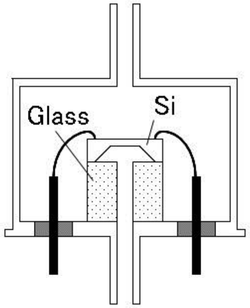
Integrated MEMS by adhesive bonding and open collaboration

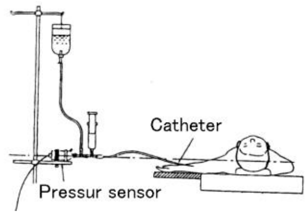
M.Esashi, S.Tanaka (Tohoku University)

1. Introduction
2. Integrated MEMS by adhesive wafer bonding
   - Principle and filters
   - Piezoelectric switches
   - Tactile sensor network
   - Massive parallel EB exposure system
3. Wafer level packaging
4. Open collaboration
5. Conclusions

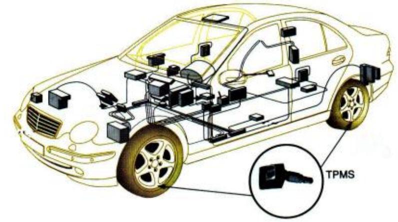
13 March. 2013, MEF2013



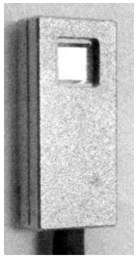
Engine control



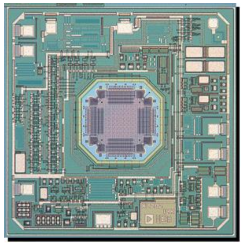
Blood pressure sensing

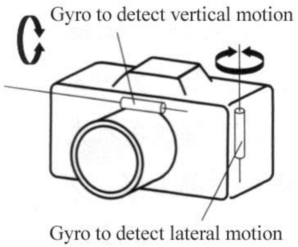


Tire pressure monitoring


Microphone

Pressure sensor


Accelerometer for airbag



Gyro for camera

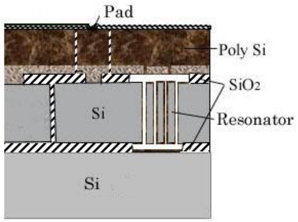

Accelerometer for user interface

Accelerometer & Gyro

Structure + sensor + circuit + actuator

Advantages

- Miniaturization (high sensitivity, low power, good spatial resolution, etc.)
- Integration (low cost, array etc.)



Oscillator


MEMS switch

Communication


Print head


Display (DMD)

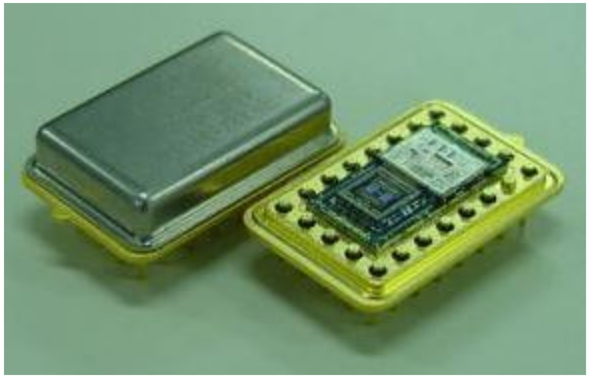

IR imager (Night vision)

Image

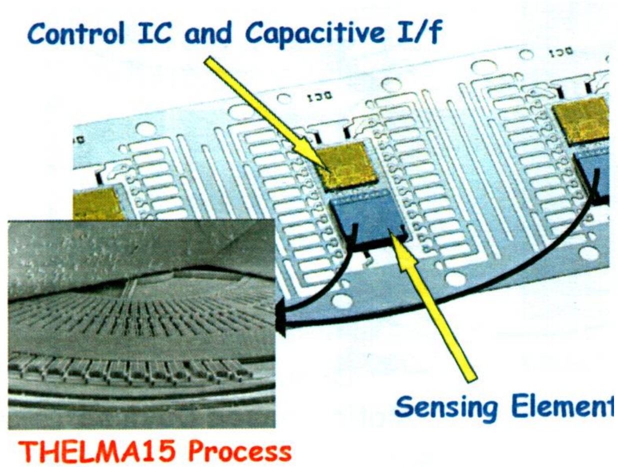
(MEMS array)

1990 2000 2010 year

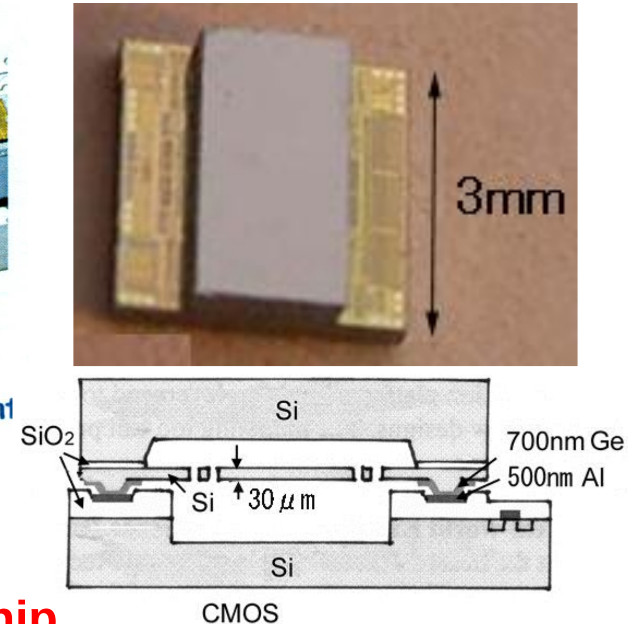
Trends of MEMS (Micro Electro Mechanical Systems) products (+13% in sales)



(Toyota)

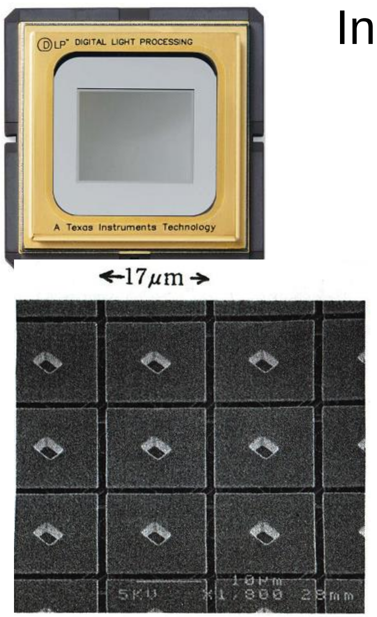


(ST microelectronics)



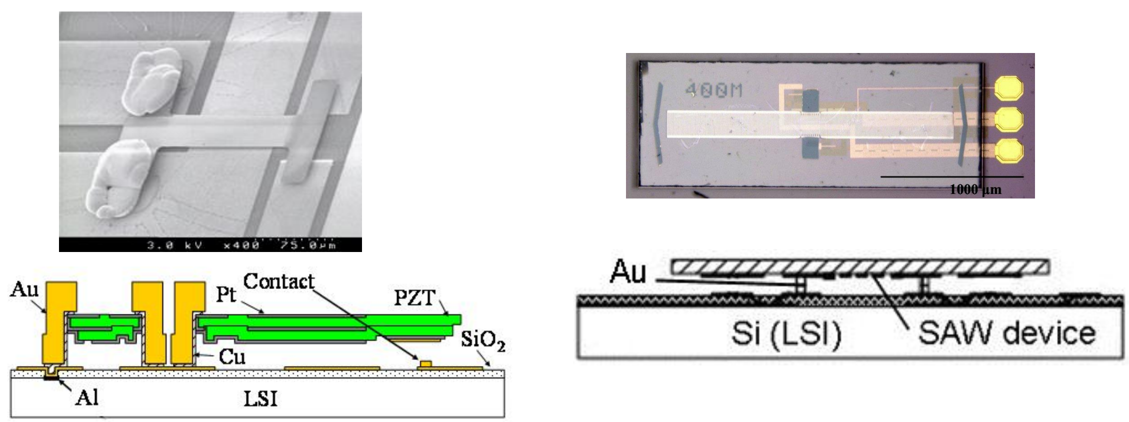
(Invensense)

Inertia sensors **(SIP) MEMS chip + LSI chip**



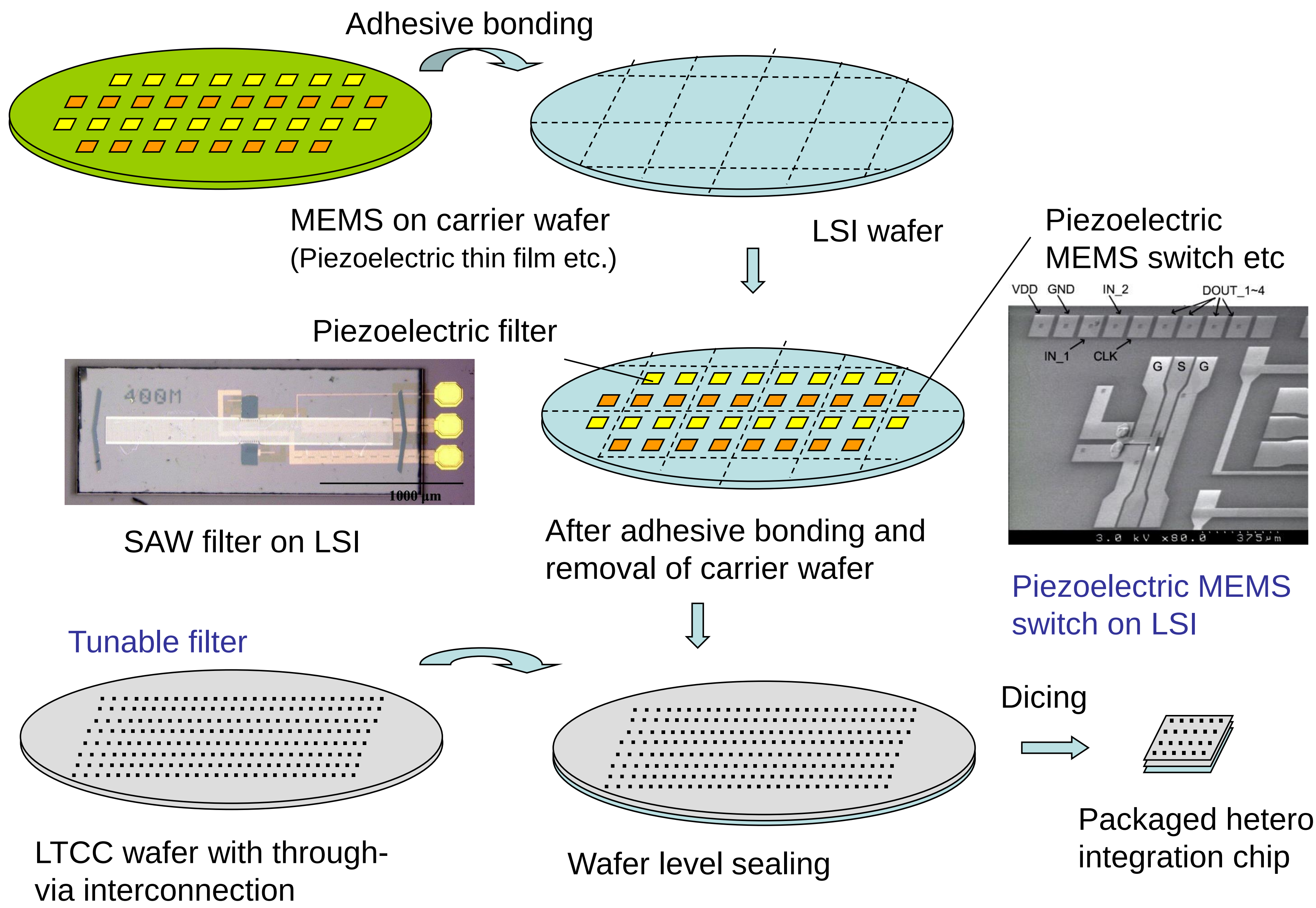
Array MEMS for display

(SOC) MEMS on LSI



MEMS for wireless communication

(Adhesive bonding of MEMS wafer on LSI wafer)



Hetero integration by adhesive bonding

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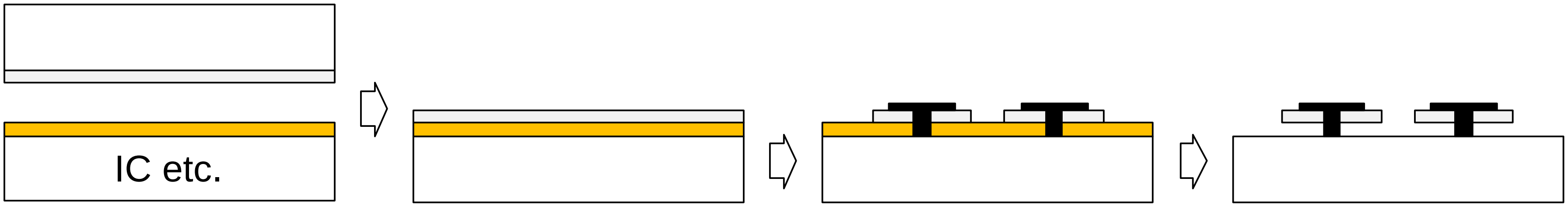
5. Conclusions

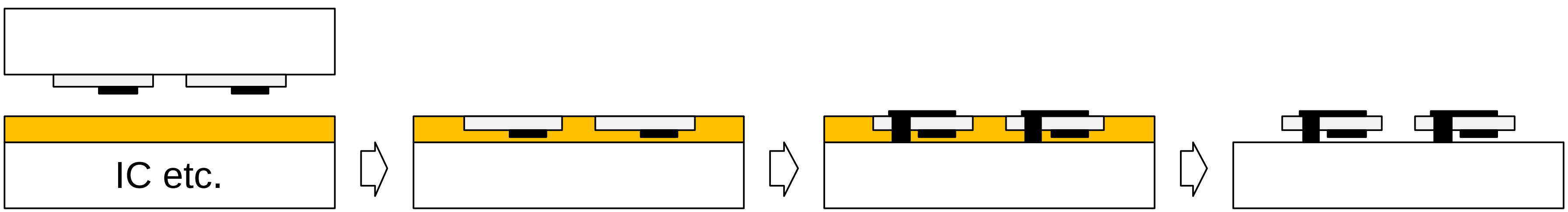
1) Film transfer using polymer → Device fabrication → Polymer removal

High temp. deposition



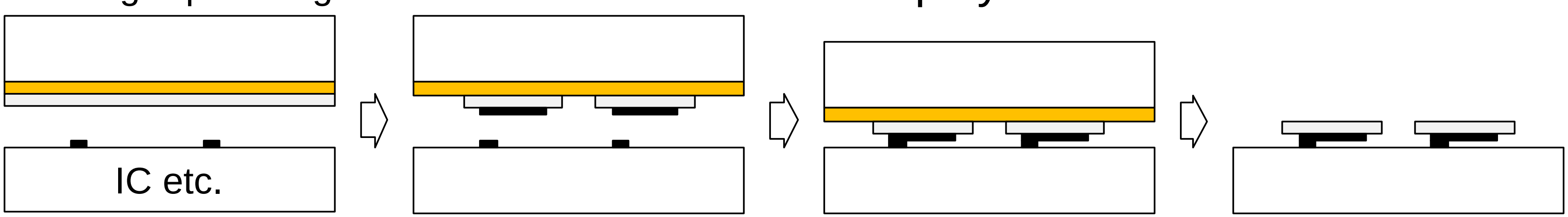
2) Device fabrication → Device transfer using polymer → Polymer removal

High temp. process



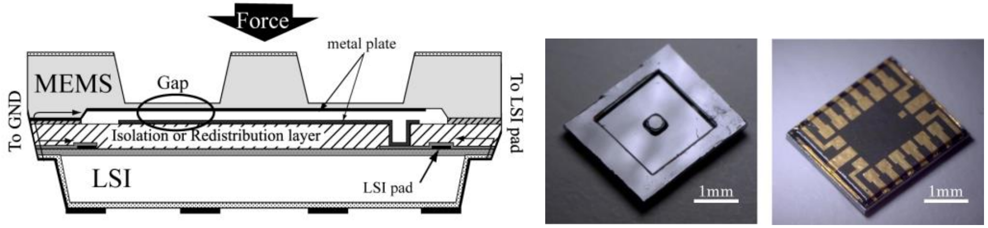
3) Film preparation → Device fabrication → Device transfer by bonding and polymer removal

Bonding & polishing

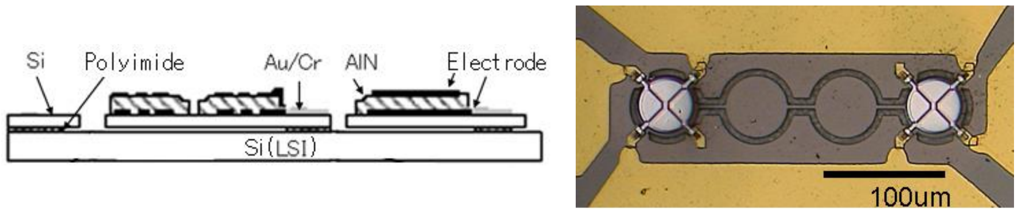


Wafer-Level Hetero Integration Processes

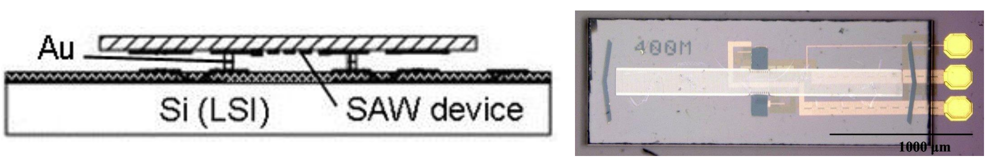
Application of adhesive bonding



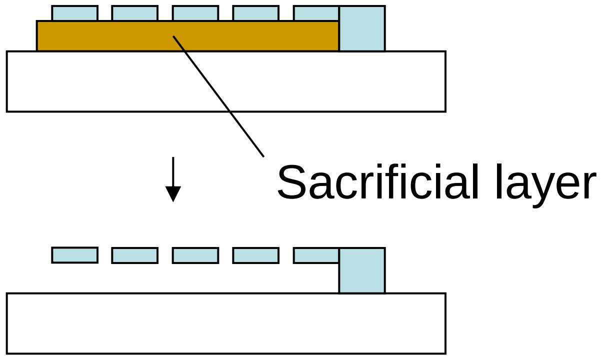
Tactile sensor
Bonding with BCB (Cyclotene)



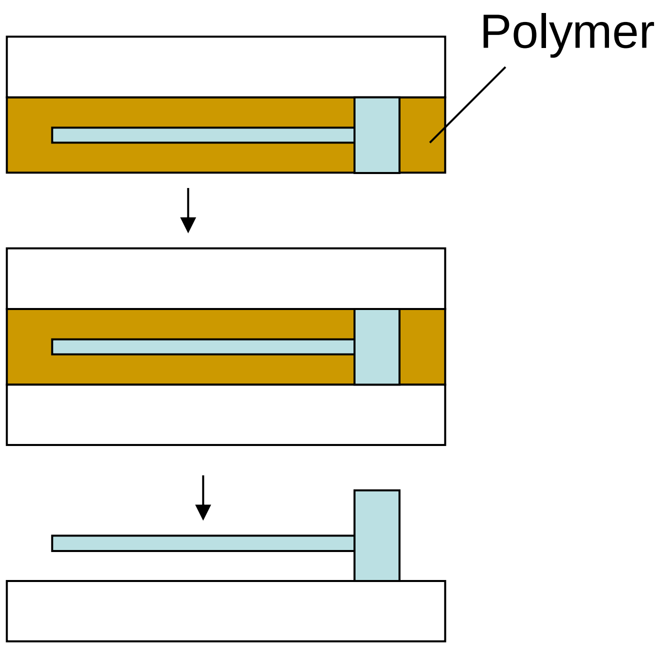
Micromechanical resonator
Bonding with polyimide
Partly etching of polymer after bonding



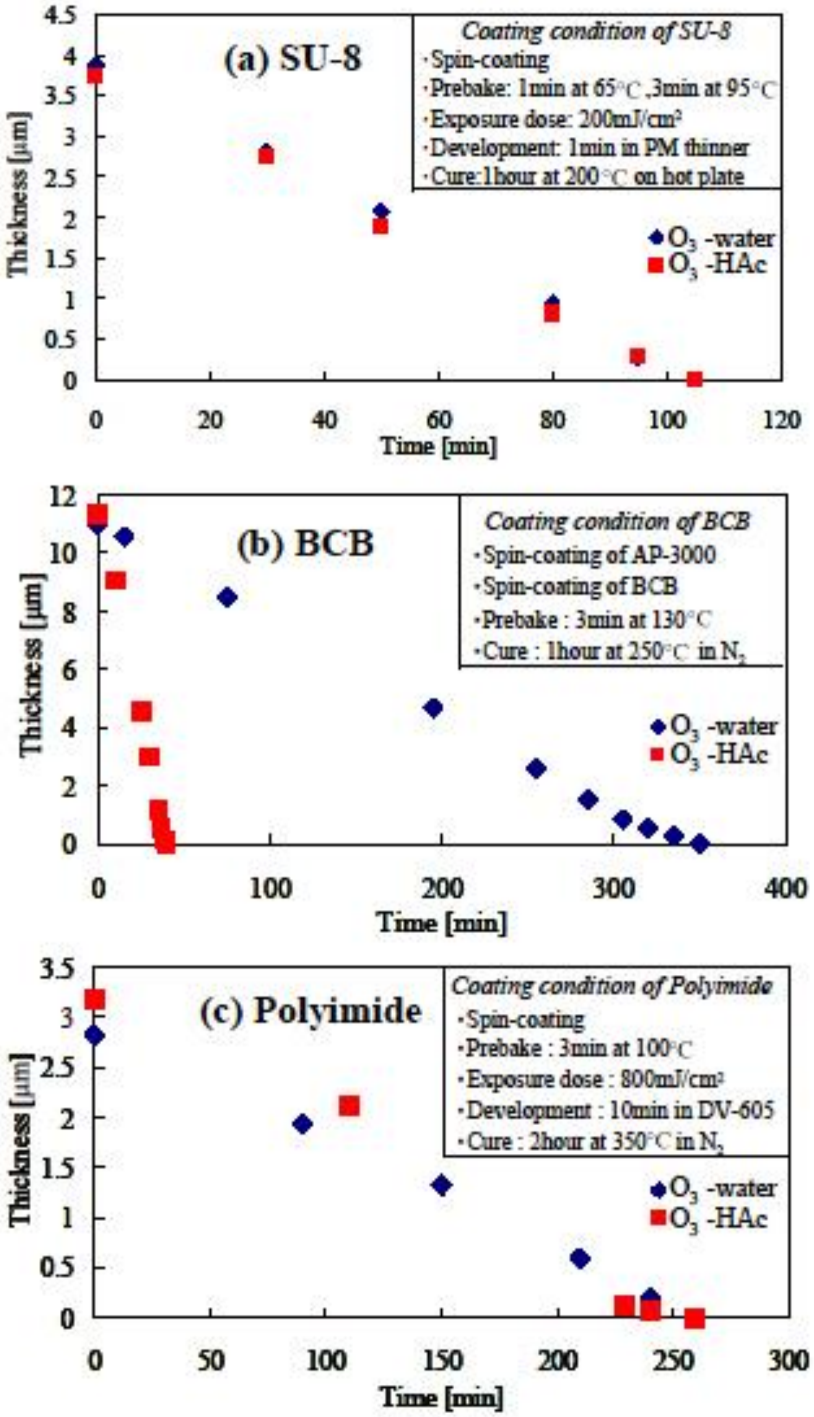
SAW filter on LSI
Bonding with UV curable resin
Remove after temporary bonding

