【MEMS Engineer Forum 2013】

MEMS - Fusion of Advanced Technologies

SPP Technologies Co., Ltd.

Susumu Kaminaga

Executive Senior Adviser

Chairman, Steering Committee

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

SPT

14th March, 2013

SPP

PR-1132

Agenda

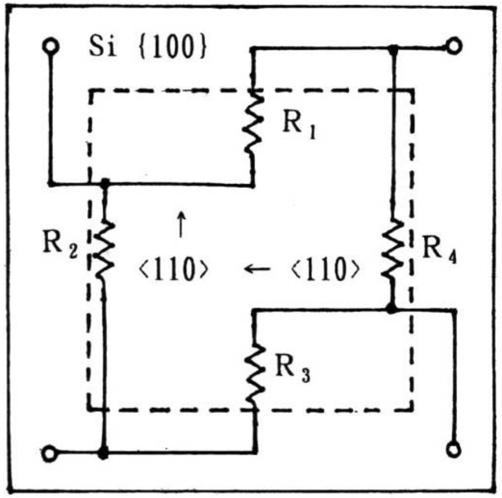
- **History of MEMS**
- **History of MEMS with Involvement of SPP**
- **MEMS Process Technology**
  - **SPP, STS, SPTS & SPT**
  - **Bosch Process & *ASE®* *(Advanced Silicon Etch)***
  - **MEMS Process Technology**
  - **Equipment for R&D**
- **MEMS Business Model**
- **Relations with Worldwide Nanotech Centers**
  - **Tsukuba Innovation Arena (TIA)**
  - **Collaboration between CEA-Leti and SPTS / SPP**
- **MEMS Improving Our Lives**
- **Summary**

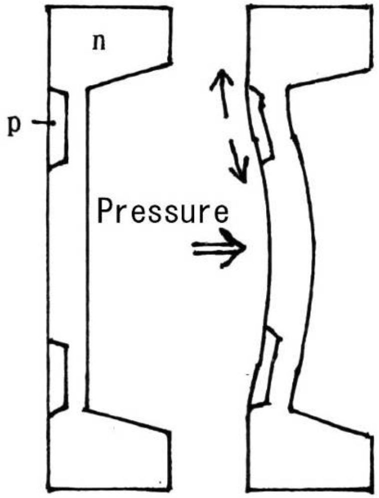
History of MEMS

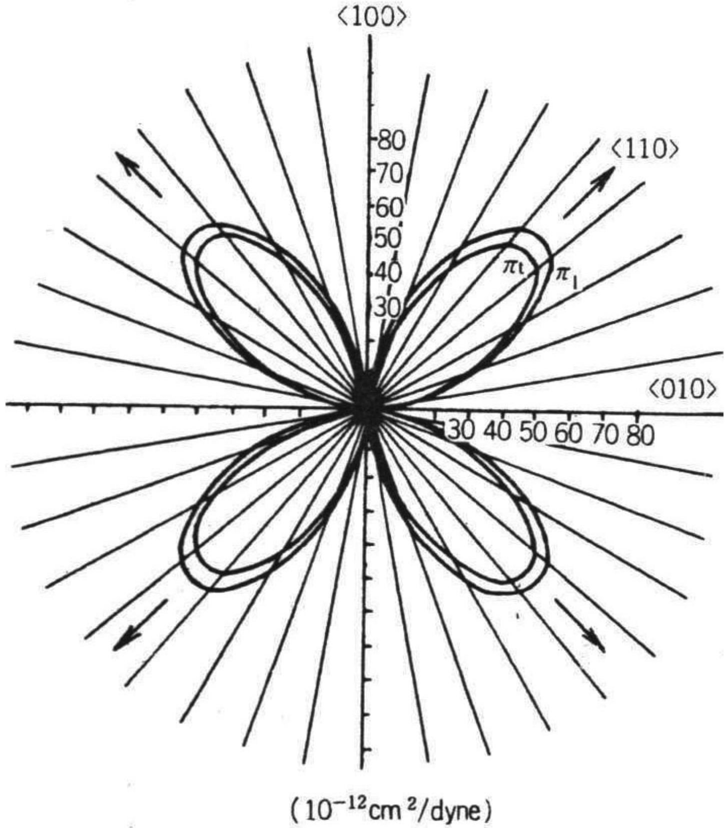
Development of MEMS

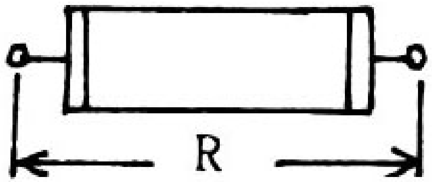
1960s : Pressure sensor development and industrialization
1970s : MEMS devices development work pioneered by Prof. Esashi of Tohoku Univ., Japan
1982 : "Silicon as a Mechanical Material" authored by Dr. Kurt Petersen
1986 : BSAC was founded
1987 : Term "MEMS" was coined in the U.S. Transducers '87 conference held in Tokyo
1992 : Integrated Wafer Process System IX200 developed / commercialized by SPP
1995 : DRIE technology based upon "Bosch Process" developed/commercialized by STS/SPP
1997 : Microturbine was 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 Phones

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.

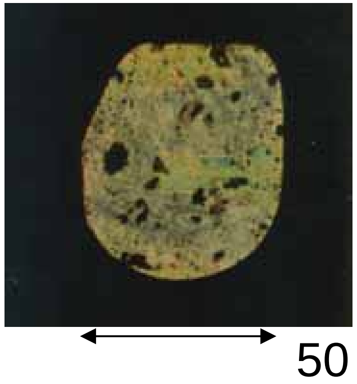
p – Si

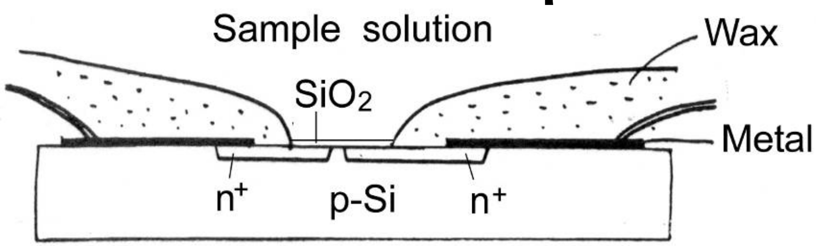
(100)

Piezoresistive coefficient

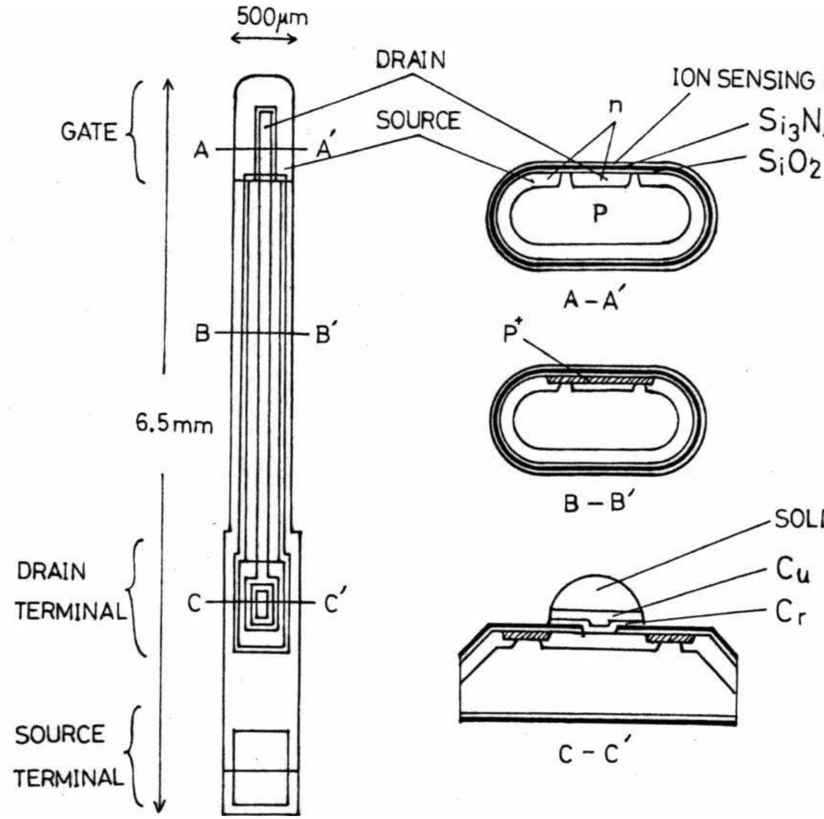
(Courtesy of Prof. Esashi)

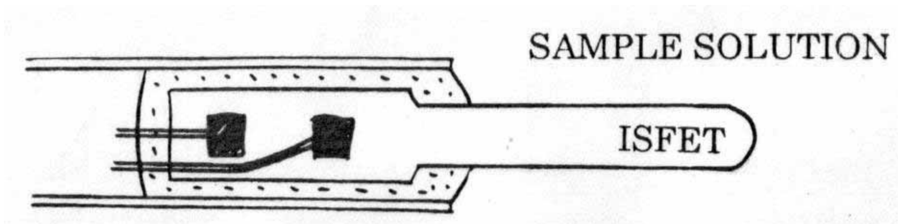
Achievement of Prof. Esashi of Tohoku Univ. in 1970s





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



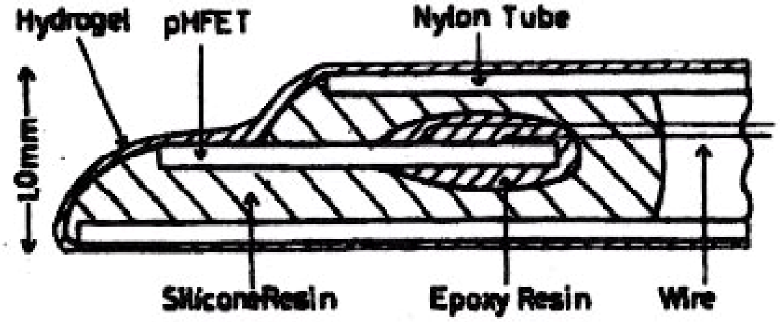


ISFET (Ion Sensitive Field Effect Transistor)

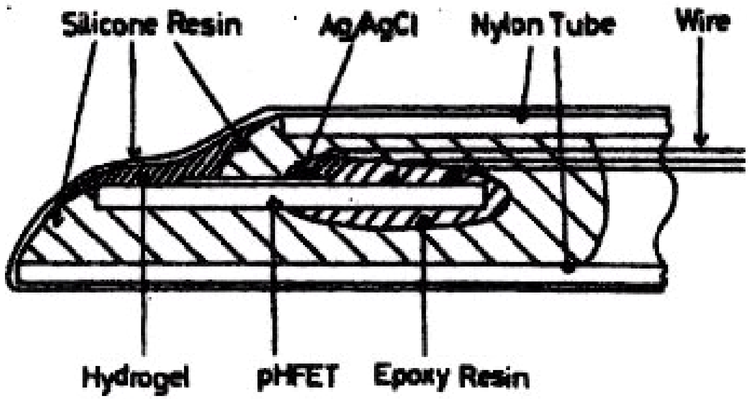
(M.Esashi & T.Matsuo, Supplement to the J.J.A.P.,44 (1975) 339)

(Courtesy of Prof. Esashi)

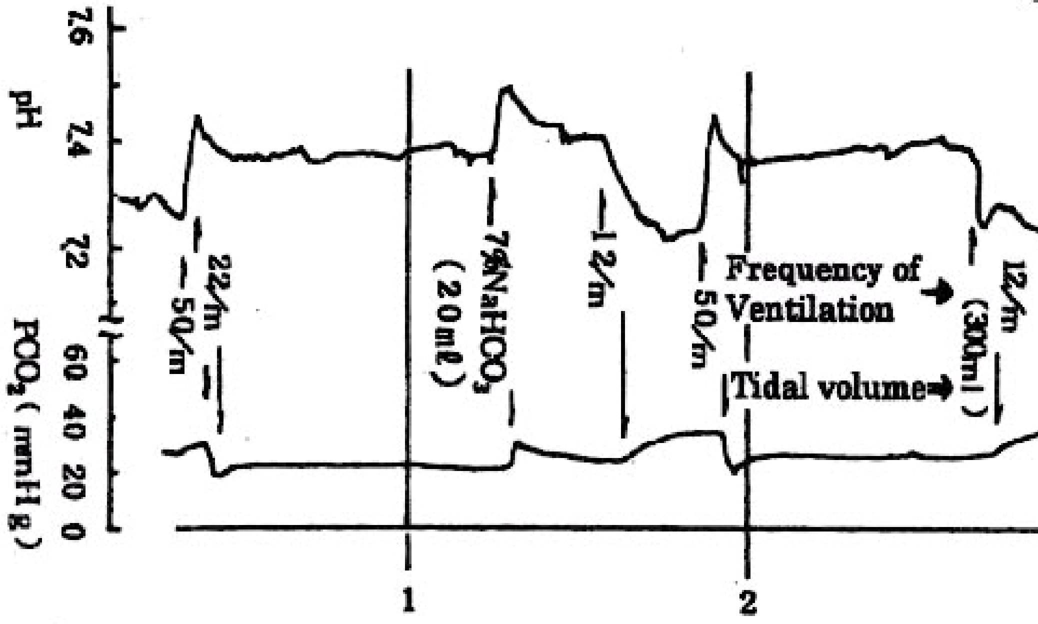
Achievement of Prof. Esashi of Tohoku Univ. in 1970s



Catheter-tip pH ISFET



Catheter-tip CO_2 ISFET



Catheter tip pH、PCO_2 sensor

(K.Shimada et.al., Med.& Biol.Eng. & Comput.,18 (1980))

(Courtesy of Prof. Esashi)

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 me chanical 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

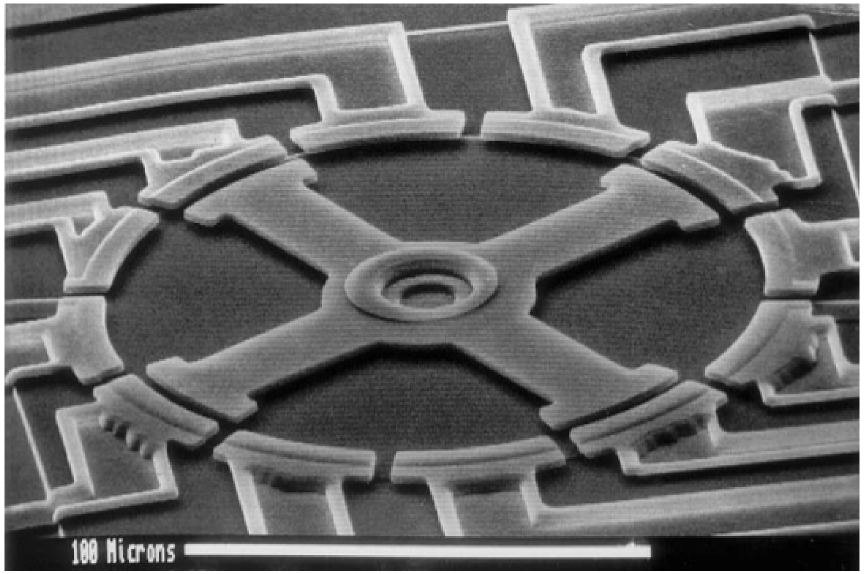
(Kurt E. Petersen, “Silicon as a Mechanical Material”, In Proc. of the IEEE, Vol.70, No.5, May 1982)

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)

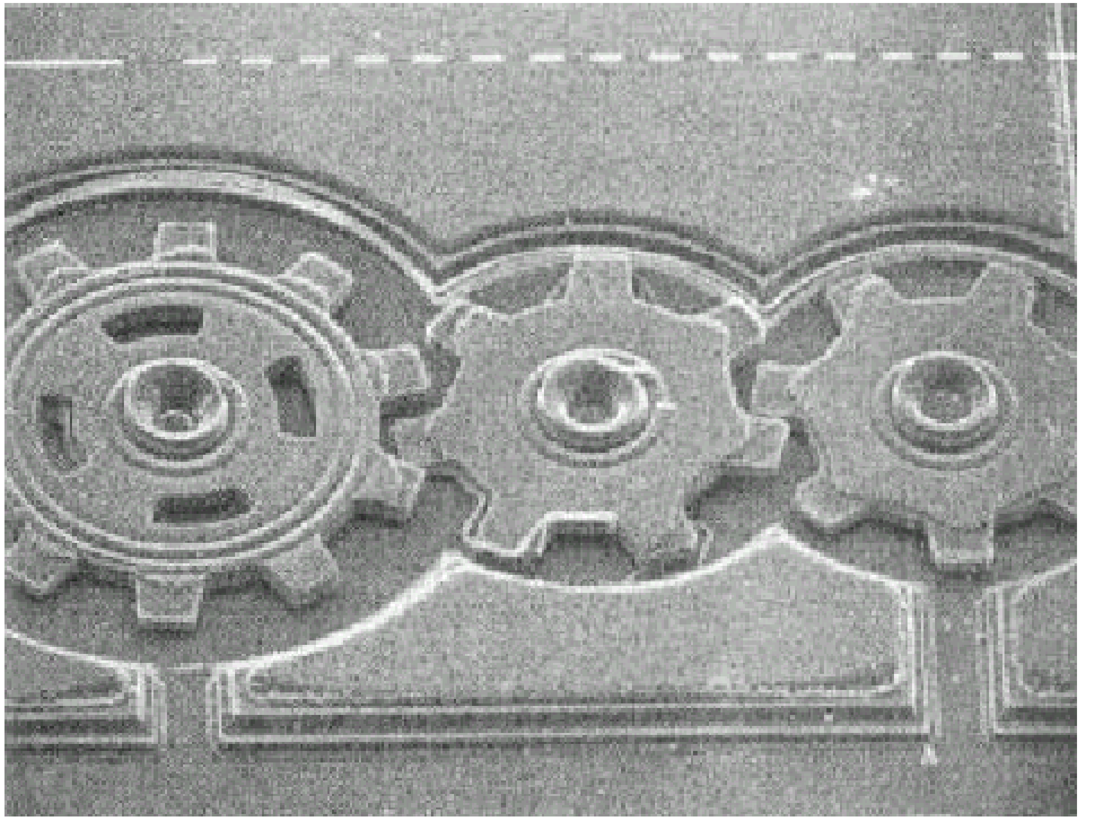


Term “MEMS” was coined in 1987

The term MEMS was coined around 1987, when a series of three workshops on Microdynamics and MEMS was held in July 1987 at Salt Lake City, Utah ; in November 1987 at Hyannis, Massachusetts ; and in January 1988 at Princeton, New Jersey, ushering in a new era of microdevices.

