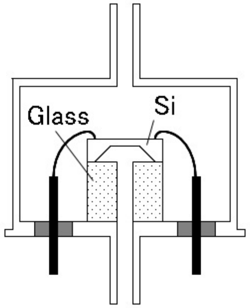
# Heterogeneous Integration by Adhesive Bonding

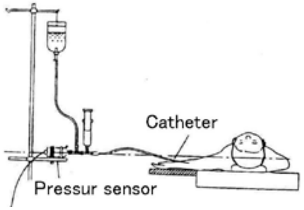
M.Esashi (WPI-AIMR, μSIC, Tohoku University)

1. Wafer level packaging and hetero-Integration by Selective Bonding
2. Multiband system for cognitive wireless communication
3. Diamond electrode array on LSI for amperometric biosensor
4. Massive Parallel EB Exposure System (Digital fabrication of LSI)
5. Open collaboration

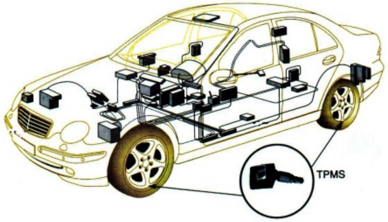
International Conf. “Global/Local Innovations for Next Generation Automobiles” October 9 (Thu) 2014, Sendai



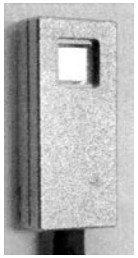
Engine control



Blood pressure sensing

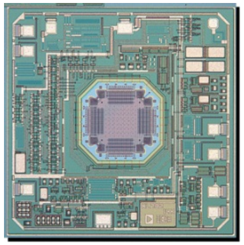


Tire pressure monitoring

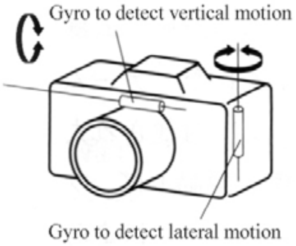


Microphone

Pressure sensor



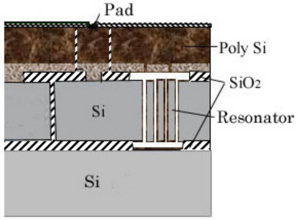
Accelerometer for airbag



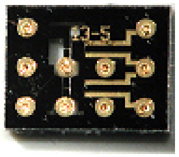
Gyro for camera

Accelerometer for user interface

Accelerometer & Gyro



Oscillator



MEMS switch

Communication

Print head

Display (DMD)

IR imager (Night vision)

Image (MEMS array)

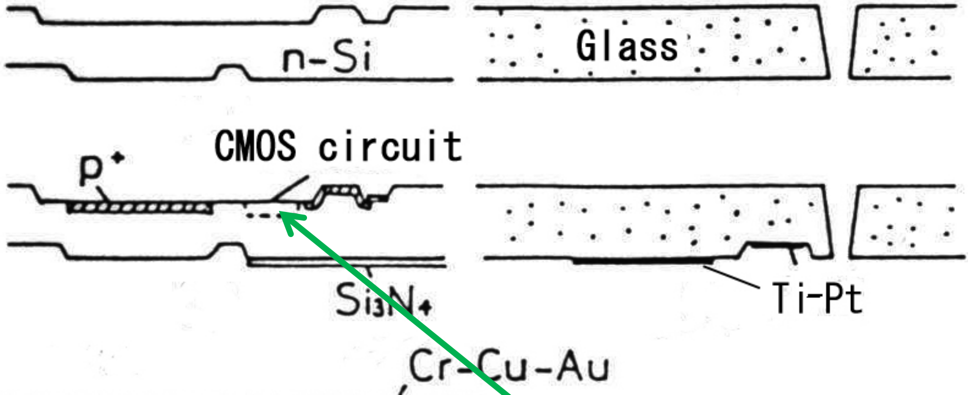
Structure + sensor + circuit + actuator

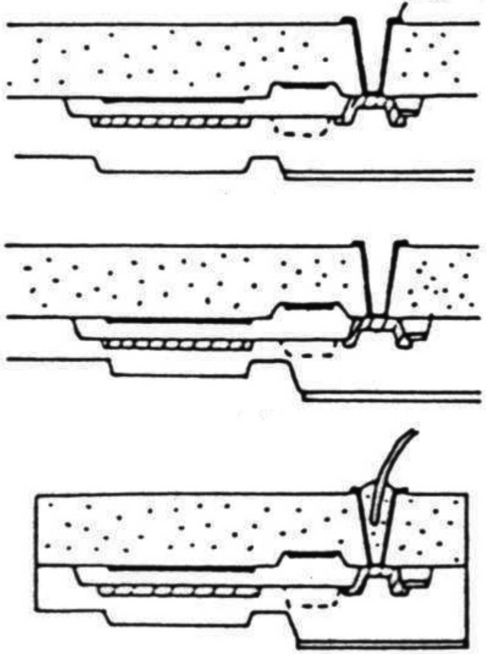
Advantages

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

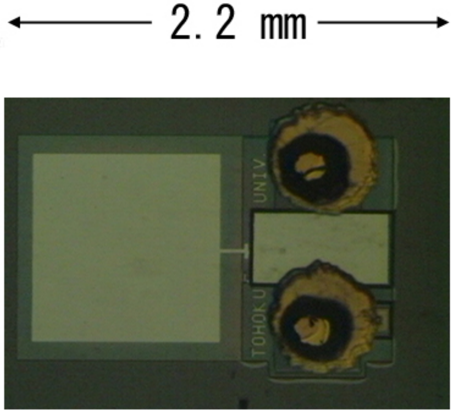
1990 2000 2010 year

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

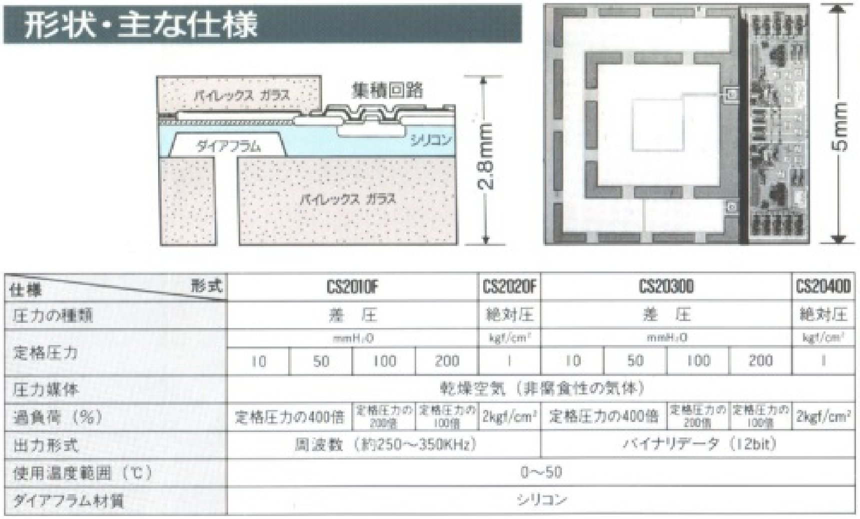




Capacitance detection circuit



Wafer level packaging



**形状・主な仕様**

| 仕様＼形式 | CS2010F | | | | CS2020F | CS20300 | | | | CS20400 |
|---|---|---|---|---|---|---|---|---|---|---|
| 圧力の種類 | 差　圧 | | | | 絶対圧 | 差　圧 | | | | 絶対圧 |
| 定格圧力 | mmH$_2$O | | | | kgf/cm$^2$ | mmH$_2$O | | | | kgf/cm$^2$ |
| | 10 | 50 | 100 | 200 | 1 | 10 | 50 | 100 | 200 | 1 |
| 圧力媒体 | 乾燥空気（非腐食性の気体） | | | | | | | | | |
| 過負荷（%） | 定格圧力の400倍 | | 定格圧力の200倍 | 定格圧力の100倍 | 2kgf/cm$^2$ | 定格圧力の400倍 | | 定格圧力の200倍 | 定格圧力の100倍 | 2kgf/cm$^2$ |
| 出力形式 | 周波数（約250～350KHz） | | | | | バイナリデータ（12bit） | | | | |
| 使用温度範囲（℃） | 0～50 | | | | | | | | | |
| ダイアフラム材質 | シリコン | | | | | | | | | |

TOYODA 豊田工機株式会社 メカトロニクス事業部

CS7000

For low pressure measurement

10mmH$_2$O～300mmH$_2$O

Frequency and analog output

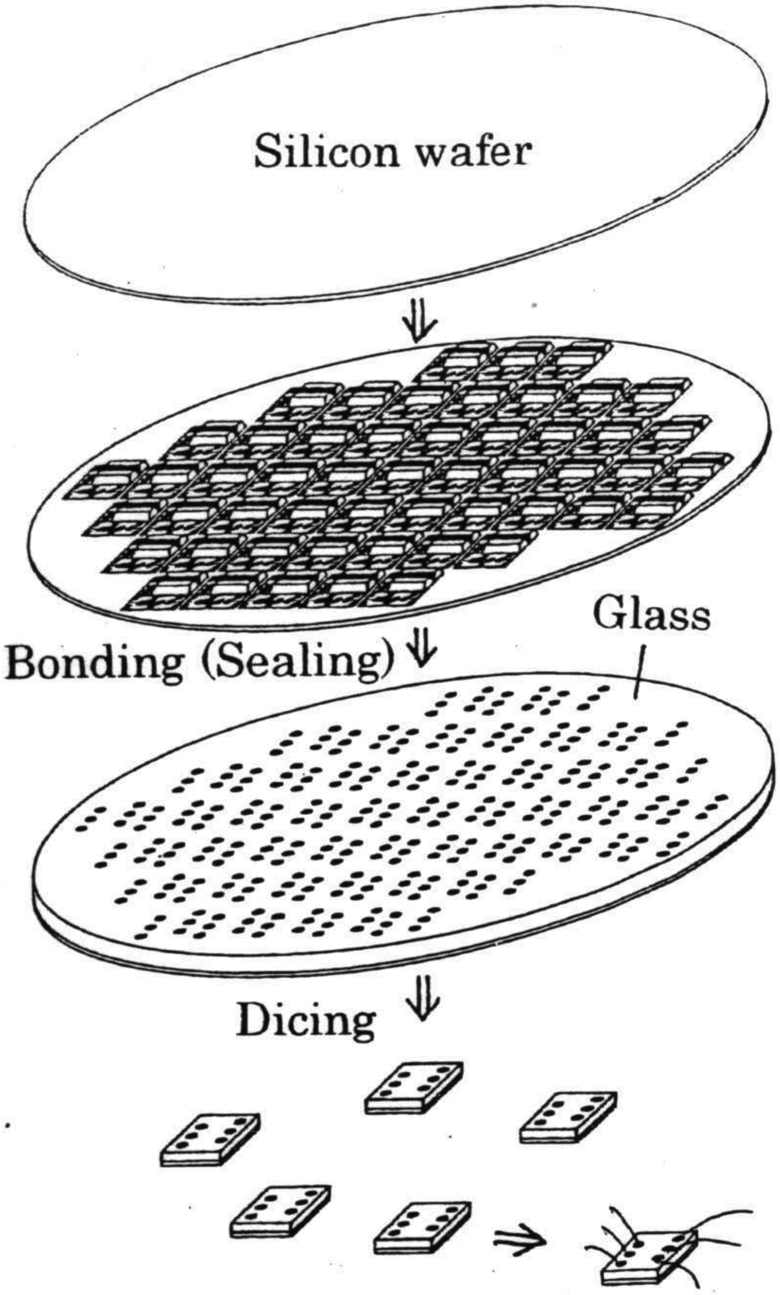
TOYODA

Toyoda Machine Works, LTD.

Monolithic capacitive pressure sensor

# Integrated capacitive pressure sensor (Toyoda Machine Works)

(Y.Matsumoto, S.Shoji, M.Esashi, 22nd Conf. on Solid State Devices and Materials (1990) 701)



MEMS have moving parts → Direct molding with plastics can not be done.

# Wafer level packaging

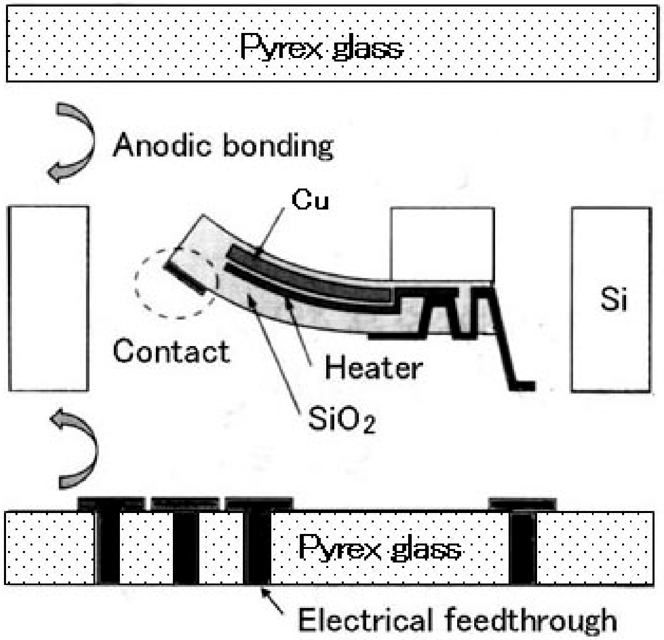
→ small size (chip size encapsulation, suitable for surface mounting)

→ 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.)

(M.Esashi, J of Micromechanics and Microengineering,18 (2008) p.073001)




アドバンテスト社製
半導体試験装置
T2000 シリーズ

半導体デバイスの性能や動作を試験して
良品だけを世の中に送り出しいるのが
アドバンテストの半導体試験装置

アドバンテスト
コンポーネント社製

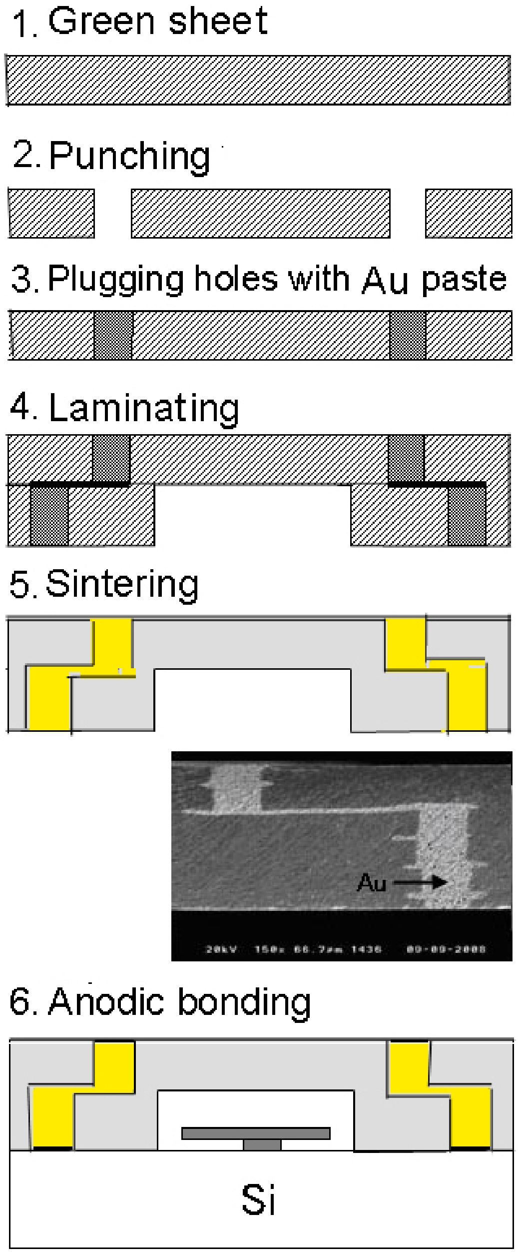
半導体試験装置を支える
キーデバイスを提供

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

MEMS switch factory
(Advantest components (Sendai))

MEMS switch for LSI tester
(Advantest)

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


1. Green sheet

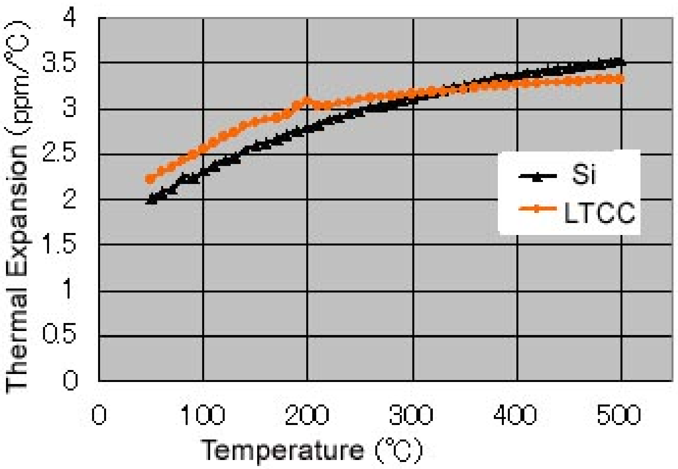
2. Punching

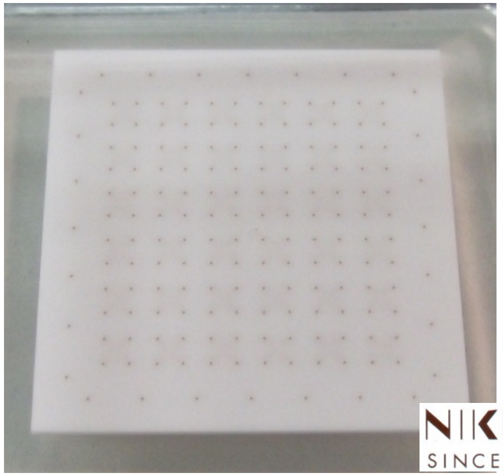
3. Plugging holes with Au paste

4. Laminating

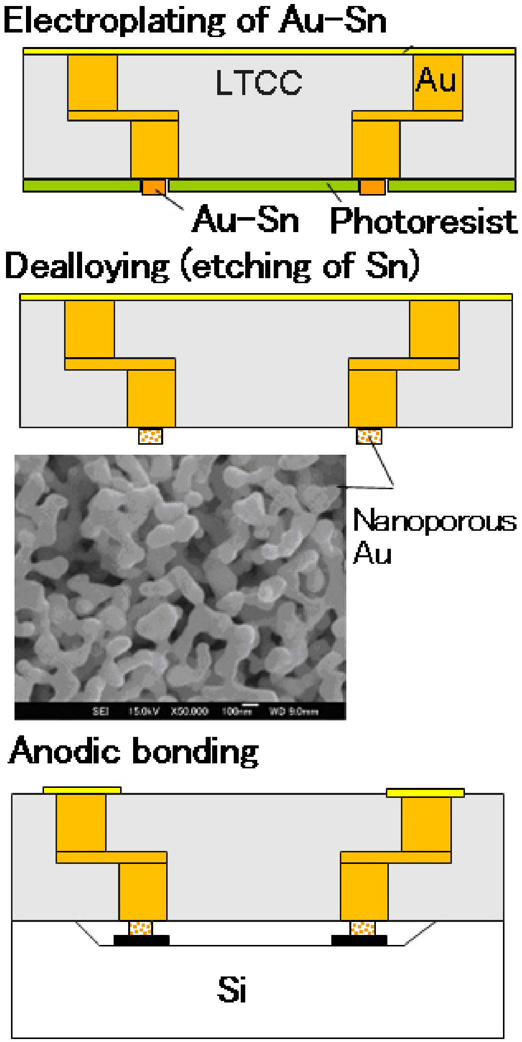
5. Sintering

6. Anodic bonding





LTCC (Low Temperature Cofired Ceramic) with electrical feedthrough for MEMS packaging（Nikko）

