Open Collaboration in Tohoku University and MEMS Park Consortium

M.Esashi, S.Tanaka (Tohoku University)

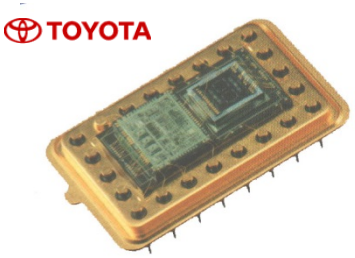
1. Introduction
2. Integrated MEMS by adhesive wafer bonding
   - Multiband system for cognitive wireless communication
   - Tactile sensor network
   - Massive parallel EB exposure system
   - Diamond electrode array on LSI for amperometric biosensor
3. Wavelength selective structure using sub-wavelength grid
4. Open collaboration by MEMS park consortium

Nikei-Sangyo newspaper (2003/12/12)
Highest evaluation by industry

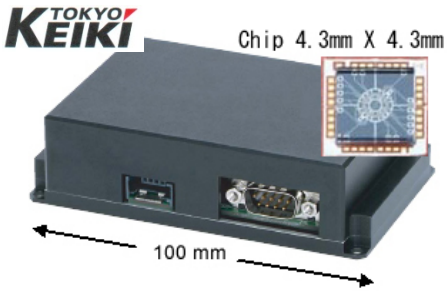
① Catheter pH, PCO_2 monitor (Kurare, Nihon Kohden)

② Portable pH sensor (Shindengen)

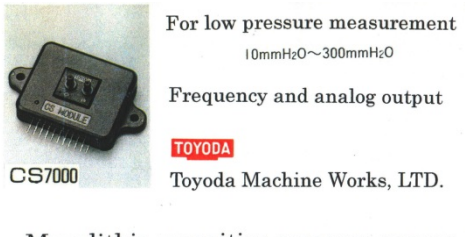
③ Instrument to detect H. pylori (Nihon Kohden)



④ Resonating gyroscope (Yaw rate Sensor & accelerometer) (Toyota)

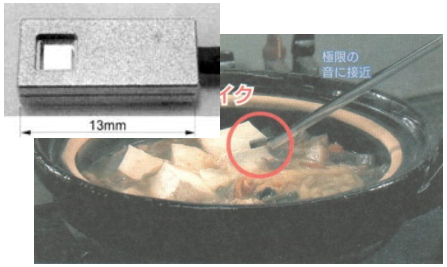


⑤ Electrostatically levitated rotational gyroscope (Tokyo Keiki)

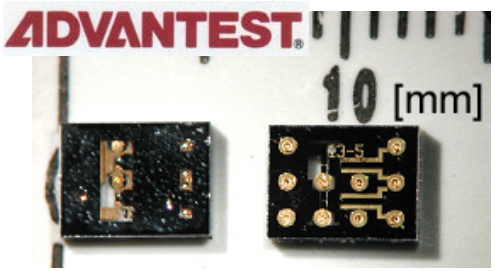


⑥ Integrated capacitive pressure sensor (Toyoda Machine Works)

⑦ Diaphragm vacuum gage (Canon ANELVA)

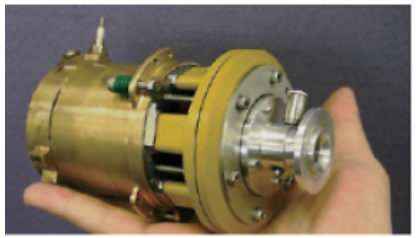


⑧ Silicon microphone (NHK, Panasonic)

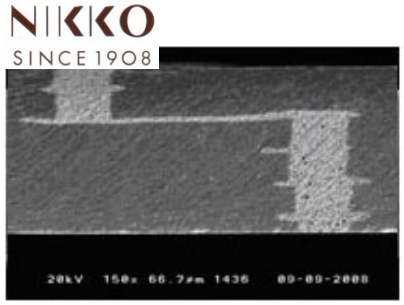


⑨ MEMS switch for LSI tester (Advantest)

⑩ 2-axes optical scanner (Nippon signal)

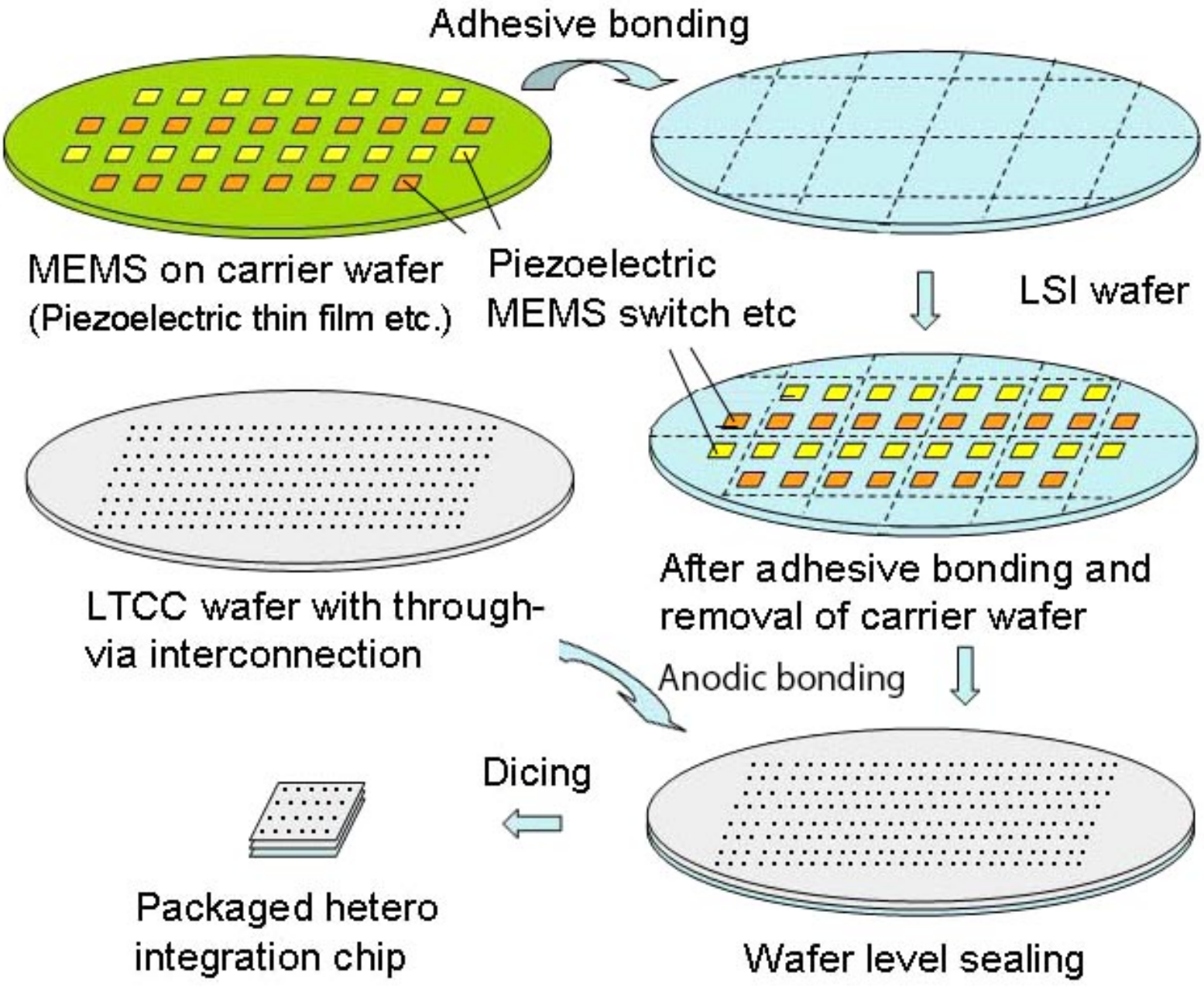


⑪ Palm-top silent gas turbine engine power generator for robot (IHI corp.)

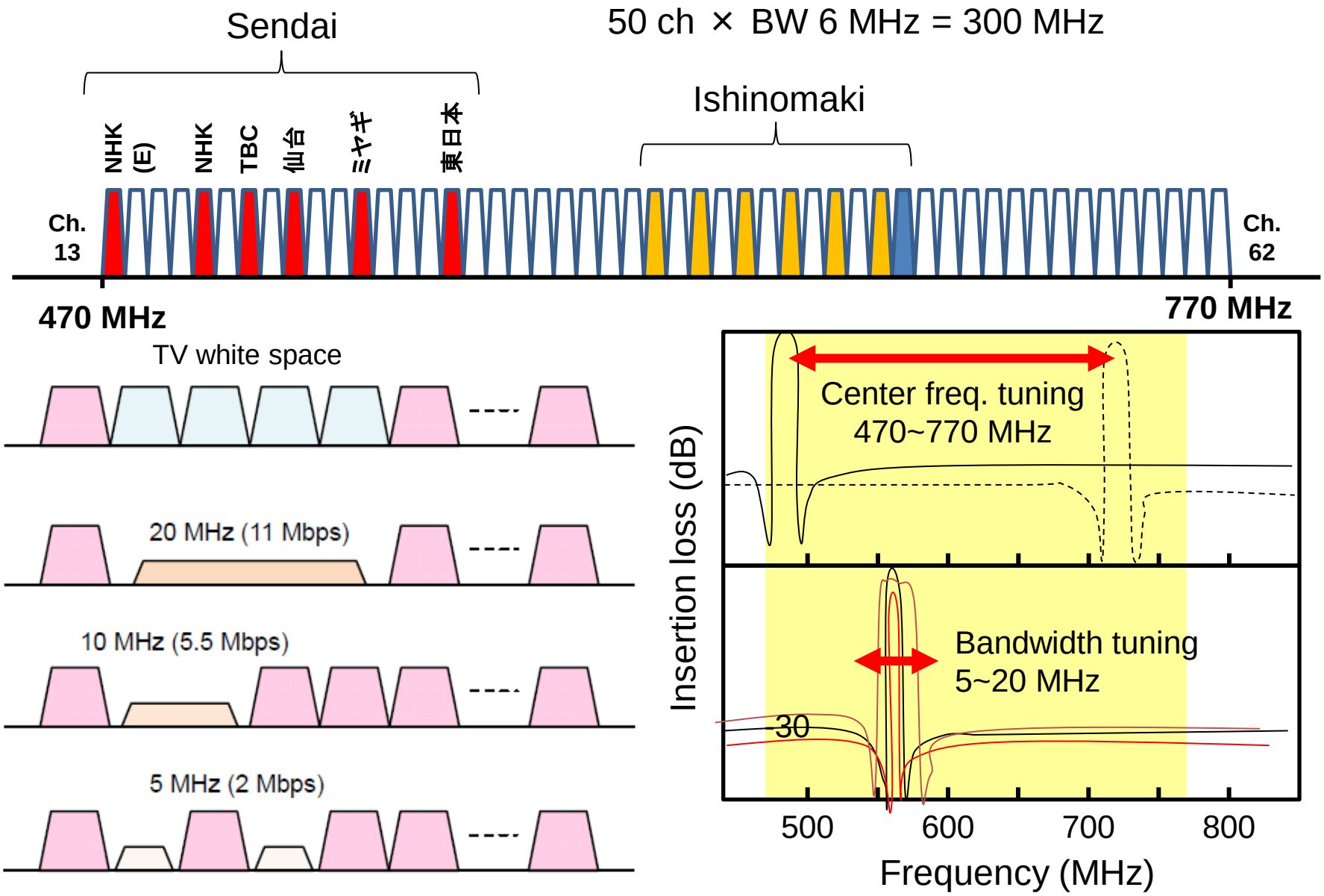


⑫ LTCC with electrical feedthrough for MEMS packaging (Nikko)

Examples of commercialized MEMS products from Esashi group

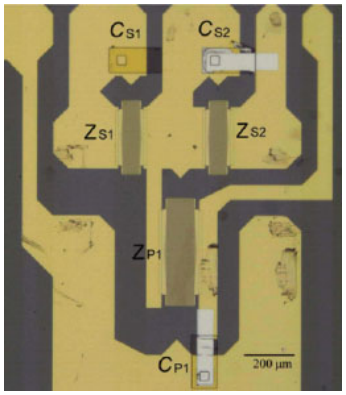


Heterogeneous integration by adhesive bonding

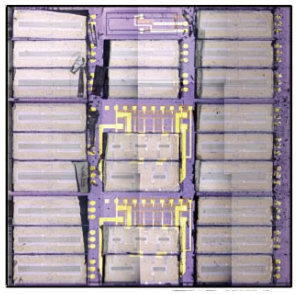


TV white space cognitive radio (IEEE 802.11af)

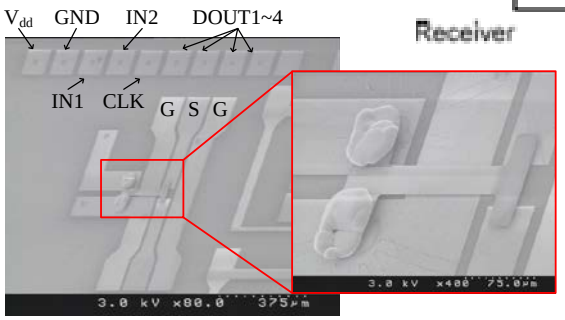
(Collaborators : NICT, Murata Manufac., Denso, Chiba Univ. ...)



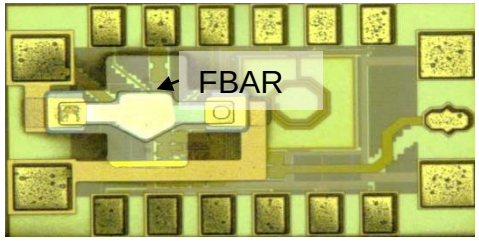
Tunable SAW filter
using BST varactor
5 ⇔ 11 ⇔ 22MHz



Multi SAW filter
on LSI



Piezoelectric
(PZT) MEMS
switch on LSI

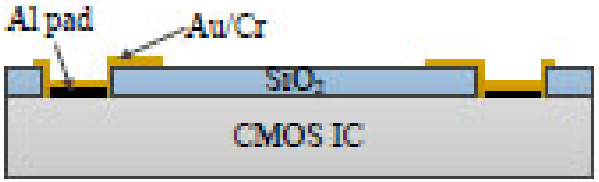


FBAR on LSI for
voltage controlled
oscillator

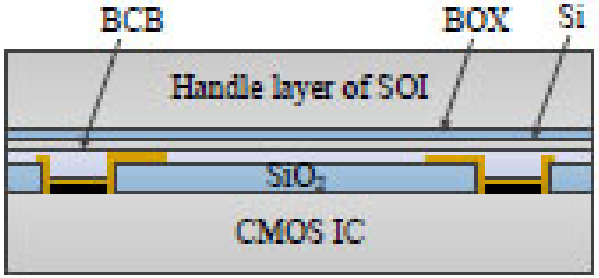
Network disorder during disaster. Traffic of mobile communication is ×2.2/year →

Multiband system for cognitive wireless communication to use available frequency bands efficiently

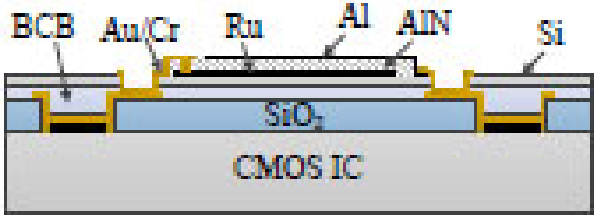
1. Preparation of CMOS IC



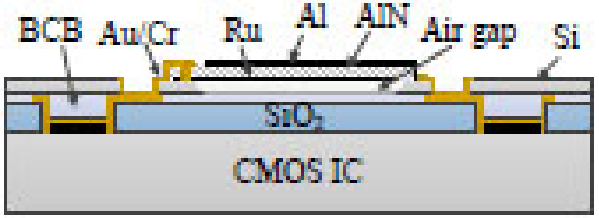
2. BCB adhesive bonding by flipping the SOI wafer on CMOS wafer and removal of handle Si & BOX layer

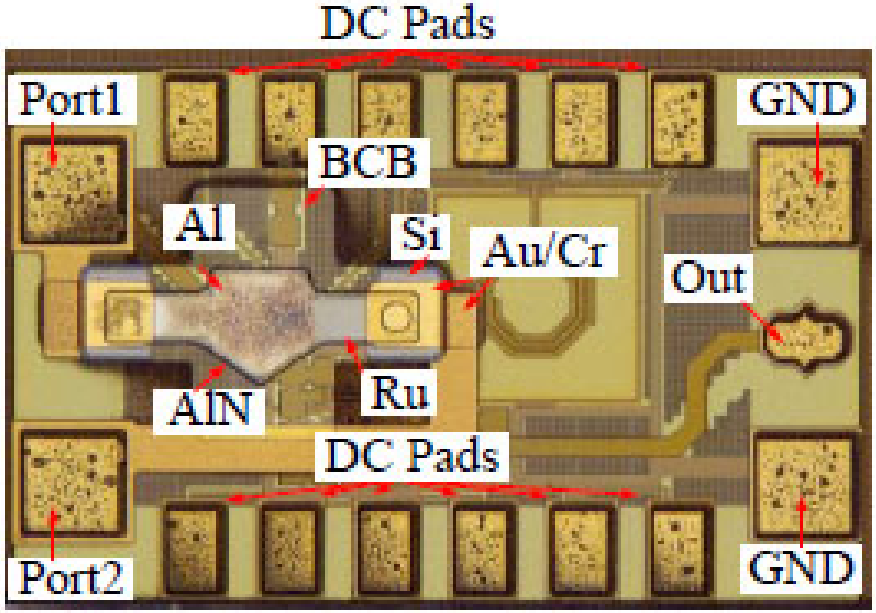


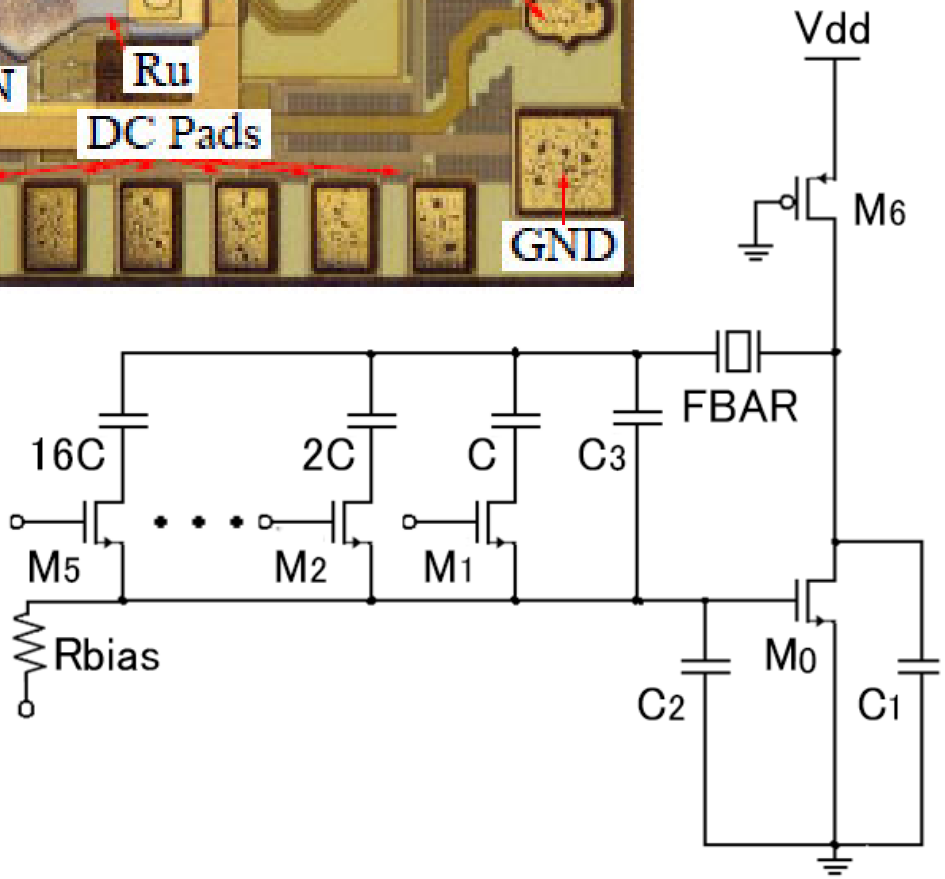
3. FBAR fabrication and its interconnection with CMOS IC



