Process Technology to Fabricate High Performance MEMS on Top of Advanced LSI

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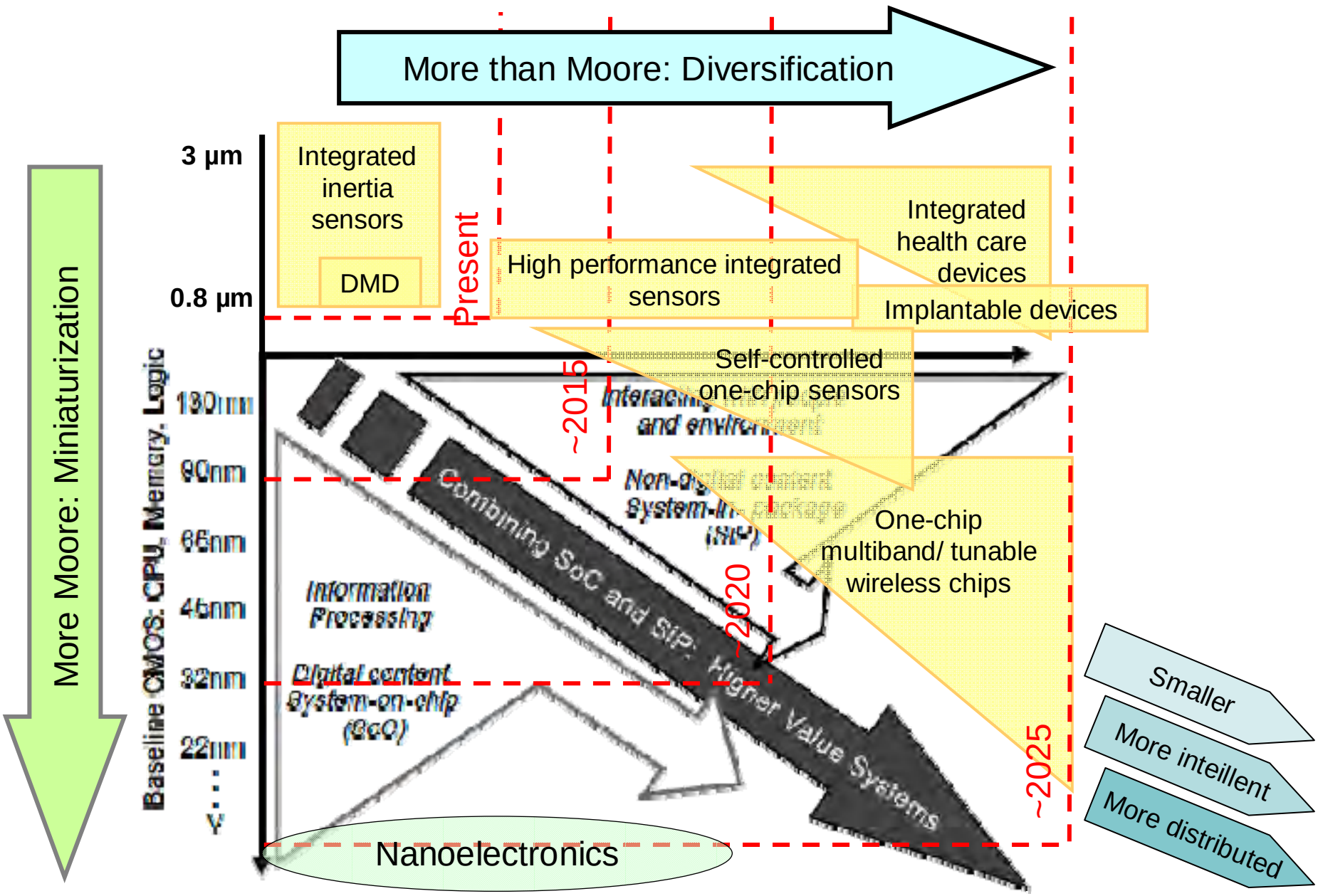
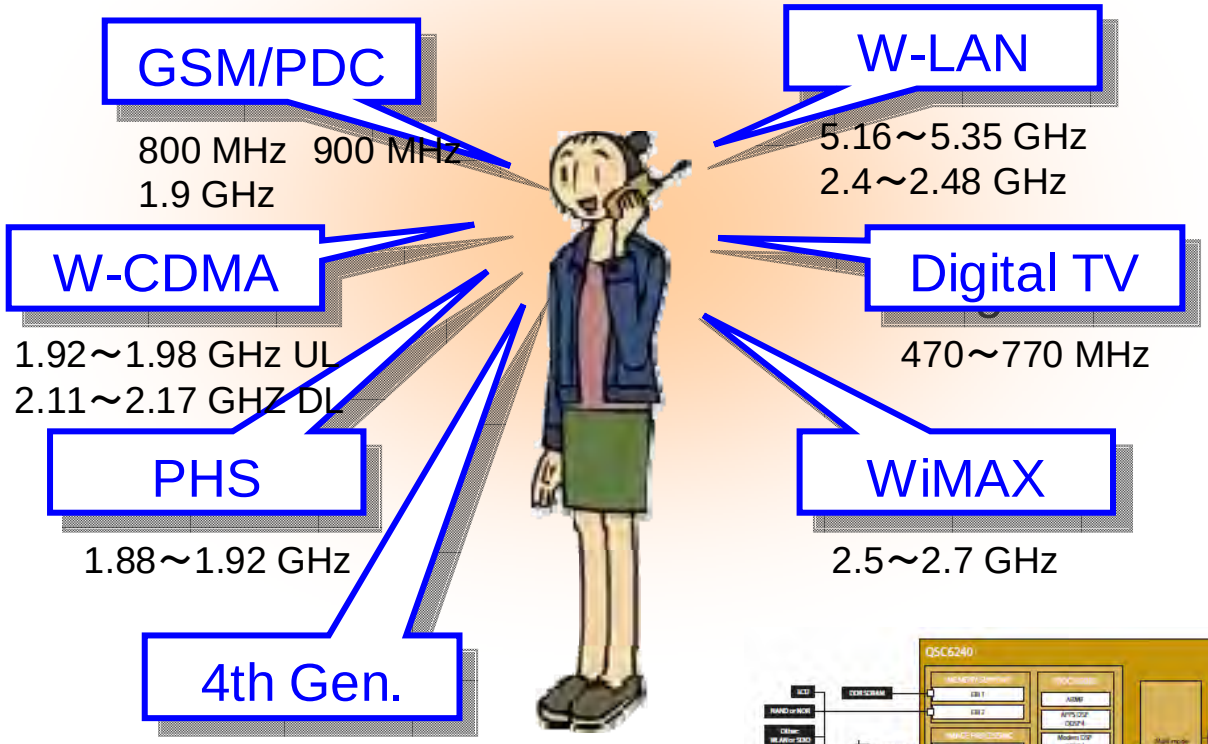
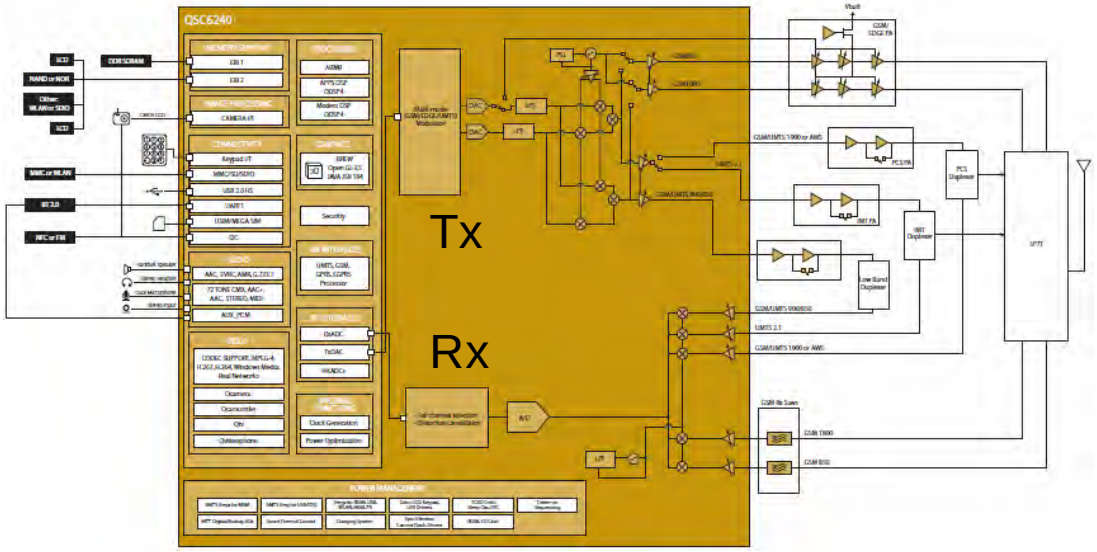
JSAP Integrated MEMS Technology Roadmap



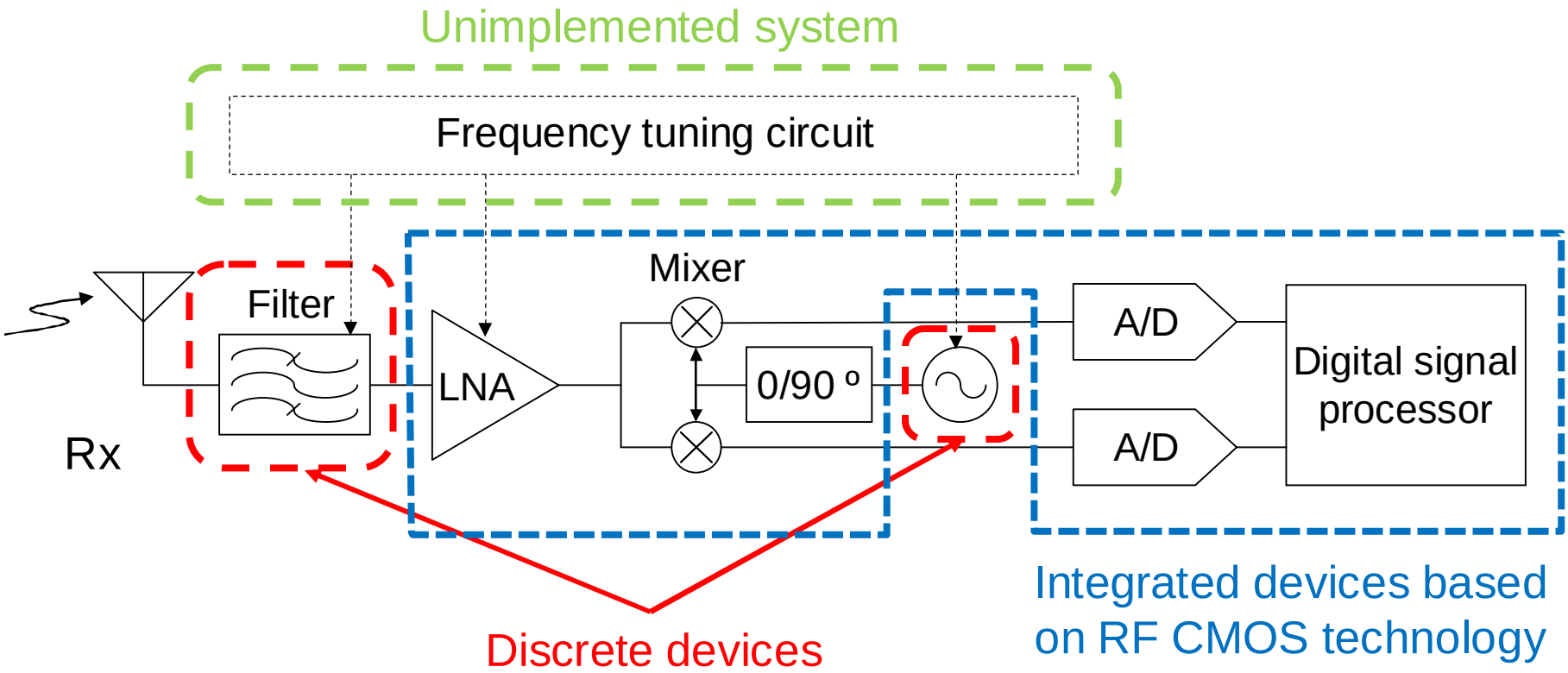
Multiband Wireless Communication





Multi-band wireless communication chip for W-CDMA + GSM/GPRS/EDGE (Qualcomm, QSC6240)