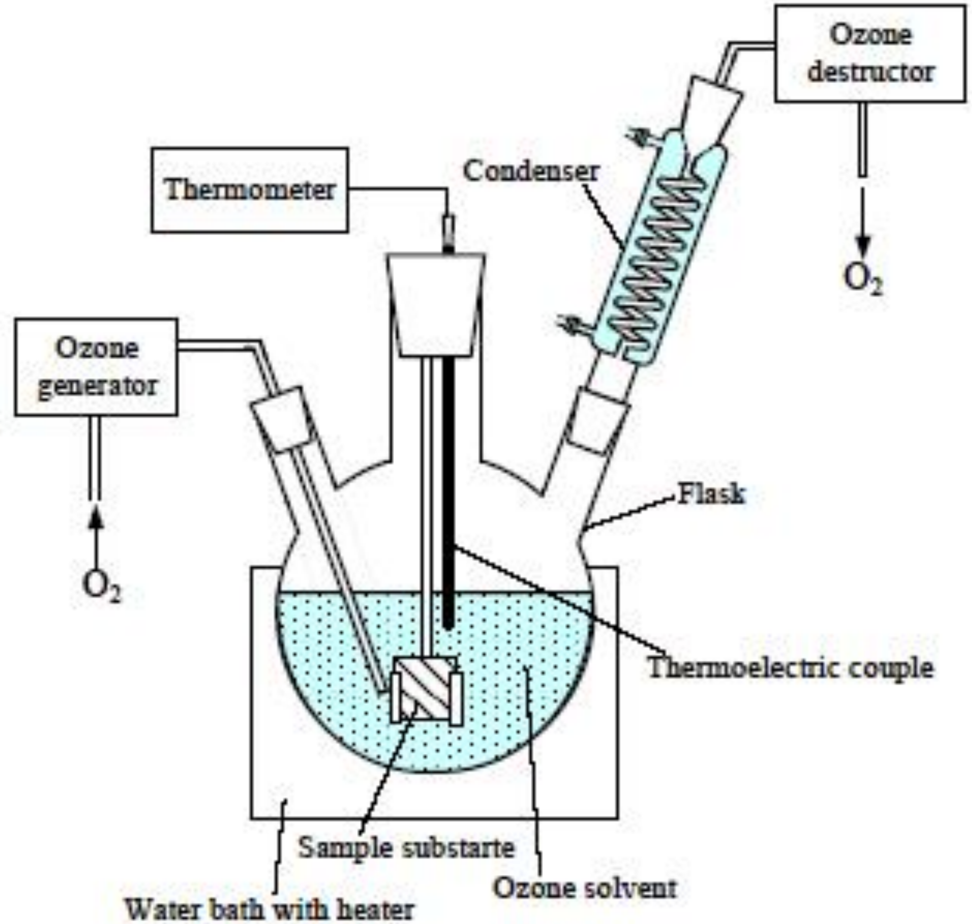


Surface micromachining



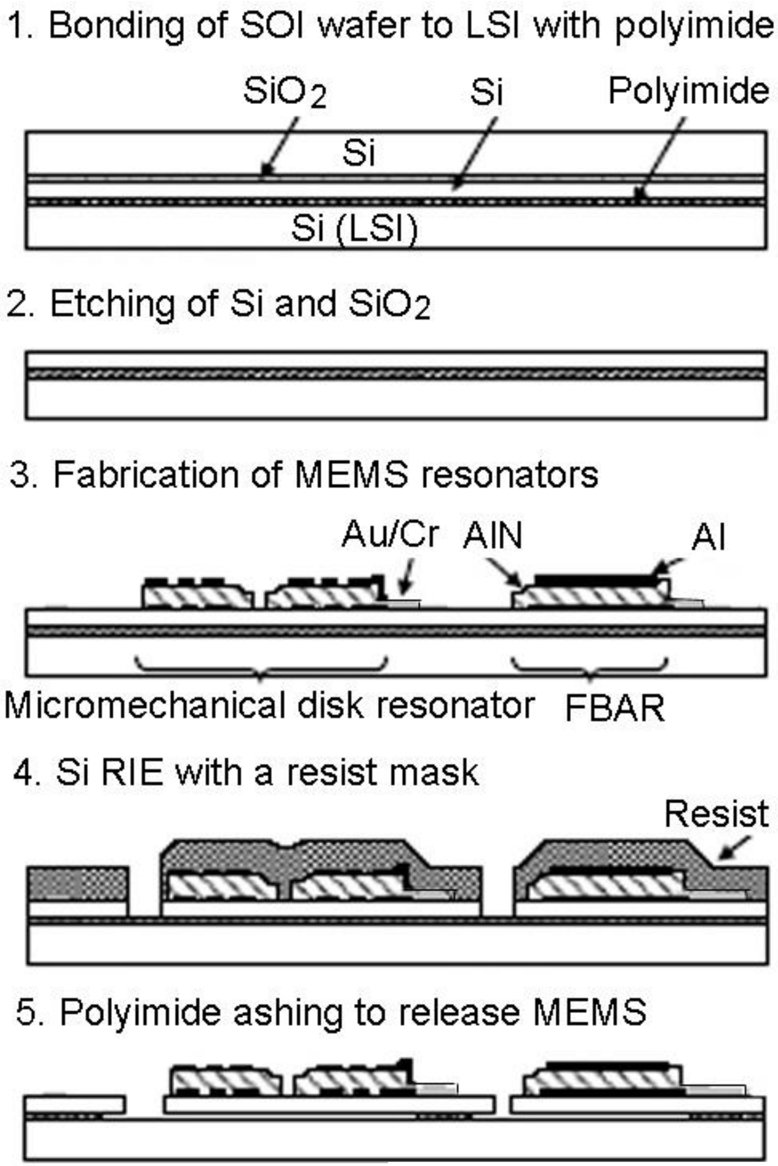
Adhesive bonding

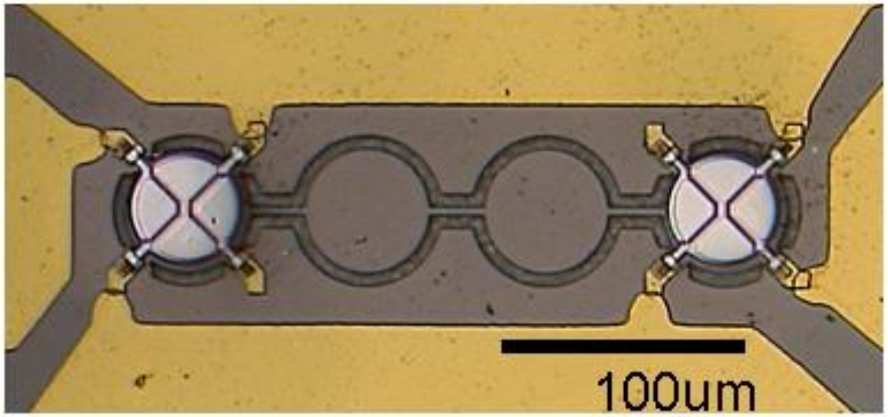


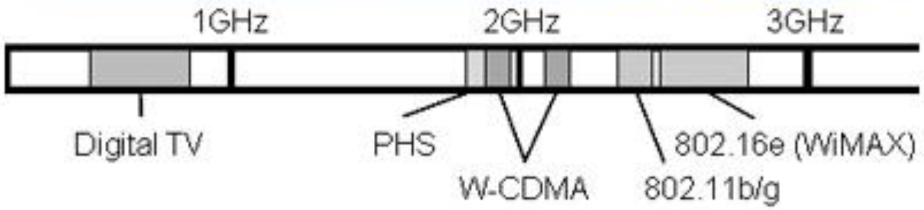


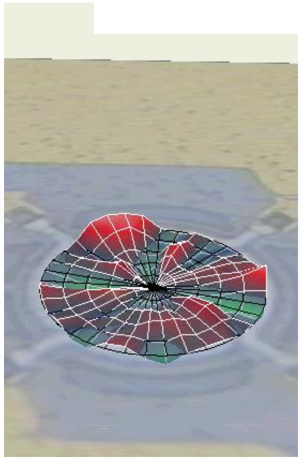
Removal of polymers by ozone in acetic acid

(H.Yanagida, IEEE MEMS2011, 324)

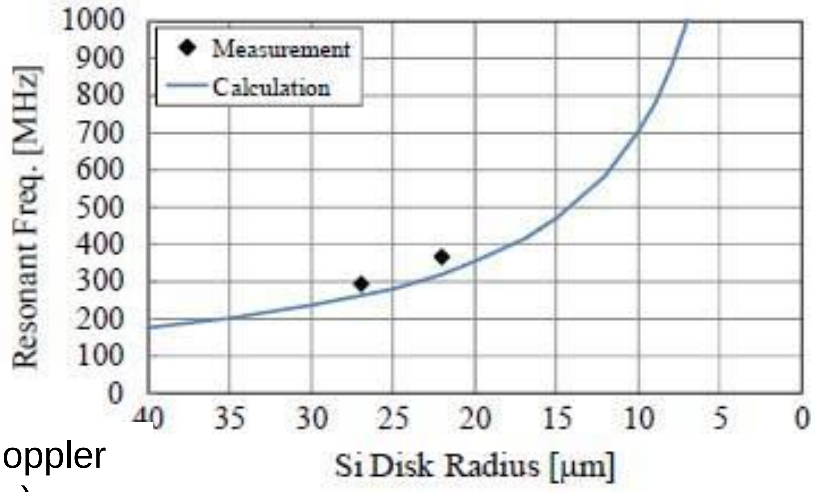






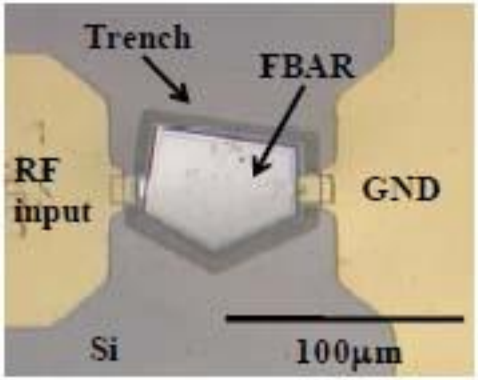


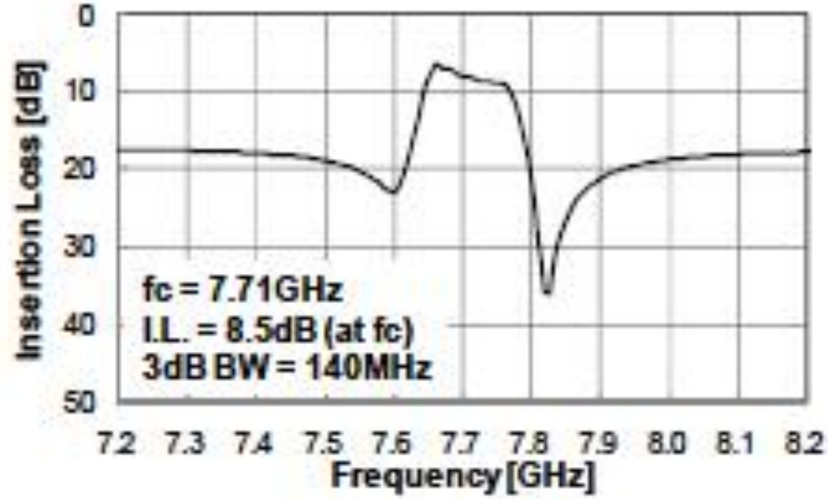
High freq. laser doppler imaging (293 MHz) (Polytec UHF120)

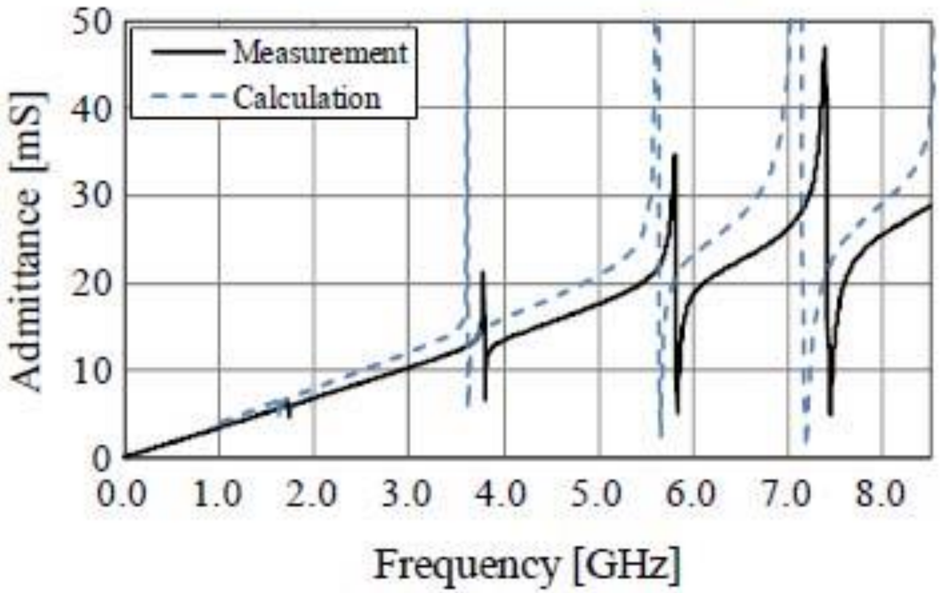


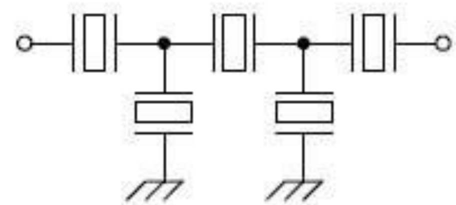
AlN/Si composite disk resonators and FBAR for multiband wireless systems

(T.Matsumura (NICT), J. of Micromech. Microeng., 20, 9 (2010) 95027)

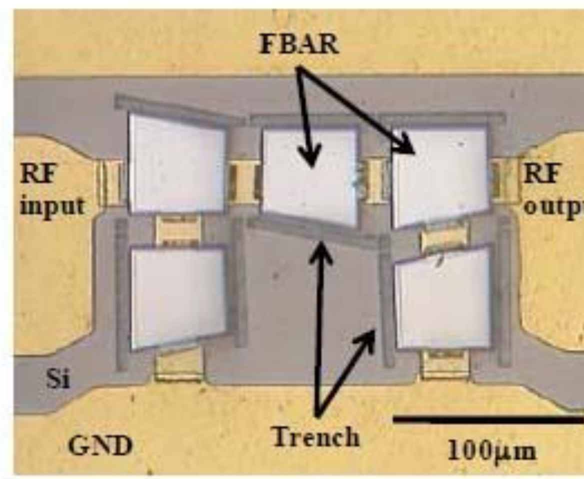








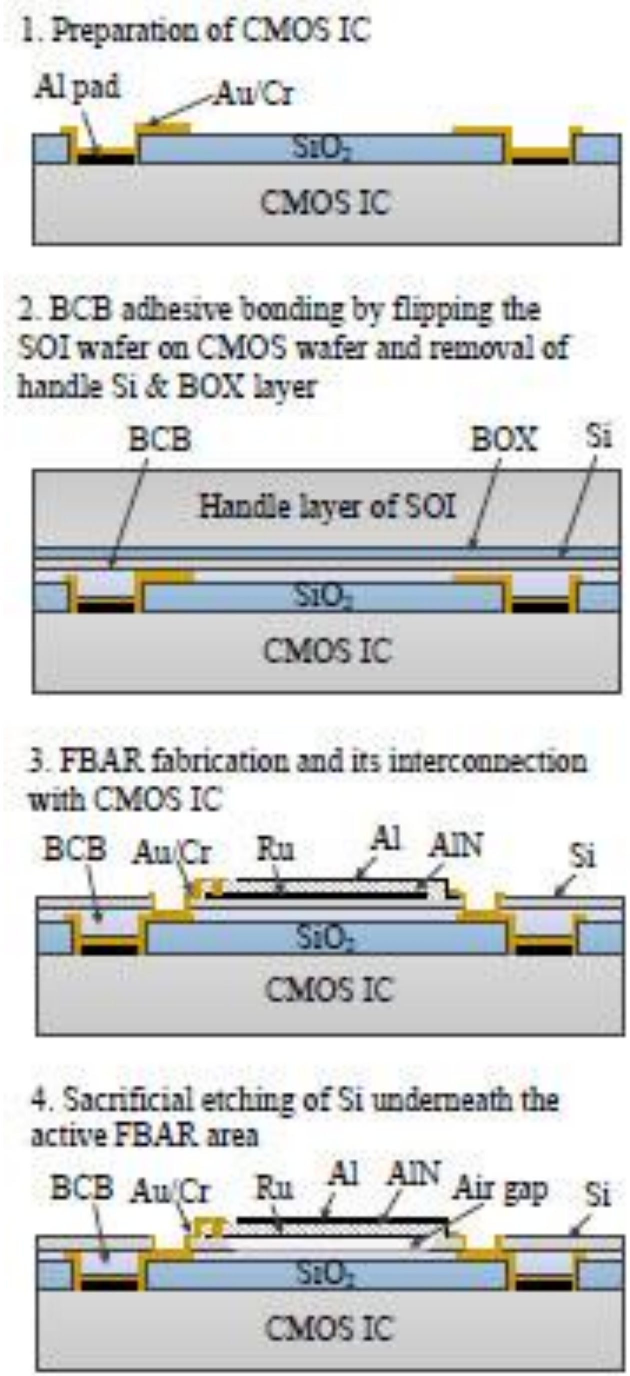
(a) Three-stage ladder-type filter topology.

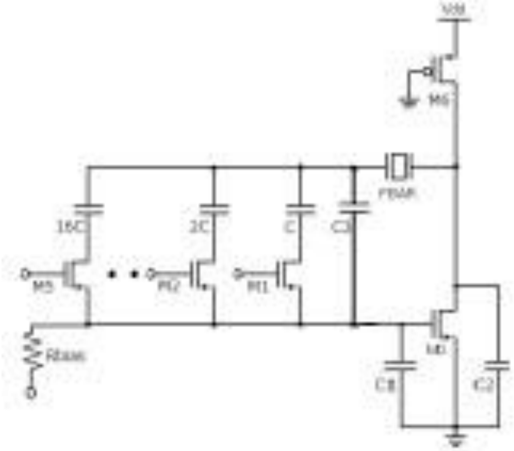


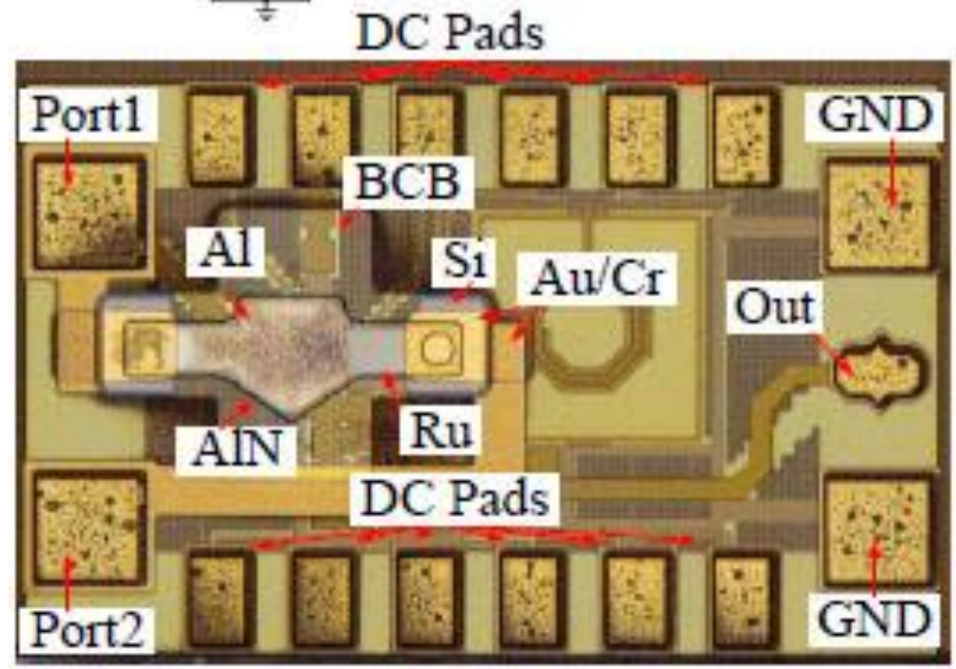
(b) Top view of the fabricated ladder-type FBAR filter.

FBAR (Film Balk Acoustic Resonator)

(T.Matsumura, M.Esashi, H.Harada and S.Tanaka, 2009 IEEE Internl. Ultrasonic Symposium (2009) 2141)

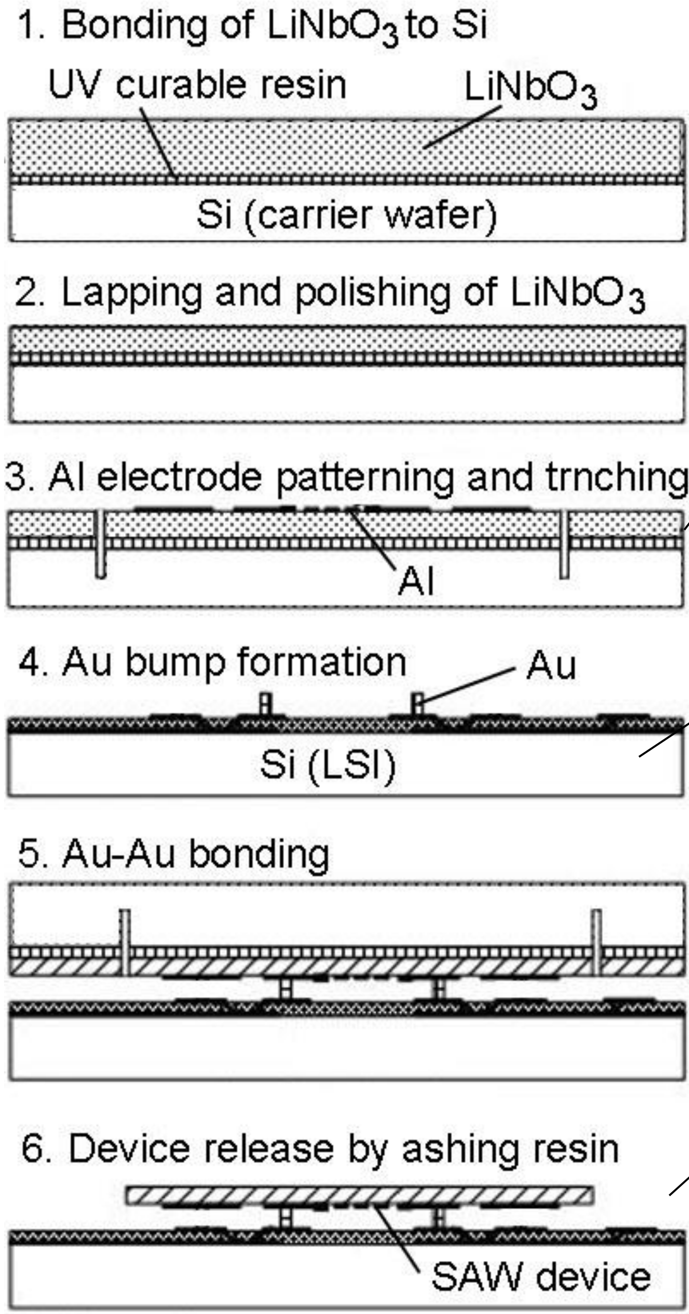


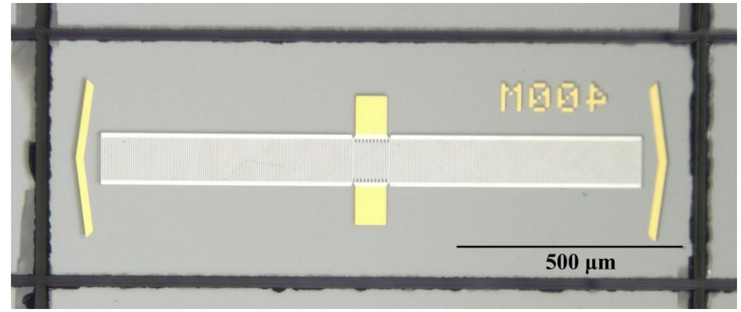




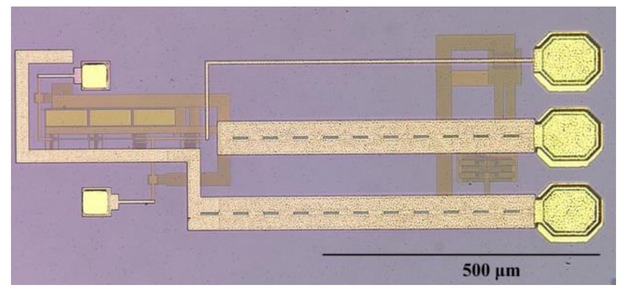
CMOS-FBAR voltage controlled oscillator

(A.Kochhar, et.al., “Monolithic fabrication of film bulk acoustic resonators above integrated circuit by adhesive-bonding based film transfer, 2012 IEEE Ultrasonics Symposium, 5E-3)

