【MEMS Engineer Forum 2014】

Global MEMS Fusion

Susumu Kaminaga

Executive Senior Adviser

Chairman, Steering Committee

SPP Technologies Co., Ltd.

(Former President, **Sumitomo Precision Products Co., Ltd.**)

Representative Director & Chief Executive

SK Global Advisers Co., Ltd.

25 April, 2014

PR-1165

Agenda

- History of MEMS and Involvement of SPP Group
- Relationship with Worldwide Institutes
- MIG Conference Japan 2014 and MEMS Engineer Forum 2014
- Trillion Sensors Summit
- MEMS Improve Your Life
- Summary

History of MEMS
and
Involvement of SPP Group

Development of MEMS

1960s : Piezoresistive pressure sensor was pioneered by Dr. Igarashi, called “Mr. Sensor” in the sensor society, at Toyota Central Research Laboratory

1970s : MEMS devices development work pioneered by Prof. Esashi of Tohoku University

1982 : “Silicon as a Mechanical Material” authored by Dr. Kurt Petersen

1986 : BSAC was founded

1987 : Term “MEMS” was coined in the U.S.

Transducers ’87 conference held in Tokyo

1992 : Integrated Wafer Process System IX200 developed and commercialized by SPP

1995 : DRIE technology based upon “Bosch Process” developed and commercialized by STS/SPP

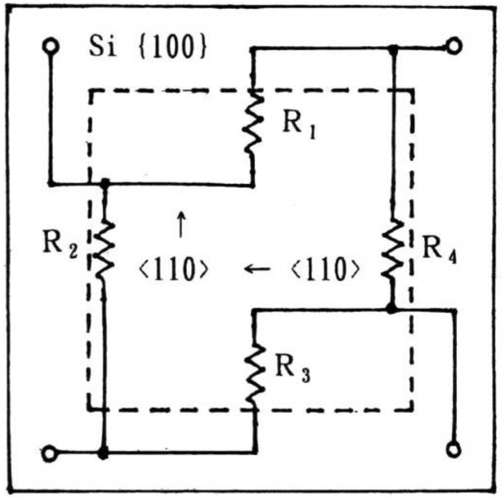
1997 : Microturbine developed by MIT

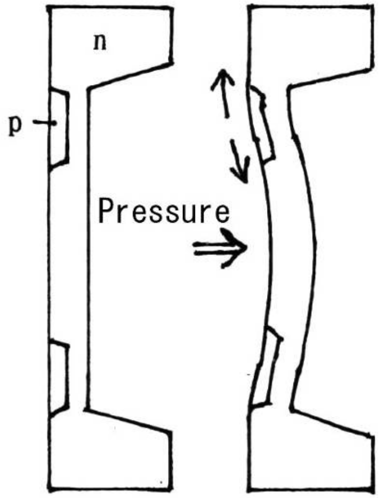
2000 : Commercial viability of Waveguide and Optical MEMS Switch

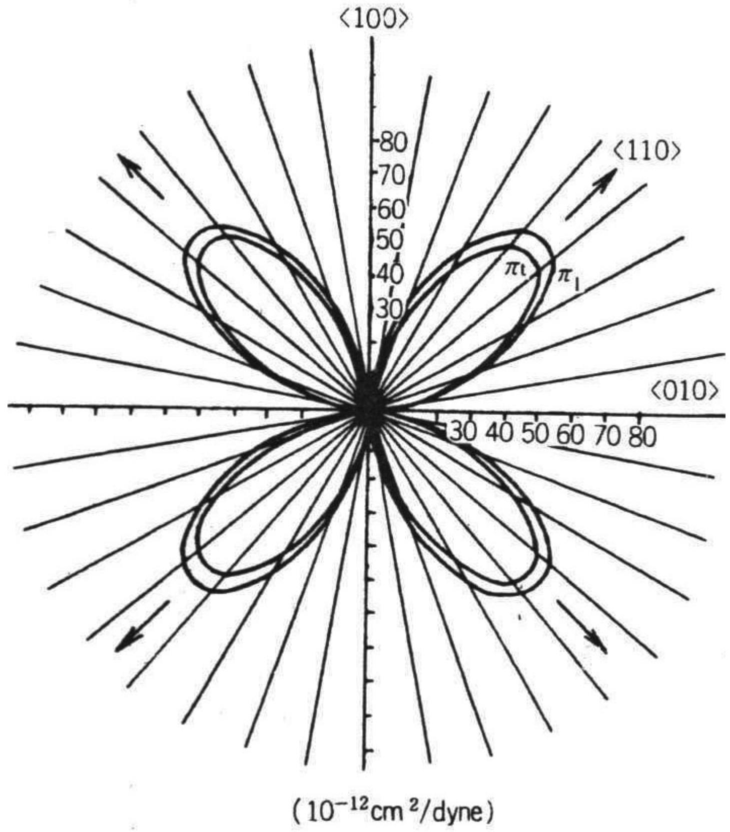
2004 : Keynote Remarks by Prof. N.F. de Rooij of Univ. of Neuchatel

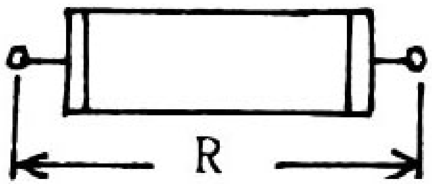
2009 : Outbreak of Smart Phone

Pressure Sensor in 1960s









→ σ_l Lateral stress

↑ σ_t Tangential stress

$$\Delta R / R = \pi_l \sigma_l + \pi_t \sigma_t = K \varepsilon$$

Resistance change — Gage factor — Strain

Lateral piezoresistive coeff. — Tangential piezoresistive coeff.

p – Si

(100)

Piezoresistive coefficient

(Courtesy of Prof. Esashi of Tohoku University)

Dr. Isemi Igarashi

(Toyota Central Research Laboratory)

He is one of pioneers of piezoresistive pressure sensor and called “Mr.Sensor” in sensor society

Invention of piezoresistive effect of Si and Ge
(C.S.Smith (Bell Lab.), Phy.Rev. 94 (1954) 42))

Piezoresistive Ge strain gauge
(I.Igarashi, Kogakuin Daigaku Research Report, 3 (1956) 1 (in Japanese))

Piezoresistive pressure sensor
(O.N.Tufte (Honeywell), J.of Applied Physics, 33 (1962) 3322)

Application of piezoresistive pressure sensor to automobile
(I.Igarashi, Jidosha Gijutsu, 18(9) (1964) 706 (in Japanese))

Piezoresistive pressure sensor and accelerometer
(T.Chiku, I.Igarashi, 20th ISA (1965) 17. 11-3-65)

Prevalence of Si piezoresistive pressure sensor for engine control in automobile (1980 ~)

Prevalence of Si capacitive accelerometer for crash sensing in air bag safety systems (1990 ~)

Piezoresistive sensors to measure strain, pressure and acceleration

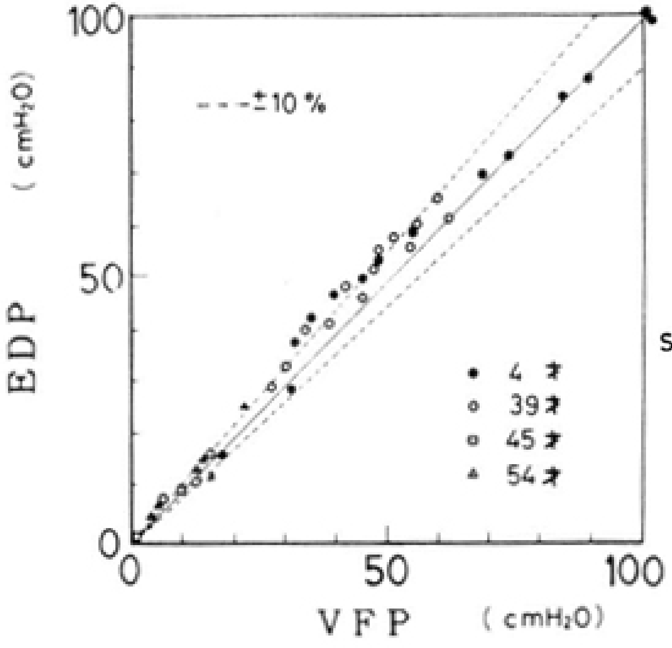
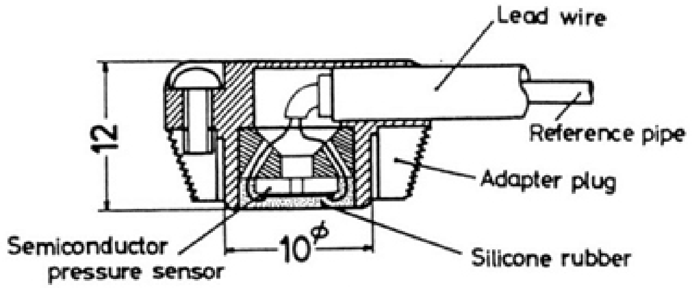
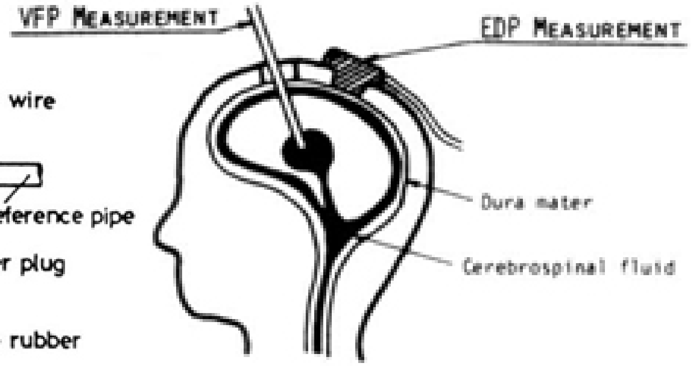


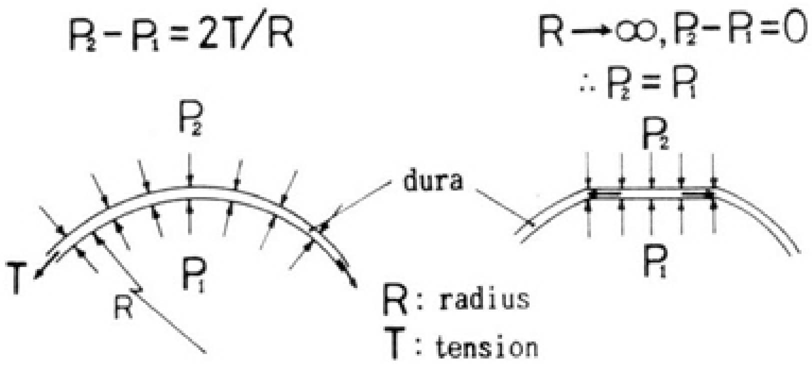
Fig.3 Relation between VFP and EDP

EDP : Epidural Pressure

VFP : Ventricular Fluid Pressure







Coplanar method

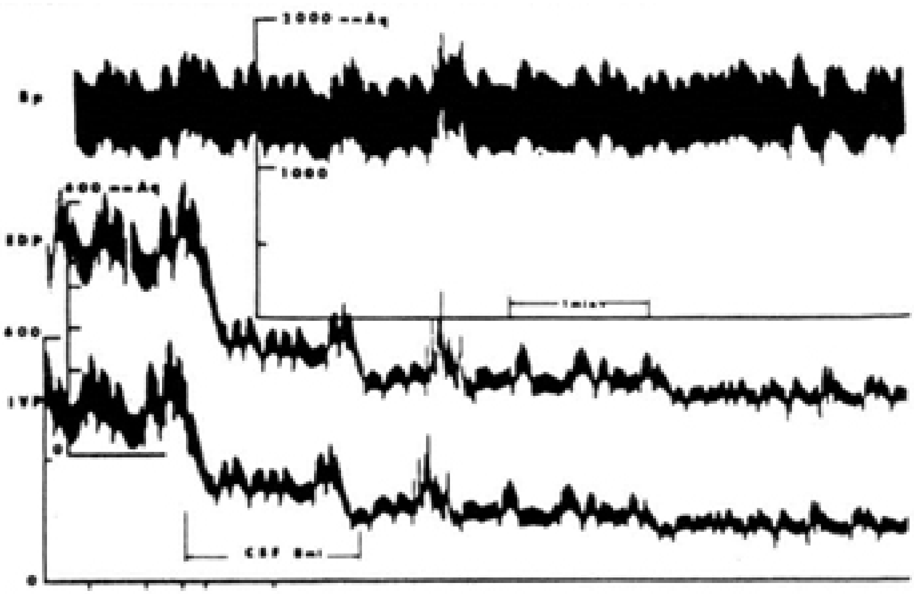
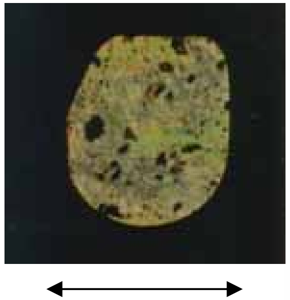