The field of solid-state transducers has traditionally been application driven and technology limited, and has emerged as an interdisciplinary field which involves many areas of science and engineering. MEMS is expected to follow a similar trend.

“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)

History of MEMS with Involvement of SPP

IX200 and its “User Laboratory” in 1992

Integrated Wafer Process System IX200 was developed / commercialized by SPP.

IX200

USER LABORATORY

Si DRIE Equipment in 1995

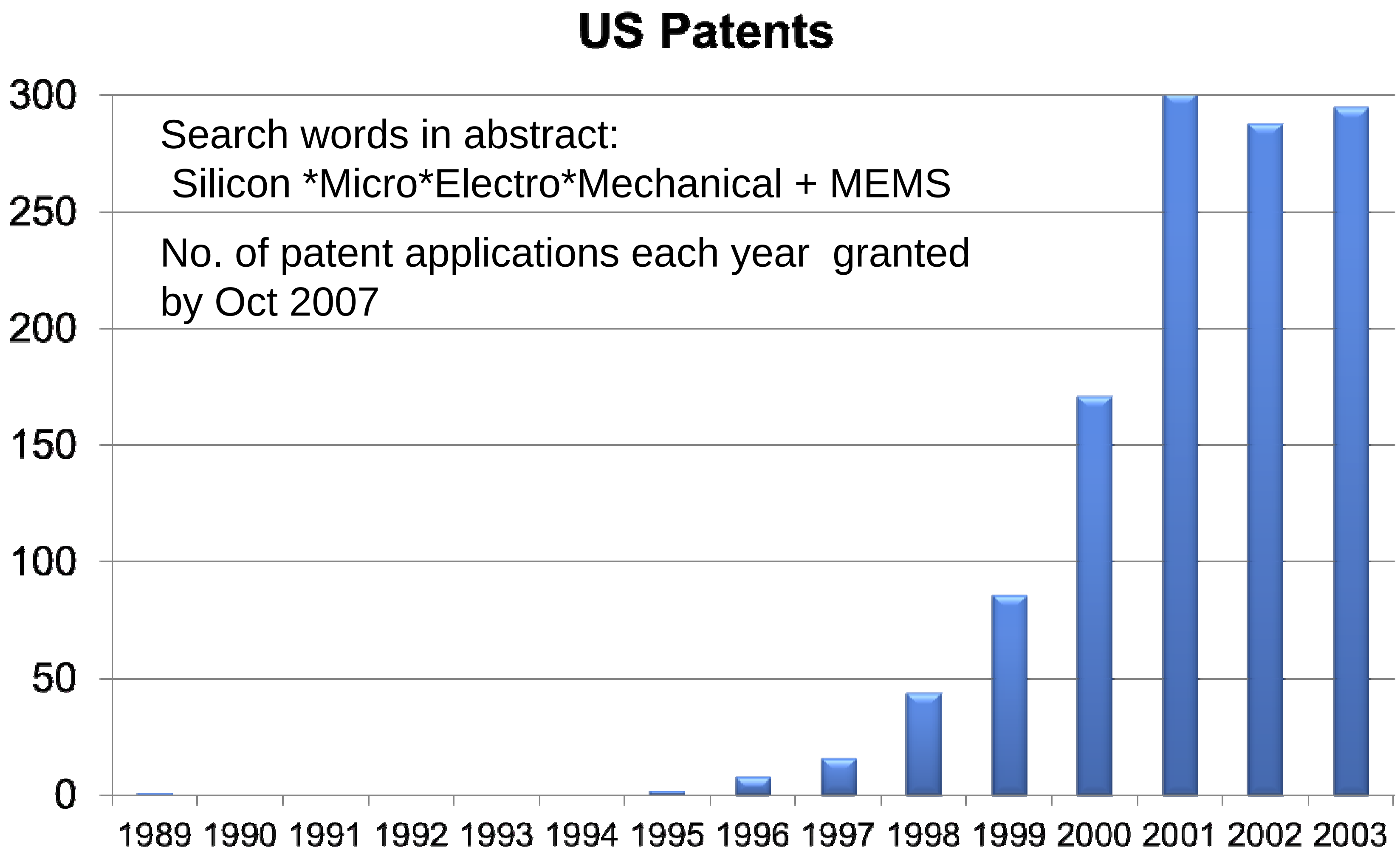
- **SPTS (STS) is Synonymous with the MEMS industry!**
- **In 1994, STS began working with Robert Bosch to develop a production version of an Etch Process that they had patented.**
- **In 1995, STS shipped 1st DRIE Equipment (*ASE*®) with Bosch process in W/W**
- **This was an enabling technology in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

Phase 1 | Phase 2 | Phase 3

Passivation | Passivation Removal | Etching

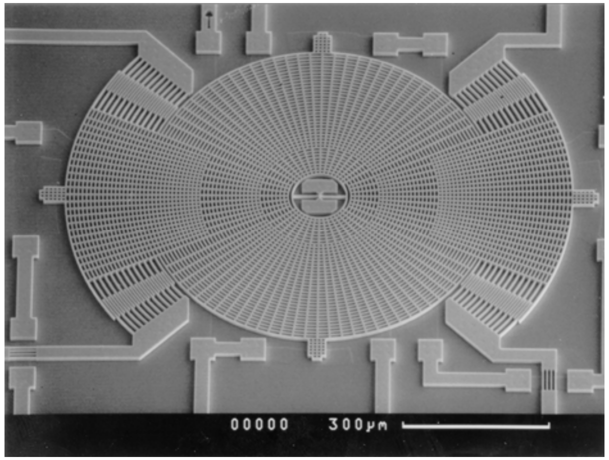
Back to Phase 1

Trend of MEMS Related Patent Application

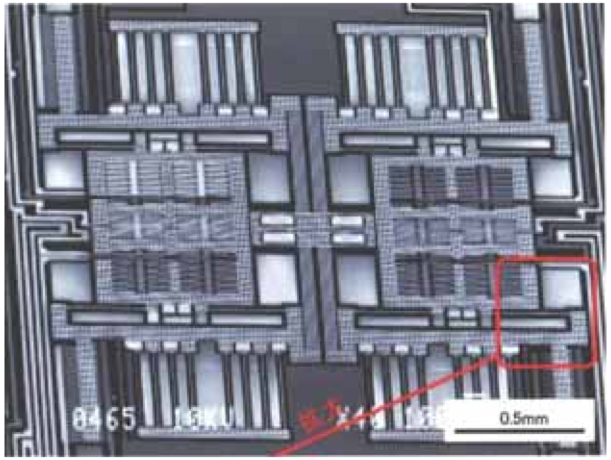


MEMS Gyro•Acceleration Sensor in 1996

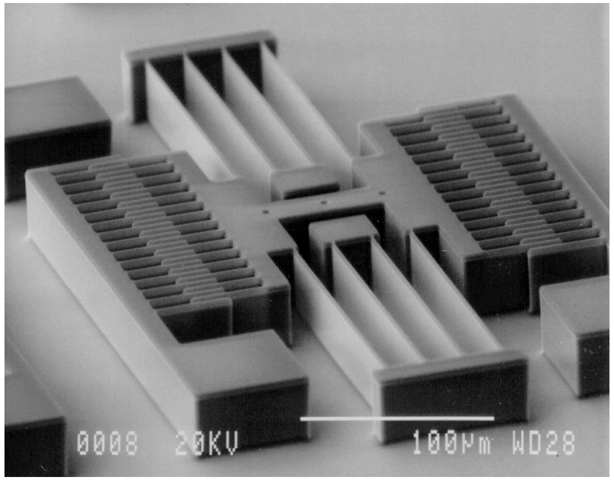
SSS



Robert Bosch



Toyota



MCNC

Ink Jet Head in 1990s

SEIKO EPSON

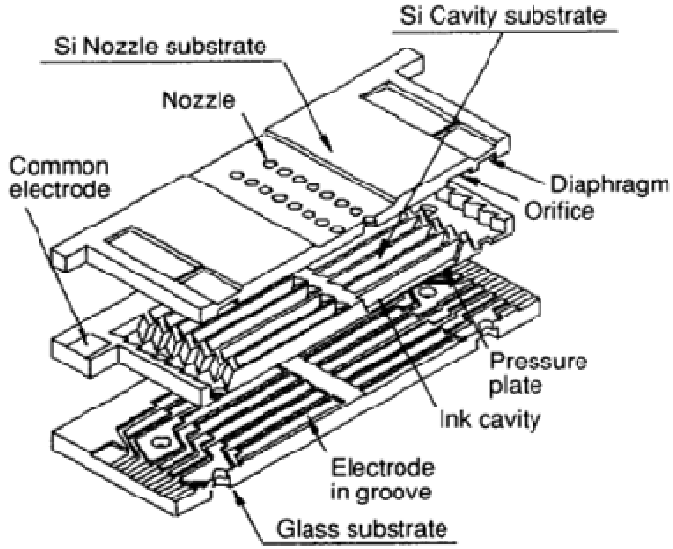


Fig.2 Exploded perspective view of the head chip

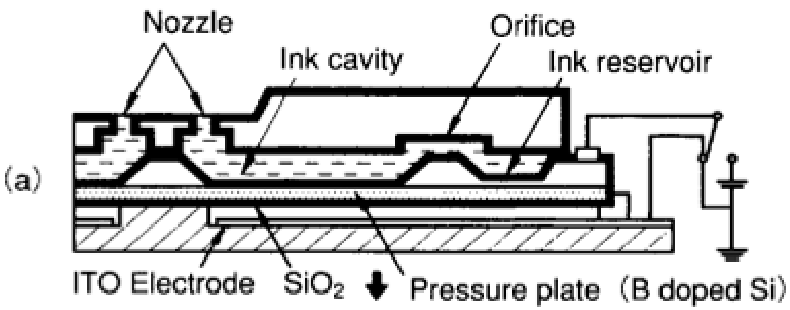


Fig.4 The mechanism of ink ejection

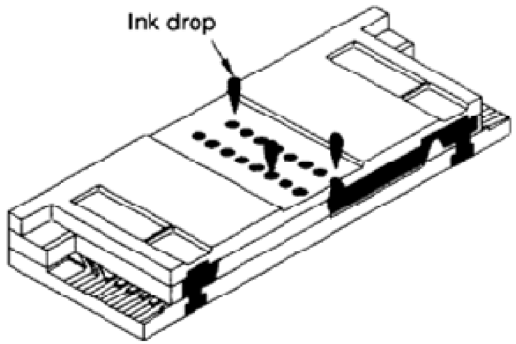
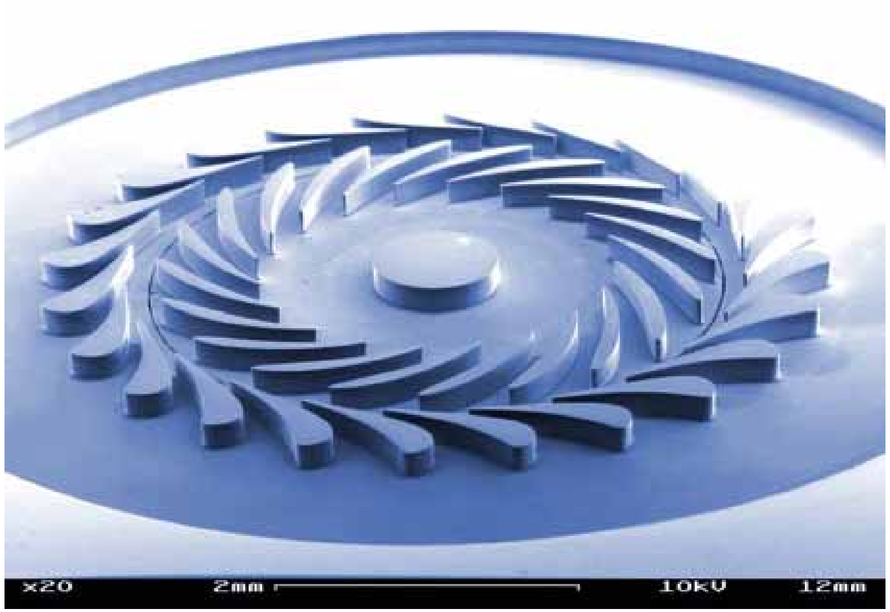


Fig.3 Perspective and cross sectional view of assembled the head chip

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

Microturbine in 1997



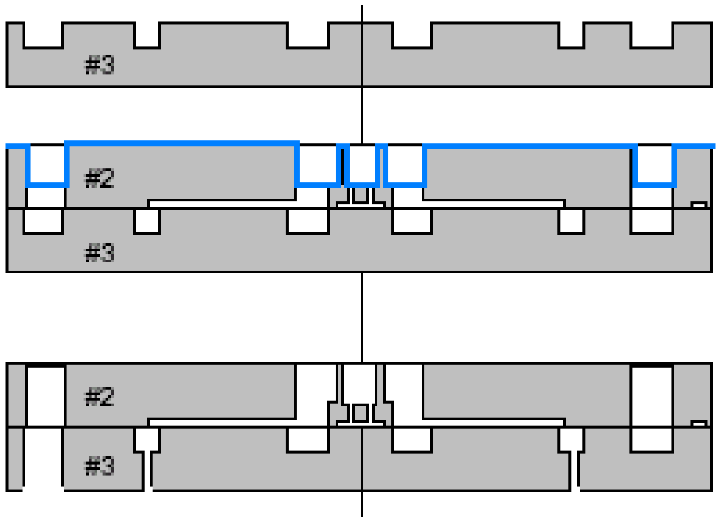
A. H. Epstein et al., Macro Power from Micro Machinery, Science, Vol.276, p.1211 (1997.5)

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

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

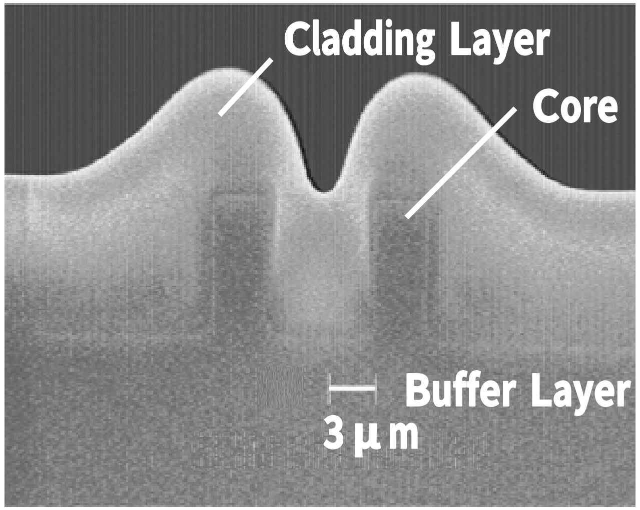
2) Bond RP to FEP, creating a tether attached to the rotor