4. Sacrificial etching of Si underneath the active FBAR area

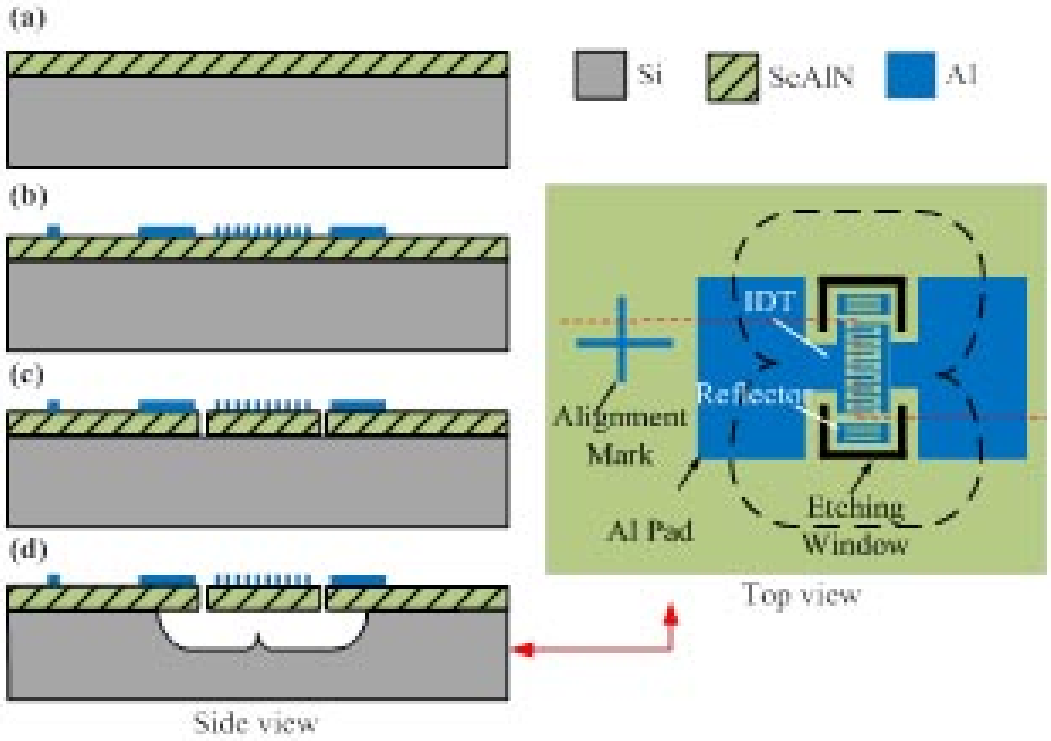


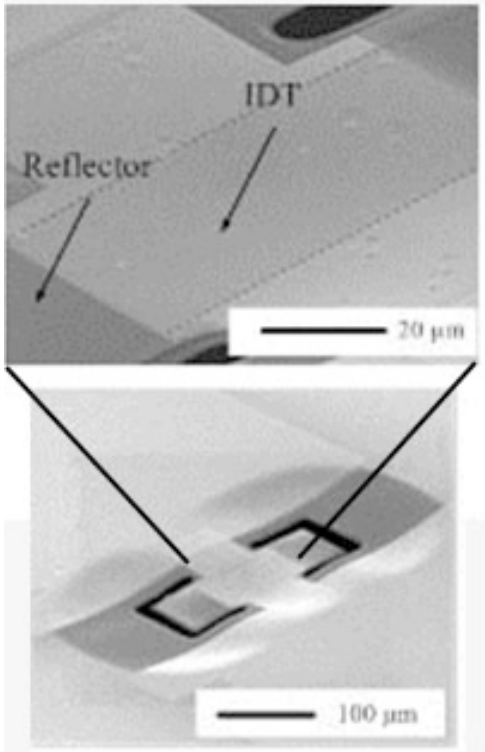


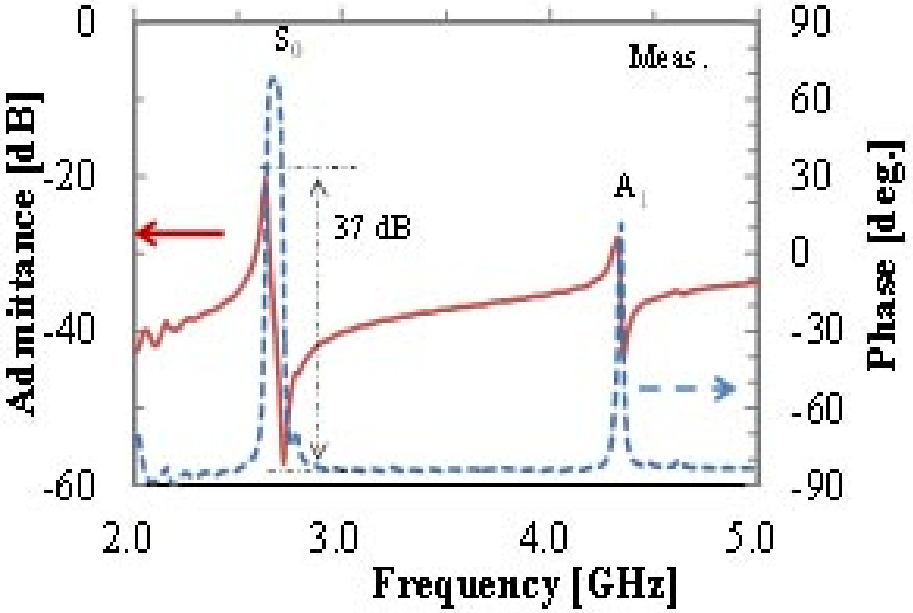


CMOS-FBAR voltage controlled oscillator

(A.Kochhar, et.al. 2012 IEEE Ultrasonics Symposium, 5E-3)



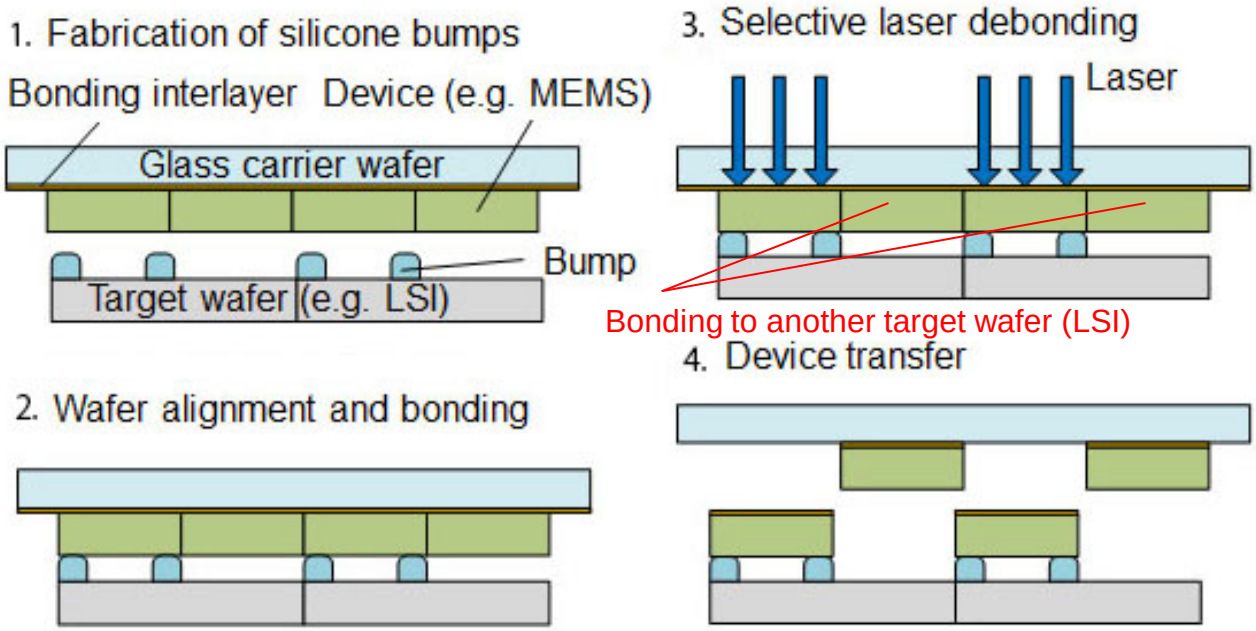




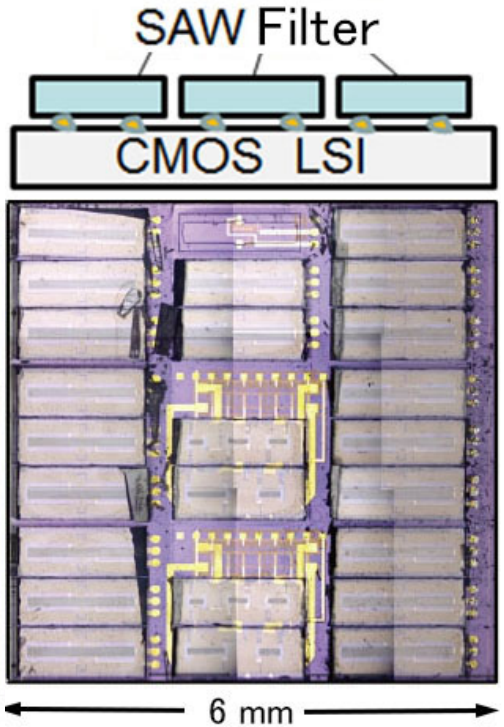
FBAR using ScAlN

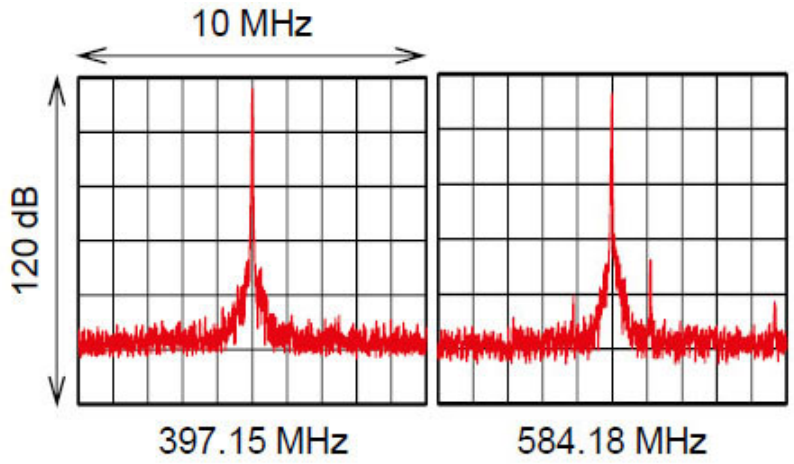
(5 times higher coupling factor than AlN)

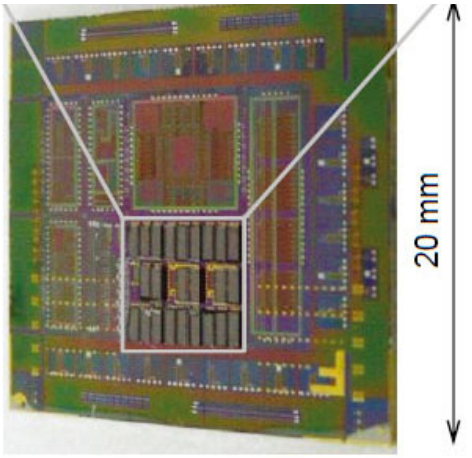
(A.Konno, H.Hirano, M.Inaba, K.Hashimoto, M.Esashi and S.Tanaka, Jap. J. of Applied Physics, 52 (2013) 07HD13(pp.5))



Selective transfer process by laser debonding

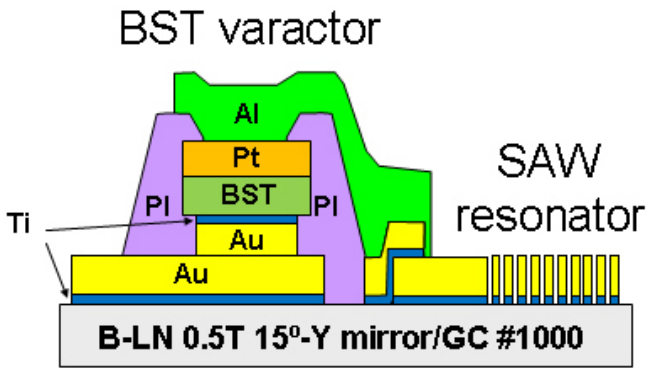


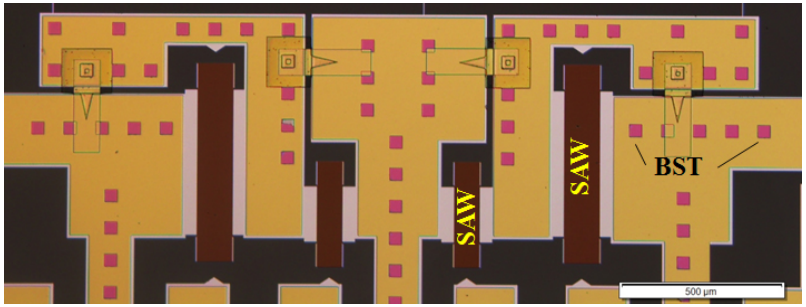


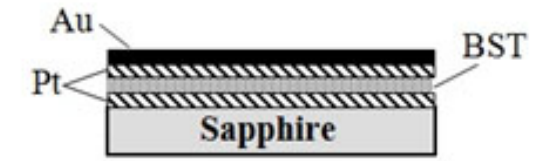


Multi SAW filters on LSI by selective transfer

・(S. Tanak, M. Yoshida, H. Hirano and M. Esashi : "Lithium niobate SAW device hetero-transferred onto silicon integrated circuit using elastic and sticky bumps", 2012 IEEE International Ultrasonics Sympsium, p.1047 (2012)).

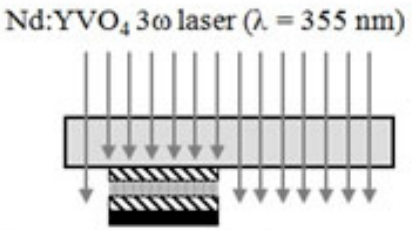




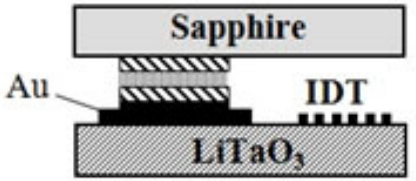


1. Deposition Pt, BST, Pt and Au.

2. Patterning Pt, BST, Pt and Au.

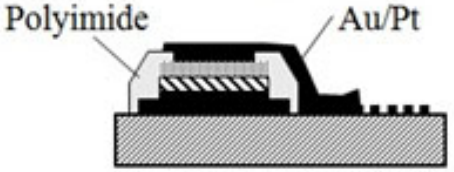


3. Laser pre-irradiation .

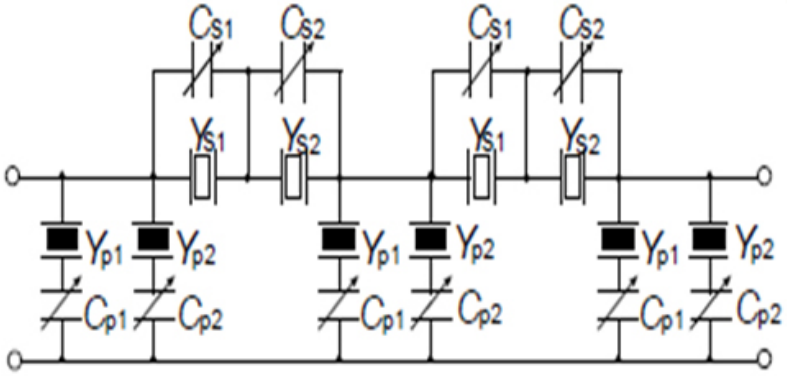


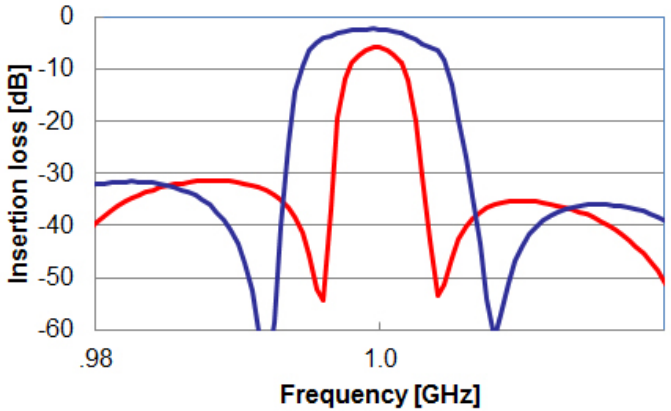
4. Au-Au bonding.

