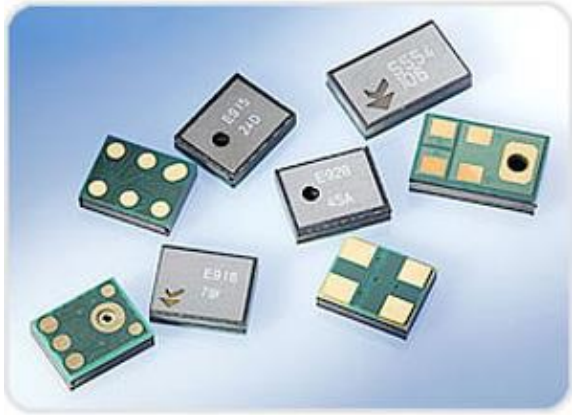
2008 Forbes: Top 10 MEMS Product



Microacclerometer: air-bag

DiCon's MEMS optical switch

HP thermal inkjet chip



MEMS-based microphone, surface mount tech

Josh Wolfe, MEMS The World, Forbes, 22 Apr 2008

HKUST

2008 Forbes: Top 10 MEMS Product

micro pressure sensor for tires (TPMS)

Texas Instrument: DLP chip (digital micromirror array

iPhone: 3-axes microaccelerometer

Man-machine interface

Wii: 3-axes microaccelerometer

Future Potential Uses of MEMS

Antennas

Color bi-stable display

Micro-switches

Tunable capacitors and inductors

Tunable filters

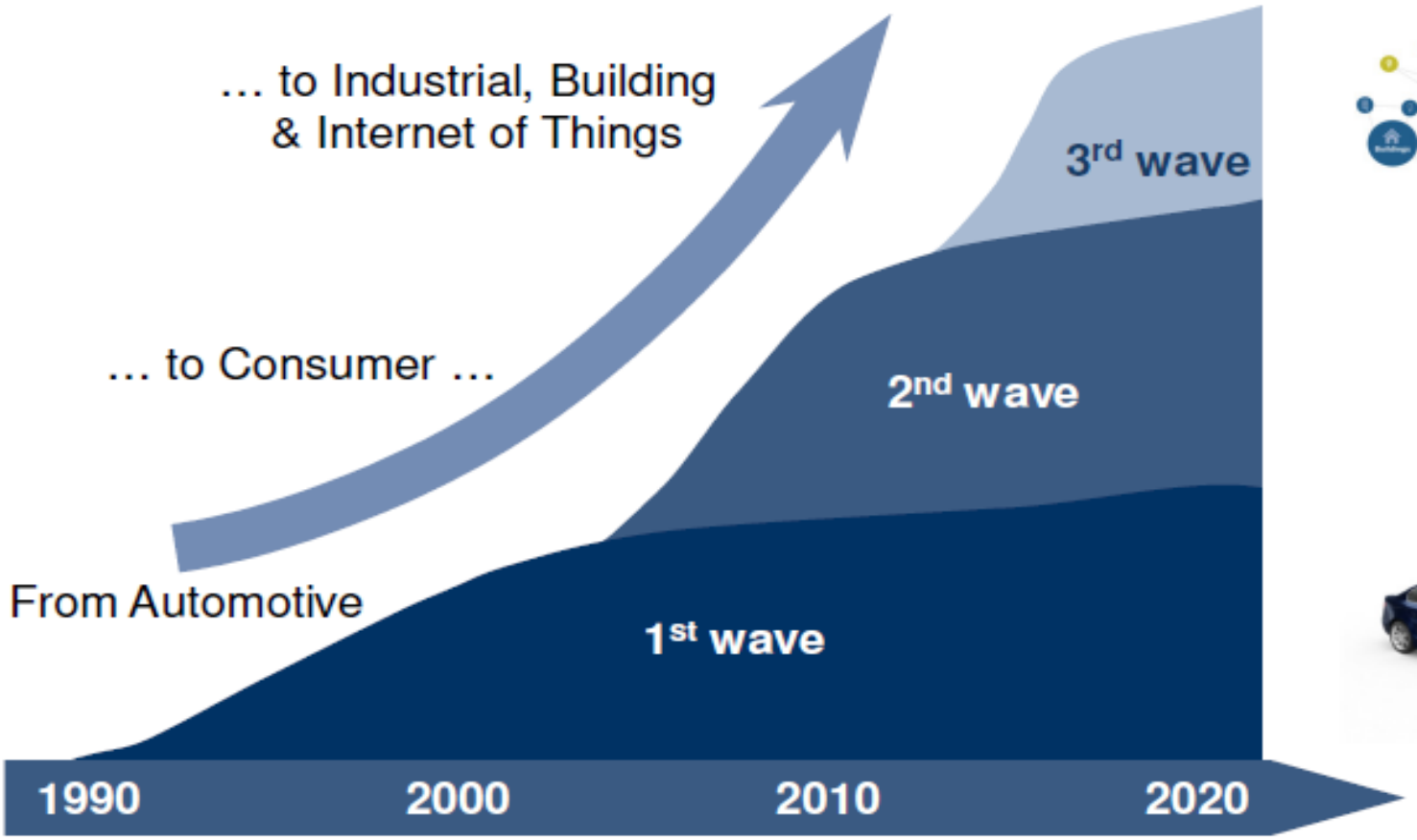
Directional microphone

HKUST

Focus: MEMS in Mobile Devices

Len Sheynblat, Qualcomm, MIG M2M Workshop, Spring 2012

IoT/A-IoT Trend



- **Mobile sensor market grew 200%/year in 2007~2013**
- **Trillion Sensor Summit initiated by MEMS entrepreneur, Dr Jansuz Bryzek (Father of Sensors) in Silicon Valley in 2013.**

MEMS Sensors for Smart Energy Efficient Buildings

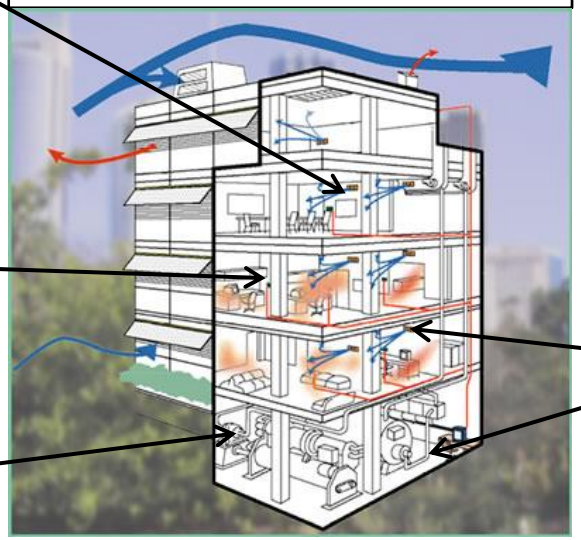
Key app: HVAC + gas/water supply system

Human Comfort Level Control :
MEMS Temperature Sensor (always integrated into other type of sensors) ;
MEMS Humidity Sensor

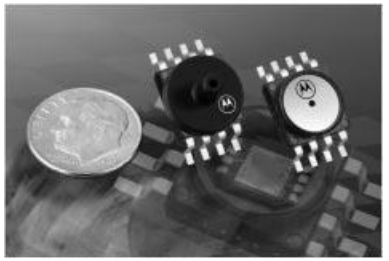
Indoor Air Quality (IAQ) control:
MEMS Gas Detector

Early Detection of Fan and Compressor Problem:
MEMS Vibration Sensor

Building HVAC system



Variable Air Volume (VAV) System (fixed-plenum-pressure method):
MEMS pressure sensor;



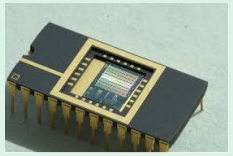
Flow Rate Control for HVAC:
MEMS Flow sensor

CMOS MEMS technology: enable Moore's law for sensors

Ref: O. Grassmann et al., Sensors in intelligent buildings, Wiley, 2002

HKUST-MIT Smart EeB: Smart Adaptive Control/Monitoring System for EeB & Low-Carbon Footprint

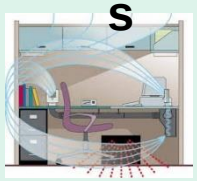
Demo room



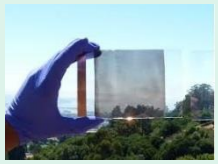

Sensors (YK Lee)

Actuator

s



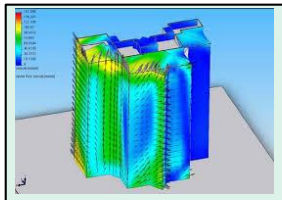

Personalized Ventilation (C. Chao)




Smart Window (N Fang)

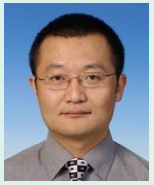
Fan Coil Unit

Sensor Data



Energy & Thermal Comfort Prediction Using CFD & EnergyPlus (L. Glicksman, J. Lu @CityU)

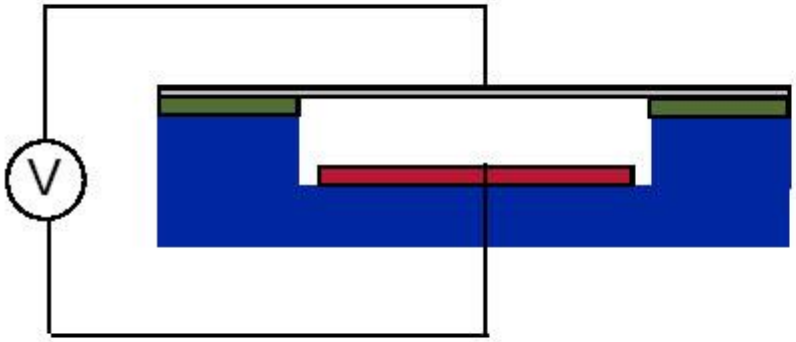
Smart HVAC system (YK Lee)


Prediction & Control Using Artificial Intelligence (L. Zheng, L. Chen)