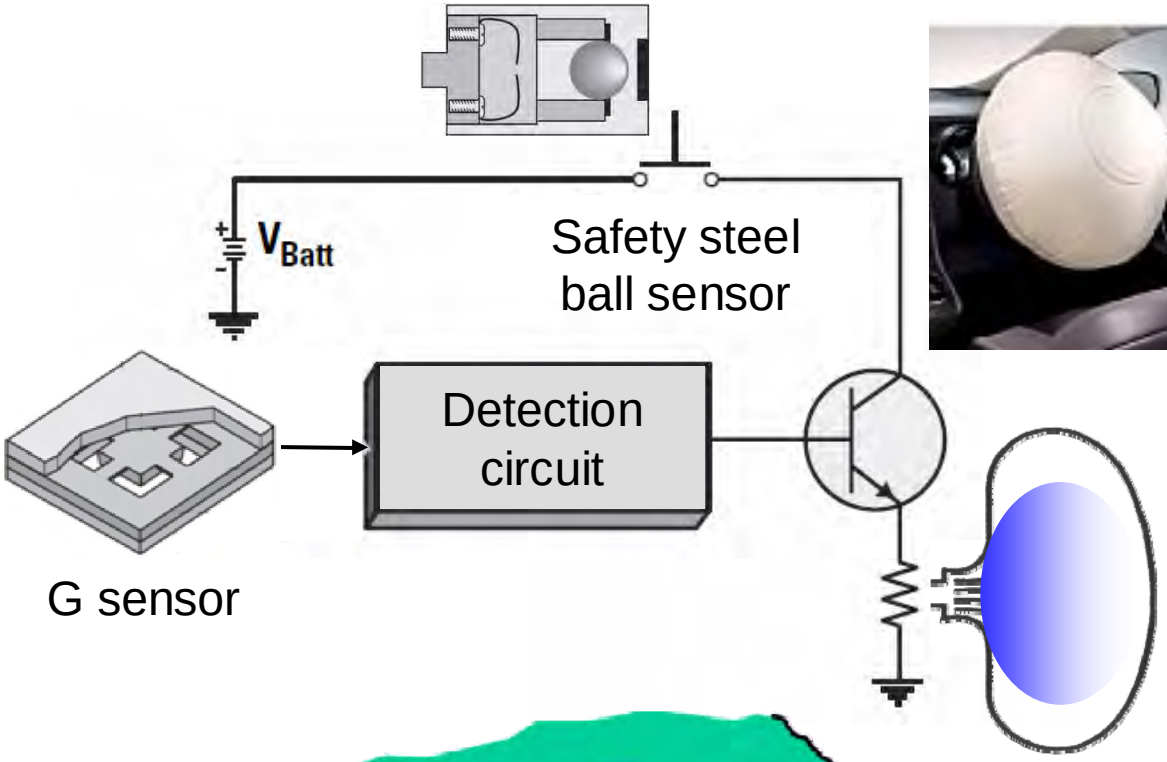
Integration of Wireless Communication System

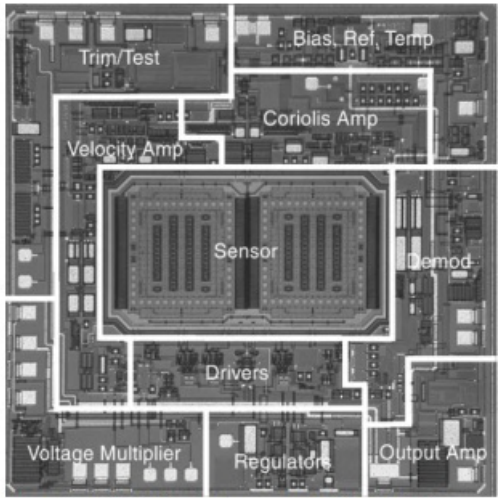


Real one-chip solution enables not only advanced mobile communication systems but also ubiquitous network sensors, wireless healthcare chips etc.

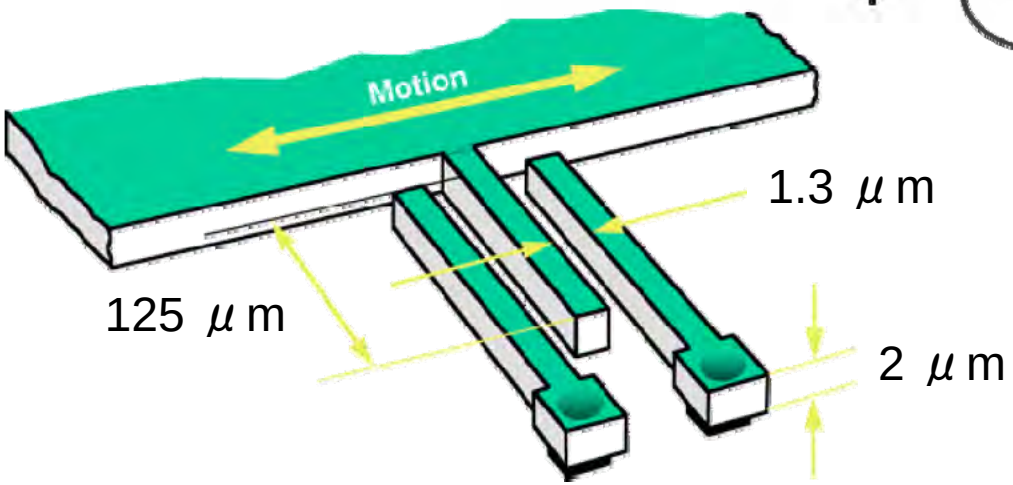
Integration of advanced LSI and "mechanical" devices (SAW/BAW filters, clock oscillators, RF MEMS switches, variable capacitors) is a key.

Inertia Sensors (Analog Devices)





ADXRS150 2-axis gyro

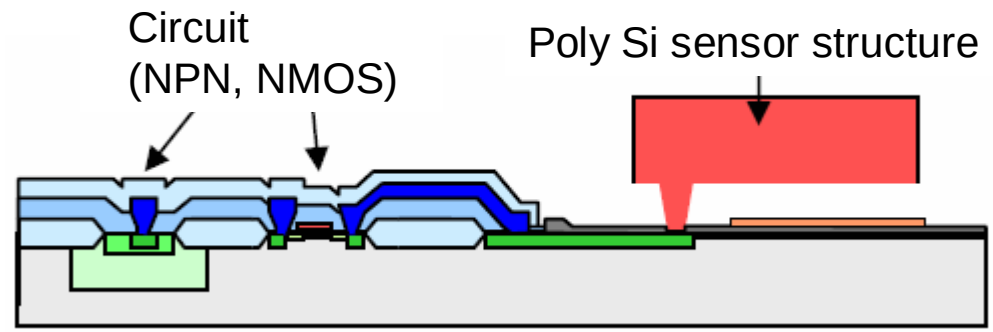


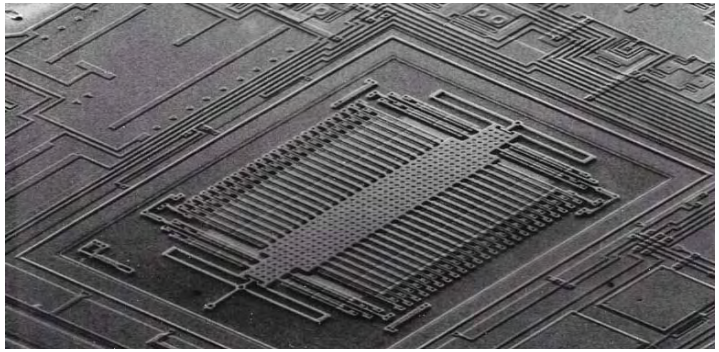
A tiny capacitance change (12 zF) corresponding to 1.6×10^{-4} Å displacement is detectable by the embedded integrated circuit in the gyro.

Integrated Accelerometer (Analog Devices)

Judy *et al.*, Hilton Head Island WS 2004, 27

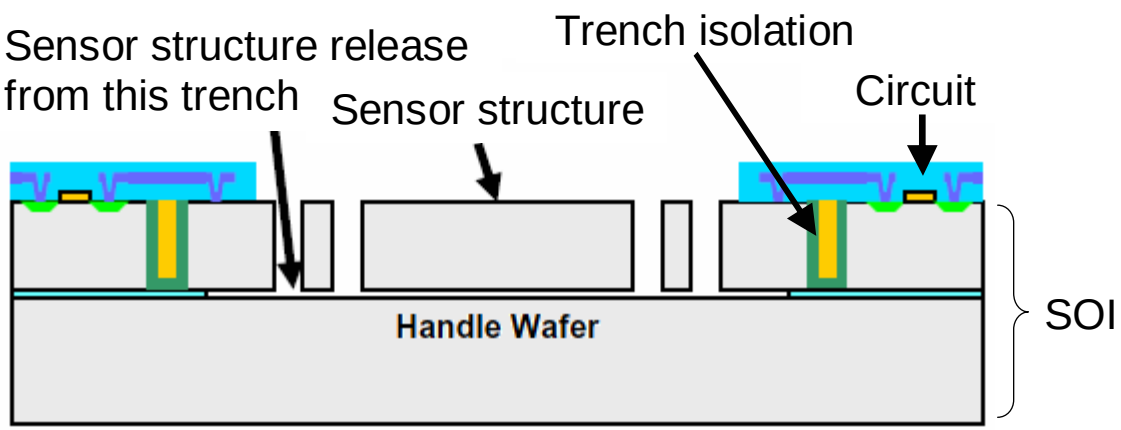
On-CMOS structure

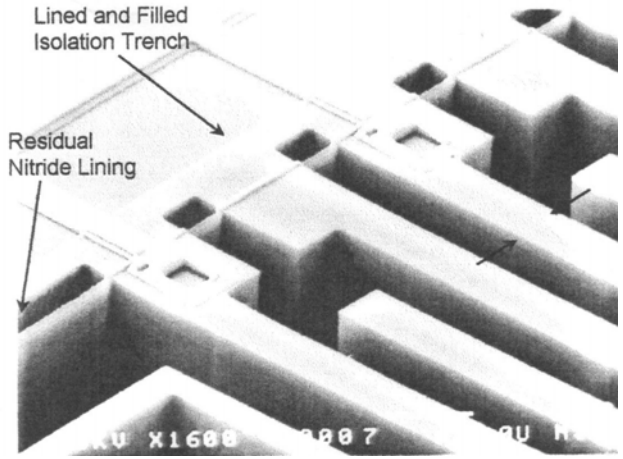




Poly-Si sensor structure on 3 µm-ruled, W-metalized BiCMOS
Poly-Si annealing at 1100 °C for 30 min, Impossible to fabricate in LSI foundry