Fig.4 Results of clnical inspection

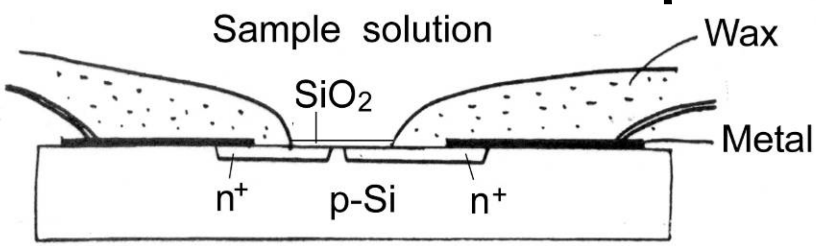
Implantable epidural pressure sensor to monitor ventricular fluid pressure by coplanar method

(A.Ikeyama, S.Maeda, H.Nagai, M.Furuse, I.Igarashi, H.Inagaki T.Kitano, Neurological medico -chirurgica, 17 (1977) 1-7)

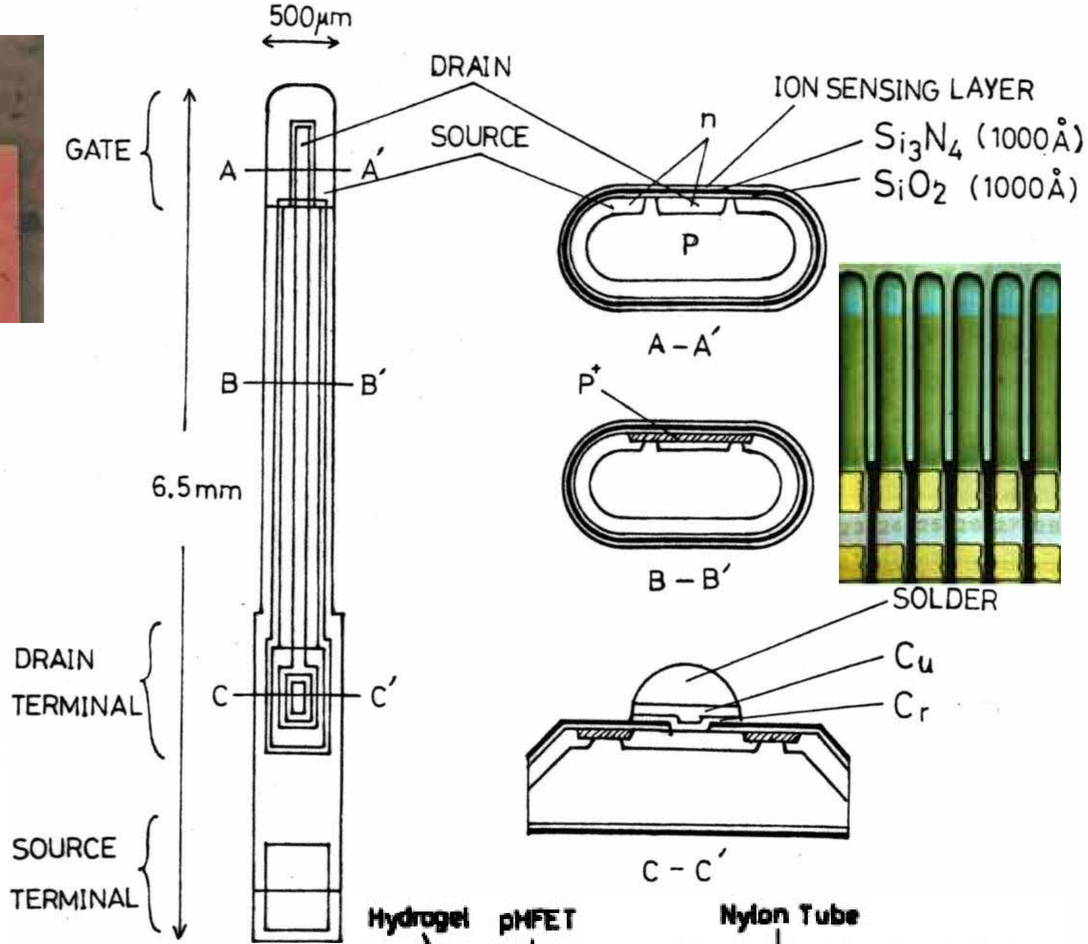
Prof. Masayoshi Esashi
(Tohoku University)

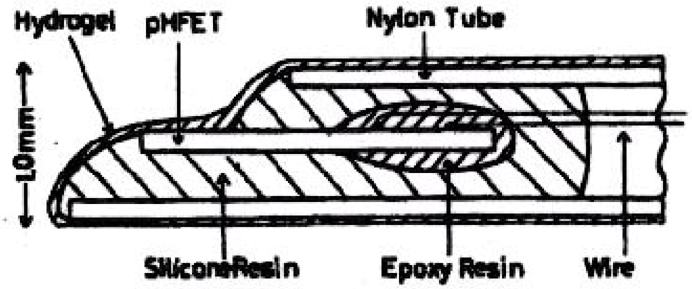


50 μm



(T.Matsuo, M.Esashi, K.Iinuma, Tohoku region meeting of Electrical Eng.(1971))



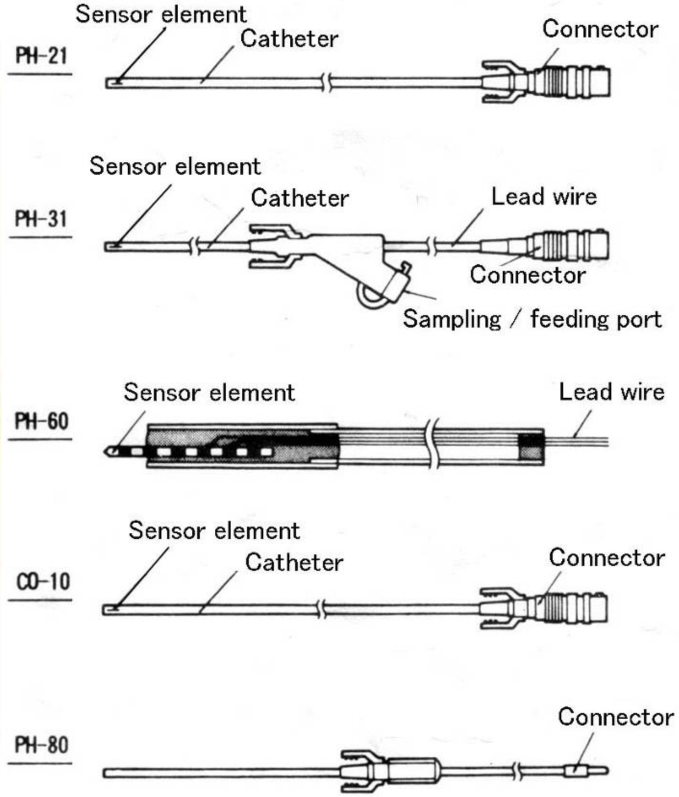


ISFET (Ion Sensitive Field Effect Transistor)

(wafer process for reliable assembly)

(M.Esashi & T.Matsuo, Supplement to the J.J.A.P.,44 (1975) 339)

(K. Shimada (Kurare), M. Esashi and T. Matsuo et.al.: Application of catheter-tip I.S.F.E.T. for continuous in vivo measurement, Med. & Biol. Eng. & Comput., Vol.18, No.11, pp.741-745 (1980))



NIHON KOHDEN

Type	Application	No	Catheter (mm)		Monitor	Note
			Length	Diameter		
PH-21	pH measurement in muscle etc	PH-2135	350	1.1	KR-5000	With reference
PH-31	pH measurement in esophagus and stomach	PH-3110 (Adult)	1000	2.4	KR-5000	With reference and feed port
		PH-3165 (Infant)	650	2.4	KR-5010	
PH-60	pH measurement in mouth	PH-6010	100	1.0	KR-5000	Without reference
PH-80	Reference electrode for PH-60	PH-8005	50	1.1	KR-5000	
CO-10	PCO_2 measurement in muscle etc	CO-1035	350	0.9	KR-5000	With reference

Catheter pH, PCO_2 monitor using ISFET (commercialized in 1980)

Dr. Kurt Petersen; "Silicon as a Mechanical Material" in 1982

420 PROCEEDINGS OF THE IEEE, VOL. 70, NO. 5, MAY 1982

Silicon as a Mechanical Material

KURT E. PETERSEN, MEMBER, IEEE

Abstract-Single-crystal silicon is being increasingly employed in a variety of new commercial products not because of its well-established electronic properties, but rather because of its excellent mechanical properties. In addition, recent trends in the engineering literature indicate a growing interest in the use of silicon as a mechanical material with the ultimate goal of developing a broad range of inexpensive, batch-fabricated, high-performance sensors and transducers which are easily interfaced with the rapidly proliferating microprocessor. This review describes the advantages of employing silicon as a mechanical material, the relevant mechanical characteristics of silicon, and the processing techniques which are specific to micromechanical structures. Finally, the potentials of this new technology are illustrated by numerous detailed examples from the literature. It is clear that silicon will continue to be aggressively exploited in a wide variety of mechanical applications complementary to its traditional role as an electronic material. Furthermore, these multidisciplinary uses of silicon will significantly alter the way we think about all types of miniature mechanical devices and componenta

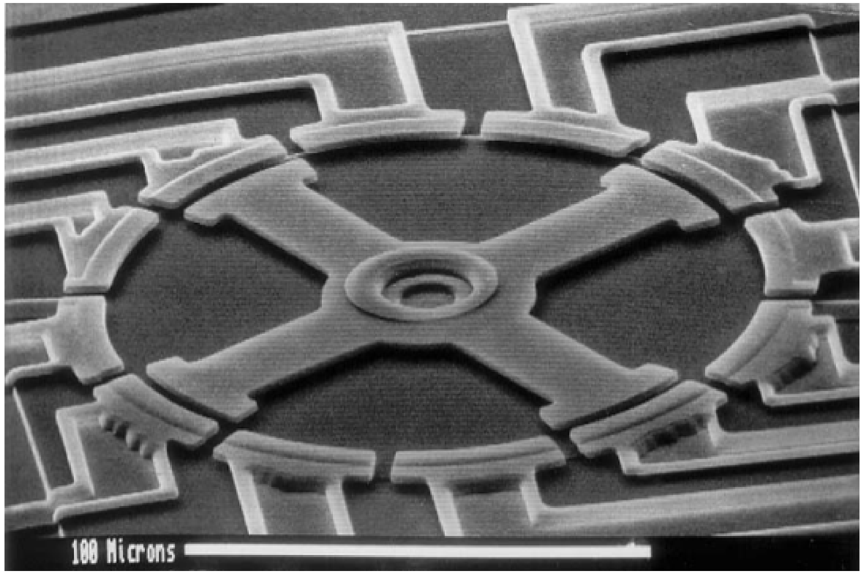
miniaturized mechanical devices and components must be integrated or interfaced with electronics such as the examples given above.