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

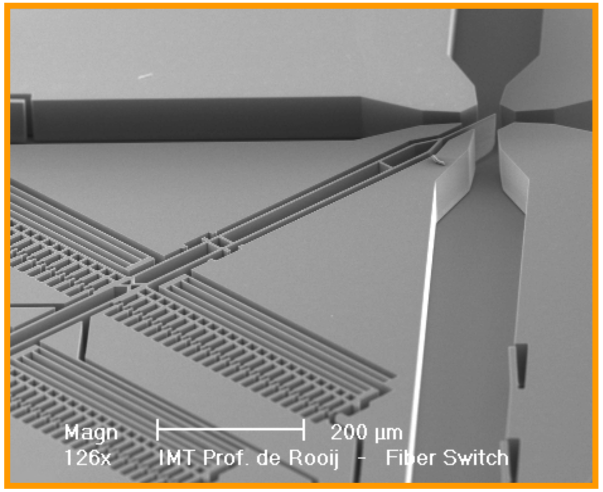


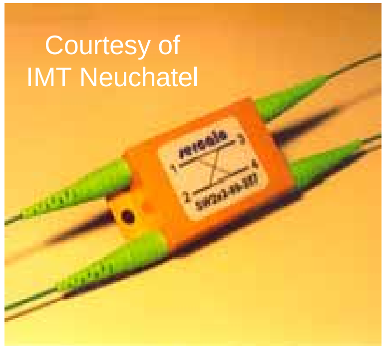
Waveguide & Optical MEMS Switch in 2000

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



Waveguide





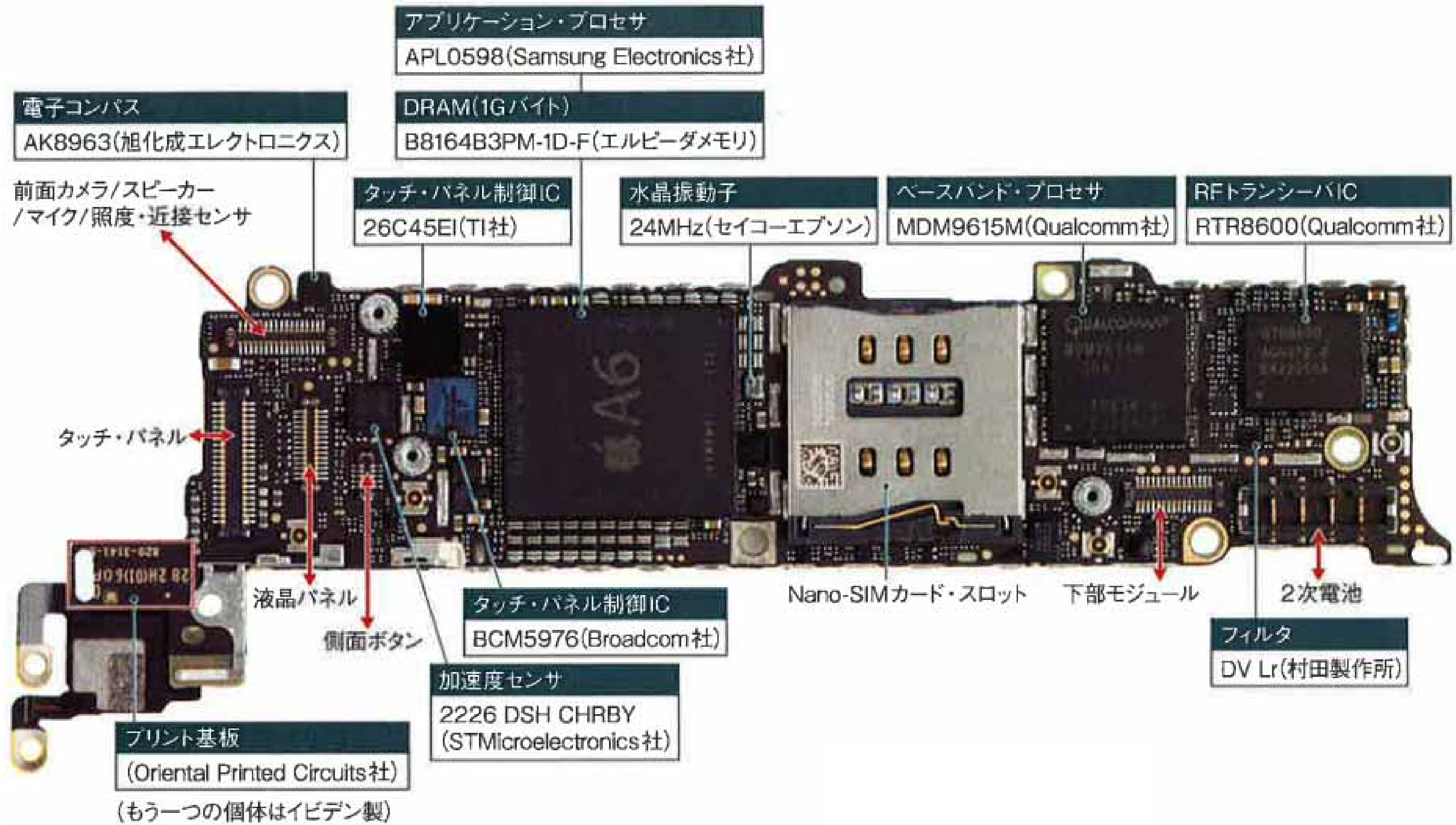
Optical MEMS Switch

The major revolution in MEMS technologies

......................N.F. de Rooij, Univ. of Neuchatel

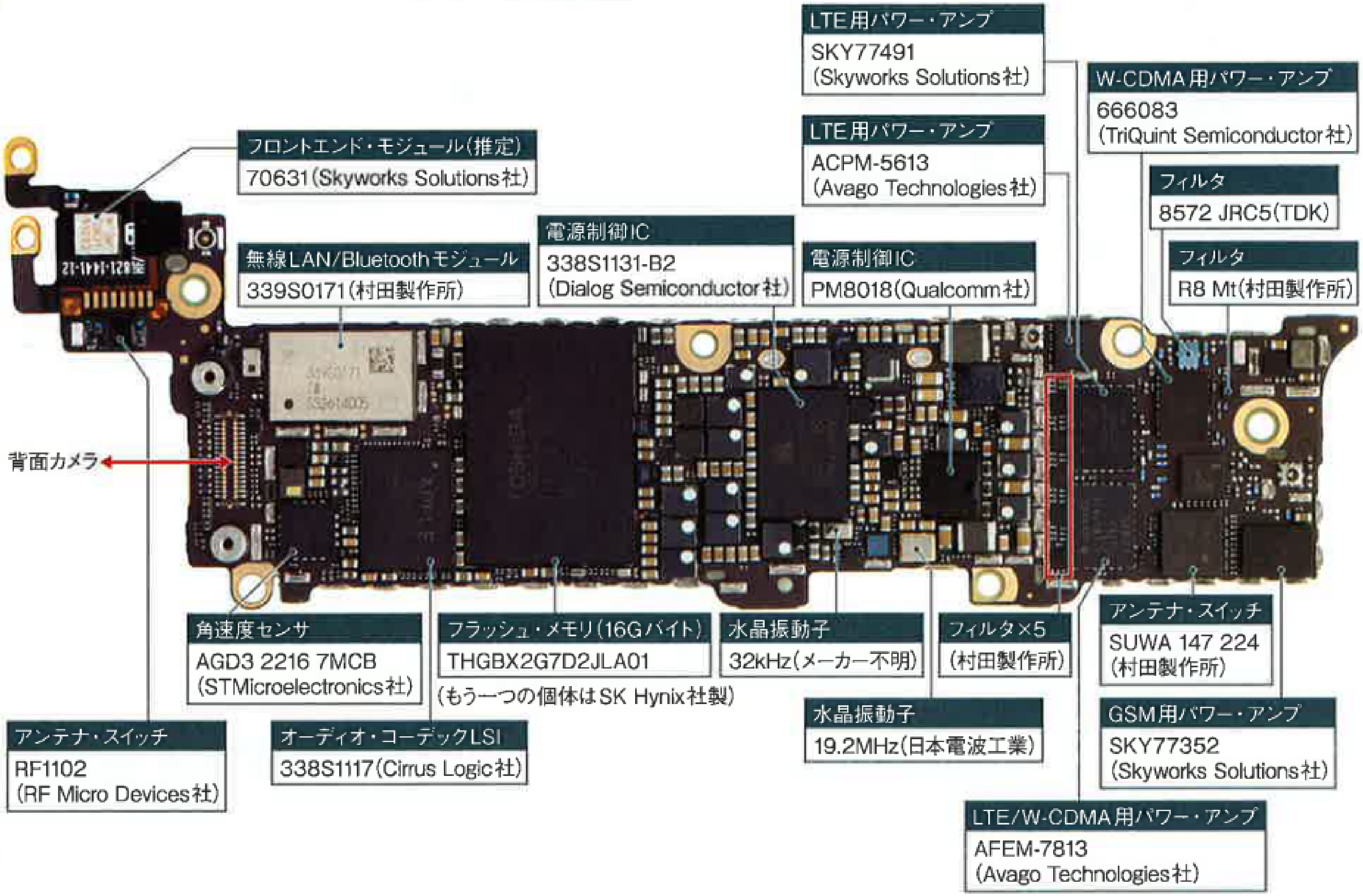
IEEE MEMS CONFERENCE 2004

Smart Phone (Apple - iPhone 5)



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

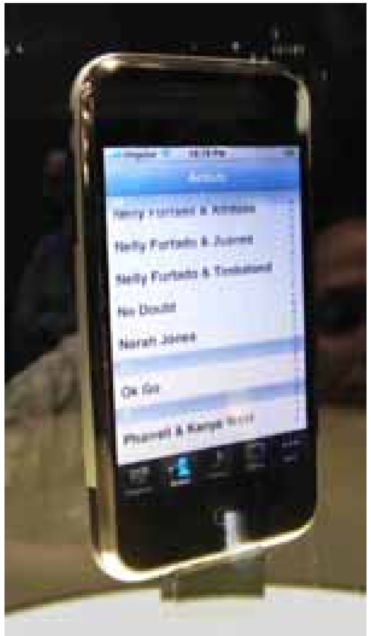
Smart Phone (Apple - iPhone 5)



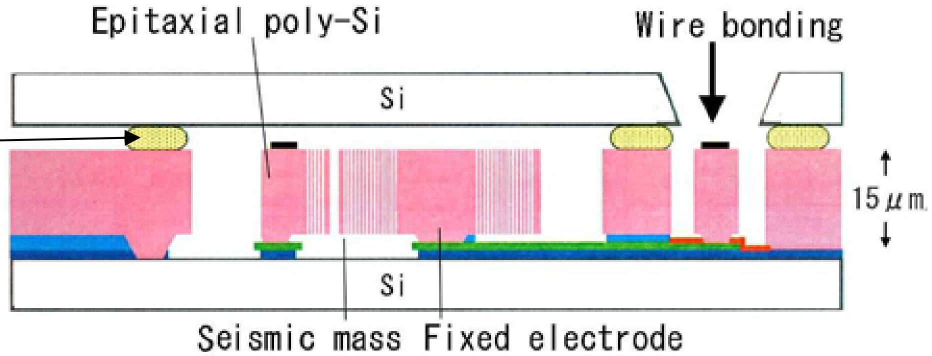
(Source: NIKKEI ELECTRONICS, October 15, 2012, pp13)

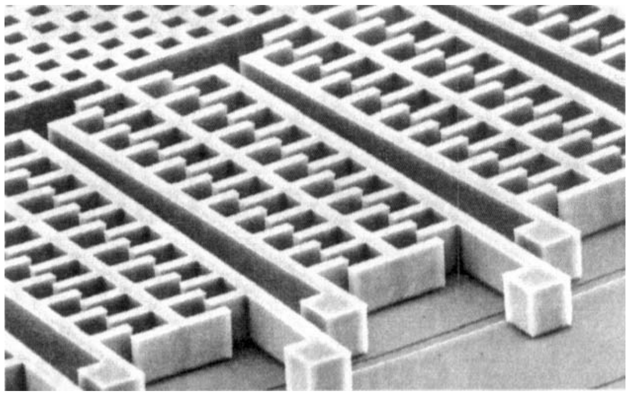
Devices for Smart Phone

~ Accelerometer ~



Frit glass seal

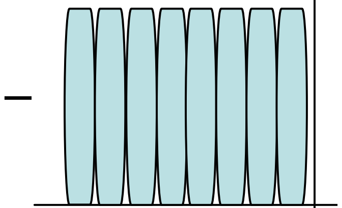




① Deposition of 125nm thick poly-Si seed layer on SiO_2 by LPCVD at 650℃.

② 15 μm thick poly-Si is grown in low pressure epitaxial reactor at 1000℃. Column like poly-Si with low stress (3MPa) and high deposition rate (0.4 – 0.7 μm / min).

Si epi layer



Low stress epitaxial poly Si

(M.Kirsten, B.Wenk (Fraunhofer-Inst.), F.Ericson, J.A.Schweitz (Uppsala Univ.) Thin Solid Films, 259 (1995) pp.181-187)

Accelerometer (ST Microelectronics)

(Courtesy of Prof. Esashi)

Devices for Smart Phone

~ MEMS Gyroscope, Motion and Magnetic Sensor ~

Gyroscope of STMicroelectronics

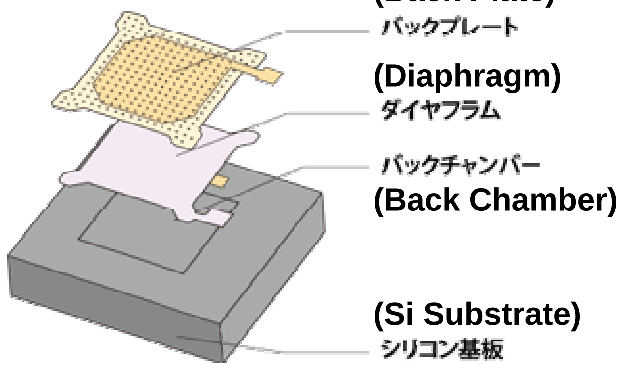
Motion and Magnetic Sensor of STMicroelectronics

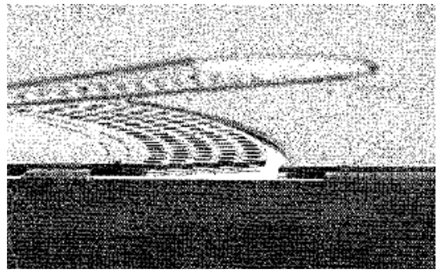
(http://www.st.com/internet/com/press_release/p3198.jsp)

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

Devices for Smart Phone

~ Si Microphone ~

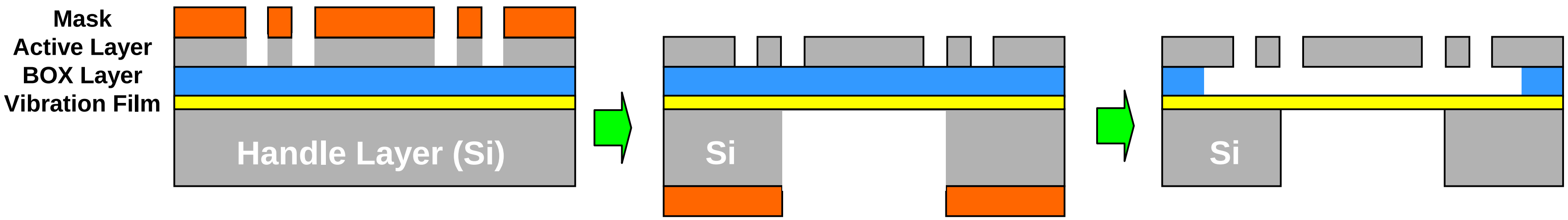




(Courtesy of Hitachi Haramachi Electronics)