SOI MEMS structure

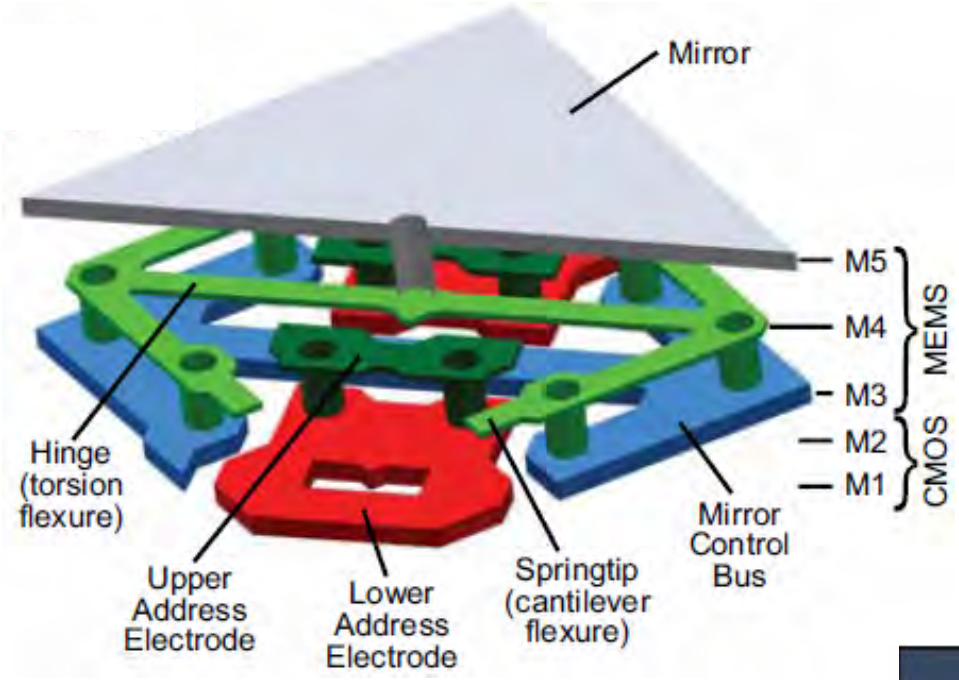


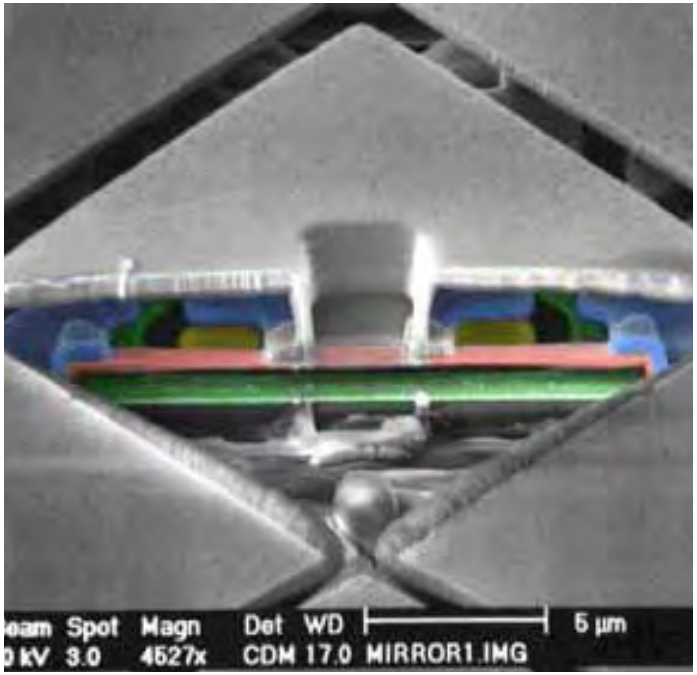


Single crystal Si sensor structure beside 0.6 μm-ruled, Al-metalized CMOS
Compatible with advanced LSI from LSI foundry, Low space efficiency

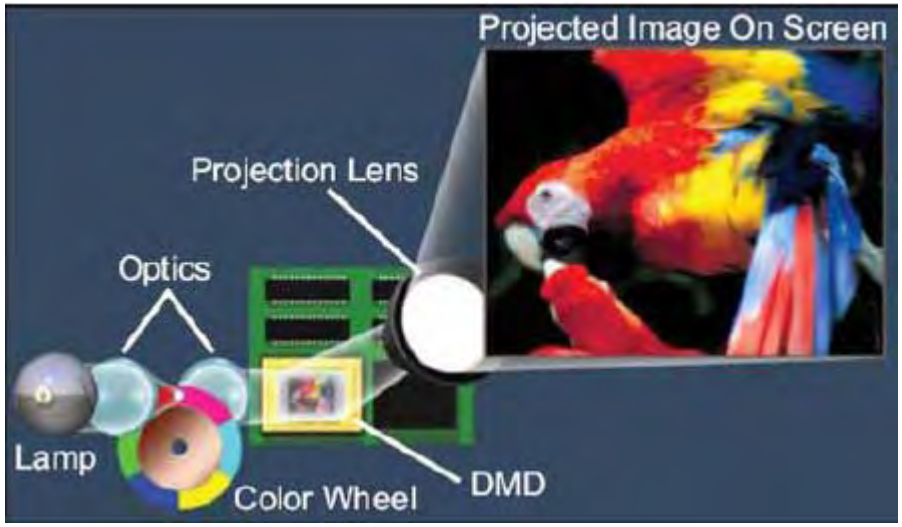
Digital Micromirror Device (TI)

Hornbeck, IEDM 2007, 17-24

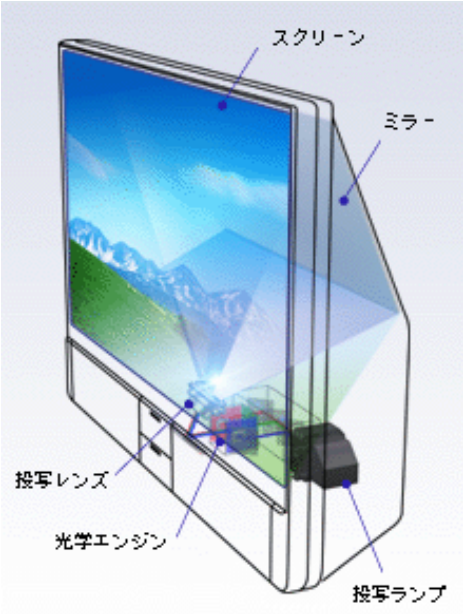




- 10~16 μm square micromirrors
- ~2 μs response time
- 8.5 V driving voltage
- $\pm 12^\circ$ tilt angle
- $848 \times 600 = 508800$ pixels for SVGA ~ $1280 \times 1024 = 1310720$ pixels for SXGA



Applications of DMD



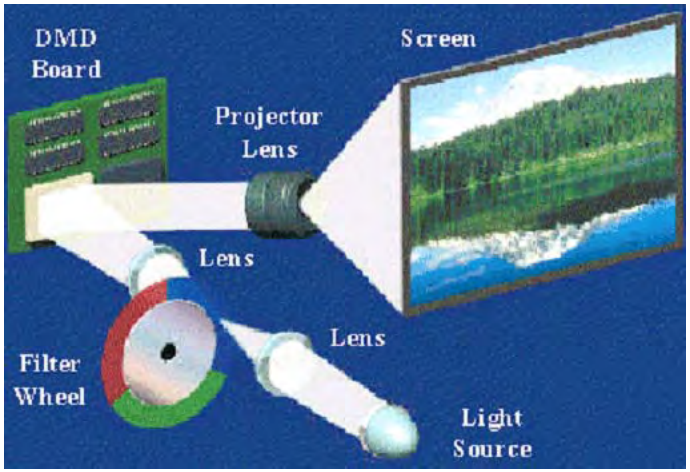
Panasonic

Rear-projection television

NEC

Weight: 1 kg

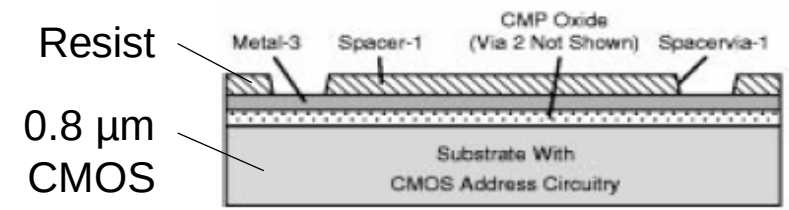
Mobile projector



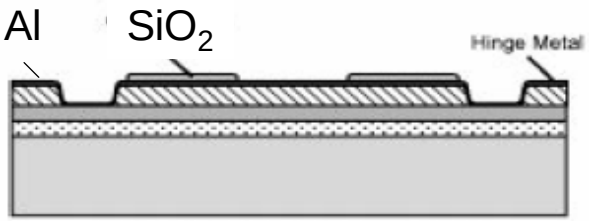
NEC

Projector for cinema complex

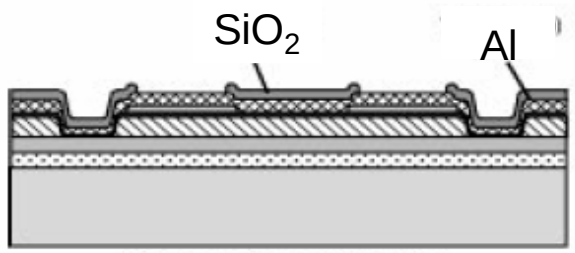
Metal Surface Micromachining for DMD (TI)