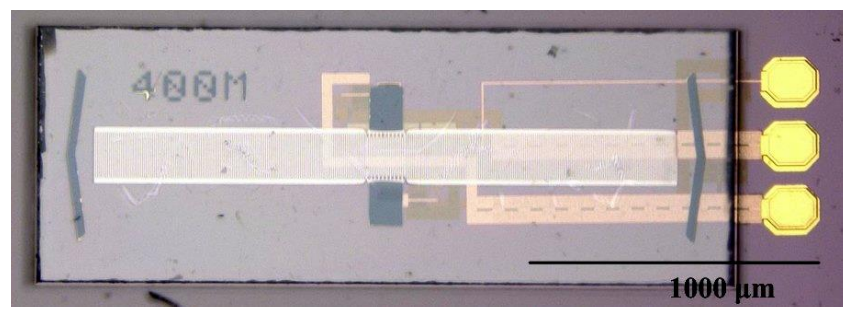




SAW device

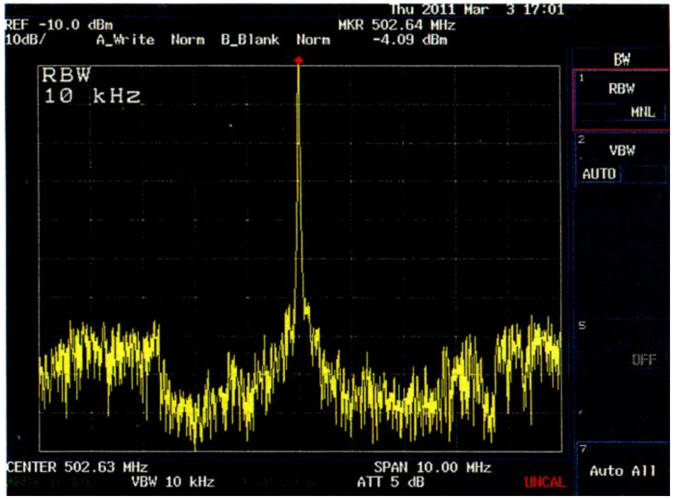


LSI

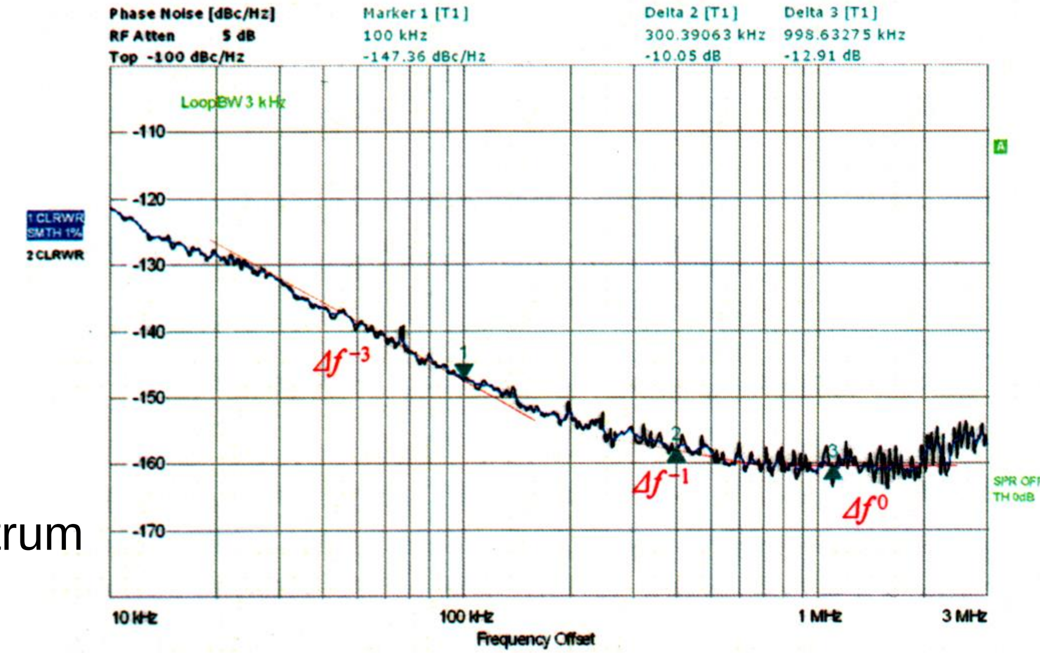


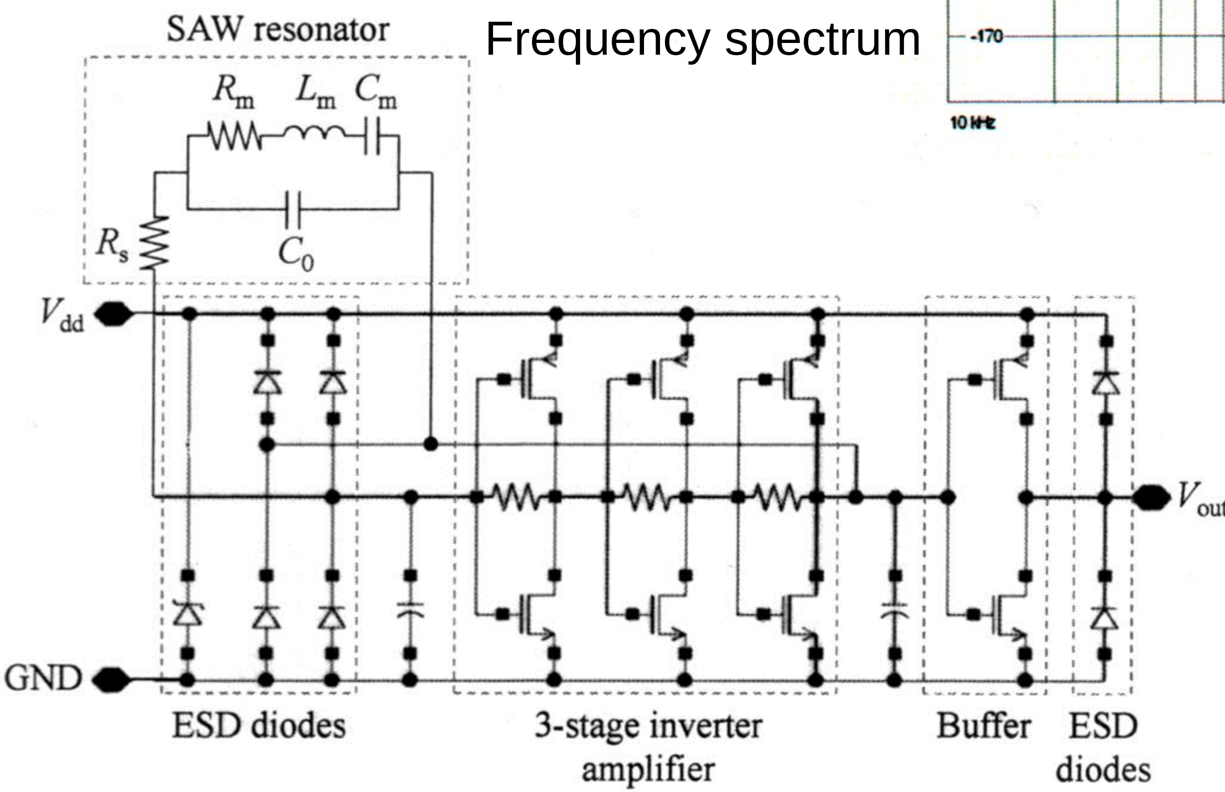
SAW devices on LSI

(K.-D.Park, M.Esashi, S.Tanaka, IEEJ The 26th Sensor Symposium, 37 (2009))



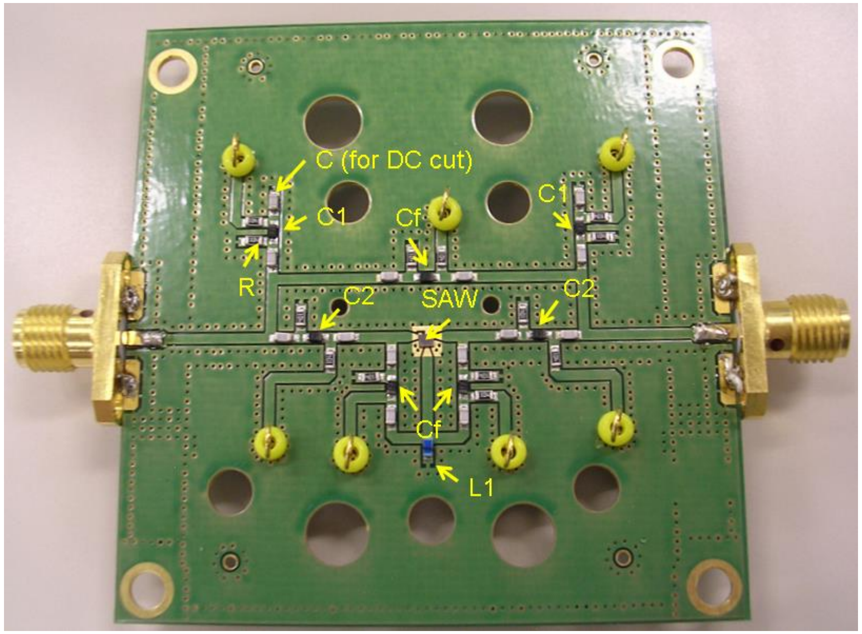
Frequency spectrum

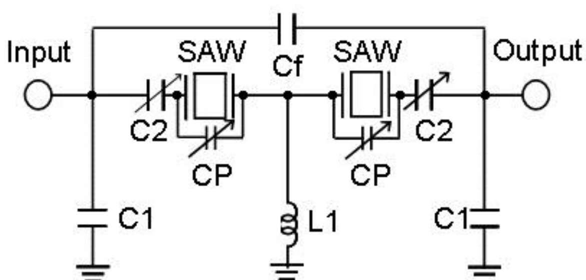


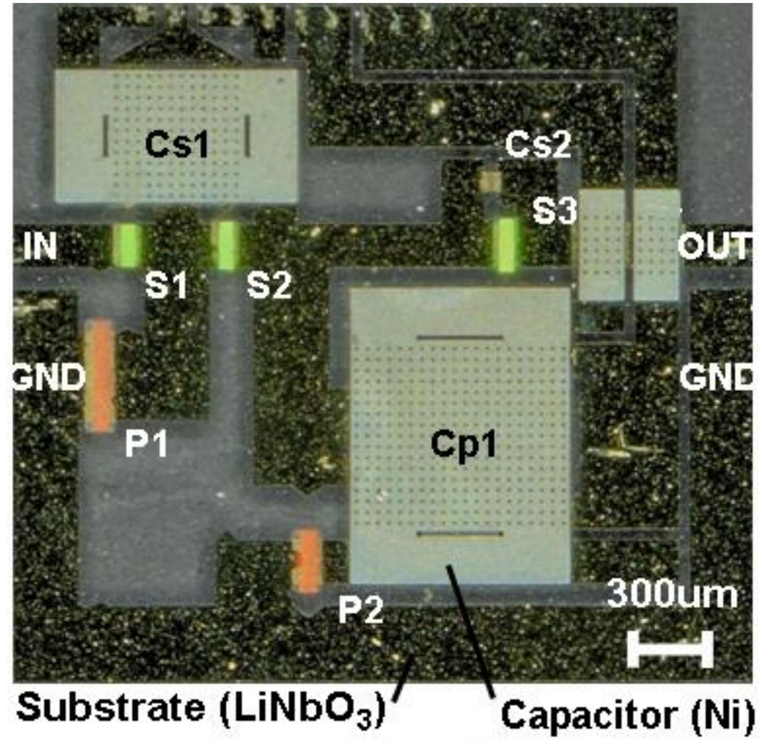


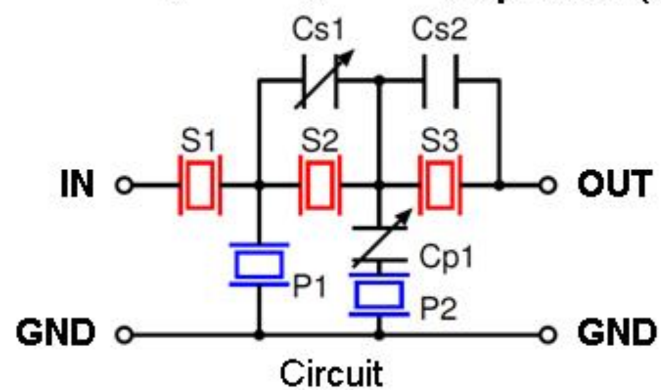
Small phase noise owing to the small stray capacitance

SAW oscillator on LSI (502 MHz)









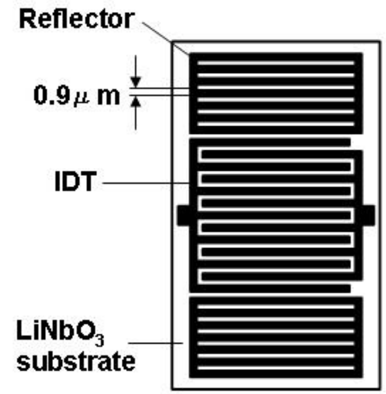
Tunable filter on breadboard using Si variable capacitors and SAW filters

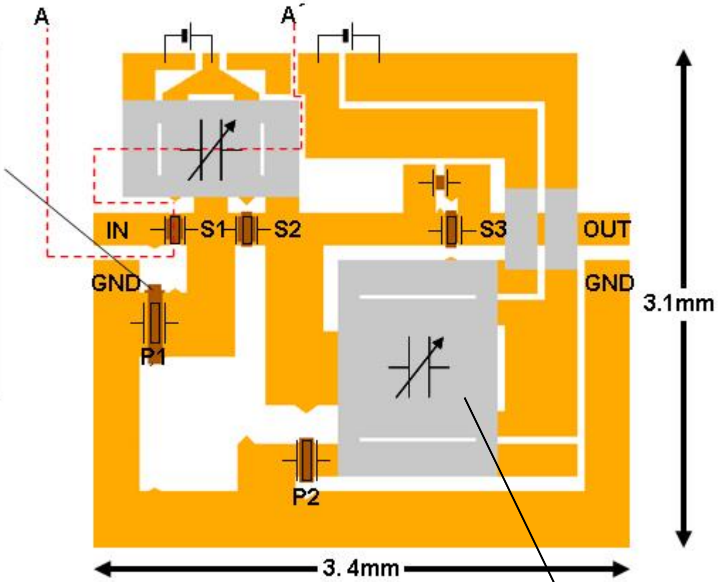
(M. Kadota *et al.* (Murata Mfg.), Jpn. J. Appl. Phys., 49 (2010) 07HD26-1)

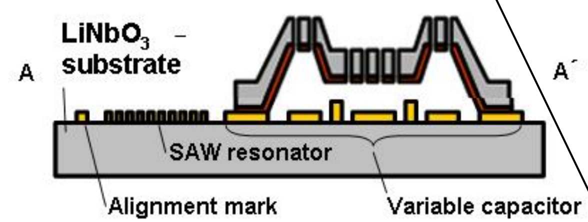
Monolithic tunable filter using MEMS variable capacitors and SAW filters

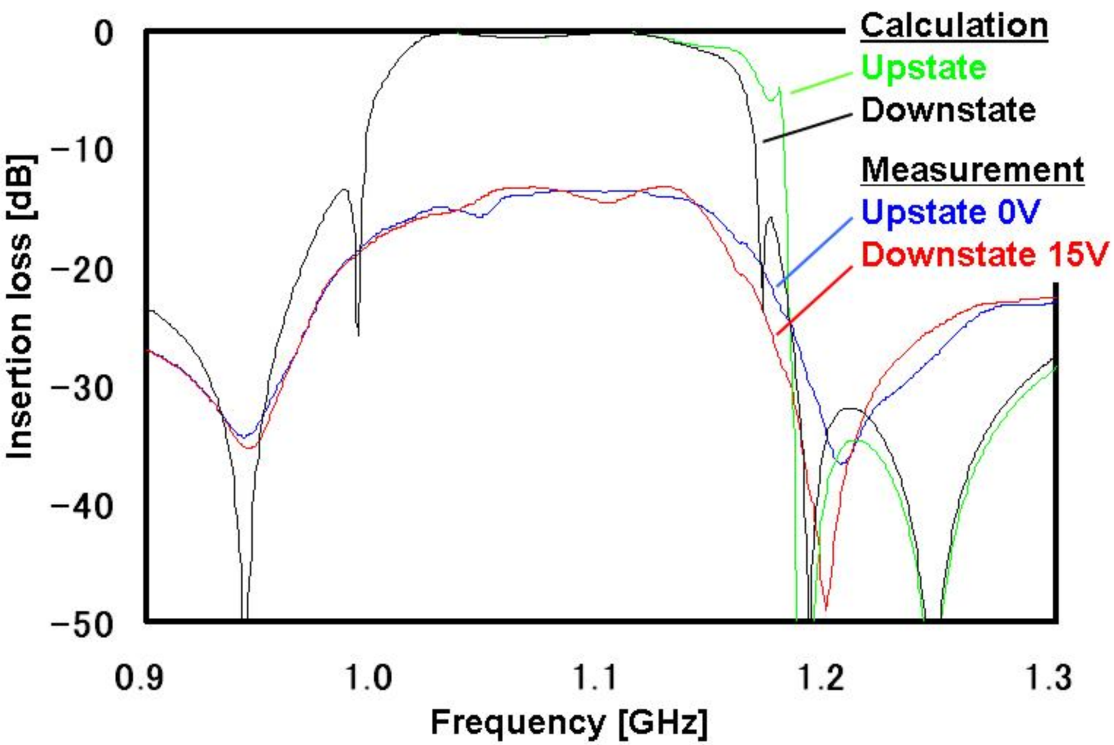
(T.Yasue, T.Komatsu et.al., Transducers 2011)

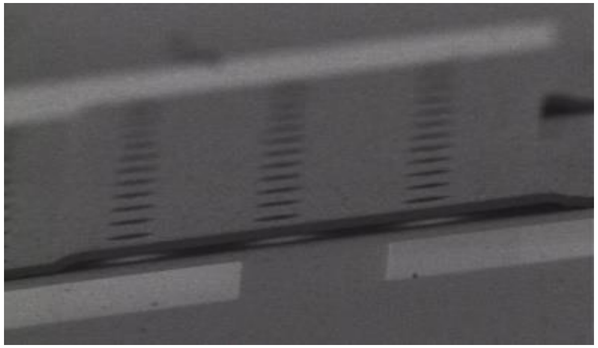
SAW device







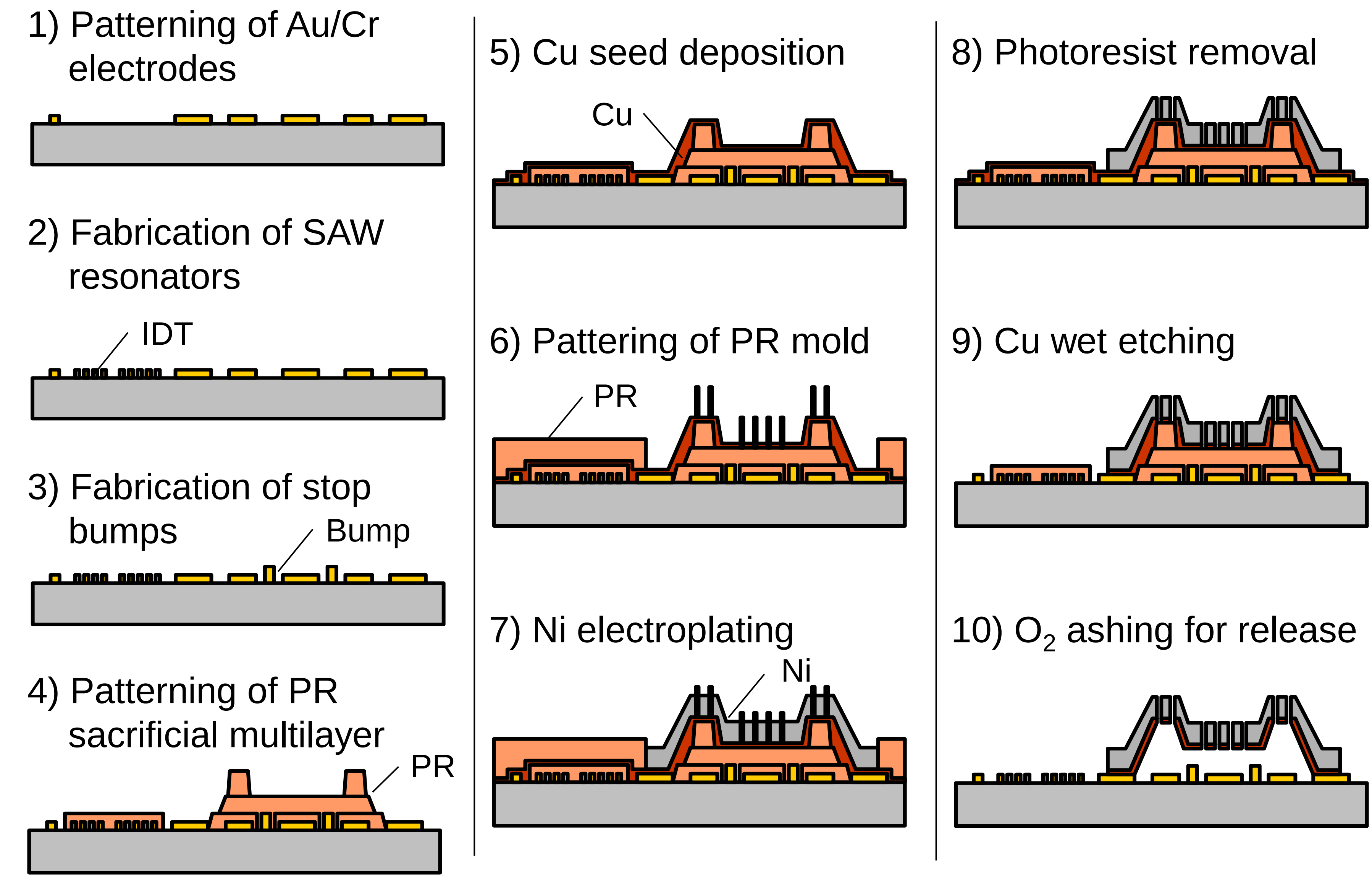




MEMS variable capacitor

Tunable SAW filter using MEMS variable capacitor

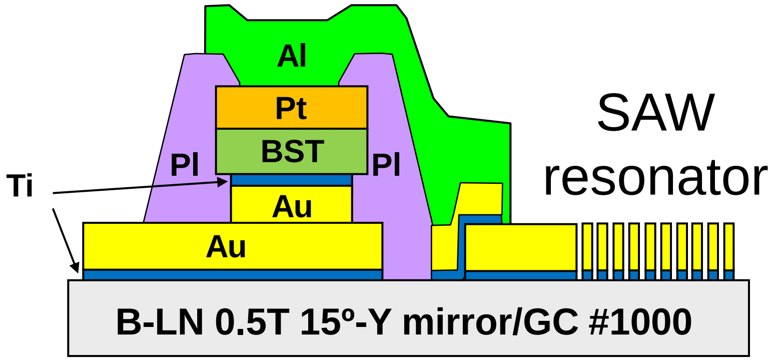
(T.Yasue, Transducers 2011, Beijing (2011) 1488)