5. Wafer separation.



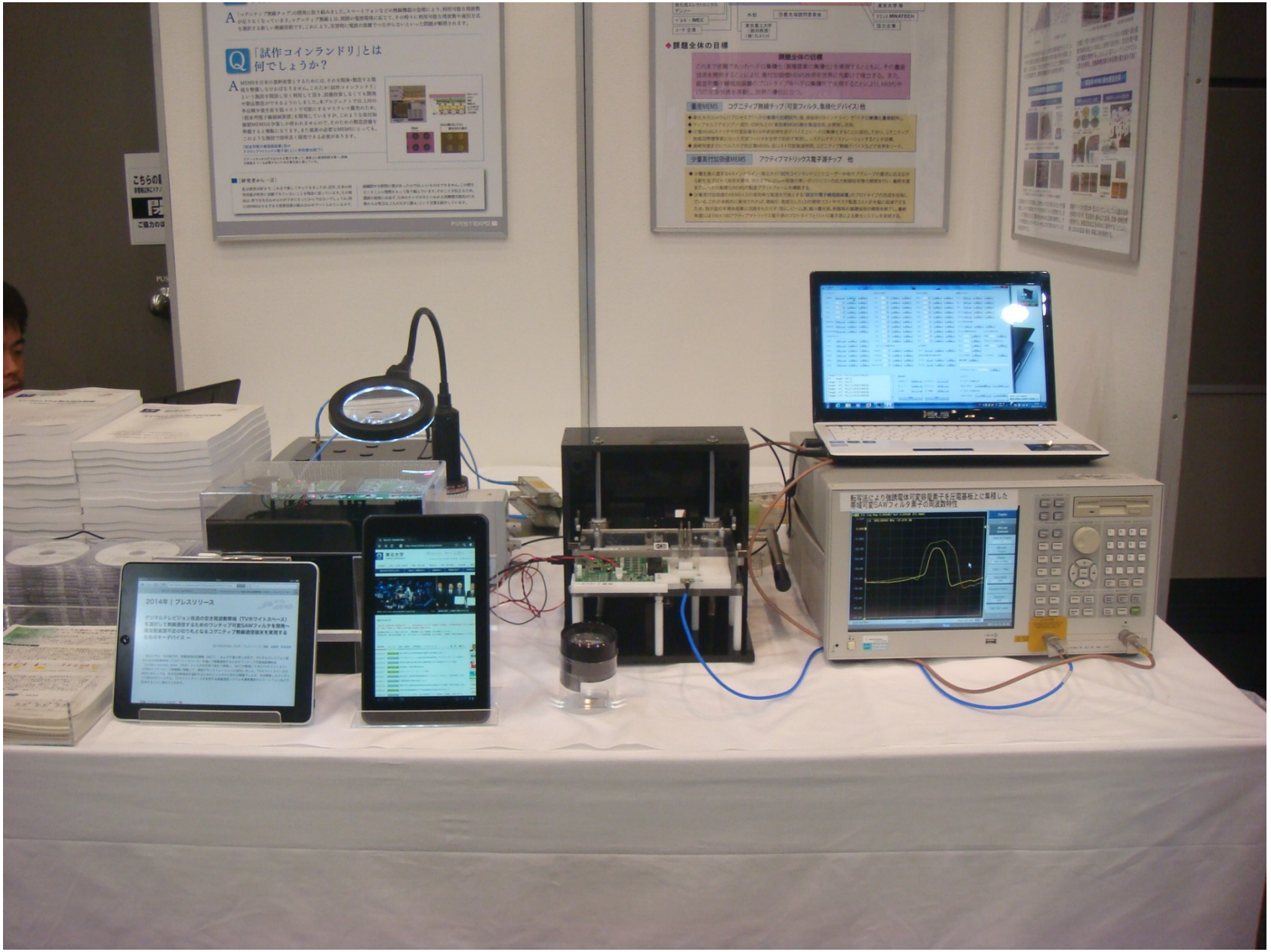
6. Wiring.



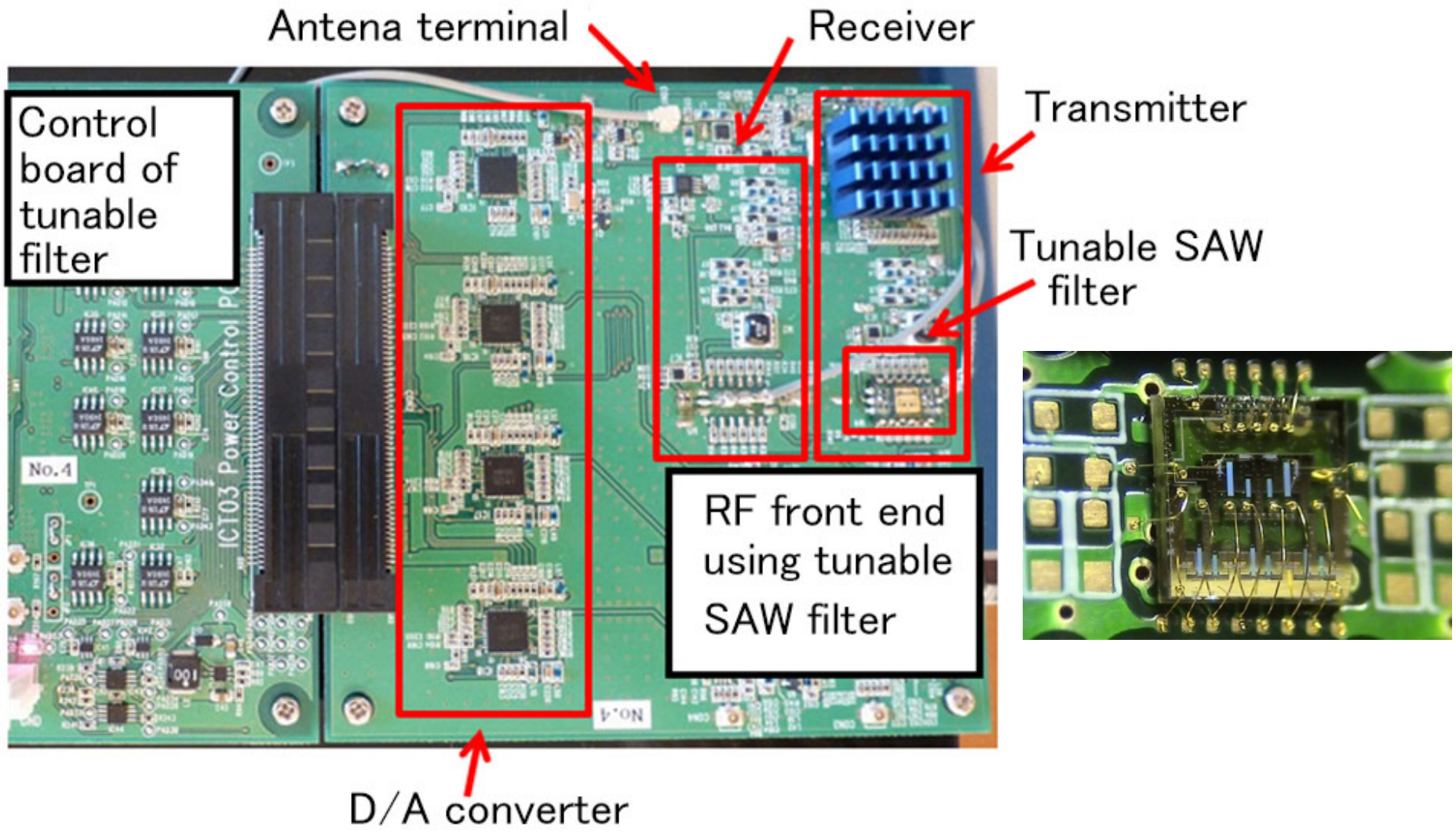


Tunable SAW filter using ferroelectric varactor

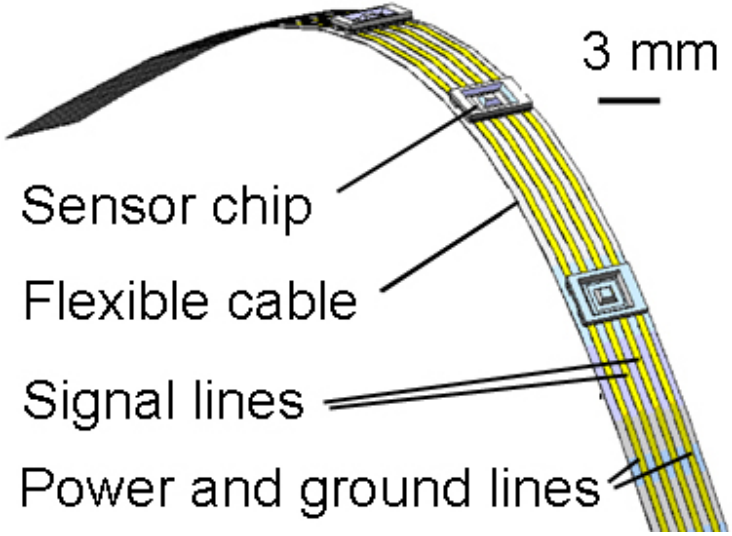
(H.Hirano, T.Kimura, I.P.Koutsaroff, M.Kodato, K.Hashimoto, M.Esashi and S.Tanaka, J. of Micromech. Microeng., 23 (2013) 025005)

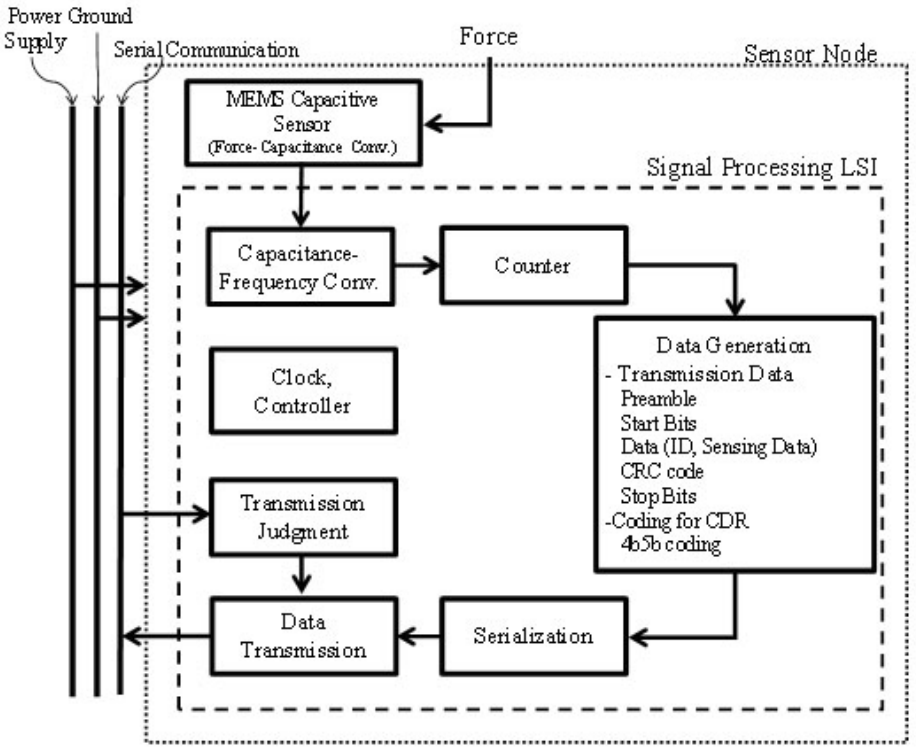


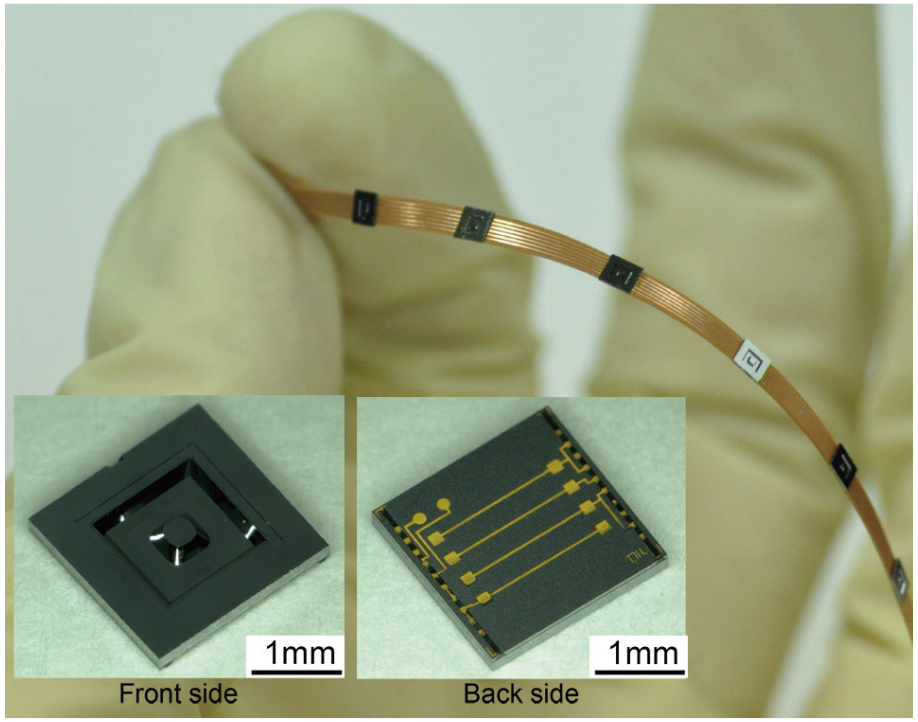
Demonstration of wireless equipment with the tunable SAW filter
(FIRST EXPO, March 1, 2014)

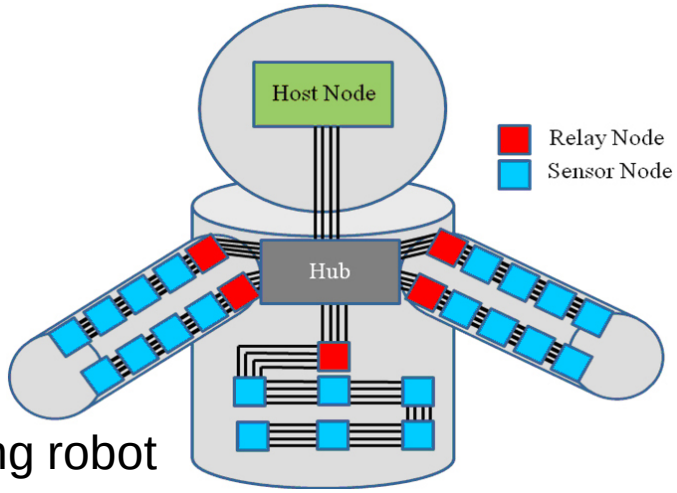


RF front end board using tunable SAW filter for IEEE802.11af wireless system





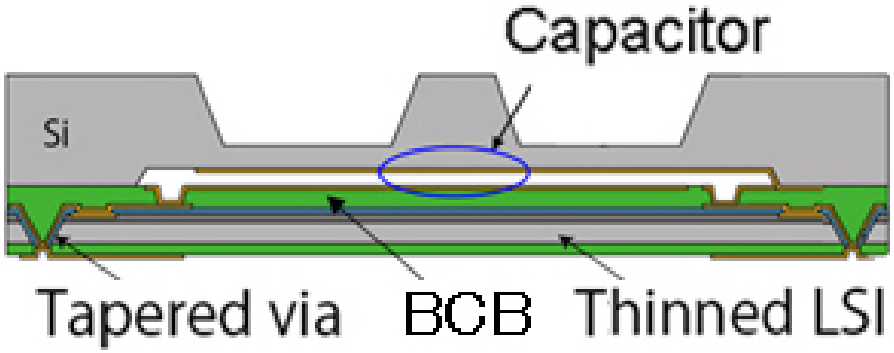


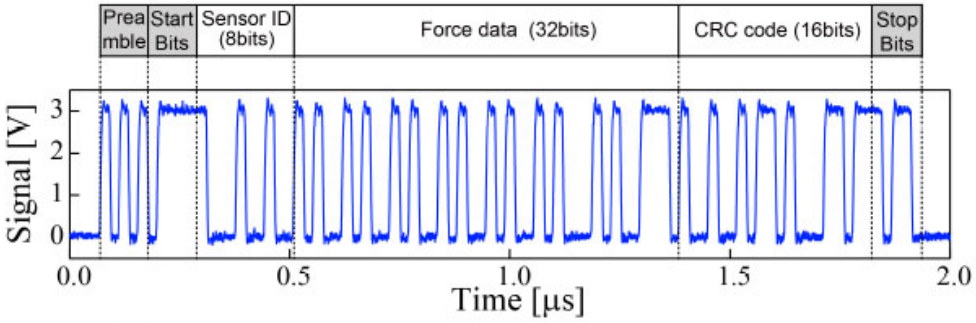


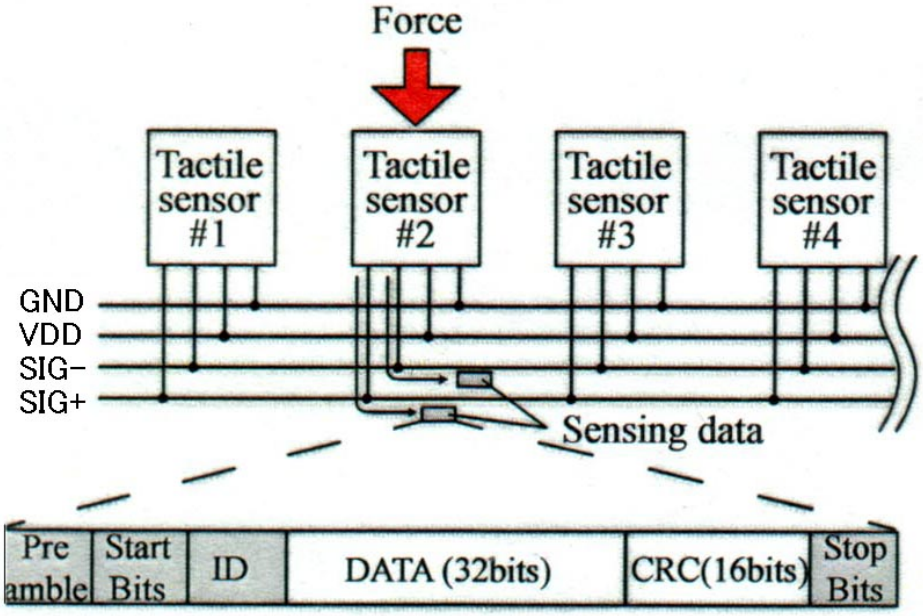
Safe nursing robot

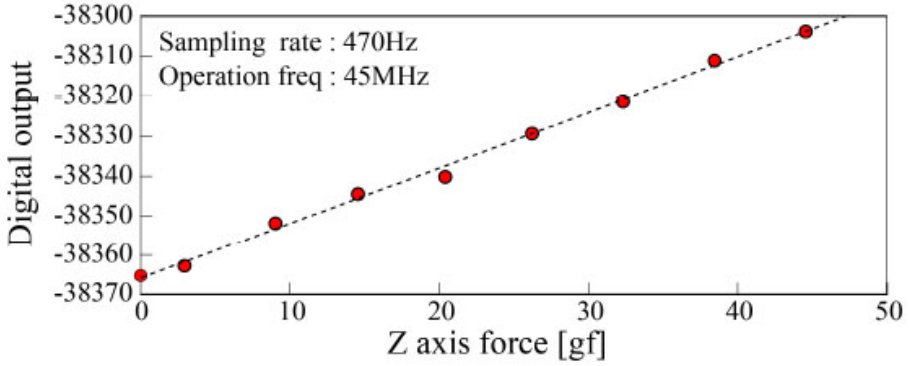
Tactile sensor network for robot (event driven type)

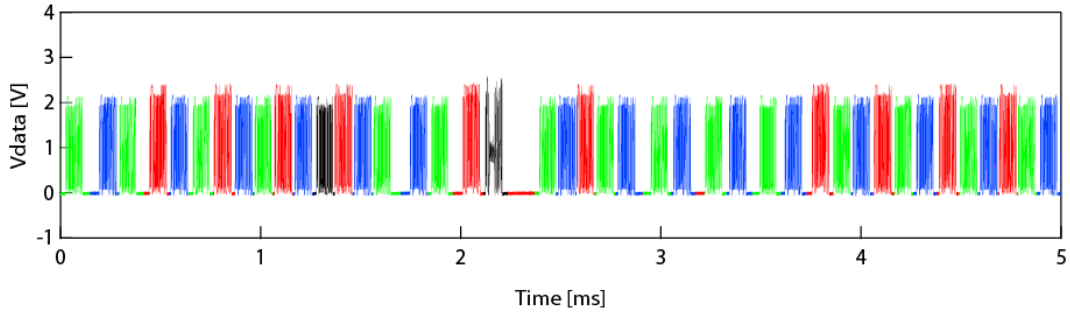
(M.Muroyama, M.Makihata et al., Smart Systems Integration (SSI) 2014, Vienna, Austria (2014, March 26))