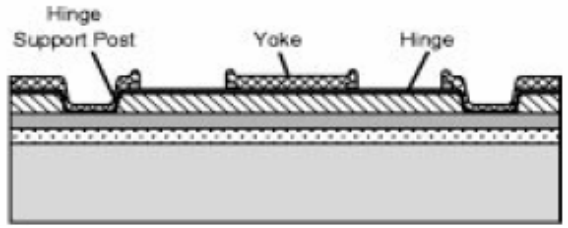
1. Sacrificial resist layer



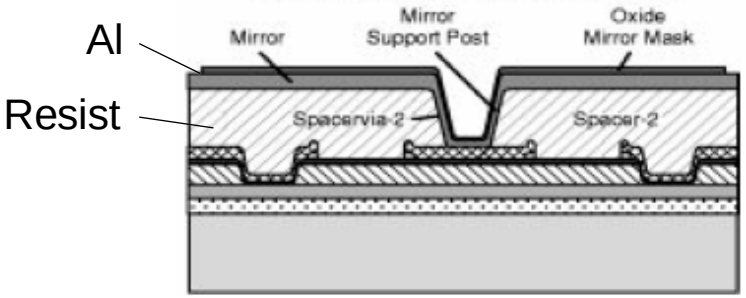
2. Al and SiO_2 mask for hinges



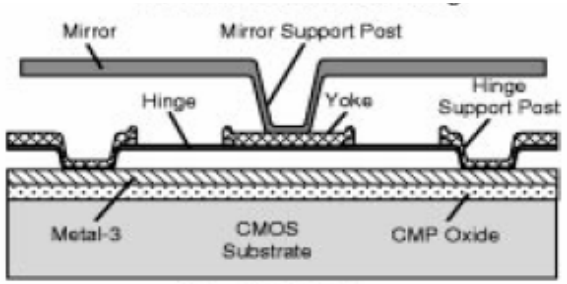
3. Al and SiO_2 mask for beams



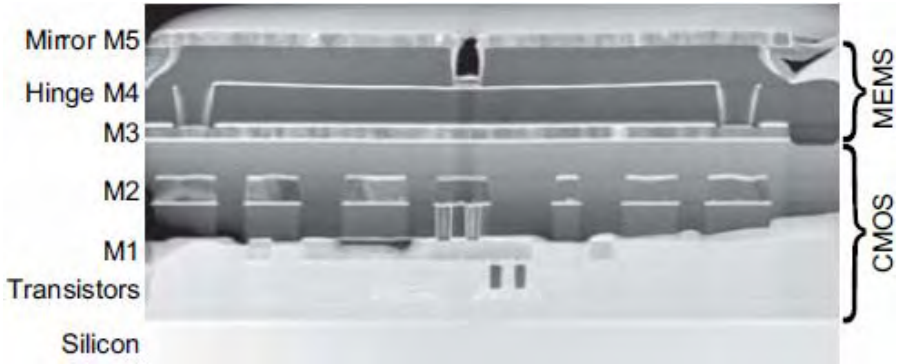
4. Al etching for beams and hinges



5. Sacrificial resist layer and Al mirror



6. Sacrificial resist etching

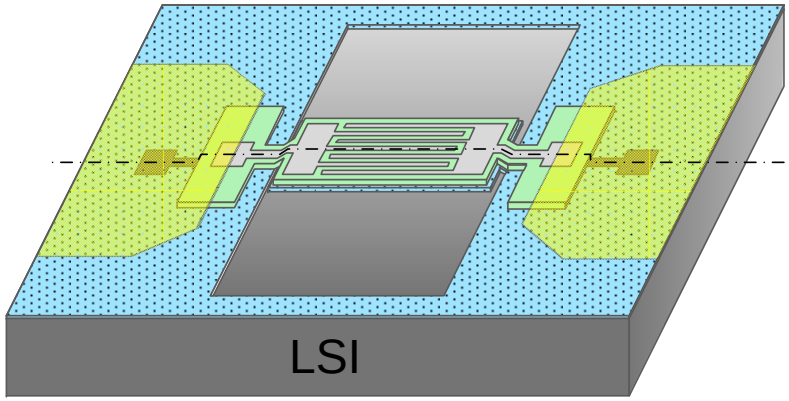


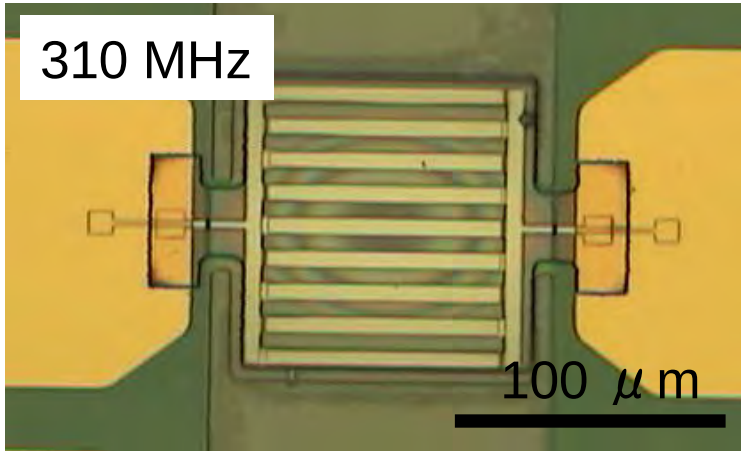
Kessel *et al.*, *Proc. IEEE*, 86 (1998) 1687

Hornbeck, IEDM 2007, 17-24

MEMS-LSI Integration using Ge Sacrificial Layer

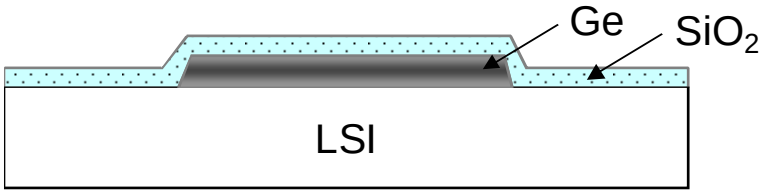
- Multi-freq. AlN Lamb wave resonator monolithically integrated with LSI
- Application to one-chip high-speed communication devices



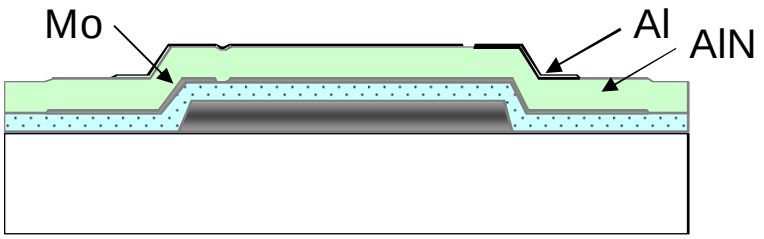


Collaboration with NDK

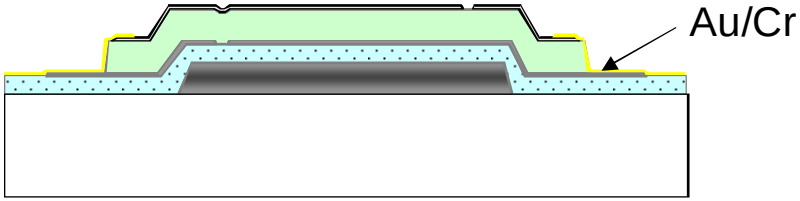
1. Ge patterning and SiO_2 deposition



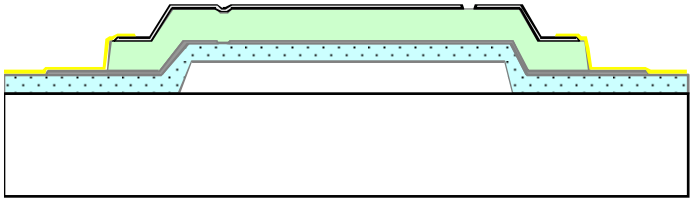
2. Metal patterning and AlN deposition



3. AlN and Au/Cr patterning



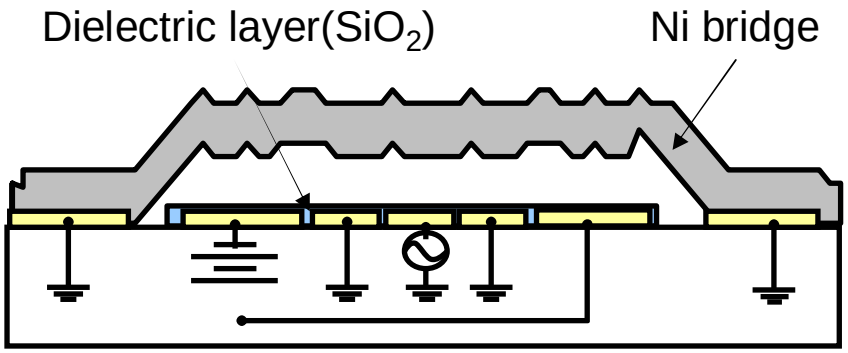
4. Ge sacrificial etching



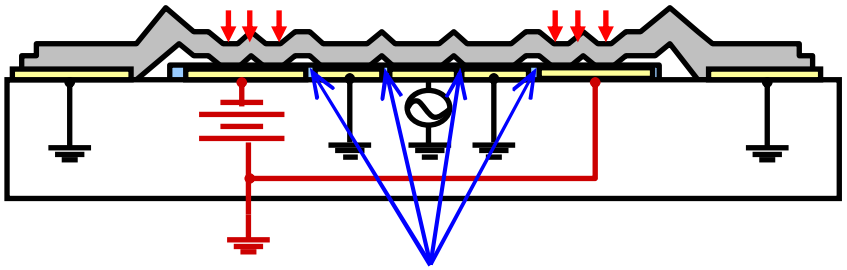
Electrostatic-Actuated Capacitive Shunt Switch