The continuing development of silicon micromechanical applications is only one aspect of the current technical drive toward miniaturization which is being pursued over a wide front in many diverse engineering disciplines. Certainly silicon microelectronics continues to be the most obvious success in the ongoing pursuit of miniaturization. Four factors have played crucial roles in this phenomenal success story: 1) the active material, silicon, is abundant, inexpensive, and can now be produced and processed controllably to unparalleled standards of purity and perfection; 2) silicon processing itself is based on very thin deposited films which are highly amenable to miniaturization; 3) definition and reproduction of the

(Kurt E. Petersen, "Silicon as a Mechanical Material", In Proc. of the IEEE, Vol.70, No.5, May 1982)

Berkeley Sensor & Actuator Center in 1986

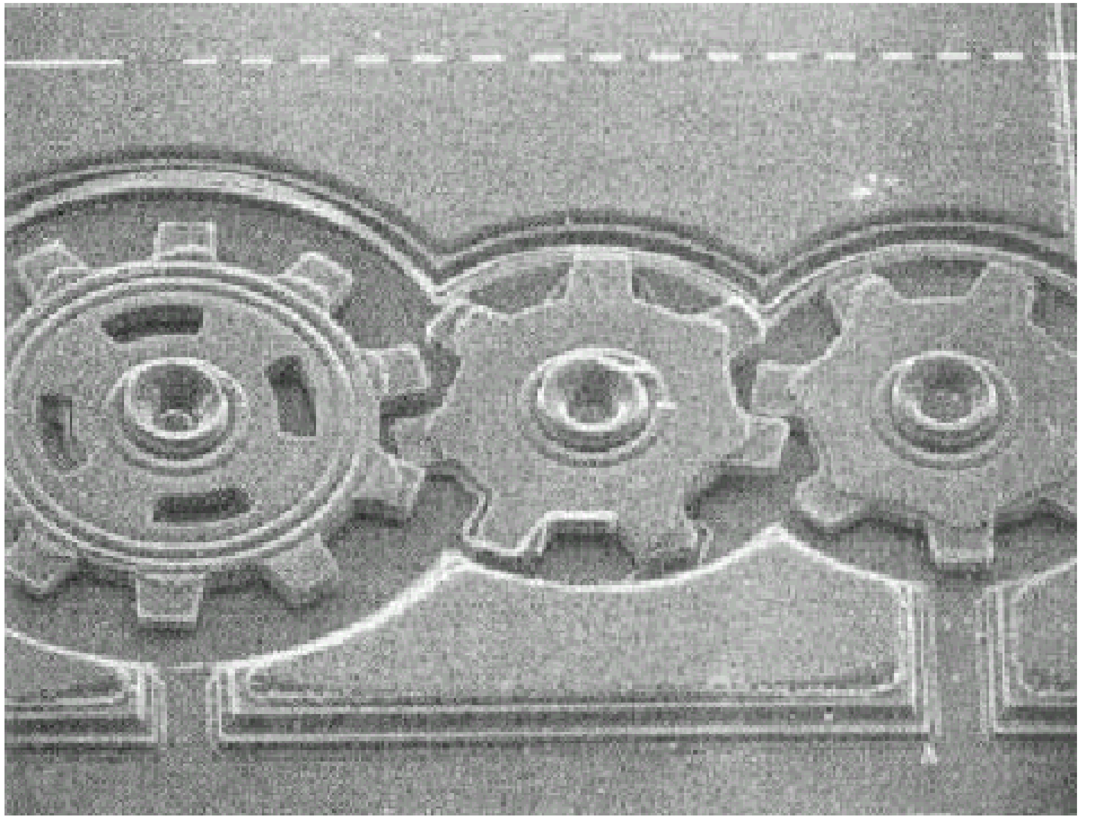
BSAC (Berkeley Sensor & Actuator Center), the NSF (National Science Foundation) Industry / University Cooperative Research Center for MEMS, was founded in 1986 to conduct commercially relevant interdisciplinary engineering research on micro- and nano-scale sensors, moving mechanical elements, microfluidics, materials, and processes that take advantage of progress made in integrated-circuit, bio, and polymer technologies.



Electrostatic Micro-motor

(L. S. Fan, Y. C. Tai and R. S. Muller, "IC-processed Electrostatic Micro-motors", IEEE Int. Electron Devices Meeting (1988), pp.666-669)

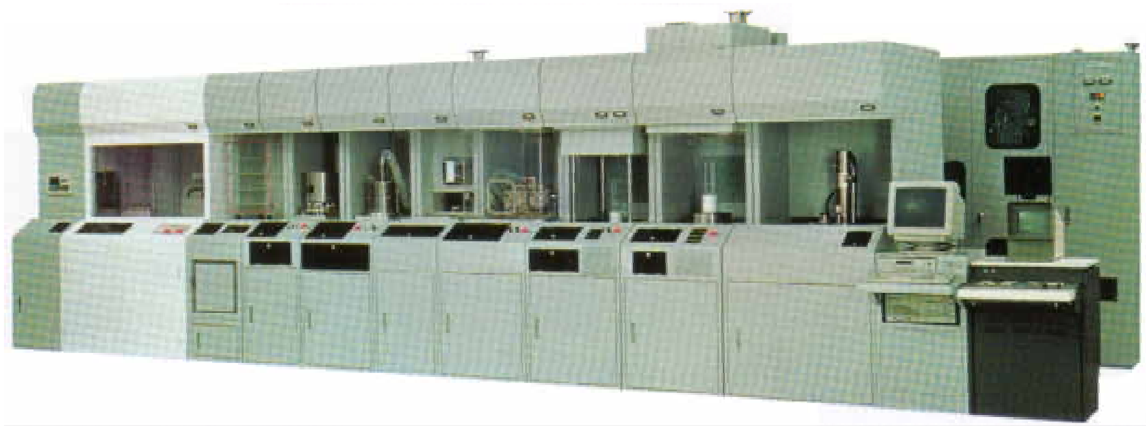
“Gear Train” in Transducers’87, Tokyo

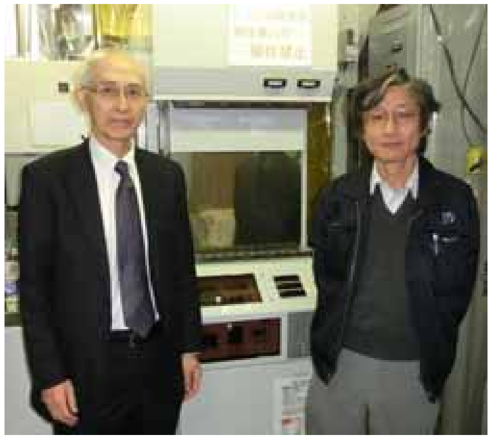


(K. J. Gabriel, W. S. N. Trimmer and M. Mehregany, “Micro gears and turbines etched from silicon”, in Tech. Digest of the 4th Int. Conf. On Sold-State Sensors and Actuators (Transducers ’87, Tokyo, June 1987), pp. 853-856)

IX200 and its “User Laboratory” in 1992

Integrated Wafer Process System IX200 developed and commercialized by SPP, **and LP-CVD of IX200 shipped to NRLM※ (AIST)**





LP-CVD of IX200

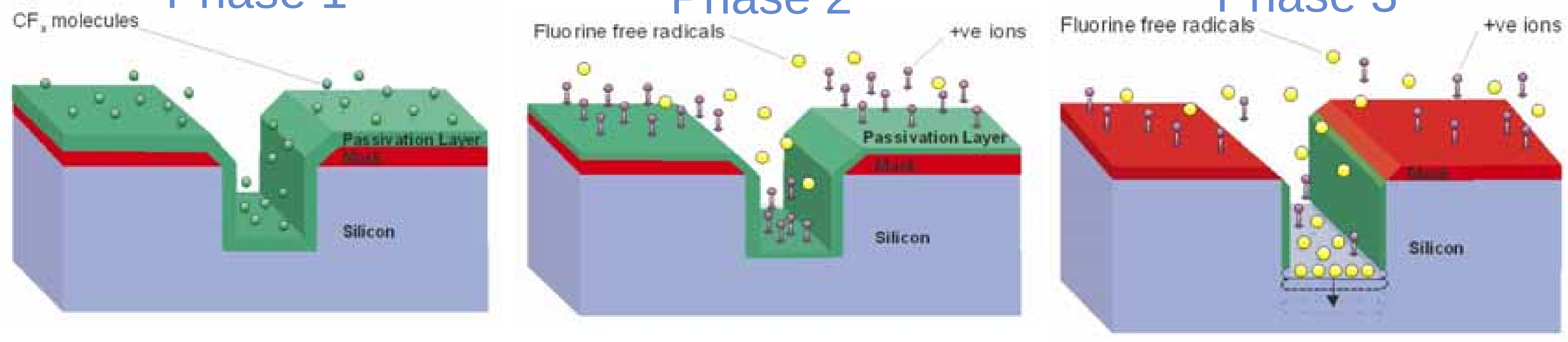
Kaminaga **Prof. Maenaka of Univ. of Hyogo**

(※ National Research Laboratory of Metrology)

Si DRIE Equipment in 1995

- **SPTS /STS is Synonymous with the MEMS industry!**
- **In 1994, STS began working with Robert Bosch to develop a production version of an Etch Process that they had patented.**
- **In 1995, STS shipped the world 1st DRIE Equipment (*ASE*®) with Bosch Process in the market.**
- **This was an enabling technology in MEMS manufacturing.**
- **Today >95% of MEMS manufacturers use this technique.**
- **The development of the technologies and business managed under control of SPP.**

Phase 1 Phase 2 Phase 3

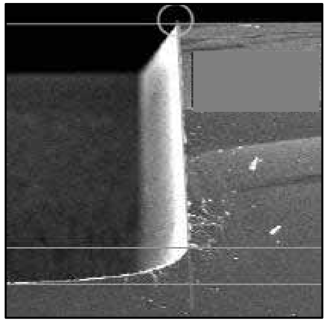


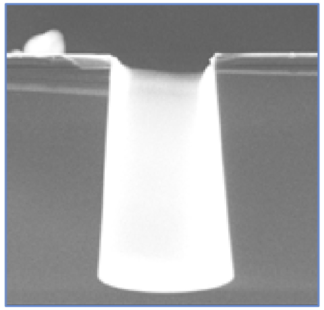
Passivation Passivation Removal Etching

Back to Phase 1

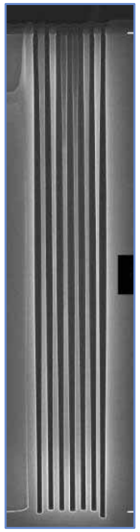
Leading DRIE Etching Capability

High Rate
Cavities, Caps,
ink-jets

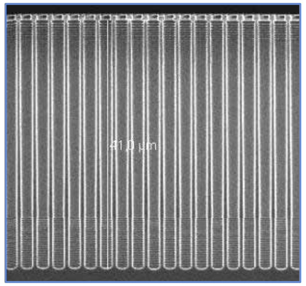




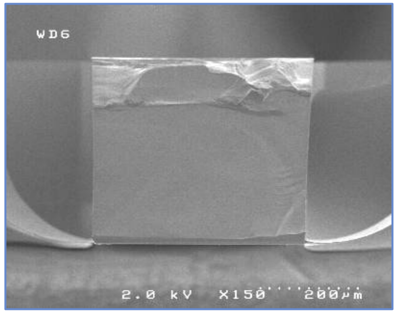
High Aspect Ratio
~0.4 µm trenches
100:1 AR