Energy Saving & Thermal Comfort

Micro pressure sensors



Capacitive sensing

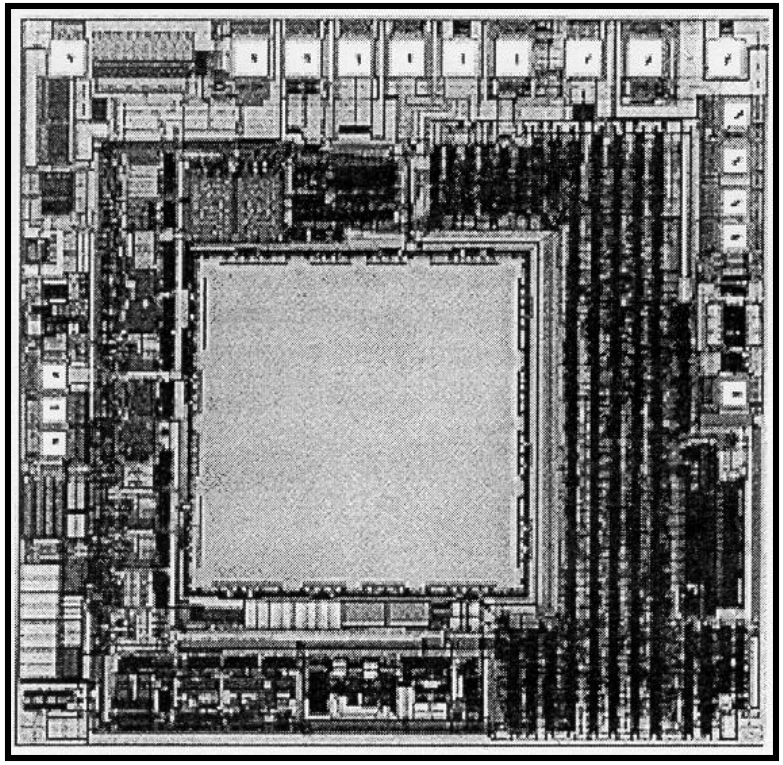
Piezoresistive sensing

Use capacitor to sense pressure

Use piezo-resistor to sense pressure

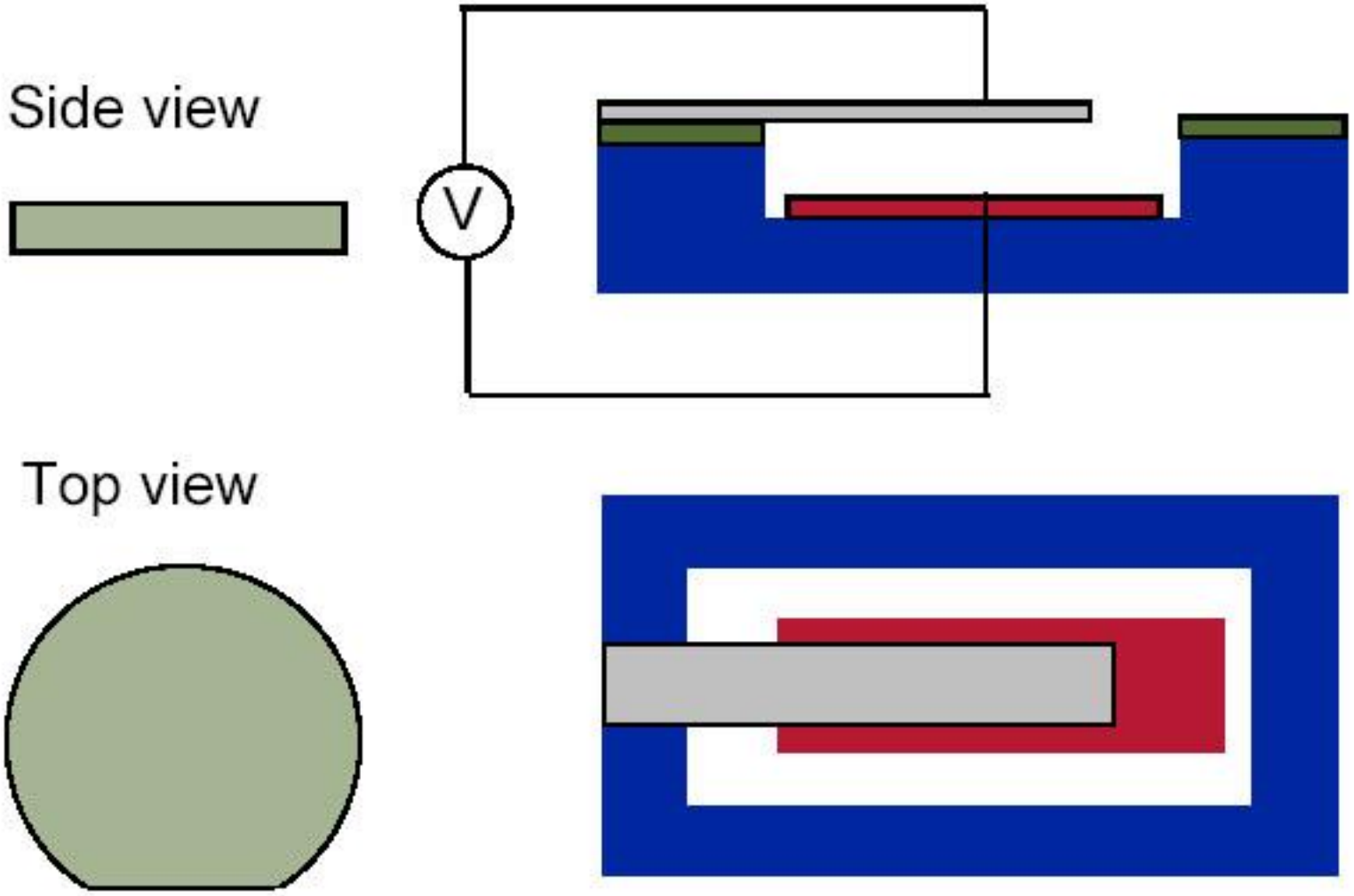
Integrated Pressure Sensors

- Silicon pressure sensors have been on the market for over 30 years
- First integration attempt
  - late 1970's
- Over 100 million units are now produced every year
- A significant portion of which has on-chip integration ranging from
  - Passive trim elements only
  - Analog signal conditioning
  - Digital signal conditioning

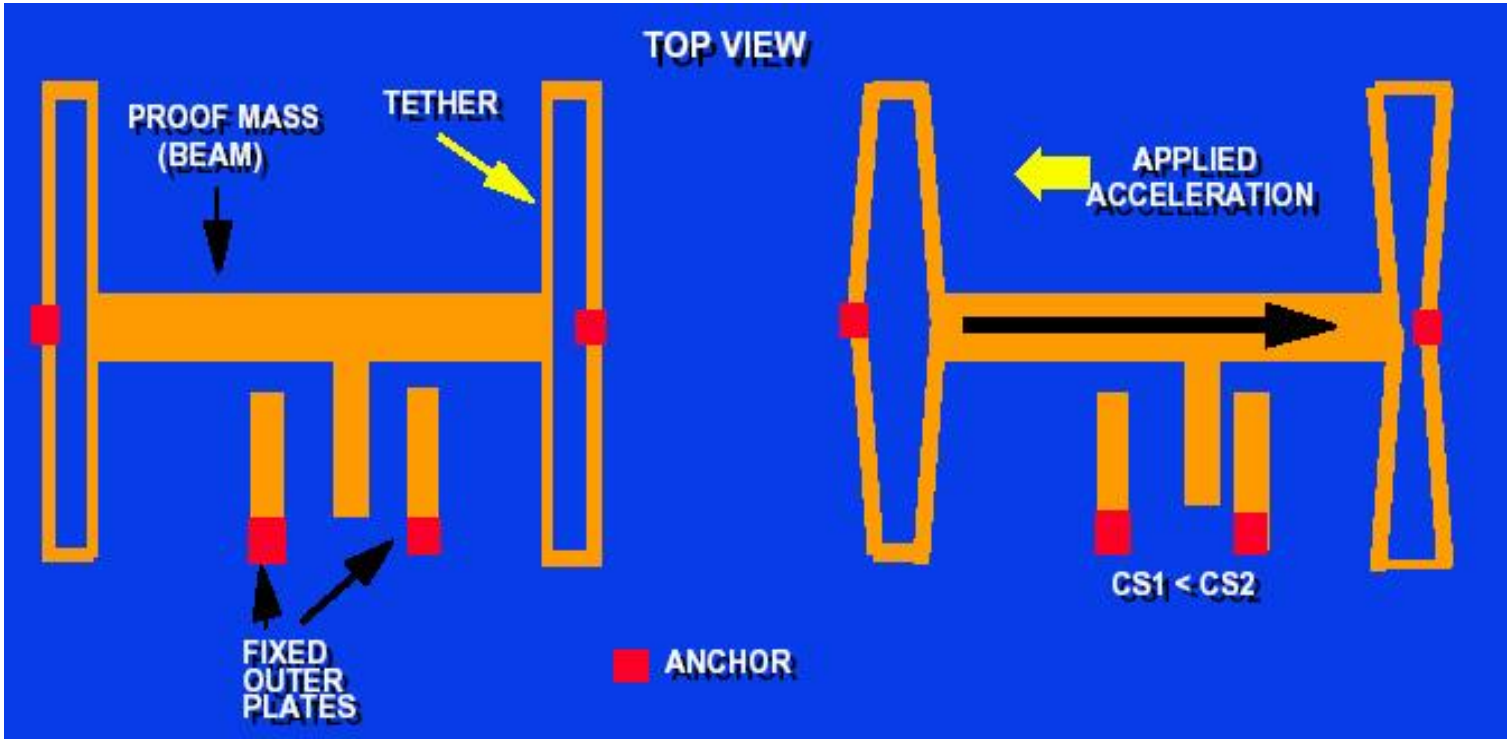


Motorola's latest Automotive Pressure Sensor with DSP

Micro accelerometer

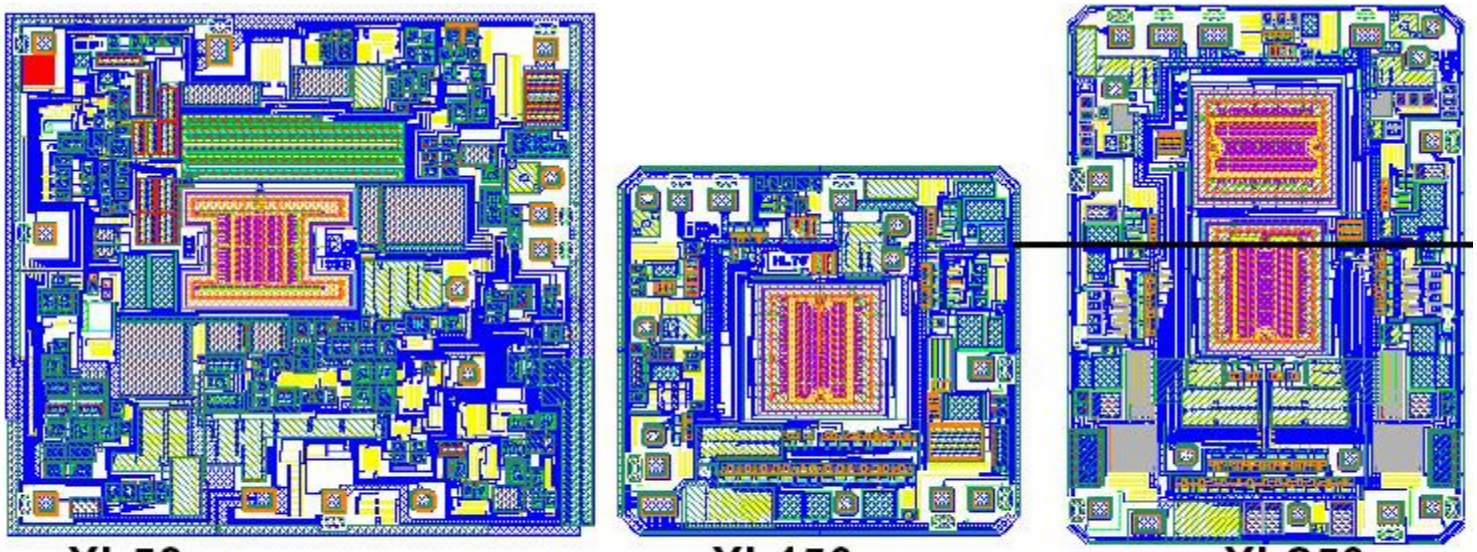


Micro accelerometer practical design



HKUST

ADI Automotive Accelerometers



XL50
Original

1993

XL150
New

~1996

XL250
2 Channel New

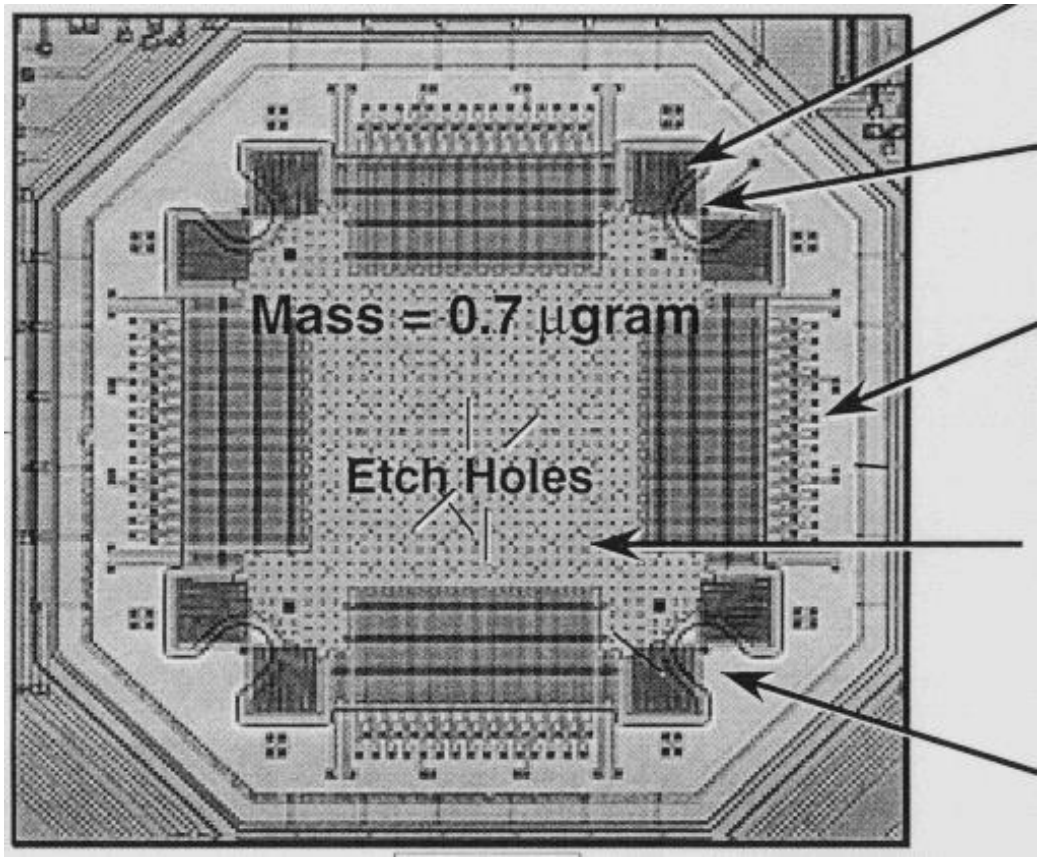
~1997

1993 Analog Device: Industry's first surface micromachined accelerometer includes signal conditioning on chip

April, 2005: Analog Device made 200 million MEMS inertia sensors

http://techon.nikkeibp.co.jp/article/COLUMN_LEAF/20050408/103555/

ADXL202 Beam structure



Tether (Spring)

Anchor point

30 sensing cells per axis
1.2μm gaps,
1μm feature size

2μm thick polysilicon structure suspended 1.6μm above substrate

10kHz resonant frequency

Deflection due to *2g* acceleration = 5nm = $250 \cdot 10^{-18}$F

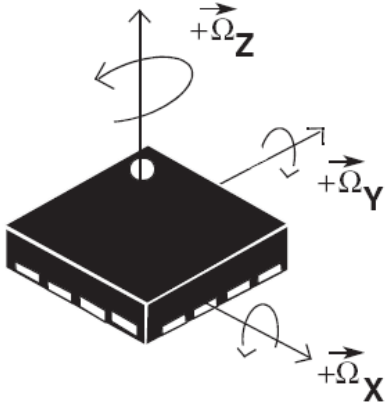
Minimum resolvable deflection = 0.04A = $90 \cdot 10^{-21}$F

iPhone and many smartphone use microaccelerometer

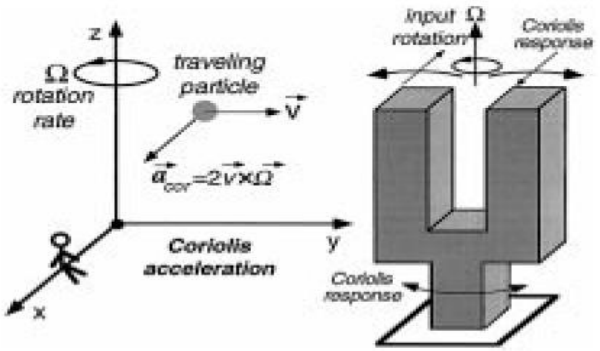
ST Microelectronics: 3-axis LIS331DL, 3×3 ×1 mm³