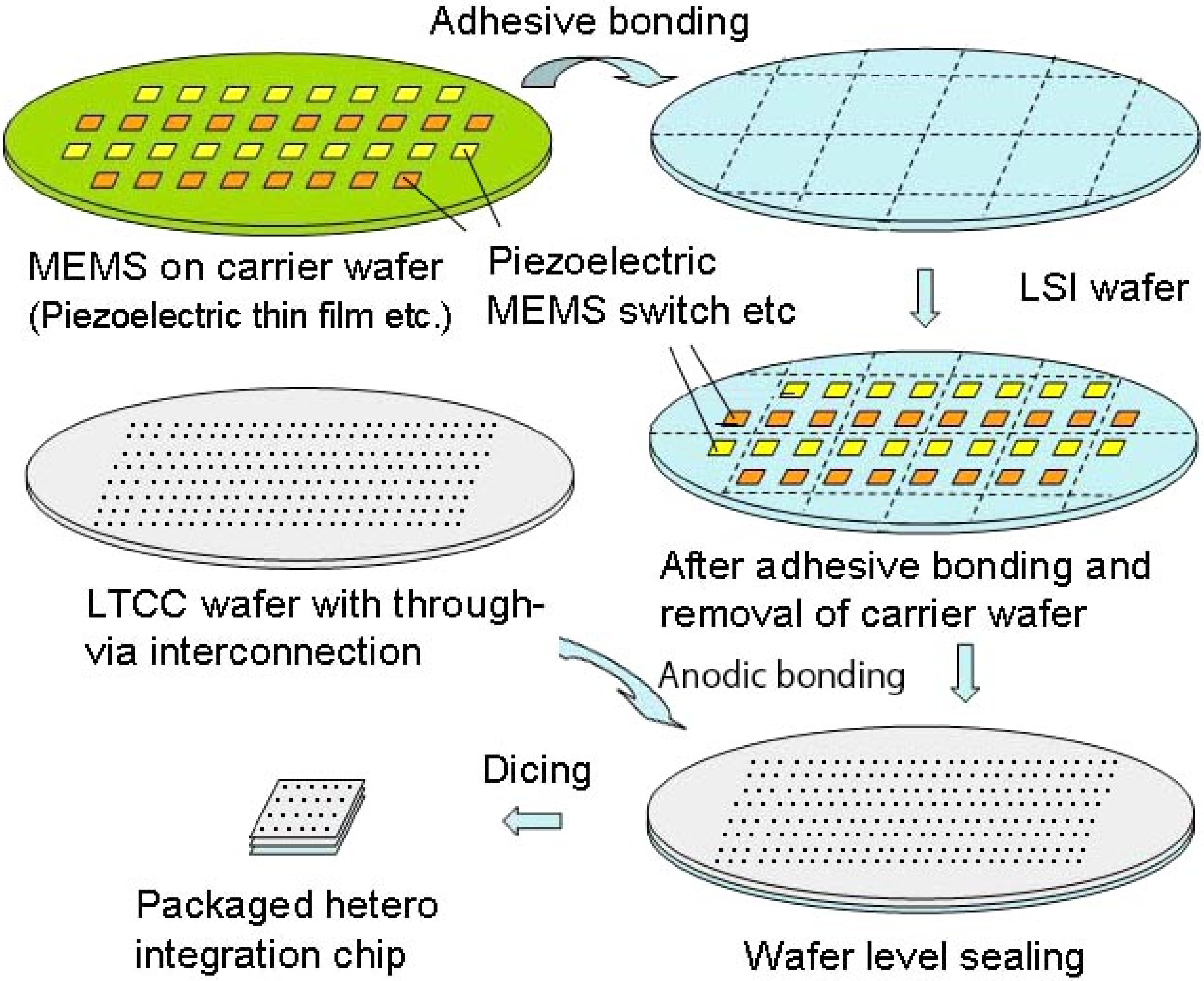

Electroplating of Au-Sn

Dealloying (etching of Sn)

Anodic bonding

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

(M. Mohri, M. Esashi and S. Tanaka : “MEMS wafer-level packaging technology using LTCC wafer”, *IEEJ Trans SM*, 132-E, No.8, pp.246-253 (2012) (in Japanese))



Adhesive bonding

MEMS on carrier wafer
(Piezoelectric thin film etc.)

Piezoelectric
MEMS switch etc

LSI wafer

After adhesive bonding and
removal of carrier wafer

LTCC wafer with through-
via interconnection

Anodic bonding

Dicing

Packaged hetero
integration chip

Wafer level sealing

# Heterogeneous integration by adhesive bonding

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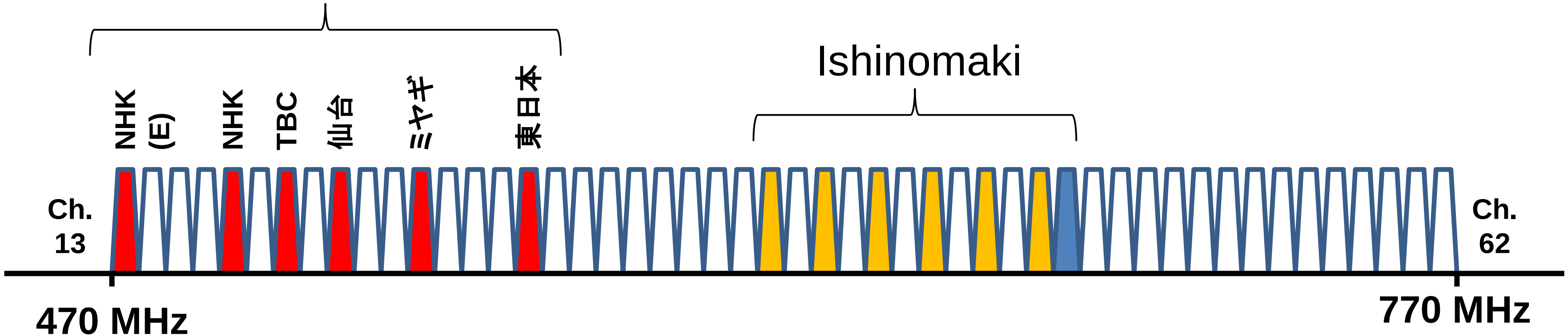
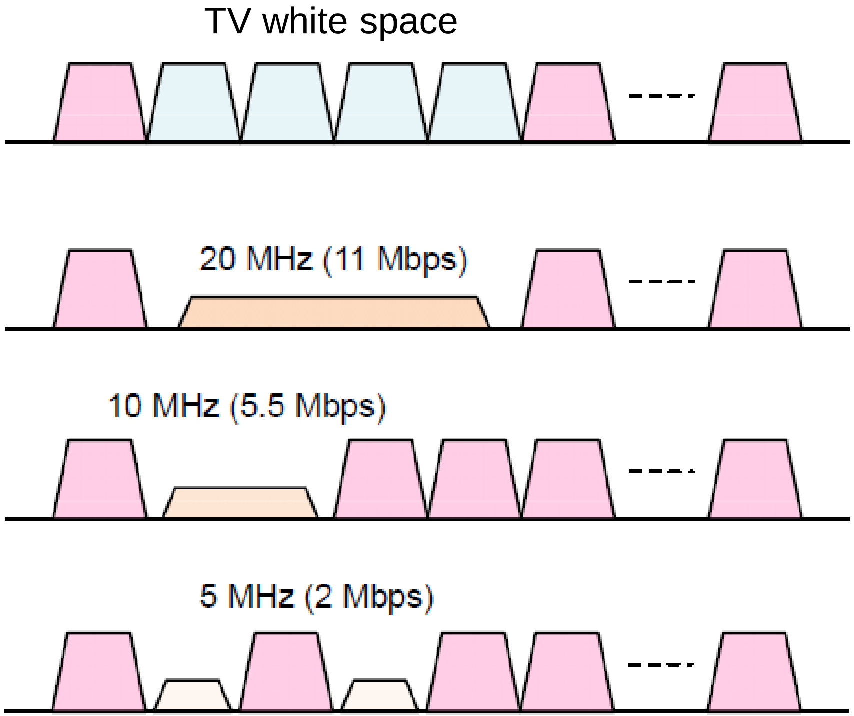
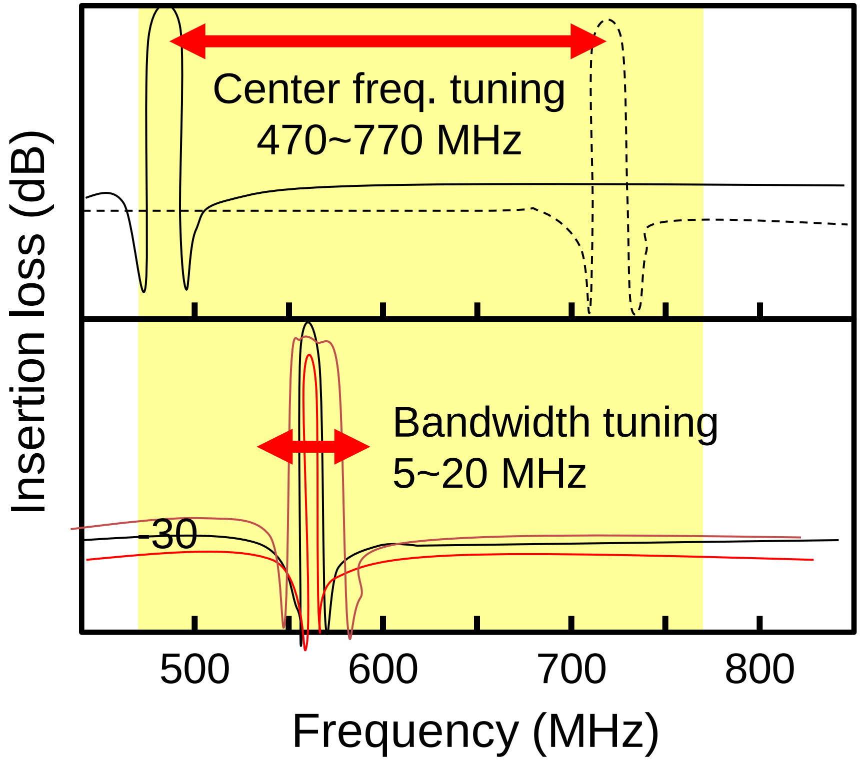
2. Multiband system for cognitive wireless communication
3. Diamond electrode array on LSI for amperometric biosensor
4. Massive Parallel EB Exposure System(Digital fabrication of LSI)
5. Open collaboration

50 ch × BW 6 MHz = 300 MHz

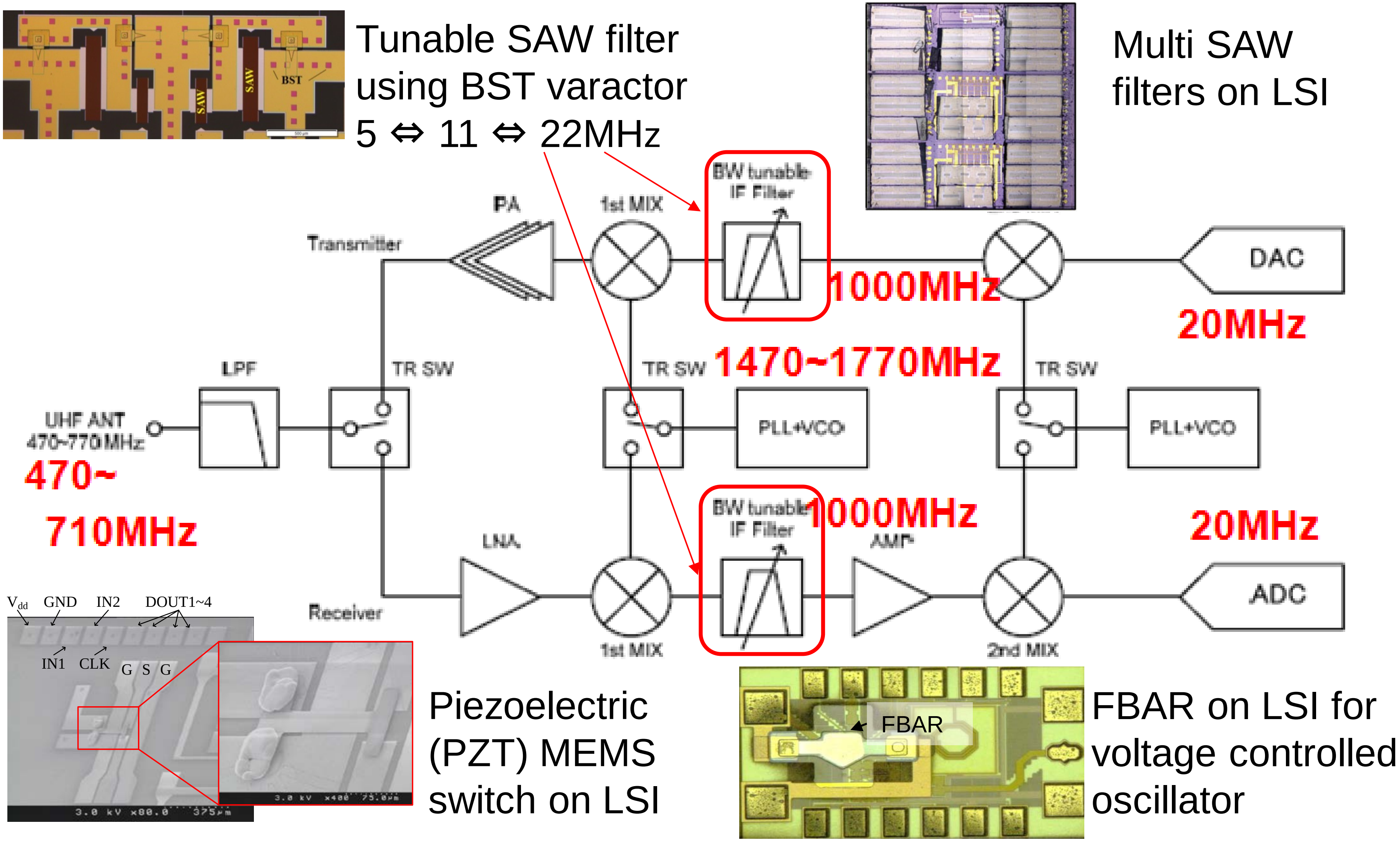






# TV white space cognitive radio (IEEE 802.11af)

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



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

Multi SAW filters on LSI

Piezoelectric (PZT) MEMS switch on LSI

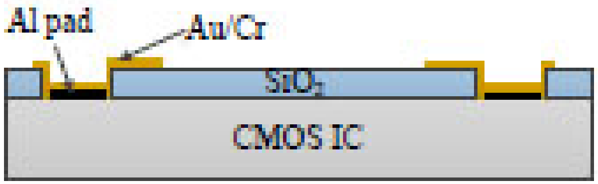
FBAR on LSI for voltage controlled oscillator

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

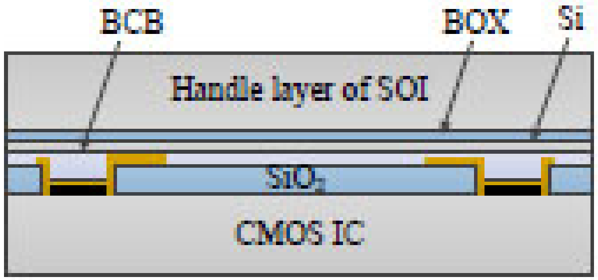
Multiband system for cognitive wireless communication to use available frequency bands efficiently

# CMOS-FBAR voltage controlled oscillator

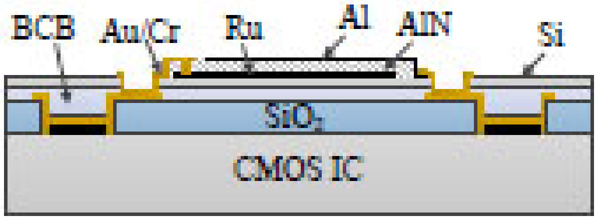
1. Preparation of CMOS IC



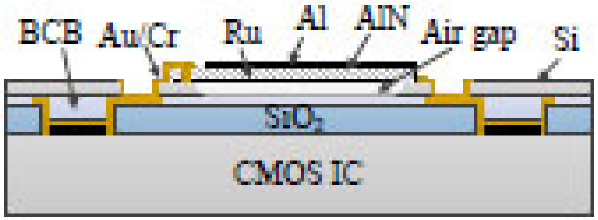
2. BCB adhesive bonding by flipping the SOI wafer on CMOS wafer and removal of handle Si & BOX layer

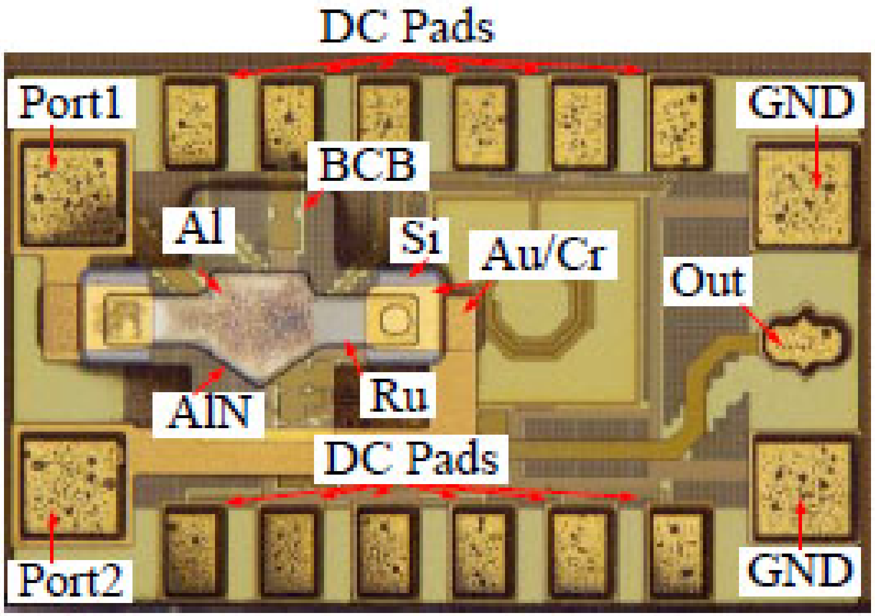


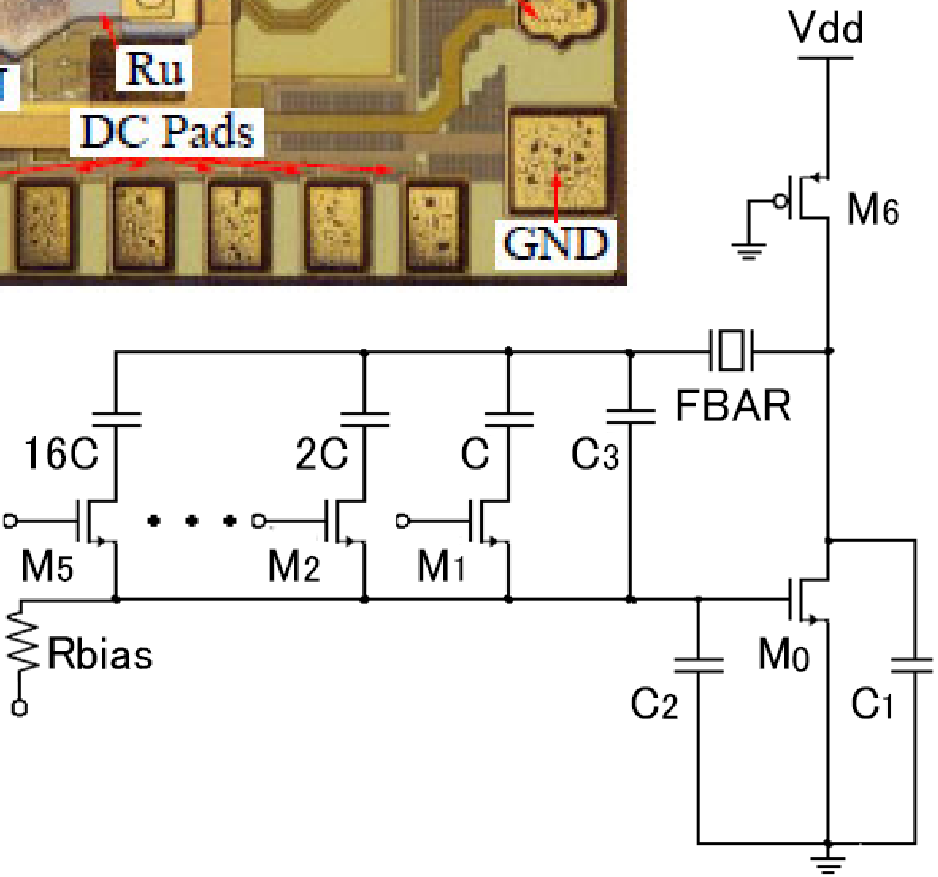
3. FBAR fabrication and its interconnection with CMOS IC