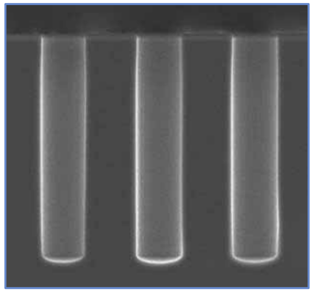
High Aspect Ratio
1.7 x 41 µm
24:1 AR

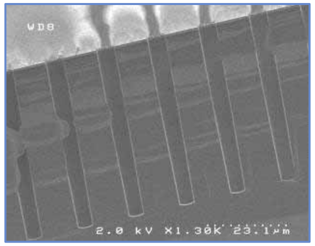


Through Wafer
Sensors
Microphones

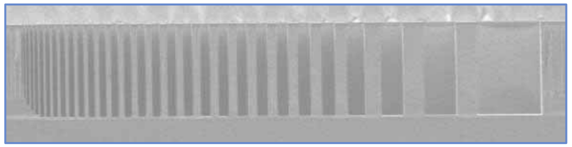


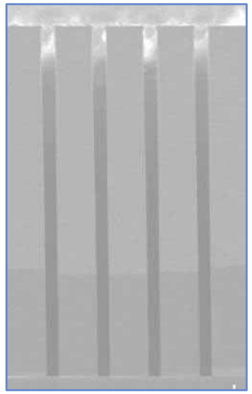
Scallop Free
<6nm 'waves'





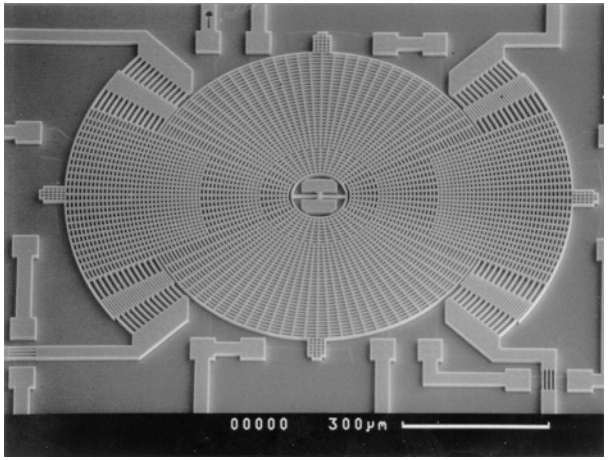
SOI
3 x 50 µm
17:1 AR



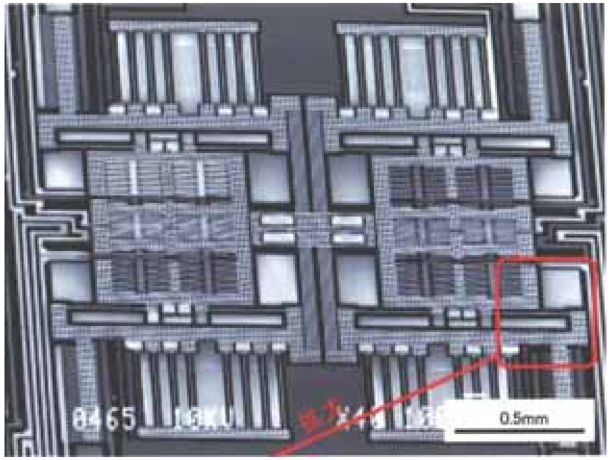


MEMS Gyro•Acceleration Sensor in 1996

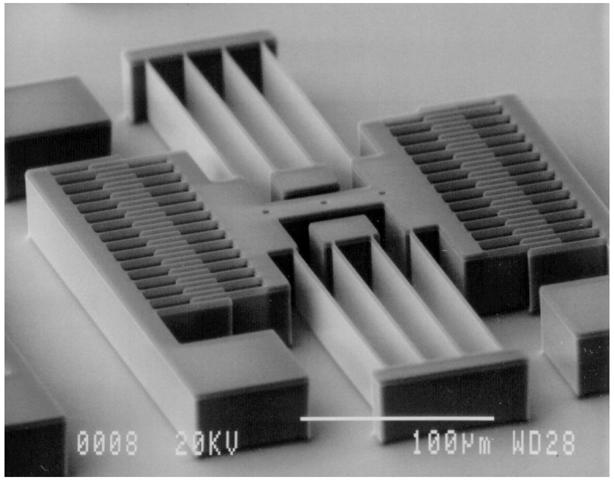
SSS



Robert Bosch



Toyota



MCNC

Ink Jet Head in 1990s

SEIKO EPSON

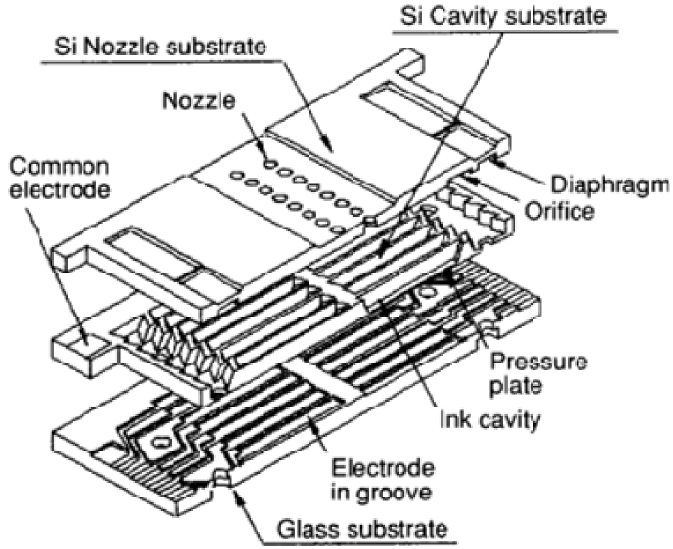


Fig.2 Exploded perspective view of the head chip

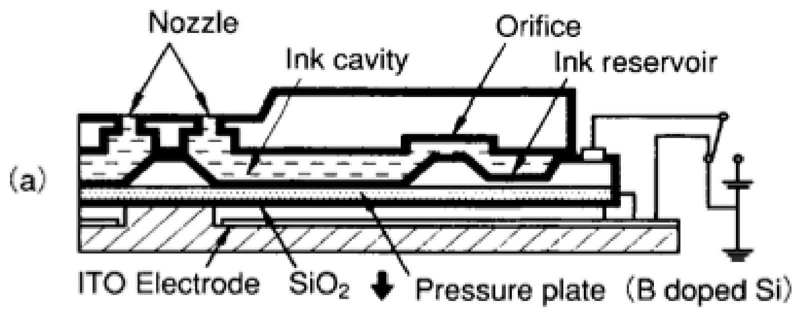


Fig.4 The mechanism of ink ejection

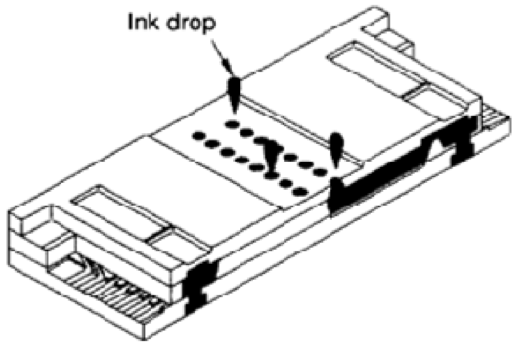
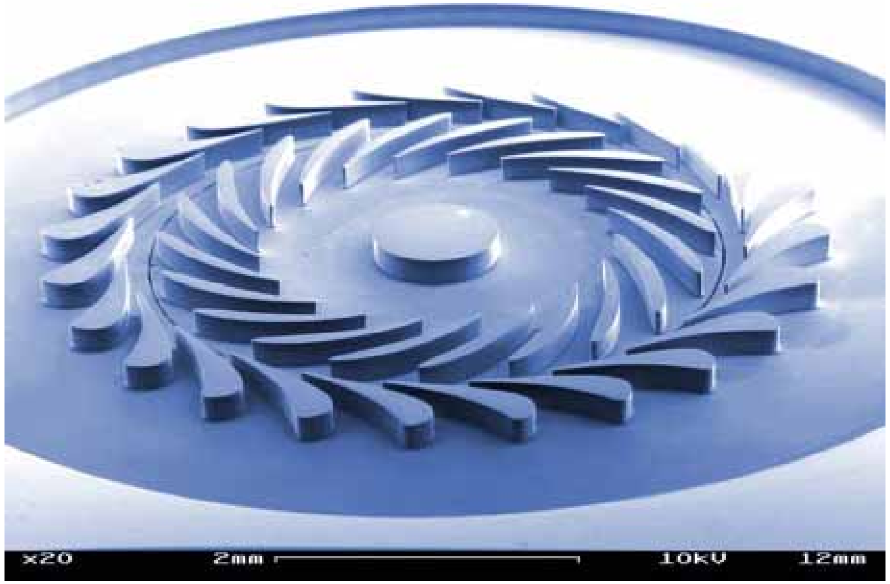


Fig.3 Perspective and cross sectional view of assembled the head chip

(Masahiro Fujii, “Micromachining Process for Inkjet Printer Head “SEAJet””, Japan Institute of Electronics Packaging Vol.5, No.6 (2002))

Microturbine in 1997



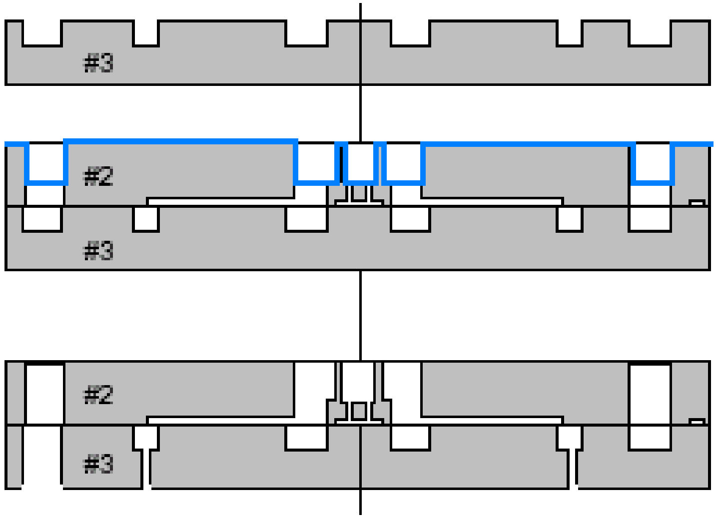
A. H. Epstein et al., Macro Power from Micro Machinery, Science, Vol.276, p.1211 (1997.5)

L.Frechette, Development of a Microfabricated Silicon Motor-Driven Compression System

1) STS etch blades and plenums (150 um) on front side (Mask C6)

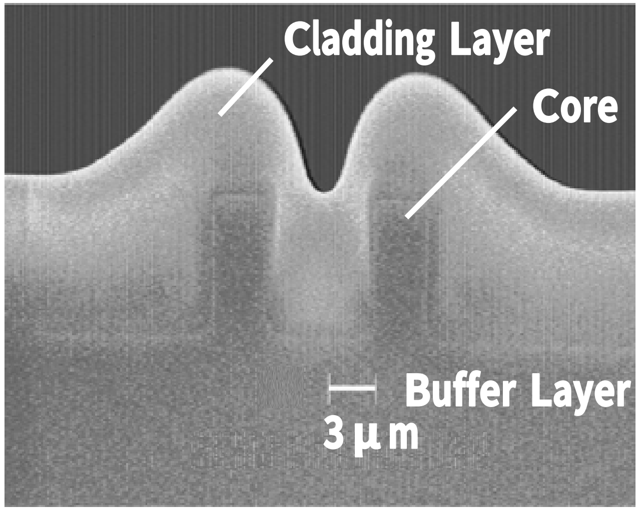
2) Bond RP to FEP, creating a tether attached to the rotor