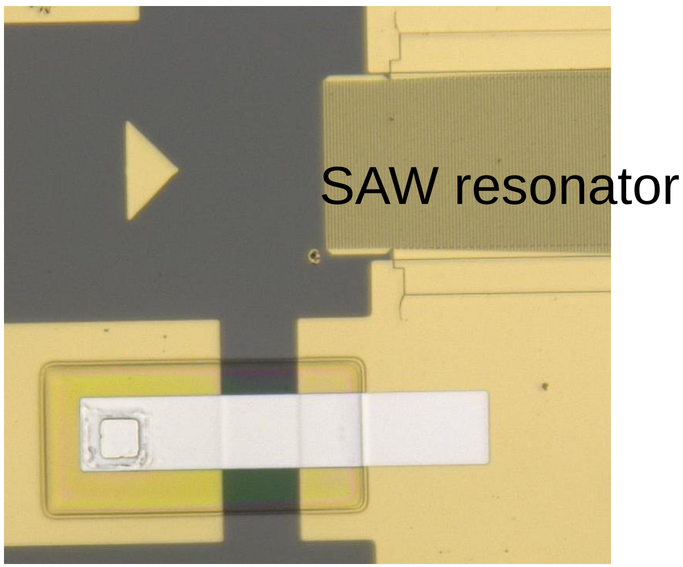


Fabrication process of tunable SAW filter using MEMS variable capacitor

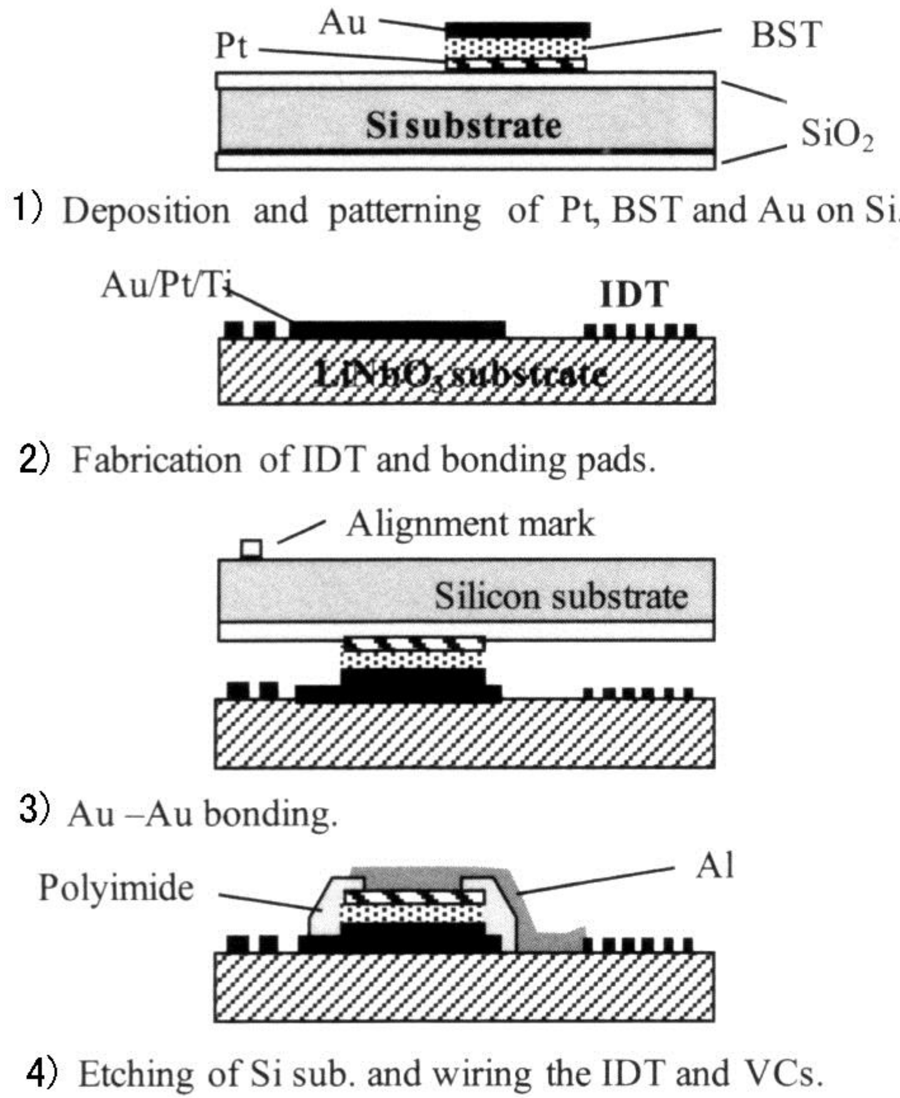
(T.Yasue, Transducers 2011, Beijing (2011) 1488)

BST ($(Ba_{1-x}Sr_x)TiO_3$) varactor



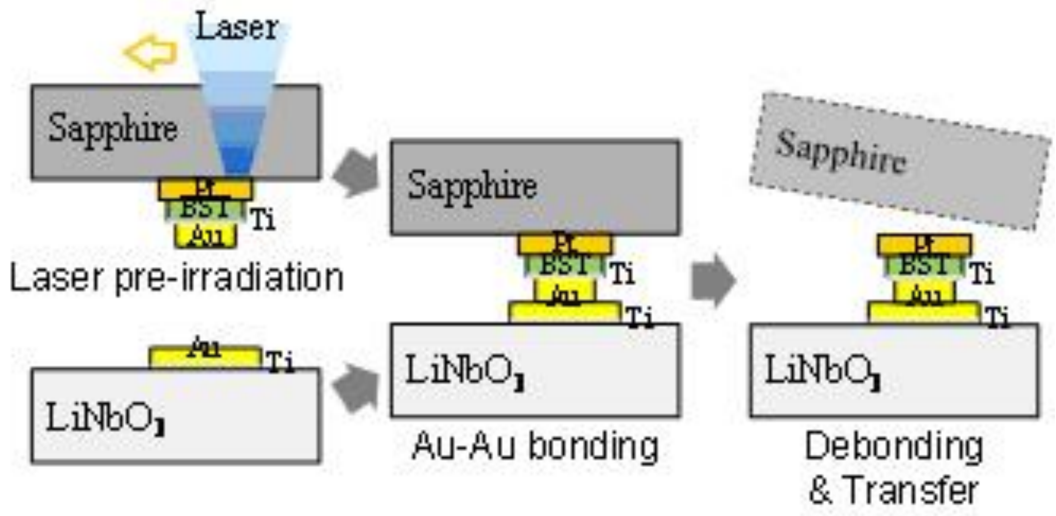


Transferred BST varactor
(Tuning ratio of 1.6 at 3 V)

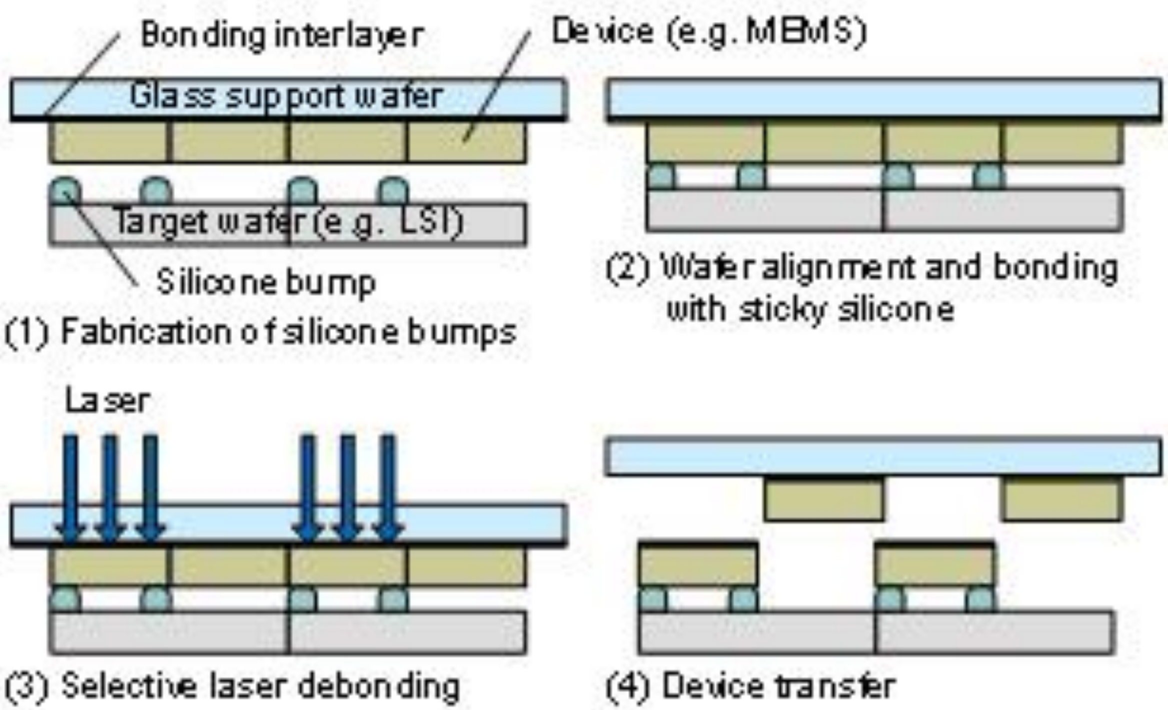


Small size ferroelectric variable capacitor for tunable SAW filter

(H.Hirano, 2011 IEEE Internl, Ultrasonic Symp., (2011))

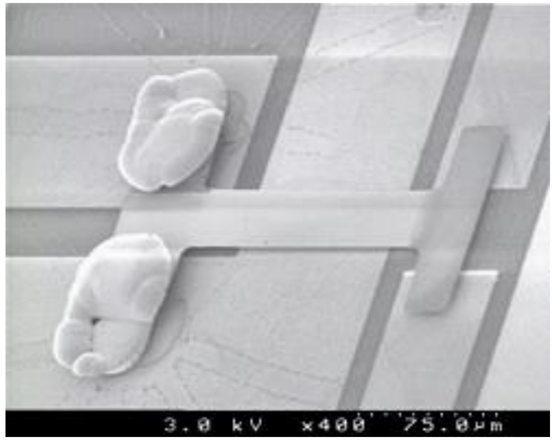


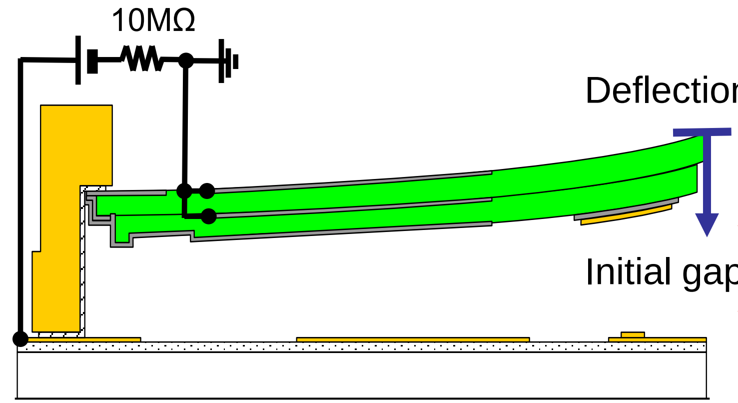
Laser debonding

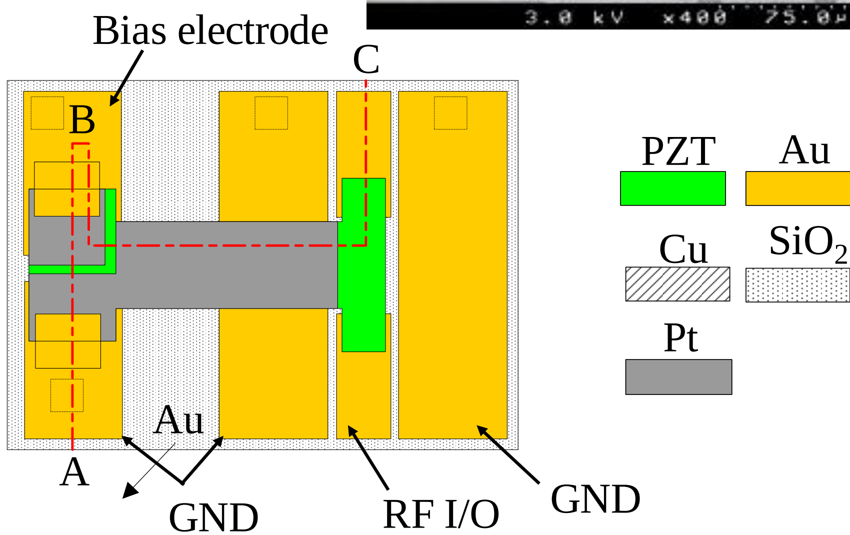


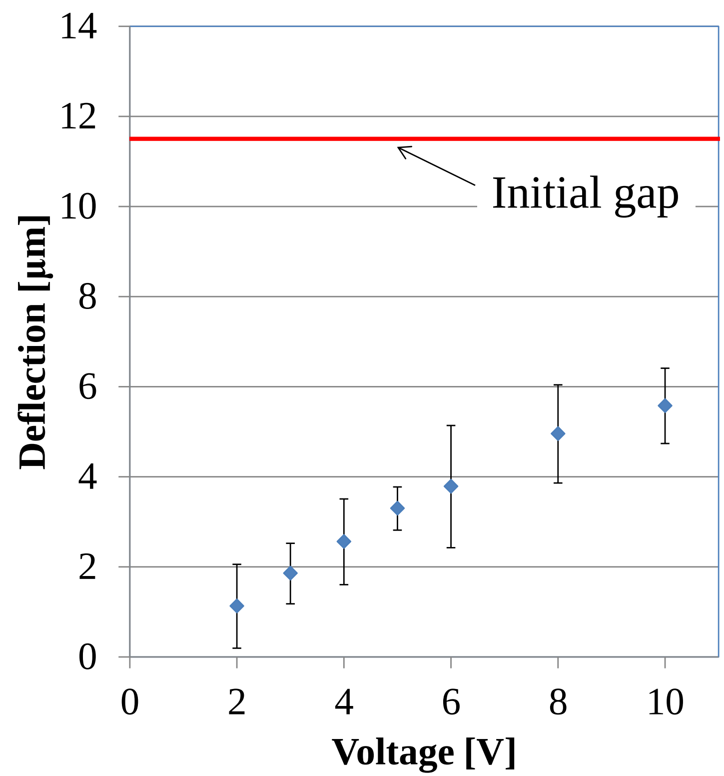
Selective transfer by laser debonding

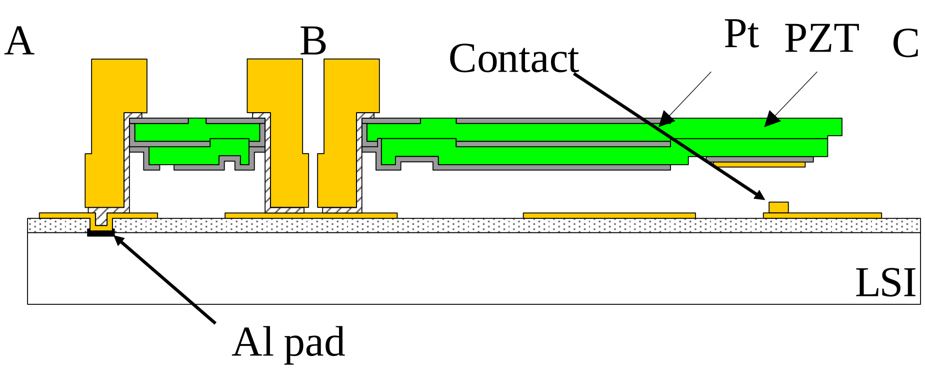
(T.Samoto, The 29th Sensor Symposium on Sensors, Micromachines and Microsystems (2012) p.35)





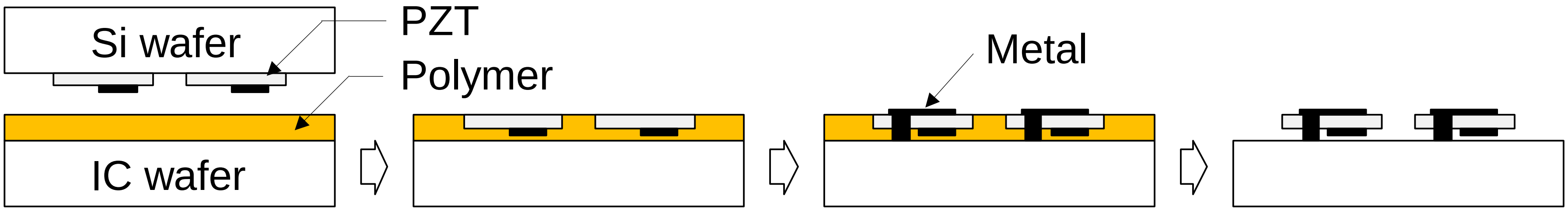


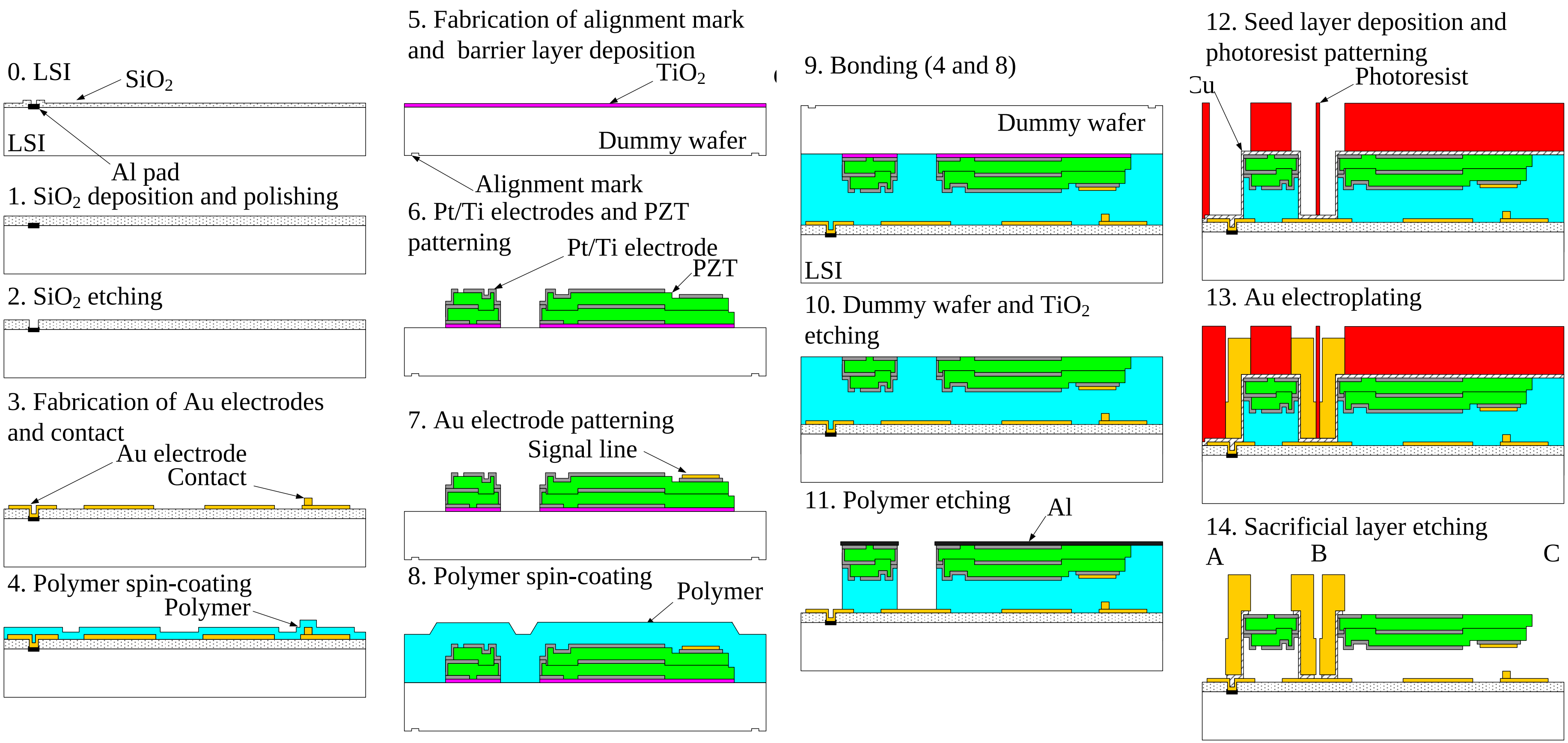




PZT MEMS Switch on LSI

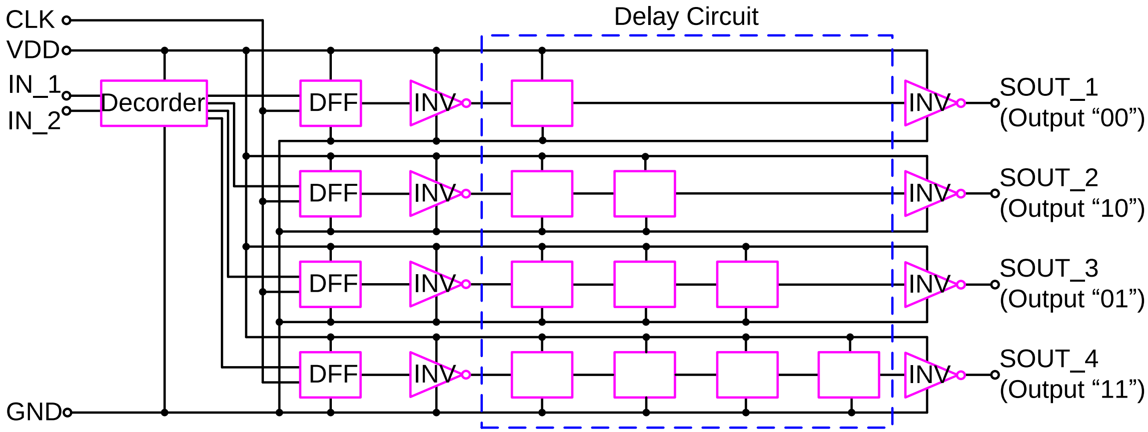
(Matsuo, Moriyama, Esashi, Tanaka (Tohoku Univ.), IEEE MEMS 2012, 1153-1156)



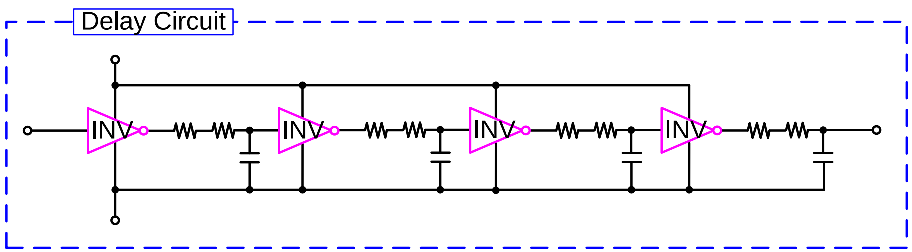


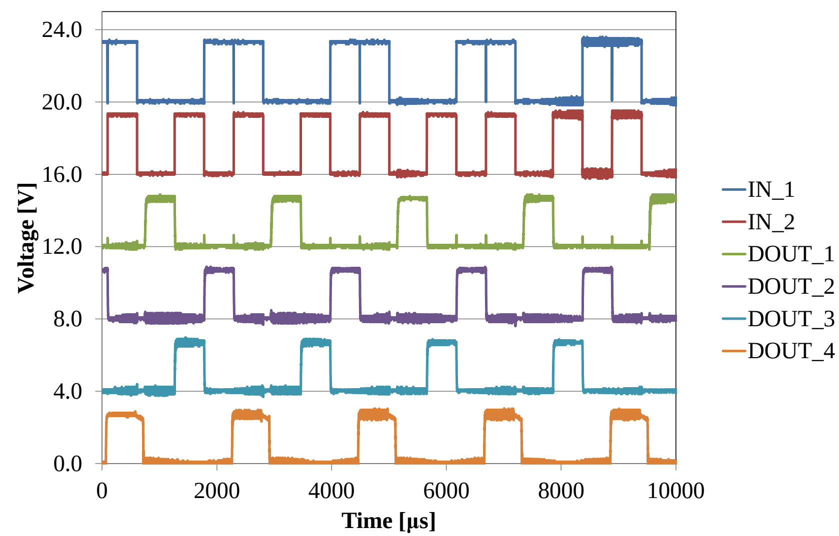
Fabrication process of PZT MEMS Switch on LSI

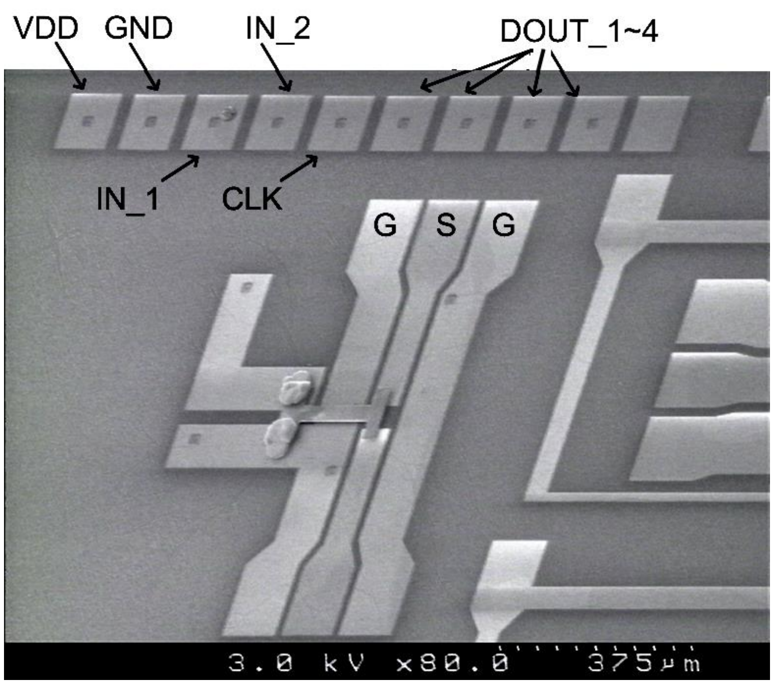
(Matsuo, Moriyama, Esashi, Tanaka, IEEE MEMS 2012, 1153-1156)