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

Process Flow



Diaphragm <SOI Notch Free Etching>

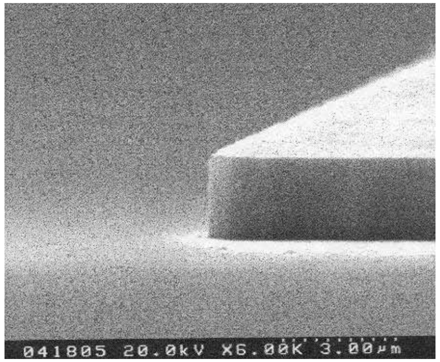
Cavity <High Rate Si-DRIE>

BOX Release <HF Vapor Etching>

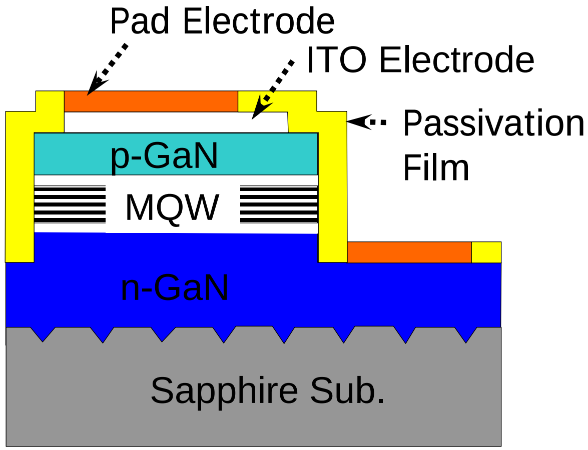
Devices for Smart Phone

~ LED ~

5 megapixel camera with LED flash in iPhone4



GaN Etching

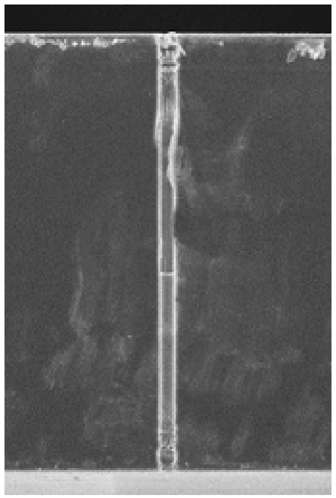


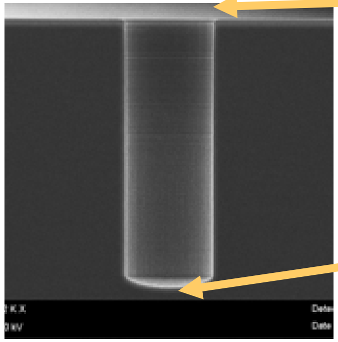
Devices for Smart Phone

~ Advanced Packaging - TSV ~

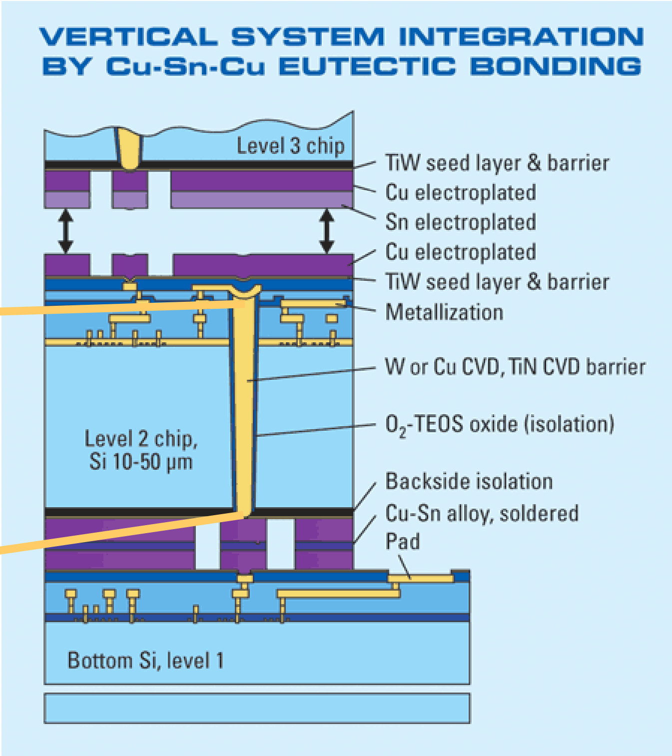
3D Interconnect

- 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)

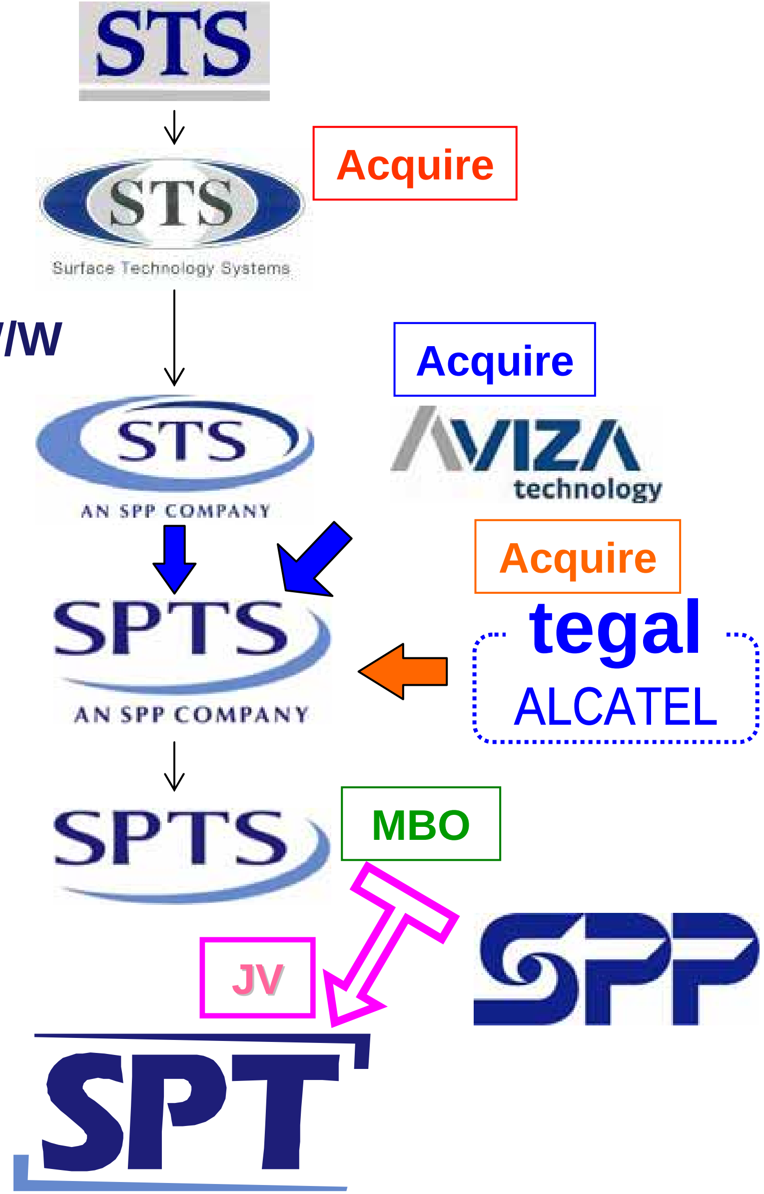
MEMS Process Technology

SPP, STS, SPTS & SPT

- **SPP:** **Sumitomo Precision Products**
- **STS:** **Surface Technology Systems**
- **SPTS:** **SPTS Technologies**
- **SPT:** **SPP Technologies**

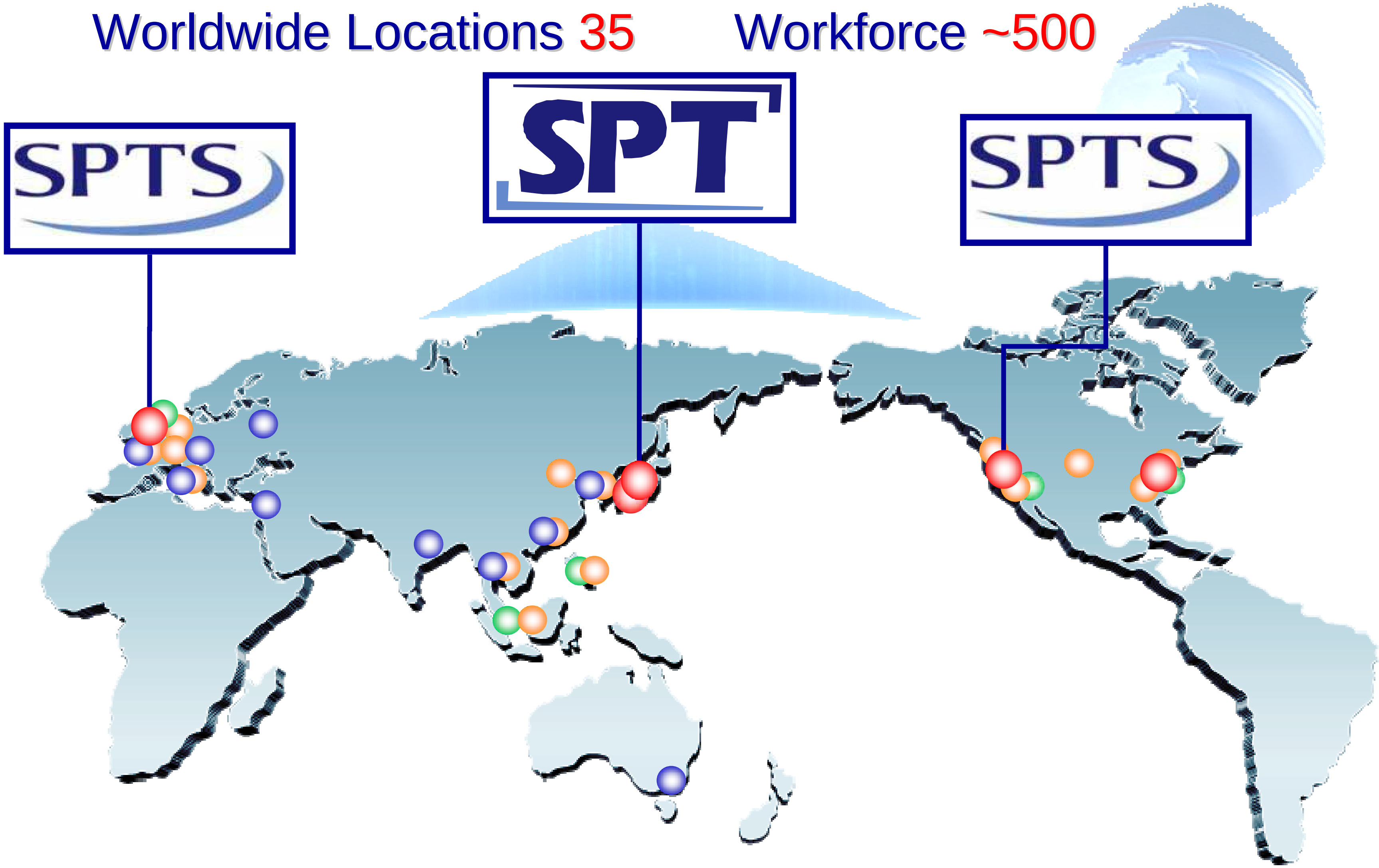
SPP/STS/SPTS/SPT - *Heritage and History*

- **February 1992**
  SPP represent STS in Japan
- **March 1995**
  SPP acquire STS
- **June 1995**
  STS ship 1st DRIE with Bosch process in W/W
- **December 2009**
  SPP acquire Aviza integrated with STS into SPP Process Technology Systems (SPTS)
- **February 2011**
  SPTS acquire Alcatel Micro Machining Systems business from Tegal
- **August 2011**
  SPTS transferred to the Management through MBO
- **December 2011**
  SPP and SPTS form joint venture, SPP Technologies (SPT) in Japan



SPT in Japan with JV of SPP / SPTS
SPTS outside Japan with SPP reinvestment

Worldwide Locations 35 Workforce ~500



Headquarters / Factories Sales offices Service Centres Sales Representatives

MEMS Process Technology

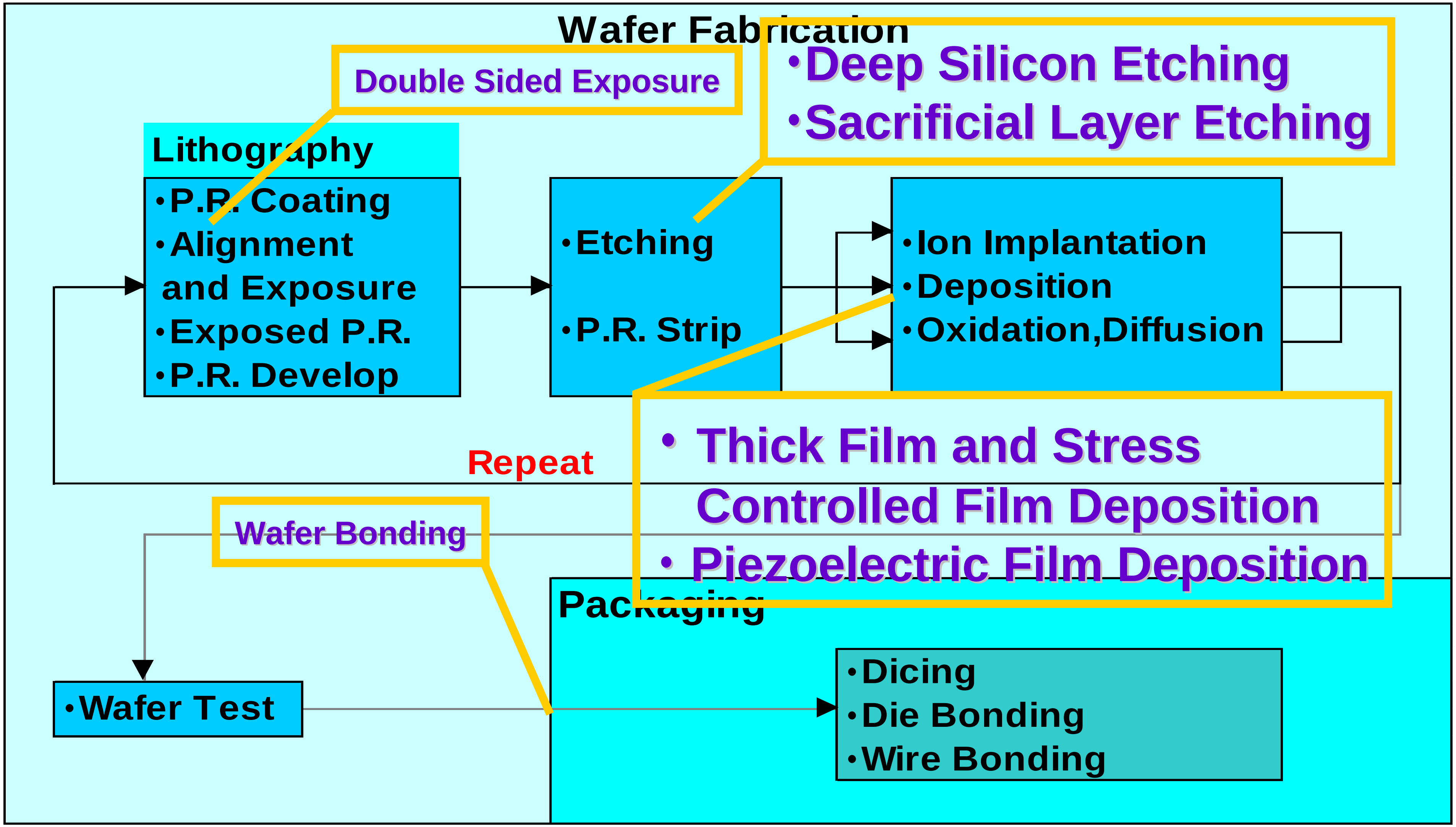
Key Technologies for MEMS Development

➔ Enabler

- **Deep Silicon Etching**
  ➔ DRIE (ICP + Bosch Process)
- **Sacrificial Layer Etching**
  ➔ SiO_2 / Si(XeF_2) Gas Etcher
- **Thick Film and Stress Controlled Film Deposition**
  ➔ SiO_2 and SiN PE-CVD
- **Piezoelectric Film Deposition**
  ➔ AlN Sputtering
- **Double Sided Exposure**
  ➔ Double Sided Contact Aligner
- **Wafer Bonding**
  ➔ Anodic Bonding

R&D and Commercialization by SPP/SPTS

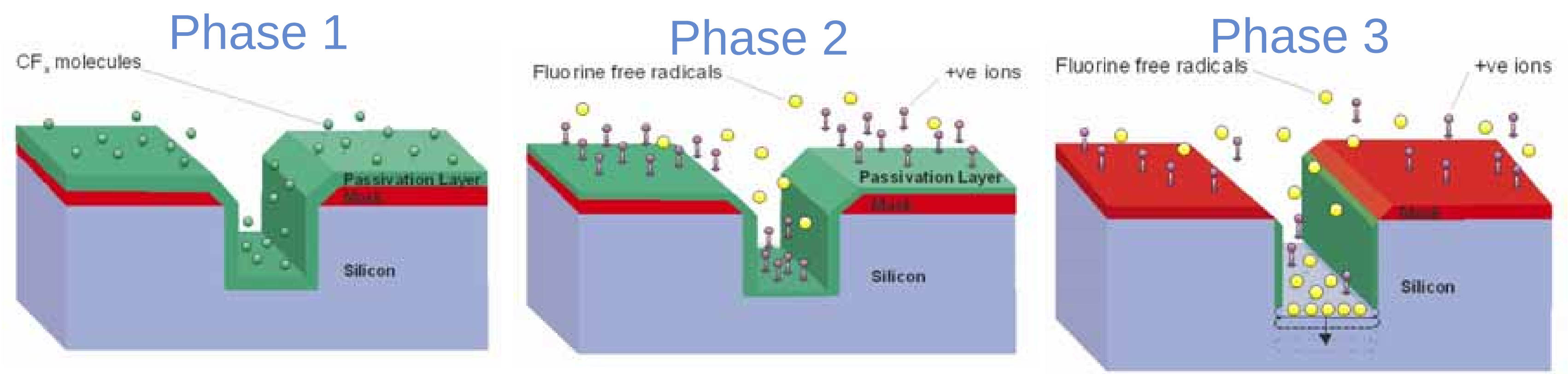
MEMS Manufacturing Flow



Bosch Process
&
ASE® (Advanced Silicon Etch)

DRIE Switched "Bosch Process"