4. Sacrificial etching of Si underneath the active FBAR area

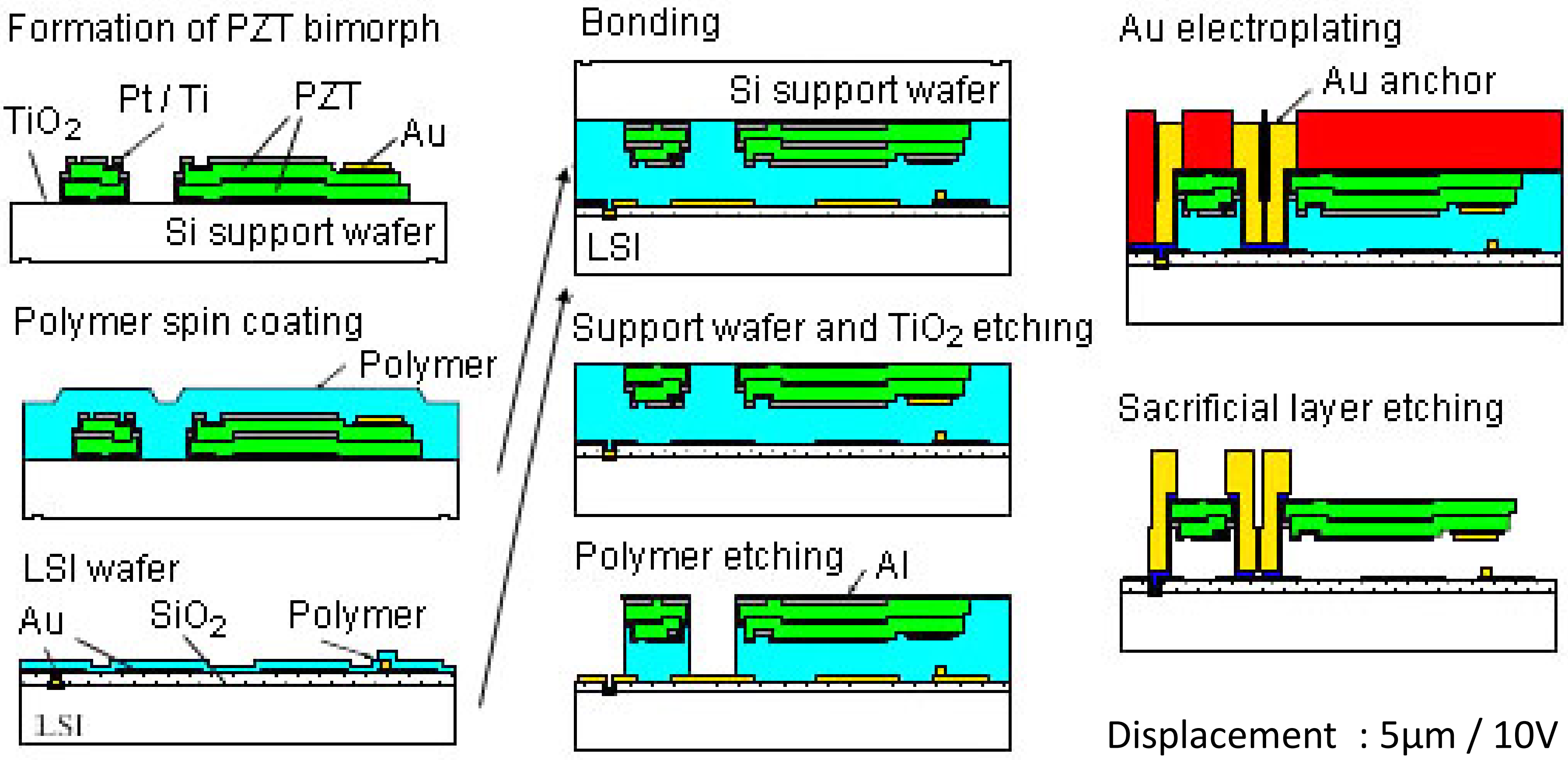




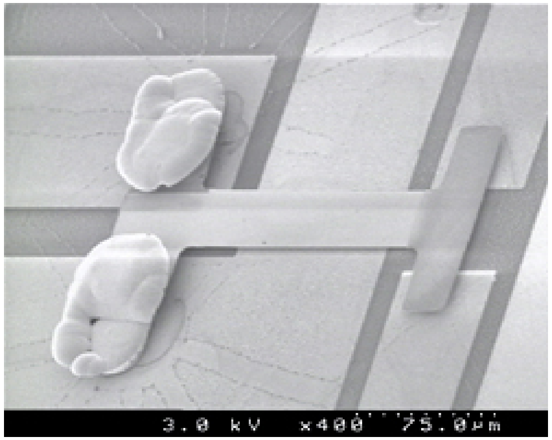


(A.Kochhar, et.al. 2012 IEEE Ultrasonics Symposium, 5E-3)

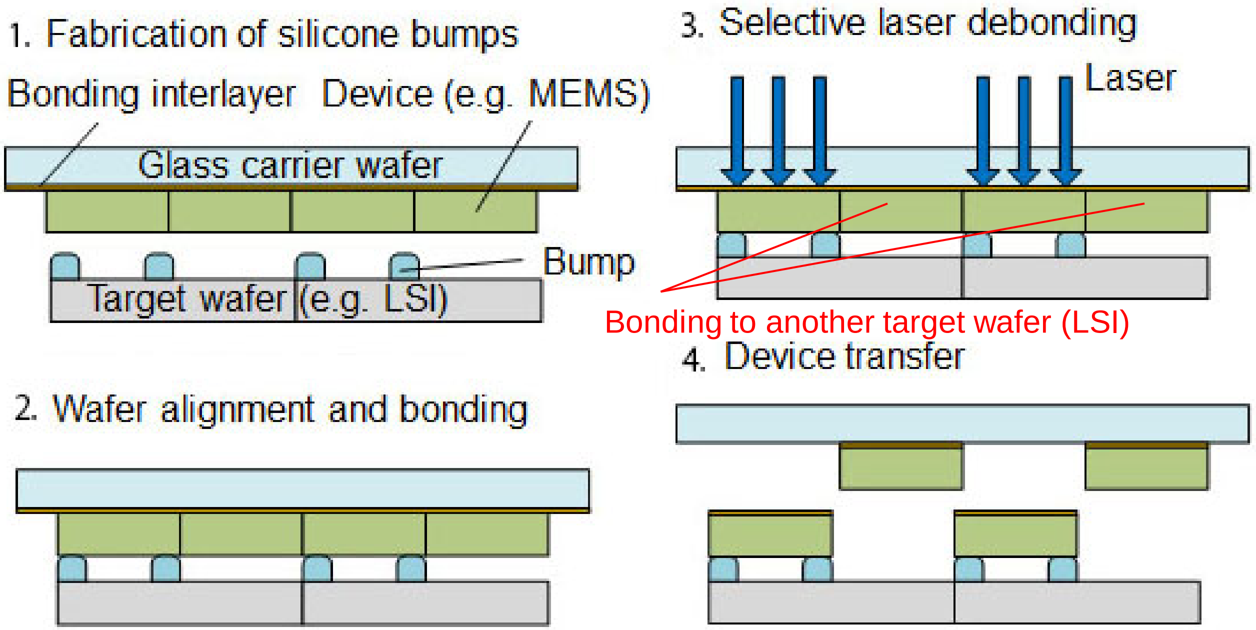
# PZT MEMS Switch on LSI



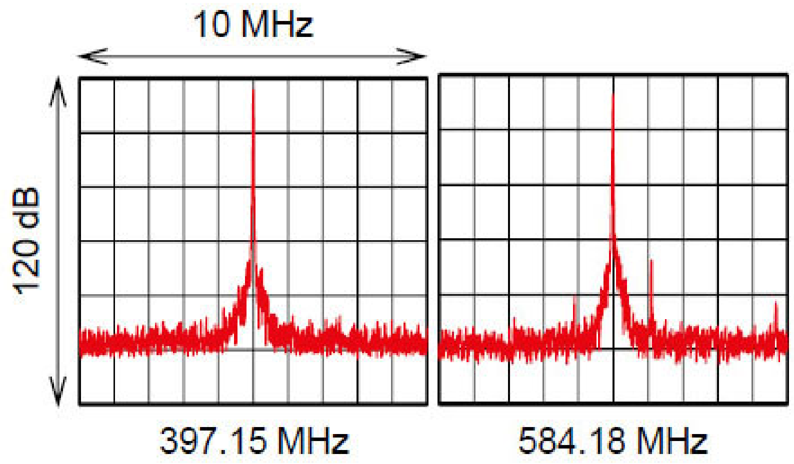
Displacement : 5µm / 10V

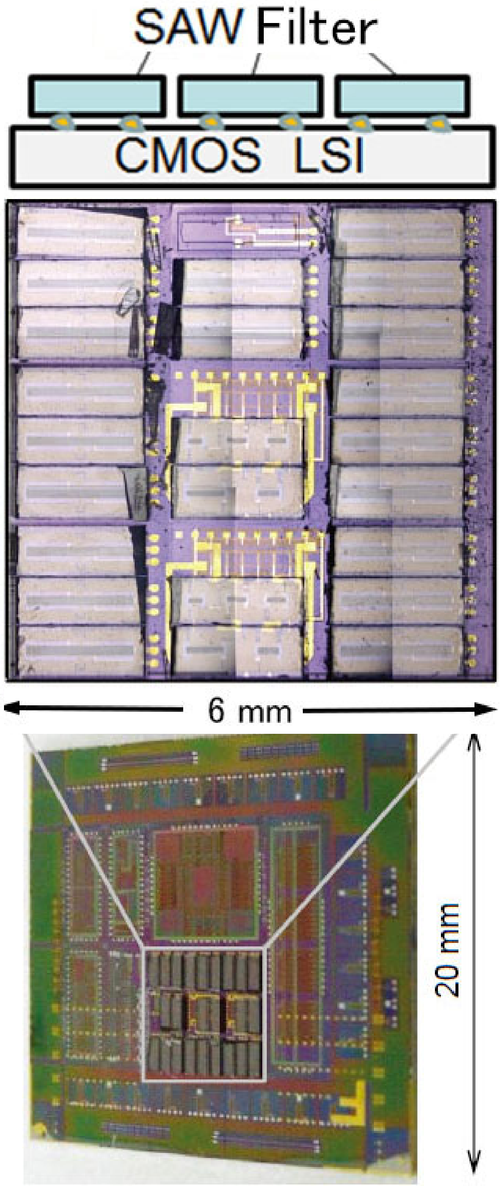


(Matsuo, Moriyama, Esashi, Tanaka, IEEE MEMS 2012, 1153-1156)



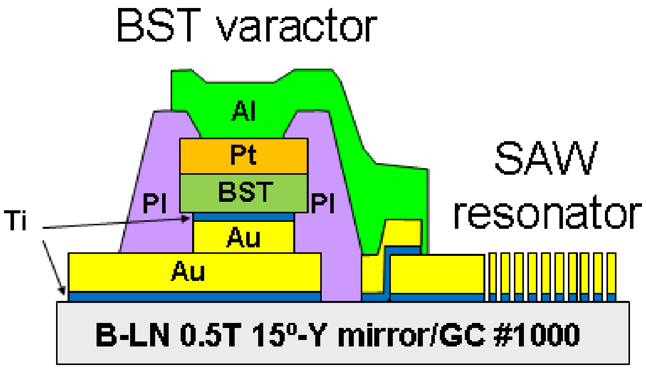
Selective transfer process by laser debonding

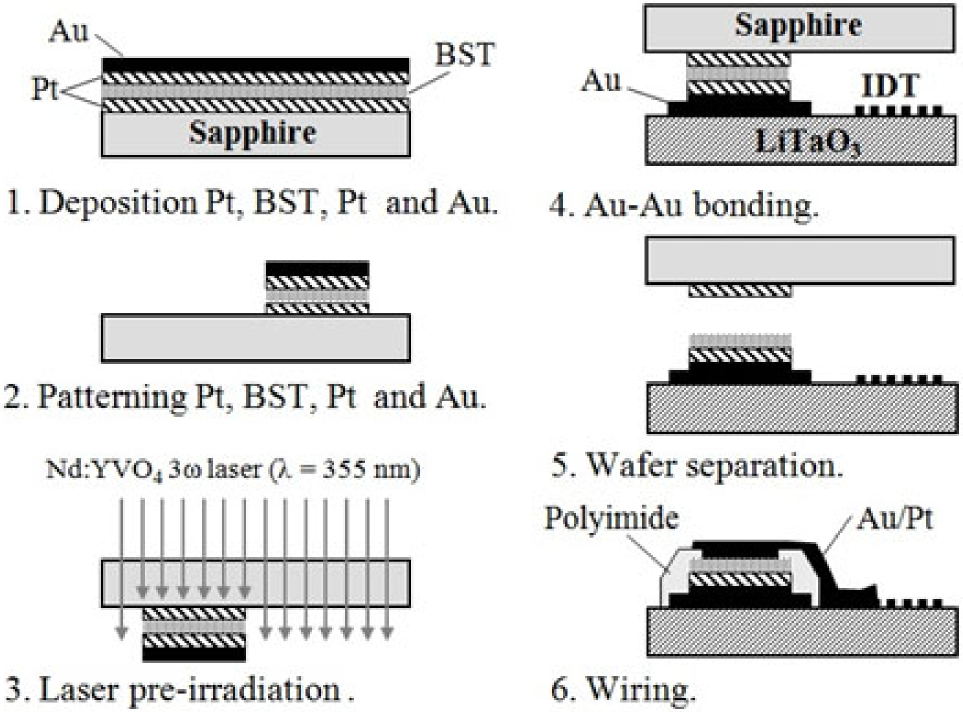


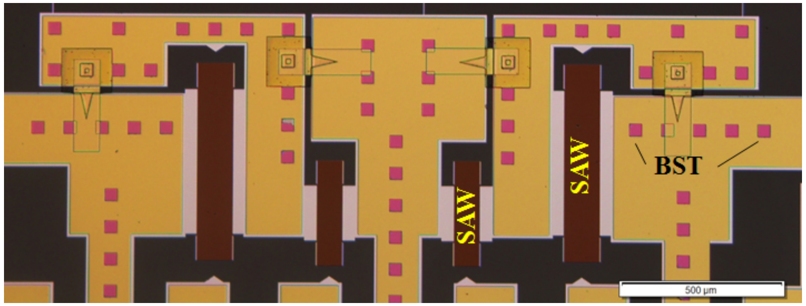


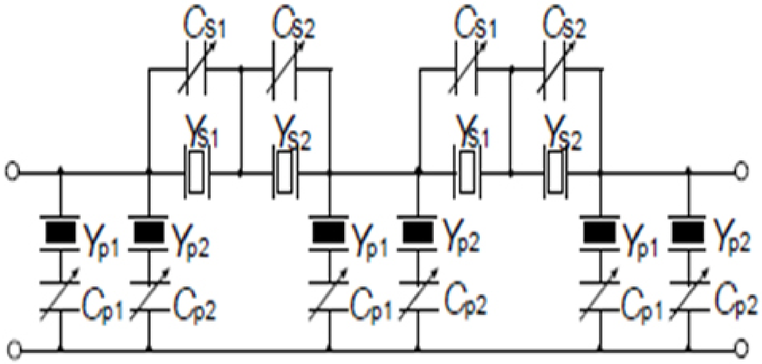
Multi SAW filters on LSI by selective transfer

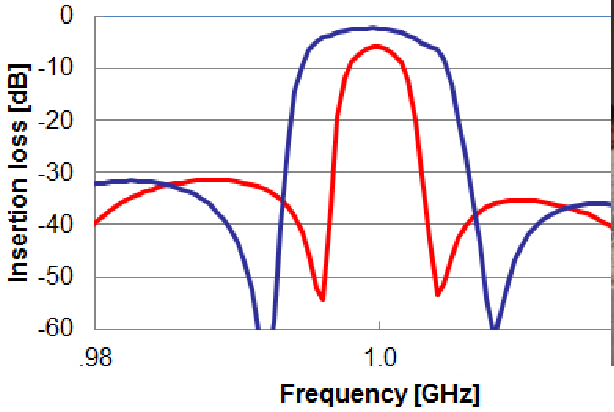
·(S. Tanak, M. Yoshida, H. Hirano and M. Esashi : “Lithium niobate SAW device hetero-transferred onto silicon integrated circuit using elastic and sticky bumps”, 2012 IEEE International Ultrasonics Sympsium, p.1047 (2012)).