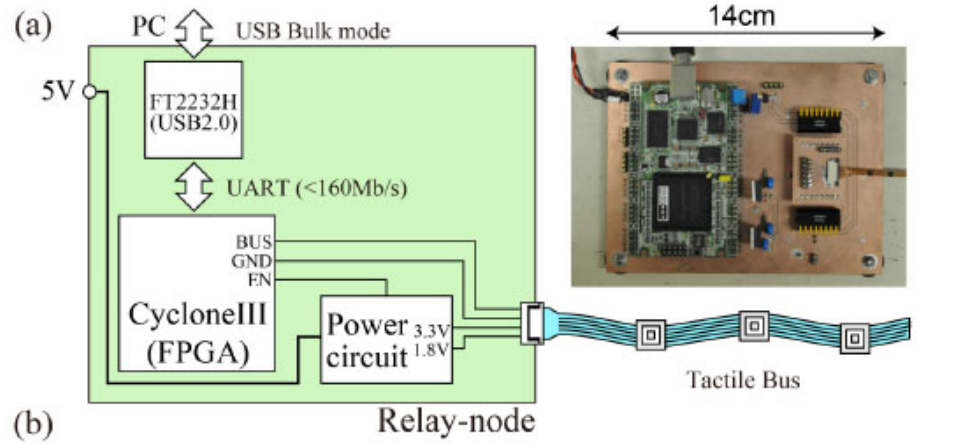


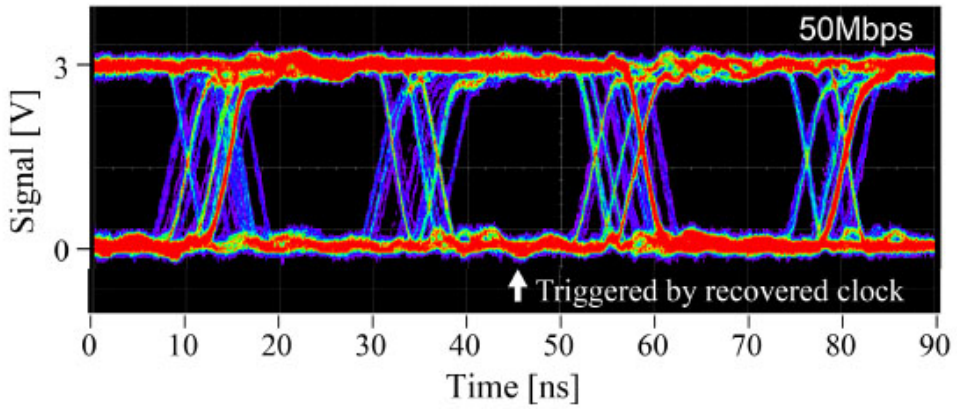


Tactile sensor network

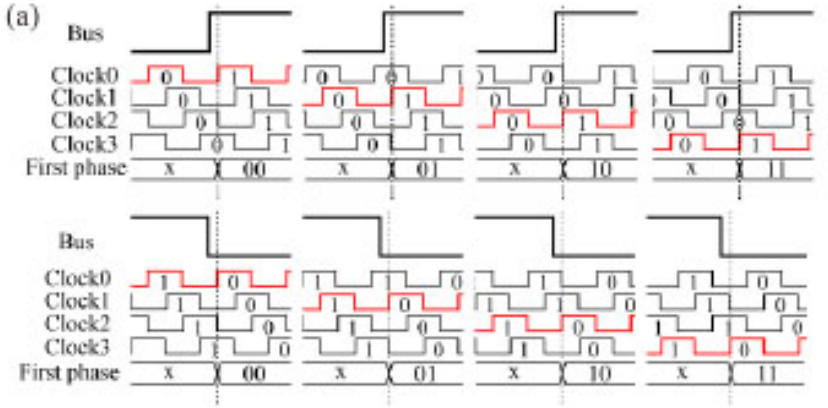
(Collaborators, Toyota, Toyota Central Res. Lab.)

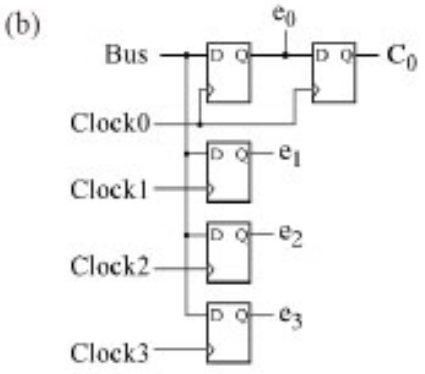
(M.Muroyama, M.Makihata et al., Smart Systems Integration (SSI) 2014, Vienna, Austria (2014, March 26))





High speed packet receiver (a) block diagram and picture of the board (b) Eye-diagram triggered by recovered clock





(c)

e_0, e_1, e_2, e_3	C_0	First Phase
1000	0	00
0100	0	01
0010	0	10
0001	0	11
0111	1	00
1011	1	01
1101	1	10
1110	1	11
Other	*	No change

Mechanism of precise timing detection

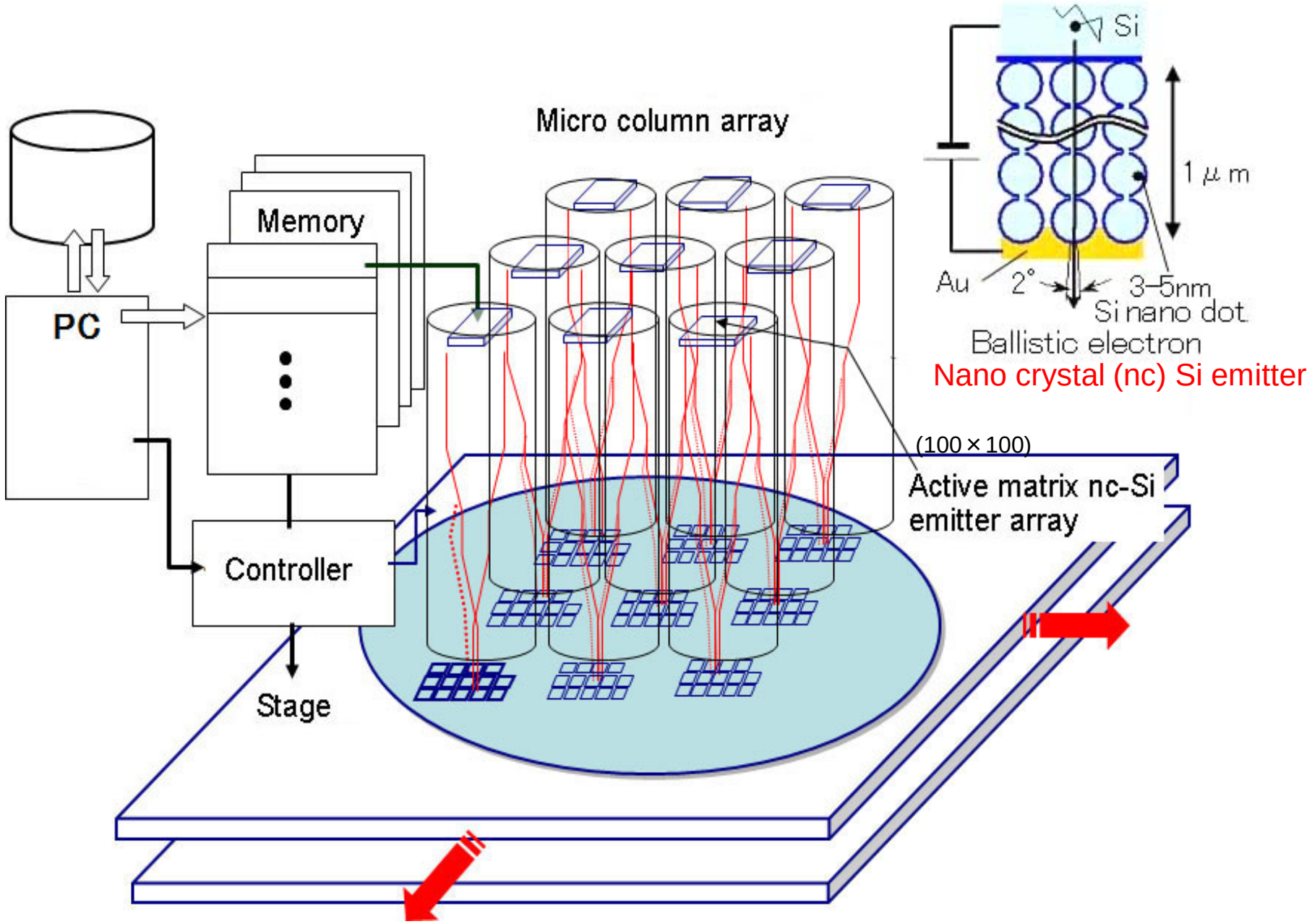
(a) relation between buffer of each phase and signal.

(b) Buffer on each phases (c) Truth table.

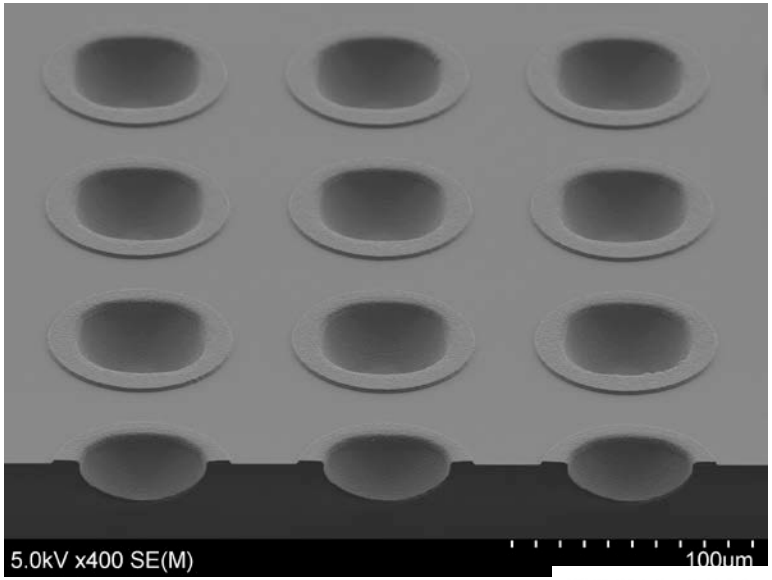
Oversampling clock data recovery

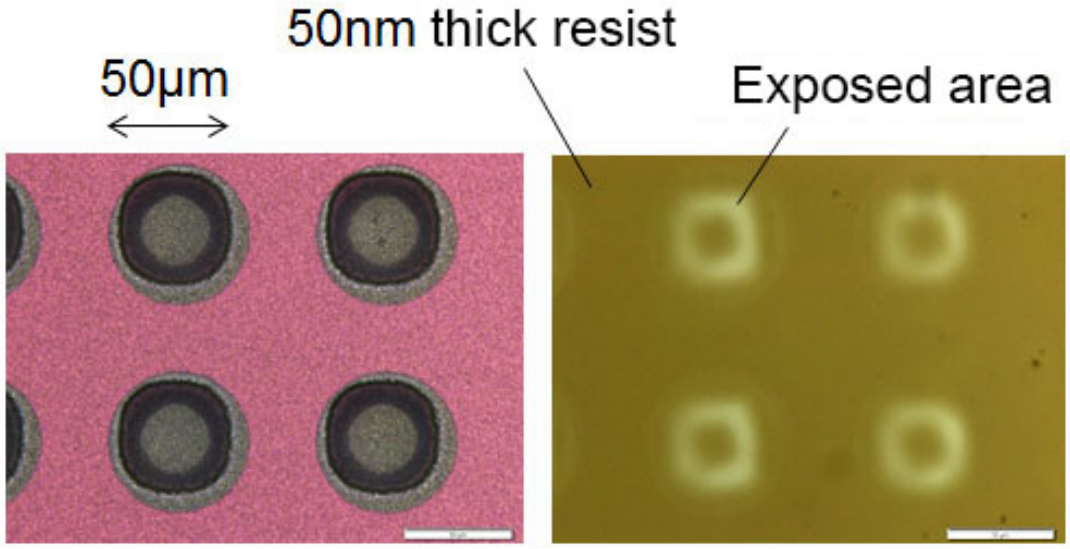
Output waveforms at the relay node and circuit for synchronization

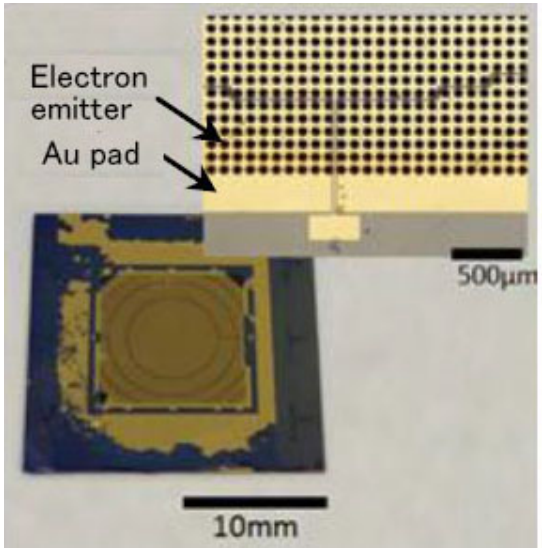
(M.Makihat et al., 30th Sensor Symposium, Sendai (2013 Nov.5-7))