- **Development of the process patented by Robert Bosch GmbH**
- **Passivation Step (C_4F_8 Plasma):**
  - **Phase 1: CF_n polymer from C_4F_8 plasma, deposited on all surfaces.**
- **Etch Step (SF_6 Plasma):**
  - **Phase 2: Polymer is removed from base at much higher rate than from side-walls by energy-controlled ions.**
  - **Phase 3: Exposed Si surfaces are etched by F radicals from the SF_6 plasma**



Passivation

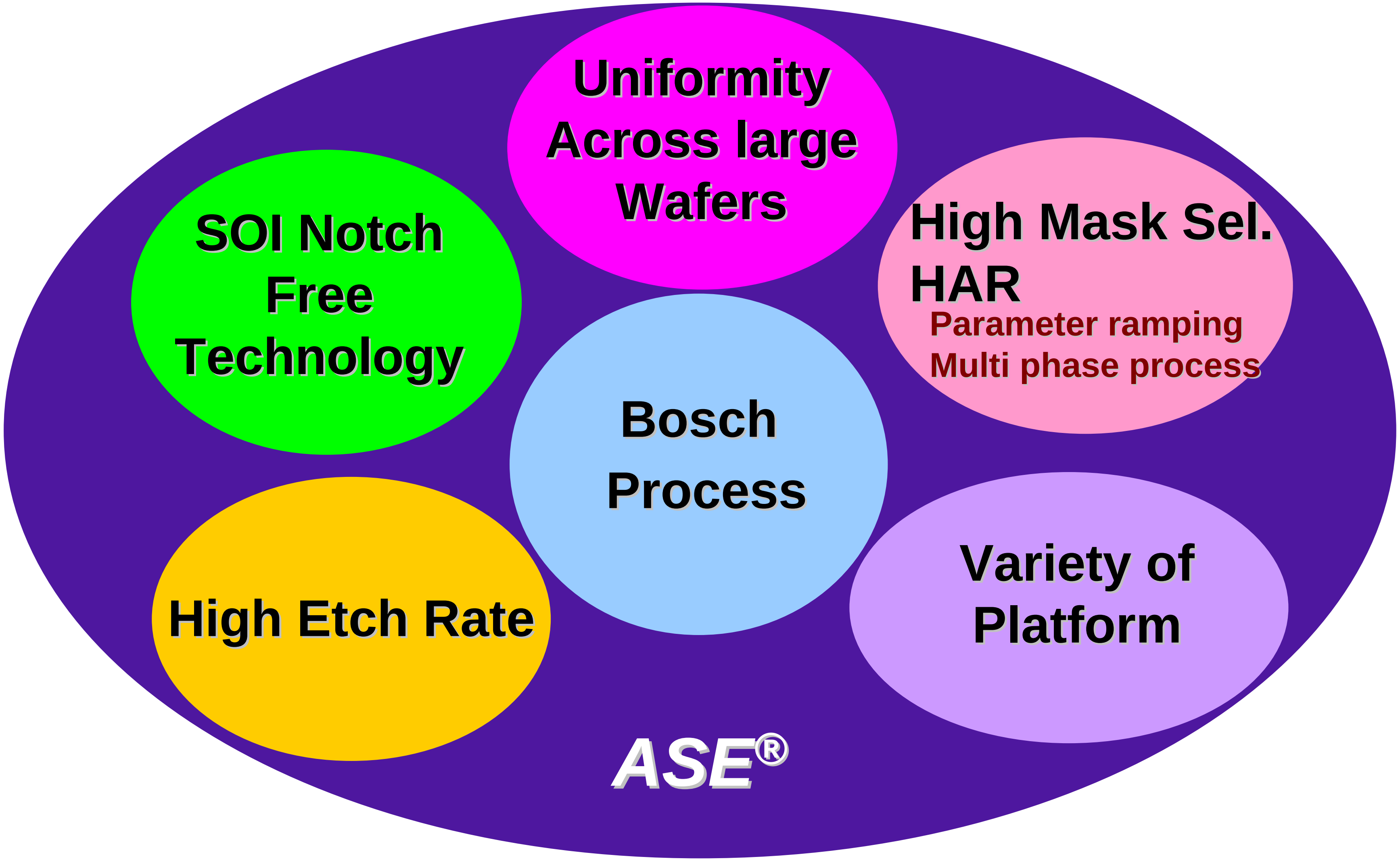
Passivation Removal

Etching

Back to Phase 1

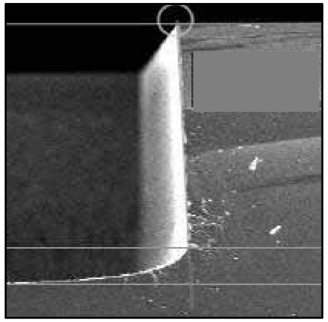
ASE® (Advanced Silicon Etch)

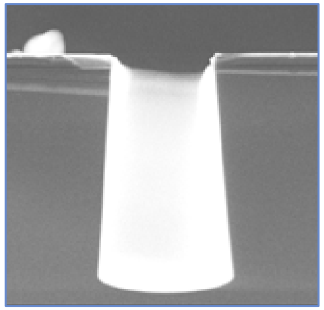
Enhanced “Bosch Process”



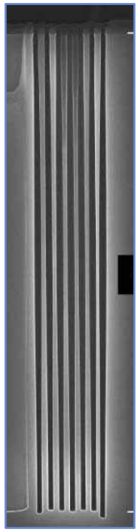
Leading DRIE Etching Capability

High Rate
Cavities, Caps,
ink-jets

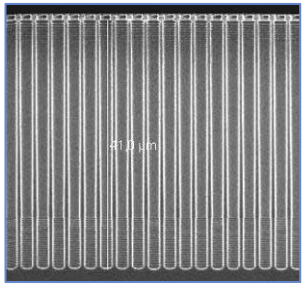




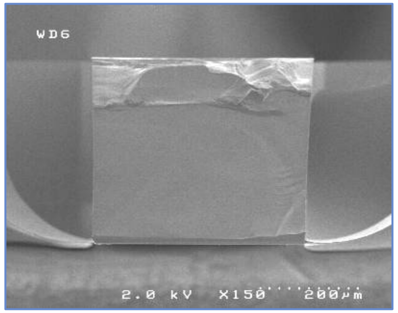
High Aspect Ratio
~0.4 µm trenches
100:1 AR



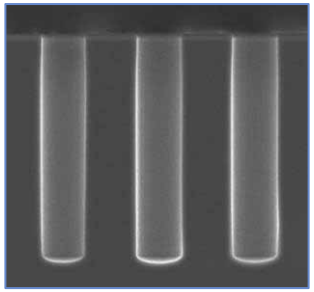
High Aspect Ratio
1.7 x 41 µm
24:1 AR

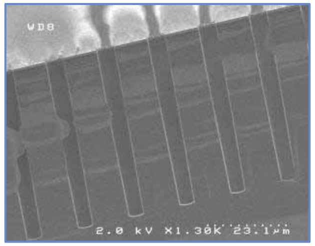


Through Wafer
Sensors
Microphones

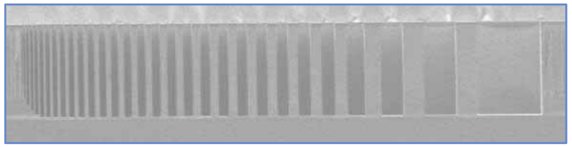


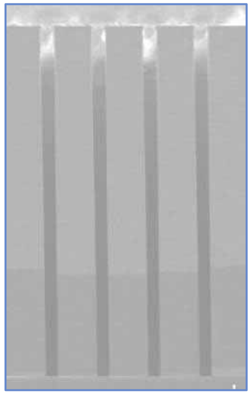
Scallop Free
<6nm 'waves'



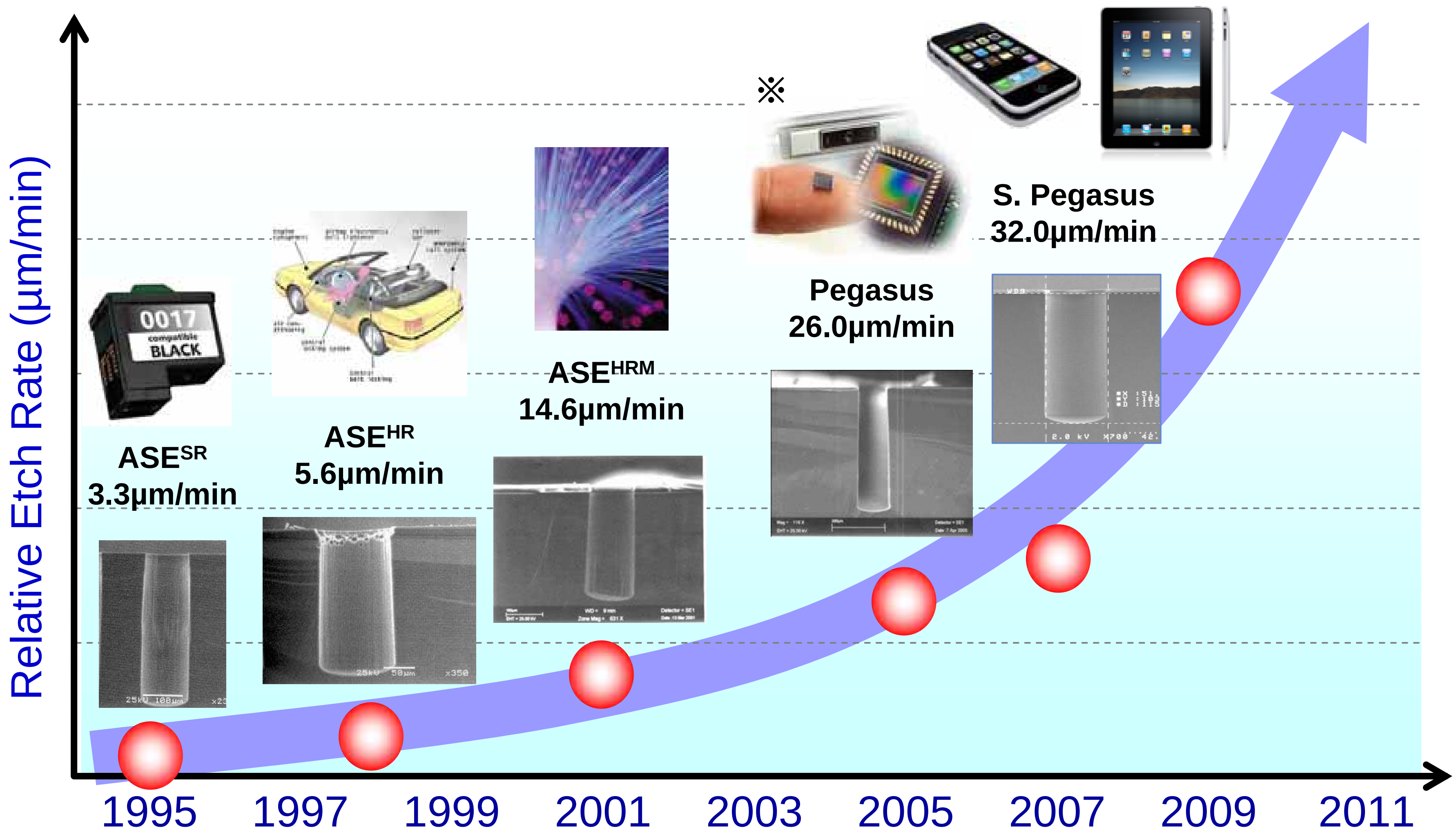


SOI
3 x 50 µm
17:1 AR





Continuous Evolution



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

***ASE®-Pegasus*: Deep Si Etcher**

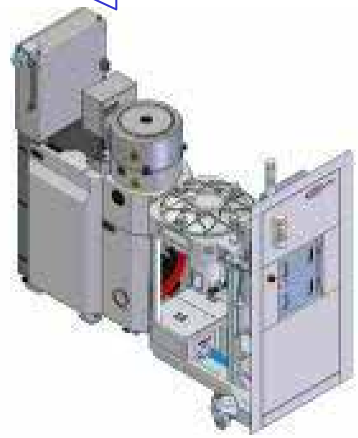
VPX ASE-Pegasus

- ***Pegasus* – SPT/SPTS' 4th Generation DRIE system**
- **Incorporates key *ASE®* technology features:**
  - **Patented Parameter Ramping capability**
  - **Unique Plasma Source Enhancer**
  - **Smooth Sidewall technology**
  - **Patented SOI Capability**
- **Leading the way in DRIE Technology**
  - **Exceptional process performance**
  - **Unparalleled throughput**

Platform(φ3inch～φ8inch)

Single Process Module

Multi Process Module



MUC-21 (MPX)

MUC-21 with MACS

VPX

CPX

R&D → Pilot Production → Volume Production

Release a New Si DRIE "*Predeus*"

- Release a New Si DRIE "Predeus " as the integration of *ASE*® (DRIE)

PREcise **D**eep-silicon etch with **E**xcellent **U**niformity of **S**pt

- Addition "Predeus " to "*Pegasus*" and "*Super-Pegasus*" as current line-up

CPX Predeus

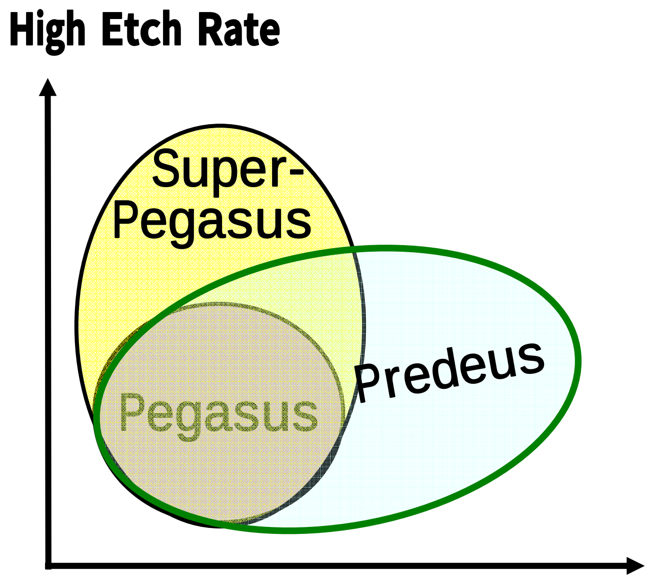
<New Technologies>
- New Plasma Source with Good Uniformity
- New quick Gas Switch System

<Capability: User Merits>
- Etching with high Precision
- Etching with Good Uniformity
- Low Scallop and High Rate Etching

<Applications>
- MEMS Devices with high Precision
- Current MEMS Devices (Yield Improvement)
- Power Devices etc

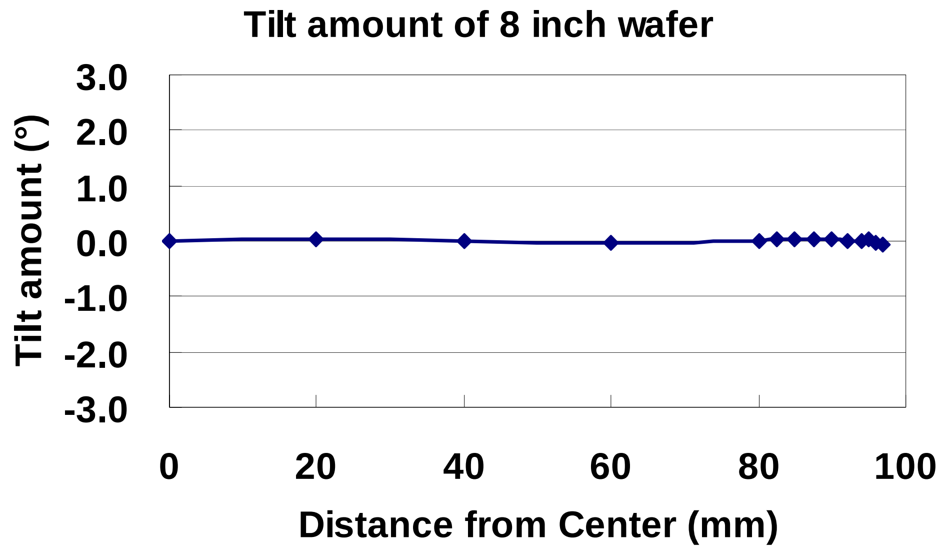
Capability of New **Si DRIE *"Predeus"***

Positioning (Capability)



- Good Uniformity
- Good Controllability of Profile
- Tilt Free

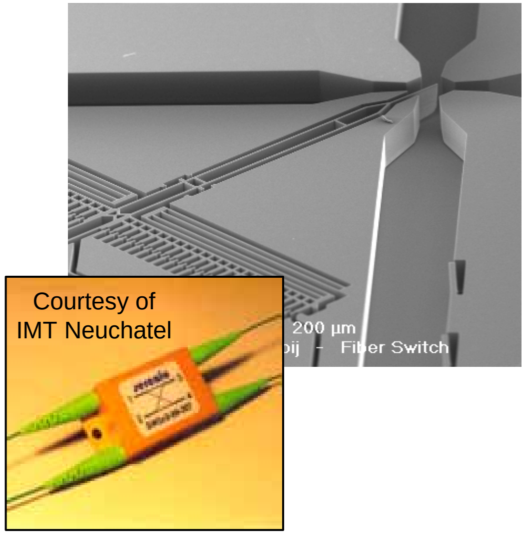
Process Capability (Tilt Amount)