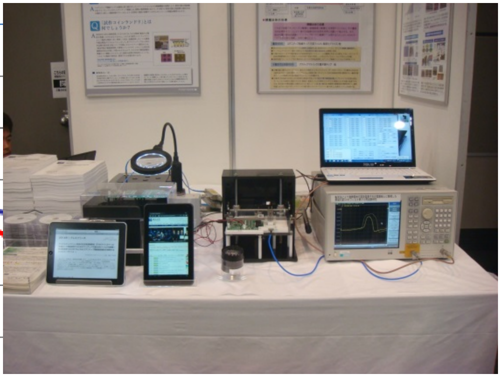












# Tunable SAW filter using ferroelectric varactor

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

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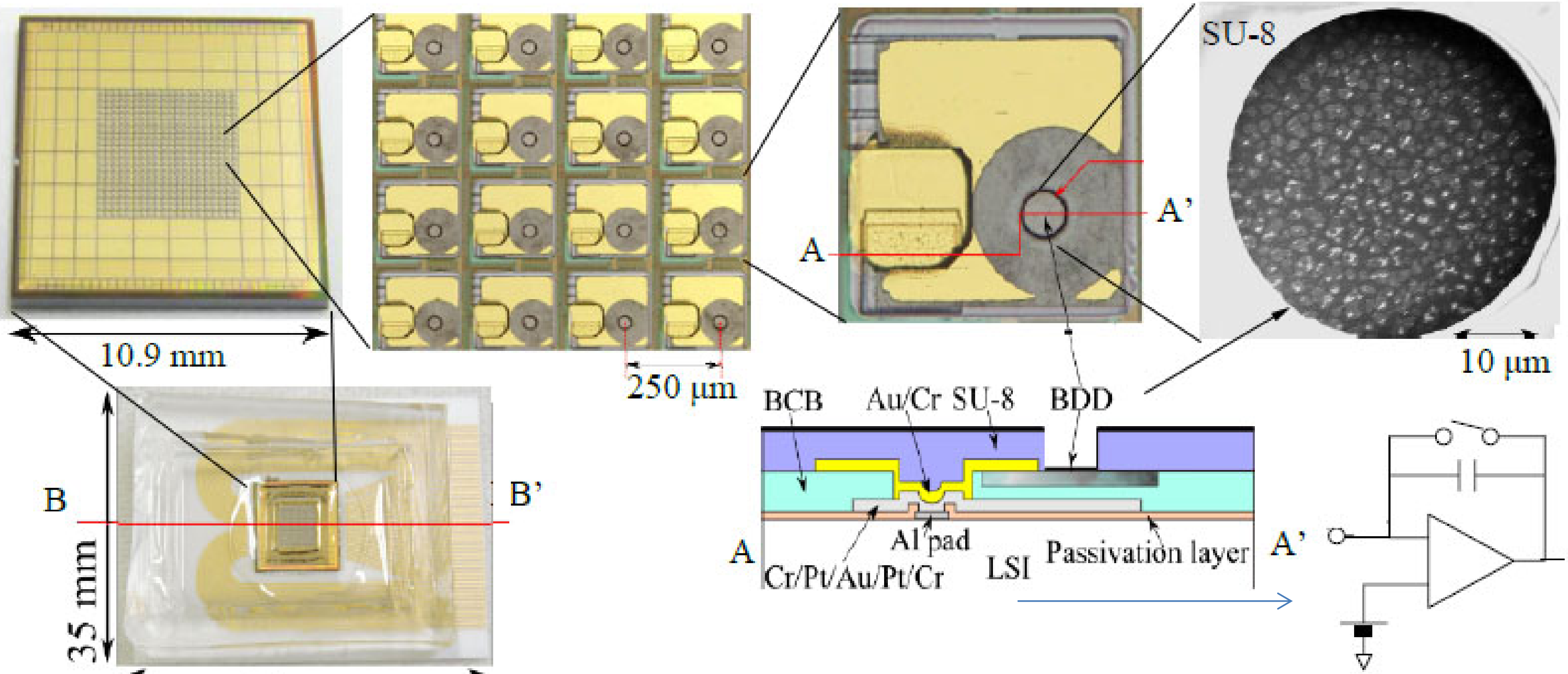
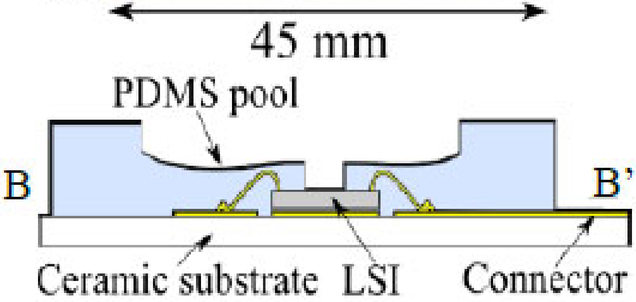
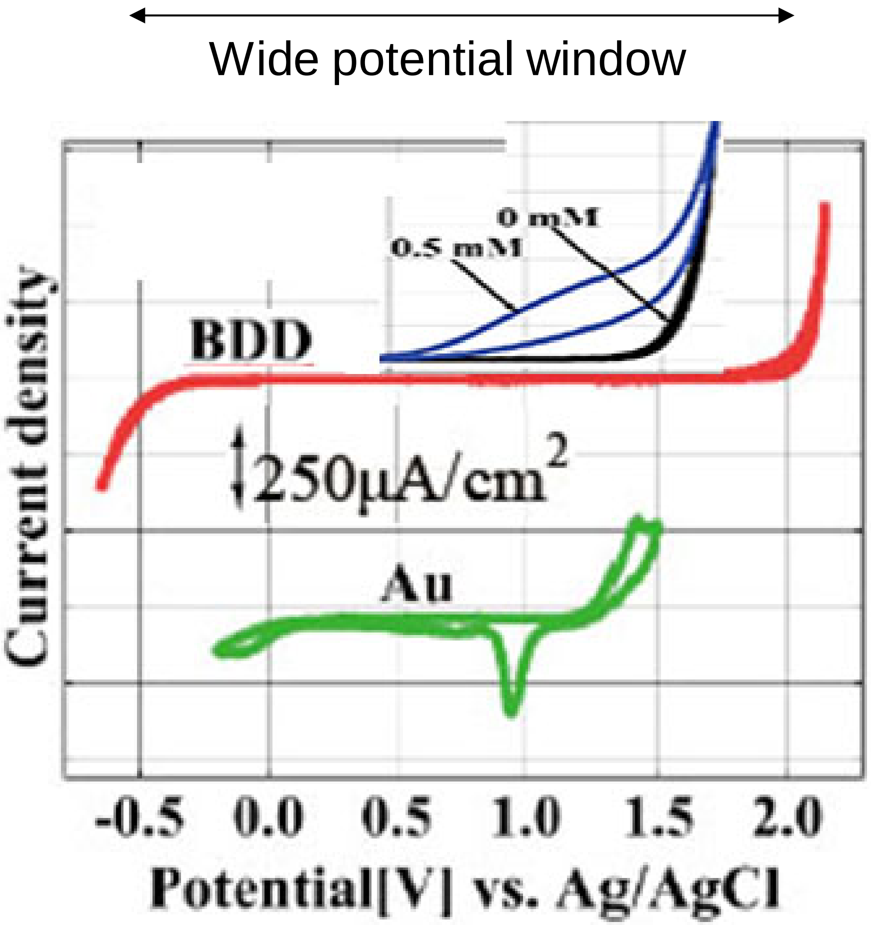


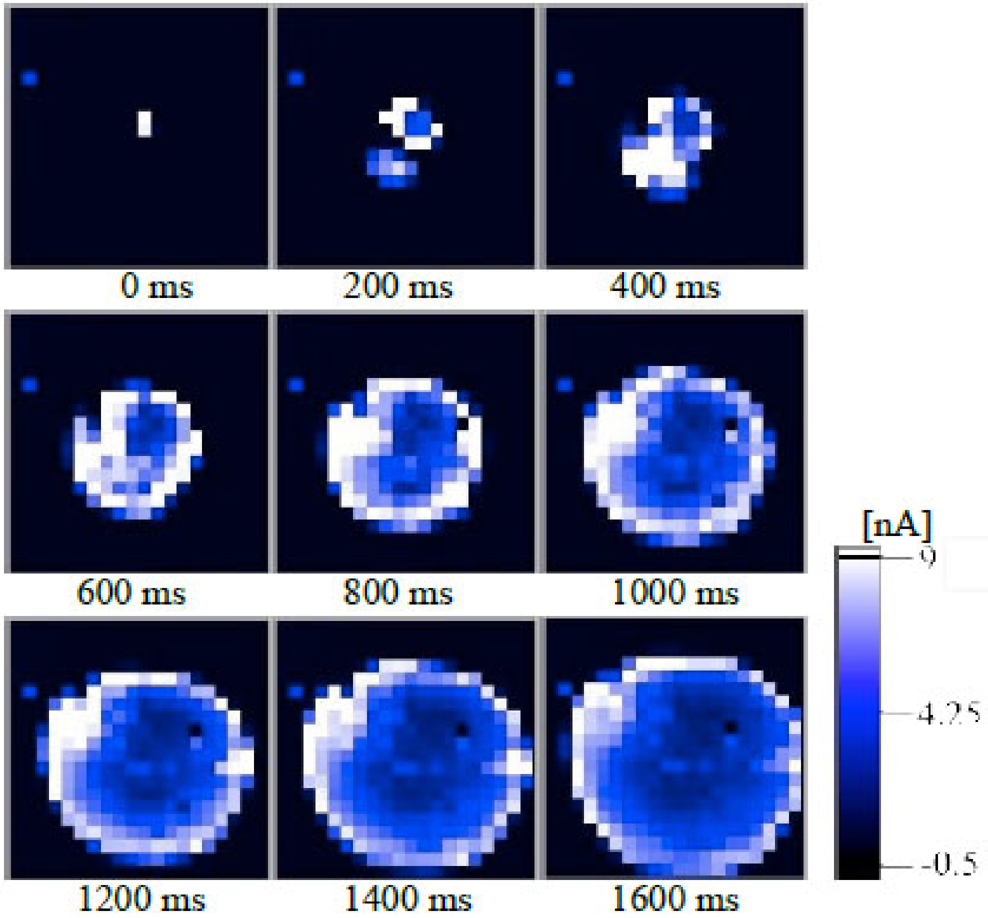


# Conductive boron doped diamond (BDD) electrode array (20 × 20) on LSI for amperometric biosensor

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



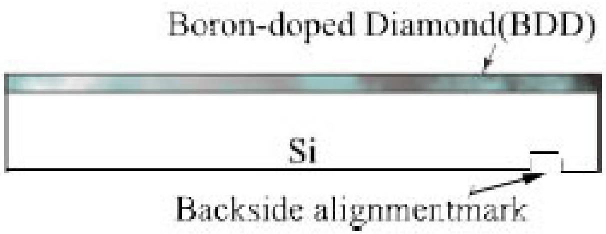
Typical cyclic voltammogram of 0.5 M $H_2SO_4$, 0 and 0.5 mM dopamine in phosphate buffer saline



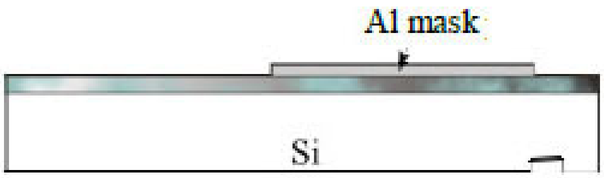
2D imaging of dopamine diffusion dissolved in the PBS near the center position of the BDD electrode array. Color maps correspond to the redox current intensities of 400 electrodes at 1.2 V.

# Fabrication process

1. Nucleation and plasma CVD of BDD at 800℃



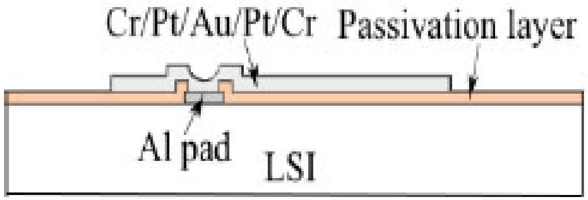
2, Al mask patterning.



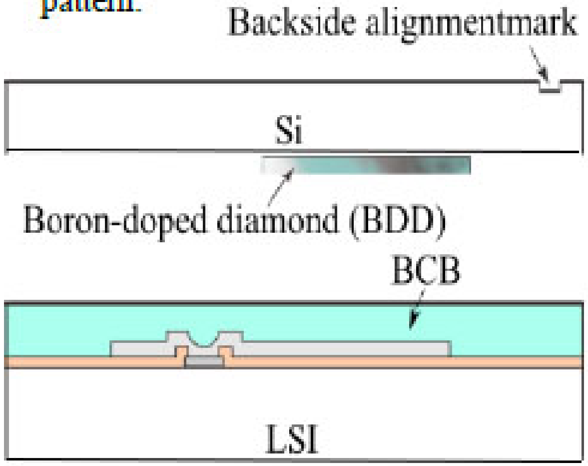
3. BDD patterning by dry etching in oxygen plasma

**Diamond formation on a carrier wafer**

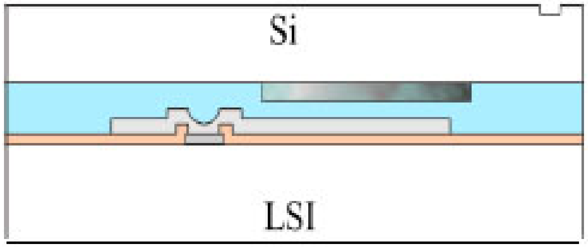
1. Cr/Pt/Au/Pt/Cr patterning



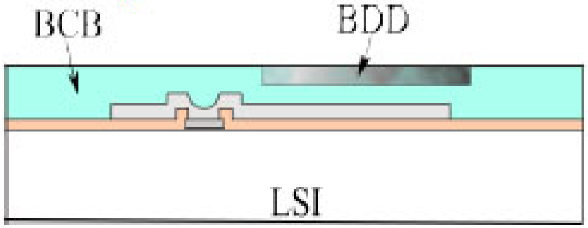
2. BCB coating and alignment of BDD electrode with the metal pattern.



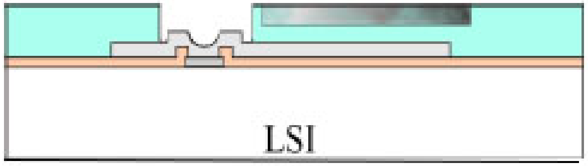
3. Bonding of LSI and Si substrate.



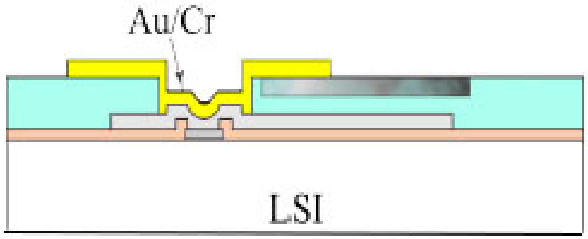
4. Remove Si substrate by dry etching.



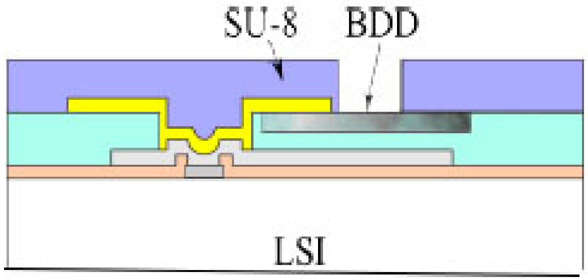
5. BCB patterning by dry etching.



6. Au/Cr patterning



7. SU-8 patterning.



8. Mount LSI onto ceramic substrate

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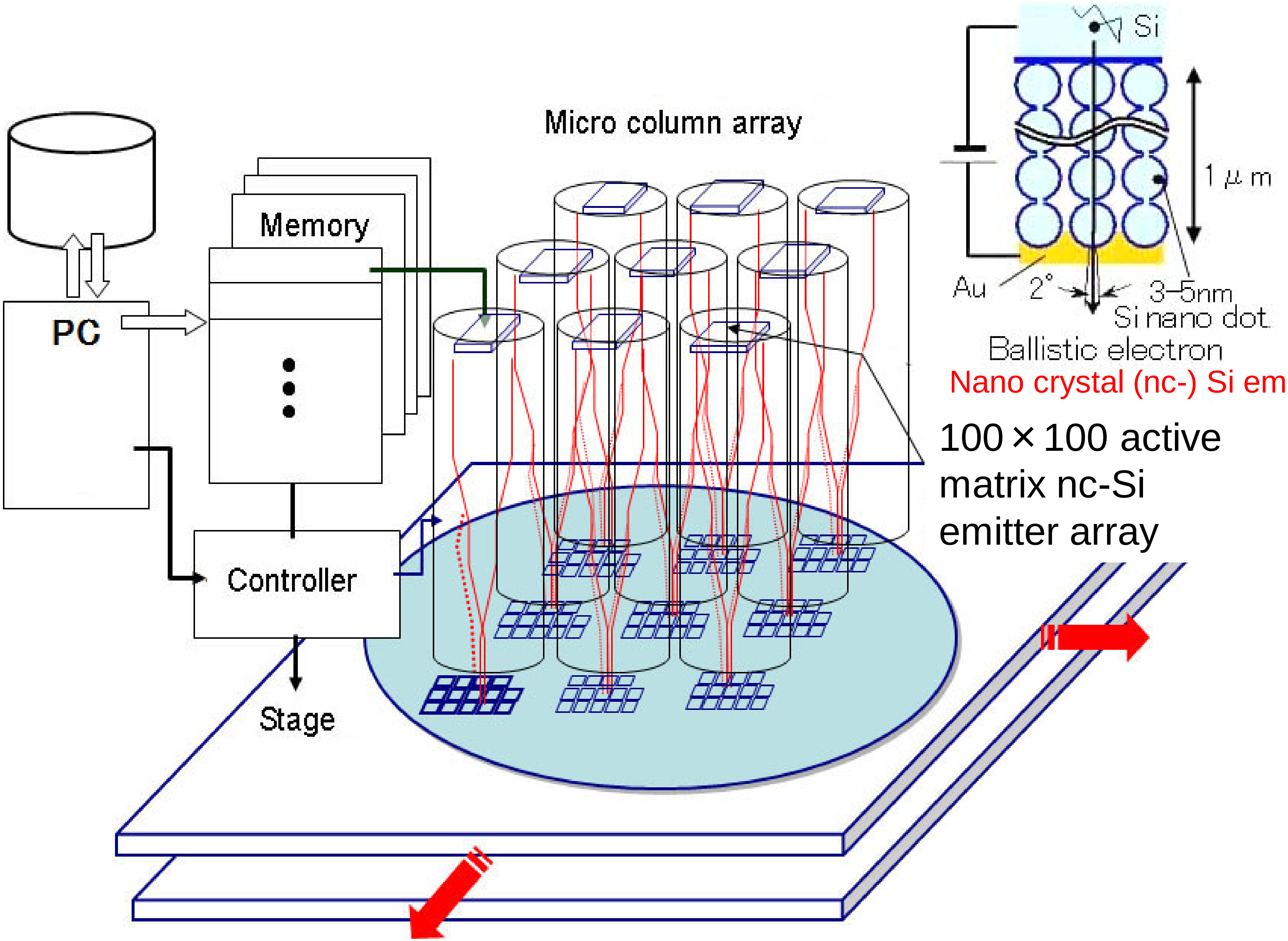
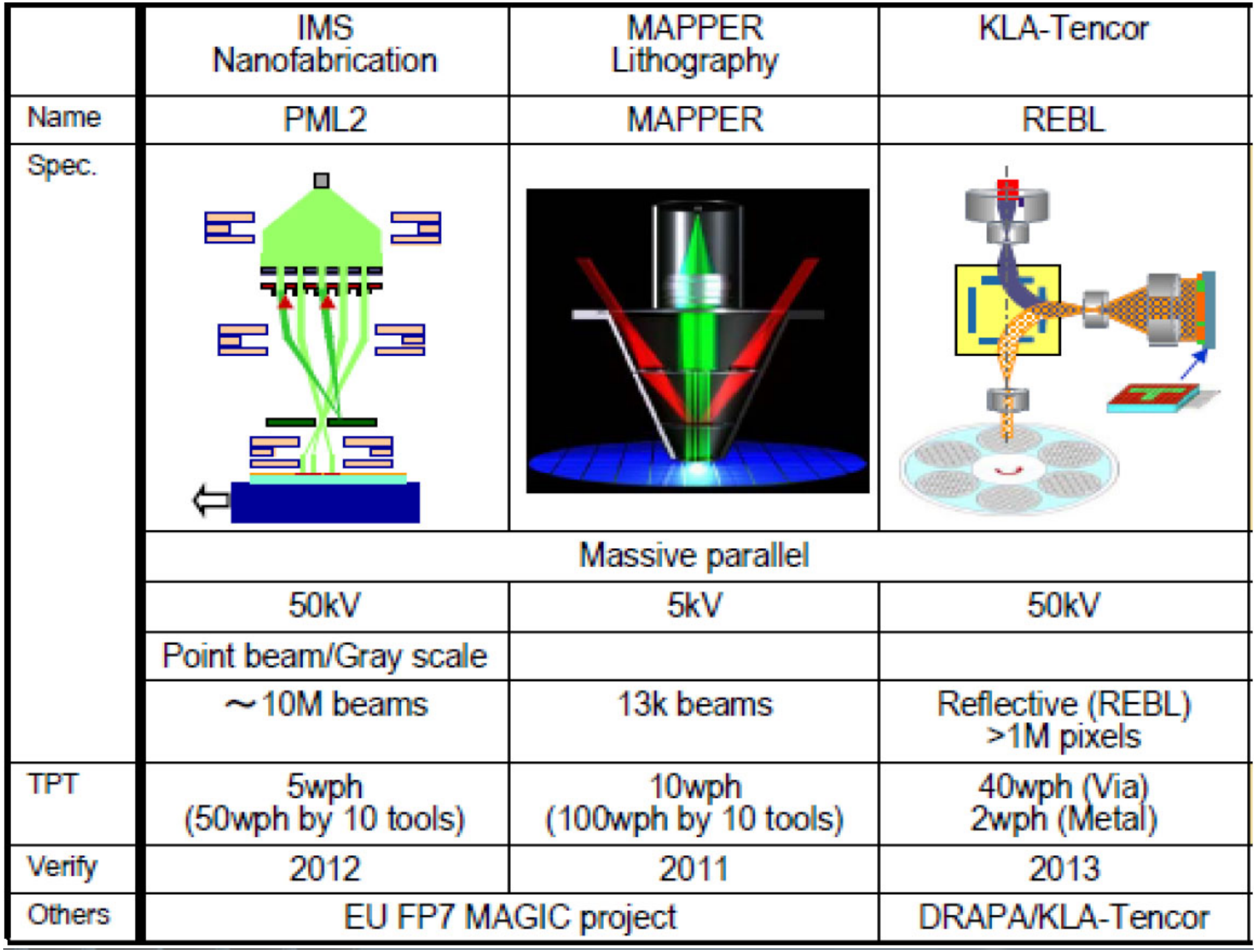
4. Massive Parallel EB Exposure System(Digital fabrication of LSI)
5. Open collaboration