Freescale MMA745xL 3-axis accelerometers

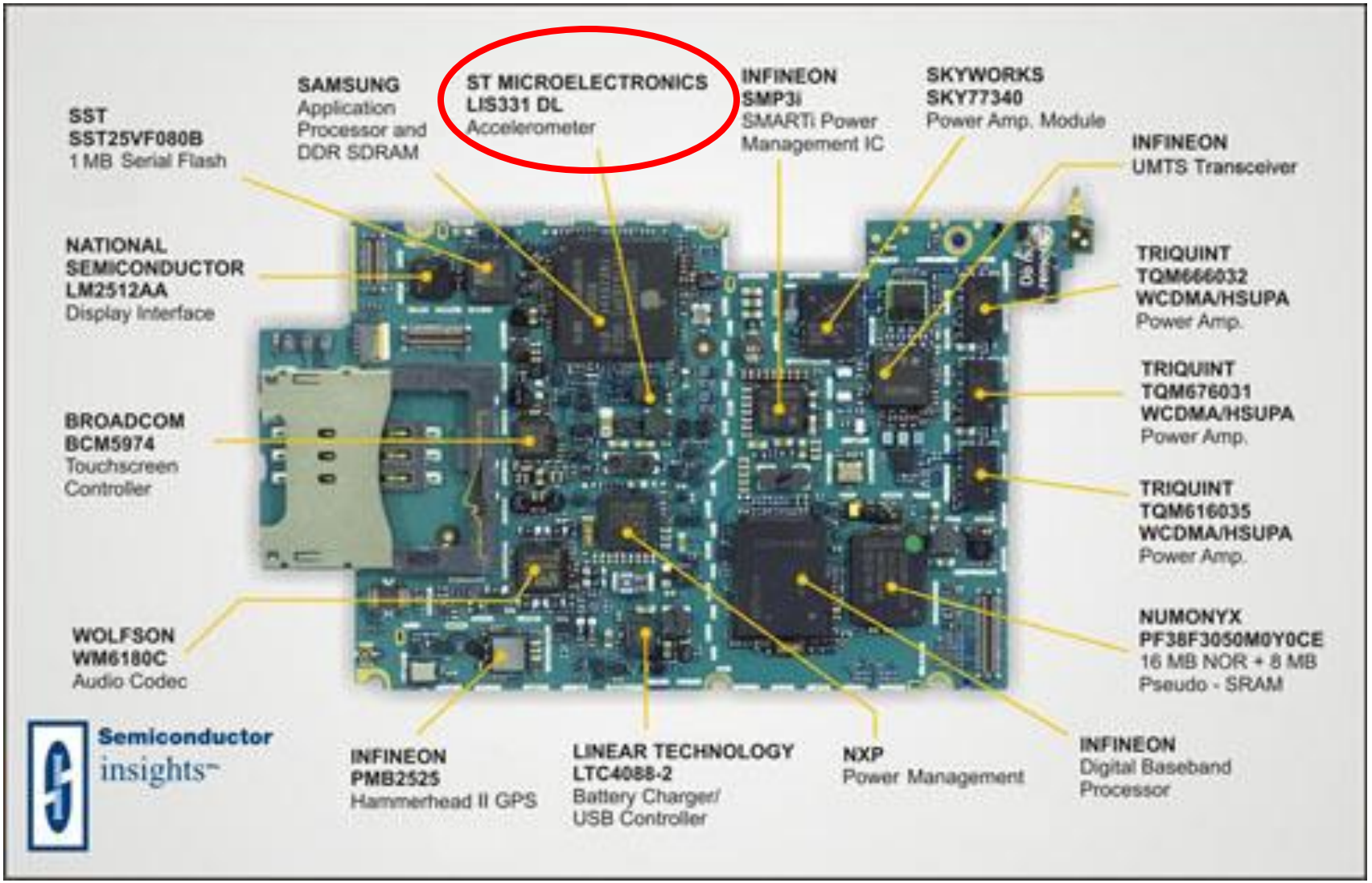
iPhone 4 uses ST Microelectronics micro gryo



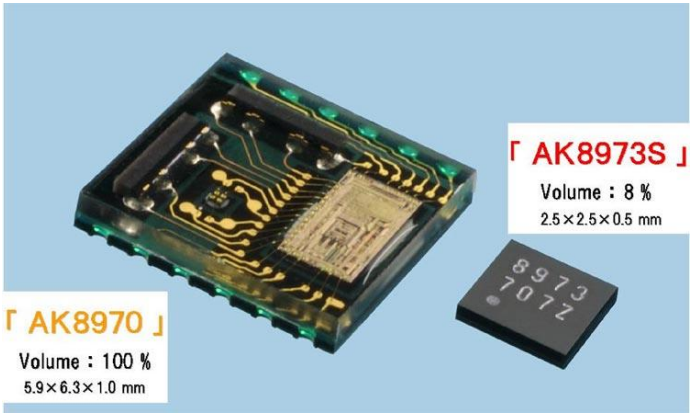
- 3-axis digital L3G4200D
- 4×4 ×1.1 mm^3
  - made by ST Microelectronics
  - First micro gryo used in smartphone
  - Vibrating tuning fork (mass-spring system)

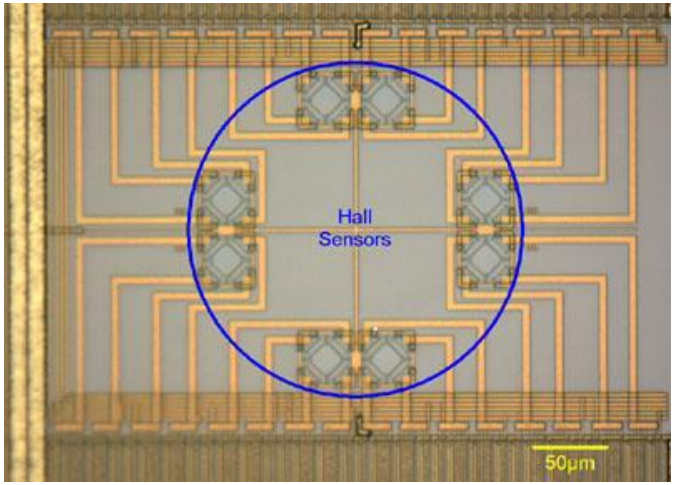


iPhone uses ST Microelectronics LIS331 DL



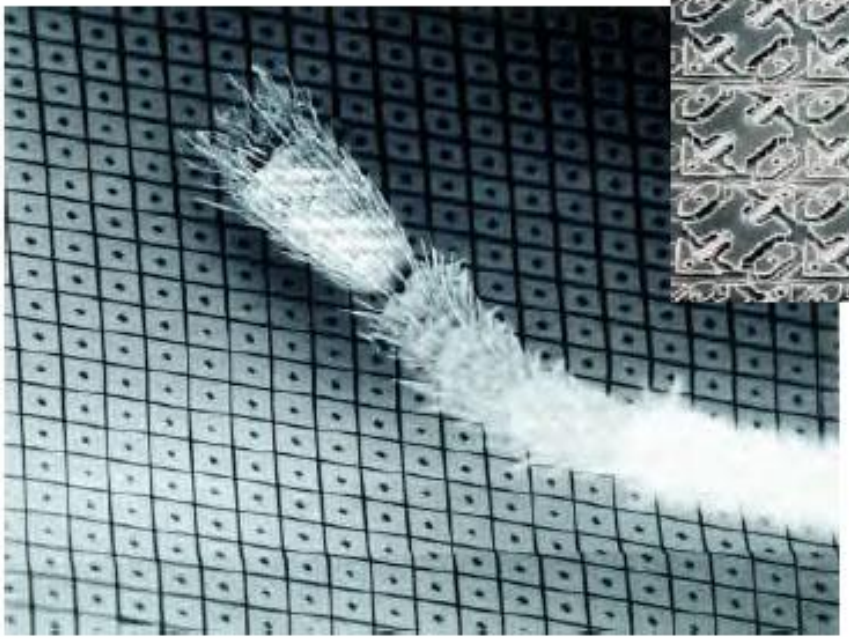
iPhone 3GS & 4 uses Japanese (Asahi Kasei) AKM's AK8973 3-axes digital compass (micro magnetic sensors/magnetometer)





TI's Digital Micromirror Device (DMD)