Achieved below 0.1 deg. Tilt Amount at 3 mm edge cut of 8 inch wafer

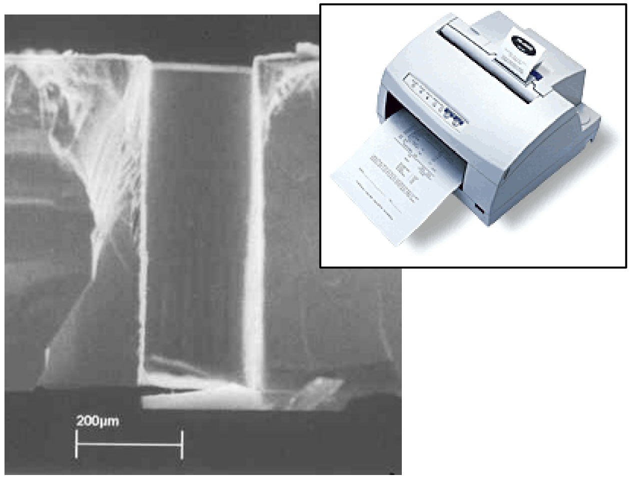
ASE®:An Enabling Process for MEMS& IC

Optical MEMS

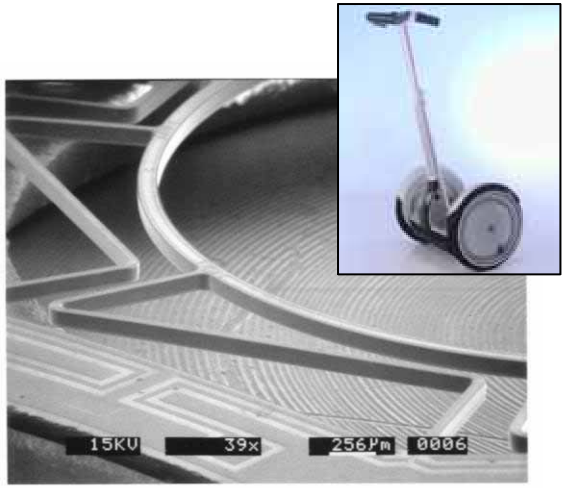


Inertial MEMS

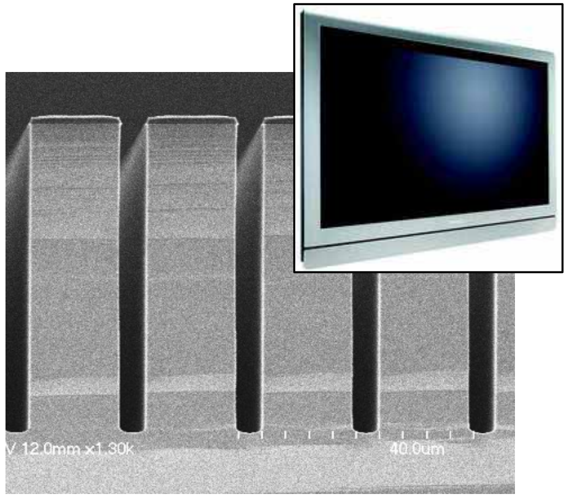
Si Microphone



Ink Jet Head Device

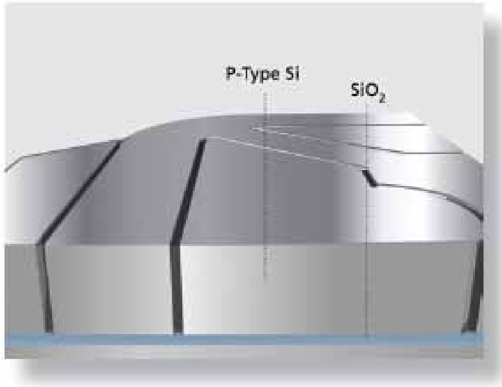


Gyro Sensor

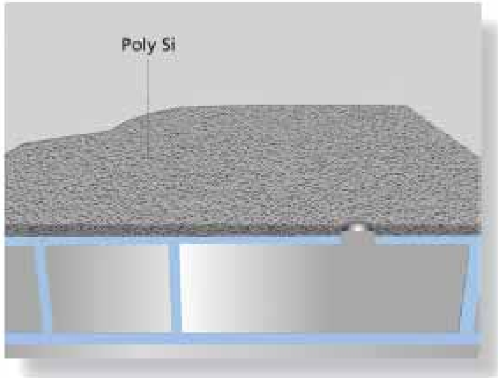


Power Device Isolation

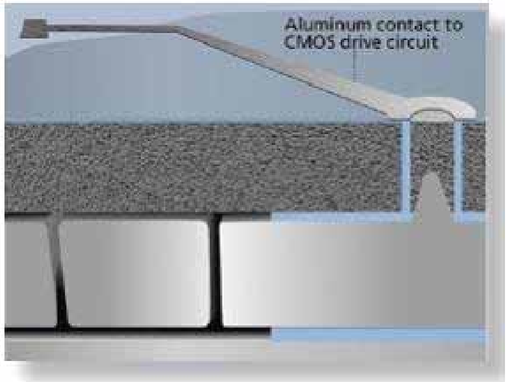
~ SiTime: DRIE and Sacrificial Layer Etching ~



Si-DRIE

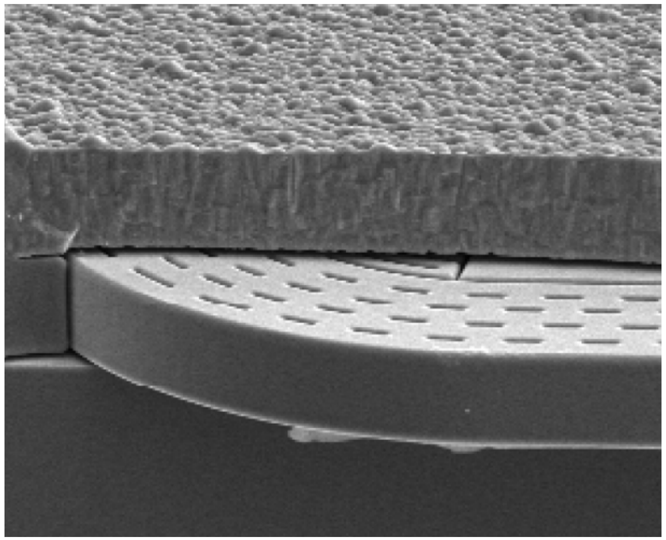


Oxide layer fill→ poly-Si Cap



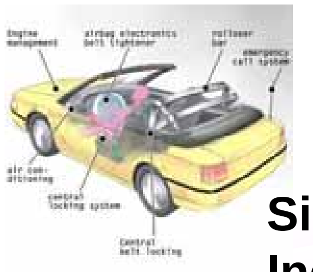
Etching & release Thick poly-Si Cap

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

RF MEMS De-coupling capacitors

Advanced Packaging

MEMS

Commercial Applications

Micro Fluidics ‘Lab on a chip’

MEMS Pressure sensors

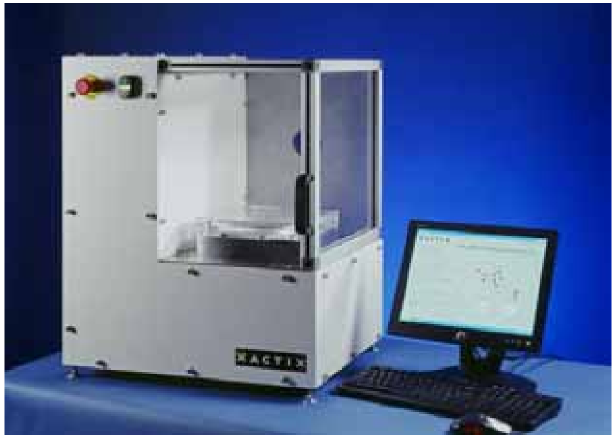


Power Devices

Equipment for R&D

Equipment for R&D

Si Deep RIE	Si Sacrificial Layer Etcher (XeF_2)	SiO_2 Sacrificial Layer Etcher (HF)



MUC-21 ASE-SRE

Xetch e1

Primaxx-uEtch

Low price & high performance model for R&D

MEMS Business Model

MEMS Business Model

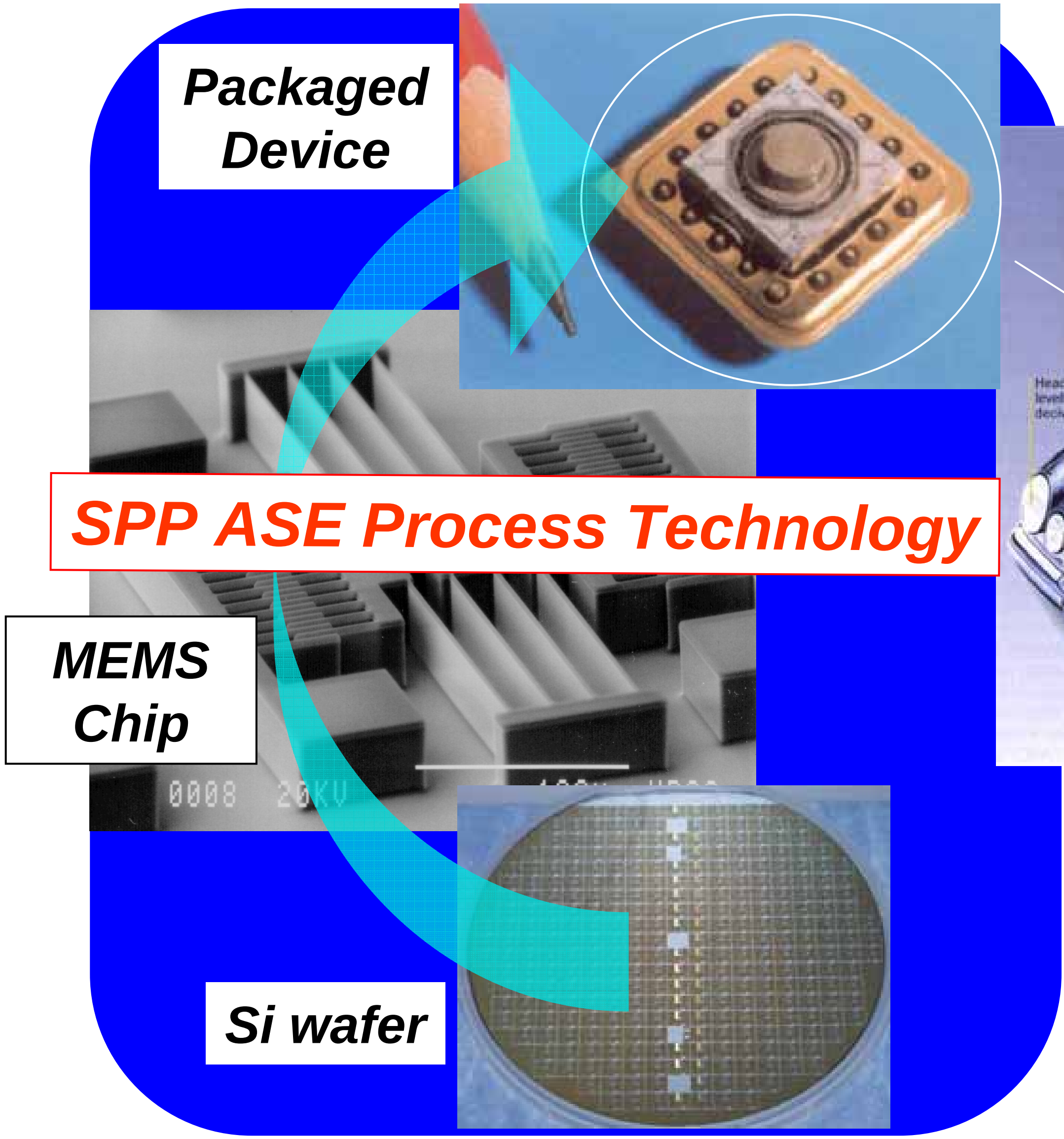
- **Variety of MEMS device**
  - Originality is important in each business model
  - Individual Speciality is needed
- **MEMS has broader industrial application**
  - Key to make commercialization possible in each application
  - Collaboration among Industry, Government and Academia: New Development
  - Collaboration between Industries: Commercialization
- **MEMS Business Model is different from Semiconductor**

One Device, One Process, One Package

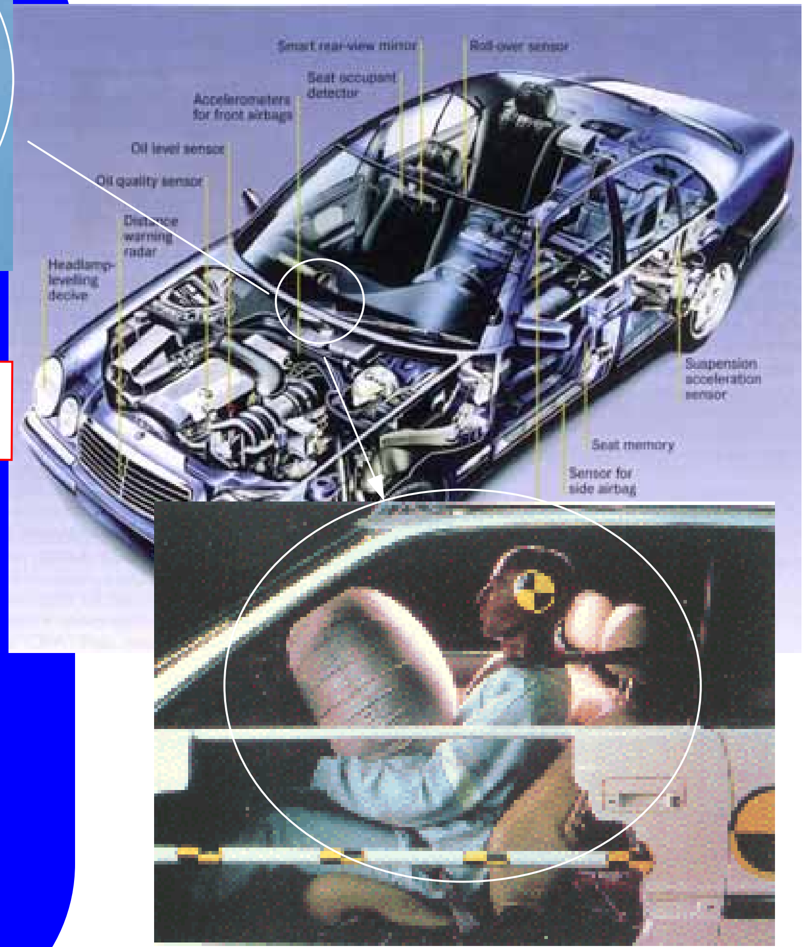
  - Inertial sensor (Accelerometer, Gyro sensor)
  - Microphone
  - Ink Jet Head
  - Micro-display