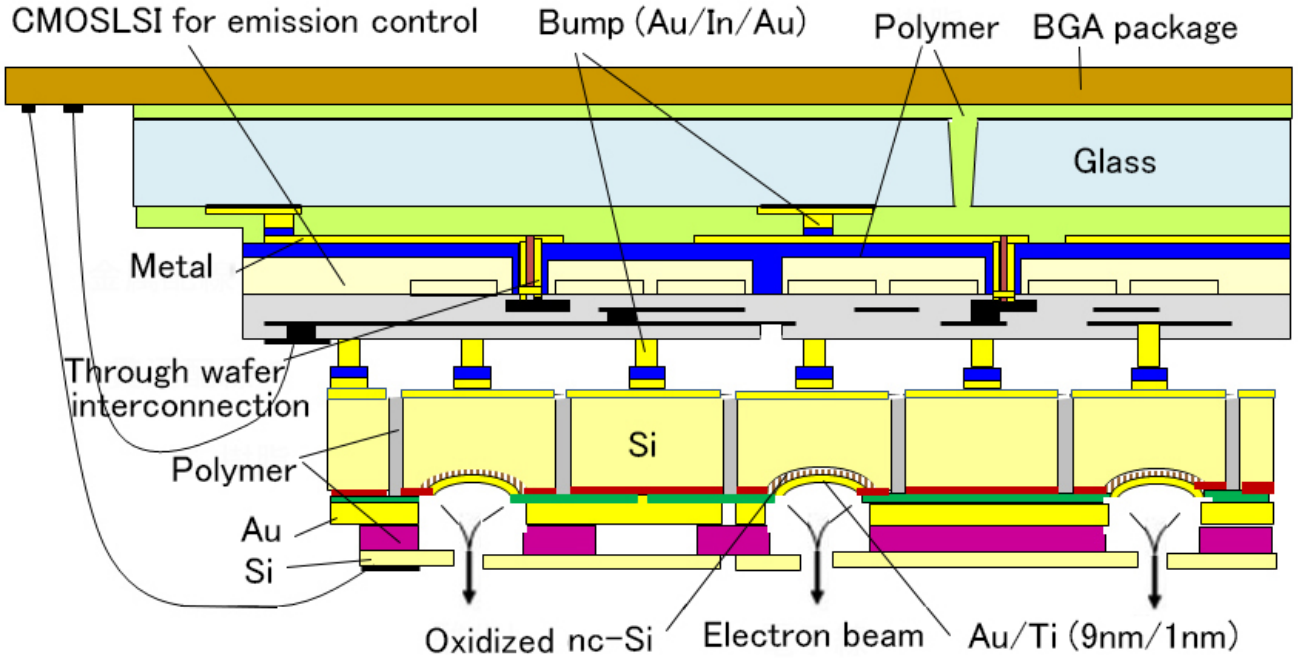


Concept of massive parallel electron beam exposure system using nc-Si emitter



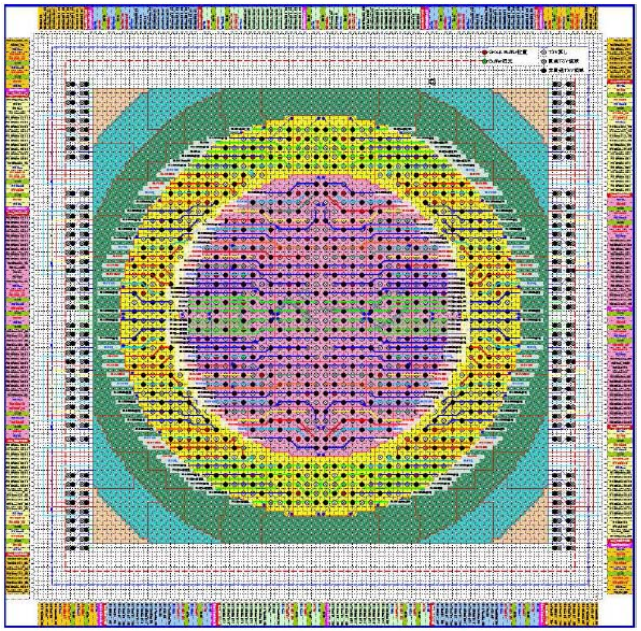


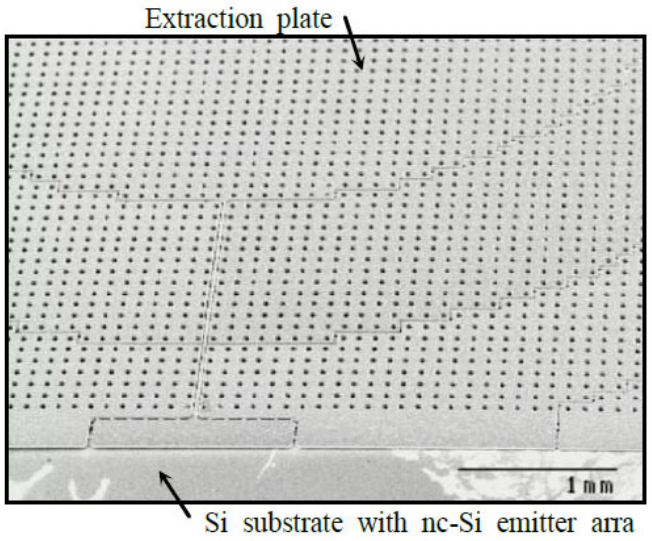


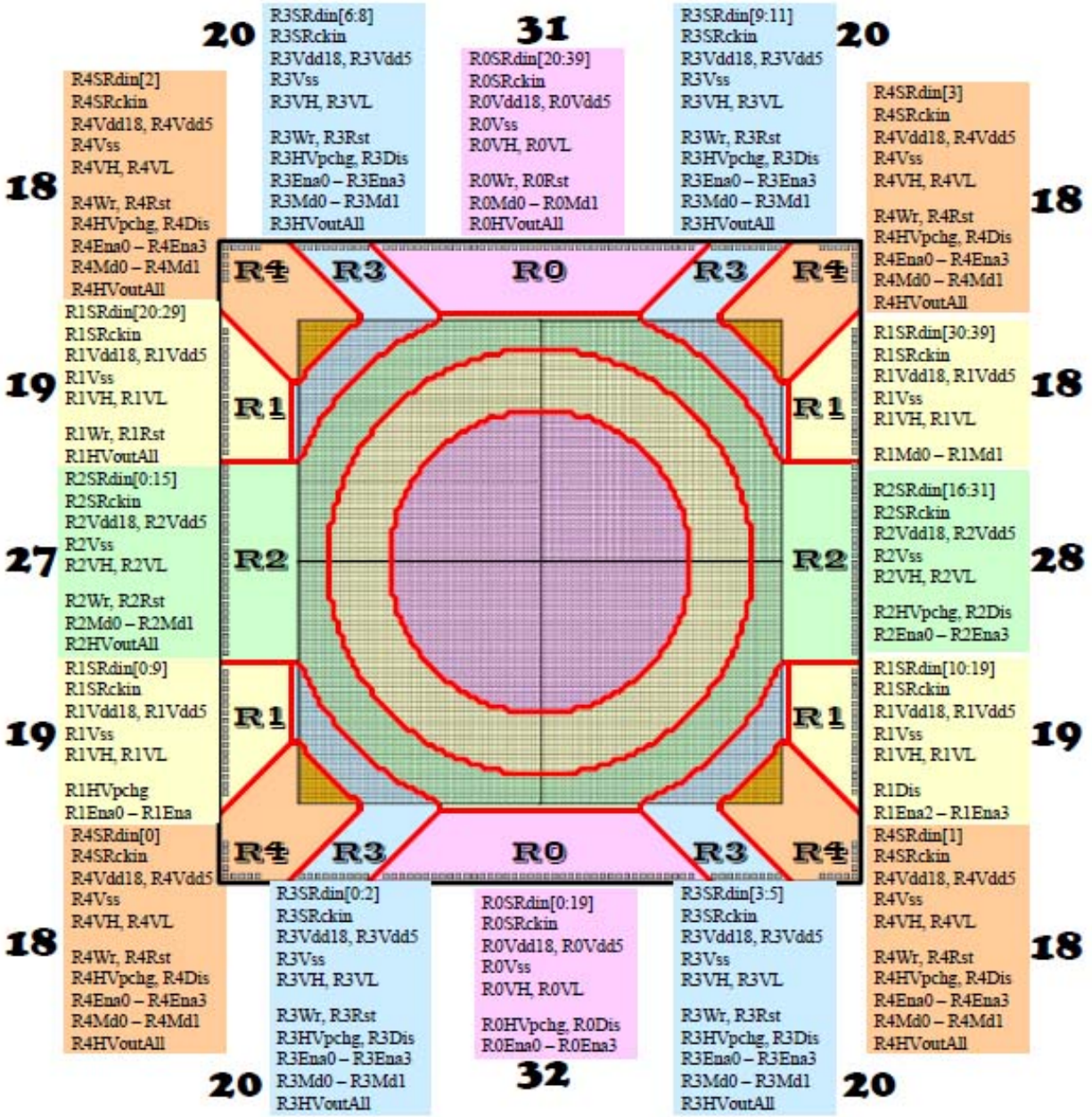


Structure of 100 × 100 active matrix nc-Si emitter

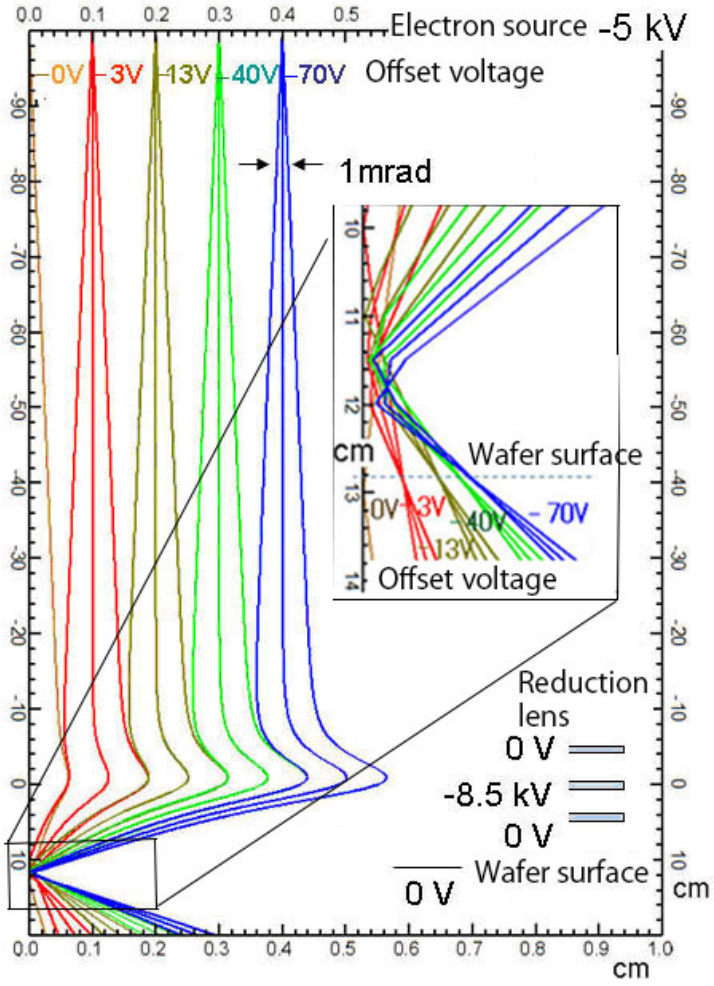
(H.Nishino, S.Yoshida, A.Kojima, N.Ikegami, N.Koshida, S.Tanaka and M.Esashi, Technical Digest IEEE MEMS 2014 (2014) 467-470)

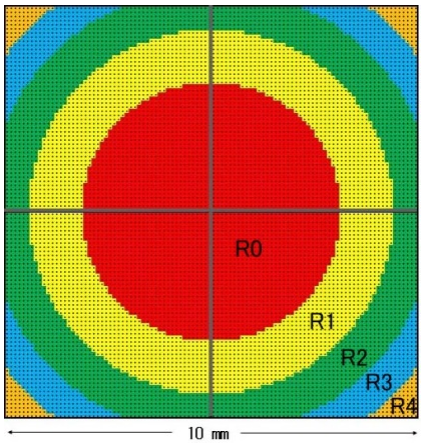




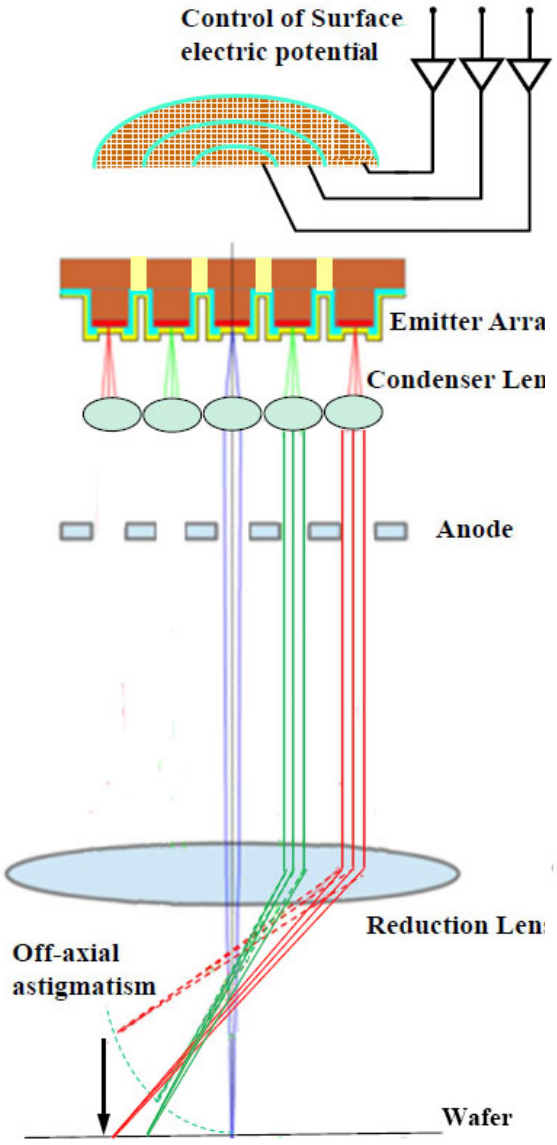


100 × 100 active matrix electron source pad layout in 430 pin package



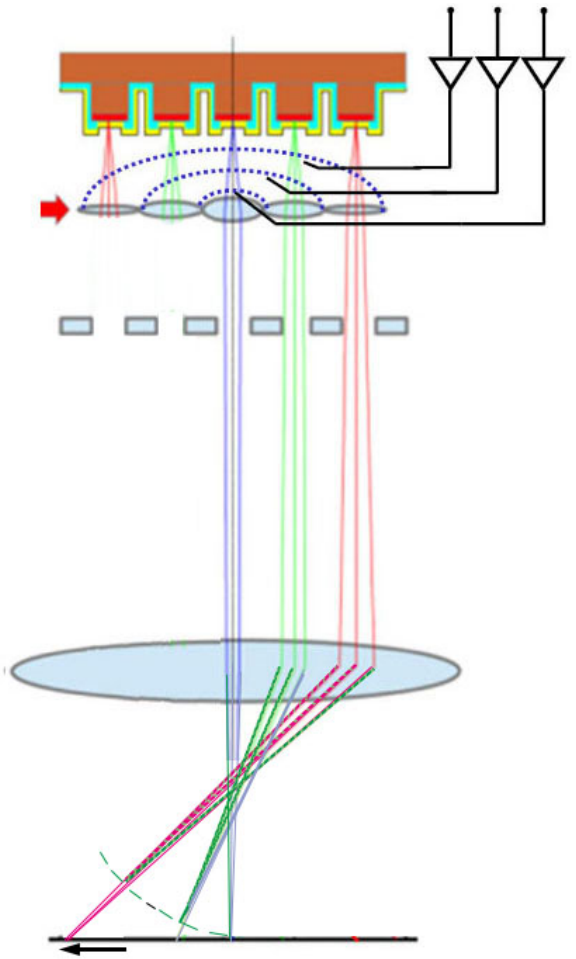


100 × 100 emitter array divided into concentric circles



Field curvature correction
像面湾曲補正

Control of convergence angle of beams with condenser lens array

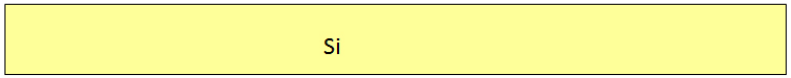


Distortion correction
歪曲収差補正

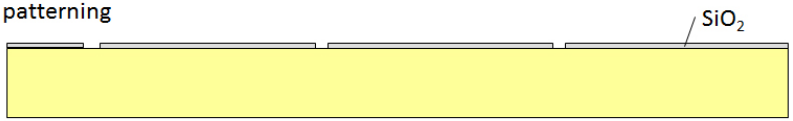
Electronic aberration compensation

(N.Ikegami, N.Koshida, A.Kojima, M.Esashi et.al, J. Vac. Sci. Technol., B31 (2013) 06F703)

A1. Si wafer

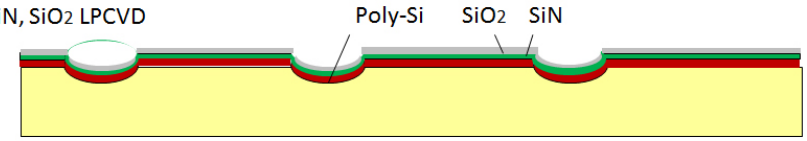


A2. Oxidation, patterning

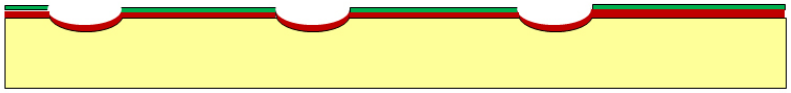


A3. Si isotropic etching, SiO_2 etching

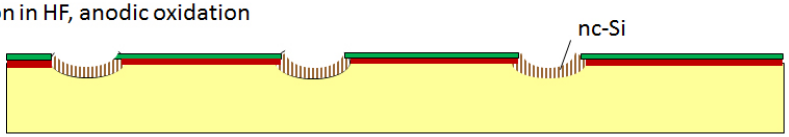
A4. Poly-Si, SiN, SiO_2 LPCVD



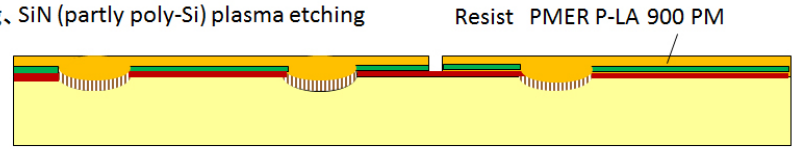
A5. SiO2, SiN, パターニング、SiO2エッチング



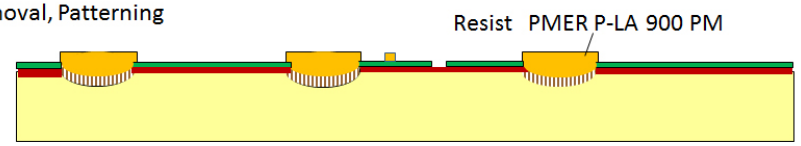
A6. Anodization in HF, anodic oxidation



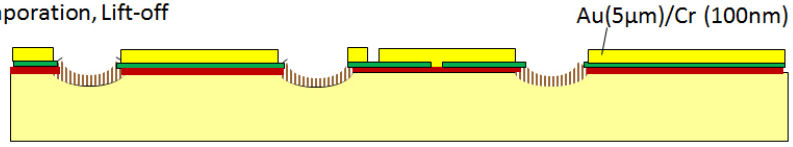
A7. Patterning、SiN (partly poly-Si) plasma etching



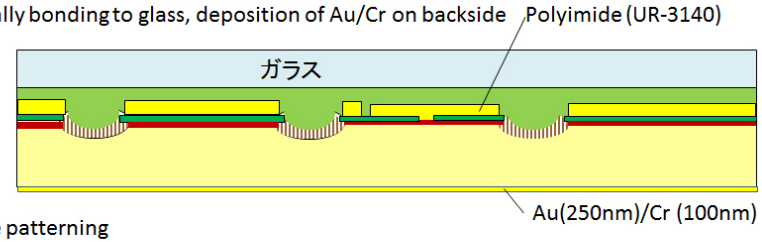
A8. Resist removal, Patterning



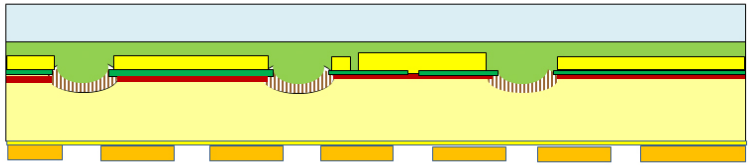
A9. Au /Cr evaporation, Lift-off



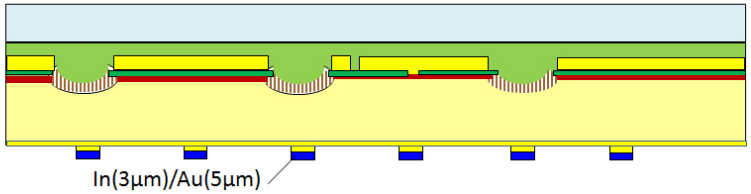
A10. Temporally bonding to glass, deposition of Au/Cr on backside



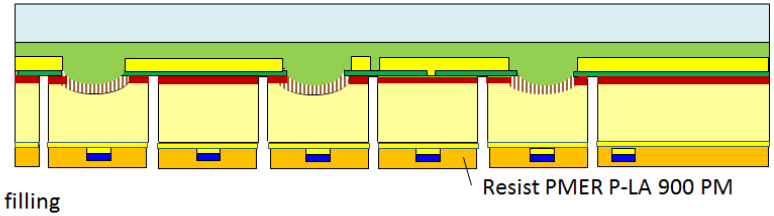
A11. Backside patterning



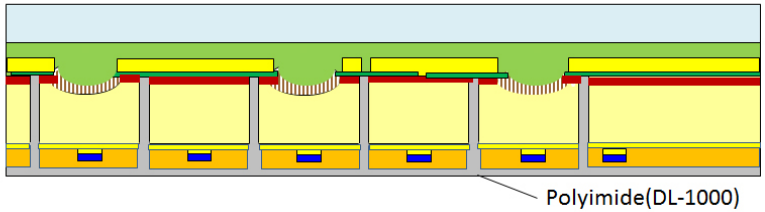
A12. Au electroplating, In evaporation



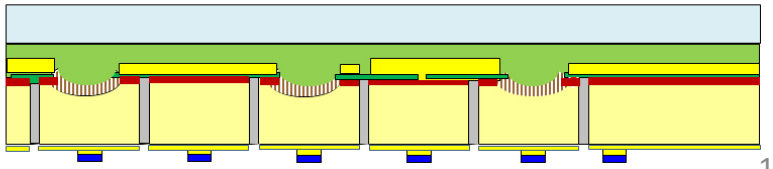
A13. Patterning, Si Deep RIE



A14. Polymer filling

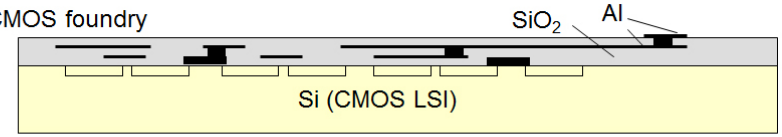


A15. Ashing of polymer

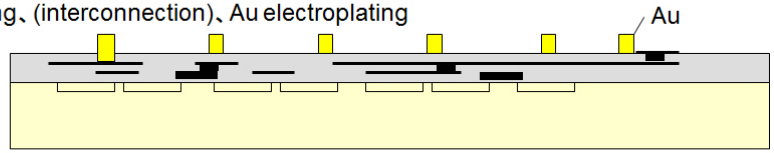


Fabrication of nc-Si Pierce type electron source

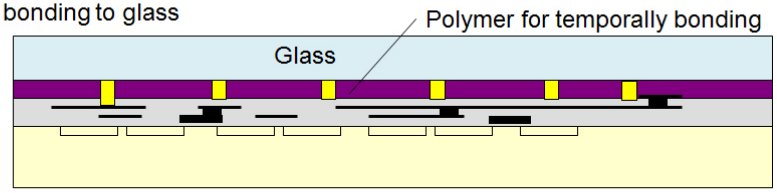
1. LSI from CMOS foundry



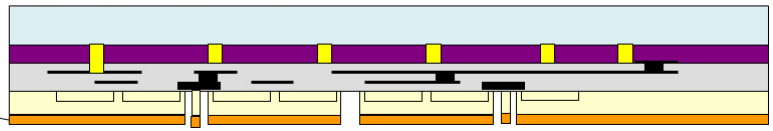
2. SiO_2 etching、(interconnection)、Au electroplating