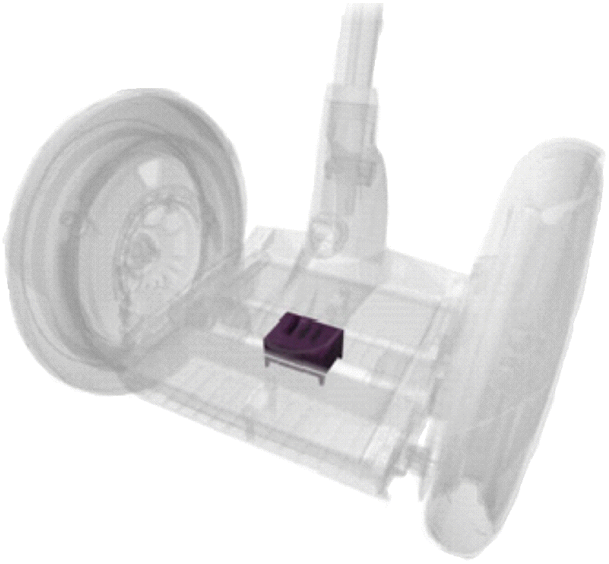
Anatomy of DLP/DMD



Ant's leg on the DMD array

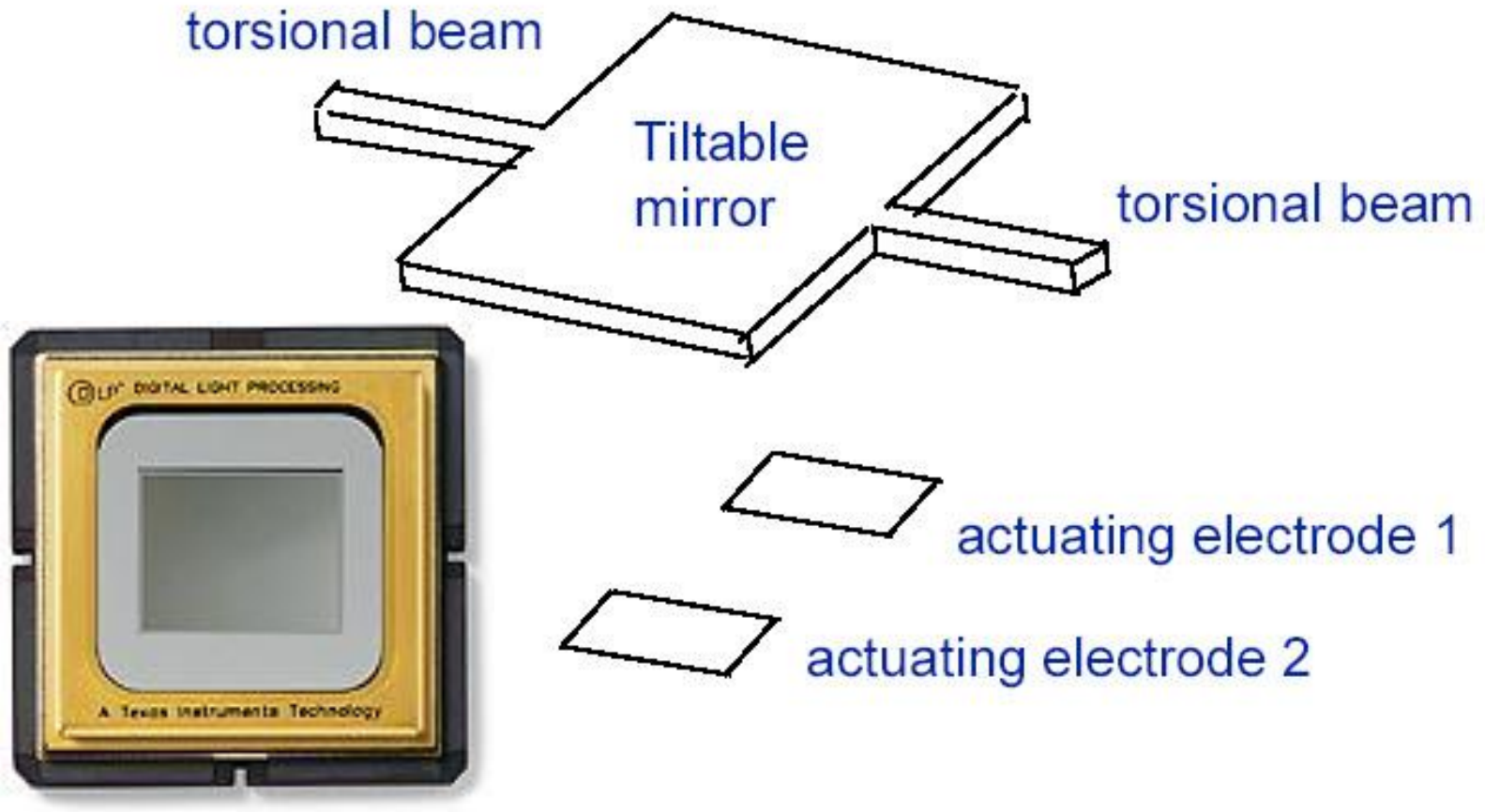
TI: started at 1977
market 1996

SEGWAY Scooter uses 5 MEMS gyro

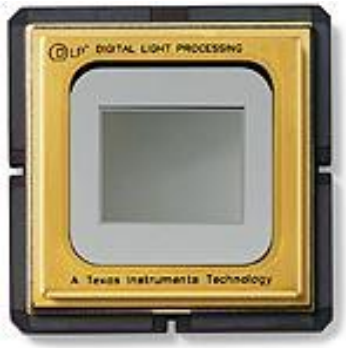


www.segway.com

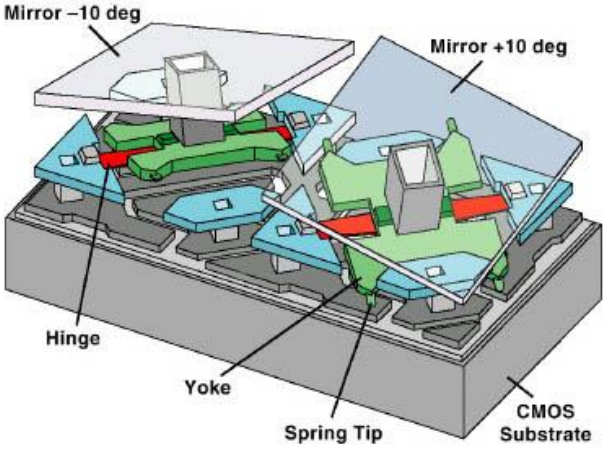
How DMD works

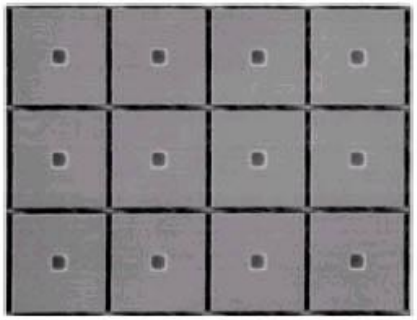


Texas Instruments' DLP Chip



DLP Pico Projector



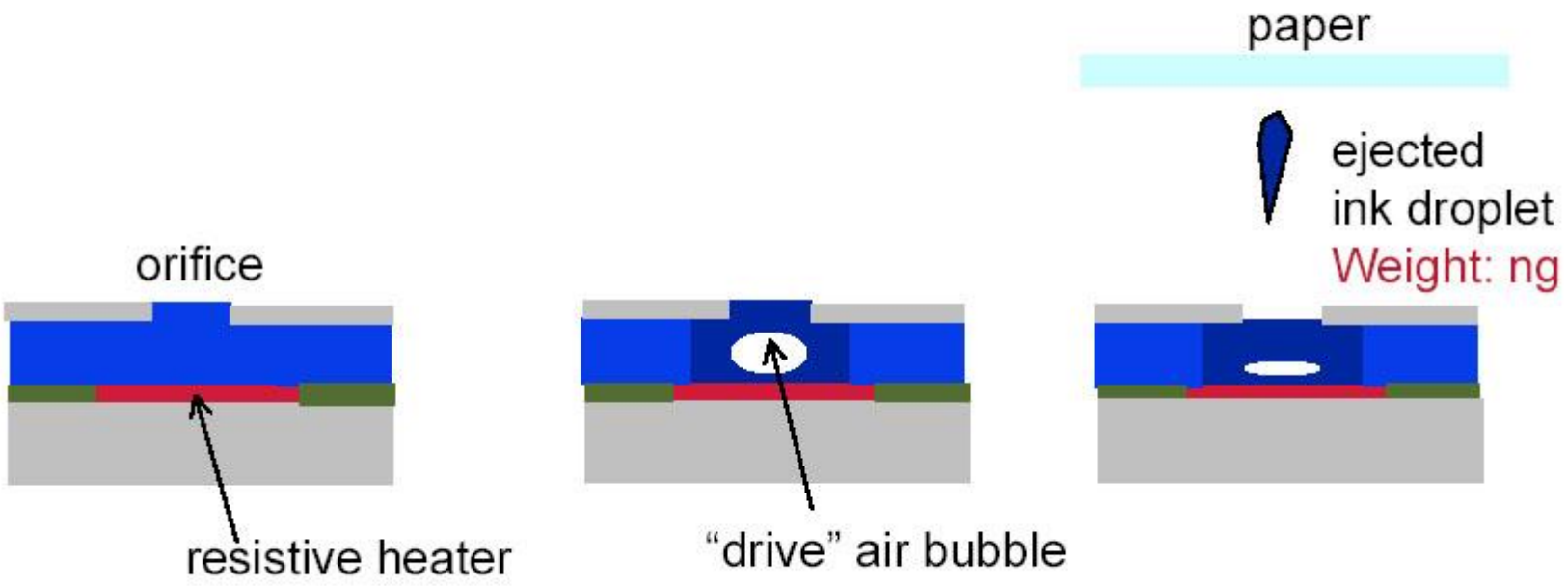


Top View of DMD

www.dlp.com

HK Fortress shop for sell: 2005

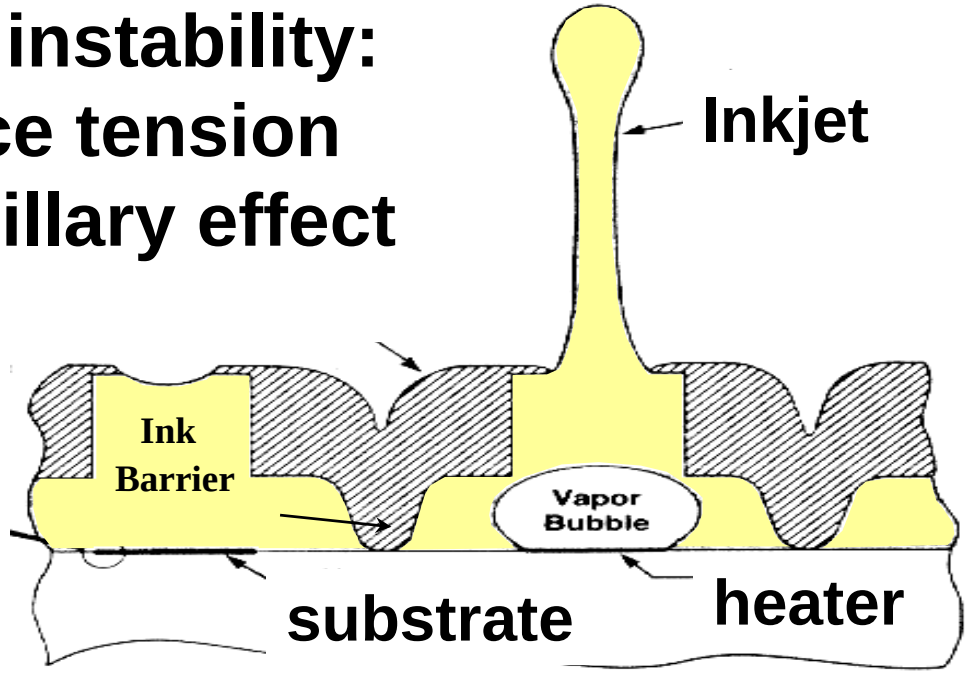
HP ink-jet printer heads



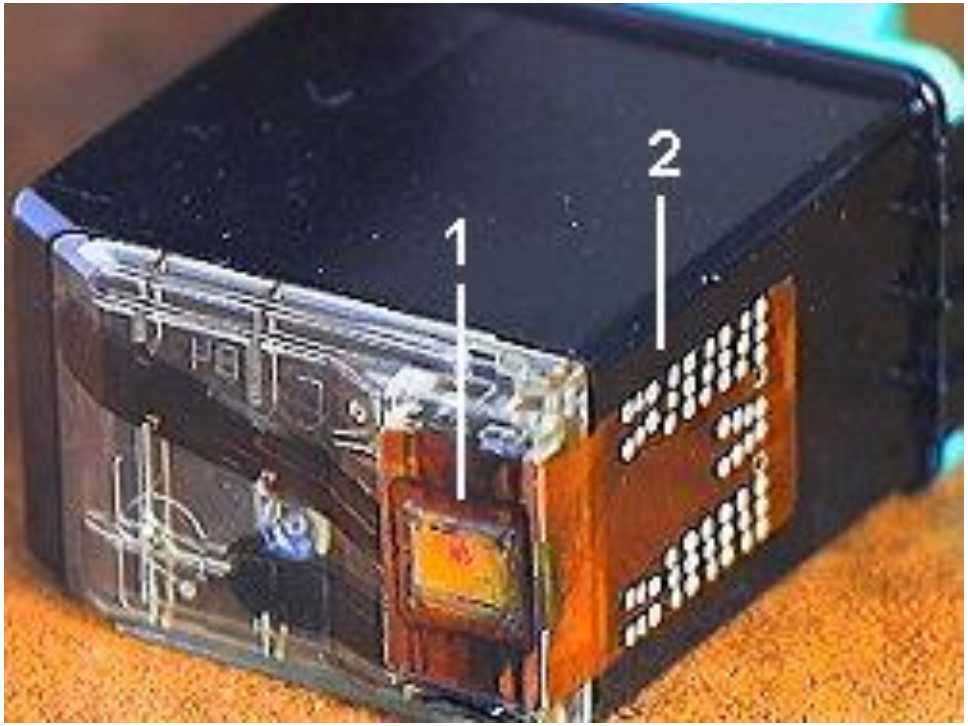
Electronic switches are also integrated to control ejection of the inkjet array

Inkjet droplet formation

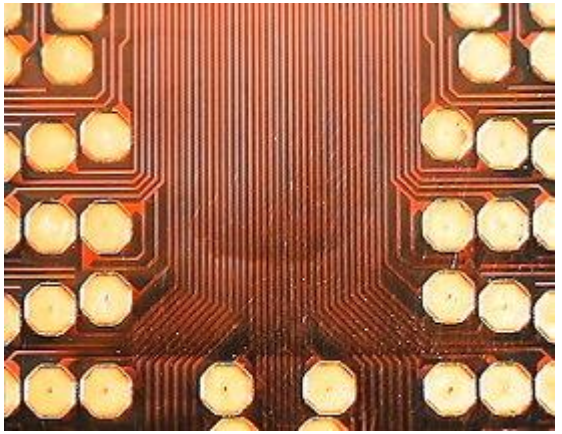
- resistive heating (1,000,000 ºC/sec)
- bubble used as a pump to push liquid out
- hydrodynamic instability: inertia & surface tension
- refilling by capillary effect



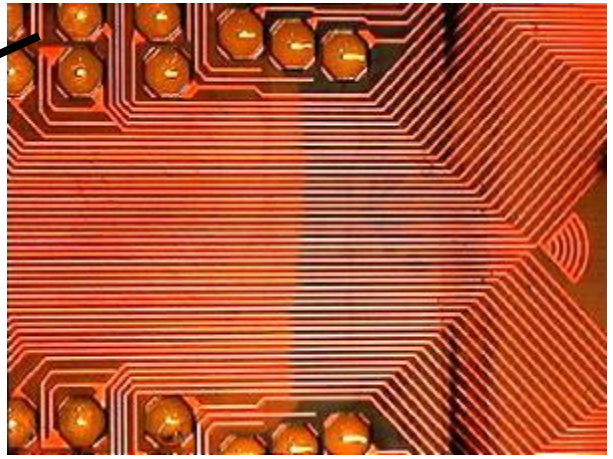
HP 550 inkjet cartridge and print head

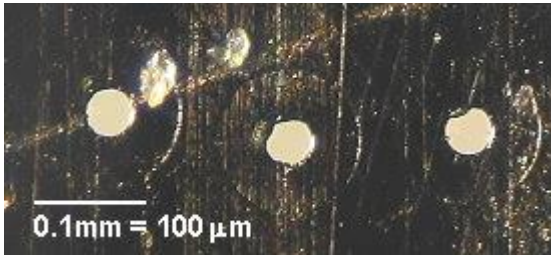


2 electric connector



1 inkjet printhead



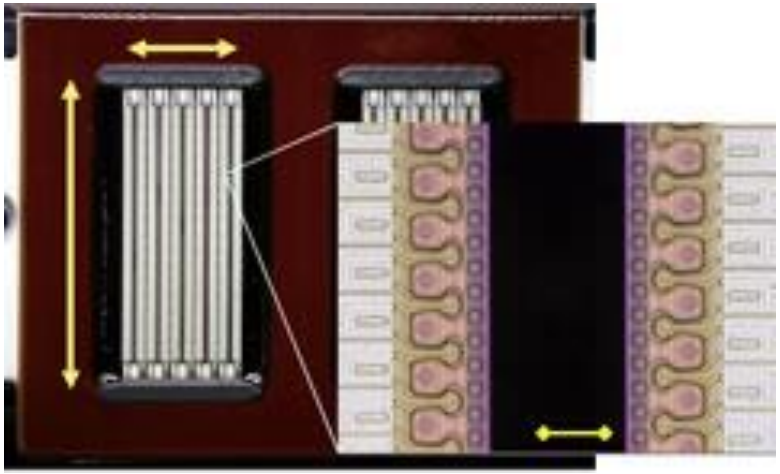


HP inkjet 51626A: 50 nozzles

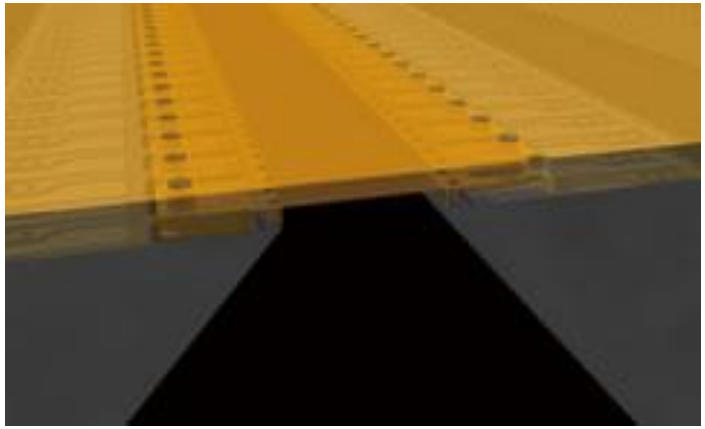
6144 Micro nozzles in canon iP8600 inkjet printhead to achieve high-speed & high-quality printing (15 A4/min)

Reach 4800 x 2400 dpi resolution

Most advanced microfluidic system in consumer electronics!