Yuki *et al.*, Sensor Symposium 2007

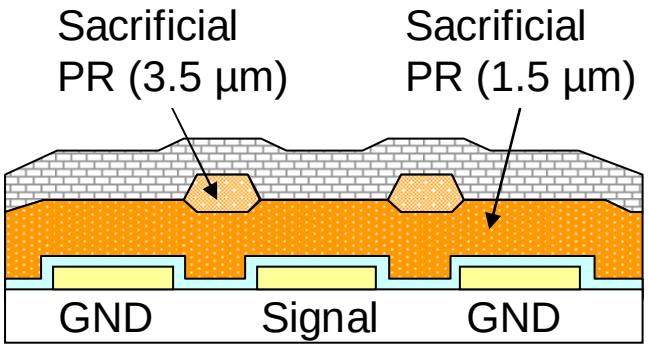
On state

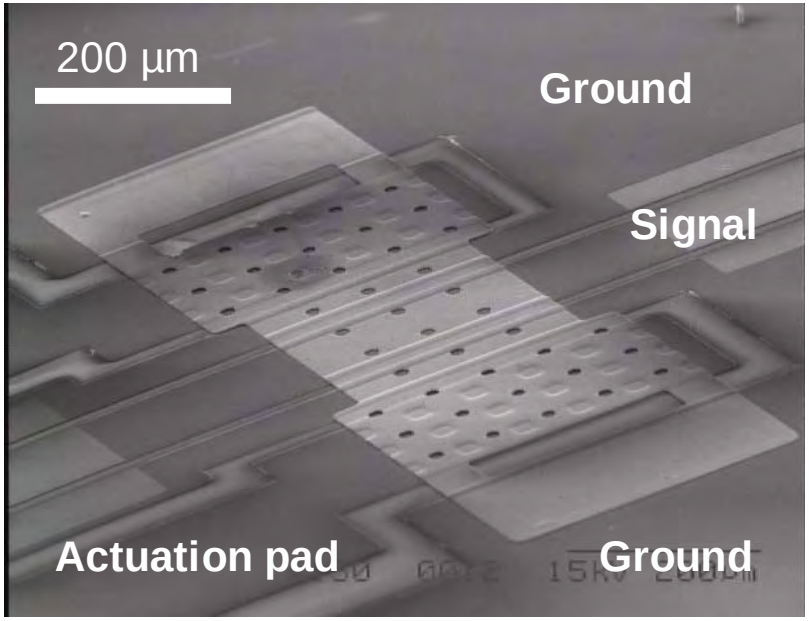


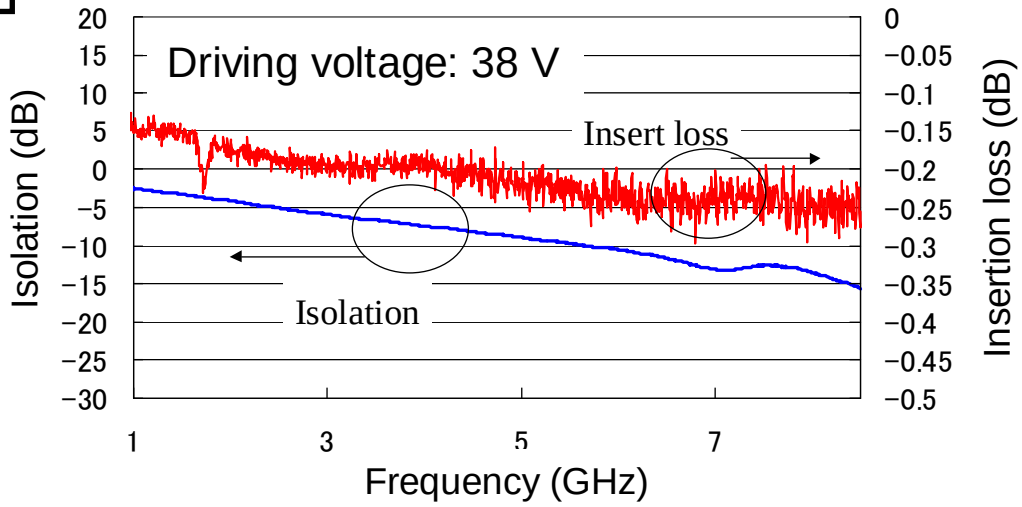
Off state



Notches for close contact

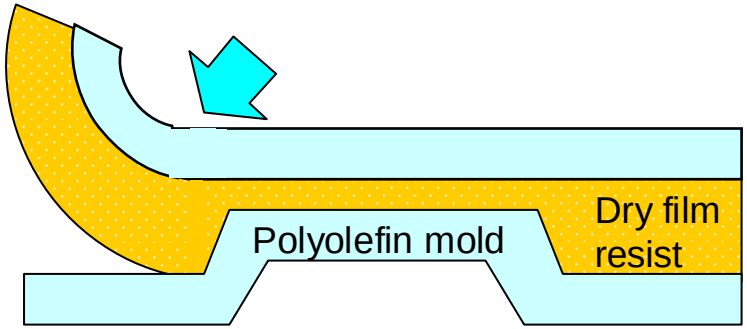




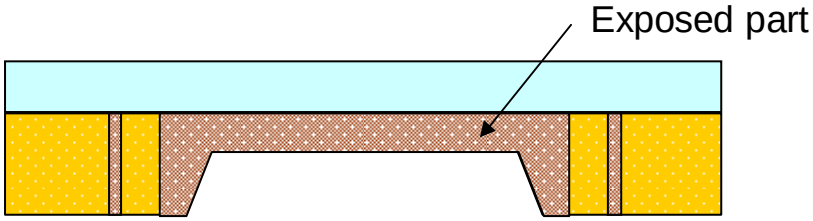


Wafer-Level Packaging of RF MEMS Switch

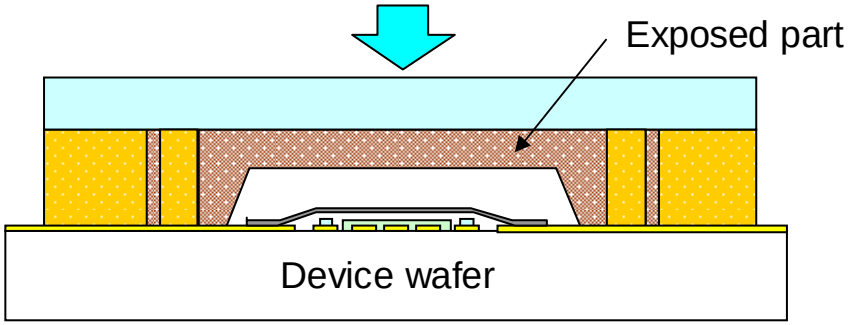
Yuki *et al.*, Sensor Symposium 2007



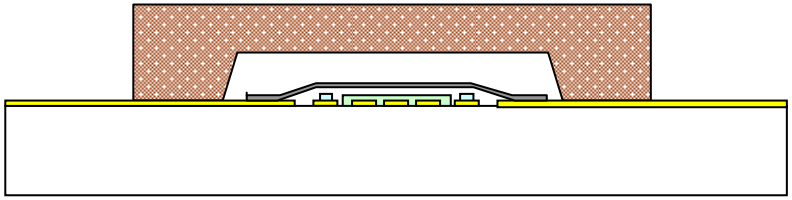
1. Molding dry film resist



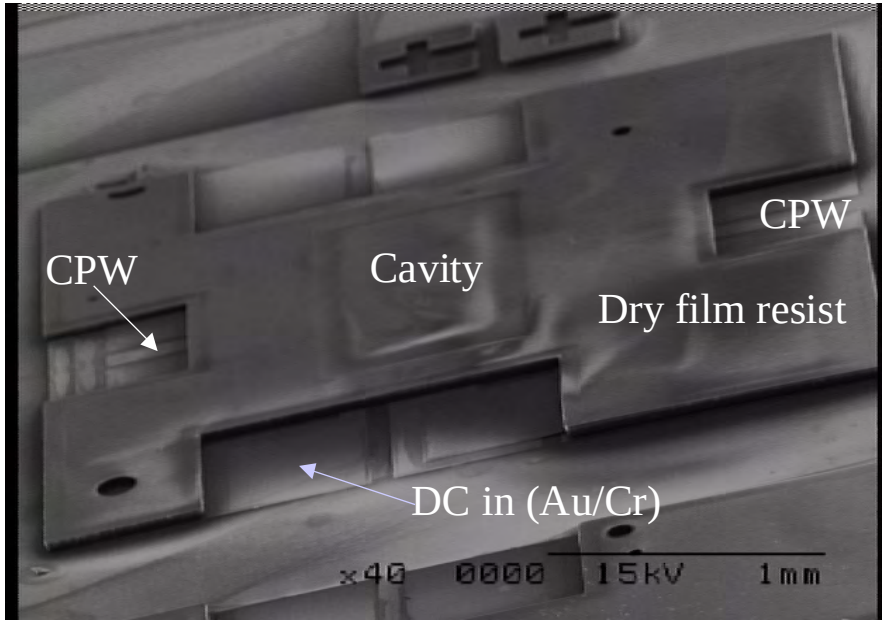
2. Exposing dry film resist



3. Laminating molded dry film resist and exposing



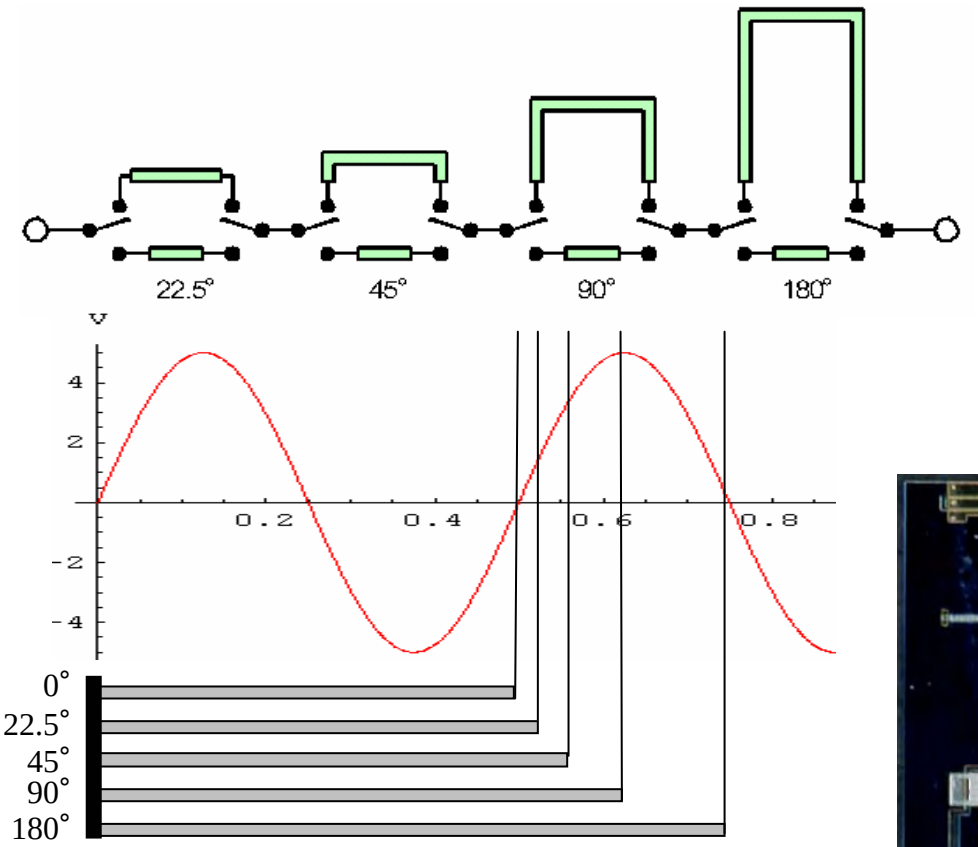
4. Developing and over-coating



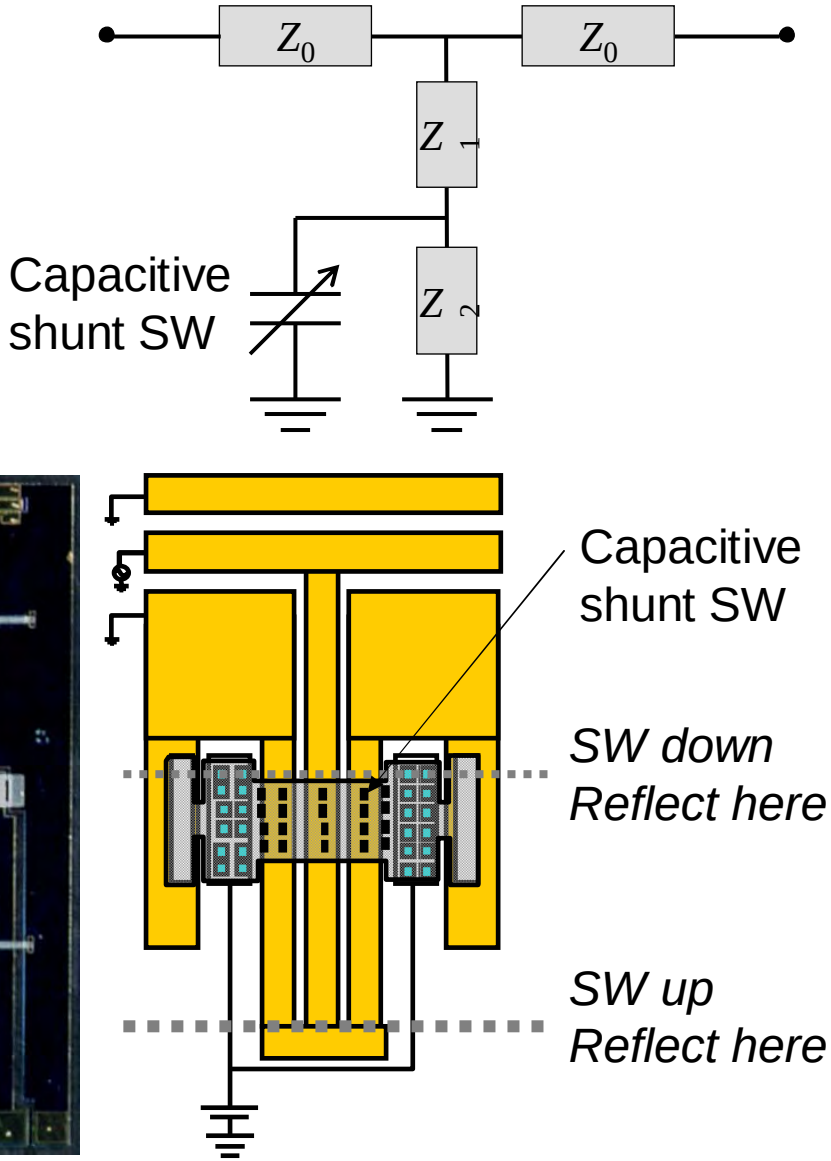
RF MEMS switch packaged by dry film resist

Phase Shifter Using RF MEMS Switches

Switching line type



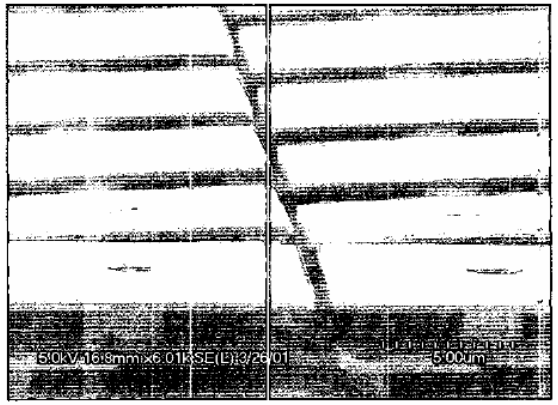
Reflection type



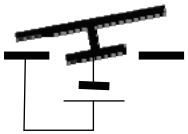
Reflection-type phase shifter using RF MEMS switch (Taiko Denki & Tohoku Univ.)