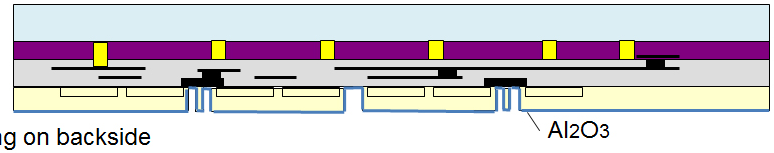
3. Temporary bonding to glass



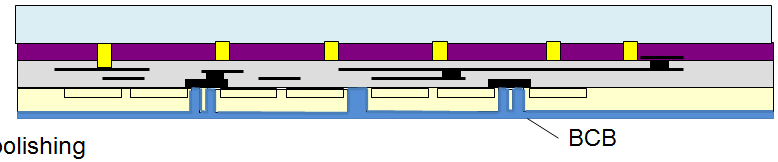
4.Backside lapping and polishing, Si Deep RIE



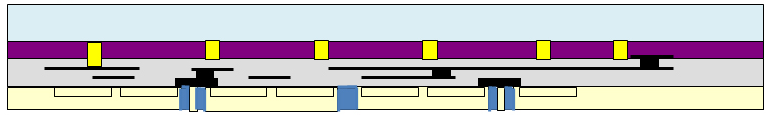
5. Al_2O_3 ALD on backside



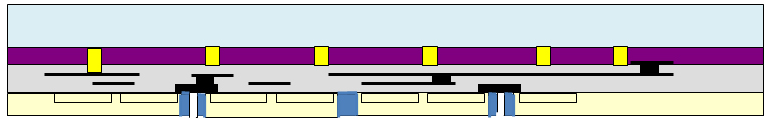
6. BCB coating on backside



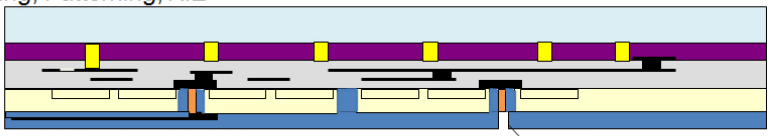
7. Backside polishing



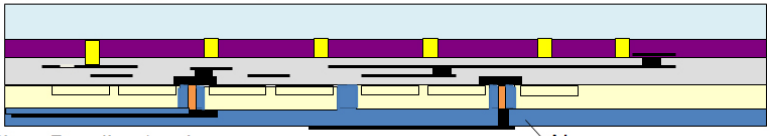
8. Patterning, Si anisotropic dry etching



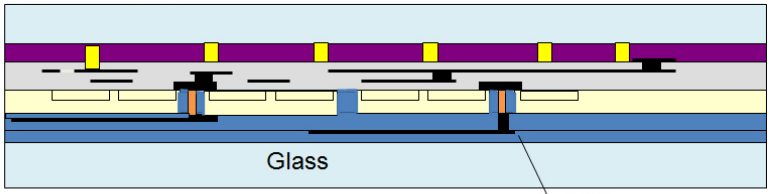
13. BCB coating, Patterning, RIE



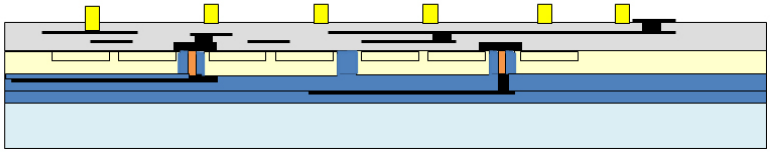
14. Al sputtering, Patterning, Al etching



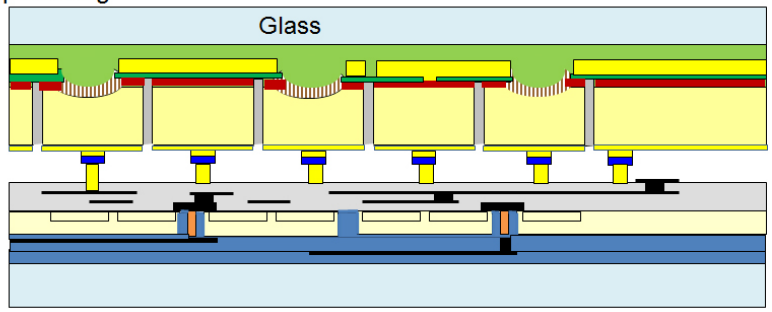
15. BCB coating, Bonding to glass



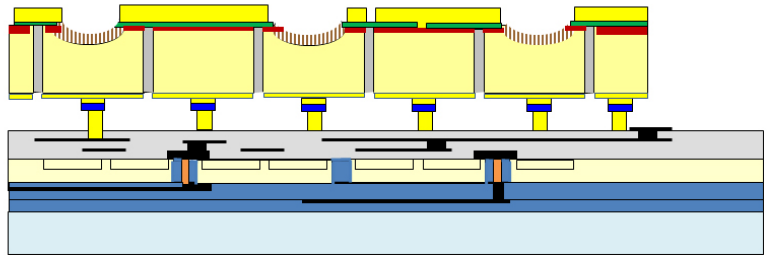
16. Remove adhesive for temporally bonding (remove glass)



17. Au-In bump bonding

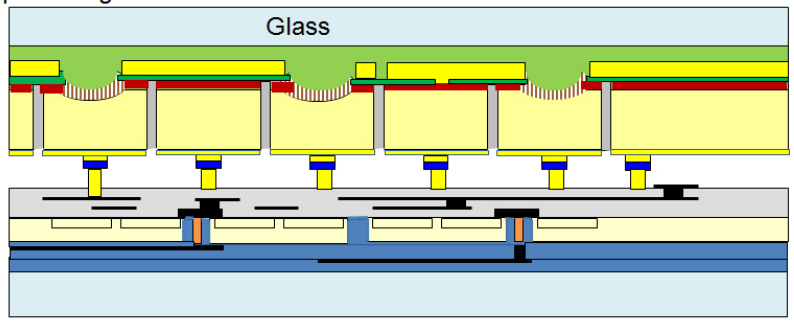


18. Dicing, Removal of adhesive for temporally bonding

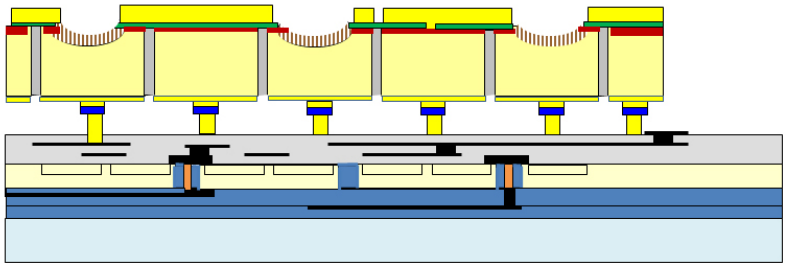


Fabrication process of active matrix nc-Si Pierce type electron source (1/2)

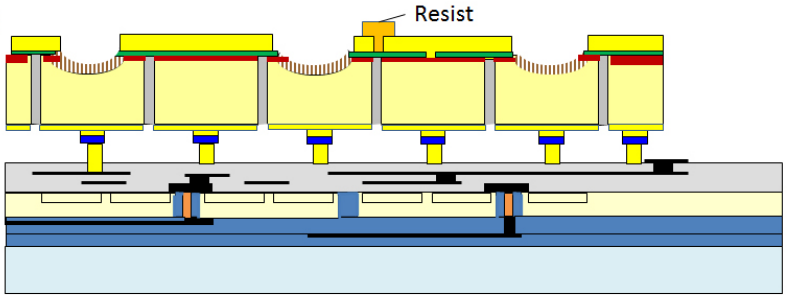
17. Au-In bump bonding



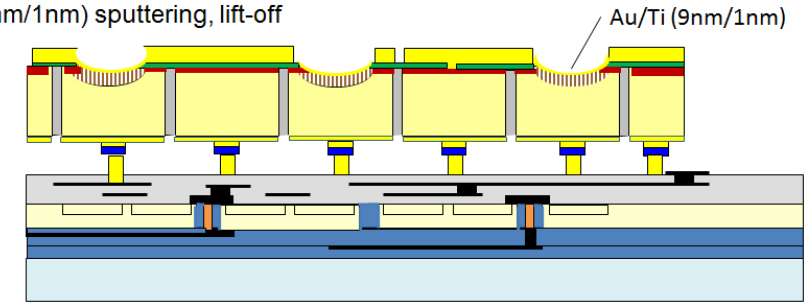
18. Dicing, Removal of adhesive for temporally bonding



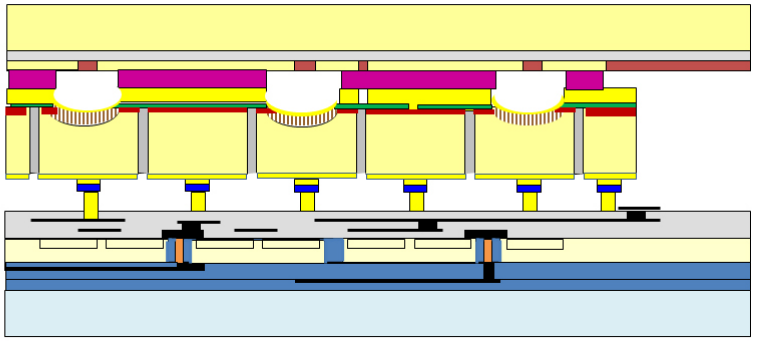
19. Patterning



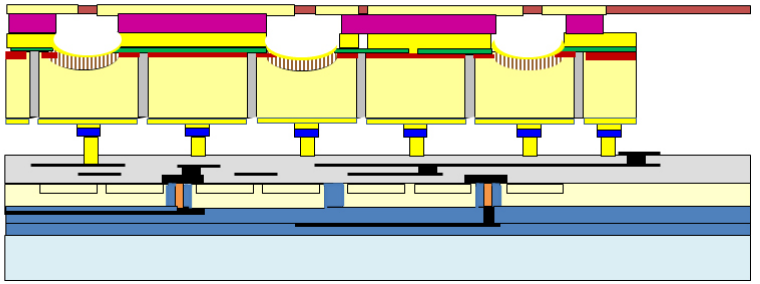
20. Au/Ti (9nm/1nm) sputtering, lift-off



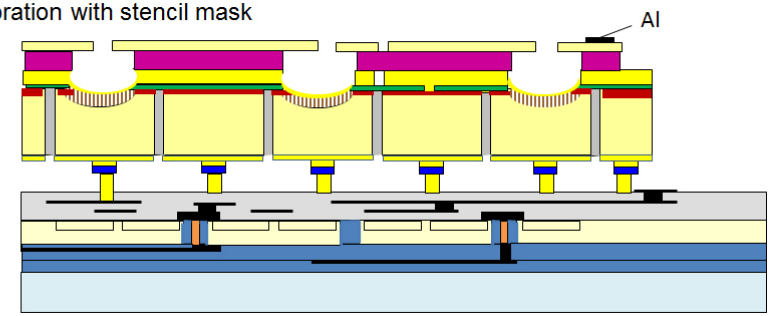
21. Bonding of extraction electrode wafer



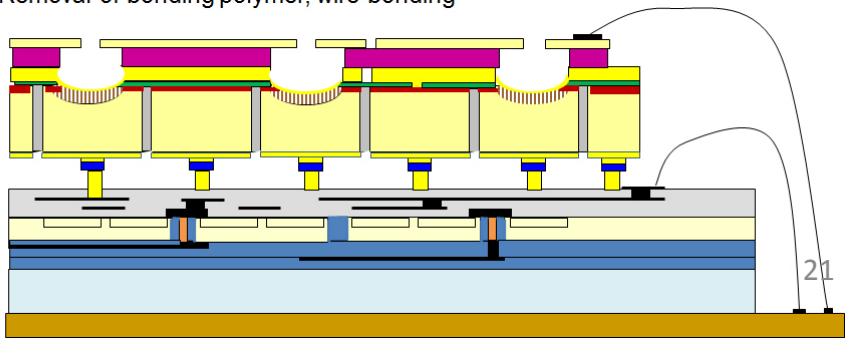
22. Si, SiO_2 etching



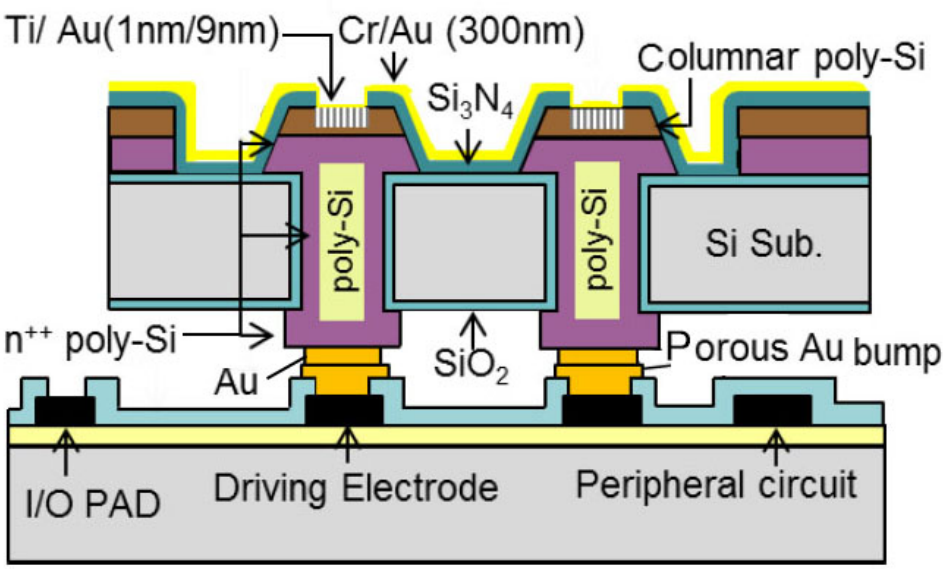
23. Al evaporation with stencil mask

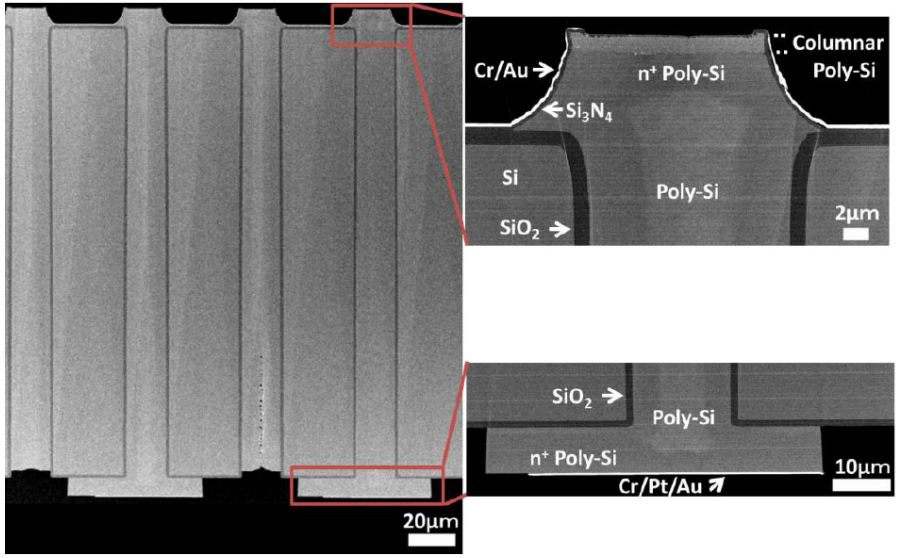


24. Removal of bonding polymer, wire bonding

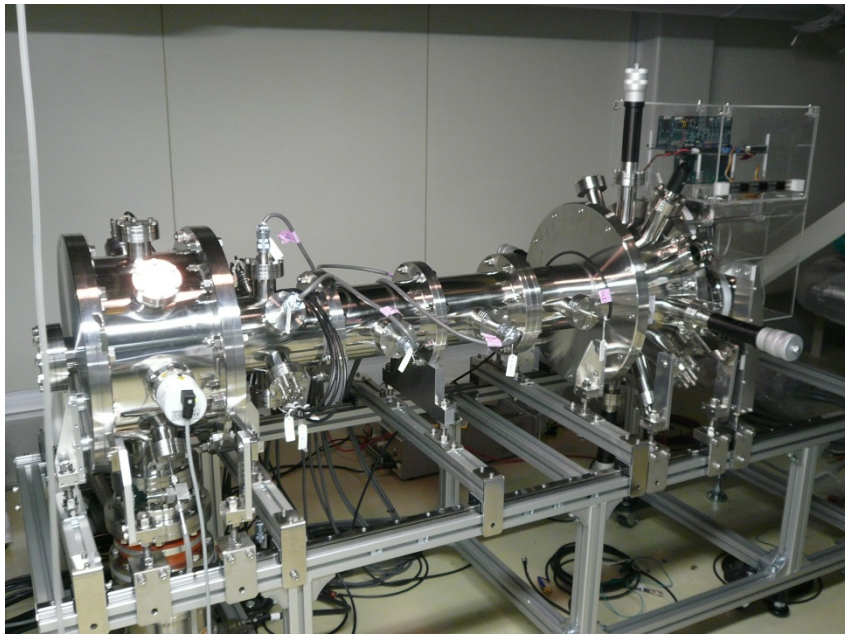


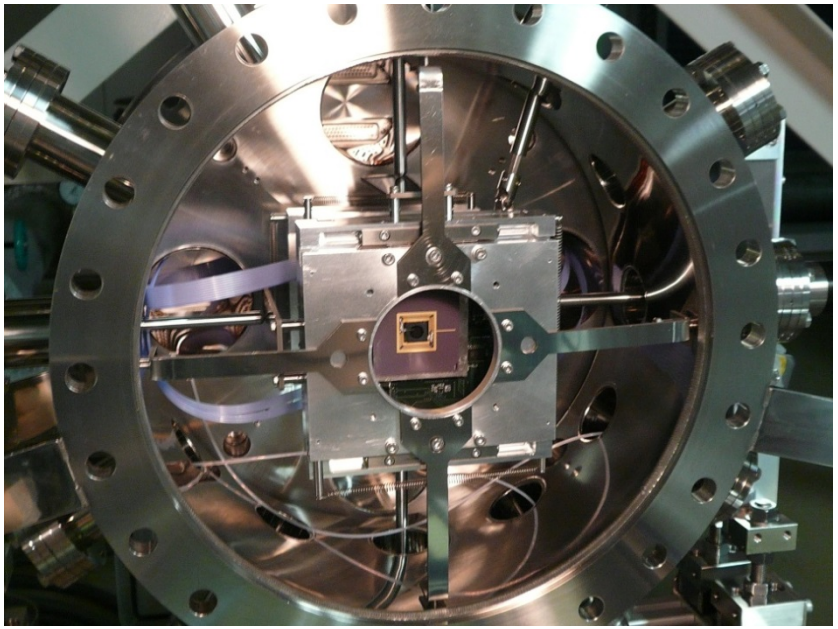
Fabrication process of active matrix nc-Si Pierce type electron source (2/2)