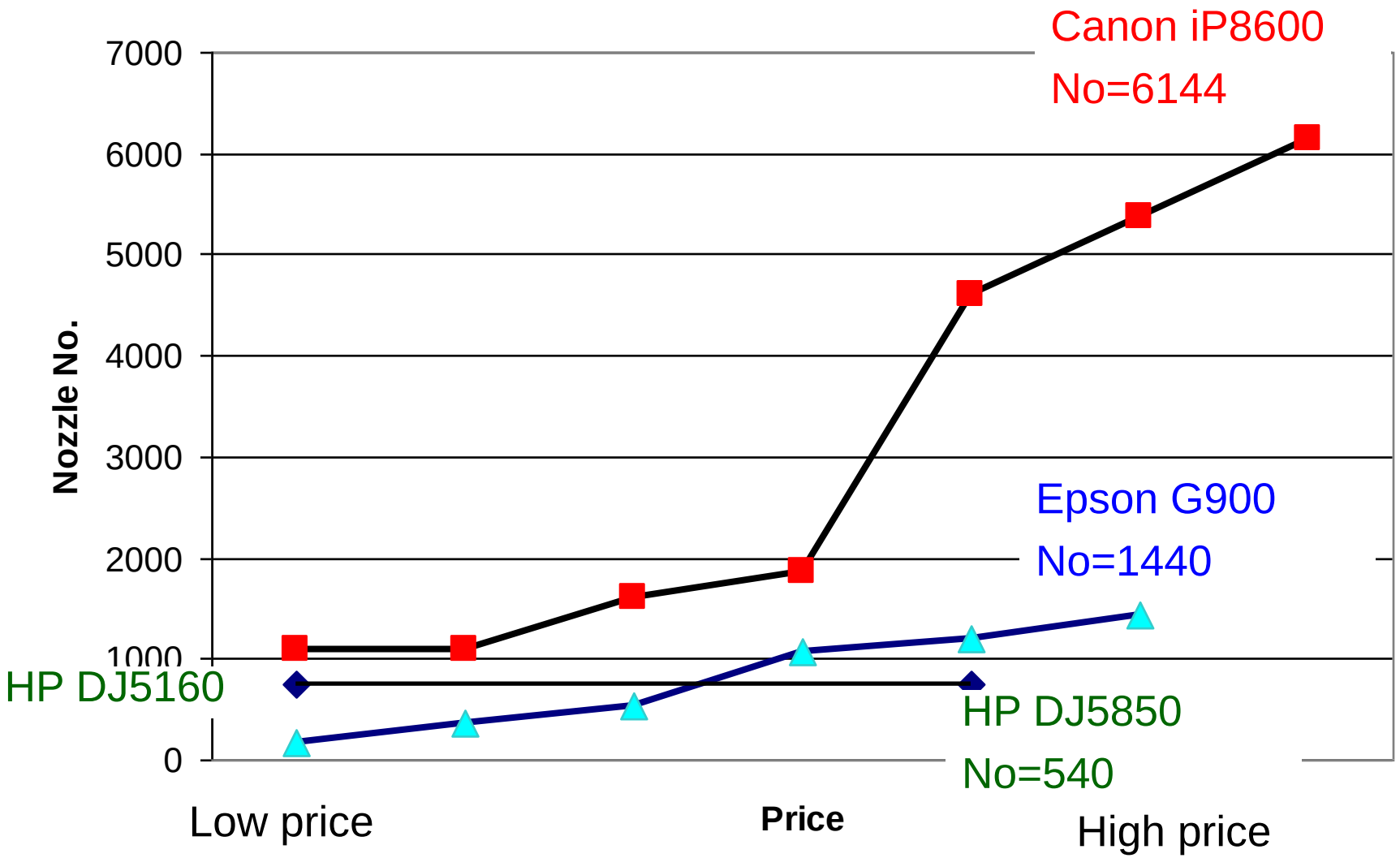


Micrographs of iP8600 inkjet



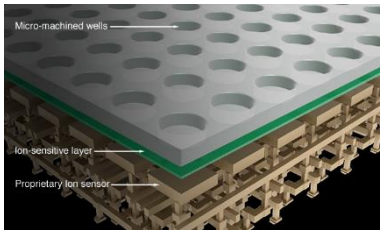
FINE（Full-photolithography Inkjet Nozzle Engineering

Large Integration of Micronozzles in Inkjet Printhead in 2004



Moore Law for DNA Sequencing

2001: *Human Genome Project*
2.7G$, 11 years



Ion Torrent: ISFET array

Oxford Nanopore MinION

2007: *454*
1M$, 3 months

2001: *Celera*
Craig Venter
100M$, 3 years

ABI 3700

2008: *ABI SOLiD*
60K$, 2 weeks

2009: *Illumina, Helicos*
40-50K$

2010: *5K$, a few days?*

2012: *100$, <24 hrs?*

$\mathbf{Log_{10}(price)}$

10
8
6
4
2

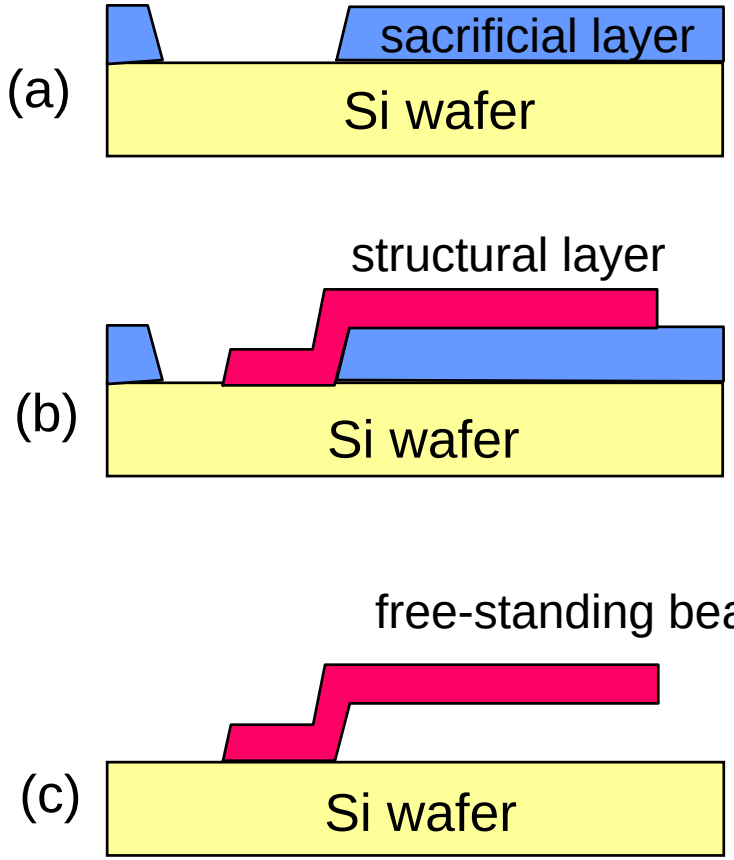
2000
2005
2010

Year

MEMS Fabrication

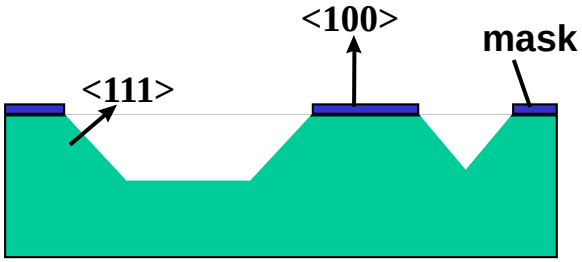
Surface micromachining

deposit and pattern thin film

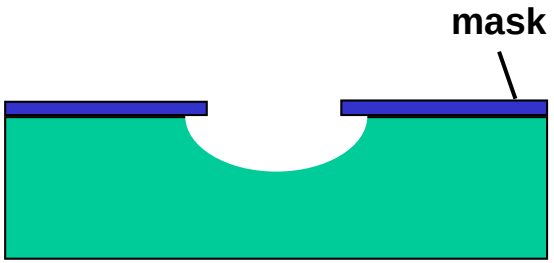


Bulk micromachining

wet etching, (KOH, EDP)



Anisotropic Etching



Isotropic Etching

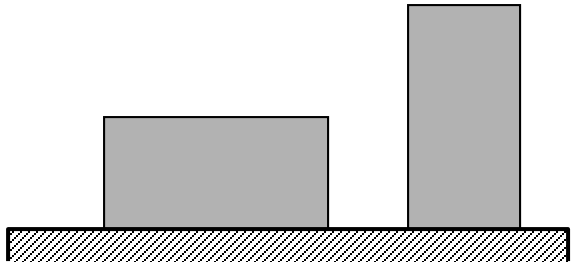
Physics of Scaling

- Forces in the micro-world
- Length scales
- Scaling Laws
- Scaling in
  - **Solid Mechanics**
  - **Fluid Mechanics**
  - **Heat Transfer**
- Micro Fluid Mechanics
  - **Gas flow in micro domain**
  - **Liquid flow in micro domain**
  - **Surface tension**
- Micro Thermal Physics
- Electrostatics

Friction and Sticiton in the microscale

- **Friction:** $f = \mu N \neq f(A)$

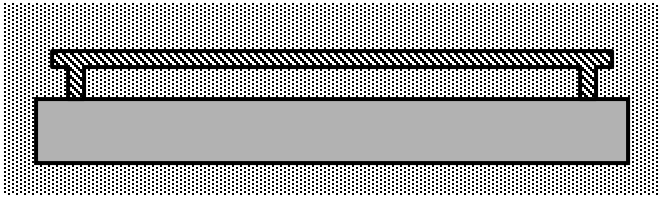
μ - friction coefficient
N - normal force
A - contact area

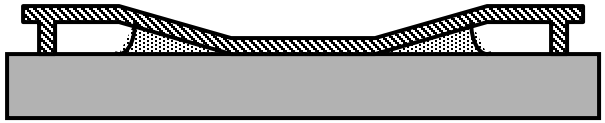


$N=mg$

In microsystems, friction force is a function of contact area.

- **Stiction:**

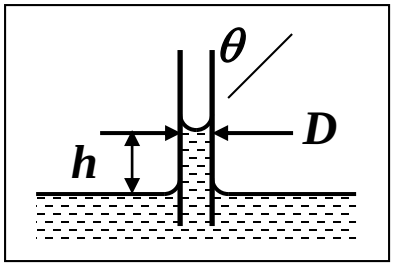




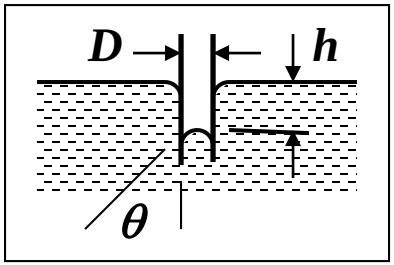
Surface Tension

- At the interface of a liquid and a gas the molecular attraction between like molecules, cohesion, exceeds the molecular attraction between unlike molecules, adhesion.
- This results in a tensile force distributed along the surface, which is the surface tension.