3) STS etch journal bearing (300 um) on back side (Mask C7), and remove protective layer

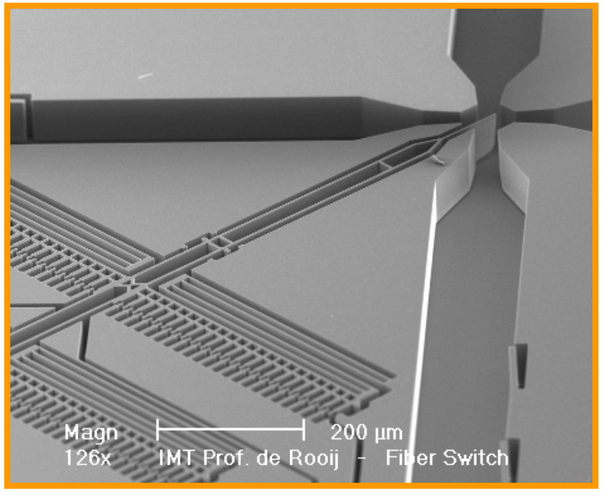


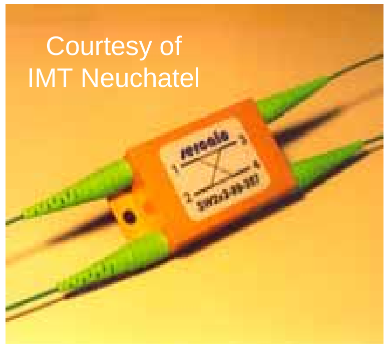
Waveguide & Optical MEMS Switch in 2000

- High-speed data transmission
- Reduced telecommunications infrastructure cost
- Increased system reliability
- Versatile data handling



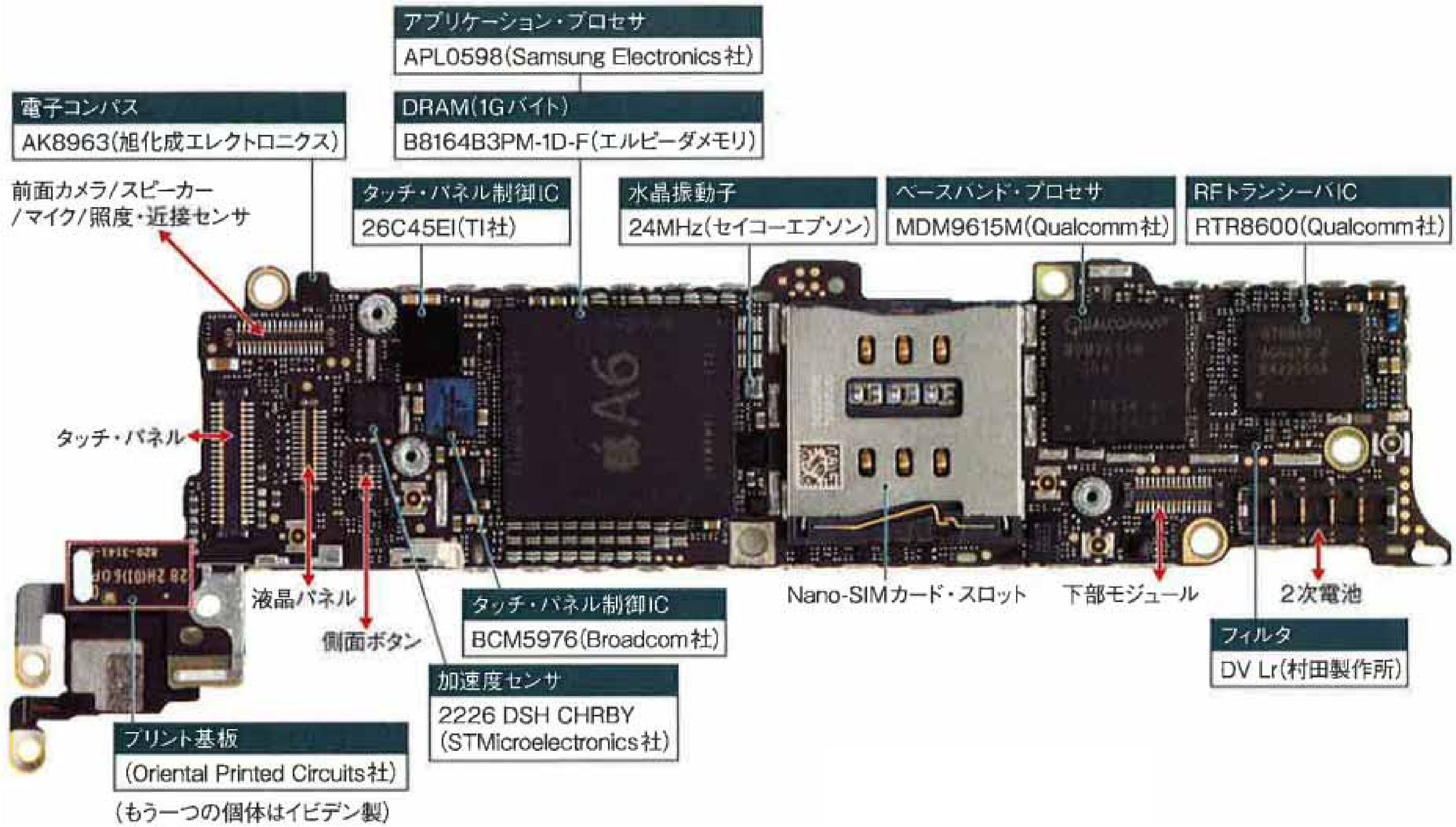
Waveguide





Optical MEMS Switch

Smart Phone (Apple - iPhone 5)



(Source: NIKKEI ELECTRONICS, October 15, 2012, pp13)

Devices for Smart Phone

~ MEMS Gyroscope, Motion and Magnetic Sensor ~

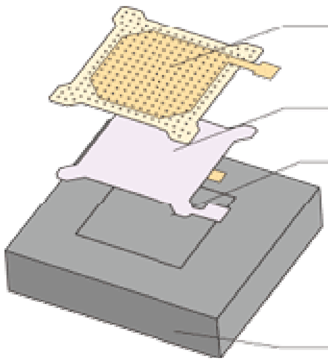
Gyroscope

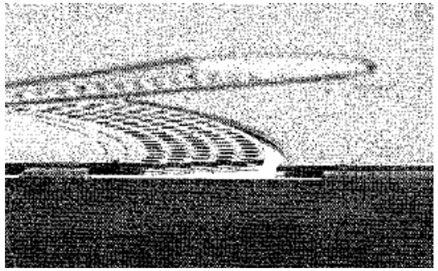
Motion and Magnetic Sensor

(http://www.st.com/internet/com/press_release/p3198.jsp)
(http://www.st.com/jp/com/press_release/p3154.jsp)

Devices for Smart Phone

~ Si Microphone ~

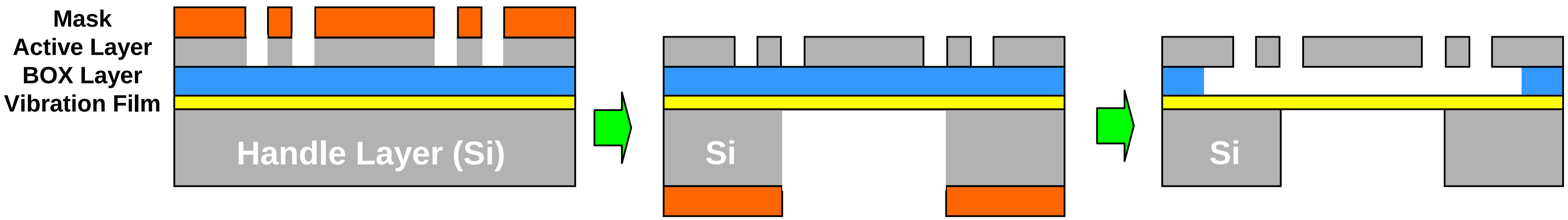




(Courtesy of Hitachi Haramachi Electronics)

(http://www.omron.co.jp/ecb/products/memsmicro/index.html)

Process Flow



Diaphragm
<SOI Notch Free Etching>

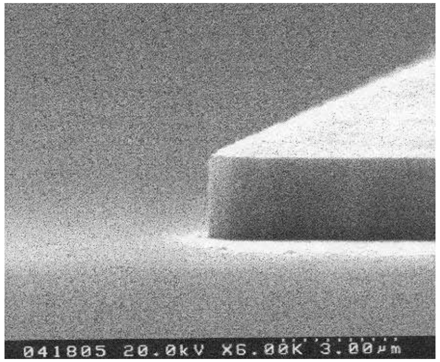
Cavity
<High Rate Si-DRIE>

BOX Release
<HF Vapor Etching>

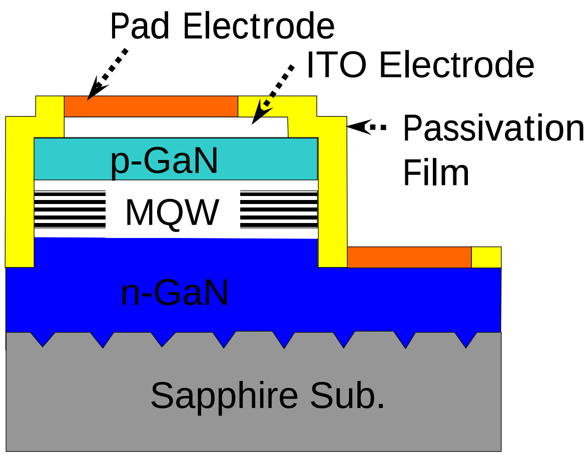
Devices for Smart Phone

~ LED ~

5 megapixel camera with <u>LED flash</u> in iPhone4



GaN Etching

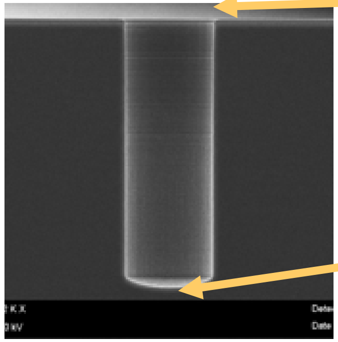


Devices for Smart Phone

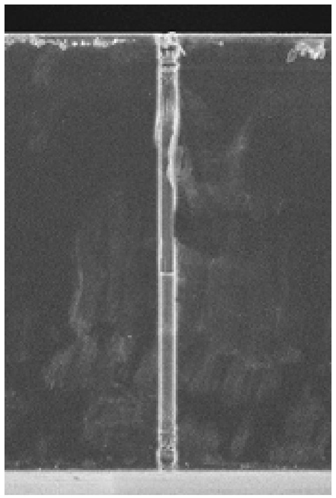
~ Advanced Packaging - TSV ~

3D Interconnect

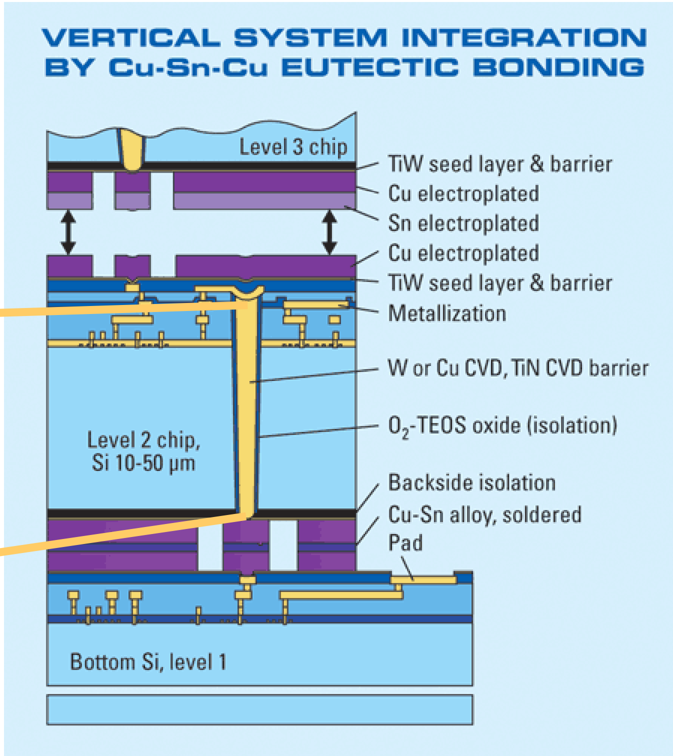
- Enables wafer level, chip scale packaging
- Increased device speed due to shorter interconnect