Nano crystal (nc-) Si emitter

100 × 100 active matrix nc-Si emitter array

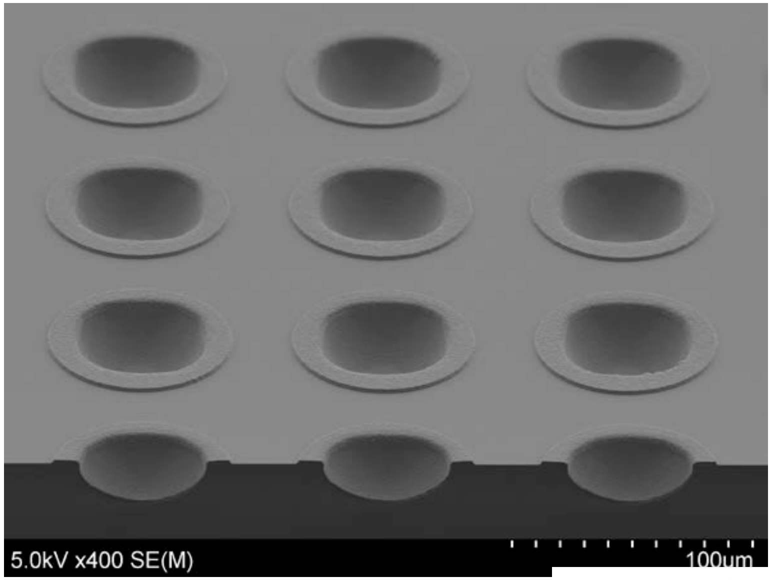
Concept of massive parallel electron beam exposure system using nc-Si emitter

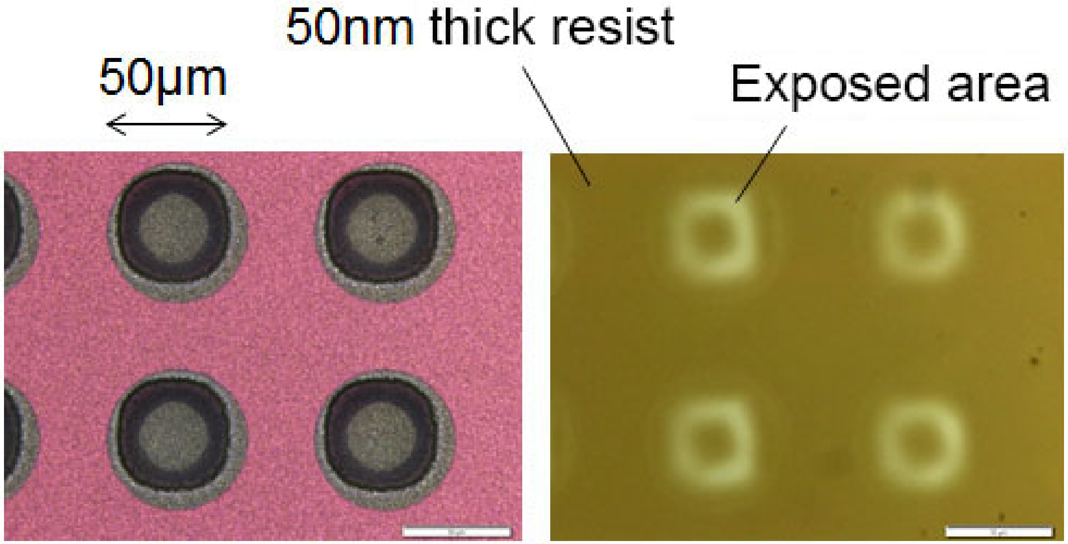


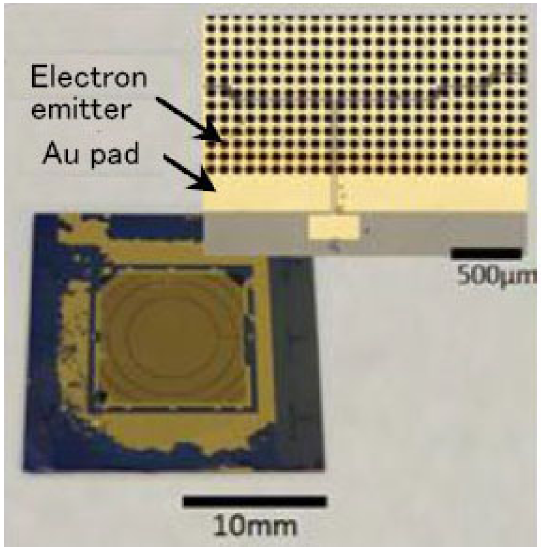
| | IMS Nanofabrication | MAPPER Lithography | KLA-Tencor |
|---|---|---|---|
| Name | PML2 | MAPPER | REBL |
| Spec. | | | |
| | Massive parallel | | |
| | 50kV | 5kV | 50kV |
| | Point beam/Gray scale | | |
| | ∼10M beams | 13k beams | Reflective (REBL)<br>>1M pixels |
| TPT | 5wph<br>(50wph by 10 tools) | 10wph<br>(100wph by 10 tools) | 40wph (Via)<br>2wph (Metal) |
| Verify | 2012 | 2011 | 2013 |
| Others | EU FP7 MAGIC project | | DRAPA/KLA-Tencor |

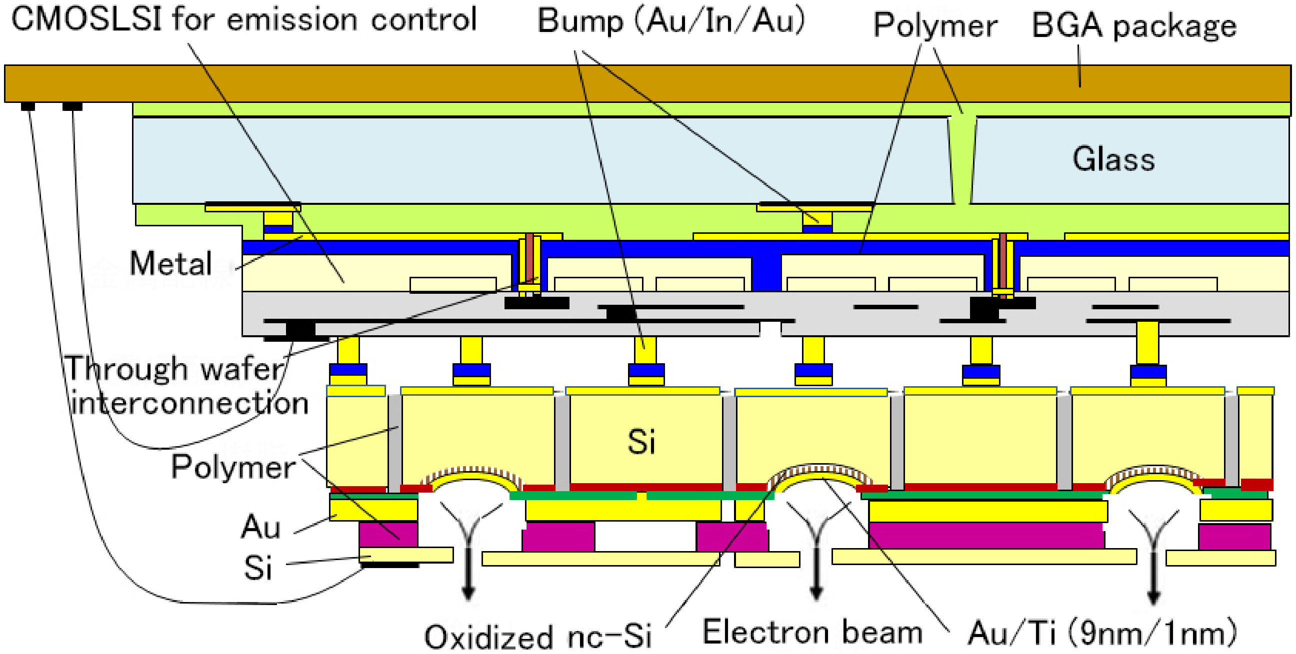
# Parallel EB exposure systems under development

(SEAJ2012 Road map p.25 http://www.seaj.or.jp/rdmp/2012roadmap/2012litho.pdf)