➔ All are MEMS, but the manufacturing methods are different

MEMS - 1 Device,1 Process,1 Package

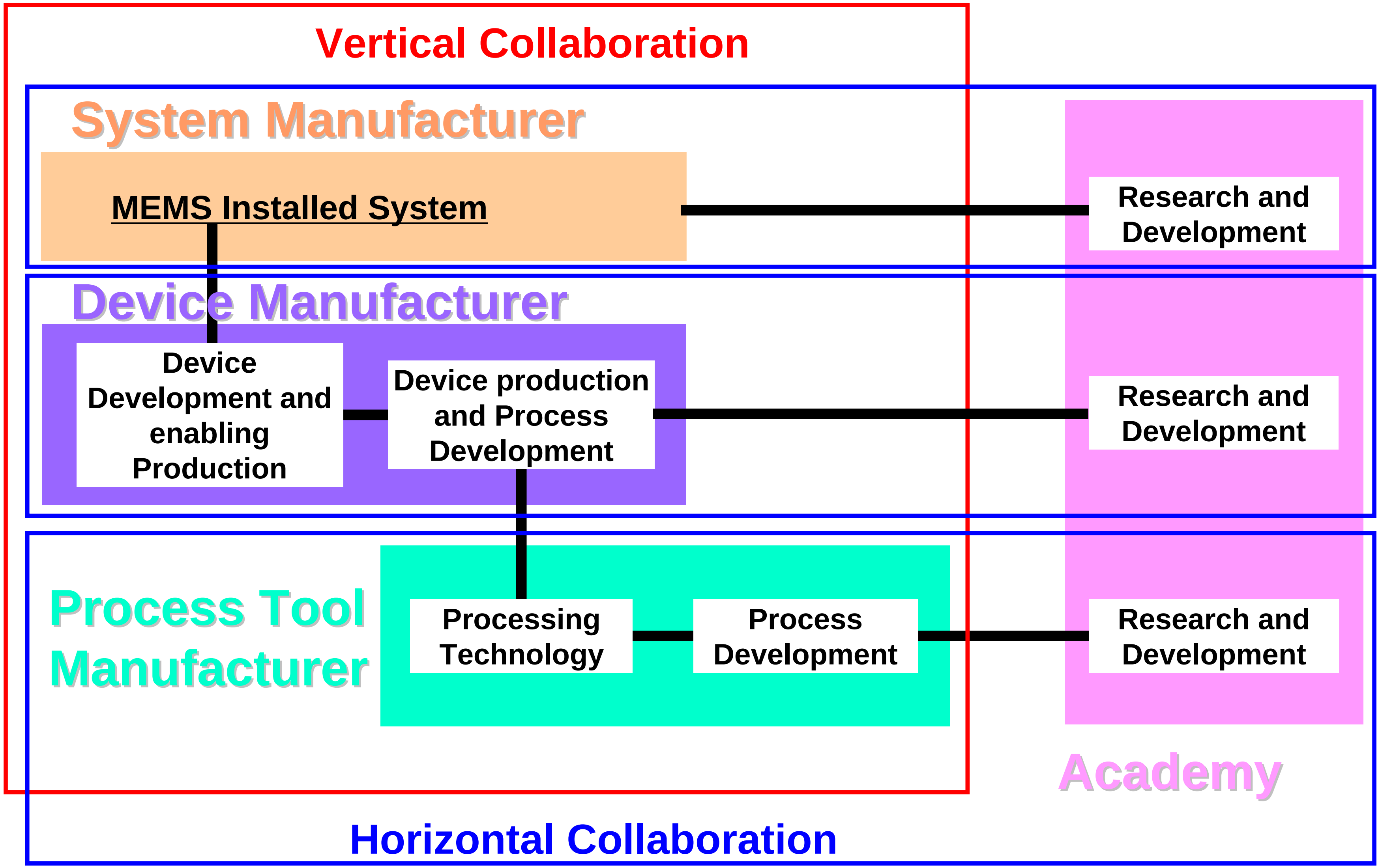


System Integration



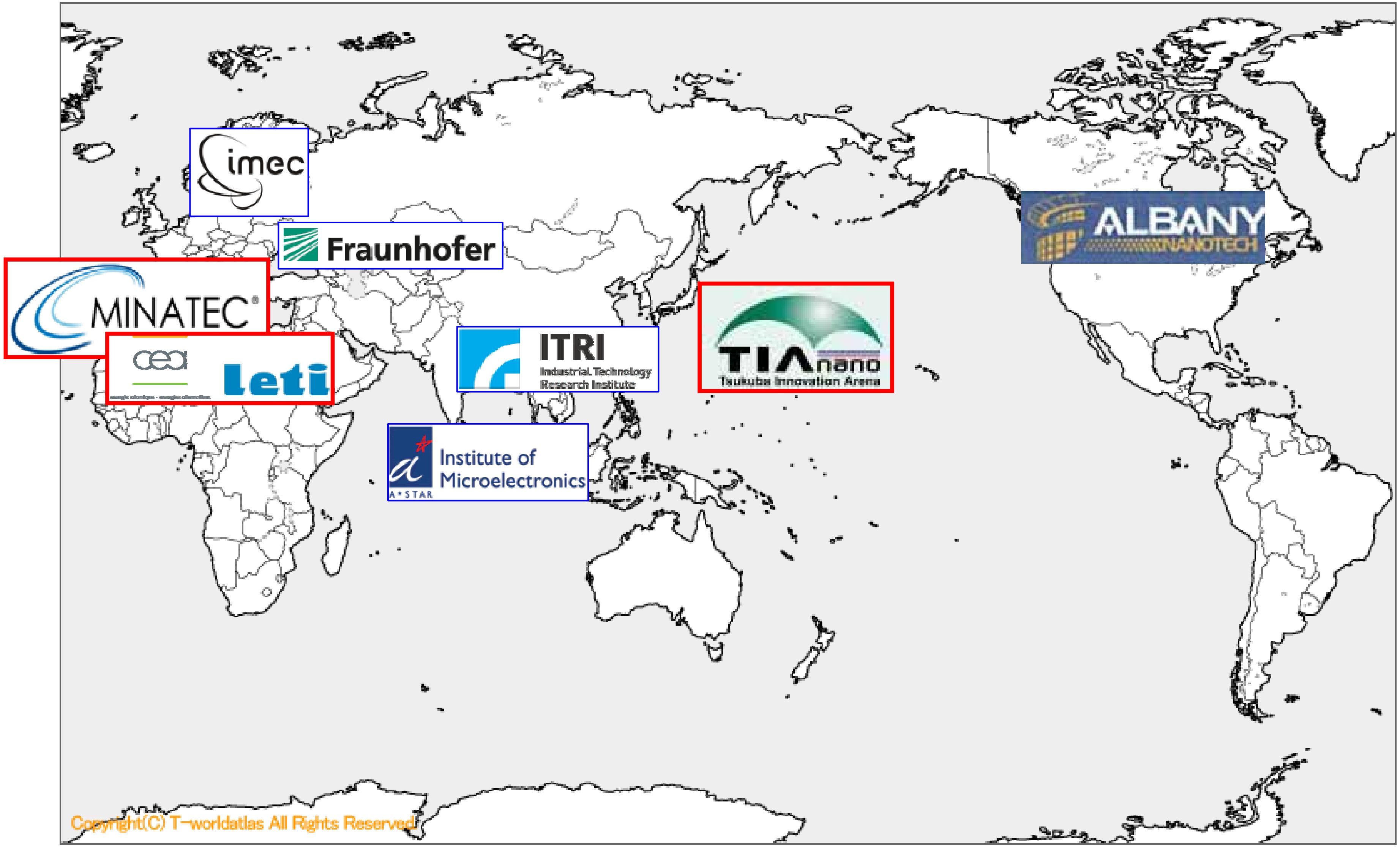
Application

MEMS - 1 Device,1 Process,1 Package



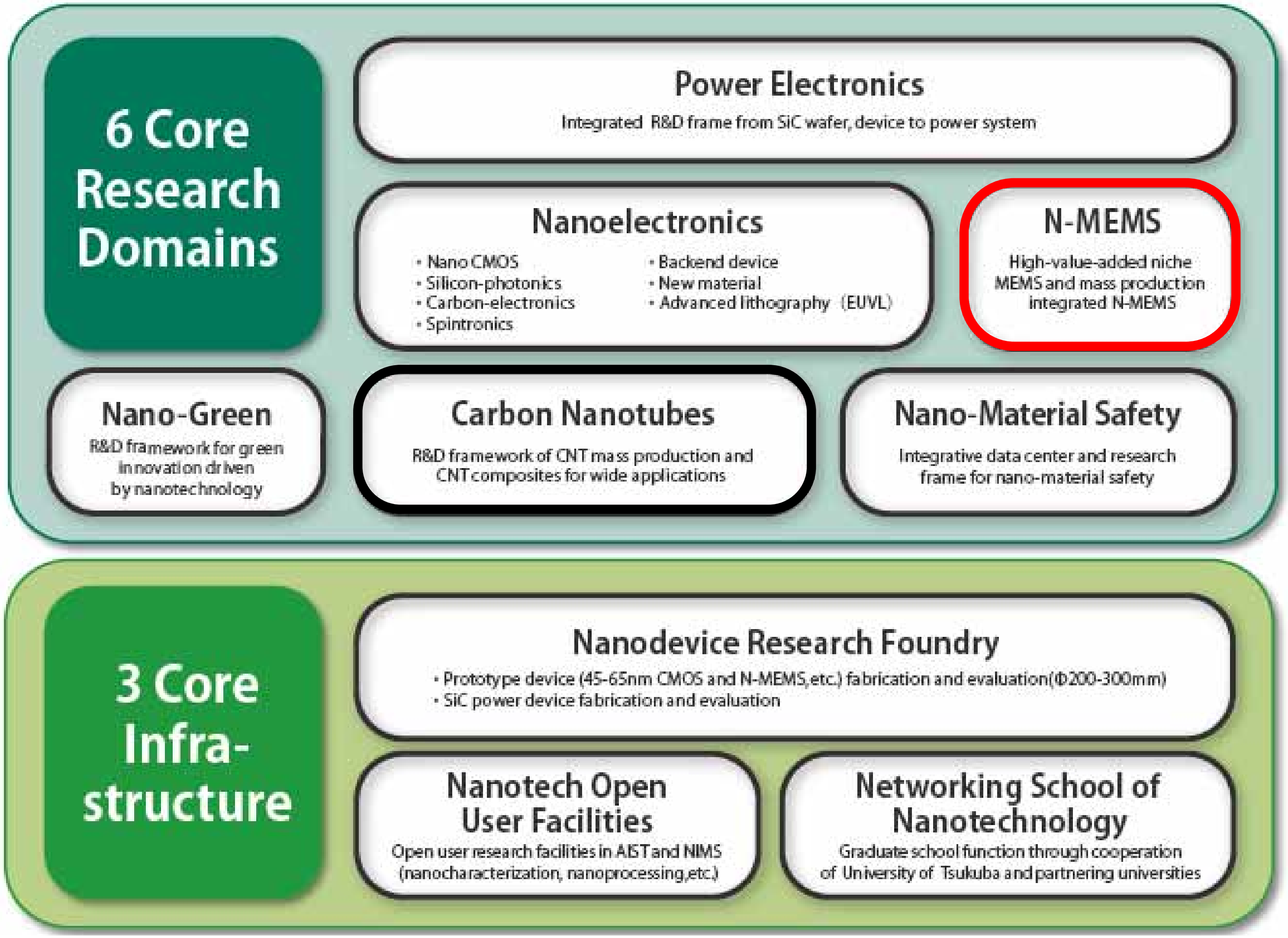
Relations with Worldwide Nanotech Centers

Worldwide Nanotech Centers



Tsukuba Innovation Arena (TIA)

Tsukuba Innovation Arena (TIA)



(http://tia-nano.jp/brochure/TIA_e.pdf)

Support to Formulate a Pilot Foundry

SPP installed 3 systems to TIA N-MEMS for prototyping service for rapid from R&D to production

Si Deep RIE
「VPX Pegasus300」

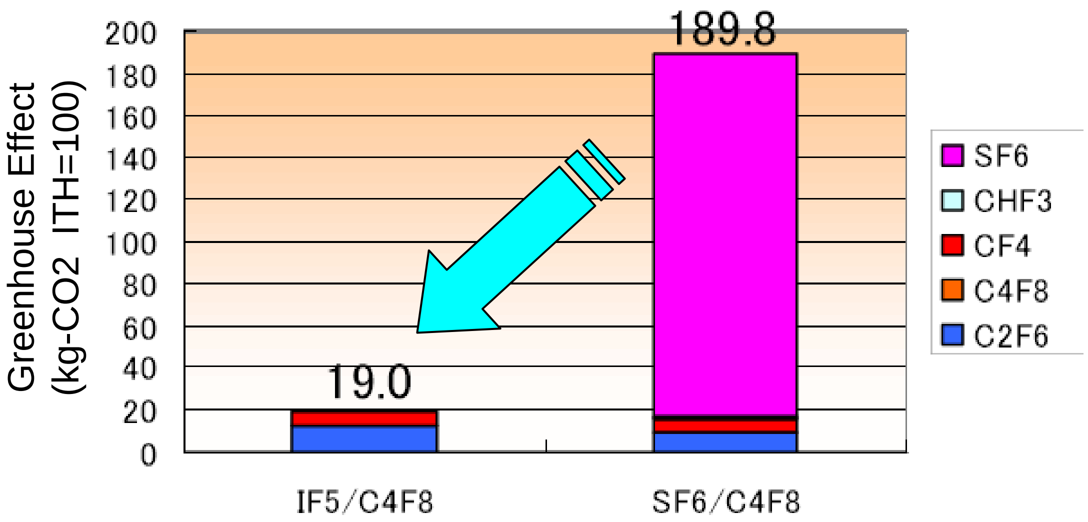
Si Deep RIE
「MUC-21 Pegasus」

Scanning Probe Nano Lithography
「MPS-1000」

~ Evaluation of IF_5 as alternative gas of SF_6 ~

1. Greenhouse Effect

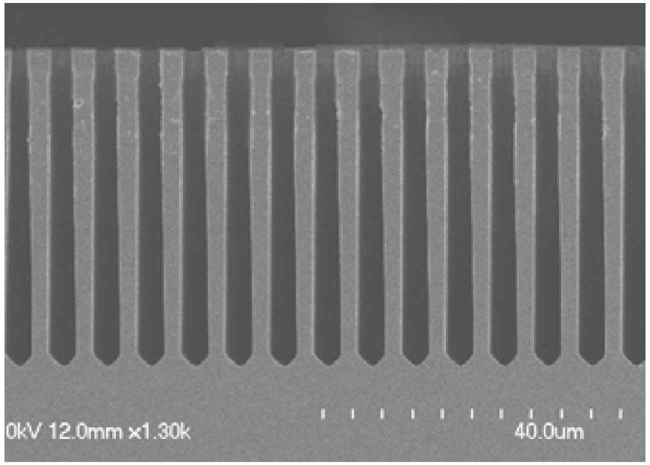
(Comparison of exhaust gas analysis)



90% reduction using IF_5 gas

2. Etching Results

- Trench pattern : 3 µm
- Etching depth : 42.6 µm
- Aspect ratio : 14



Achieved high aspect ratio (14) etching profile using IF_5 gas

(Courtesy of AIST and Taiyo Nippon Sanso)

Collaboration between CEA-Leti and SPTS/SPP

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

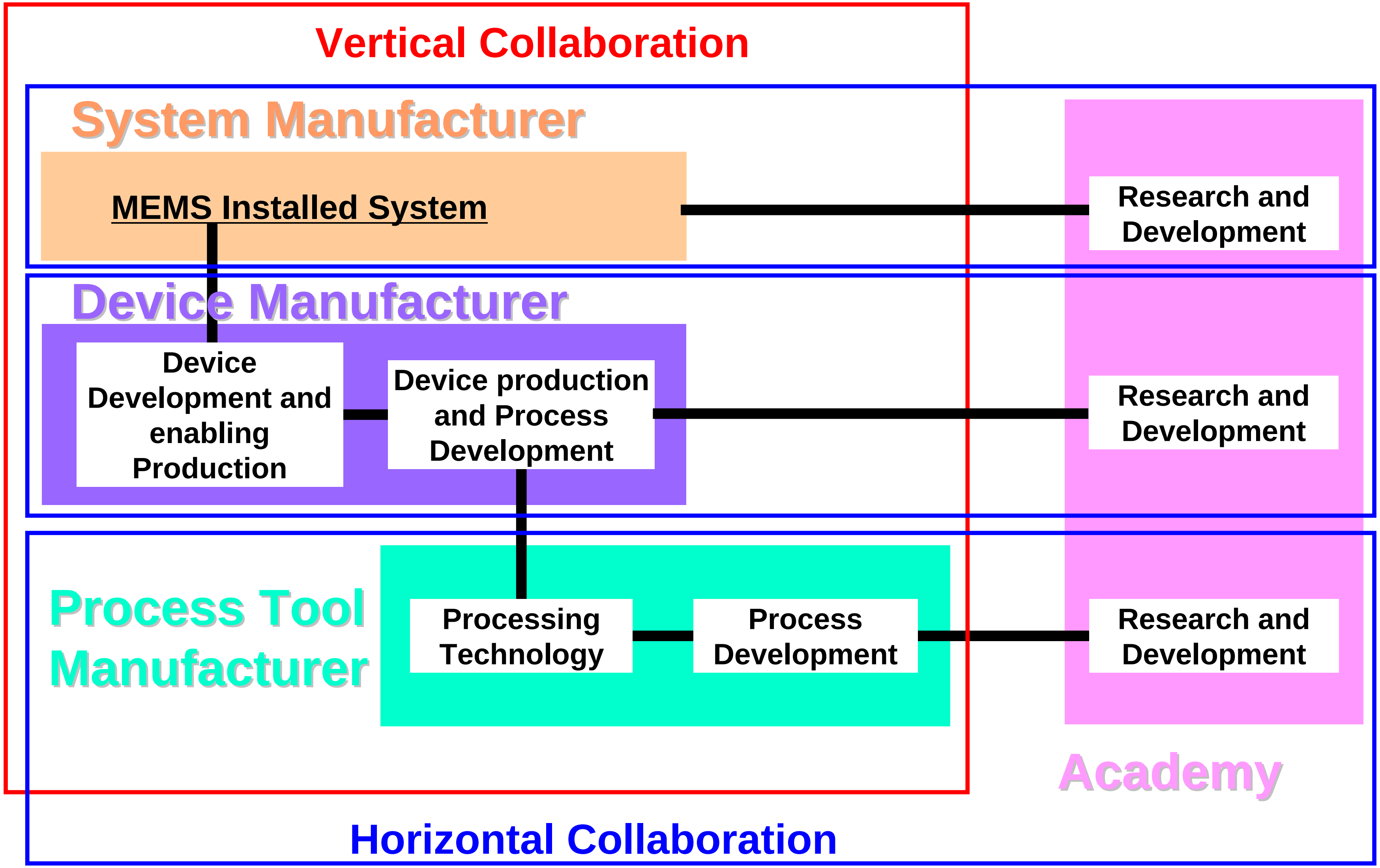
TOKYO, Japan, and GRENOBLE, France – Oct. 6, 2010 – CEA-Leti and SPP Process Technology Systems (SPTS) today announced an agreement to develop advanced 300mm through-silicon via (TSV) 3D-IC processes at CEA-Leti's 300mm facilities in Grenoble, France. The agreement defines their collaboration on a range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