- **Capillary effects:**



adhesion of liquid to solid
> cohesion in liquid

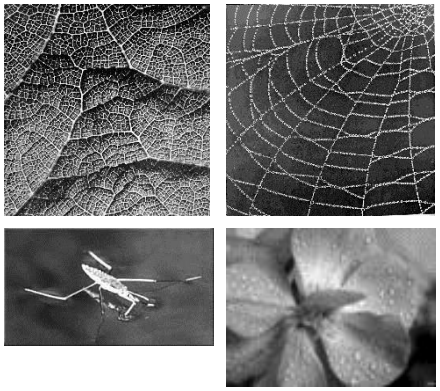


cohesion in liquid **>**
adhesion of liquid to solid

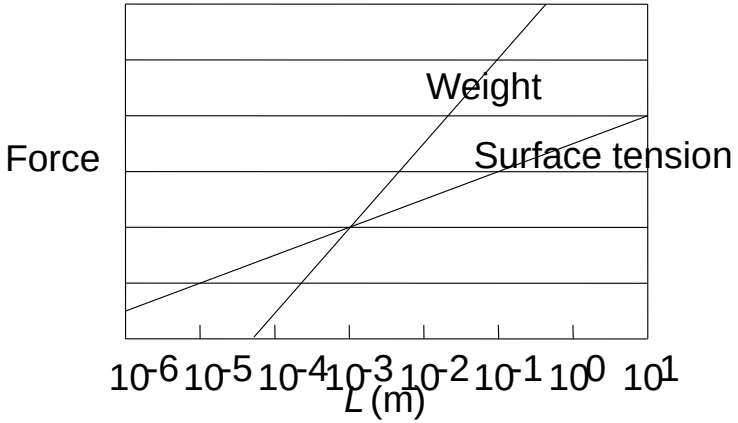
HKUST

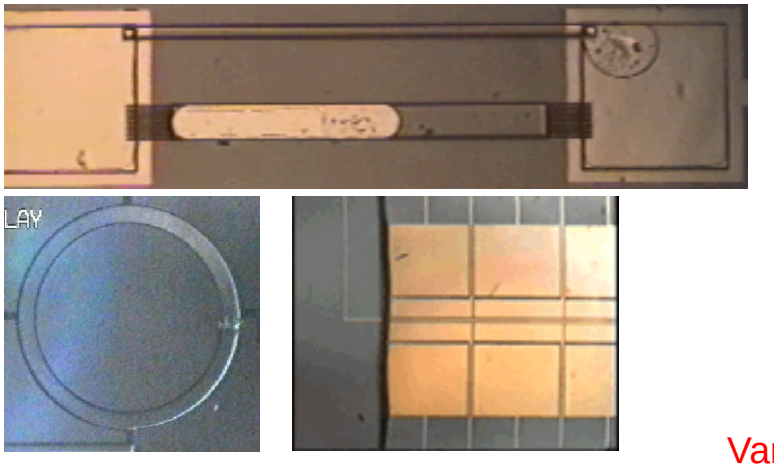
Surface Tension Driven Microfluidics

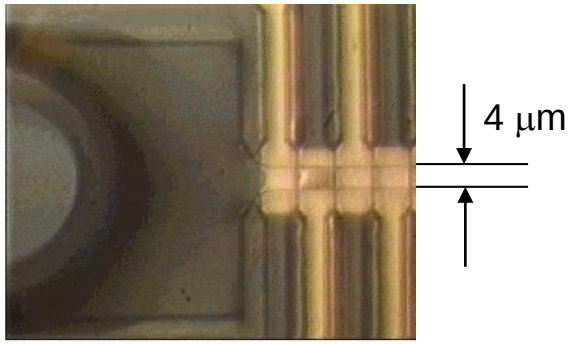
Surface tension: Dominant force in microscale



From Movie ANTZ







From Prof Junghoon Lee in Seoul National Univ, Korea

Varioptics, France: zoom lens for mobile phone camera

Critical success factors for integrated MEMS products

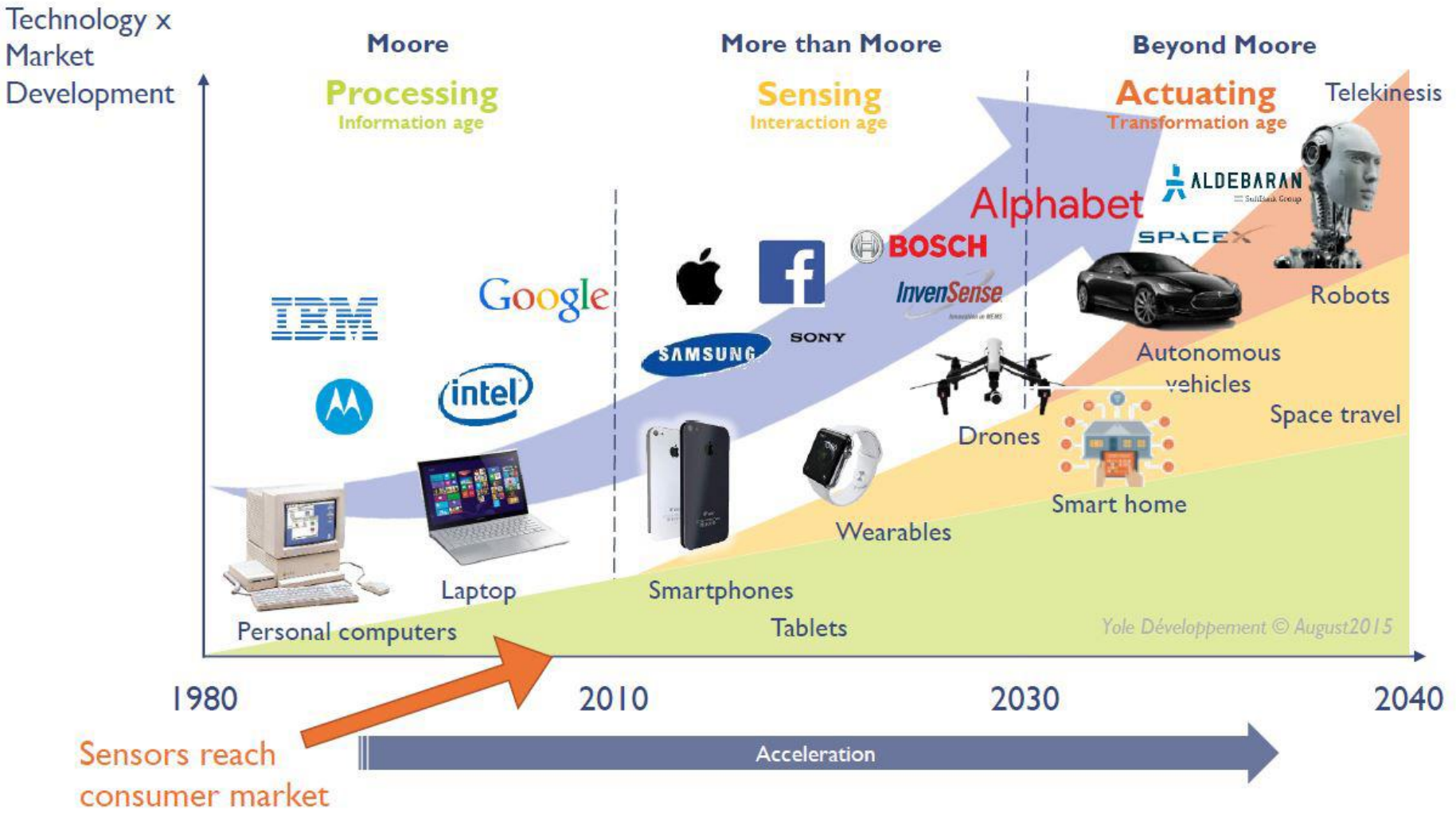
- **Market drive exists**
  - **Large existing market (Volume x Average selling price)**
    - **This is needed to justify the development cost of integration**
  - **Opportunity to replace existing bulky devices**
    - **Reduces component count**
    - **Offers smaller package**
    - **Reduces weight**
  - **Provide improvements in**
    - **Cost**
    - **Performance**
    - **Quality and Reliability**
    - **Functionality**

- **Overcome technology compatibility issues**
  - **Impact of MEMS processing on electronics**
    - **Transistor performance compromised (limited process choices)**
    - **wet etching**
    - **Sacrificial layer etching**
    - **Wafer-to-wafer bonding**
  - **Impact of electronics processing on MEMS**
    - **Sensor mechanical properties compromised**
    - **Residues, particles left on sensor**
  - **Impact of integration on the overall yield**
  - **Packaging and media compatibility**

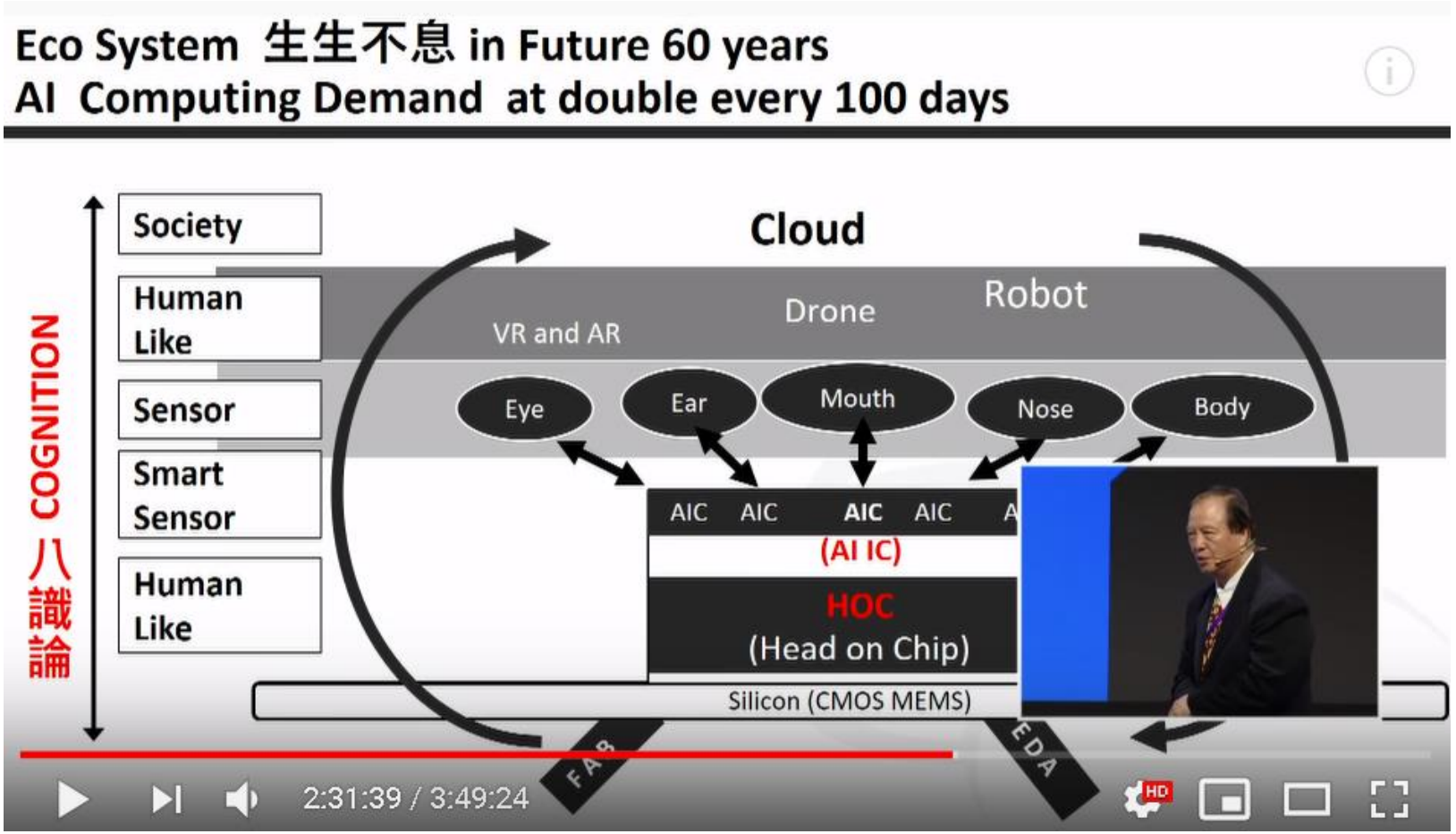
- **Manufacturing infrastructure in place**
  - **A large and mature IC fab**
    - **To provide expertise on integration**
  - **A dedicated MEMS fab**
    - **To perform the non-standard wafer processing steps**
  - **Low cost MEMS assembly and test facilities**
    - **Half of the production cost is backend**
  - **Yield improvements, quality and reliability supports**

Only major semiconductor and automotive companies have resources for all of the above