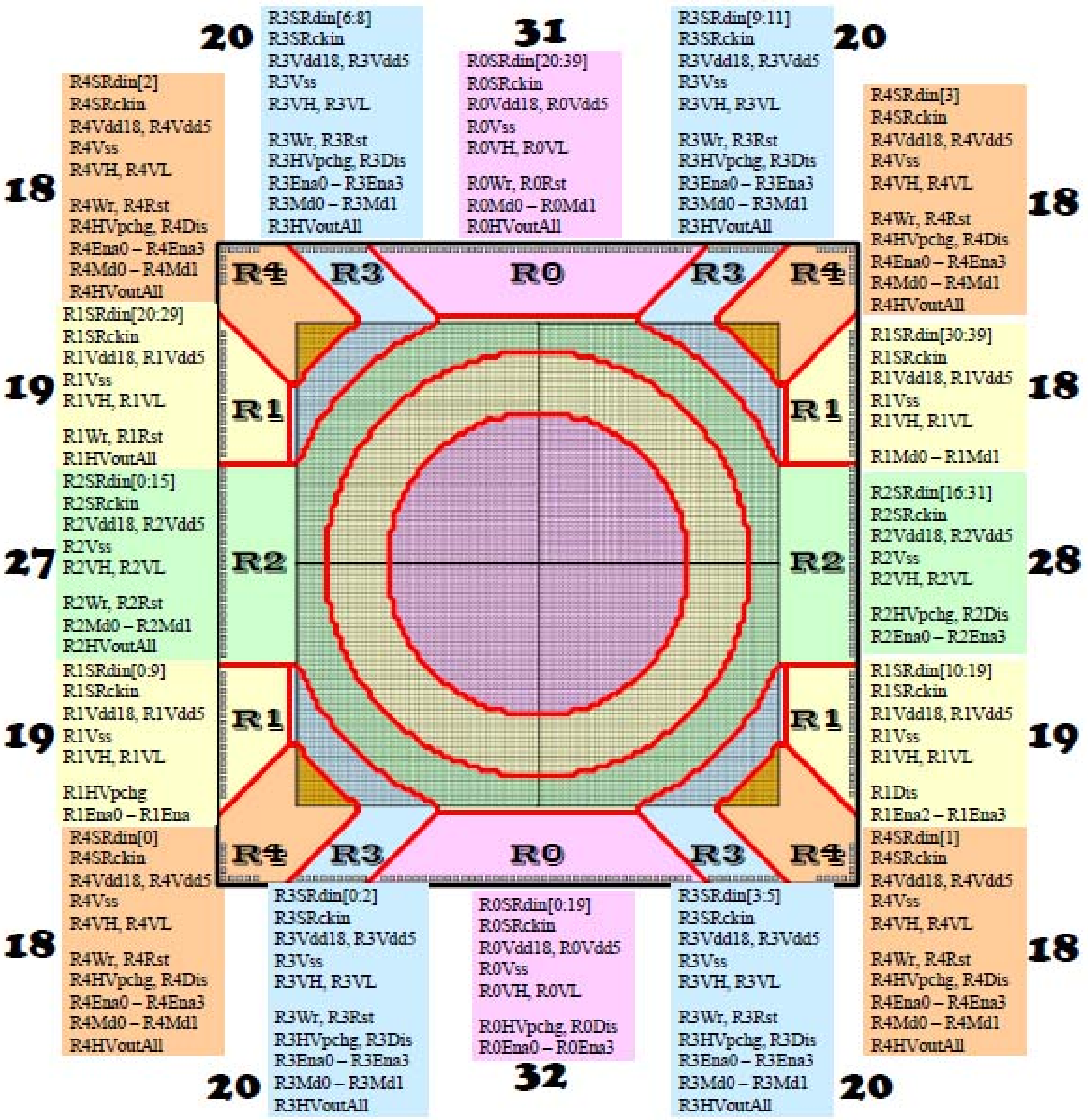






Structure of 100×100 active matrix nc-Si emitter

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



20

R3SRdin[6:8]
R3SRckin
R3Vdd18, R3Vdd5
R3Vss
R3VH, R3VL

R3Wr, R3Rst
R3HVpchg, R3Dis
R3Ena0 – R3Ena3
R3Md0 – R3Md1
R3HVoutAll

31

R0SRdin[20:39]
R0SRckin
R0Vdd18, R0Vdd5
R0Vss
R0VH, R0VL

R0Wr, R0Rst
R0Md0 – R0Md1
R0HVoutAll

R3SRdin[9:11]
R3SRckin
R3Vdd18, R3Vdd5
R3Vss
R3VH, R3VL

R3Wr, R3Rst
R3HVpchg, R3Dis
R3Ena0 – R3Ena3
R3Md0 – R3Md1
R3HVoutAll

20

18

R4SRdin[2]
R4SRckin
R4Vdd18, R4Vdd5
R4Vss
R4VH, R4VL

R4Wr, R4Rst
R4HVpchg, R4Dis
R4Ena0 – R4Ena3
R4Md0 – R4Md1
R4HVoutAll

19

R1SRdin[20:29]
R1SRckin
R1Vdd18, R1Vdd5
R1Vss
R1VH, R1VL

R1Wr, R1Rst
R1HVoutAll

27

R2SRdin[0:15]
R2SRckin
R2Vdd18, R2Vdd5
R2Vss
R2VH, R2VL

R2Wr, R2Rst
R2Md0 – R2Md1
R2HVoutAll

19

R1SRdin[0:9]
R1SRckin
R1Vdd18, R1Vdd5
R1Vss
R1VH, R1VL

R1HVpchg
R1Ena0 – R1Ena

18

R4SRdin[0]
R4SRckin
R4Vdd18, R4Vdd5
R4Vss
R4VH, R4VL

R4Wr, R4Rst
R4HVpchg, R4Dis
R4Ena0 – R4Ena3
R4Md0 – R4Md1
R4HVoutAll

R4SRdin[3]
R4SRckin
R4Vdd18, R4Vdd5
R4Vss
R4VH, R4VL

R4Wr, R4Rst
R4HVpchg, R4Dis
R4Ena0 – R4Ena3
R4Md0 – R4Md1
R4HVoutAll

18

R1SRdin[30:39]
R1SRckin
R1Vdd18, R1Vdd5
R1Vss
R1VH, R1VL

R1Md0 – R1Md1

18

R2SRdin[16:31]
R2SRckin
R2Vdd18, R2Vdd5
R2Vss
R2VH, R2VL

R2HVpchg, R2Dis
R2Ena0 – R2Ena3

28

R1SRdin[10:19]
R1SRckin
R1Vdd18, R1Vdd5
R1Vss
R1VH, R1VL

R1Dis
R1Ena2 – R1Ena3

19

R4SRdin[1]
R4SRckin
R4Vdd18, R4Vdd5
R4Vss
R4VH, R4VL

R4Wr, R4Rst
R4HVpchg, R4Dis
R4Ena0 – R4Ena3
R4Md0 – R4Md1
R4HVoutAll

18

R3SRdin[0:2]
R3SRckin
R3Vdd18, R3Vdd5
R3Vss
R3VH, R3VL

R3Wr, R3Rst
R3HVpchg, R3Dis
R3Ena0 – R3Ena3
R3Md0 – R3Md1
R3HVoutAll

20

R0SRdin[0:19]
R0SRckin
R0Vdd18, R0Vdd5
R0Vss
R0VH, R0VL

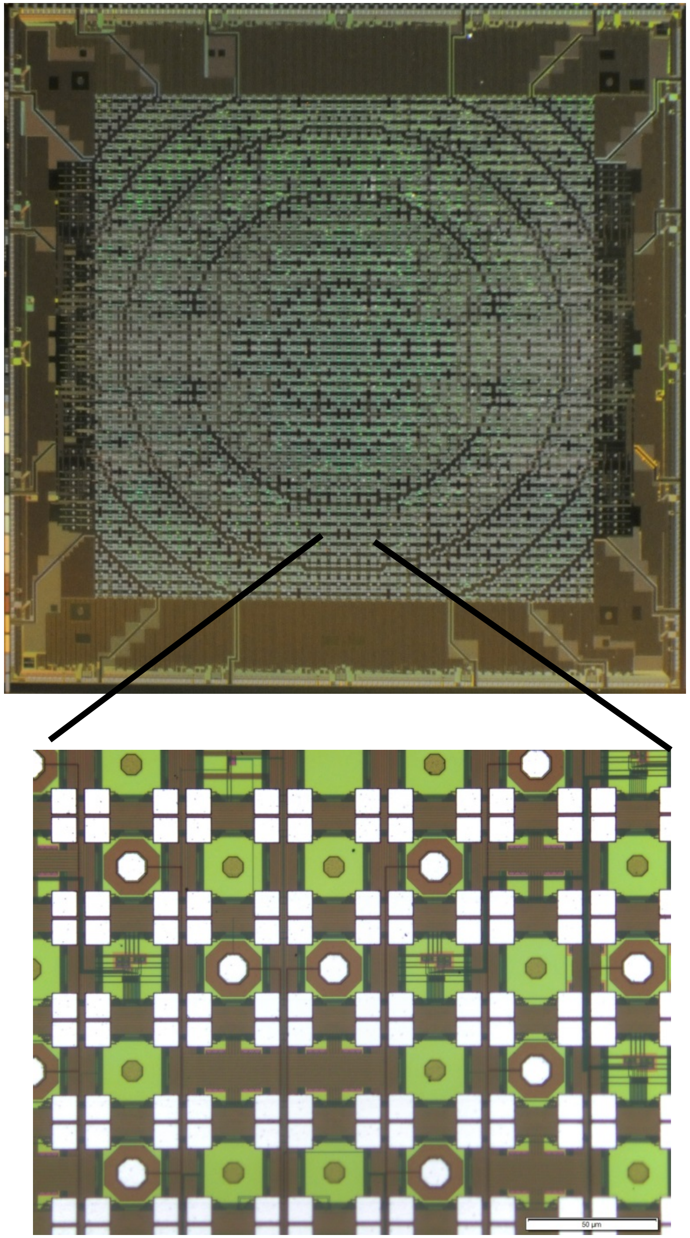
R0HVpchg, R0Dis
R0Ena0 – R0Ena3

32

R3SRdin[3:5]
R3SRckin
R3Vdd18, R3Vdd5
R3Vss
R3VH, R3VL

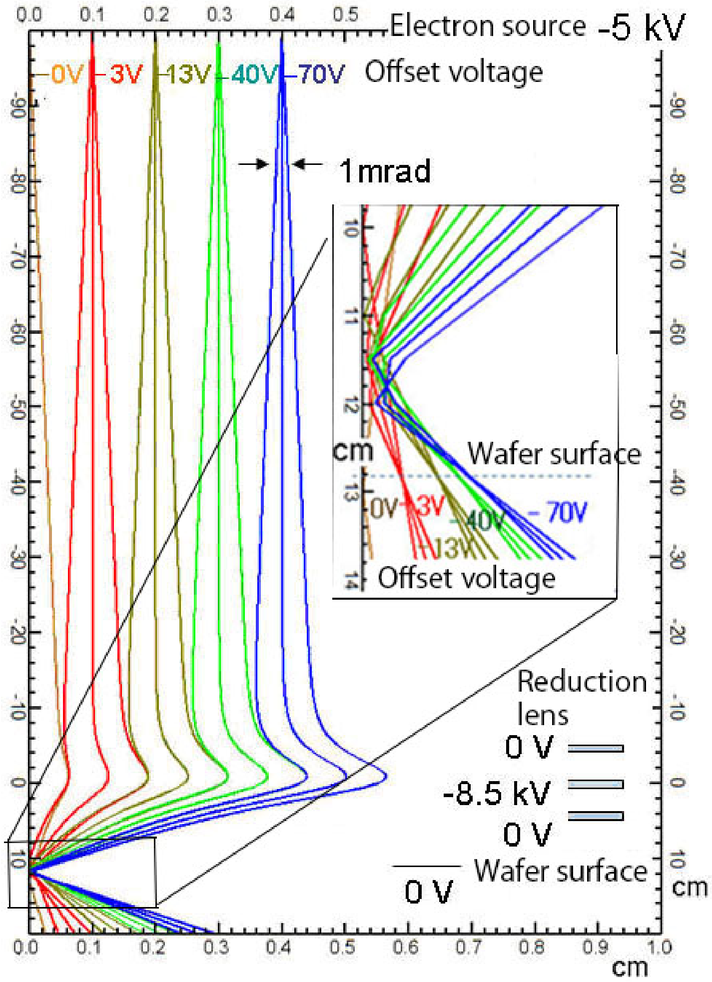
R3Wr, R3Rst
R3HVpchg, R3Dis
R3Ena0 – R3Ena3
R3Md0 – R3Md1
R3HVoutAll

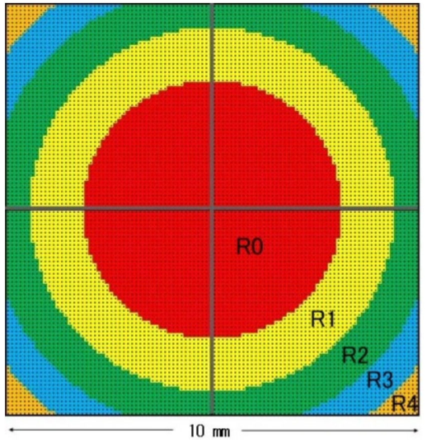
20



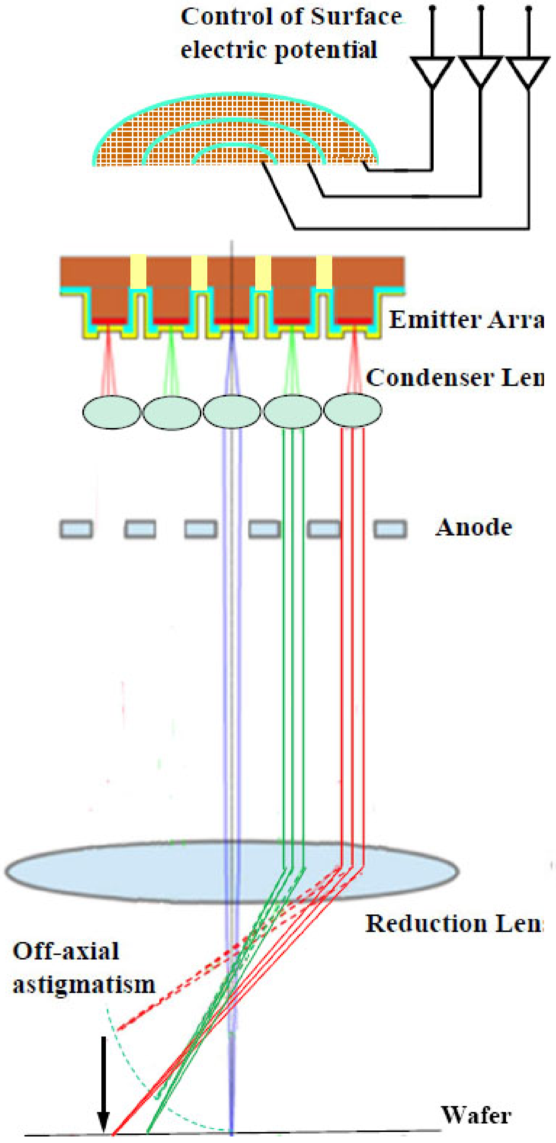
100 × 100 active matrix electron source LSI and pad layout in 430 pin package

# Electronic aberration compensation

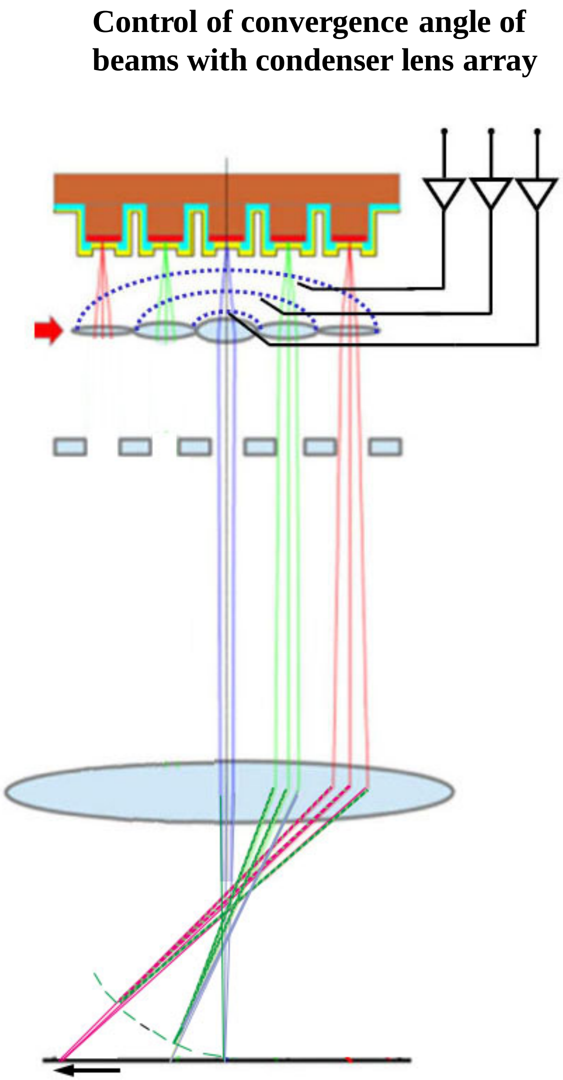




100×100 emitter array divided into concentric circles

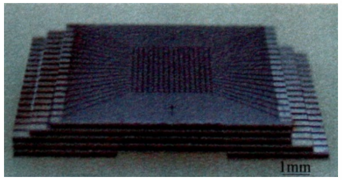


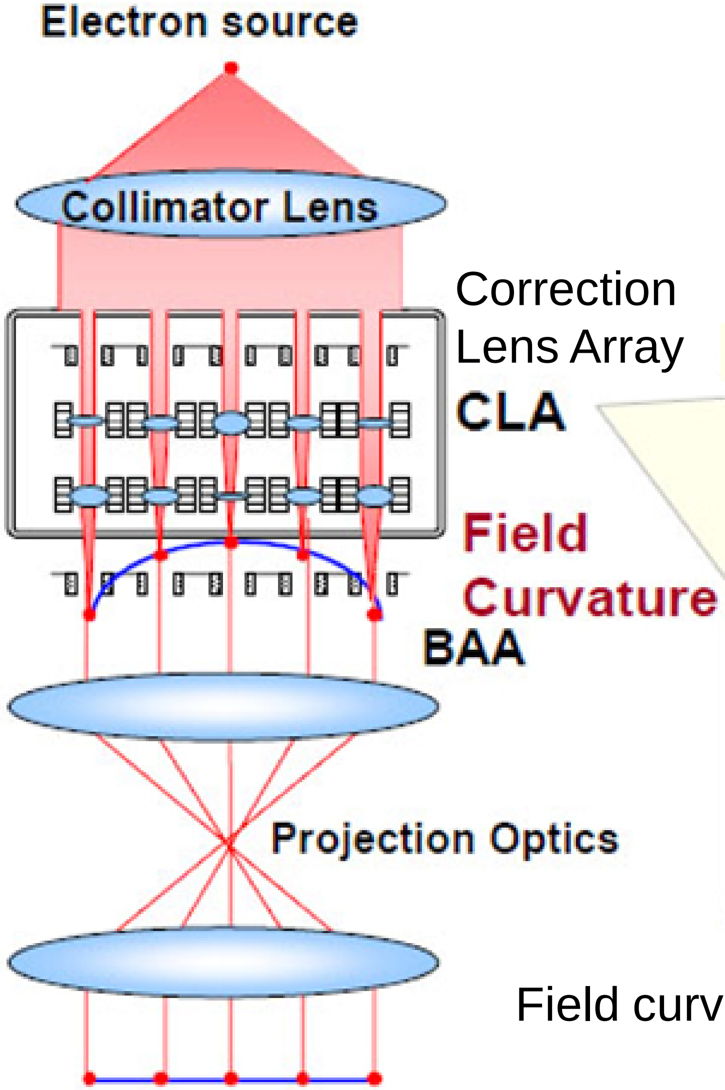
Field curvature correction
像面湾曲補正



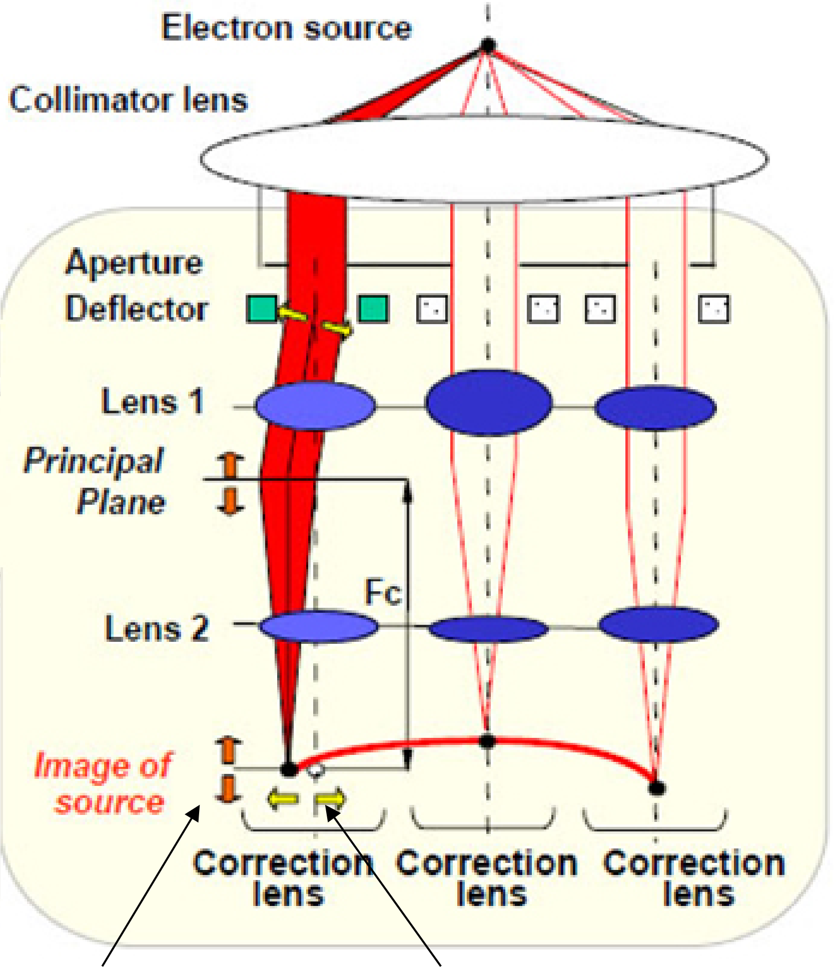
Distortion correction
歪曲収差補正

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



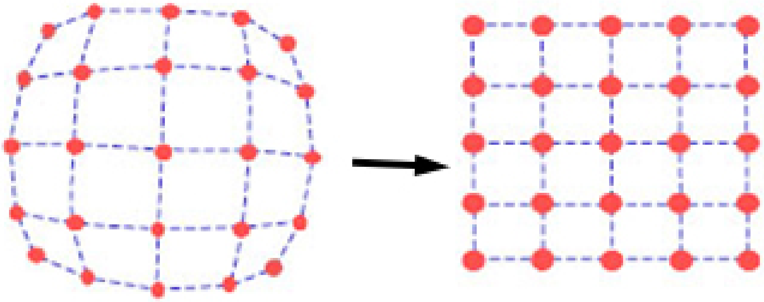


Correction
Lens Array



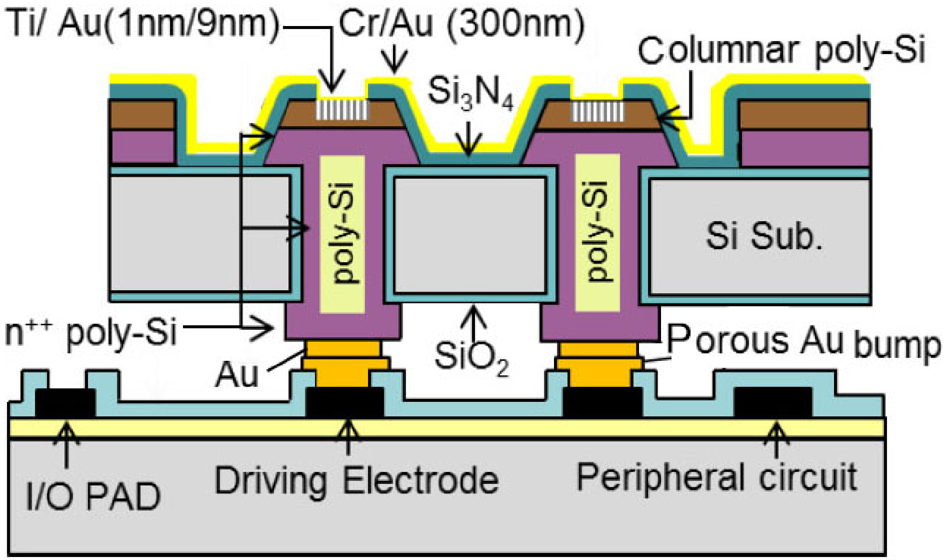
Field curvature correction

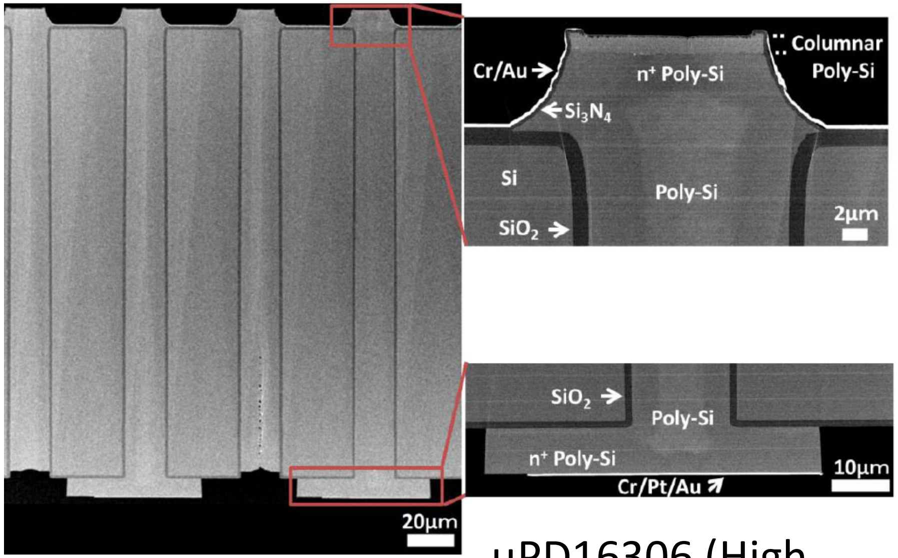
Distortion correction



# CANON ML2

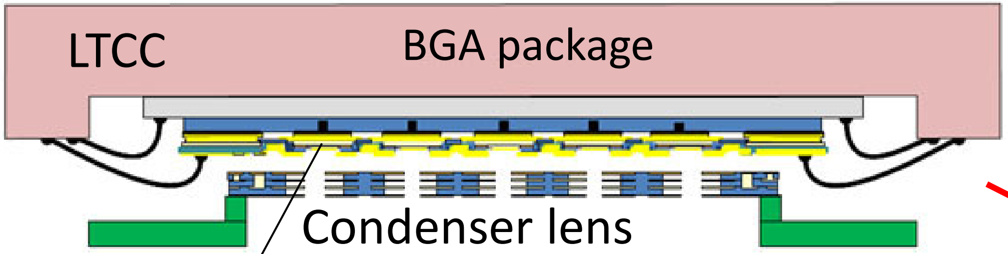
(M.Muraki, S.Gotoh (Canon), J.Vac.Sci.Tech., B18 (6) (2000) 3061)