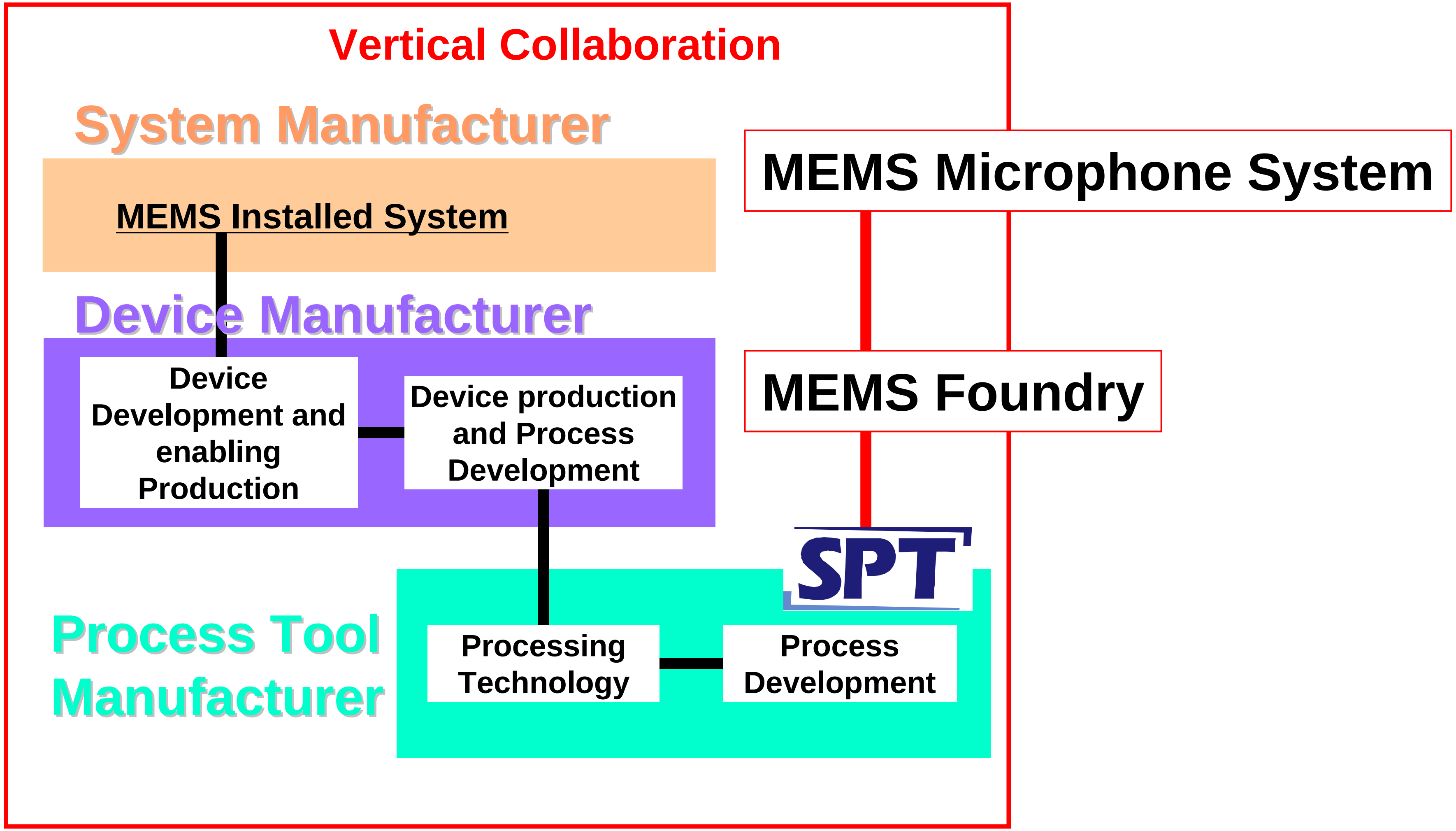
The partners will research alternative hardware and processes to address the need for new methods of cost-effective via fill. In some via-middle applications, where the via is created between contact and first back end of line (BEOL) metal layer, via aspect ratios may extend beyond 10:1, and these very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

MEMS - 1 Device,1 Process,1 Package




Vertical Collaboration
System Manufacturer
MEMS Installed System
Device Manufacturer
Device Development and enabling Production
Device production and Process Development
Process Tool Manufacturer
Processing Technology
Process Development
MEMS Microphone System
MEMS Foundry

MEMS Improving Our Lives

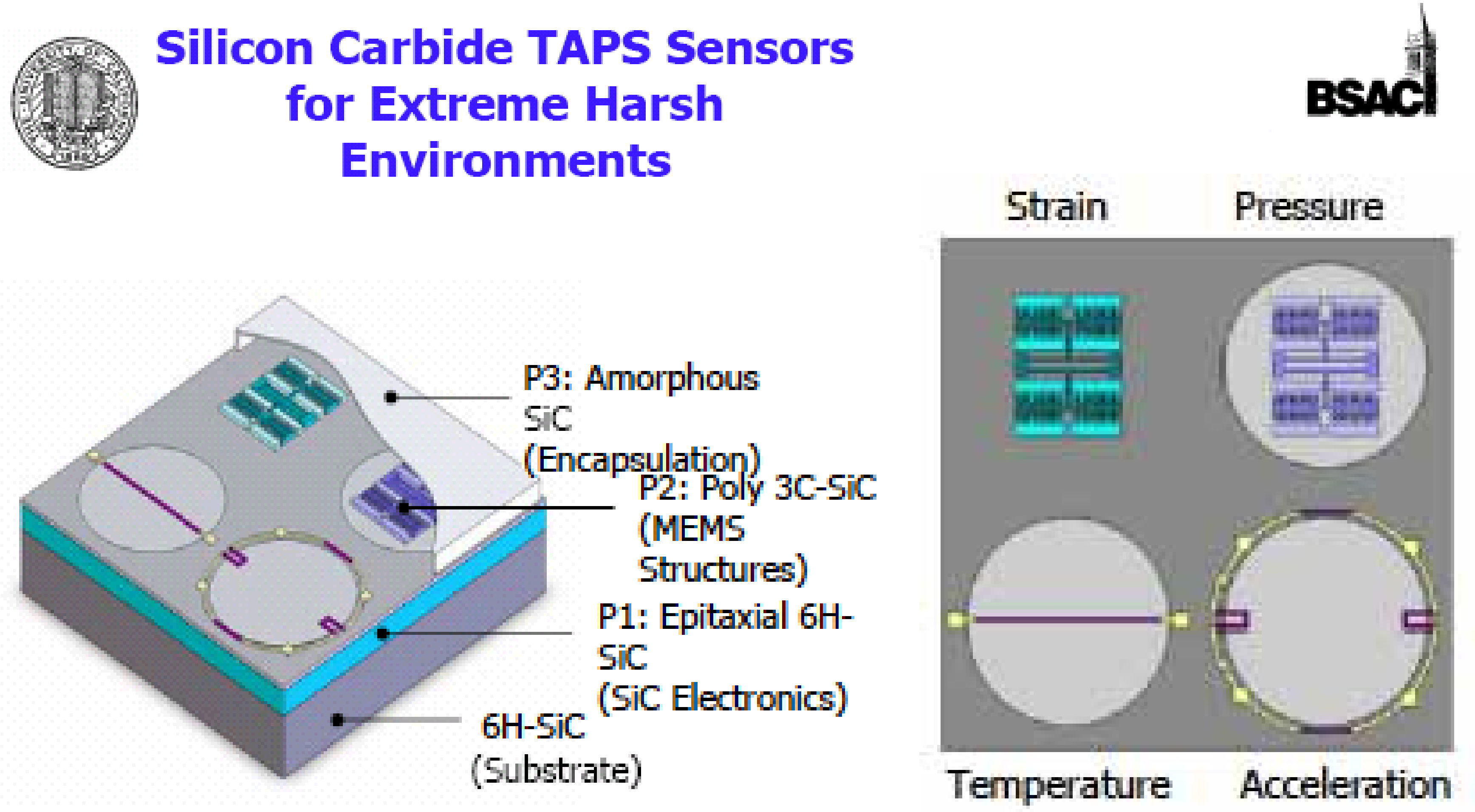
MEMS Improving Our Lives

- MEMS sensors contribute to improving society ;

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

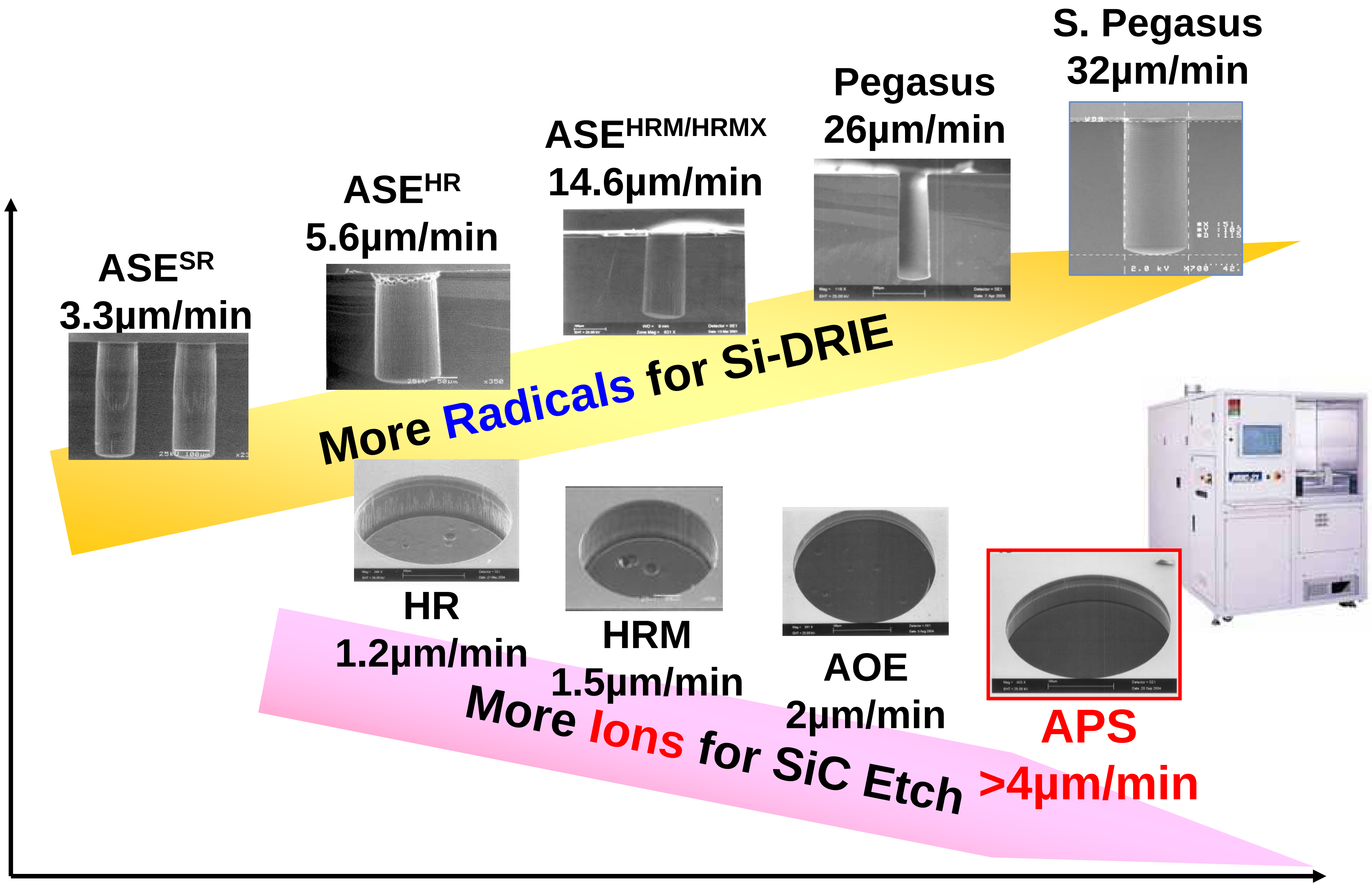
Motivation for SiC Etch :

MEMS for Harsh Environment



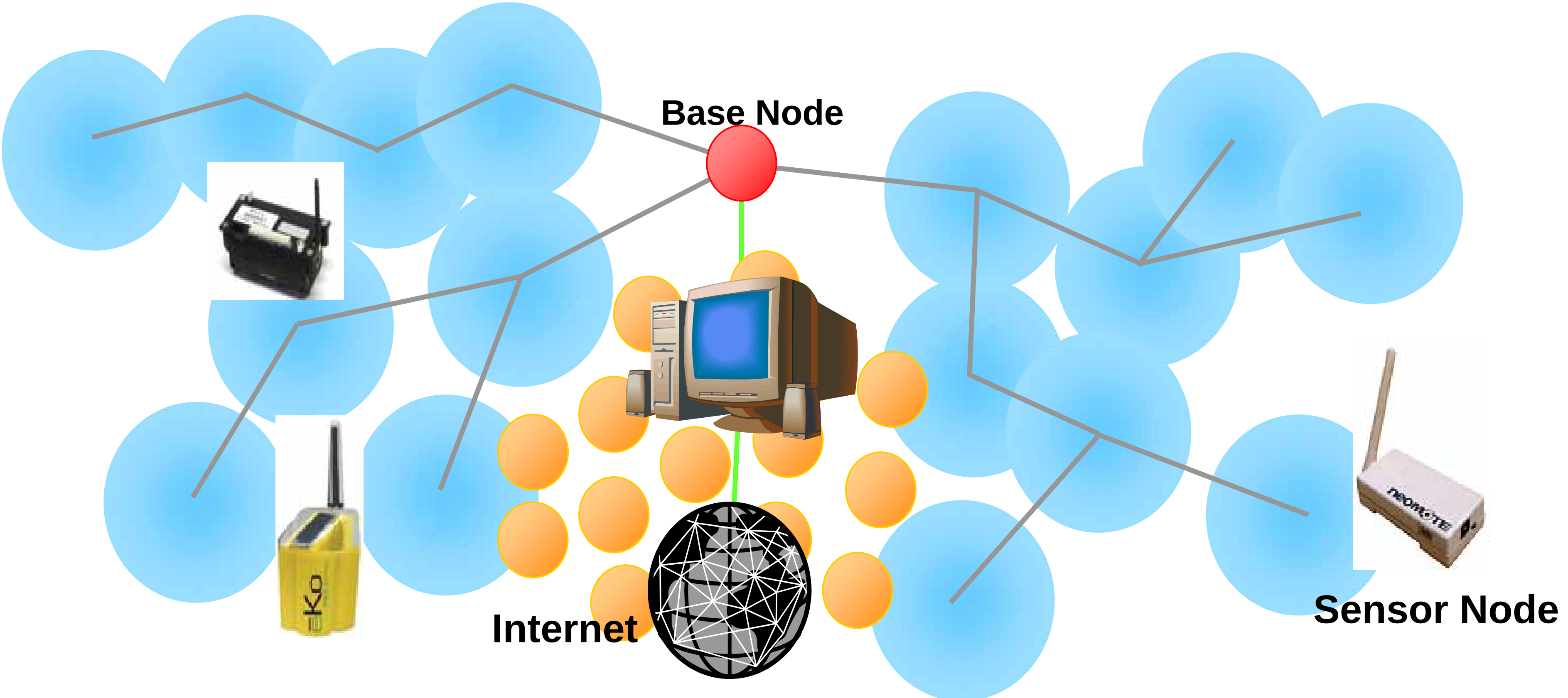
(2006 Micro-Nano Tech for Aerospace. A. Pisano ,BSAC)

ASE® Si-DRIE and SiC Etch



Networking the MEMS Sensors Wirelessly

- 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.



[Information and Telecommunications]

- Large Scale Host Computer

⇒ PC ⇒ Smart Phone

[Energy]

- Large Scale Power Generation

⇒ New / Alternative Energy

[Life]

- Large Scale Hospital provide Medical Care

⇒ Self-medical Examination and Cure

Large Scale Centralization (一極集中)

⇒ Autonomous Self-Control (自律分散)

Enabling Key Technology

"MEMS"

Summary

Summary

- **MEMS process technology specifically developed / commercialized beyond semiconductor process technology has enabled broad application to be realized in the market.**

  (Smart phones, games, automobile, …)

- **MEMS contribute to innovation in our life.**

  (Information and Telecommunications, Energy, Life)

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

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

Toward a Promising Future

Thank you for your attention !

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