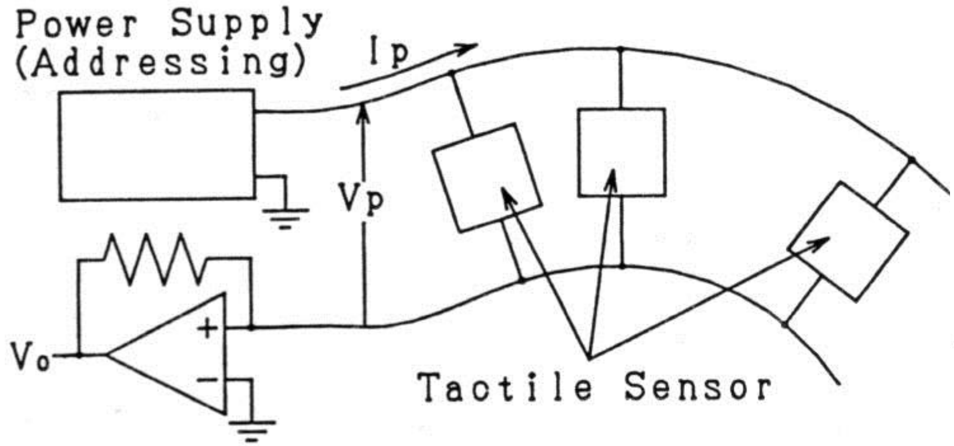
VDD : power supply, 3.3V
CLK : clock signal,3.3 V, 5 MHz
IN_1, IN_2 : switching signal, 3.3 V
DOUT_1~4 : D flip-flop’s output

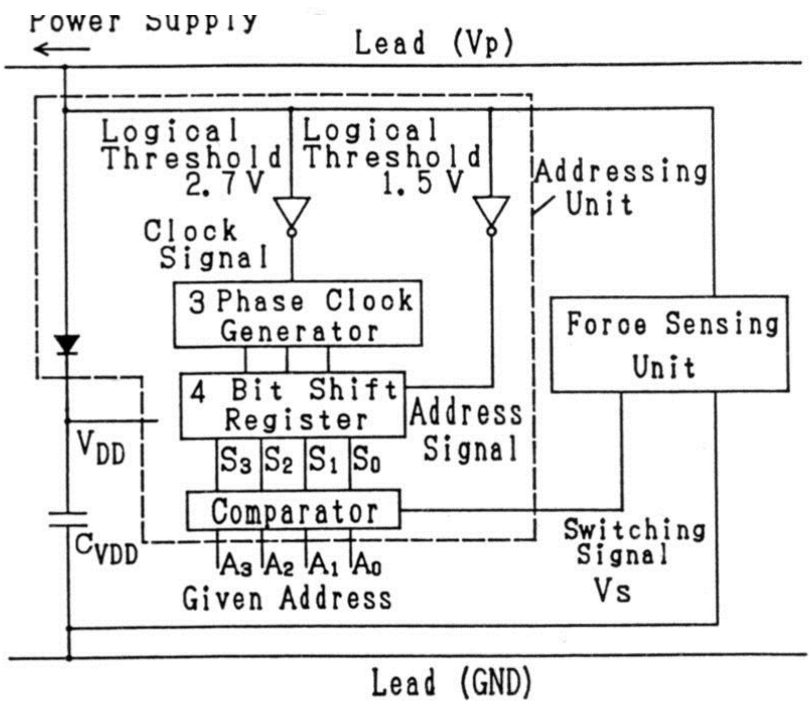


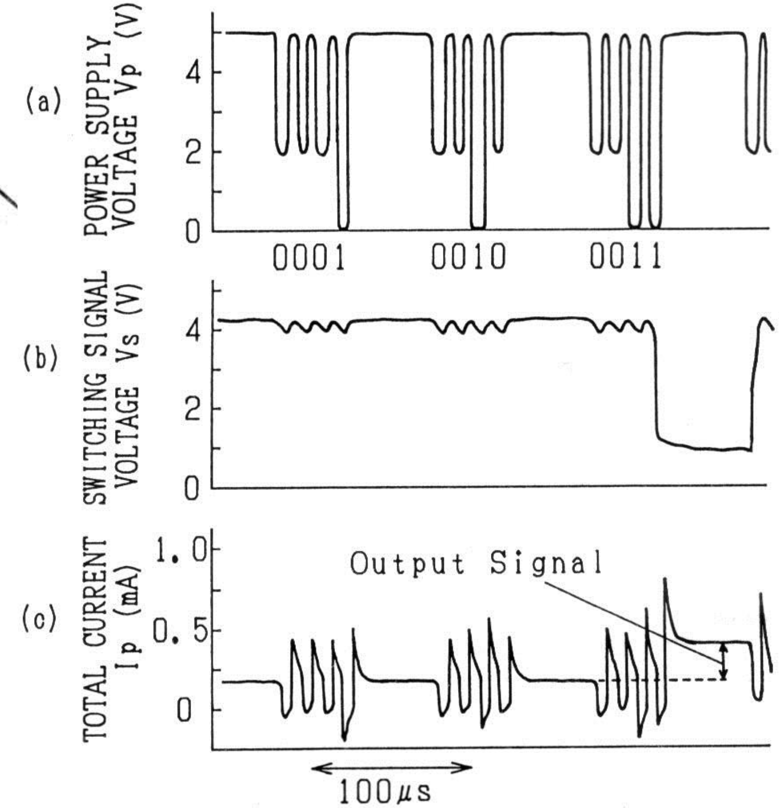


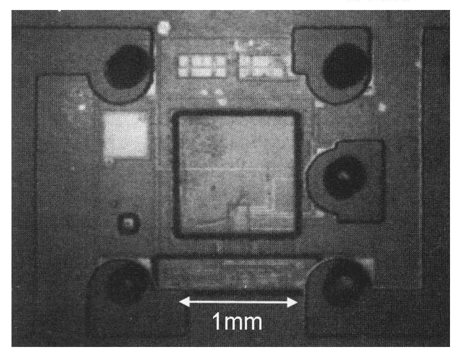


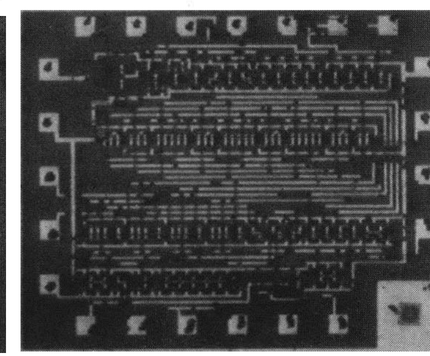
CMOS switch control circuit







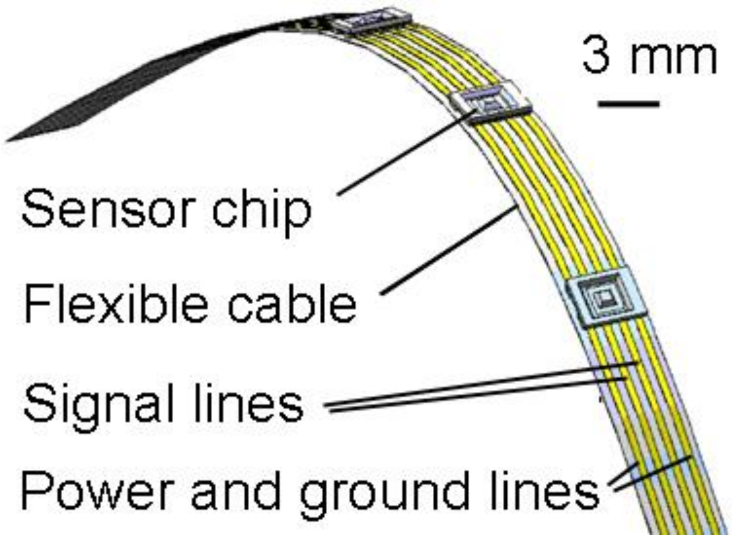


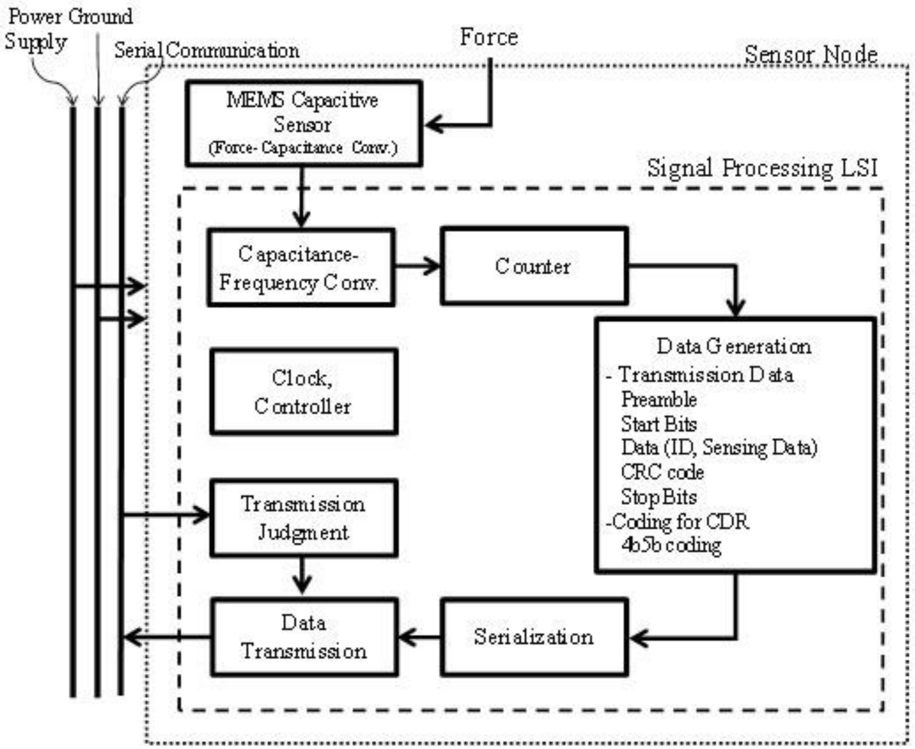


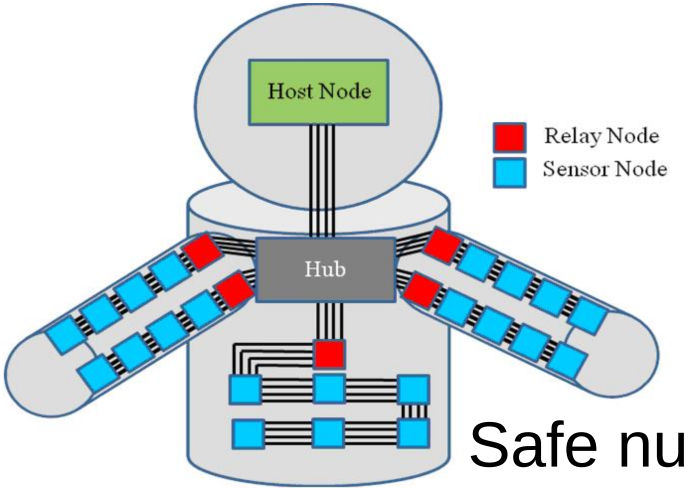
(1,000 Tr./chip in our lab., 1,000,000 Tr./chip in company, 10,000,000,000 Tr/chp now)

Common 2 wires tactile sensor array (polling type)

(S.Kobayashi & M.Esashi, Technical Digest of the 9th Sensor Symposium,(1990),137)



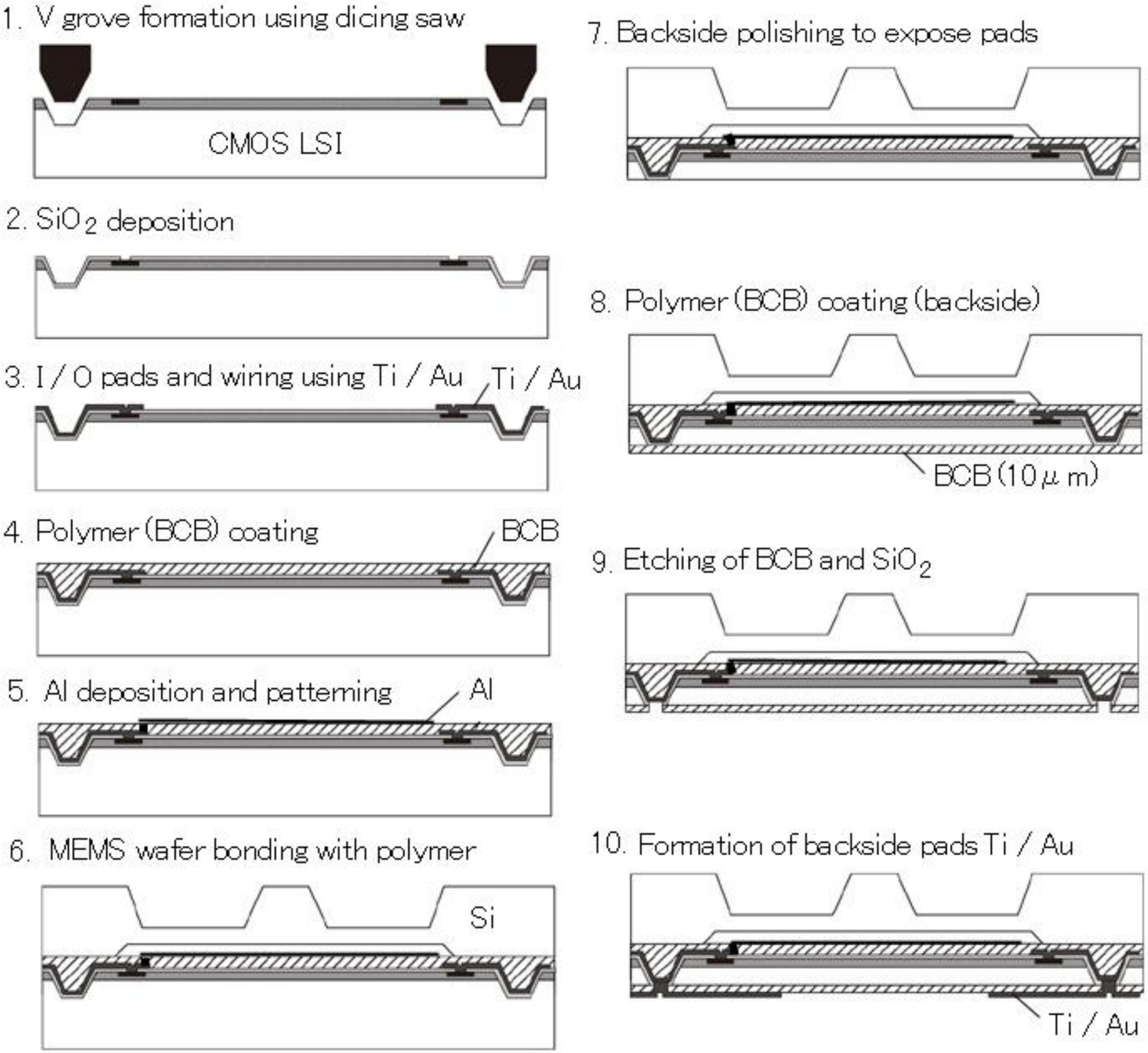


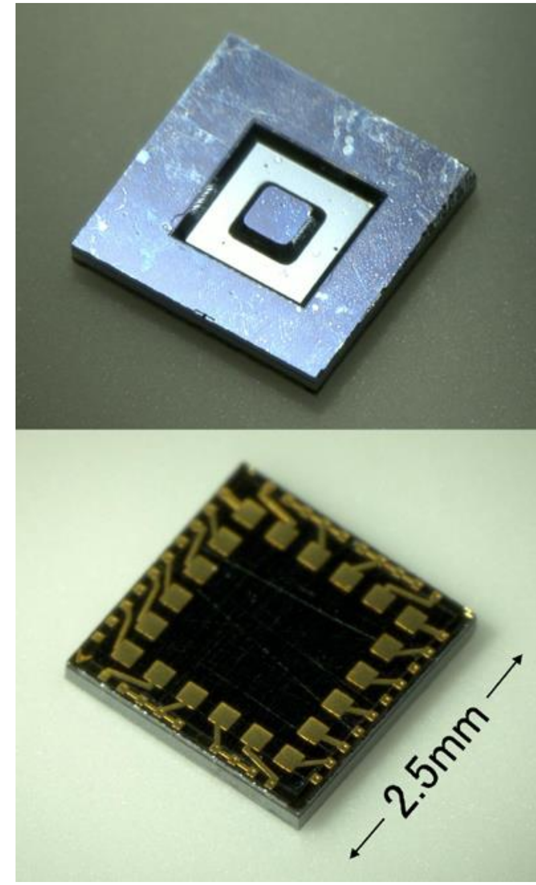


Safe nursing robot

Tactile sensor network for robot (event driven type)

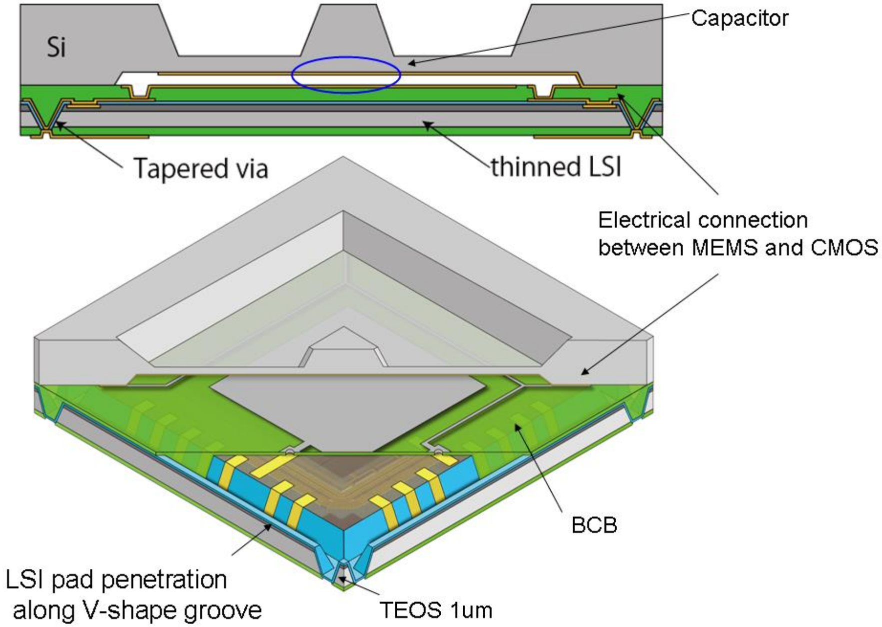
(M.Makihata, M.Muroyama, 26th Sensor Symposium (Oct. 15-16, 2009))

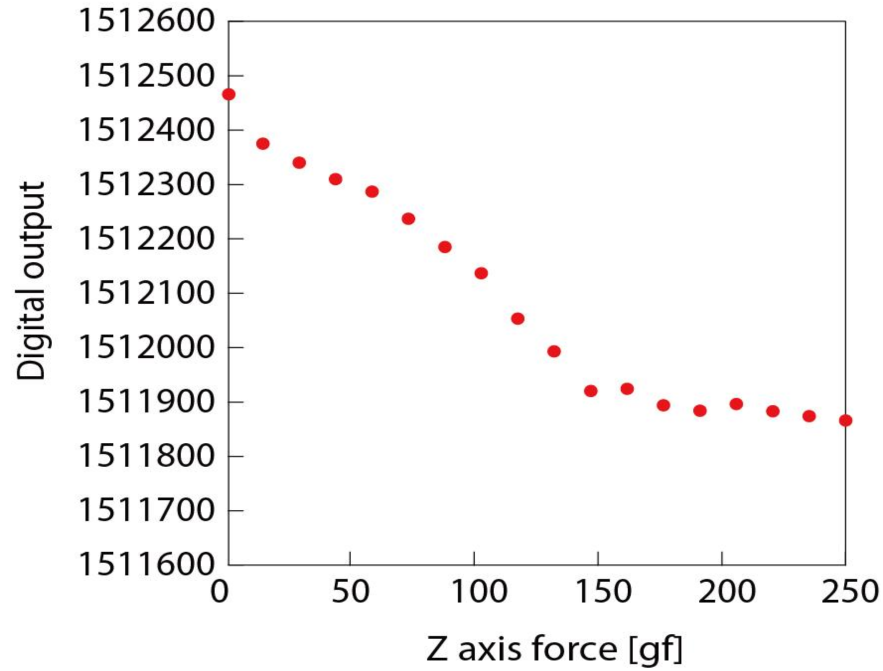


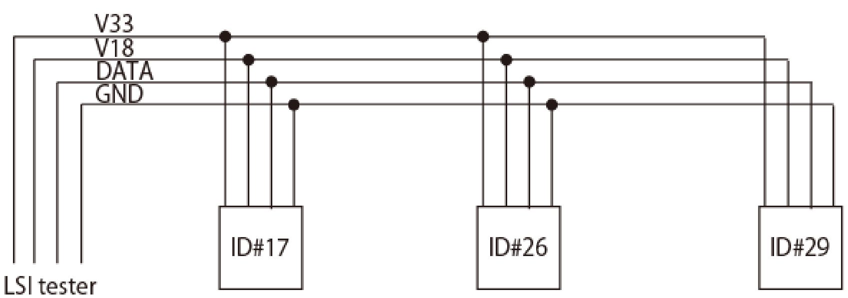


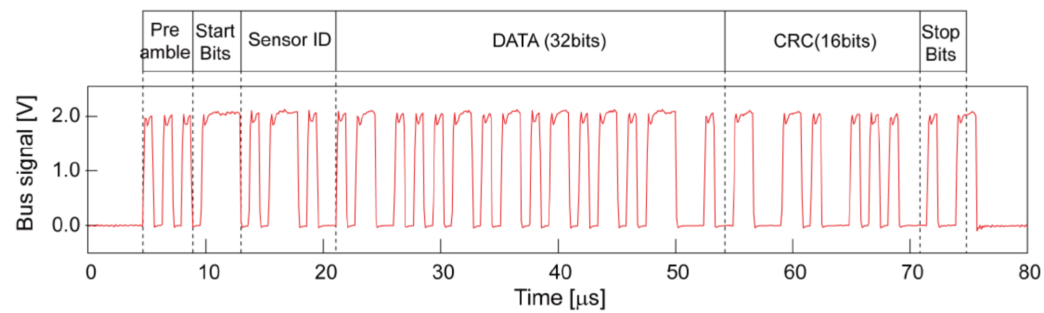
Fabrication process of tactile sensor

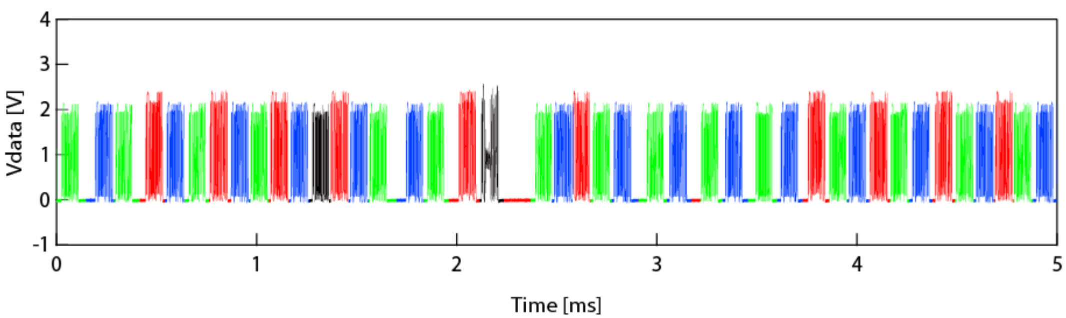
(M.Makihata, M.Muroyama et.ai., 2012 MRS Spring Meeting, San Francisco (2012) B3.2)