60µm Diameter Via Hole etched to a depth of 200µm



400µm Via Hole courtesy of STMicroelectronics

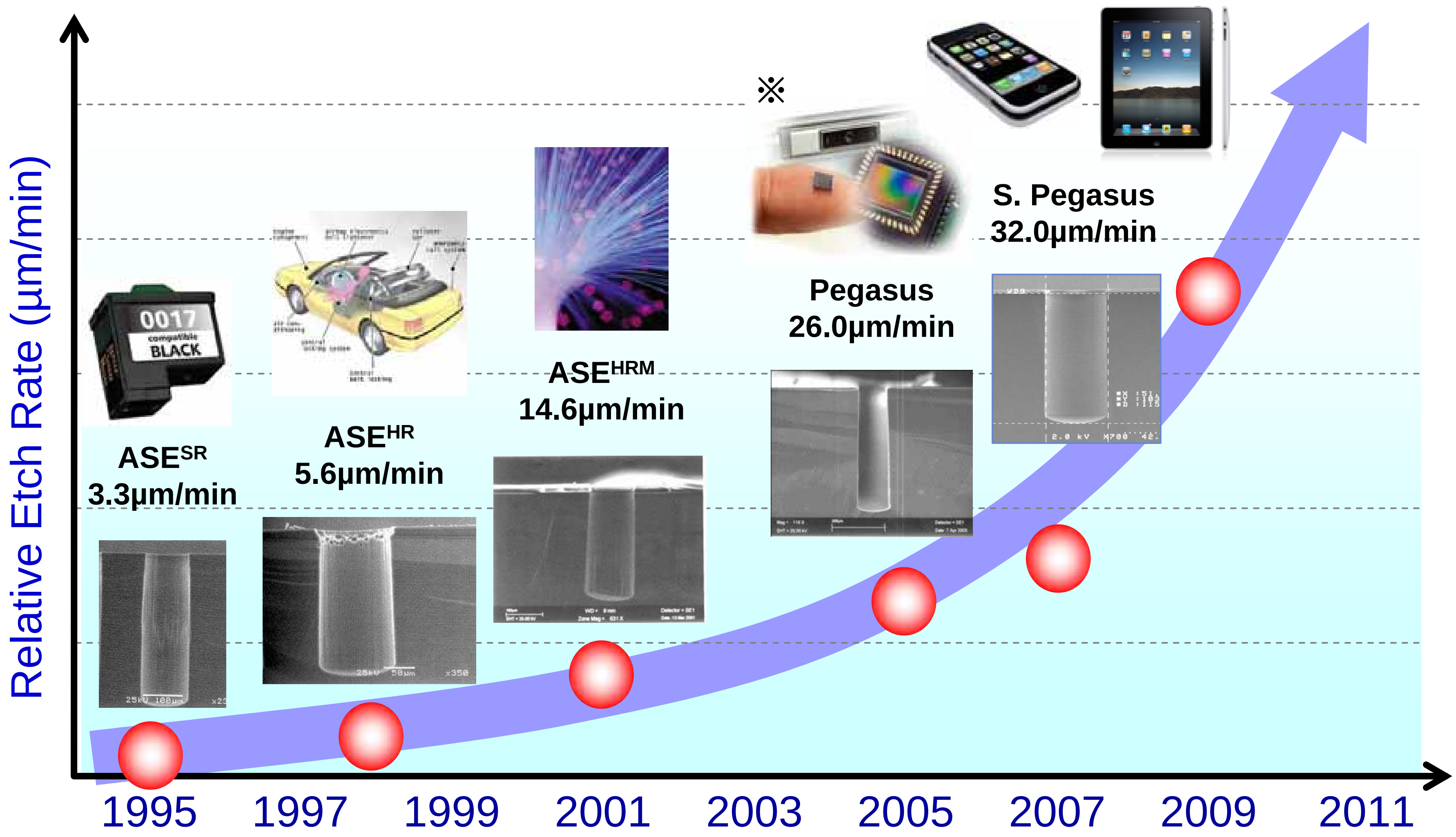


Trend of Apple - iPhone

1 ECM microphone	1 ECM microphone	1 ECM microphone	2 MEMS microphone + 1 MEMS microphone for Headset	3 MEMS microphone + 1 MEMS microphone for Headset

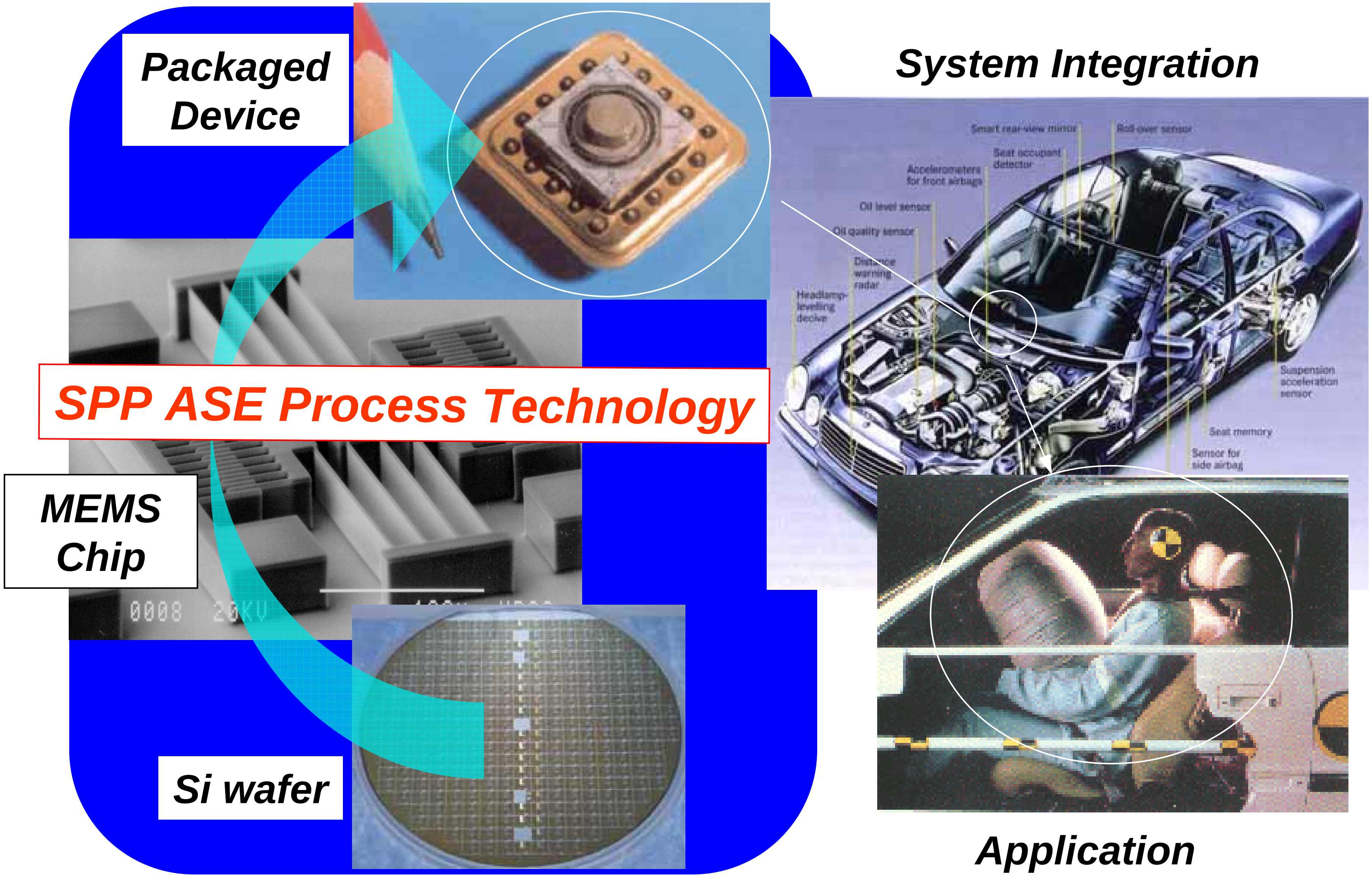
(Source: IHS iSuppli: MEMS Exec Congress 2012)

Technology for Process Continuous Evolution



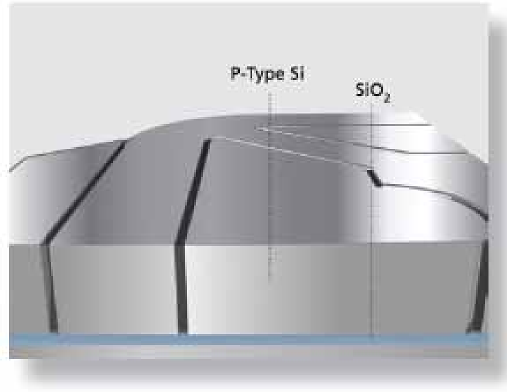
(※：http://www.xintec.com.tw/index.php?lang=ja&p=cis)

MEMS - 1 Device,1 Process,1 Package

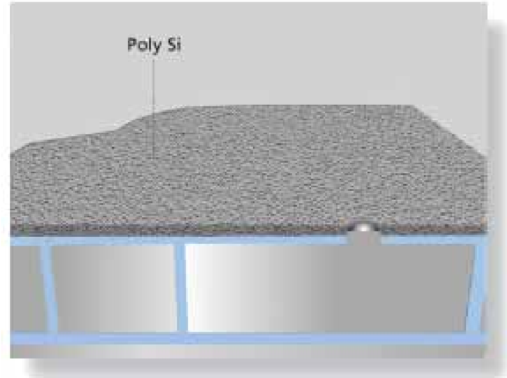


Technology for Devices

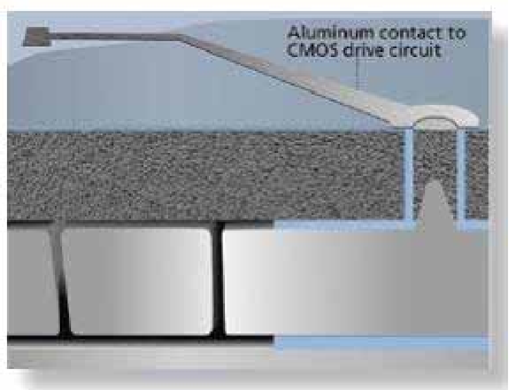
SiTime MEMS Oscillator



Si-DRIE

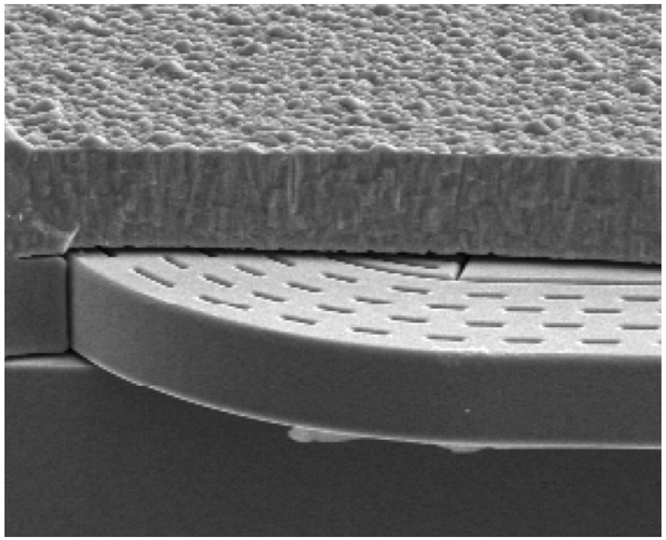


Oxide layer fill→
poly-Si Cap



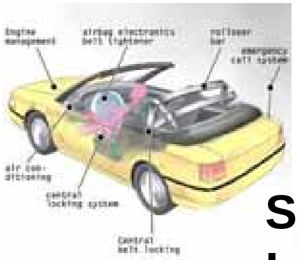
Etching & release
Thick poly-Si Cap

Process combination with Si-DRIE (ASE) and Sacrificial layer etching (Primaxx CET)