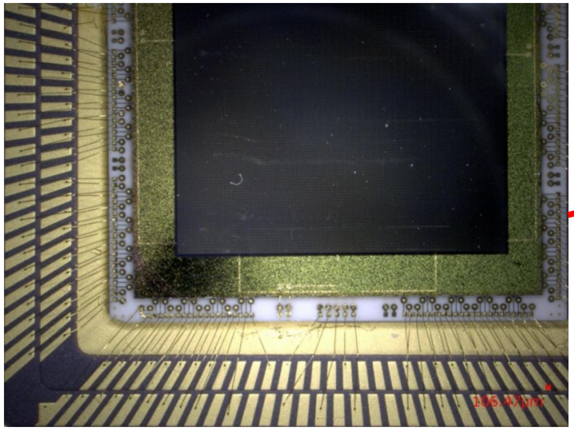


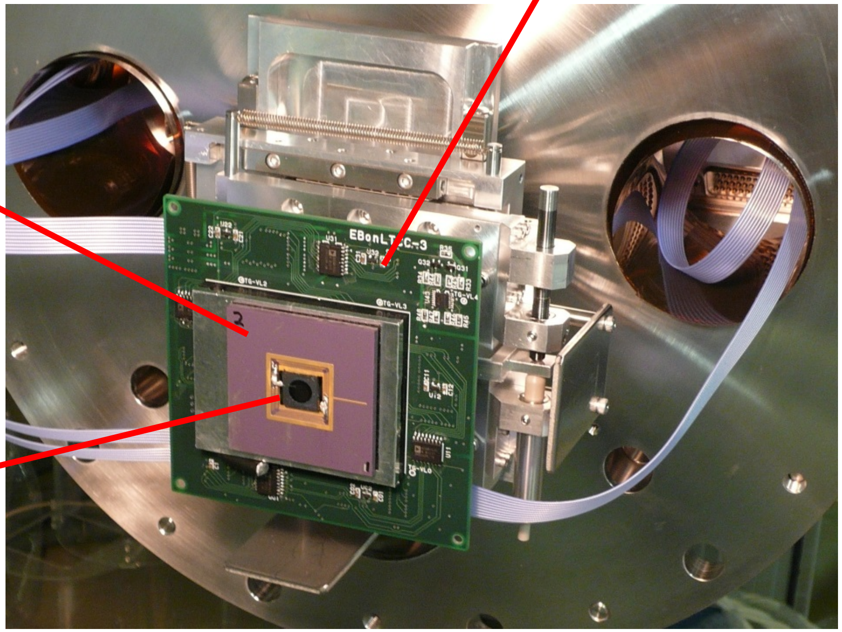
Planer nc-Si electron source with through Si via (TSV)

µPD16306 (High voltage CMOS driver)

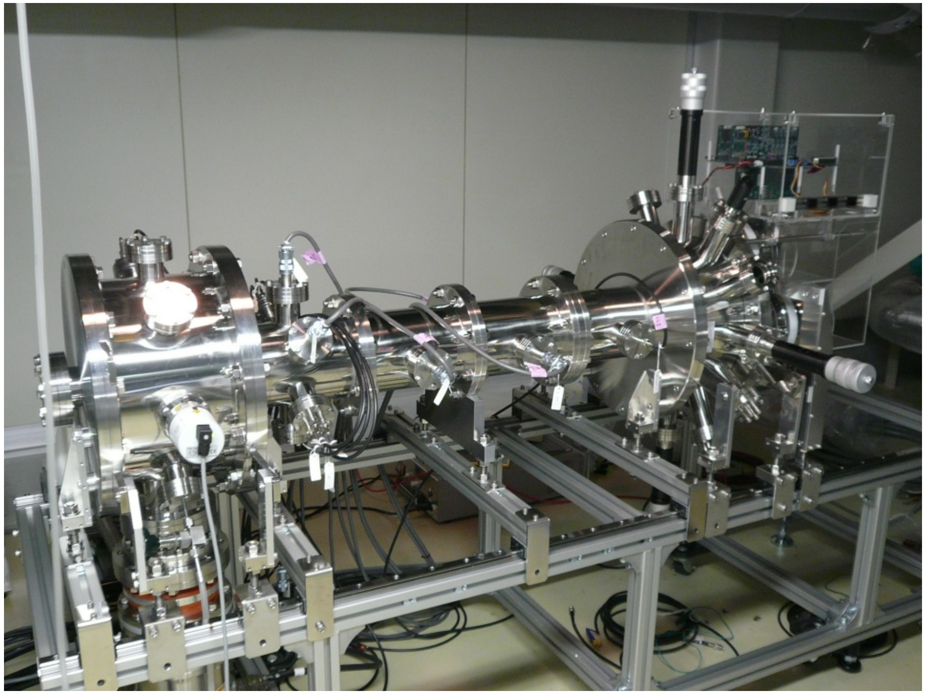


Planer nc-Si electron source chip with TSV

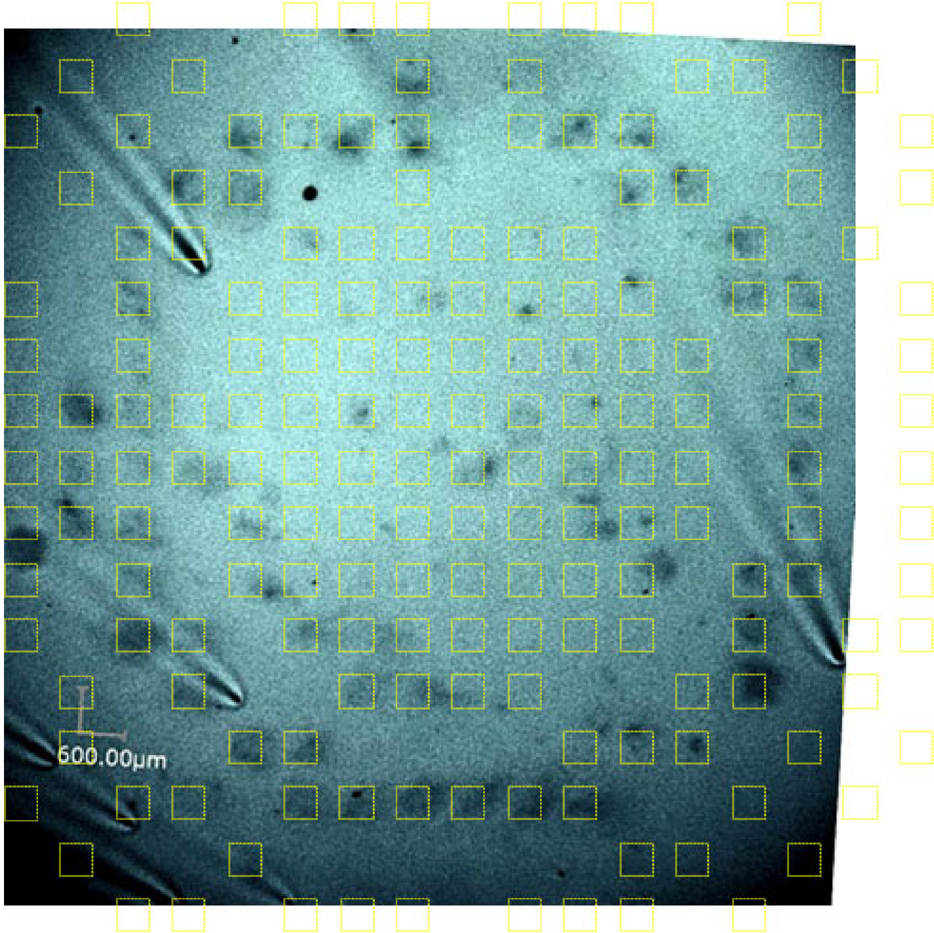




# 15 × 15 electron source using planer nc-Si emitter and commercial LSI



Experimental setup for 1/100 and 1/1 exposure test.



Exposed patter on a resist using 1:1 projection system with 15 × 15 planer type nc-Si 27electron source (Electron source pattern is superimposed in the right photograph)

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

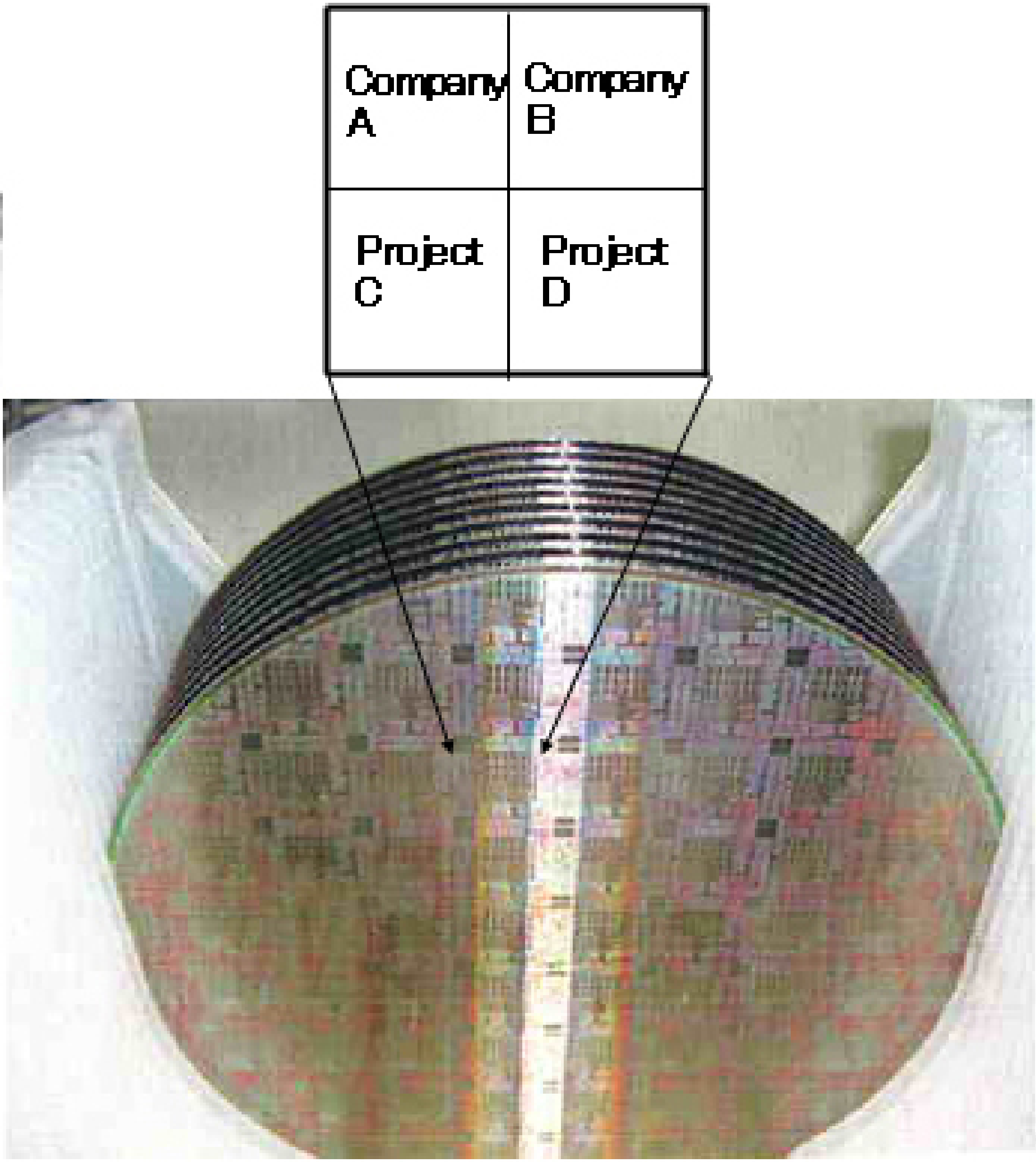
1. Wafer level packaging and hetero-Integration by Selective Bonding

2. Multiband system for cognitive wireless communication

3. Diamond electrode array on LSI for amperometric biosensor

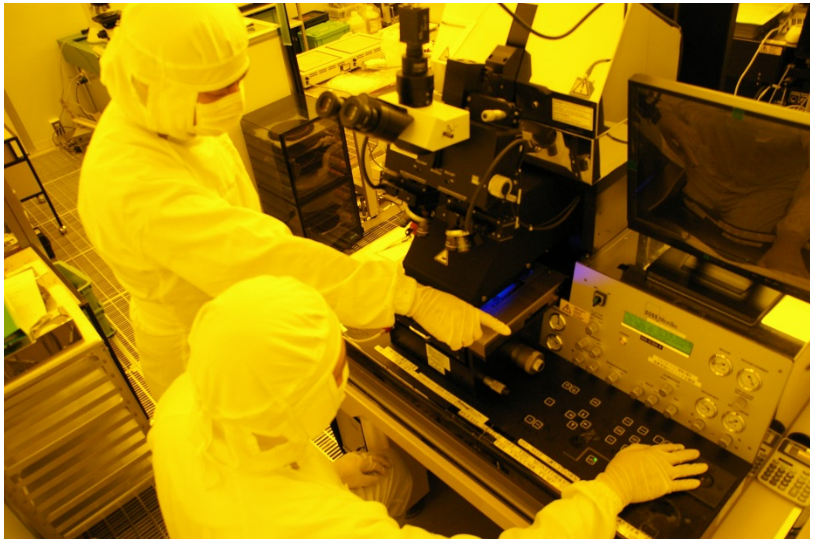
4. Massive Parallel EB Exposure System(Digital fabrication of LSI)

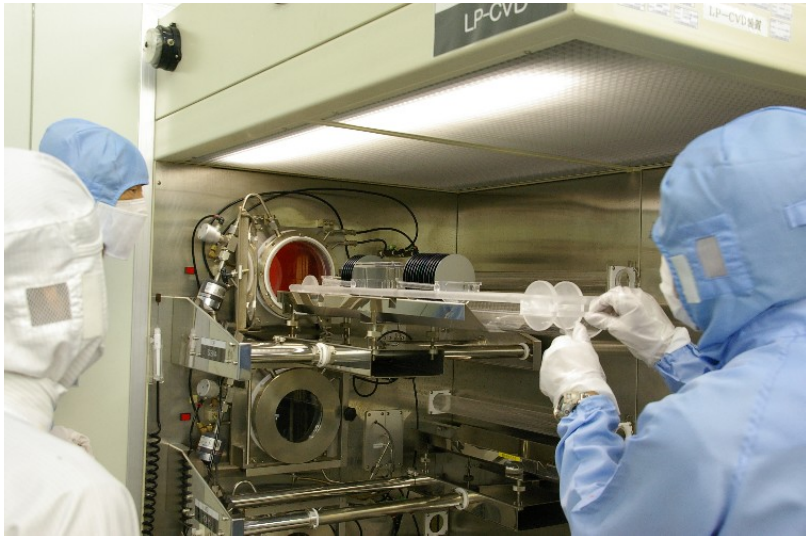
5. Open collaboration



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



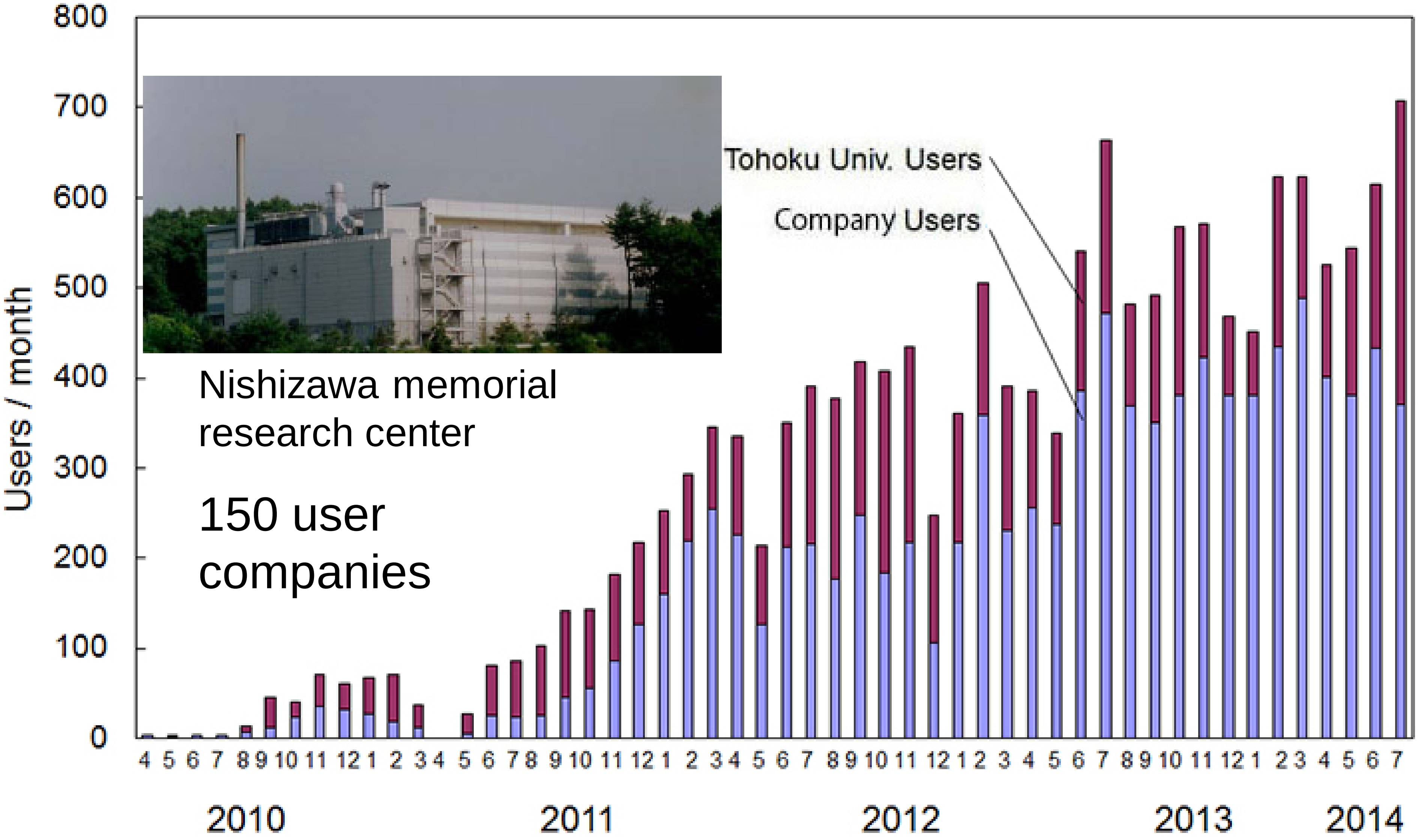


Companies which can not prepare their own facility dispatch their employees to operate equipments by themselves for development and small volume production.