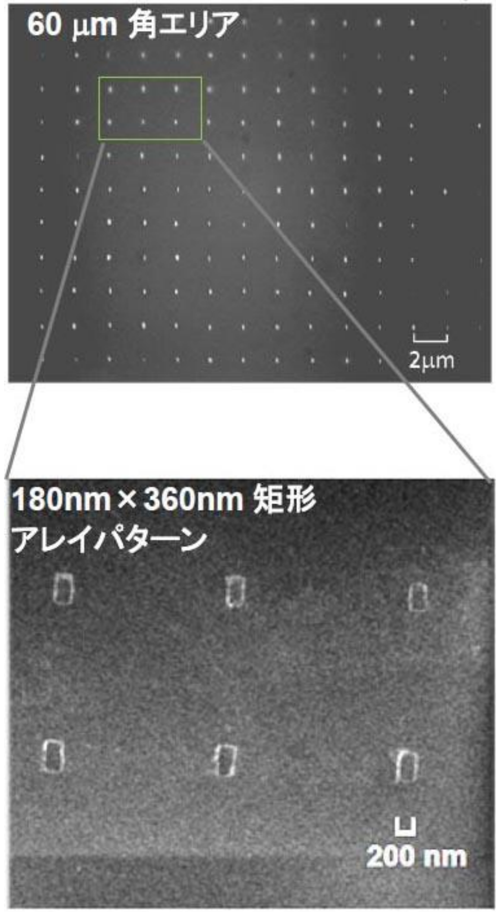


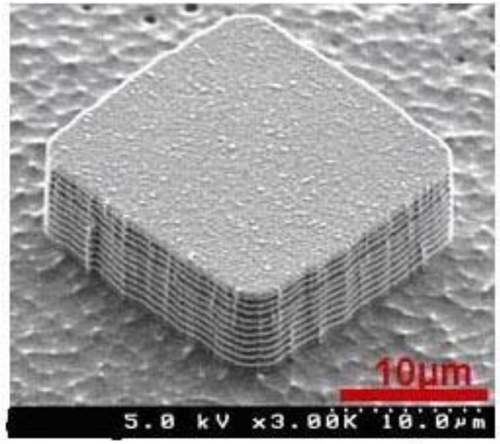


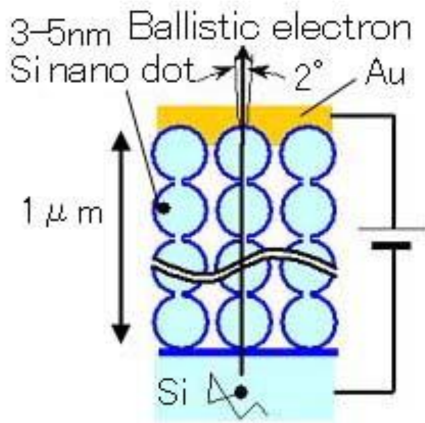


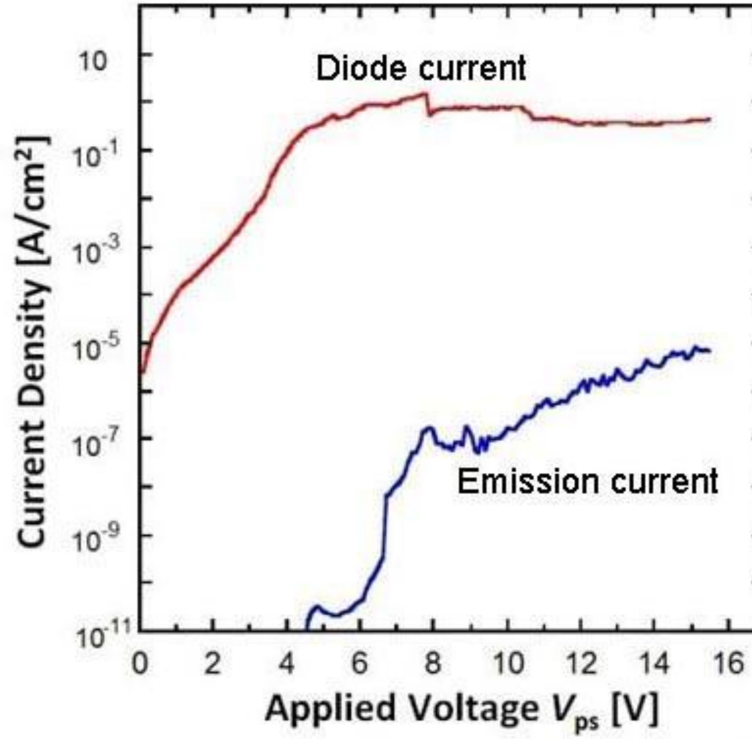
Tactile sensor network

(M.Makihata, M.Muroyama et.ai., 2012 MRS Spring Meeting, San Francisco (2012) B3.2)

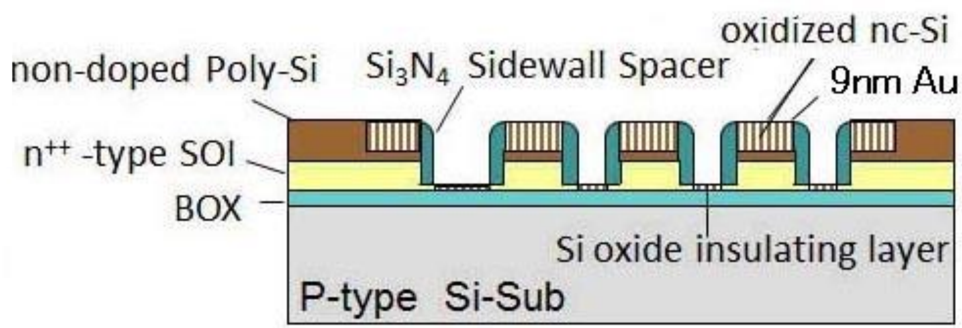






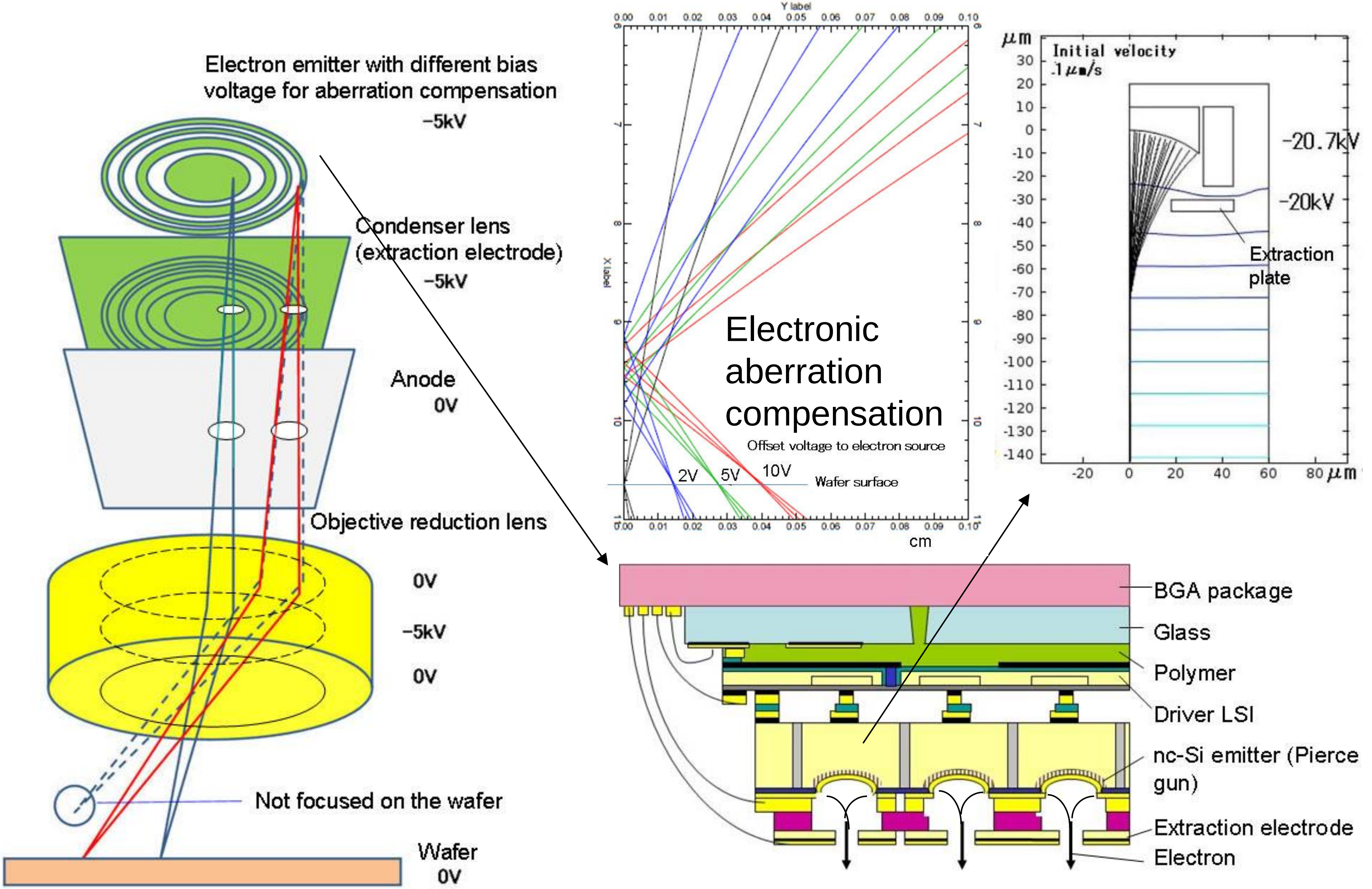


resist pattern by 1:1
EB exposure



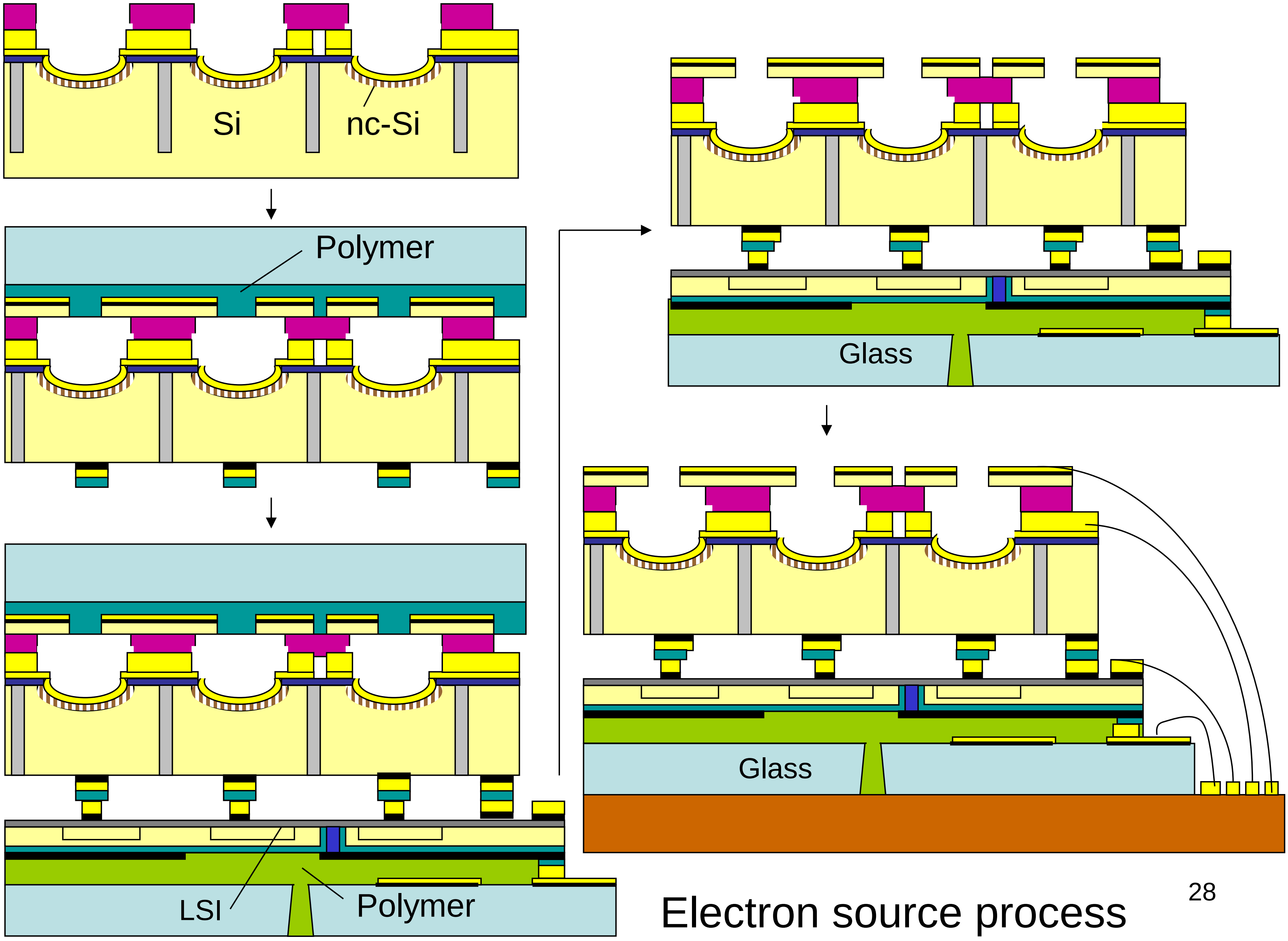
nc (nanocrystalline)-Si emitter array fabricated on SOI substrate

(N.Ikegami et.al., Active-Matrix nc-Si Electron Emitter Array for Massively Parallel Direct-Write Electron-Beam System, SPIE 2012 Advanced Lithography (2012/2/12-16) San Jose, USA)



Structure of 100×100 active matrix nc-Si emitter

Massively Parallel EB (Electron-Beam) Exposure System



Electron source process

1. Introduction

2. Integrated MEMS by adhesive wafer bonding

    Principle and filters

    Piezoelectric switches

    Tactile sensor network

    Massive parallel EB exposure system

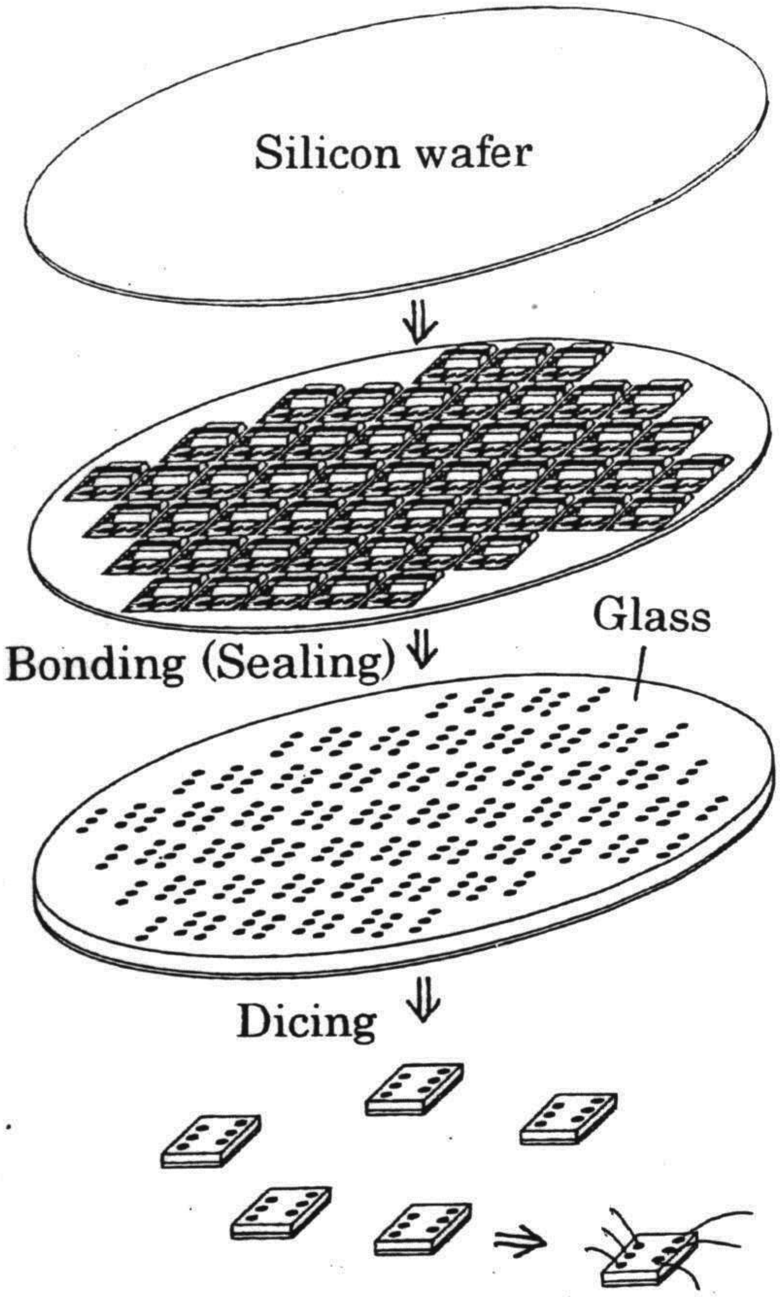
3. Wafer level packaging

4. Open collaboration

5. Conclusions

MEMS have moving parts

→ Direct molding with plastics can not be done.



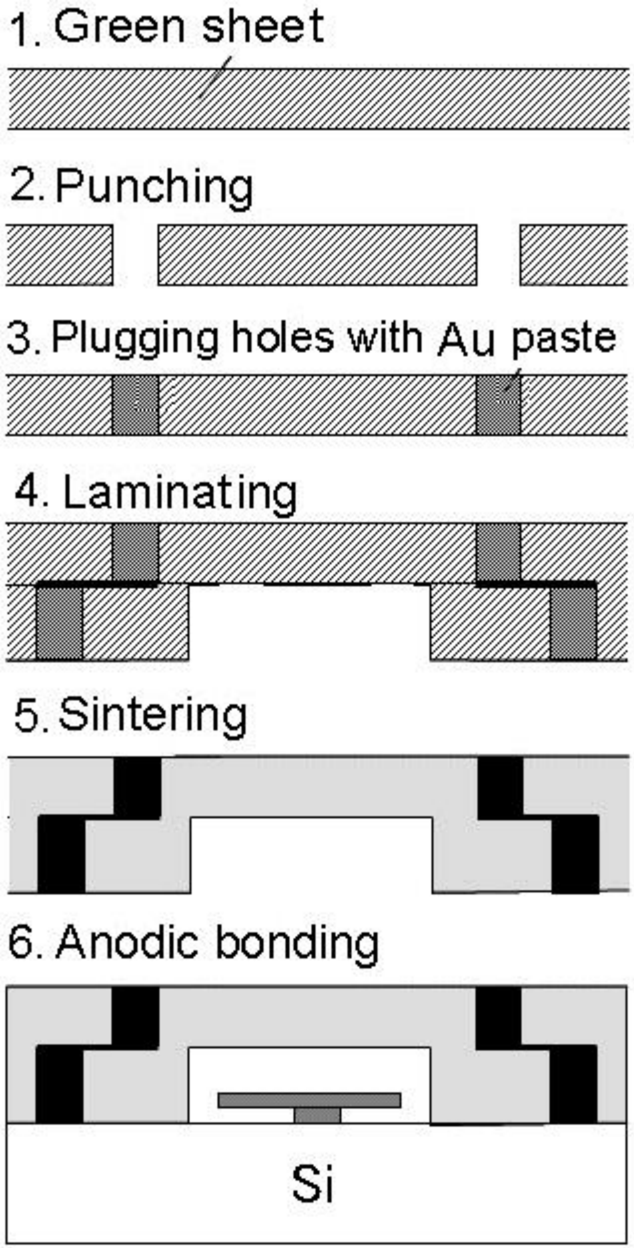
→ small size (chip size encapsulation, suitable for surface mounting)

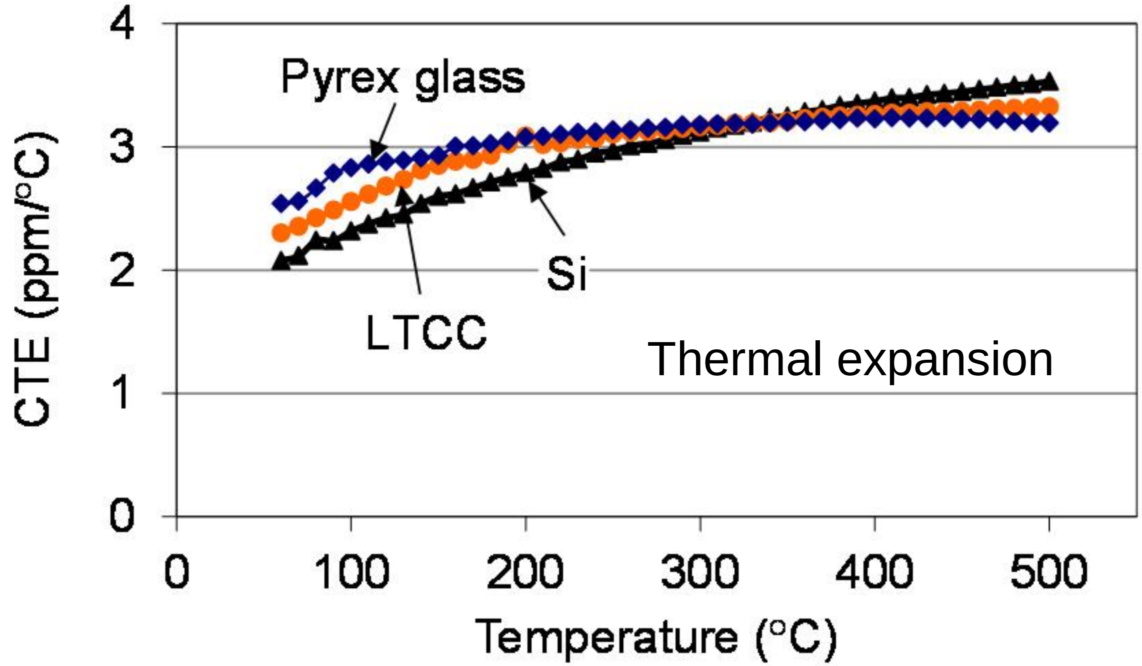
→ high yield (protection of MEMS structures during dicing)

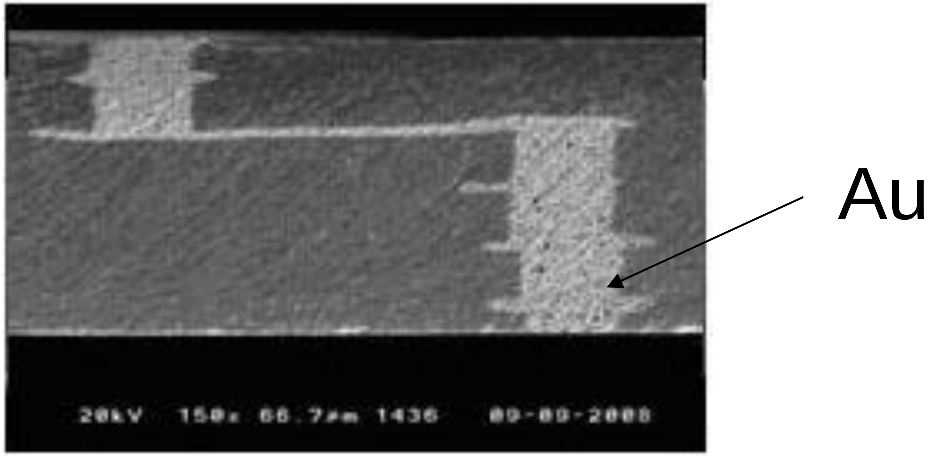
→ high reliability (hermetic sealing)

→ low cost (minimal investment for assembly, no use of expensive ceramic packages etc)