Memory Effect of Metal Hinges in DMD

A. B. Southeimer, IEEE 40th Annual International Reliability Physics Symposium, Dallas, TX, 2002

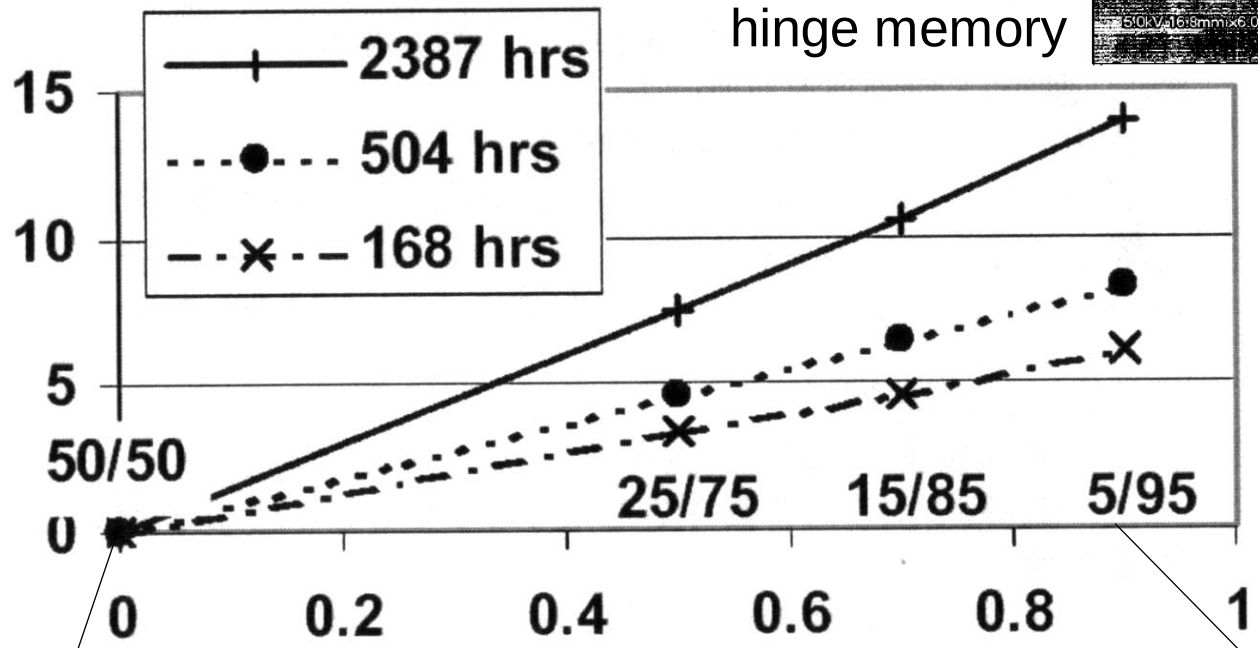


Mirrors exhibiting hinge memory



Shift (%) of bias voltage at which a half of mirrors land on the left side

Test duration



Duty cycle in accelerating test

50 % / 50%

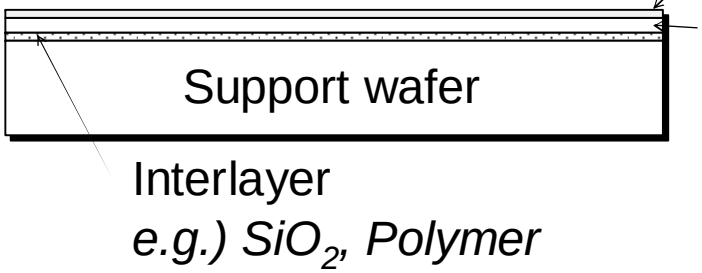
Simulating random image

5 % / 95%

Simulating static image

Wafer Bonding-based MEMS-LSI Integration

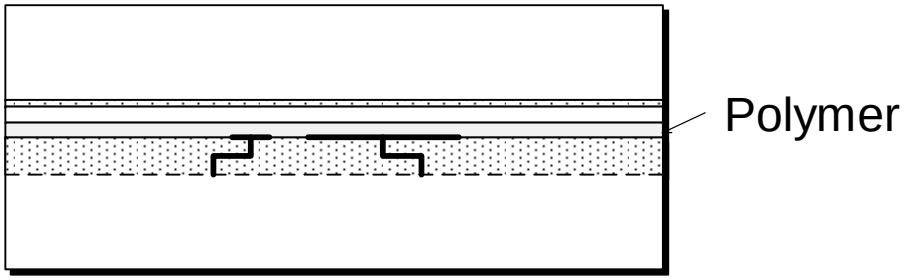
1. Preparation of a device layer on a support wafer



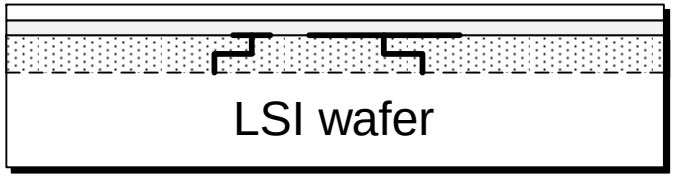
e.g.) Single crystal Si, Piezoelectric materials, Diamond, Compound semiconductors

2. Fabrication of a LSI wafer

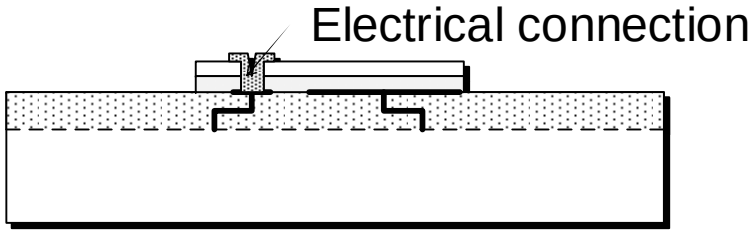
3. Low temperature bonding of the device layer and the LSI wafer



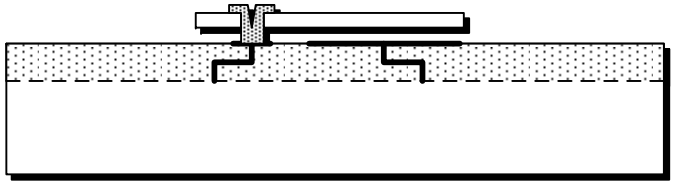
4. Removal of the support wafer/Thinning of the device wafer