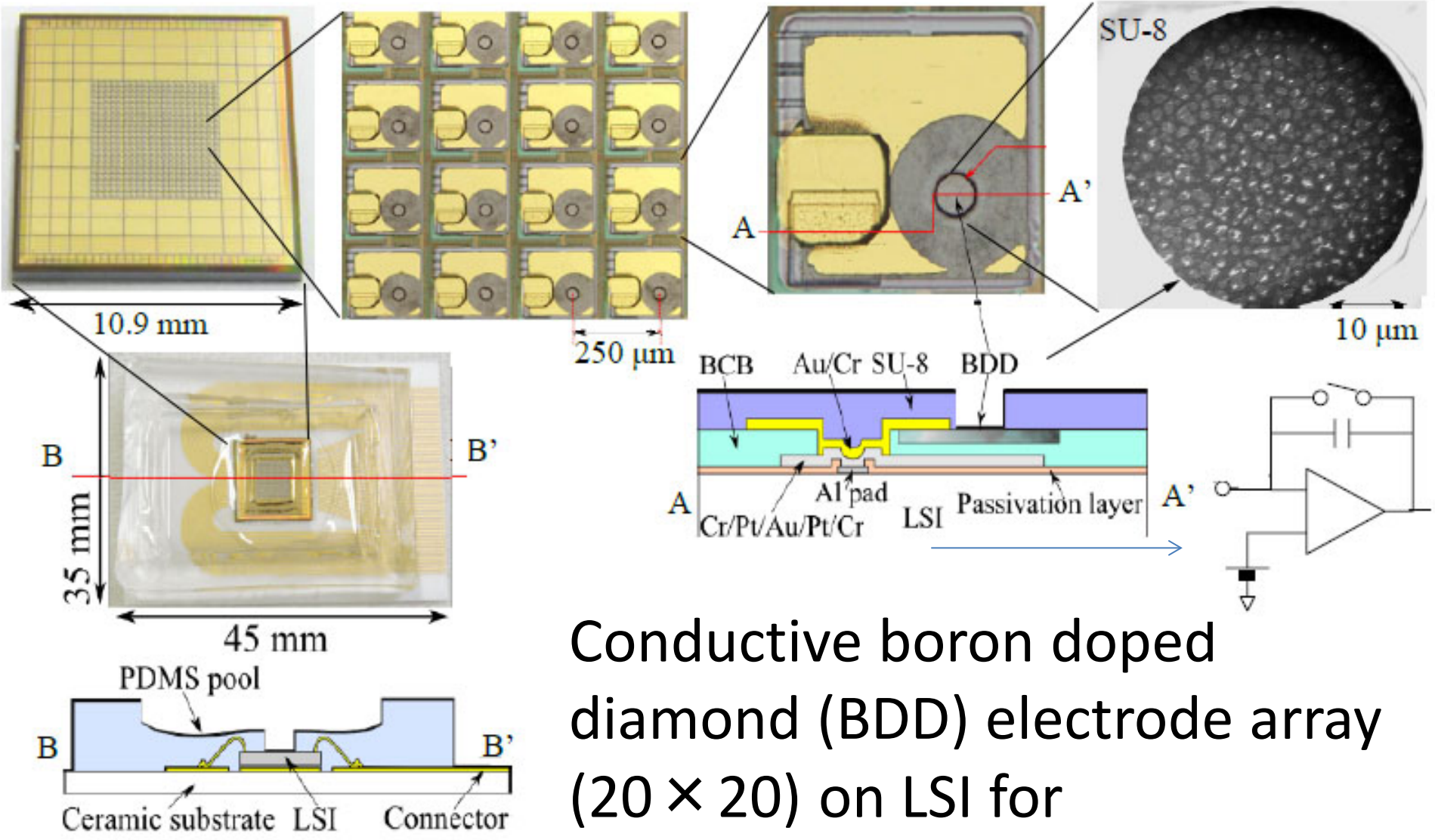
Planer type nc-Si electron source having through Si via





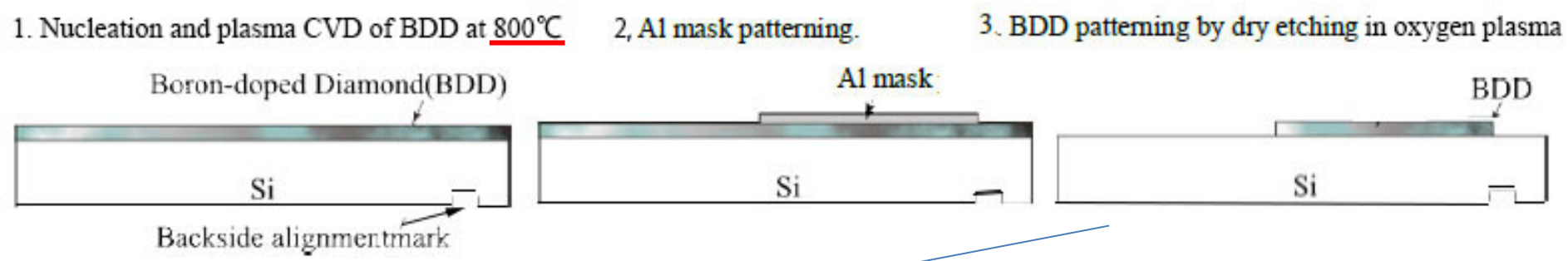
Experimental setup for 1/100 and 1/1 exposure test. Attached planar type nc-Si electron source

(A.Kojima, N.Ikegami, et.al.,Proc. SPIE Alternative Lithography Technologies V, 8680 (2013) 868001-868017)

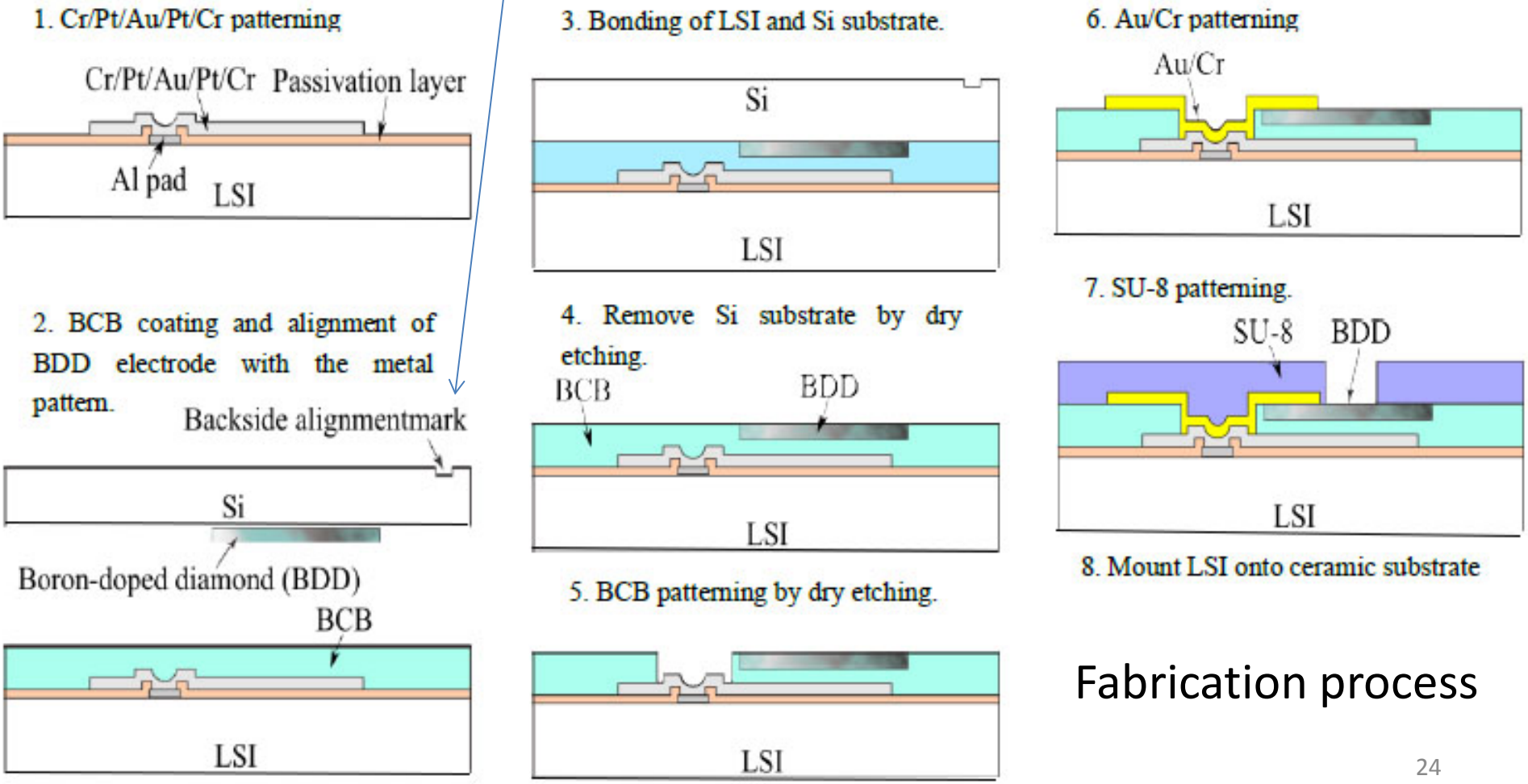


Conductive boron doped diamond (BDD) electrode array (20 × 20) on LSI for amperometric biosensor

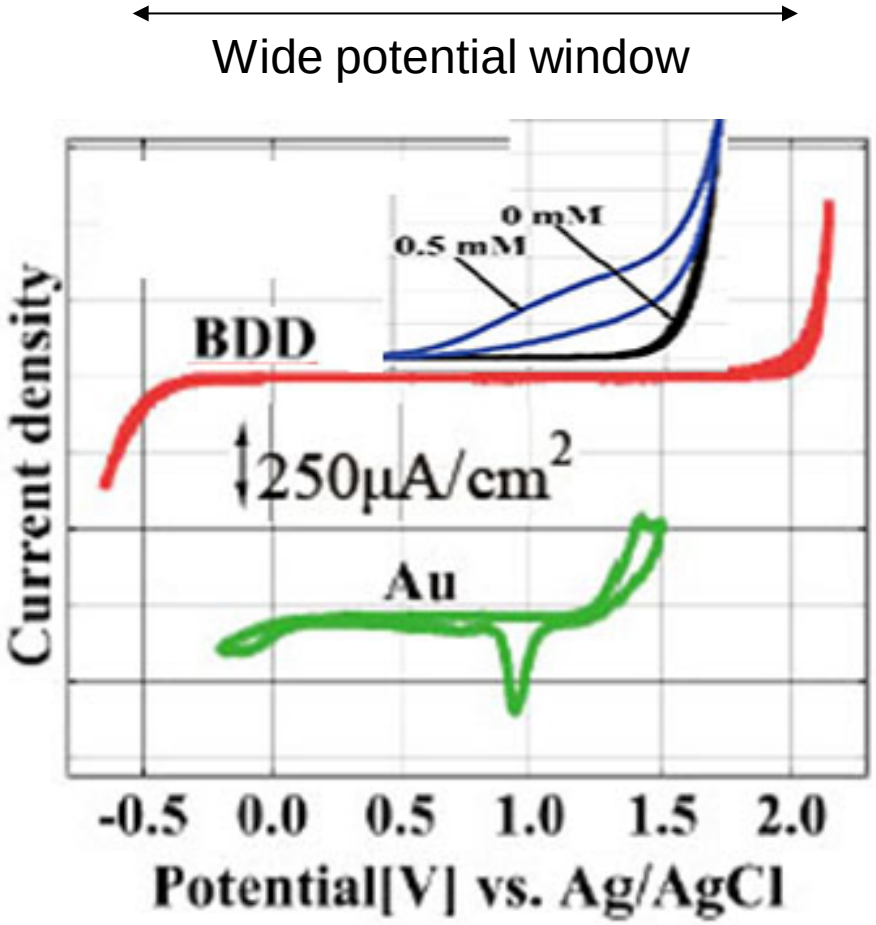
(T.Hayasaka, S.Yoshida, K.Inoue, T.Matsue, M.Esashi and S.Tanaka, Sensor symposium , Sendai (2013/11/6))



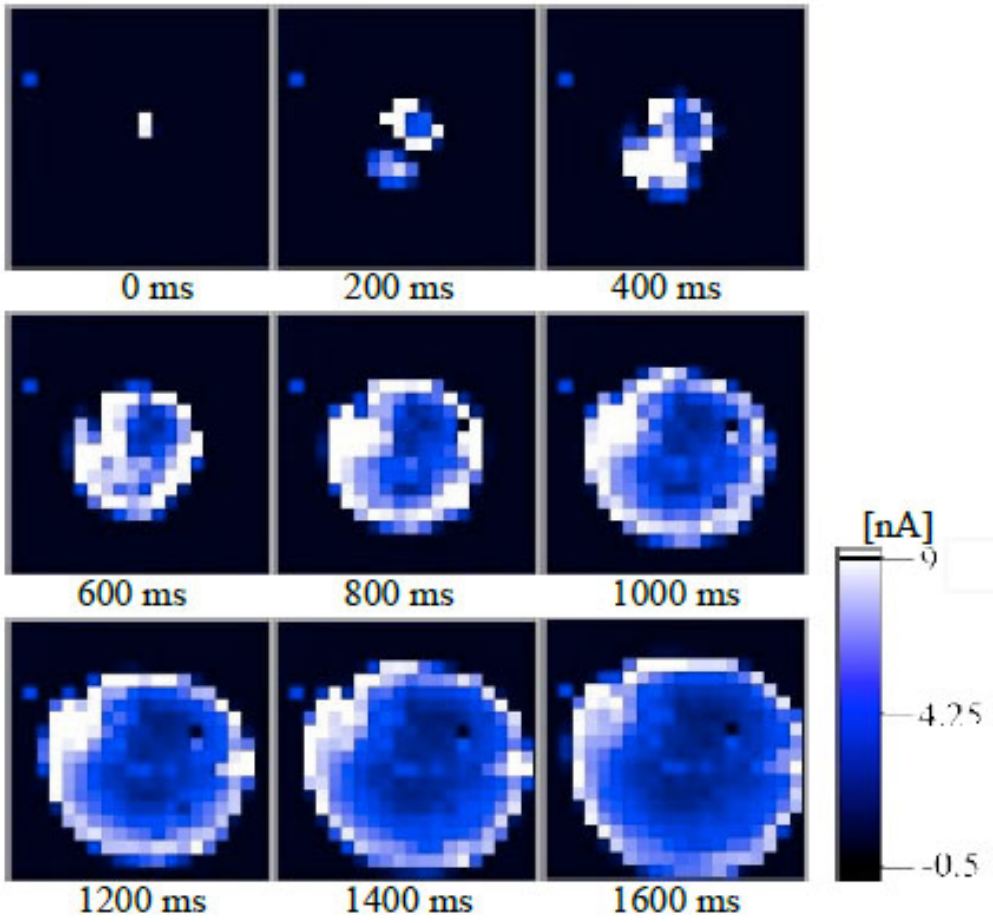
Diamond formation on a carrier wafer



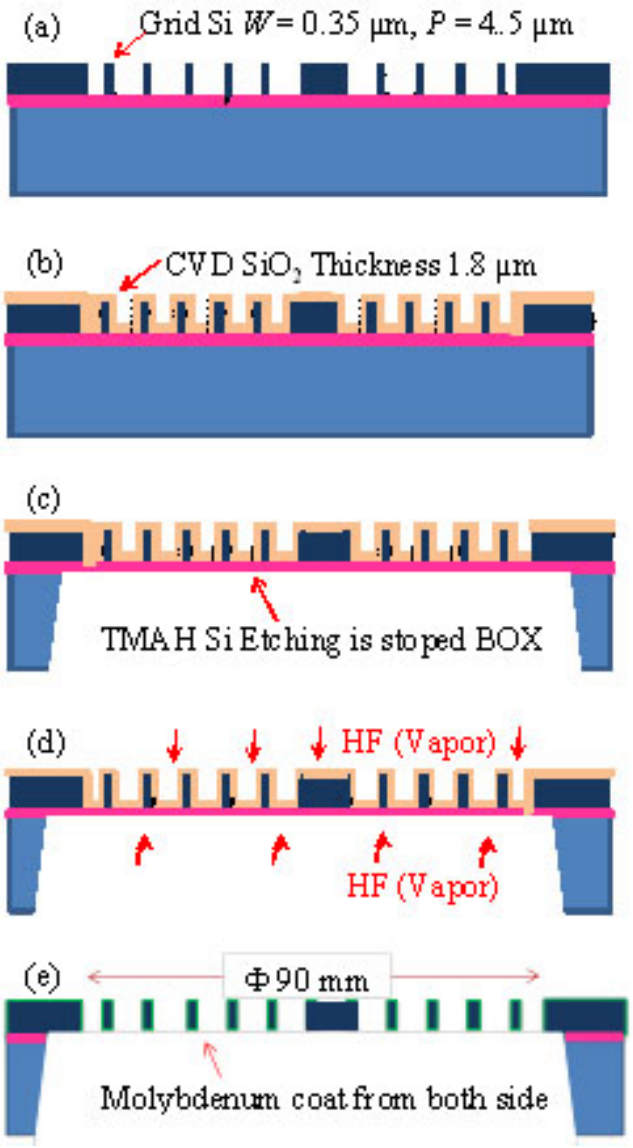
Fabrication process

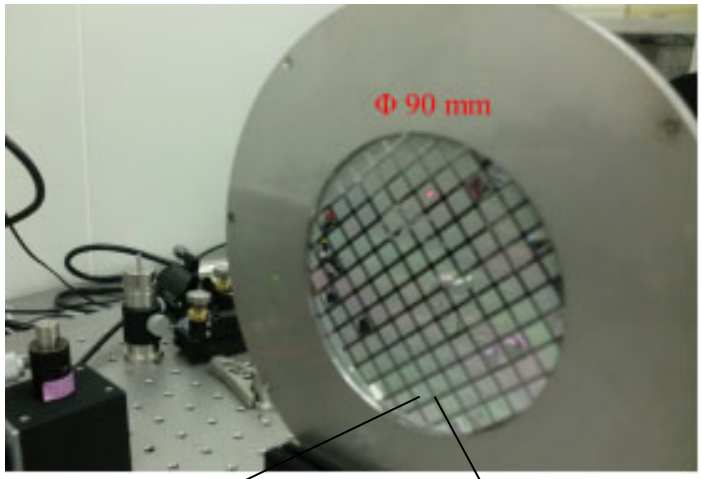


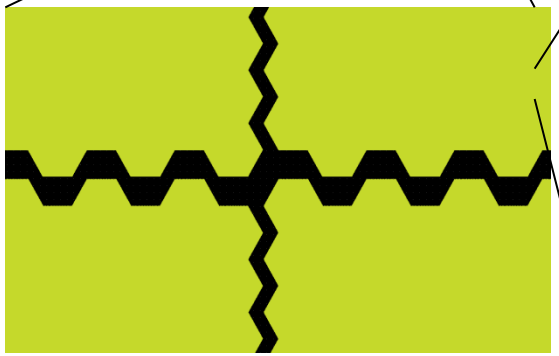
Typical cyclic voltammogram of 0.5 M H_2SO_4, 0 and 0.5 mM dopamine in phosphate buffer saline

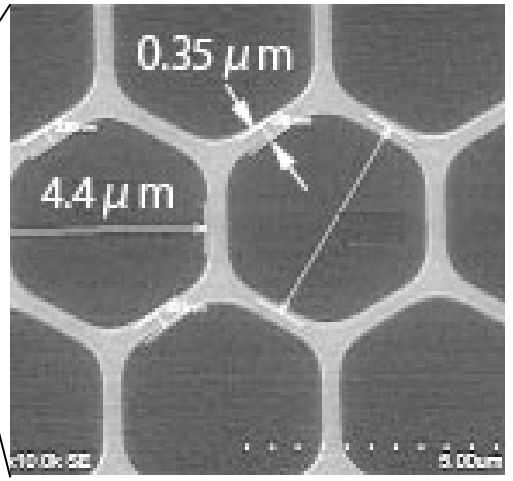


2D imaging of dopamine diffusion dissolved in the PBS near the center position of the BDD electrode array. Color maps correspond to the redox current intensities of 400 electrodes at 1.2 V.