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

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

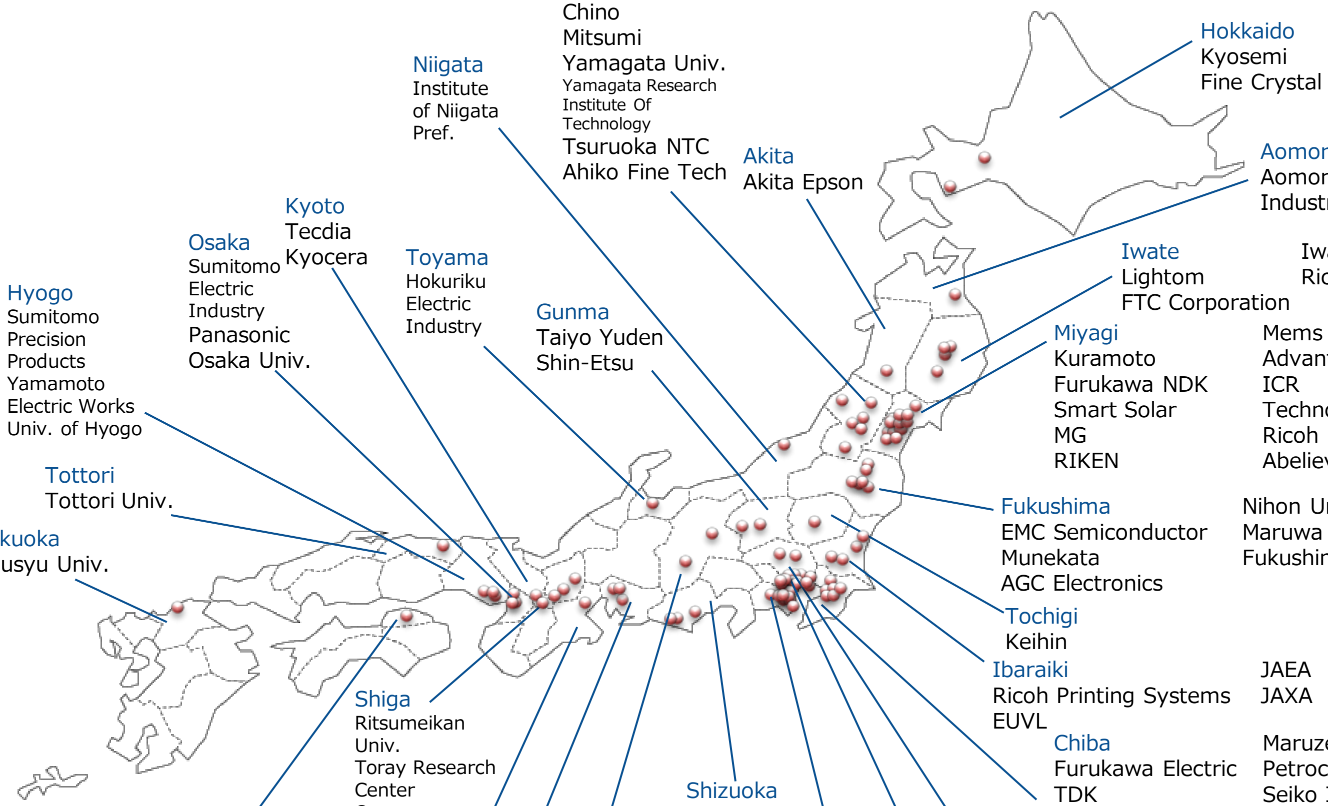
Contact person : Assoc. Prof. Kentaro Totsu [totsu@mems.mech.tohoku.ac.jp](mailto:totsu@mems.mech.tohoku.ac.jp)



Nishizawa memorial research center

150 user companies

# Users of the Hands-on-access fab.



**Hyogo**
Sumitomo Precision Products
Yamamoto Electric Works
Univ. of Hyogo

**Osaka**
Sumitomo Electric Industry
Panasonic
Osaka Univ.

**Kyoto**
Tecdia
Kyocera

**Toyama**
Hokuriku Electric Industry

**Niigata**
Institute of Niigata Pref.

**Yamagata**
Chino
Mitsumi
Yamagata Univ.
Yamagata Research Institute Of Technology
Tsuruoka NTC
Ahiko Fine Tech

**Gunma**
Taiyo Yuden
Shin-Etsu

**Akita**
Akita Epson

**Hokkaido**
Kyosemi
Fine Crystal

**Aomori**
Aomori Pref. Industrial Technology Research Center

**Iwate**
Lightom
FTC Corporation
Iwate Univ.
Ricoh Optical

**Miyagi**
Kuramoto
Furukawa NDK
Smart Solar
MG
RIKEN
Mems Core
Advantest
ICR
Technofine
Ricoh
Abelieve
Nakatani Sangyo
Pacal Technologies Japan
Mitsumaru
Photonic Lattice
Dexerials
Tohoku Univ.

**Tottori**
Tottori Univ.

**Fukuoka**
Kyusyu Univ.

**Fukushima**
EMC Semiconductor
Munekata
AGC Electronics
Nihon Univ.
Maruwa Quartz
Fukushima Sanken

**Tochigi**
Keihin

**Ibaraiki**
Ricoh Printing Systems
EUVL
JAEA
JAXA

**Shiga**
Ritsumeikan Univ.
Toray Research Center
Omron

**Chiba**
Furukawa Electric
TDK
Youtec
Maruzen Petrochemical
Seiko Instruments

**Shizuoka**
Hamamatsu Photonics
AZ Electronic Materials
Shizuoka Univ.

**Kagawa**
Aoi Electronics

**Mie**
Toho Engineering

**Nagano**
Seiko Epson
Nagano Keiki

**Saitama**
Nippon Signal
Wacom

**Tokyo**
Takion
Infinity Storage Media
BN Technology
Yuka Industries
MD Innovations
Namiki Precision Jewel
Univ. of Tokyo
BEANS Laboratory
Rion
ASET
Yokogawa Electric
Nanox Japan
Oji Holdings
Konica Minolta
Adamant

**Aichi**
NGK
Nagoya Institute of Technology
CKD

**Kanagawa**
NTT-AT
Tokyo Polytechnic Univ.
JVC Kenwood
Suss Micro Tech
M.T.C
NLT Technologies
Kyodo International
NICT
Toshiba
Keio Univ.
Fujitsu Laboratories

## Overseas

**Korea**
Samsung

**Singapore**
Institute of Microelectronics (IME)

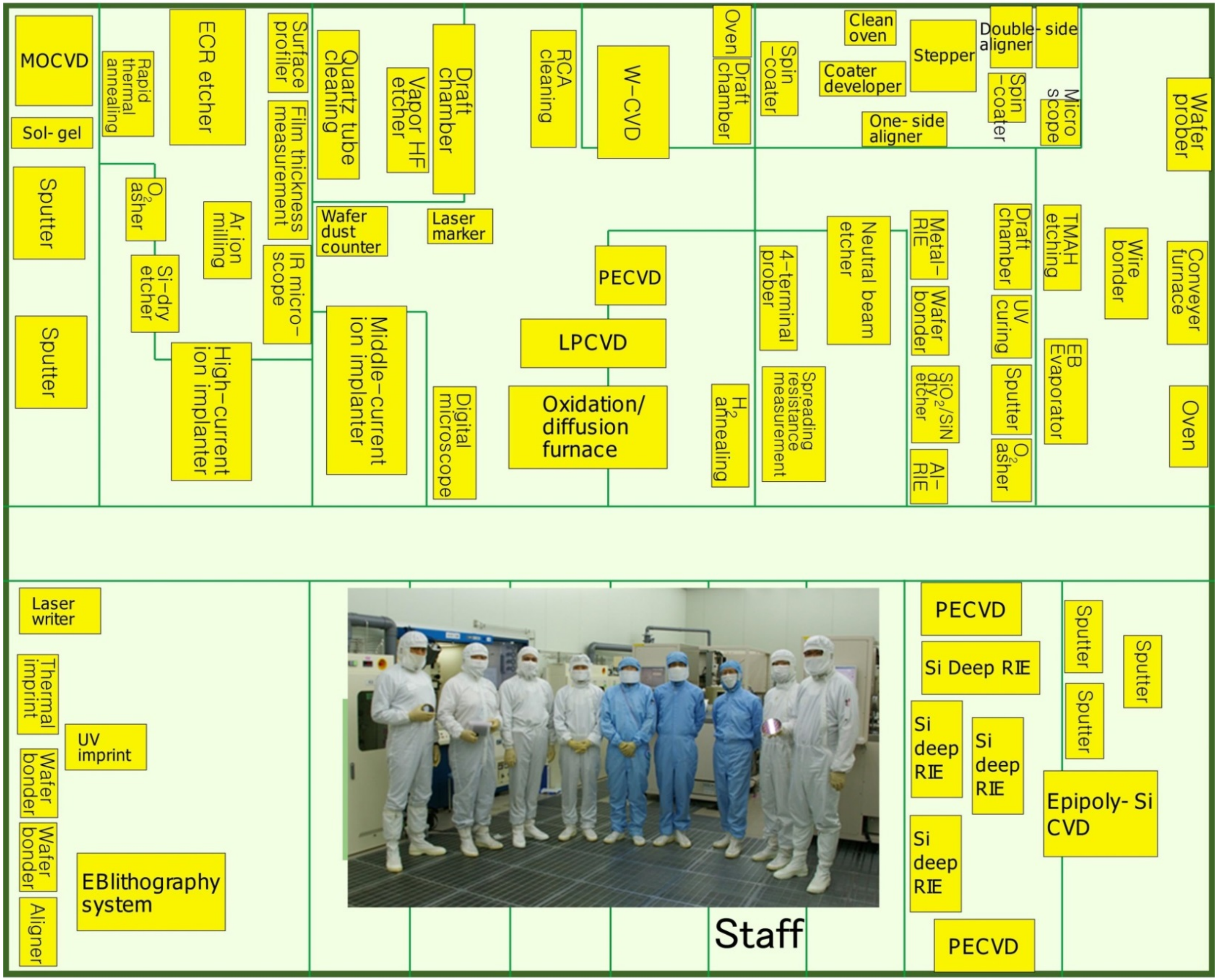
# Hands-on-access fab. users (~150 companies)

## Equipment were moved from Tr. Factory or donated

Companies are allowed to sell MEMS devices produced in the “Hands-on-access fab.” (2013/7 ~)

平成二十五年度
経済産業大臣賞
産学官連携功労者表彰記念
試作コインランドリ ～豊富な設備とノウハウを提供する
MEMS 開発オープンプラットフォーム～
東北大学マイクロシステム融合研究開発センター
准教授 戸津 健太郎 殿

Government award



(1800 $m^2$) Layout of Hands–on–access Fab.

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

MEMS core Co.Ltd.
(Contract development)

MEMS Park Consortium (MEMSPC)

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)
(8 inch production stage prototyping)

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

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

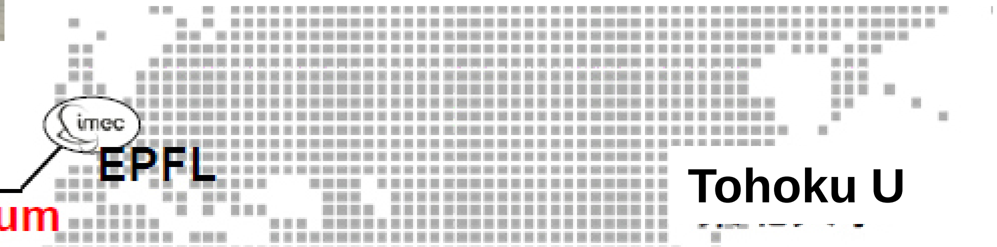
# Collaboration with FhG (Fraunhofer Institute) in Germany

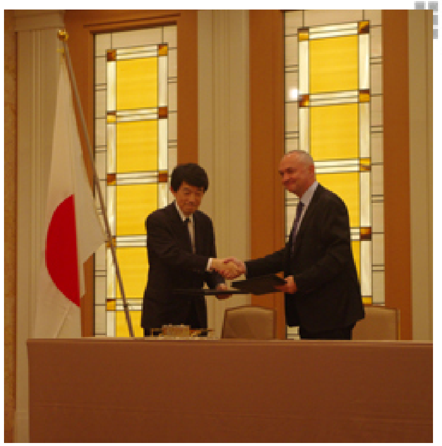
# IMEC-Tohoku Seminar in Belgium (2012/6/21)

(2014/11/12)
"your lab and imec are very complimentary"
Rudy Lauwereins, Vice-President of IMEC

## Strategic Partner

Tohoku U · Stanford U · EPFL



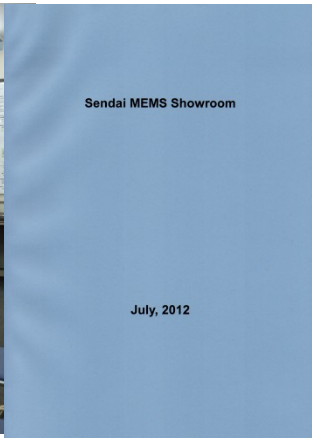


**Signing ceremony (2012/6/11)**

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

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

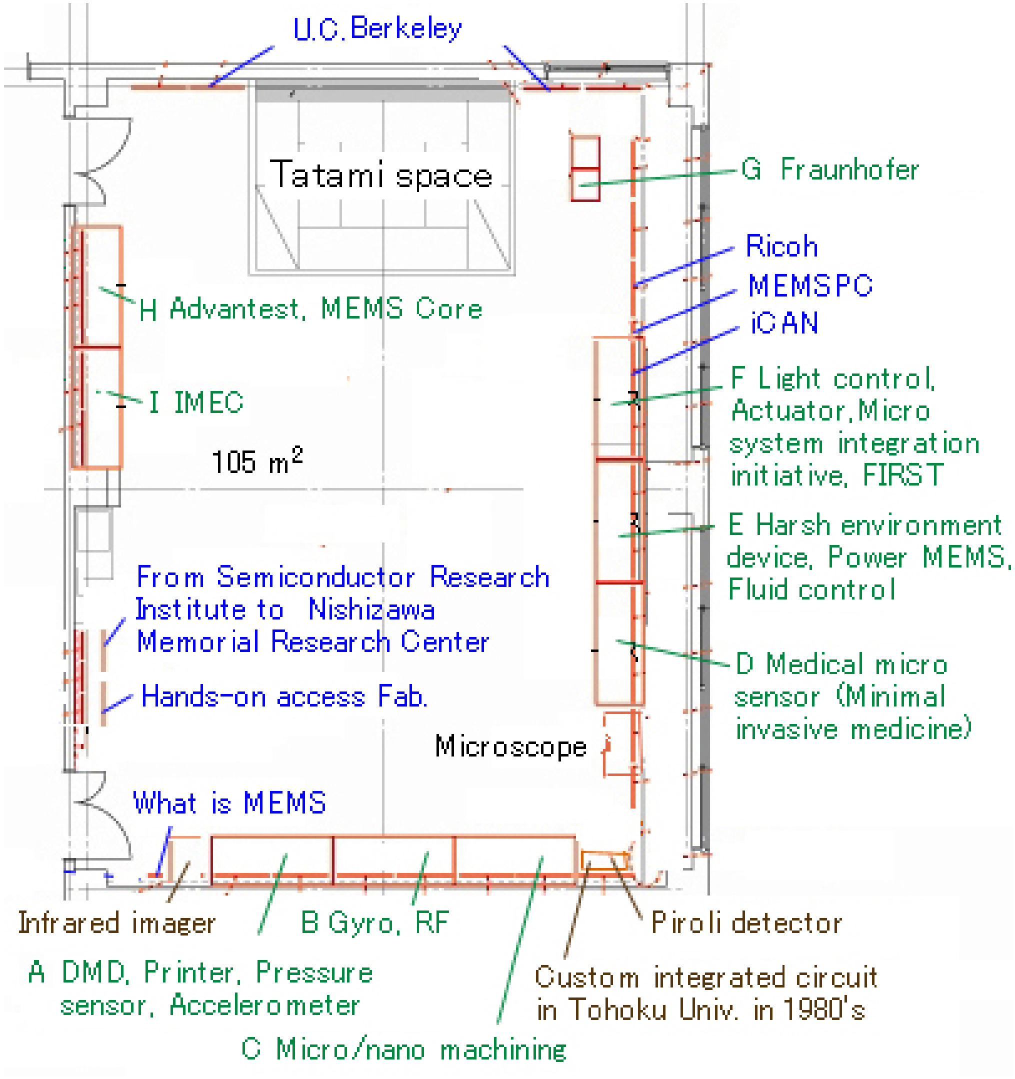
(IMEC M.Yoneyama
2012/6/12)



Sendai MEMS Showroom

July, 2012

Catalog



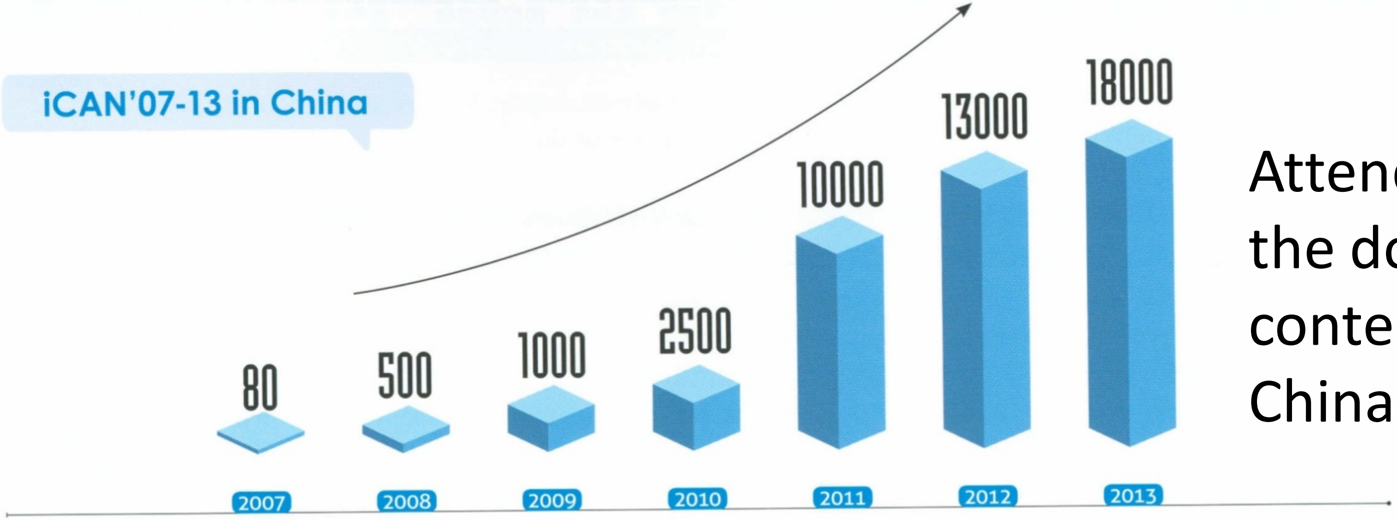
Efficient way to access accumulated knowledge is important for heterogeneous integration

# Sendai MEMS showroom

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

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

5th International Contest of Application in Nano / micro technologies (iCAN'14）July 20, 2014 in Sendai (for high school and university students) http://www.ican-contest.org/index.html



Attendee in the domestic contest in China

2007

2013

# Conclusions

## 1. Hetero-Integration by AdheSelective Transfer

Multiband system for cognitive wireless communication

Diamond electrode array on LSI for amperometric biosensor

Tactile Sensor Network

Massive Parallel EB Exposure System

## 2. Open collaboration for MEMS on LSI

Prof.
S.Tanaka
(RF MEMS)

Assoc. Prof.
K.Totsu
(Open collaboration)

Assos.Prof.
M.Muroyama
(LSI design)

Assis.Prof.
S.Yoshida
(Piezo electric)

Acknowledgment to collaborators