(Courtesy of SiTime)

MEMS Applications



Silicon Inertial Sensors

Ink Jet Heads

Optical MEMS Switching

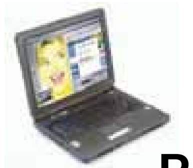
MEMS Commercial Applications

RF MEMS De-coupling Capacitors

Advanced Packaging

Micro Fluidics 'Lab on a chip'

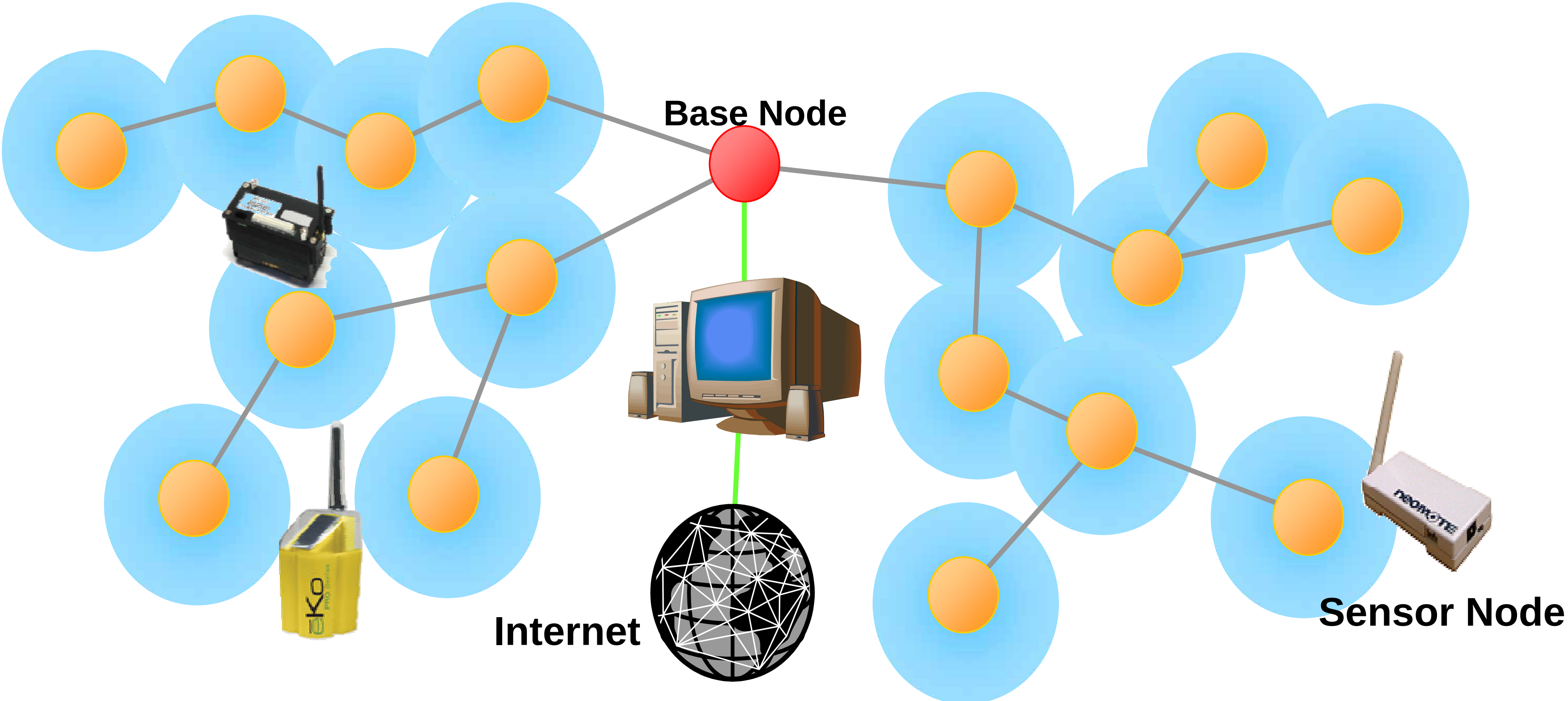
MEMS Pressure Sensors



Power Devices

Technology for Systems
Wireless Sensor Network

- Each sensor node forms multi-hop wireless route to the base station; AND self-heals.
- Saves wiring costs on industrial metering or energy-saving system. Because of wireless, a layout change requires no re-wiring costs.
- SPP/Crossbow's NeoMOTE has numerous deployment cases in various situations: proven immunity in communication robustness.



Wireless Sensor Network

Wireless monitoring the electric power, temp etc

--> Control the energy saving (Smart Grid)

▲ Wireless monitoring the temp and vibration without circuiter

Monitoring the state of conservation ▼

Information by mail alarm

Technology for Systems
Applications of WSN

Power Savings

- Energy management
- Building management
- Micro Smart Grid

Agri/Natural Environment

- Outdoor sensing
- Precision farming
- Forestry

Civil Engineering

- Structural- Health-Monitoring

Security

- Elderly Well-Being monitor
- Location system
- Intruder detection

Maintenance

- Equipment operation rate
- Predictive maintenance
- Wiring reduction of metering
- Monitoring storage conditions

Healthcare/Medical

- Health monitoring
- Medical sensors
- Pharmacology storage

SPT's Product Line-up

Si DRIE

ASE-Predeus / Pegasus / Pegasus300 / SRE

Comp.Semi. / Dielectric Etch

APS / ICP / SPTS-Omega

Isotropic SiO_2 Release Etch(HF)

SLE-Ox / SPTS-CET25 / SPTS-uEtch

Chemical Vapor Deposition

PE-CVD / SPTS-Delta

Physical Vapor Deposition

SPTS-Sigma

Furnace

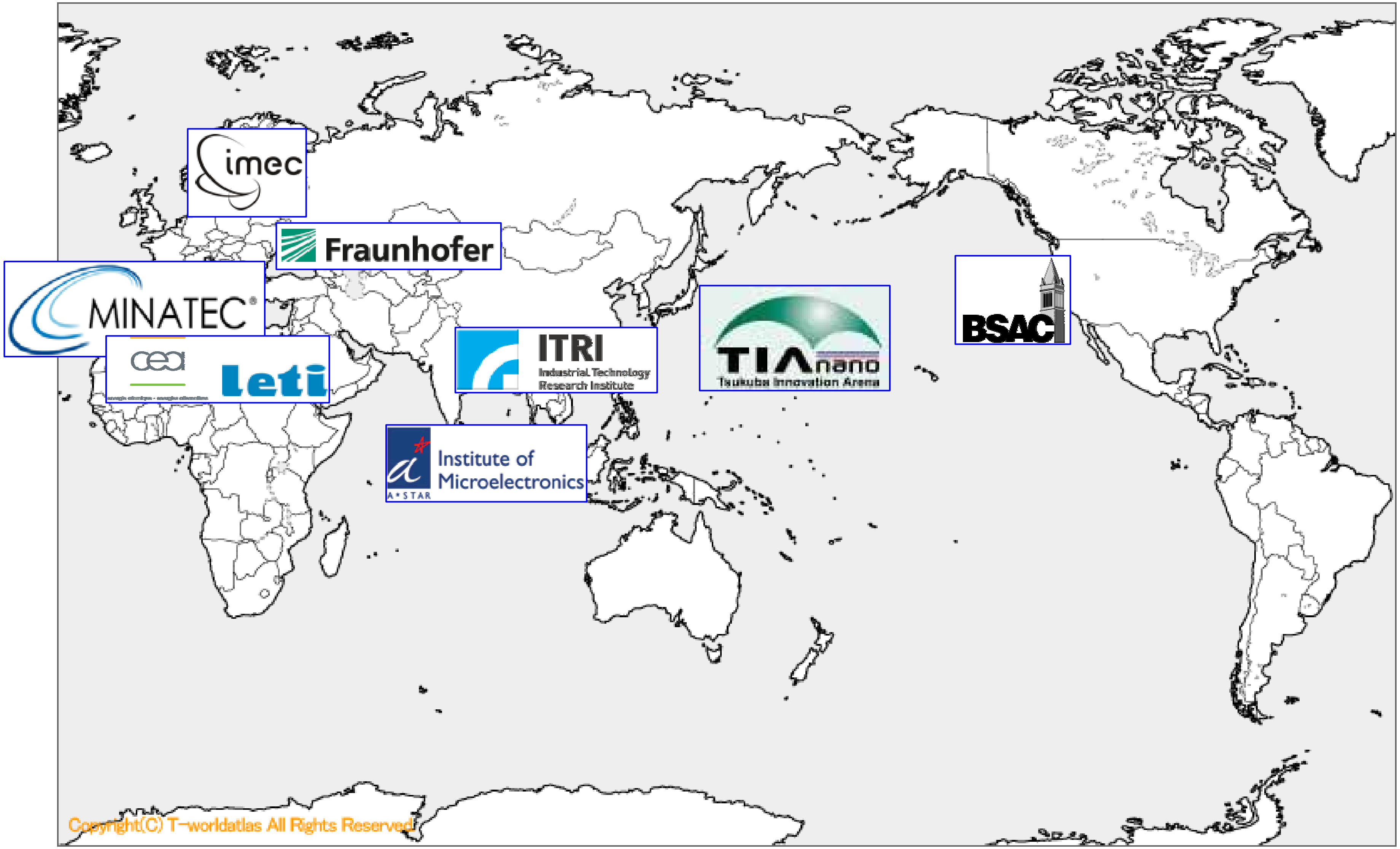
SPTS-AVP / RVP / RVP300plus

Isotropic Si Release Etch(XeF_2)

SPTS-XACTIX-Xetch / CVE

Relationship with Worldwide Institutes

Worldwide Institutes



Fraunhofer ENAS

Started Project-Center between Tohoku Univ. and Fraunhofer ENAS (April, 2012)

FhG Germany – Sendai city partnership singing ceremony in Munich (July 15, 2005)

1st Fraunhofer Symposium in Sendai (October 19, 2005)

(Courtesy of Prof. Esashi of Tohoku University)

TOHOKU UNIVERSITY

Fraunhofer ENAS

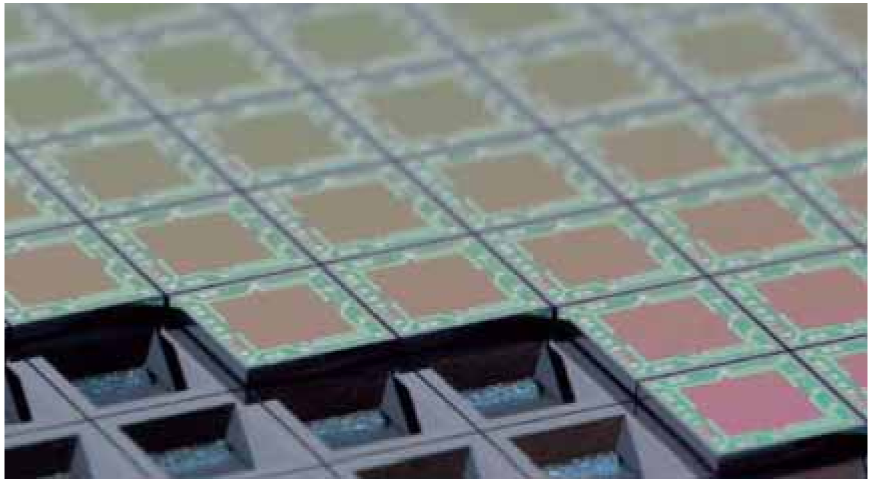
Prof. Thomas Gessner

Director of Fraunhofer Institute for ENAS (Electronic Nano Systems)

Prof. in Chemnitz University of Tech.