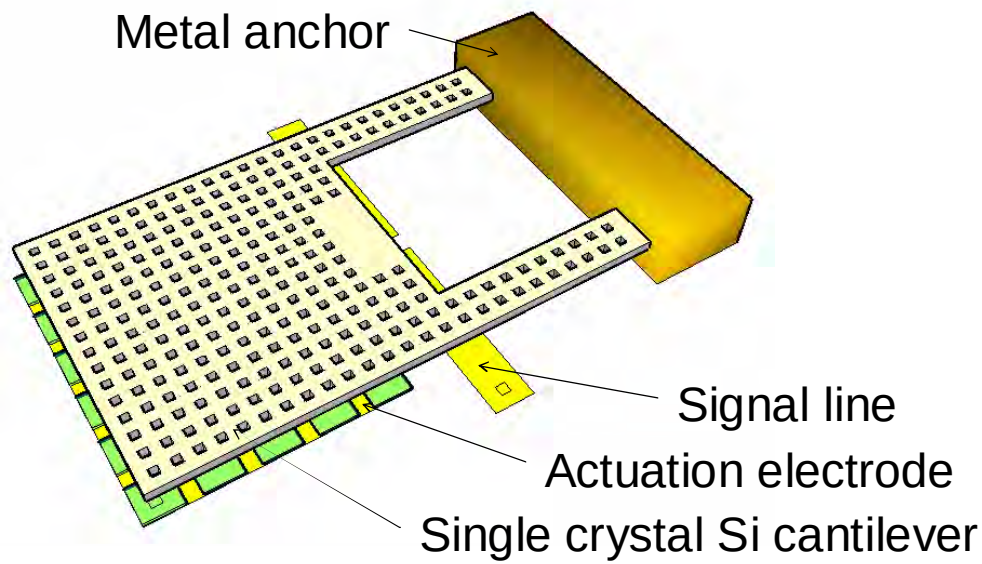
5. Fabrication of MEMS *(e.g. RF MEMS switch, variable capacitor)* or SAW/BAW devices

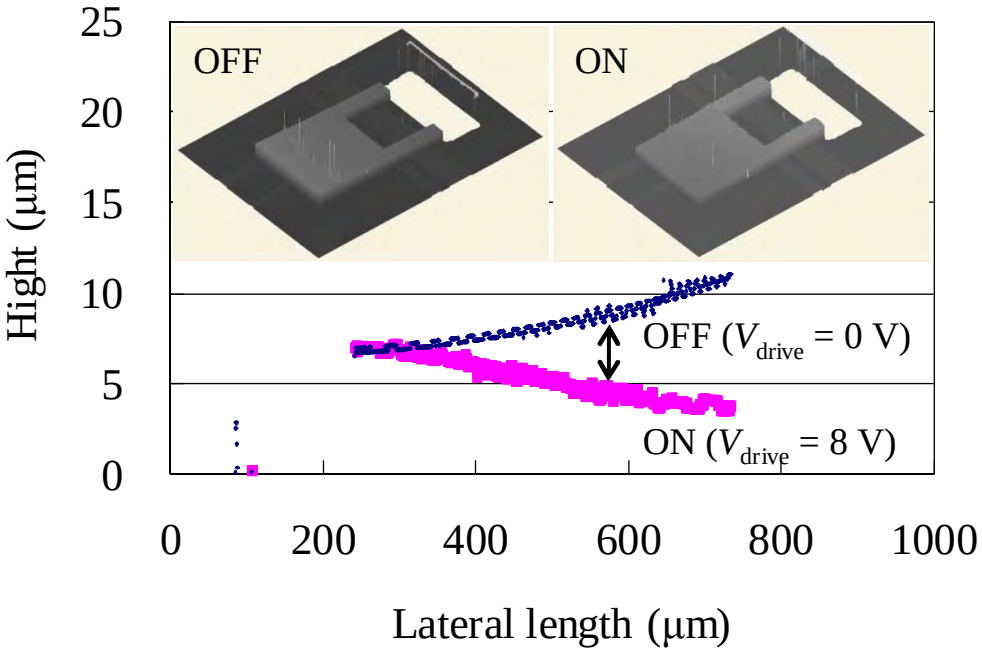


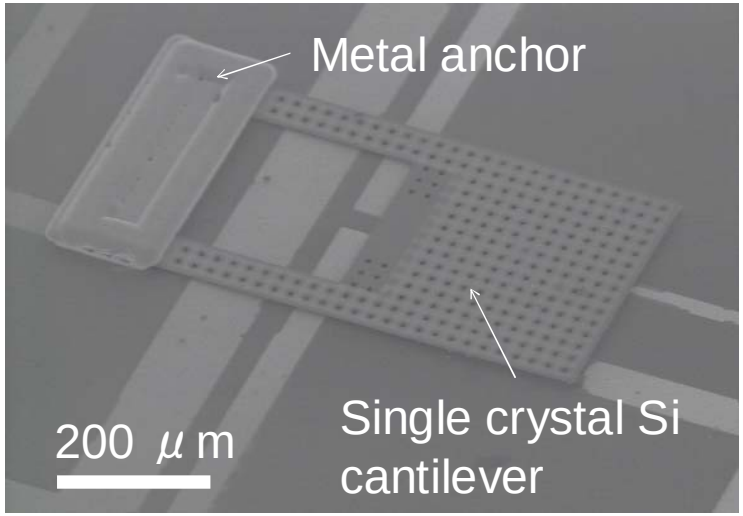
6. Release of the device by sacrificial etching

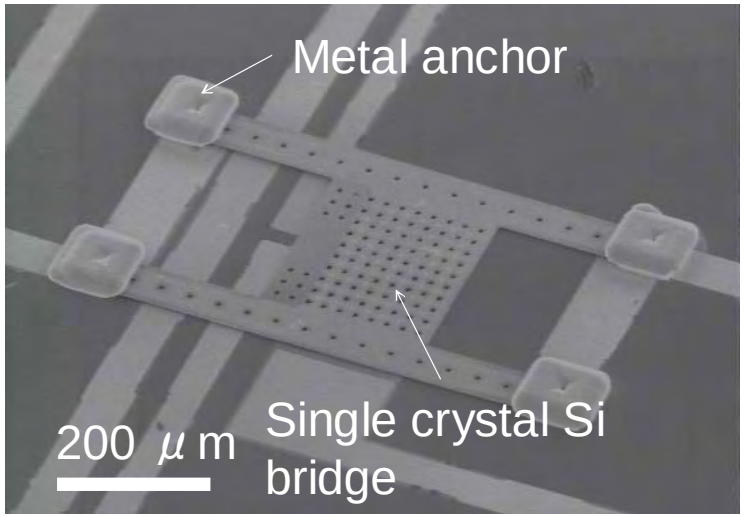


Single Crystal RF MEMS Switch on Top of LSI







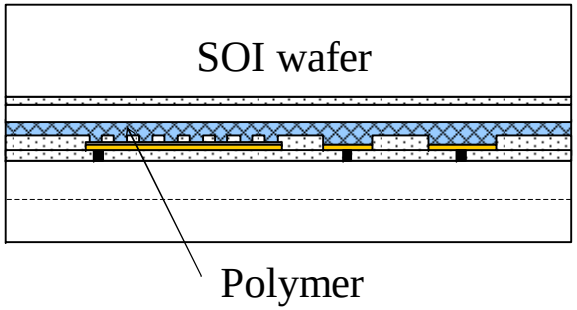


RF MEMS switches on a dummy LSI wafer

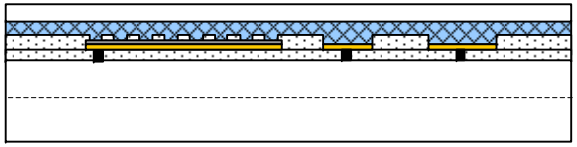
Single-Crystal-Si-on-LSI (SOL) Technology

1. Fabrication of metal pads on a (dummy) LSI wafer

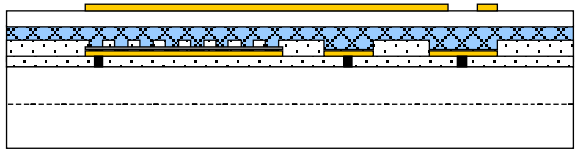
2. Bonding a SOI wafer on the LSI wafer using polymer interlayer



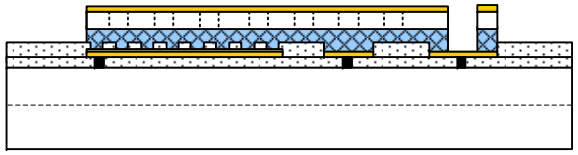
3. Etching of the handle and BOX layers



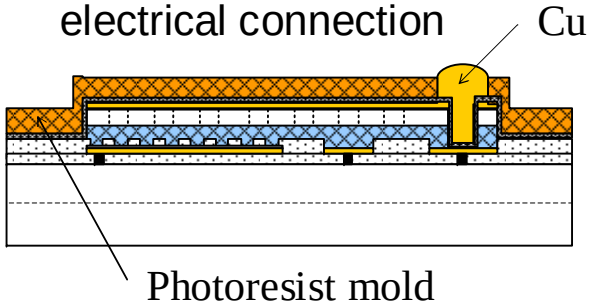
4. Patterning of metal electrodes



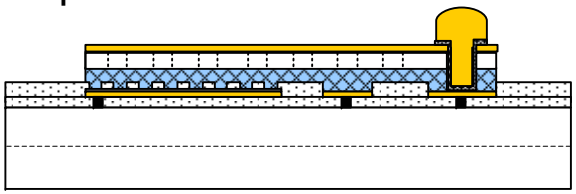
5. Shape formation of the device by reactive ion etching



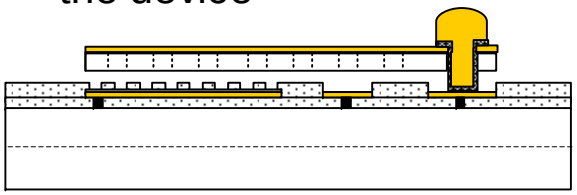
6. Cu electroplating using photoresist molds for electrical connection

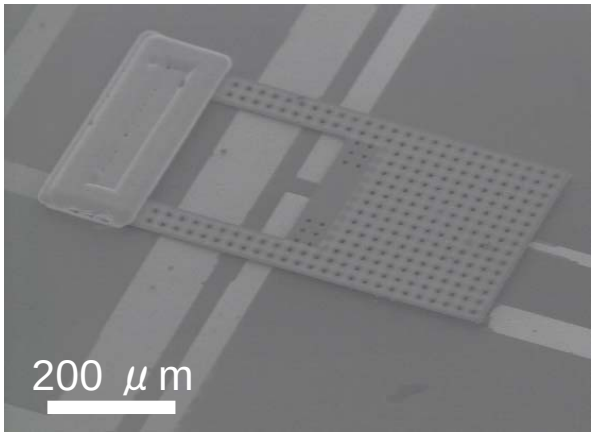


7. Removal of the photoresist molds



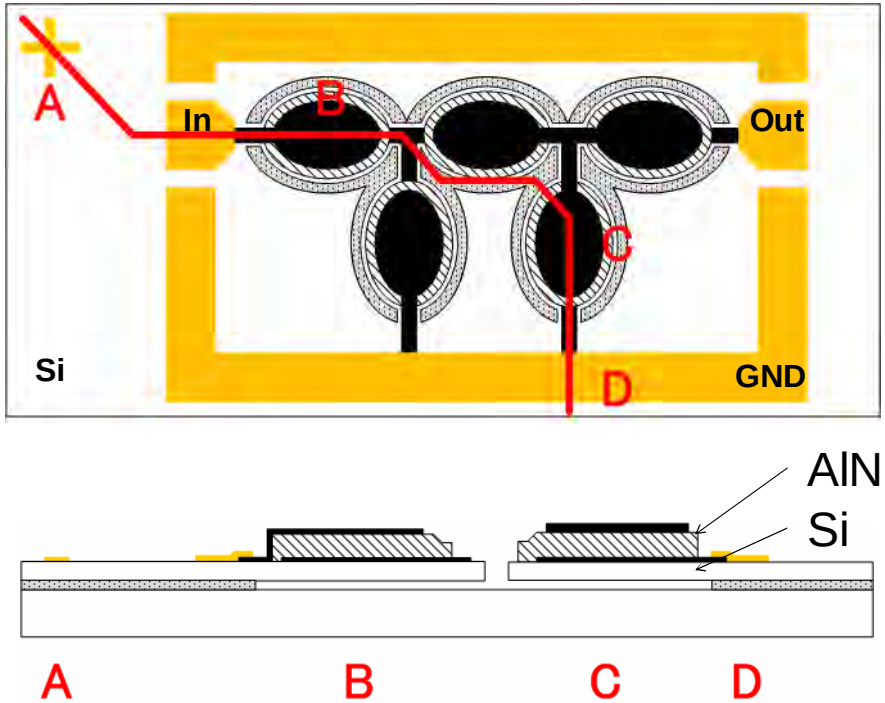
8. Sacrificial polymer etching by O_2 ashing to release the device