Tech App Trend of MEMS Sensors & Actuators

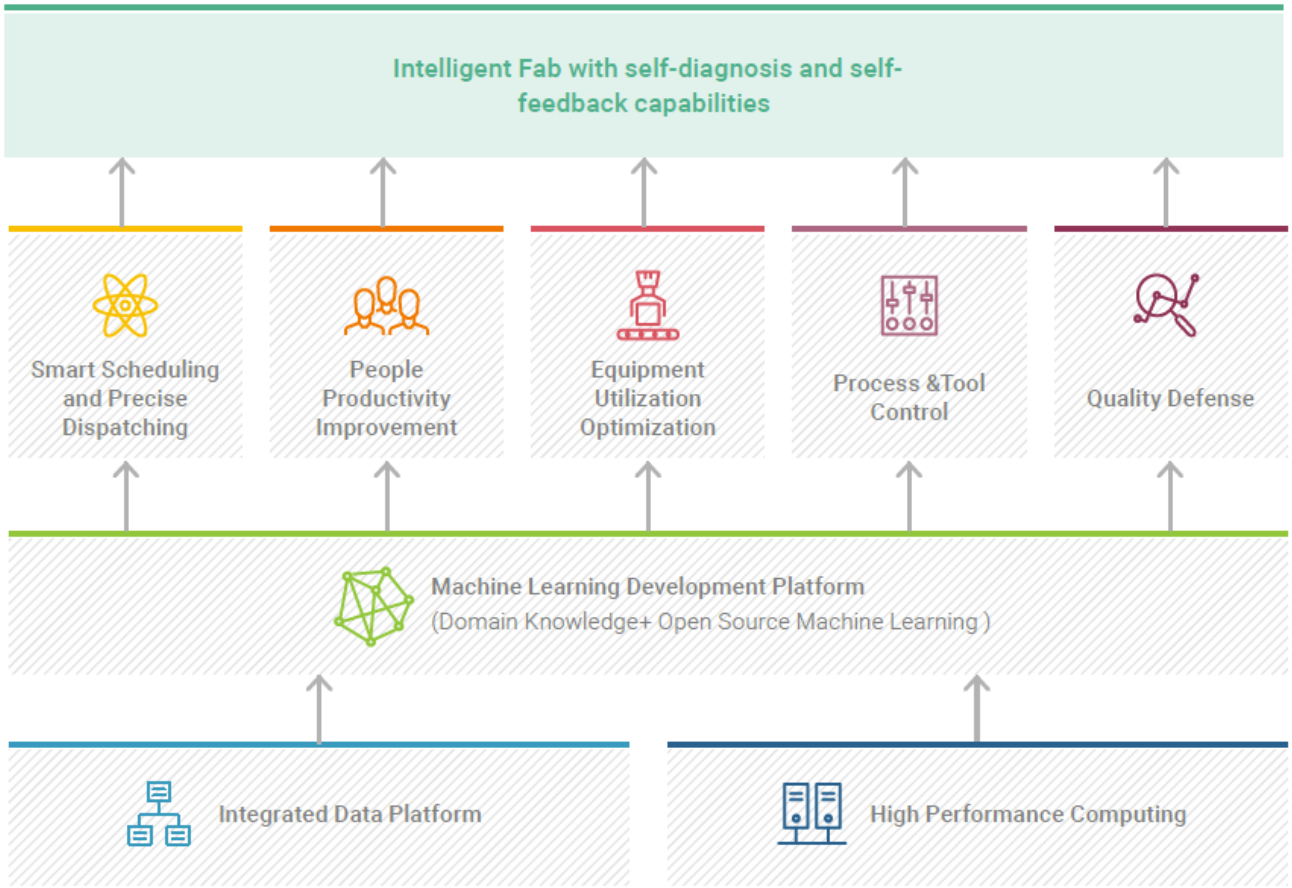


Integration of CMOS MEMS with AI: SOC → HOC



Lecture by Dr Paul Huang, founder of Cadence Design System & ForteMedia (MEMS microphone + AI) in IC60 Forum in Taiwan (World's No.2 in semicond) in 2018 https://youtu.be/lHoWXuYPKak

TSMC Smart Autonomous Semiconductor Manufacturing: World's Leading Industry 4.0 System



- Fab equipment automation
  Transportation automation
  Dispatch automation
  Machine learning and deep learning are applied to achieve manufacturing with self-diagnosis and self-feedback
- Each equipment (per 12-inch fab chief tech director, Dr Yu-Fong Huang)
  before '14: 200~500 sensors
  2014: 500~1,000 sensors

  The most advanced lithography system: 7,000 sensors

- 12-inch fab: **generate 1 million data per second**

TSMC 2018 annual report; ITHome Article , 20 Nov 2014
https://www.cw.com.tw/article/article.action?id=5093674

Summary

- What's MEMS (Microsystem)
- MEMS history and market
- What are the applications of MEMS
- How MEMS devices works
- How MEMS are made
- MEMS : Small machines, big opportunity
- Try free app: iSeismometer on iOS/Android phones

References

- Nobel laureate Richard Feynman's talk

  http://www.zyvex.com/nanotech/feynman.html
- Forbes magazine special issues on micromachine, Apri 2 2001

  http://www.forbes.com/asap/2001/0402/
- US Sandia National Laboratories: MEMS research

  http://mems.sandia.gov/scripts/index.asp
- NEXUS's MEMS market analysis

  http://www.sgt-sensor.de/NEXUS.html
- Special Issues in MEMS: Proceedings of the IEEE, Vol.86, No.8, 1998

  HKUST online library: IEEE Xplore

MEMSIC CUP

美新杯
国际物联网创新创业大赛
International Contest of Applications in Nano-Micro Technology

www.iCAN-contest.org

ORGANIZERS

Peking University

Chinese International NEMS Society (CINS)

Chinese Science & technology Museum

MEMS Park Consortium Japan

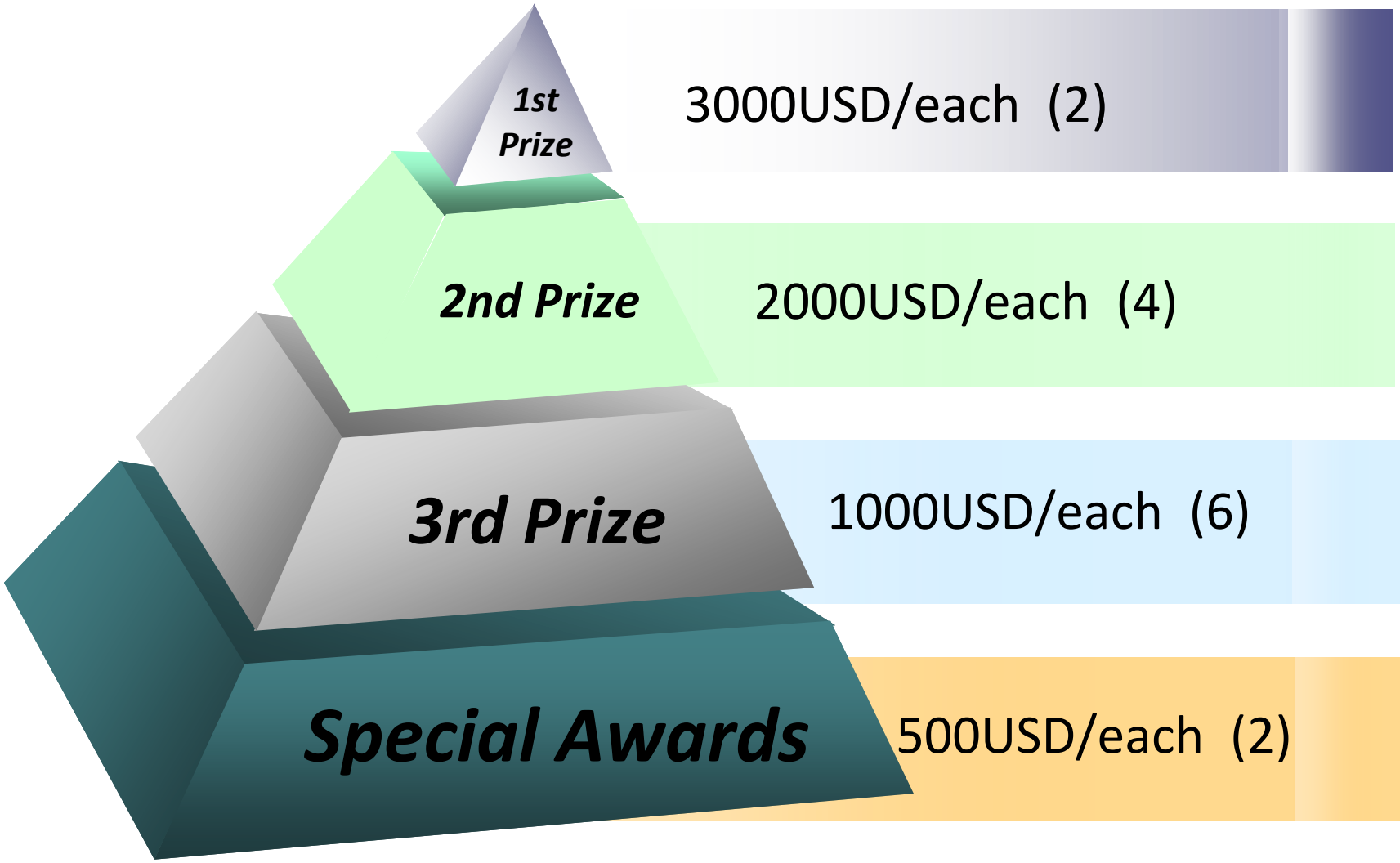
IEEE Nanotechnology Council

ANF (Asian Nano Forum)

Nano-Tera, Switzerland

VDE (Association for Electrical, Electronic & Information Technologies), Germany

AWARDS


1st Prize
3000USD/each (2)
2nd Prize
2000USD/each (4)
3rd Prize
1000USD/each (6)
Special Awards
500USD/each (2)

Title Sponsor: MEMSIC (China)

- ChinaStar (China)
- Guangwei IC（ China ）
- The CAEP S&T PARK （ China ）
- Intellisense China （ China ）
- Suzhou MEMSensing （ China ）
- The CMP PARK （ China ）
- Vimicro （ China ）
- Winsen （ China ）
- Senodia （ China ）
- Smartec B.V. （ Holland ）
- Wave80 （ USA）
- Nippon Signal （ Japan）
- Xerox （ USA）

Sponsored Device（Standard）

美新 MEMSIC

Accelerometer —**MXC6225XU**
Magnetic Field Sensor——
MMC314xMS

敏芯 苏州敏芯微电子技术有限公司 MEMSensing Microsystems Co., Ltd

Pressure Sensor——**MSPA15A**
Silicon Microphone——
MSMAS42Z

SMARTEC

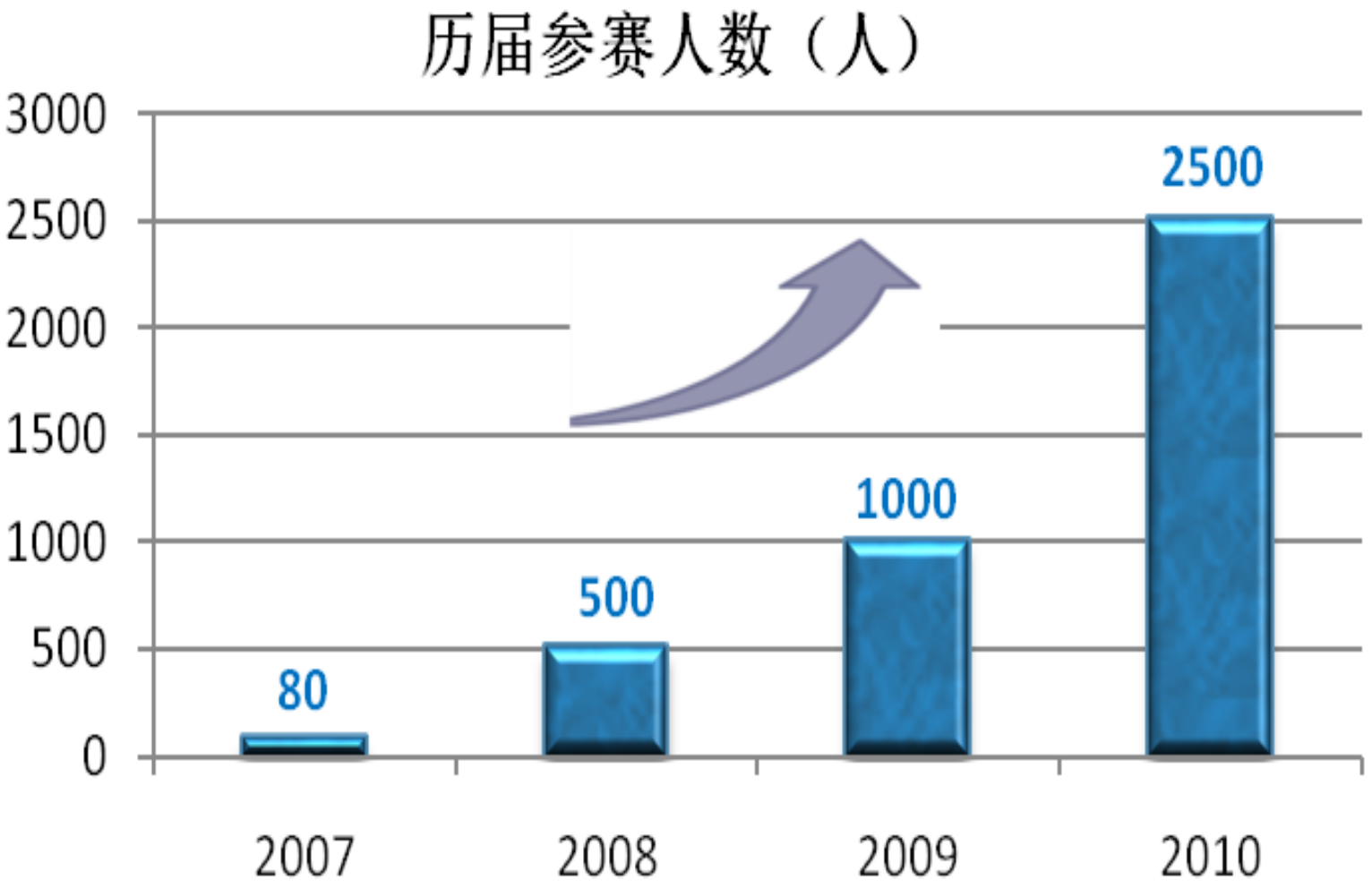
Universal Transducer Interface ——**UT103-A07A**
Temperature Sensor——
SMT16030