Wafer level packaging

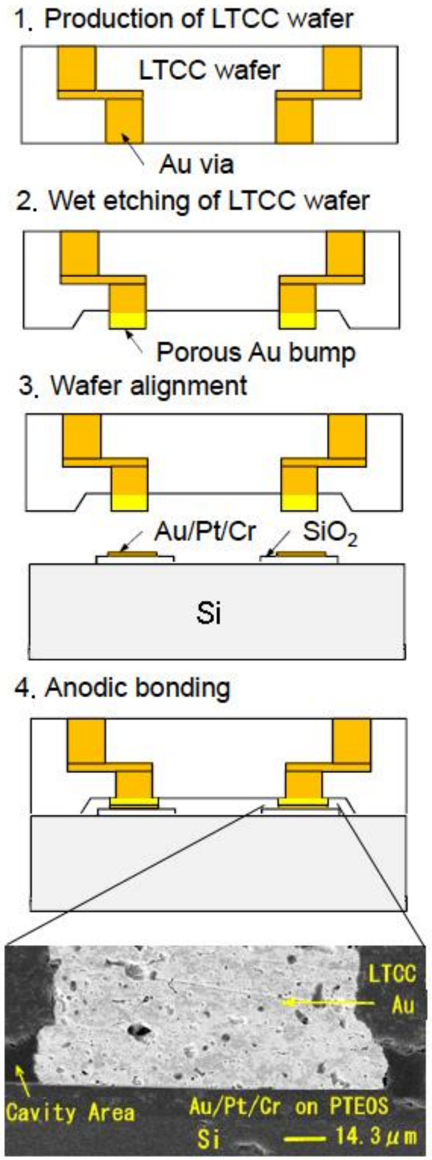




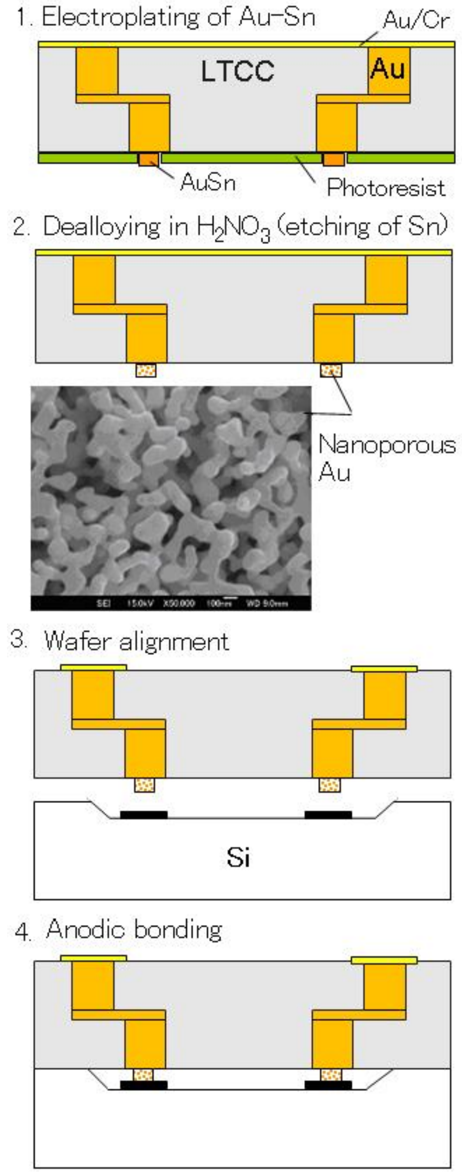


LTCC with through-via interconnection

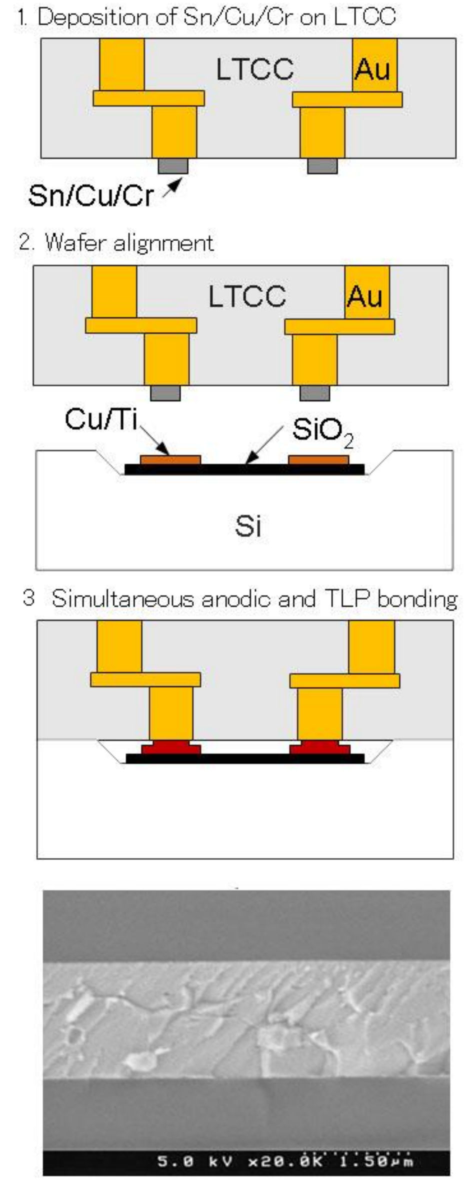
(M.Mohri (Nikko Ltd.), A.Okada, H.Fukushi, S.Tanaka and M.Esashi, 23th Convention on Electronic Packaging, Yokohama, p.51 (March 11,2009))



(a) Porous Au bump by etching of LTCC

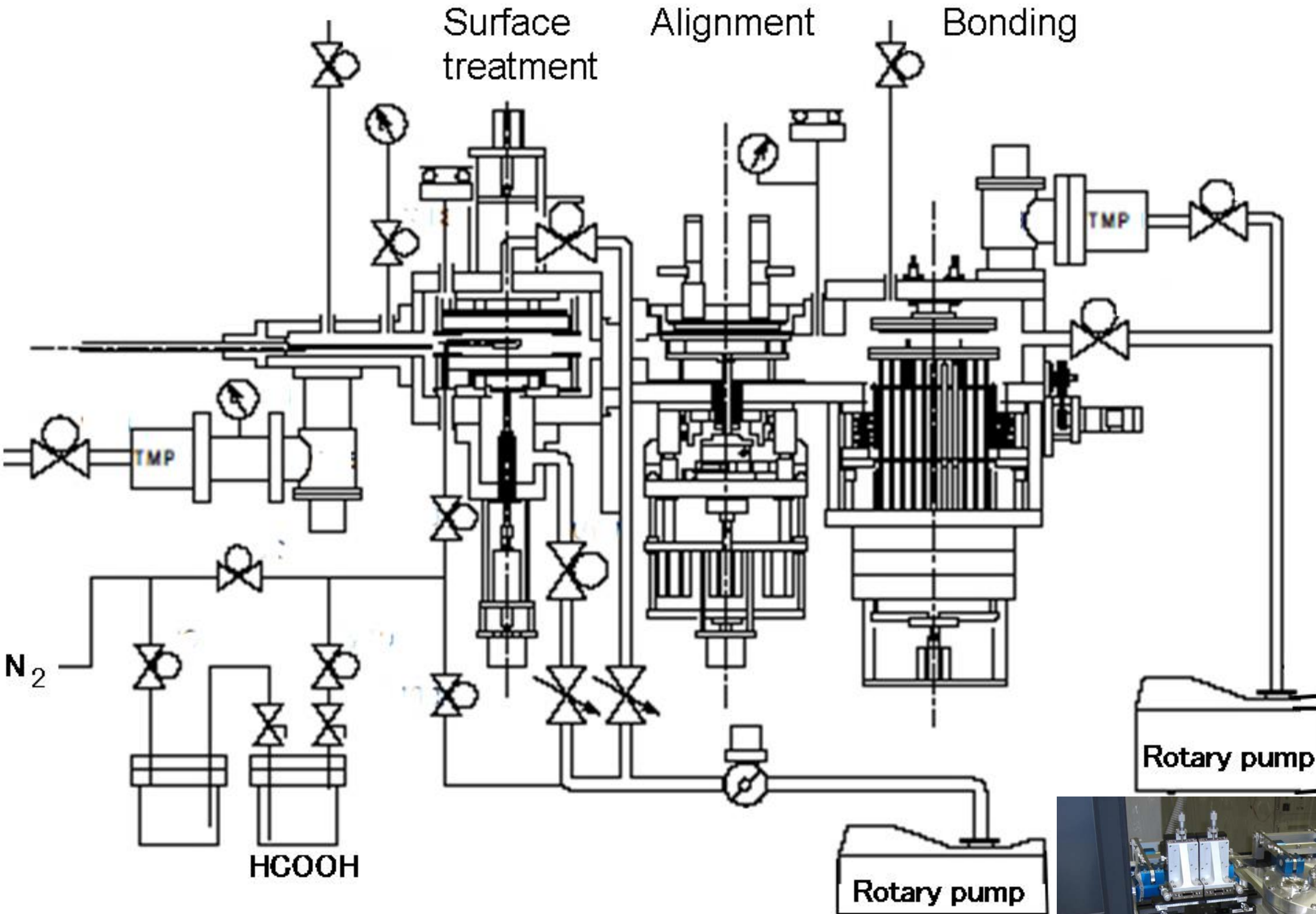


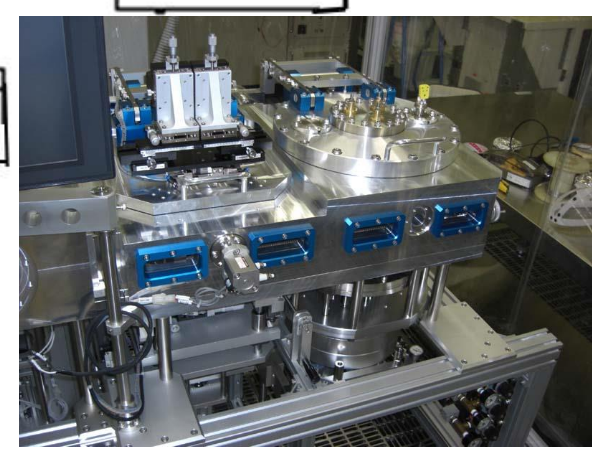
(b) Nano-porous gold bump by etching out of Sn from Au-Sn (Collaboration with FhG ENAS)



(c) TLP (SLID) bonding using Cu-Sn-Cu

Electrical Interconnection from the feedthrough of LTCC





Metal-metal bonder

(S.Matsuzaki, S.Tanaka, T.Baba and M.Esashi, The 28th Sensor Symposium on Sensors, Micromachines and Applied Systems, Tokyo (2011) 63)

1. Introduction

2. Integrated MEMS by adhesive wafer bonding

    Principle and filters

    Piezoelectric switches

    Tactile sensor network

    Massive parallel EB exposure system

3. Wafer level packaging

4. Open collaboration

5. Conclusions

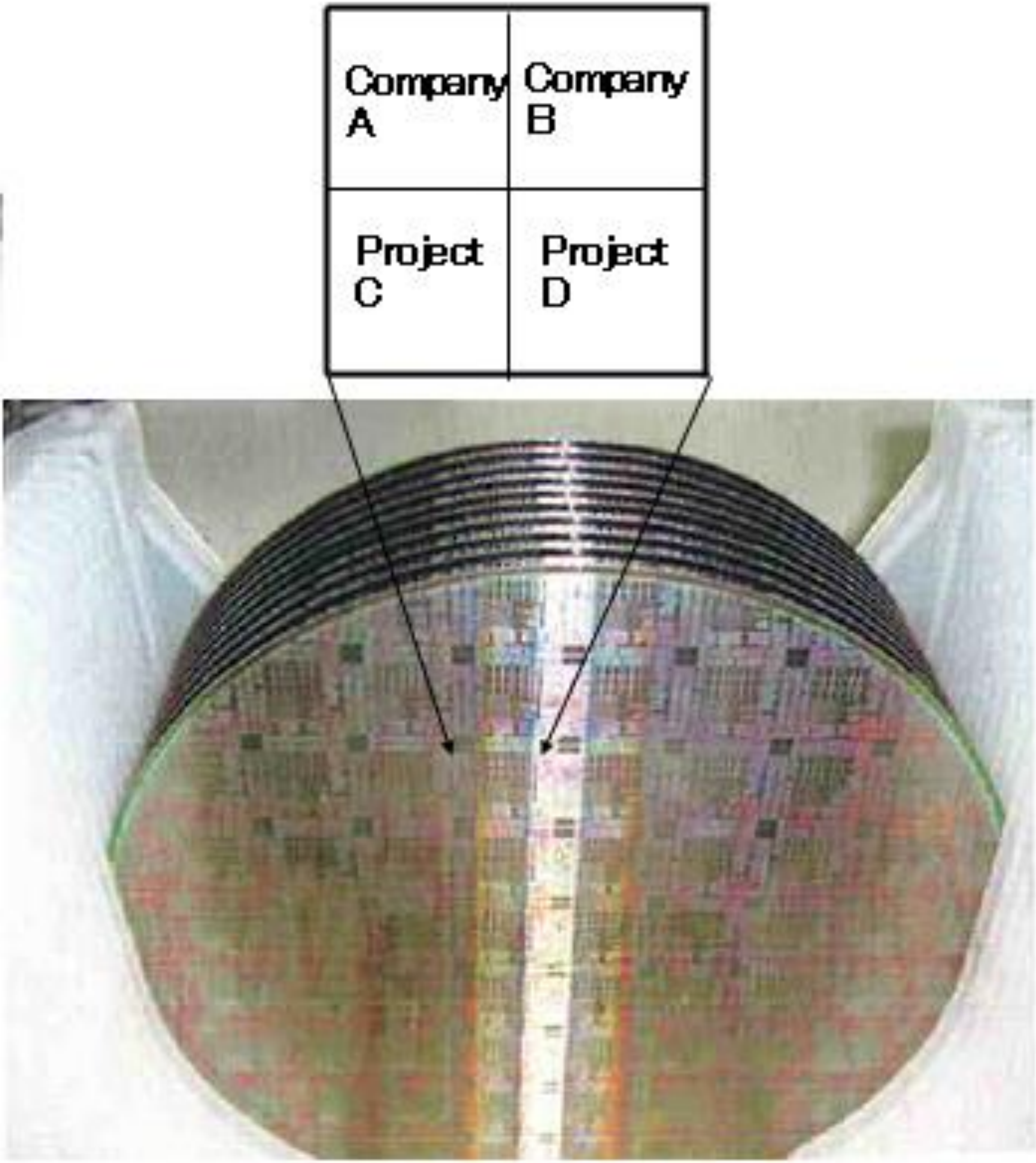
Unique facility like toy for MEMS prototyping

MEMS process facility for 20 mm wafer

Many process equipments have been made in house.

Simple and basic equipments are suitable for training people who have experiences of all the process and for developing new devices taking advantages of process flexibility.

The facility has been shared by many laboratories.
More than 100 companies dispatched researchers (full time, 2years).

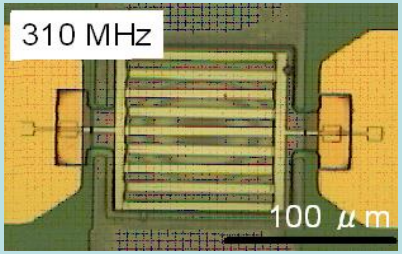


Ricoh,
Toyota motor,
Pioneer,
Nippon signal,
Toppan TDC,
Kitagawa iron works,
Sumitomo precision, NIDEC COPAL elec. Nikko,
Toyota central R&D lab,
Nippon dempa kogyo, Japan aviation elect. Ind., MEMS core,
MEMSAS,
Furukawa Electric,
Denso
Laboratories in Tohoku Univ.

Shared CMOS LSI wafer

Next generation wireless system group

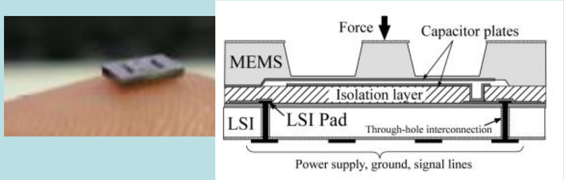
Yugami, Tanaka, Yamaguchi, Endo, Iguchi Toppan TDC, Nippon Dempa Kogyo



Multi-frequency Lamb wave oscillator

Sensor network, functional sensor group

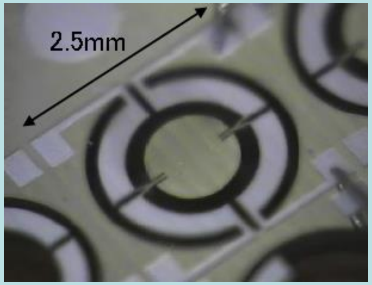
Kuwano, Miura, Ono, Tanaka, Nagasawa, Muroyama Kitagawa, Sumitomo precision product, Nidec copal electronics, Toyota, Toyota Central R&D, Pioneer



Tactile sensor network

Optical microsystem group

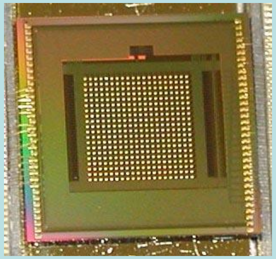
Hane, Kanamori, Kawai Ricoh, Nippon signal, Toyota, Toyota Central R&D, Furukawa Electric



2D PZT optical scanner

Biomedical microsystem group

Matsue, Nishizawa, Haga, Kusu Japan aviation electronics industry MEMSAS



Bio LSI

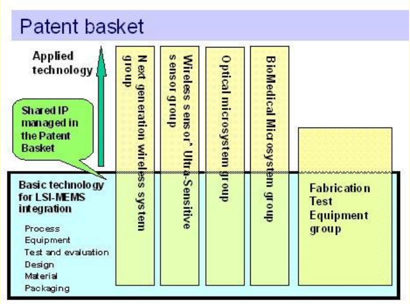
Fabrication test equipment group

Samukawa, Esashi, Miura, Ono, Yamaguchi, Kumano, Miyashita MEMS core, Nikko

Metal-metal boner

Technology society system working group

Harayama, Sionoya, Kawai, Miyashita, Matsuzaki



Shared patent

Tohoku Univ. Aobayama campus

Micro-nanomachining research and education center (2 inch LSI process line)

Jun-ichi Nishizawa memorial research center (4/6 inch MEMS process line)
(Hands-on access fab.)

MEMS prototyping room in Tohoku Univ.(20mm)

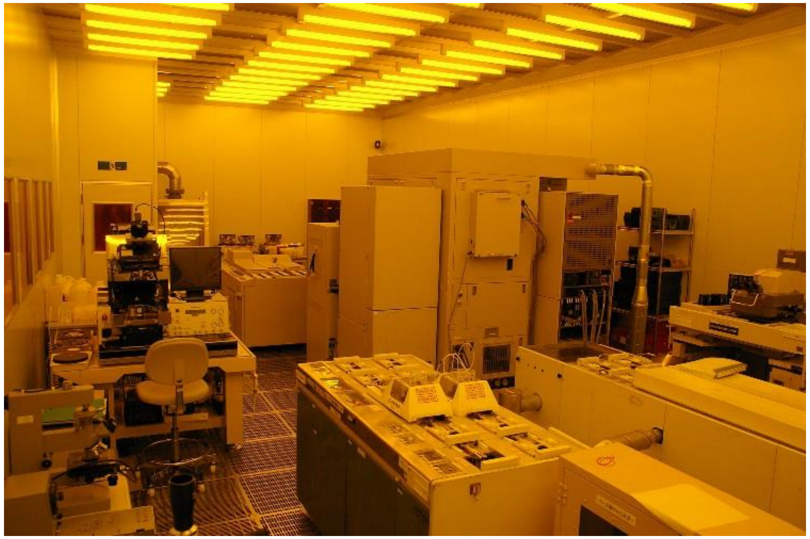
(Initial stage prototyping)

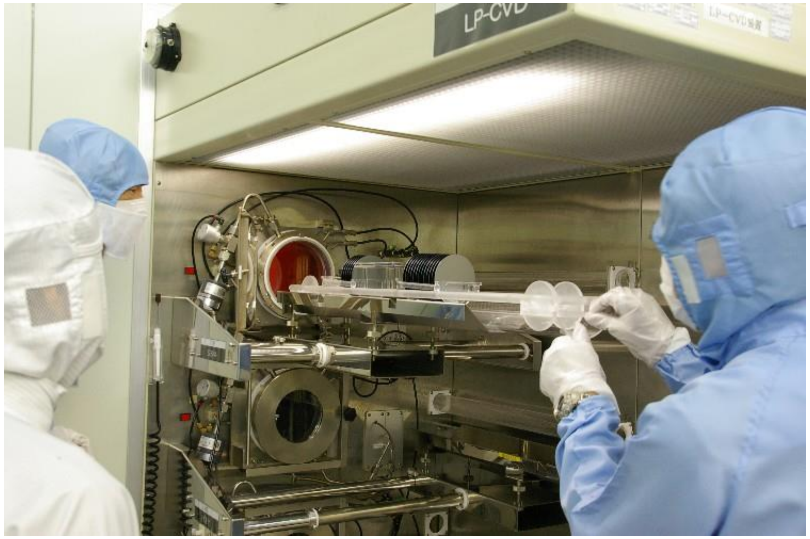
AIST MEMS building in Tsukuba (8 inch process line) (R.Maeda)

(Production stage prototyping)

Prototyping facilities

World-leading innovative R&D project 2010 ~ 2013FY





Companies which cannot prepare their own facility dispatch their employees to operate equipments by themselves.

Shared facility for industry to prototype MEMS devices (4 / 6 inch)

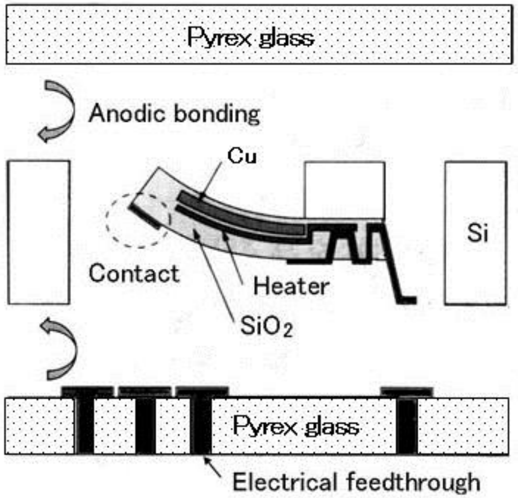
Hands-on access fab. (Nishizawa memorial research center in Tohoku Univ.)

Contact person : Assoc. Prof. Kentaro Totsu totsu@mems.mech.tohoku.ac.jp

MEMS Core Co.Ltd (President : K.Honma)

MEMS contract development, prototyping and small volume production (2001~)

http://www.mems-core.com/



ADVANTEST

Immune to electrostatic discharge up to 1000V
Wide frequency range (DC~10GHz)

MEMS switch for LSI tester

MEMS switch factory
(Advantest components (Sendai))

(A.Nakamura et.al.,Advantest Technical Report, 22 (2004), 9-16)

ADVANTEST ADVANTEST CORPORATION

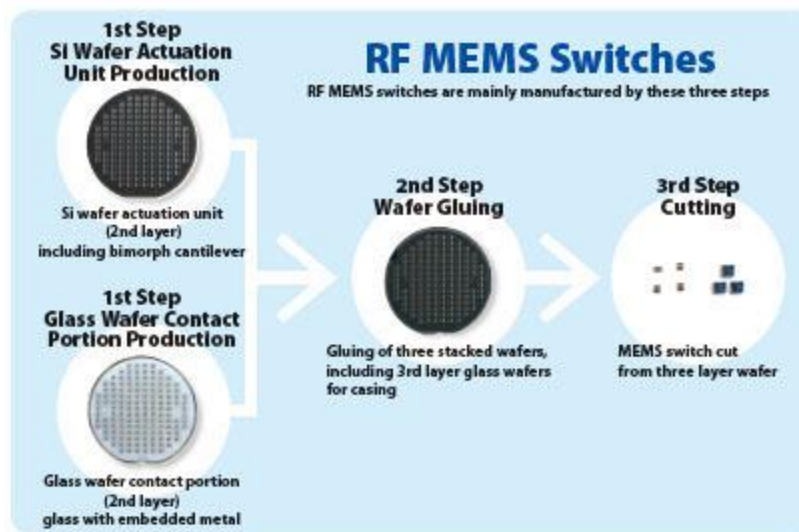
High-Frequency, Low Power Consumption MEMS Relay

Advantest's high-frequency MEMS relay utilizes piezoelectric actuation to achieve low power consumption and high reliability. Via Advantest's proprietary deposition technology, the relay features a piezoelectric film only 1 micron thick, making low actuation voltage possible. The relay also has high reliability, using contact-point control technology honed in Advantest's semiconductor testing equipment, and it can handle up to 20 GHz high-frequency transmission, using Advantest's high-frequency measurement technology.