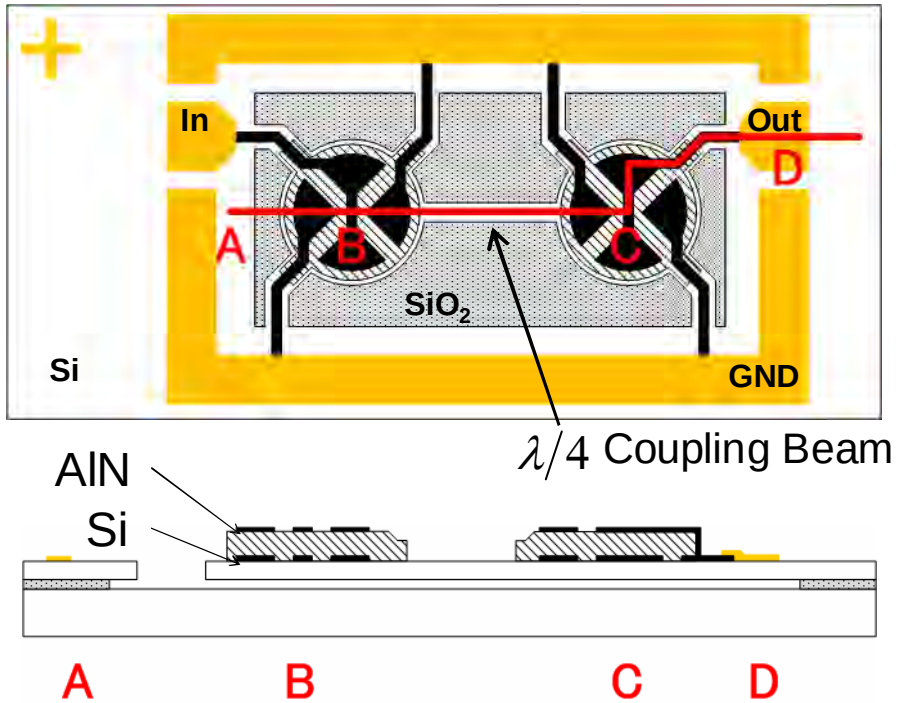


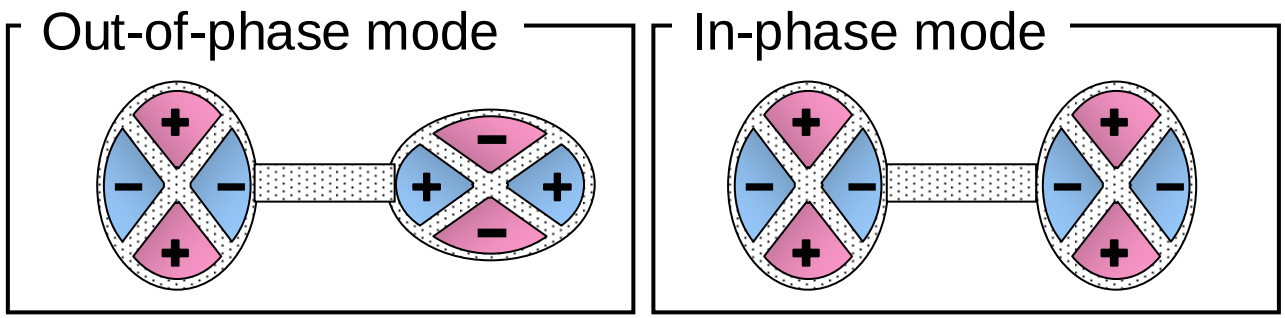
AlN/Si Composite Resonators on Top of LSI

1. Electrically-coupled AlN/Si composite thickness-mode filter



2. Mechanical-coupled AlN/Si composite disk array filter

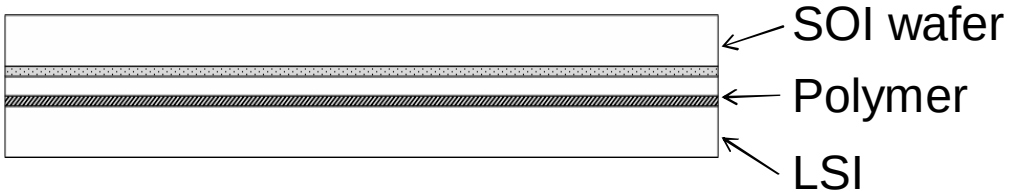




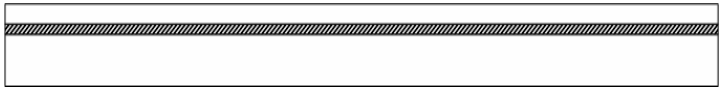
Collaboration with
Mr. Matsumura (NiCT)

Single-Crystal-Si-on-LSI (SOL) Technology

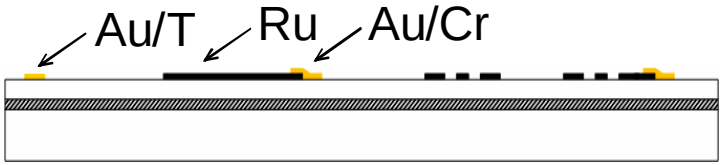
1. Wafer bonding using polymer



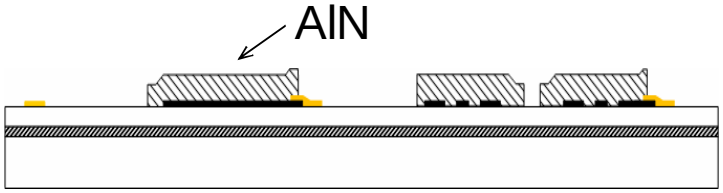
2. Handle layer and BOX layer etching



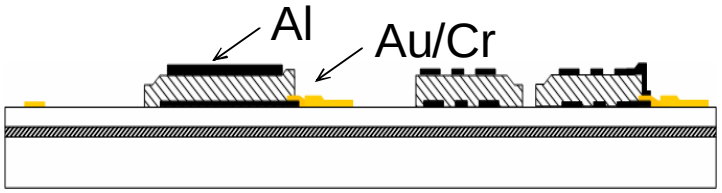
3. Metal patterning



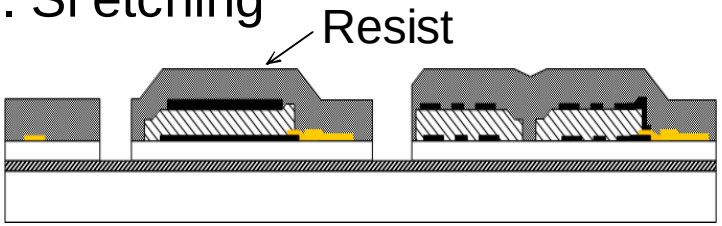
4. AlN deposition and patterning



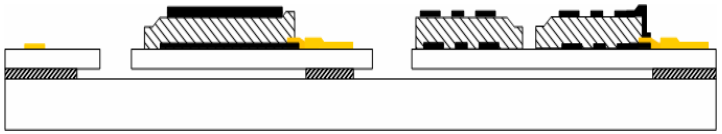
5. Metal patterning

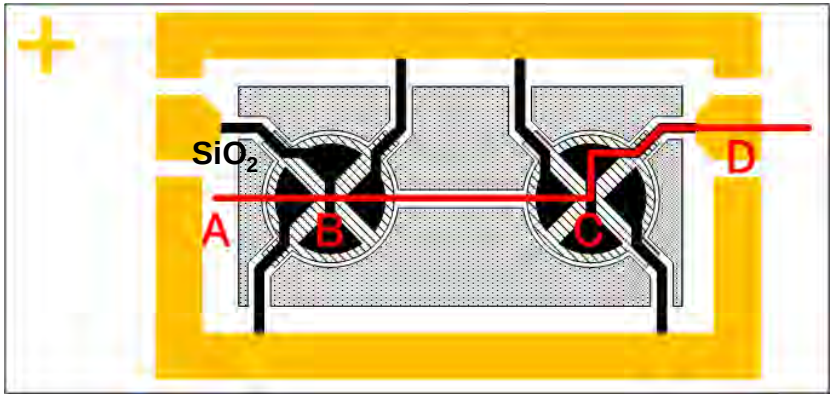


6. Si etching



7. Sacrificial polymer etching





AlN/Si Composite Resonators on Top of LSI

Unpublished data

Share Wafer System in Tohoku University

Shuttle service

Given process
→ Call for devices

Registration from A corp., B univ. …

A	B	C
D	E	F
G	H	I

A

B

⋮

Delivery after chip separation

Share wafer system

Group A
Sensor circuit

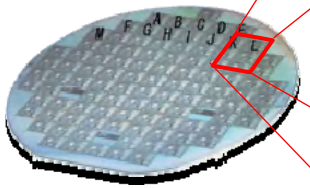
Group B
Driver circuit

Group C
Oscillator circuit

Group D
Actuator circuit

Is there a common process?

Coordination with LSI foundry



Multiple devices in each shot

A	B
D	C

A	B
D	C

A	B
D	C

⋮

Full wafers to each group

MEMS fabrication by each group

Project members (NDA is concluded.)

Summary

- There is strong demands for monolithic integration of advanced LSI and “mechanical” devices such as clock oscillators, mechanical filters, switches and sensors. “More than Moore” with “Moore Moore” and “Biyond CMOS”
- There are varieties of existing MEMS-LSI integration technology, but they are not suitable for the above applications.
- We have developed new versatile microprocess technology for the monolithic integration of high-performance MEMS on top of advanced LSI.
- Using the developed technology, we fabricated RF MEMS switches/variable capacitors, RF mechanical resonators and filters etc.

Acknowledgement: This study was partly supported by Special Coordination Funds for Promoting Science and Technology.