炜盛 Winsen

Pyroelectric Infrared Sensor —— **RD-622**
Air Quality Control Sensor——
MP-135

More information: www.iCAN-Contest.org

iCAN'07-'10 Participants Keep Increasing



HKUST

List of iCAN-China'08 Winners

The First Prize		
ZENG Xiangyu, Wang En, LI Jianzhe and Zhang Jinjing	Fudan University	3-D Virtual Display Device
The Second Prize		
Li Boyao, YIN Liang and Wang Di	Heilongjiang University	Visible Electronic Float
Zhang Feng, Qin Wei, Li Bin, Ren Jun and Zhang Ge	NWPU (China)	Control system of Micro-helicoptor
The Third Prize		
Song Wei and Cao Jiamu	Harbin Institute of Technology	Curve Safety Alarm System for Trains
Min Kunlong, Wu Gang, Liu Tiantian, Zhu He and Zhou Peng	Northeast Forestry University	Sign Language Recognition System
Yang Qi, Chen Yao, Zhou Yuhan, Miao Dongliang and Yang Yehua	Nankai University	Wireless Parking Management System
Ren Sen, Chang Jie, Zhang Xingyu and Luo Jian	NWPU	Multifunctional Electronic Float
Wang Zihan, Hou Poyuan and Yao Xiaoyu	Heilongjiang University	Traffic Police Gesture Recognition System

HKUST

More & More Countries/region joined iCAN

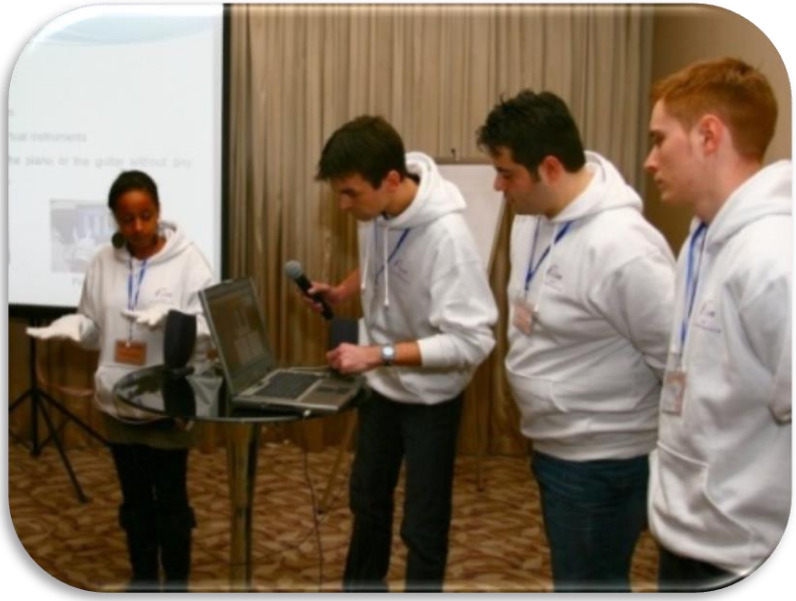
HKUST

iCAN'10, Xiamen

Jan 20th-23rd, 2010，More than 1500 students from 60 universities of the United States, Japan, Germany, Hong Kong, Taiwan and mainland China have attended iCAN'10

Music Gloves

Universität des Saarlandes,Germany
Manuel Barra Christian Bur
Eliseo Pignanelli Esther Tesfagiorges



Intelligent Crib

North University of China
WANG Erwei, MO Runquan, LIN Hanbin and
ZHANG Wenhong

The First Prize		
LIN Hanbin, WANG Erwei, MO Runquan, ZHANG Wenhong	North University of China (Mainland, China)	Intelligence Baby's Crib
Manuel Barra, Christian Bur, Eliseo Pignanelli, Esther Tesfagiorges	Saarland University (Germany)	Music Glove
The Second Prize		
LIU Miao, WU Jun, XU Xiaoxiang, YAO Shujun	Tianjin University (Mainland, China)）	Automatic Ray-Following System Based on Magnetic Sensors
SHEN Qiang, ZHOU Jie，WANG Huanxin	Northwestern Polytechnical University (Mainland, China)	Table Q
Tetsu Miyatake, Kazuya Fujimoto, Akira Takahashi	Kyoto Univesity（Japan）	Sky Fish
HOI Man Yiu, CHOW Ka Hei, LEI Kwong Pui, MAK Tsz Wai	HKUST（Hong Kong）	Wireless Landslide Alert
The Third Prize		
Wei-Chih HSU, Yi-Chung LAN, Wen-Wei CHANG	National Taiwan University(Taiwan)	Sensor Mechanism on WSN Smart Pillbox
YANG Lei, GE Junjie, WEI Zheng	HUST (Mainland China)）	Automatic Submarine
Yoshihide Makino, Tatsuya Kataoka, Akira Taniyama, Yusuke Nakai, So Nishino	Kyoto Univesity（Japan）	Micro Electro Mechanical Guitar
Michael Junkin, Yi Lu, Priyanca Sarkar	University of Arizona (USA)	Noninvasive Blood and Fluid Flow Measurement
Sascha Gress, Daniel Schafer, Christian Wern	Saarland University (Germany)	Automatic Barbecue
WANG Zhenghan, HOU Puyuan, CAO Bo	Heilongjiang University (Mainland, China)	Multi-Dimensional Controlling Device

HKUST

iCAN'11, Beijing

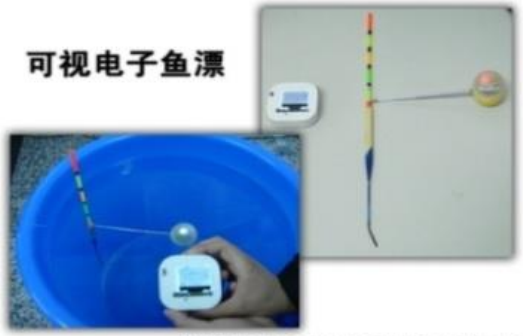
June 5th-7th，27 teams from universities of the United States, Japan, Germany, Hong Kong, Taiwan and mainland China have attended iCAM'11 together with the TRANSDUCERS'11.

Anti-Collision Flight Assistance System

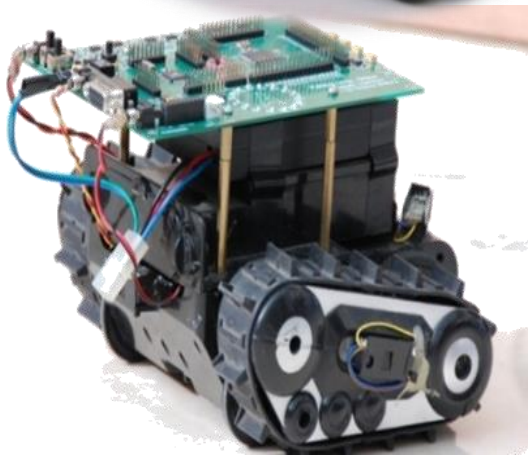
Universität des Saarlandes,Germany
Helwig Nikolai , Peter Jens, Wick Michael

TEMS

Kyoto University of Japan
T. Akishiba, A. Uesugi,
Y. Okazaki, H. Katayama,A. Kitamura

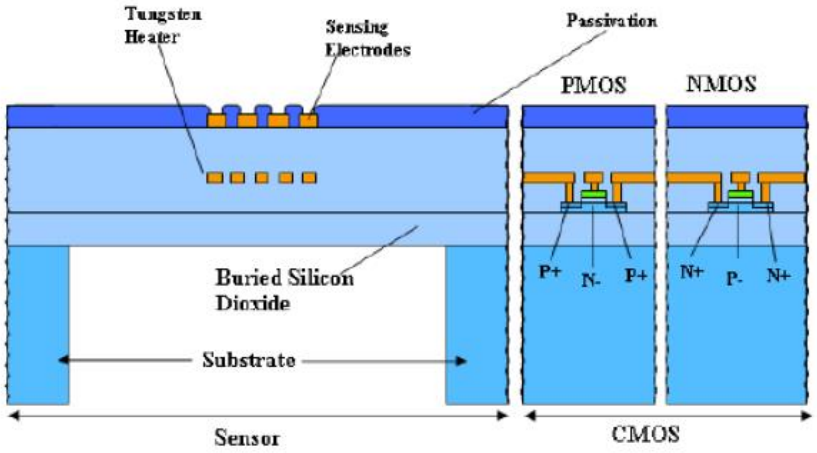


Visible Electronic Fishing Floater

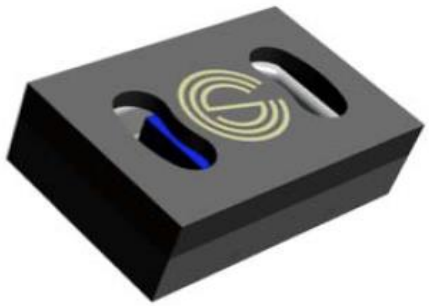


Samsung SGH-i677: First cell-phone with a tunable antenna impedance matching network: RF MEMS

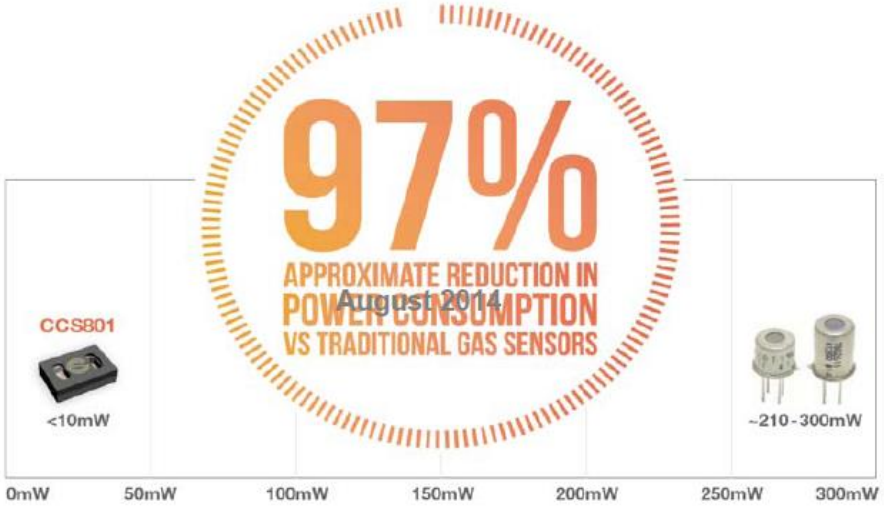
Small Low-Power Smart CMOS Gas Sensor (CCS800)



Sensor 1 mm by 1mm



Package 2 mm by 3mm



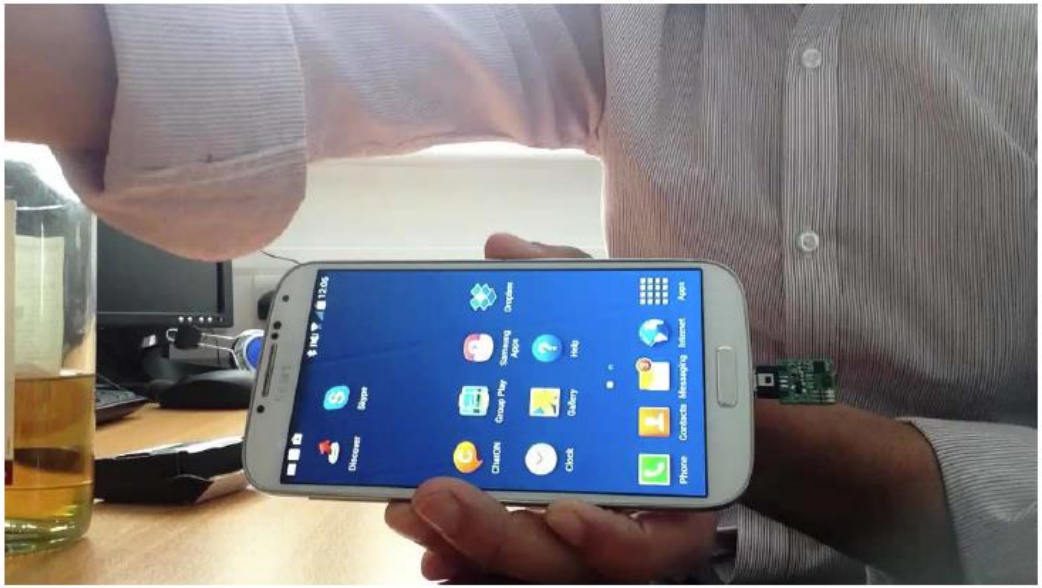
From Cambridge CMOS Sensors Ltd

HKUST

Alcohol Breathalyser (CCS801)

- CCS801 responds to Ethanol (ppm in Breath) is down to 10ppm within ±25% accuracy over temperature and humidity range ~4 s required for breath analysis
- Phone apps could be user activated or enabled while on call
- Smartphone apps monitors ppm level in breath. Rather than giving the user a PPM / BAC reading the app provides Low / Medium / High warning indication
- It is an alcohol indicator and not a certified sensor

ppm in Breath	BAC	Note
52	0.02%	China legal driving limit
104	0.04%	Concentration impairment
208	0.08%	UK legal driving limit
520	0.20%	Severe motor impairment Loss of consciousness



From Cambridge CMOS Sensors Ltd