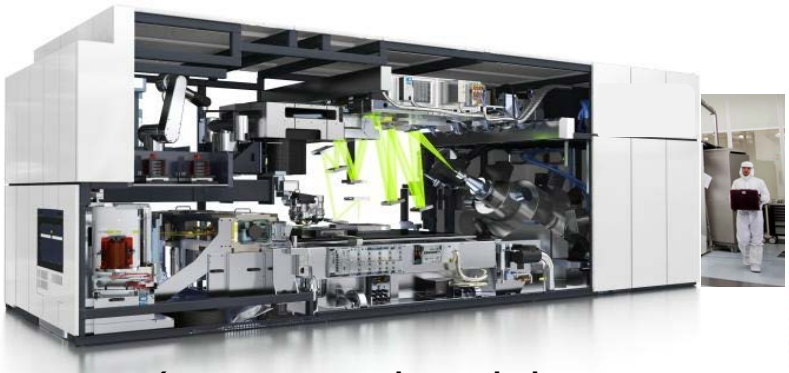




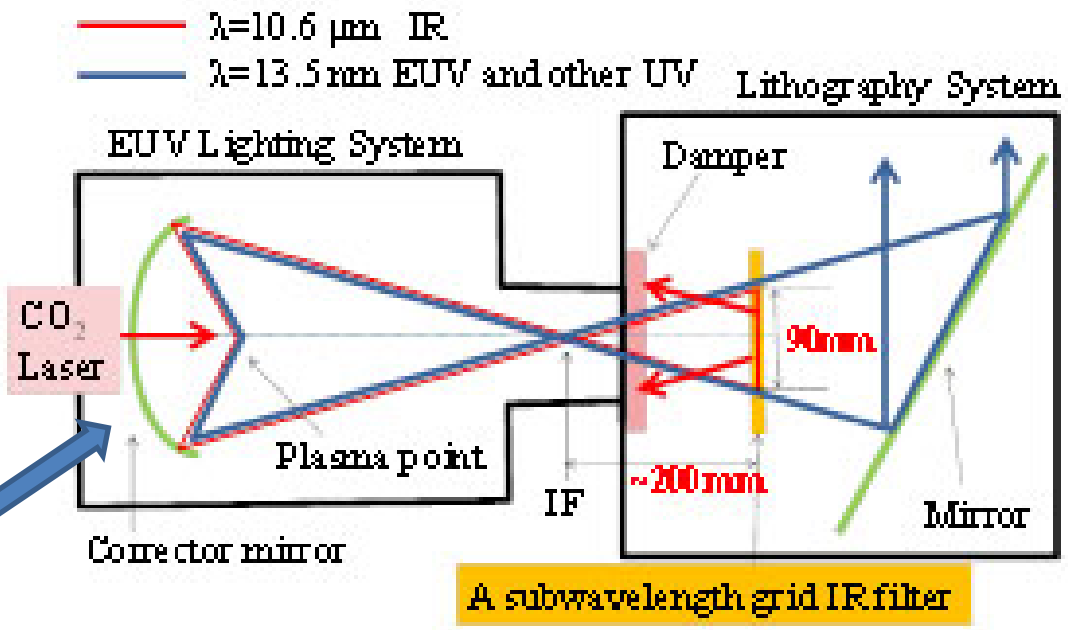


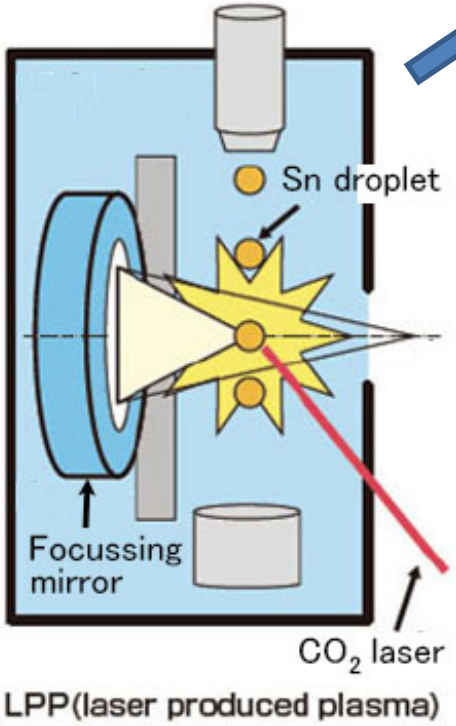
Wavelength selective structure using sub-wavelength grid

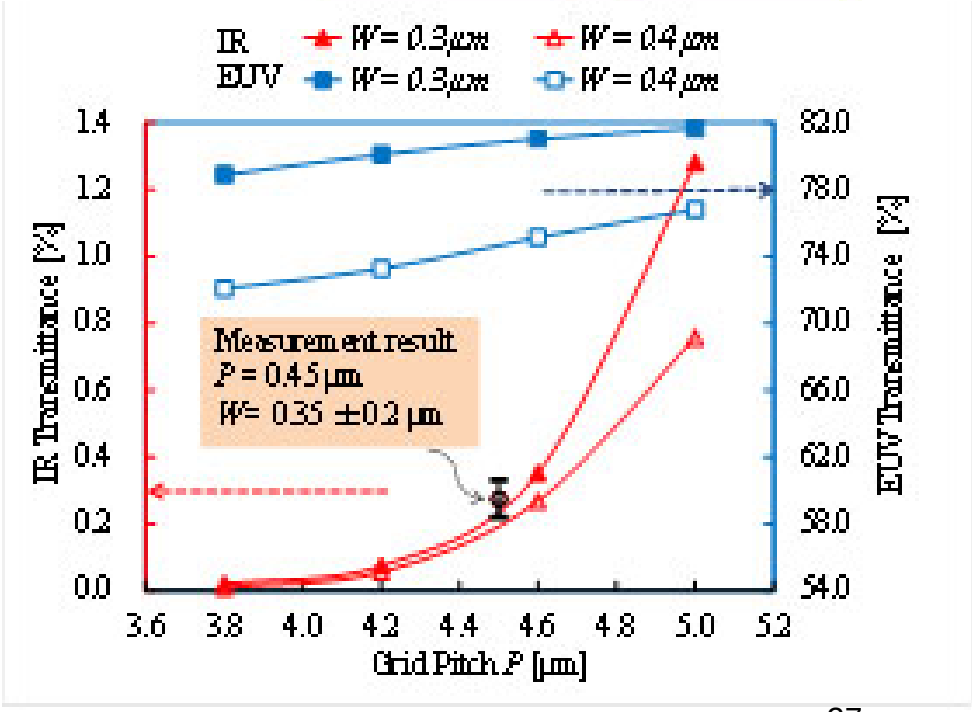
(Y.Suzuki, K.Totsu, M.Moriyama, M.Esashi and S.Tanaka, MEMS2014 (2001) 482-485)



EUVL (Extreme UltraViolet Lithography)







Wavelength selective structure using sub-wavelength grid

(Y.Suzuki, K.Totsu, M.Moriyama, M.Esashi and S.Tanaka, MEMS2014 (2001) 482-485)

FhG Germany – Sendai city partnership signing ceremony in Munich (July15,2005)

1st Fraunhofer Symposium in Sendai "Doing Worldwide Business via MEMS technology" (Oct.19, 2005)

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

FhG Project center in WPI-AIMR, Tohoku Univ. (April 1, 2012)

Collaboration with FhG (Fraunhofer Institute) in Germany

IMEC-Tohoku Seminar in Belgium (2012/6/21)

"your lab and imec are very complimentary"
Rudy Lauwereins, Vice-President of IMEC

Strategic Partner

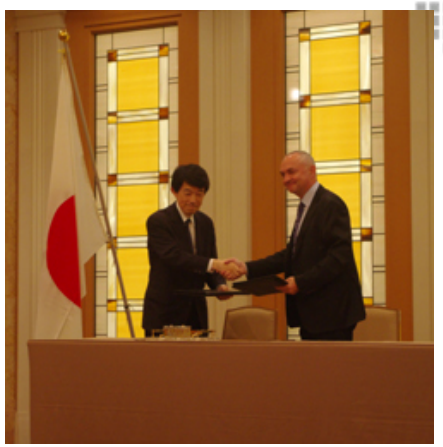
Tohoku U · Stanford U · EPFL

Stanford U

imec Belgium

imec EPFL

Tohoku U



Signing ceremony (2012/6/11)

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

IMEC-Tohoku Seminar in Sendai (2013/11/8)

imec

(IMEC M.Yoneyama 2012/6/12)

MEMS Park Consortium (MEMSPC)

MEMS core Co.Ltd.
(Contract development)

Advantest component Co.Ltd.
(Contract production)

(Initial stage prototyping)

Micro System Integration Center (μSIC), Tohoku Univ.

Nishizawa center, (Tohoku Univ.)
(Hands-on access fab.)

AIST (Tsukuba)
(Production stage prototyping)

Local companies

Advantest Components Co. Ltd. (Contract production)

MEMS Core Co. Ltd.

(Contract development)

Annex Esashi lab.

Sendai stealth dicing lab.

Hamamatsu Photonics. et.al.

MEMS PC member companies (70)

R&D Center of Excellence for Integrated Microsystems (2007-2016)
Ricoh, Toyota motor, Nippon signal, Toppan technical design center, Kitagawa iron works, Nikko, Denso, NIDEC COPAL electronics, MEMSAS, Toyota central R&D labs, MEMS core, Japan aviation electronics industry, Nippon dempa kogyo, Sumitomo precision, Furukawa Electric, Crestec

Domestic companies

MEMS Park Consortium (MEMSPC) (2004 ~)

Sendai MEMS show room

MEMS Training Program

MEMS Seminar

iCAN (International Contest of Applications in Nano-Micro Technologies)

Sendai

Sendai city

Tohoku Univ.

μSIC MicroSystemIntegrationCenter

Micro System Integration Center

・MEMS prototyping facility (20mm □)

・Micro/Nanomachining research and education Center (MNC) (2 inch)

・Hands on access fab. (4/6 inch)

AIST (Natl. Inst. of Advanced Industrial Science and Tech.)
Research Center for Ubiquitous MEMS and Micro Eng.(UMEMSME)

MEMS Industry Group in USA

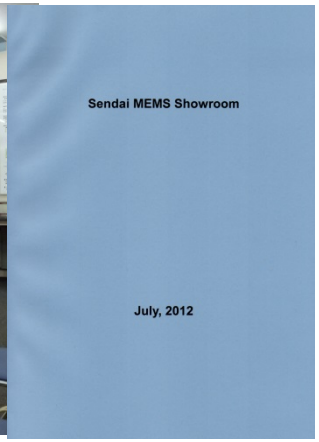
Germany FhG

Project center in Tohoku Univ. WPI-AIMR

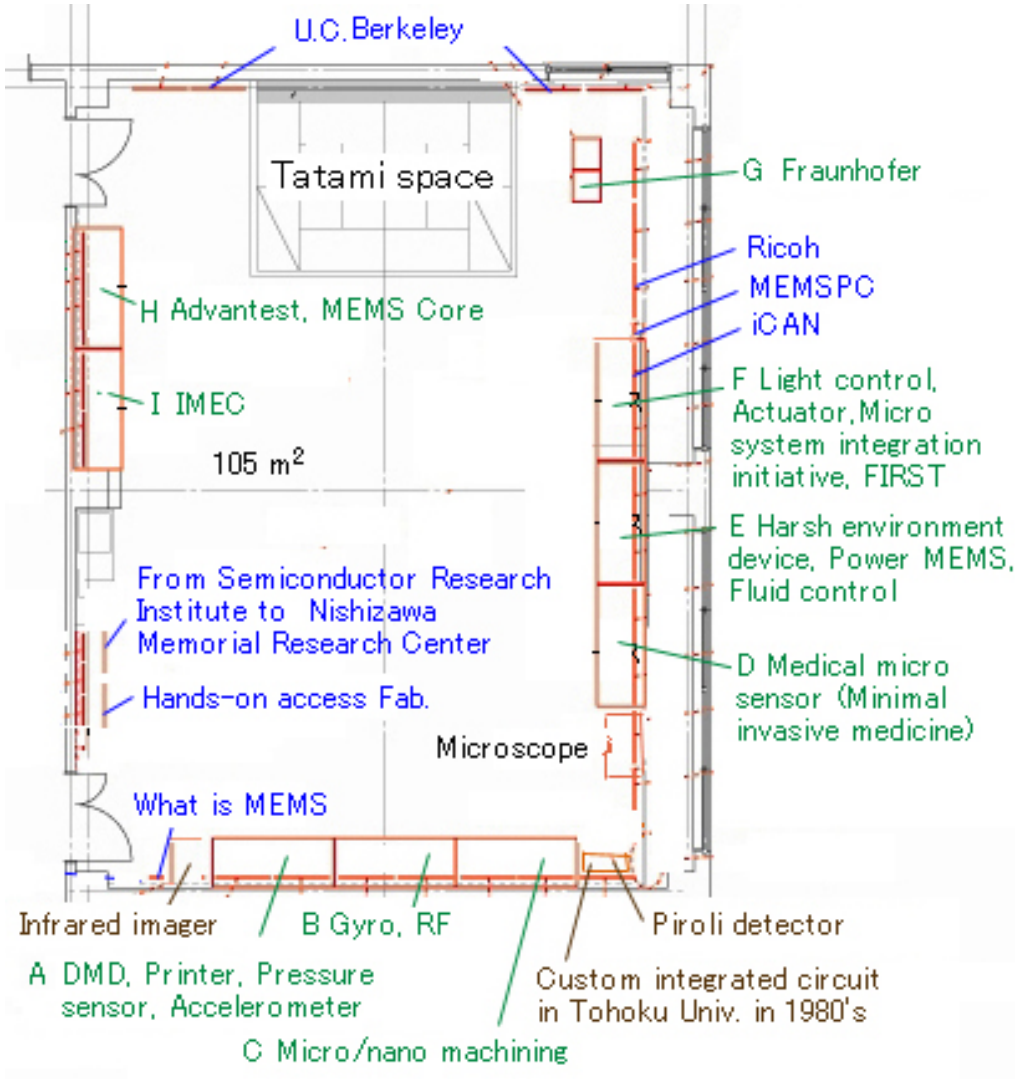
Belgium IMEC

Oversee

Collaboration



Catalog



Efficient way to access accumulated knowledge is important for heterogeneous integration

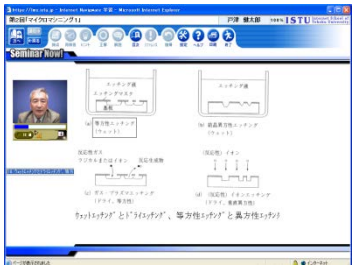
Sendai MEMS showroom (2012/5/16 renewal opening)

http://www.mu-sic.tohoku.ac.jp/showroom/index.html (Japanese)

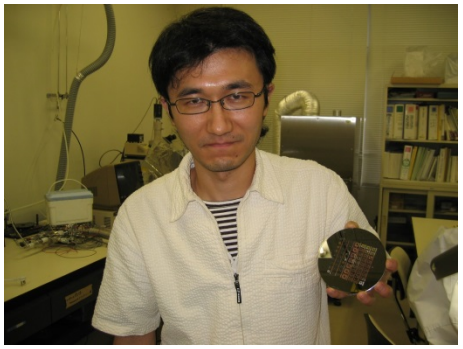
http://www.mu-sic.tohoku.ac.jp/showroom_e/index.html (English)

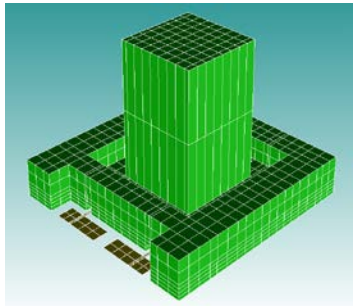
3 months

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



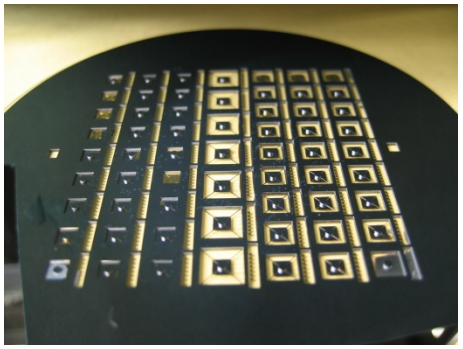
Lectures on Internet School of Tohoku University





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.

ADVANTEST

ADVANTEST CORPORATION

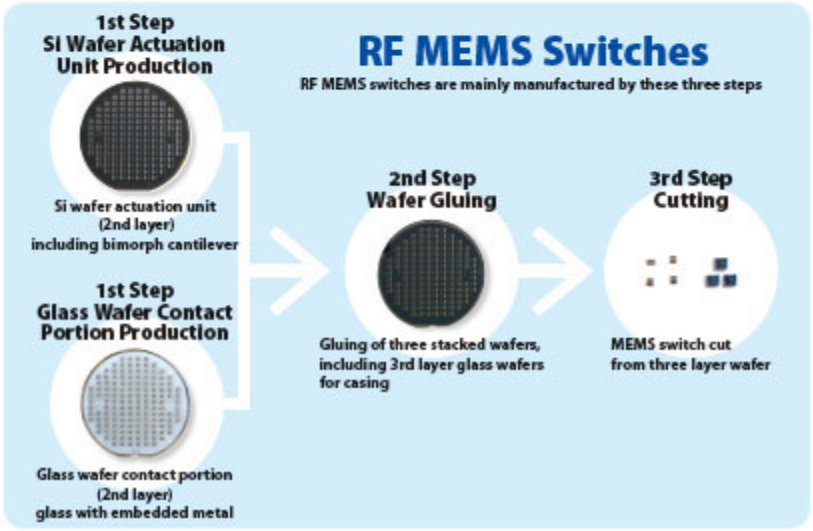
High-Frequency, Low Power Consumption MEMS Relay

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



Commercialization extended from the MEMS Training Program

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

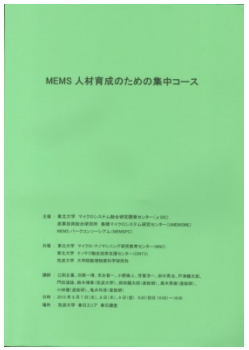
Free MEMS Seminar in Tsukuba Univ.(Aug.7-9,2013)110 attendees

Free MEMS Seminar in Osaka (Aug.5-7) Kansai University

High-tech. small volume production

Efficient utilization of facilities

MEMS seminar



iCAN’11 (2011) Peijing

MEMS application contest for high school and university students.

iCAN’13 in Balselona ; 2nd winner, Koriyama North Technical High School

http://www.rdceim.tohoku.ac.jp/iCAN13/

TEMS（Talking Equipment from Manual Sign）iCAN’11 winner, Kyoto Univ.

iCAN (International Contest of Application in Nano / micro technologies)

- Domestic contest, (May 16(Fri.)) at Sakura hall in Tohoku Univ.
- International Contest（iCAN'14）in Sendai (July 19(Sat.)~21(Mon.)) at Kawauchi campus, Tohoku Univ. http://www.rdceim.tohoku.ac.jp/iCAN14_sendai/