PI in WPI-AIMR, Tohoku University

Collaboration between Tohoku Univ. and Fraunhofer ENAS



Pressure Sensor using Wafer-level Bonding

(Source: Sendai MEMS Show Room in Micro System Integration Center, Tohoku University)

CEA-Leti

3D-IC Development by Collaboration

07/10/2010- CEA-Leti and SPTS to collaborate on next-generation TSV development

Leading Research Institute and Equipment Maker to Develop New Process Technologies for 3D-ICs

TOKYO, Japan, and GRENOBLE, France – Oct. 6, 2010 – CEA-Leti and SPP Process Technology Systems (SPTS) today announced an agreement to develop advanced 300mm through-silicon via (TSV) 3D-IC processes at CEA-Leti's 300mm facilities in Grenoble, France. The agreement defines their collaboration on a range of 3D TSV processes to optimize etch and deposition technologies used to create next-generation high aspect ratio TSVs.

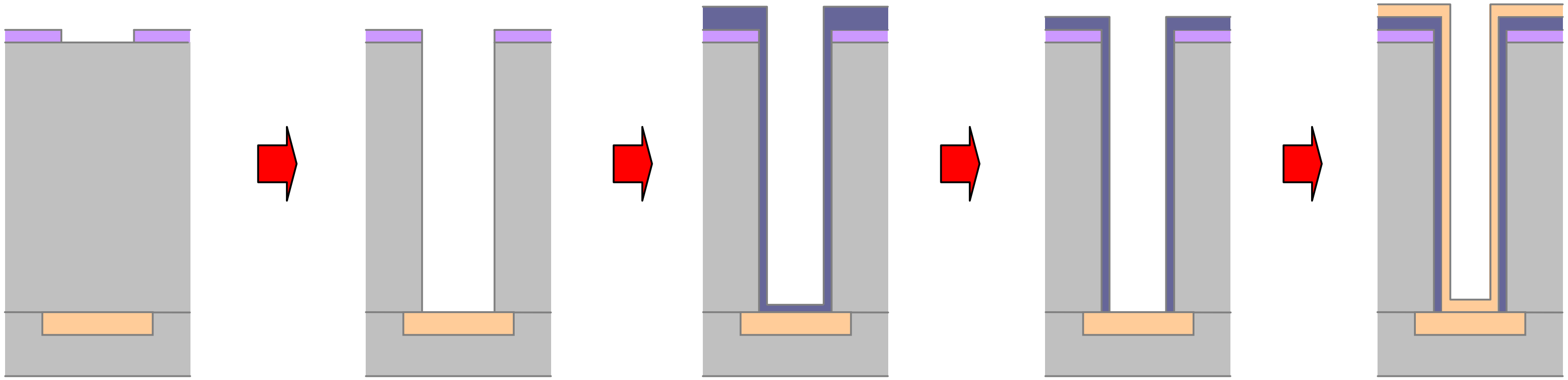
The partners will research alternative hardware and processes to address the need for new methods of cost-effective via fill. In some via-middle applications, where the via is created between contact and first back end of line (BEOL) metal layer, via aspect ratios may extend beyond 10:1, and these very high aspect ratios require a new approach to current etch and deposition techniques.

- Strategic alliances between tool vendors and technology developers will accelerate 3D-IC development

Laurent Malier (CEO CEA-LETI) & Susumu Kaminaga (President SPP & Chairman SPTS) signing the agreement in Oct 2010; receiving the first Leti 300mm wafer in Jan 2011

Fraunhofer IZM

TSV - *Key Technology*



Open multilevel oxide → Open deep Si via → Deposit dielectric isolation liner → Open liner at base → Deposit metal barrier & seed

APS → Si-DRIE → PE-CVD → APS → Sigma: PVD

Technologies are available

- Technologies are available for
  - Process
  - Devices
  - Systems

- Technologies are ready for further development to satisfy emerging application.

- New demand（usage/application）is required.

USERS

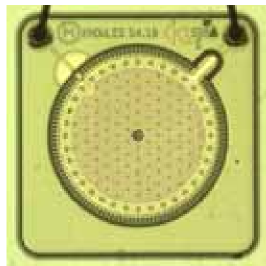
Vertical Collaboration

System Manufacturer

Sensor Installed System

MEMS Microphone System

Device Manufacturer



Device Development and enabling Production

Device production and Process Development

MEMS Foundry

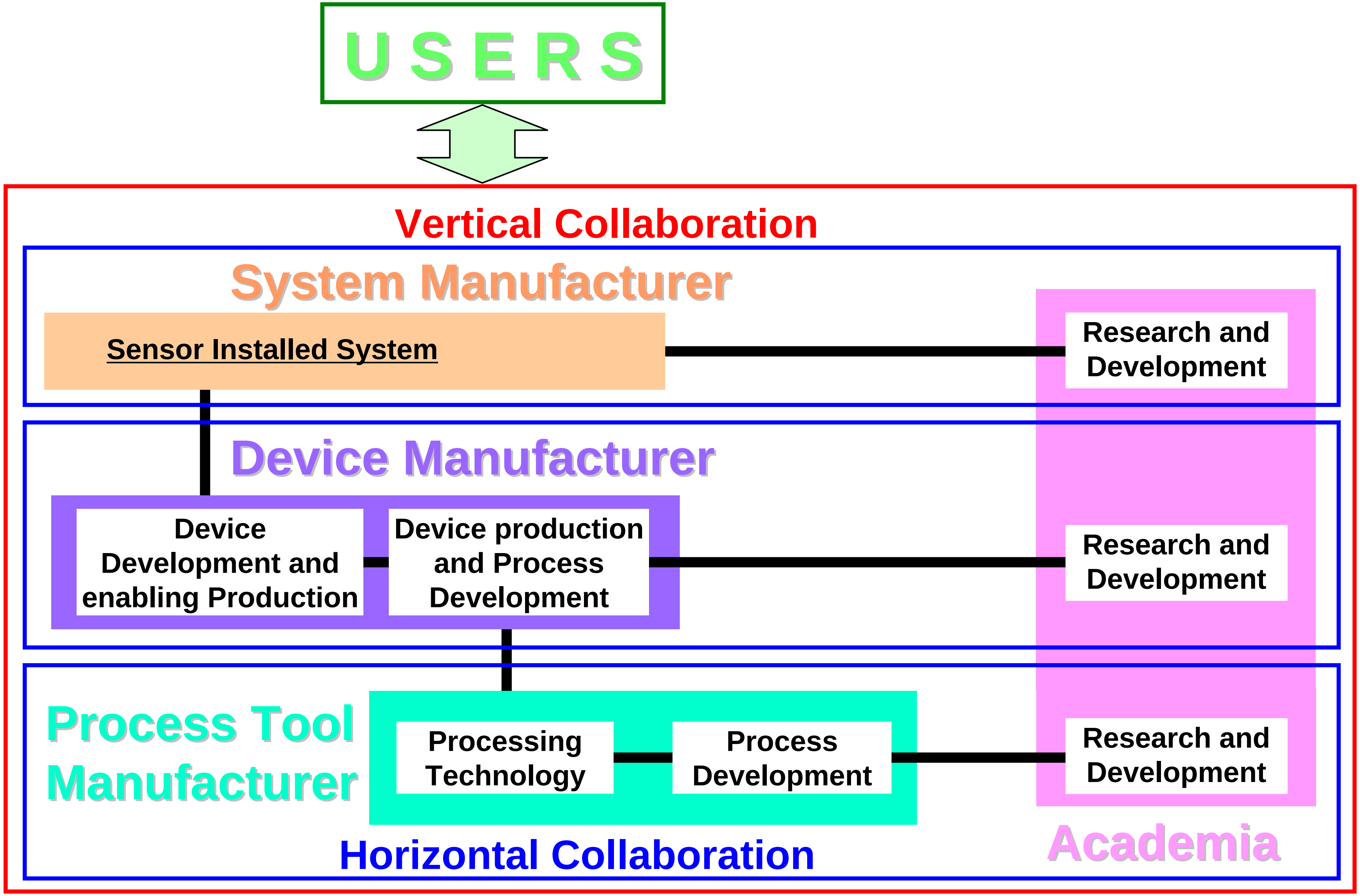
Process Tool Manufacturer

Processing Technology

Process Development

"ACTUAL EXAMPLE"

How to Accelerate the Development Cycle



MIG Conference Japan 2014
and
MEMS Engineer Forum 2014

MIG and MEF

MEMS Industry Group® (MIG)

- the trade association advancing MEMS across global markets
- holds MEMS Executive Congress US and MEMS Executive Congress Europe
- now, MEMS Industry Group Conference Japan

MEMS Engineer Forum (MEF)

- a unique opportunity operated mainly among engineers close to the MEMS technology
- held annually with MEMS researchers, developers, engineers gathering in one place since the start in March 2009
- the mission is the fusion and creation of the new movement based on MEMS

MIG and MEF co-located this year here in Ryogoku

Trillion Sensors Summit

Trillion Sensors Summit

Mar. 2013:	**"Trillion Sensors Universe" workshop at University of California, Berkeley**
Oct. 2013:	**"Trillion Sensors Summit 2013" at Stanford University**
Feb. 2014:	**"Trillion Sensors Summit Japan 2014"**
Aug. 2014:	**"Trillion Sensors Summit China" (TBD)**
Sep. 2014:	**"Trillion Sensors Summit Germany"**
Nov. 2014:	**"Trillion Sensors Summit US"**
Dec. 2014:	**"Trillion Sensors Summit Japan"**

Trillion Sensors

- Abundance movement forecasts elimination in one generation (20 to 30 years) of major global problems.
- Abundance forecasts the need for (among others) 45 trillion sensors, many not yet developed.
- Historical sensor development cycles from prototypes in academic labs to volume production were 30 years.
- TSensors (Trillion Sensors) Movement aims at acceleration of new sensors development cycle.

- **TSensors Roadmap**

  TSensors Summits will collect visions for the ultrahigh volume sensor applications likely to emerge over the next decade.

- **TSensors Movement Strategy**
  1. **Invite visionaries to "invent" new sensor applications expected to drive ultrahigh volume demand for sensors.**
  2. **Group these applications into the common application platforms (TApps).**
  3. **Develop TSensors Roadmap**
  4. **Develop strategy for selected sensor technology platforms development acceleration, e.g.**
  5. **Facilitate funding of the acceleration effort.**

MEMS Improve Your Life

MEMS Improve Your Life

MEMS sensors contribute to improvement of society ;

- **Environment** **(Sensor Network)**
- **Energy** **(**Energy Harvest / Sensor Network**)**
- **Security** **(Sensor Network)**
- **Life** **(Bio Technology)**

Summary

Summary

MEMS contribute to innovation in your life on the basis that

- ***Global Fusion of System / Device / Process is essential for MEMS.***

- ***Global Fusion of Various Specialities such as Electro / Mechanical / Electronic / Optical /Bio-Medical is also essential.***

- ***Global Fusion of Knowledge/ Technology/ Usage is further essential.***

Toward a Promising Future

Thank you for your attention !

JP : SPP Technologies Co., Ltd.
UK : SPTS Technologies Ltd.
US : SPTS Technologies Inc.