MEMS Relay Applications

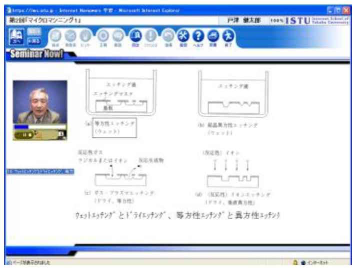
Semiconductor Testing Equipment, High-Speed Communications Devices, High-Frequency Measurement Equipment

MEMS Relay Production Process

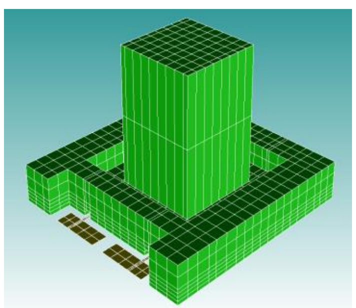


3 months

10 ~ 20 d	30 ~ 60 d	~ 10 d	3 d
Planning, design	Fabrication (4 inch process)	Testing	Presentation, report

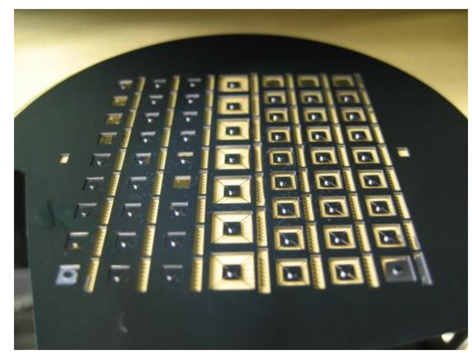


Lectures on Internet School of Tohoku University



Design

Training of Fabrication

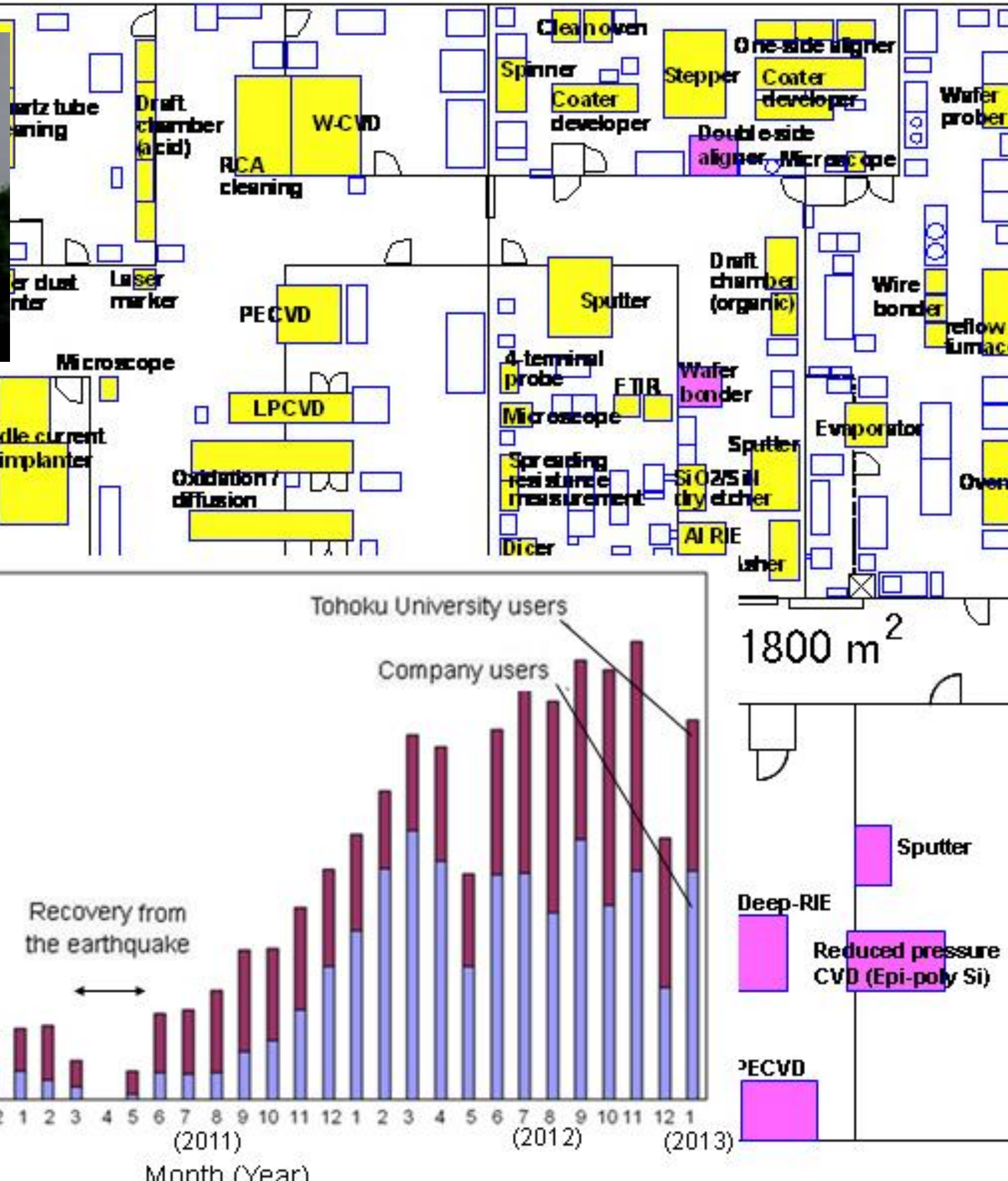


Ex. Capacitive 3-axis accelerometer

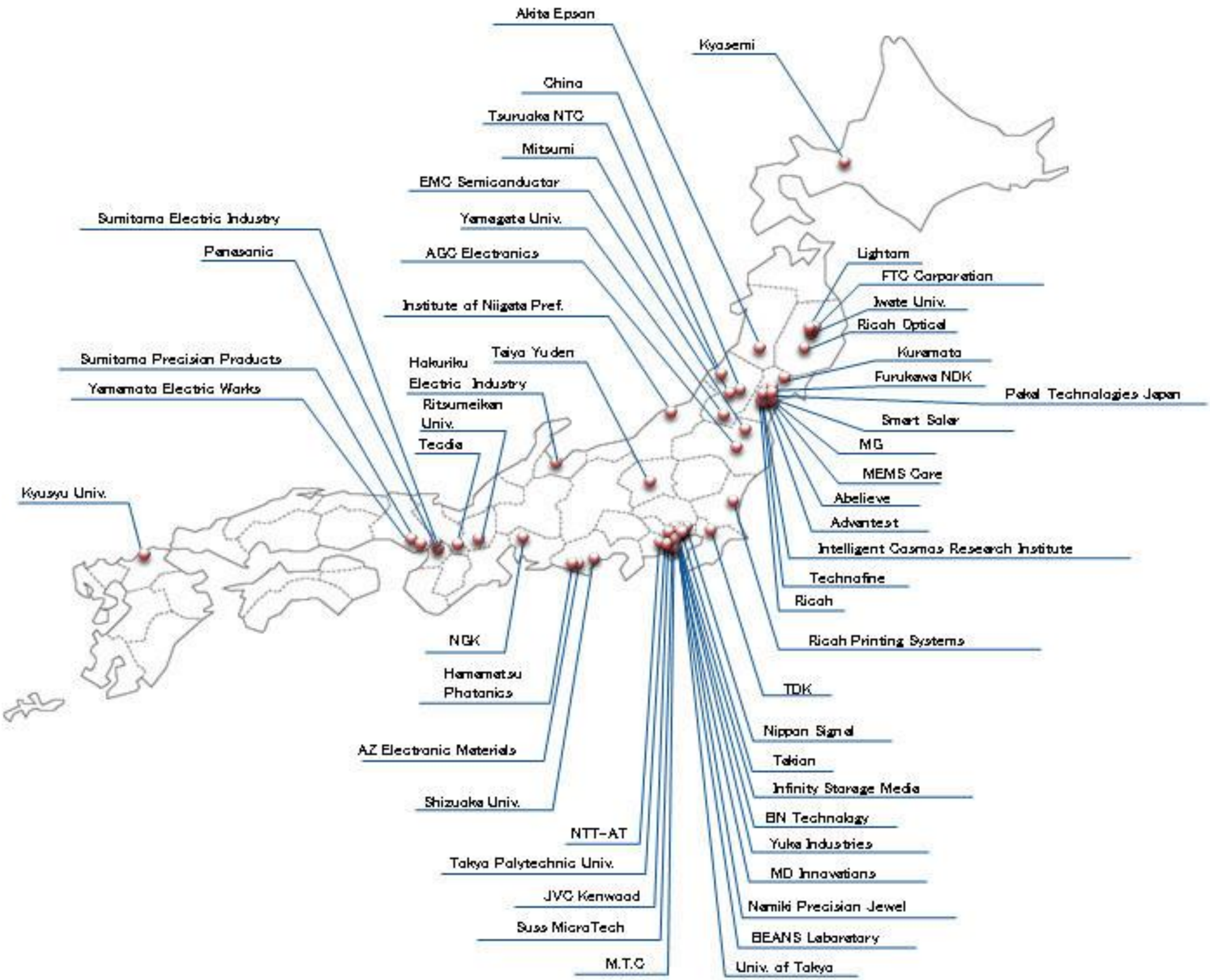
MEMS Training Program in Sendai MEMS park consortium

Since Apr.2007. Fee 1 million yen. Trainee participate with own subject.
16 companies participated.

Nishizawa memorial research center

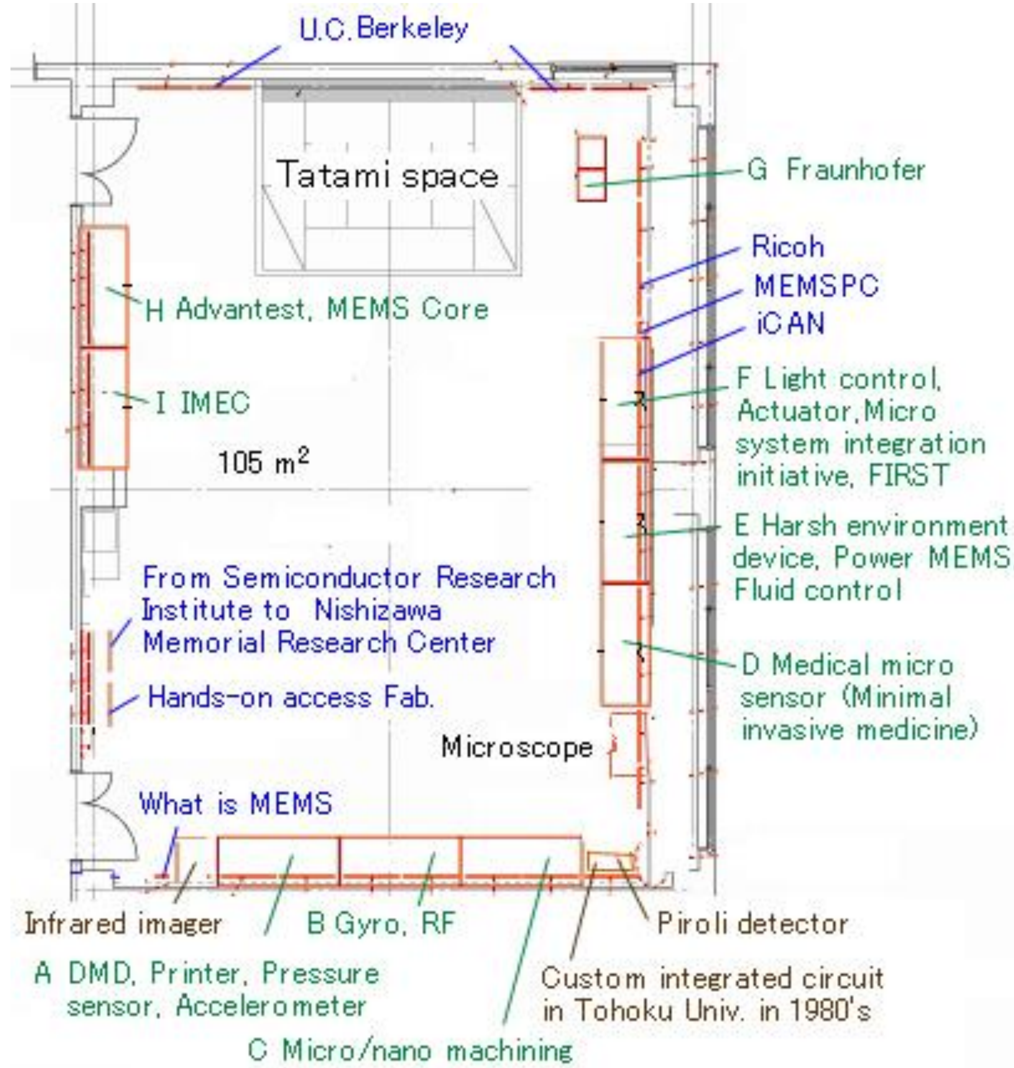


Shared facility for industry to prototype MEMS devices (4 / 6 inch) Hands-on access fab.



Users approximately 80 companies

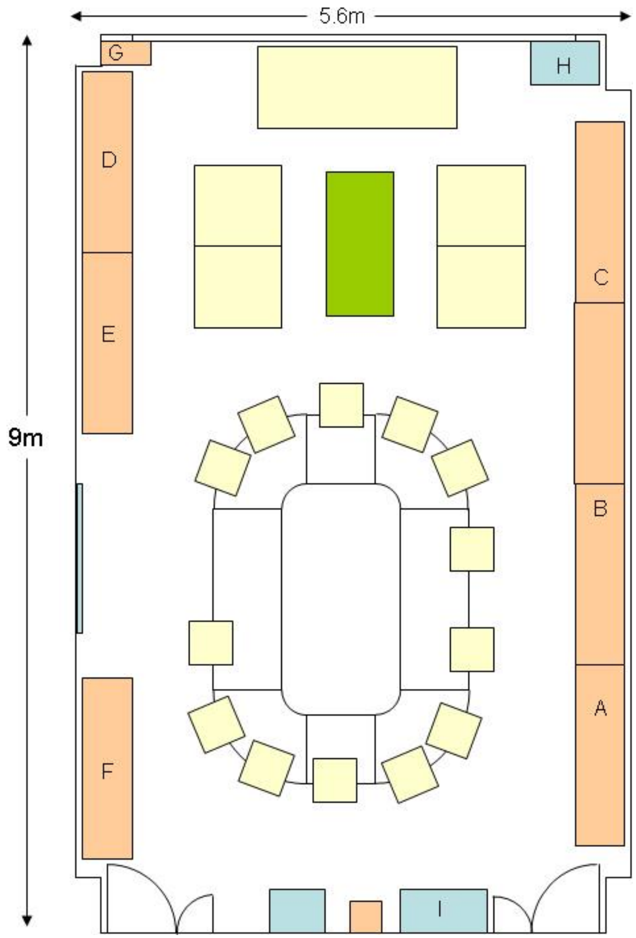
Catalog



Efficient way to access accumulated knowledge is important for heterogeneous integration

Sendai MEMS showroom (2012/5/16 renewal opening)

http://www.mu-sic.tohoku.ac.jp/showroom_e/index.html



A1 Electrical measurement : Galvanometer etc.
A2 Wired communication : Microphone, Headphone
A3 Wireless communication : Vacuum tube radio, Transistor radio
B1 Recording : phonograph (Edison), Vacuum tube magnetic tape recorder
B2 Computer : Mechanical computer, calculator
C1 Vacuum tube : Various vacuum tubes, Vacuum tubes for take-out, Manuals
C2 Transistor・IC : From vacuum tube to transistor, Development of LSI
C3 Haggerty's forecast (1964)
D1 Optical equipments : Microscope×3, Analog recording camera, 8mm movie etc.
D2 Optical instruments : Radiation thermometer etc.
E1 Hobby : Mechanical doll, Aibo, Micro flying robot and computer controlled model car
E2 Automobile museum: Model T Ford、Model A Ford
E3 Nishizawa memorial room
F Materials for take-out (history of technology)
H Books on the history of technology
I Materials related to Tohoku Univ. and companies

Historical Museum of Technology

http://www.mu-sic.tohoku.ac.jp/museum/

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

FhG Germany – Sendai city partnership extension signing ceremony (July 13, 2010)

FhG Germany – Tohoku Univ. partnership signing ceremony in Sendai (Nov. 8, 2011) →

Mayer of Sendai city Ms.E.Okuyama and president of FhG Prof. H.-J.Buringer

FhG Project center in WPI-AIMR, Tohoku Univ. (2012)

WPI-AIMR core members in IMEC (2012/6/21) Pi's Esashi, Ohno and Matsue

Strategic Partner

Tohoku U · Stanford U · EPFL

- One university from each region,
  Japan, USA and Europe
- Promotion of international research exchange
- Exchange of researchers and students

Hiroshi Kazui (Director, Tohoku Univ.) and Luc Van Den Hove (IMEC president)

Signing ceremony (2012/6/11)

(IMEC M.Yoneyama 2012/6/12)

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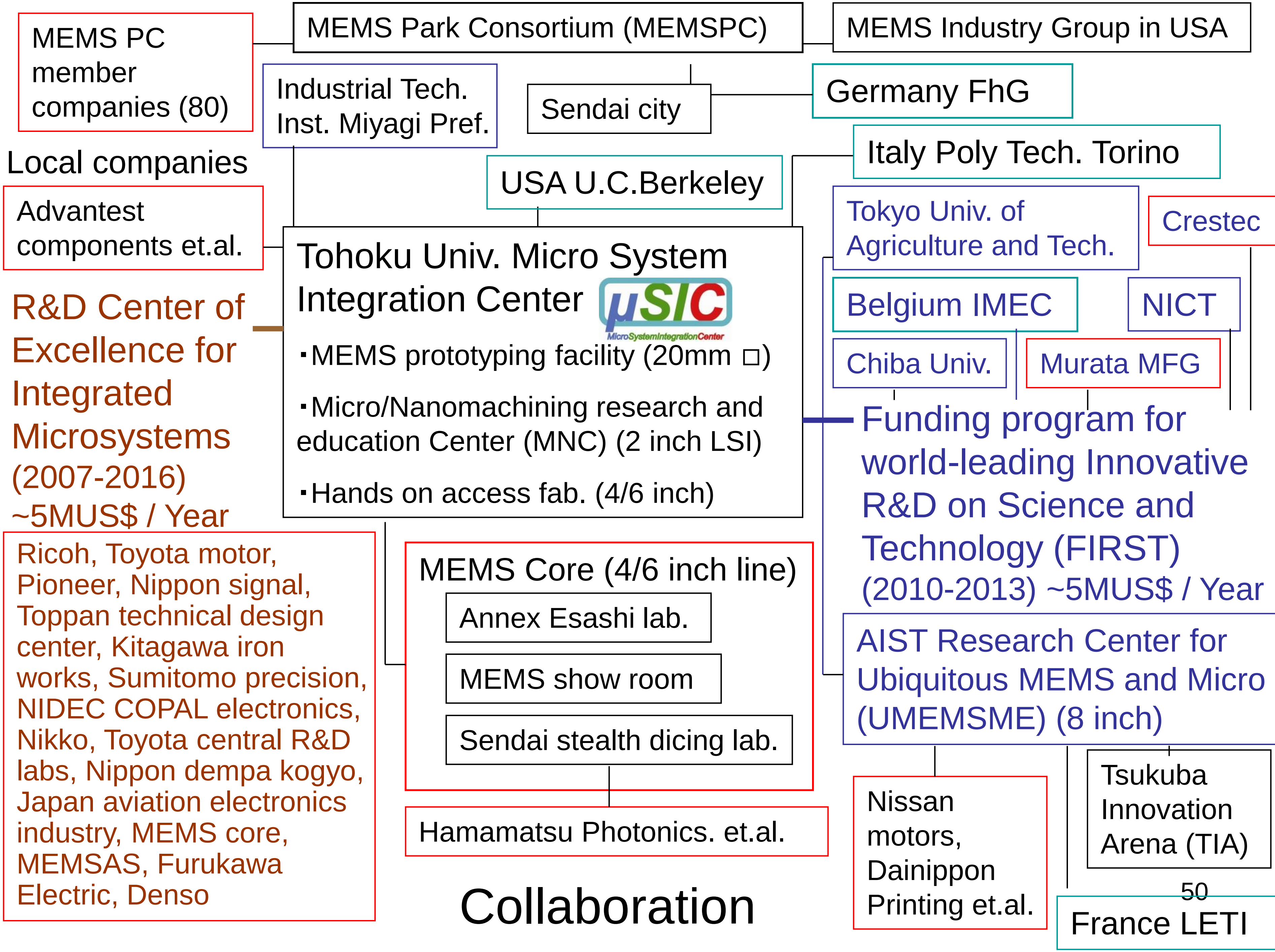
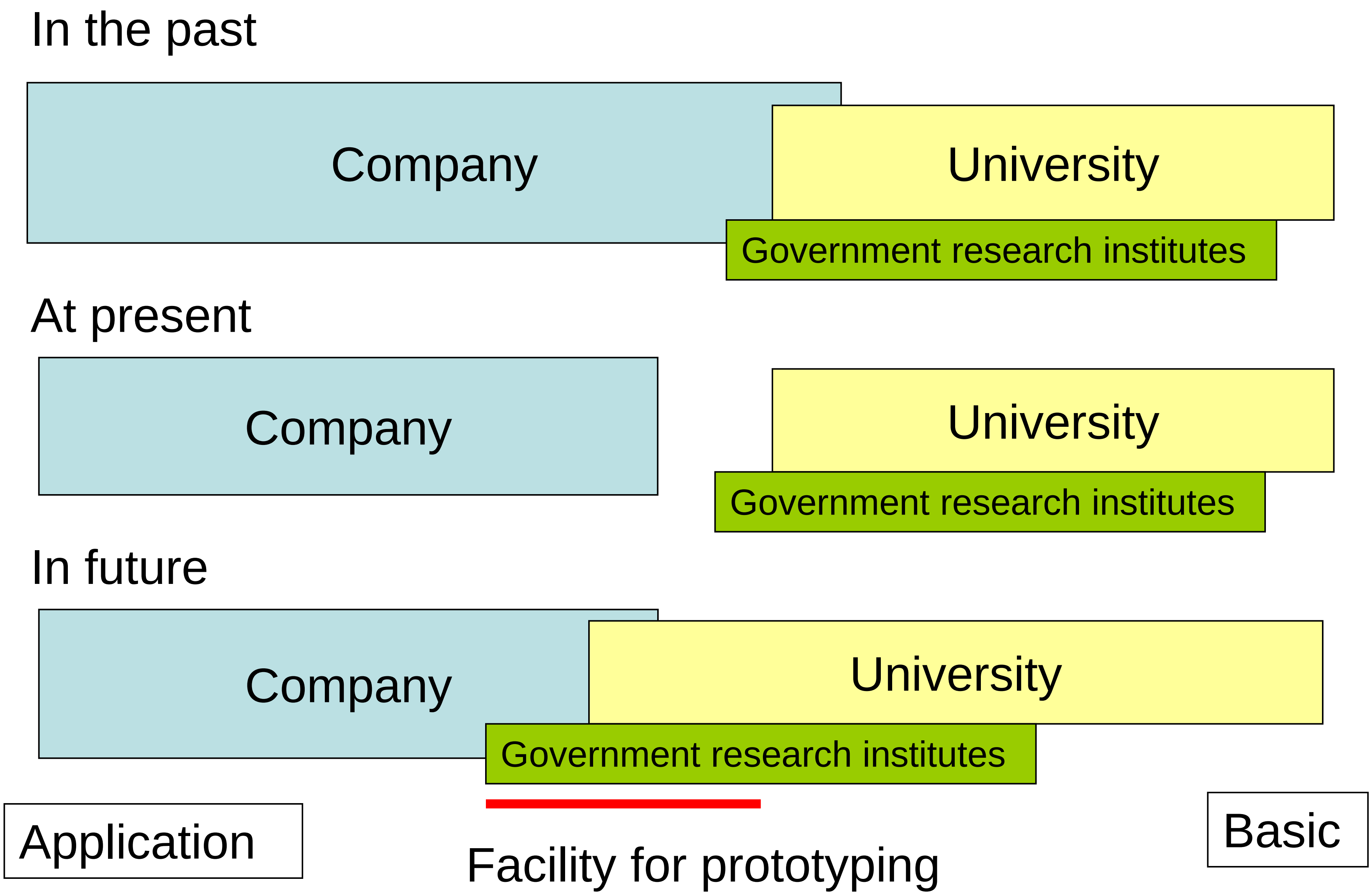


Collaboration


In the past
Company
University
Government research institutes
At present
Company
University
Government research institutes
In future
Company
University
Government research institutes
Application
Facility for prototyping
Basic

Efficient development for heterogeneous integration

Information from universities

（MEMS park consortium http://www.memspc.jp）

Free MEMS Seminar in Tokyo (Aug. 23-25, 2006) 280 attendees

Free MEMS Seminar in Sendai (Aug. 22-24, 2007) 75 attendees

Free MEMS Seminar in Fukuoka (Aug.20-22, 2008) 150 attendees

Free MEMS Seminar in Nagoya (Aug.4-6, 2009) 100 attendees

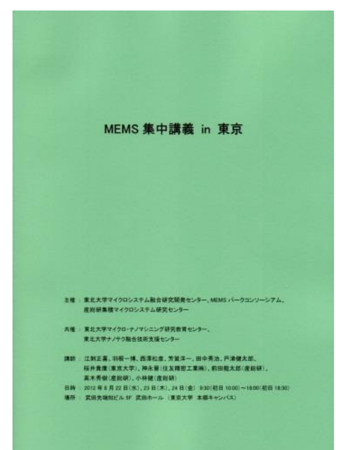
Free MEMS Seminar in Tsukuba (Aug.5-7, 2010) 211 attendees

Free MEMS Seminar in Kyoto (Aug.9-11, 2011) 175 attendees

Free MEMS Seminar in Tokyo (Aug.22-24, 2012) 226 attendees

High-tech. small volume production

Efficient utilization of facilities



MEMS seminar

Conclusions

1. Adhesive bonding for Wafer-Level Hetero Integration
   (Filters, Piezoelectric switches, tactile sensor network, massive parallel EB exposure system).
2. Wafer level packaging using LTCC with through-via interconnection.
3. Open collaboration for MEMS on LSI.

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Acknowledgment to collaborators

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