MEMS Packaging 기술 및 마이크로센서

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MEMS Packaging Technology and Micro Sensors

(Samsung Advanced Institute of Technology)

최 상 언

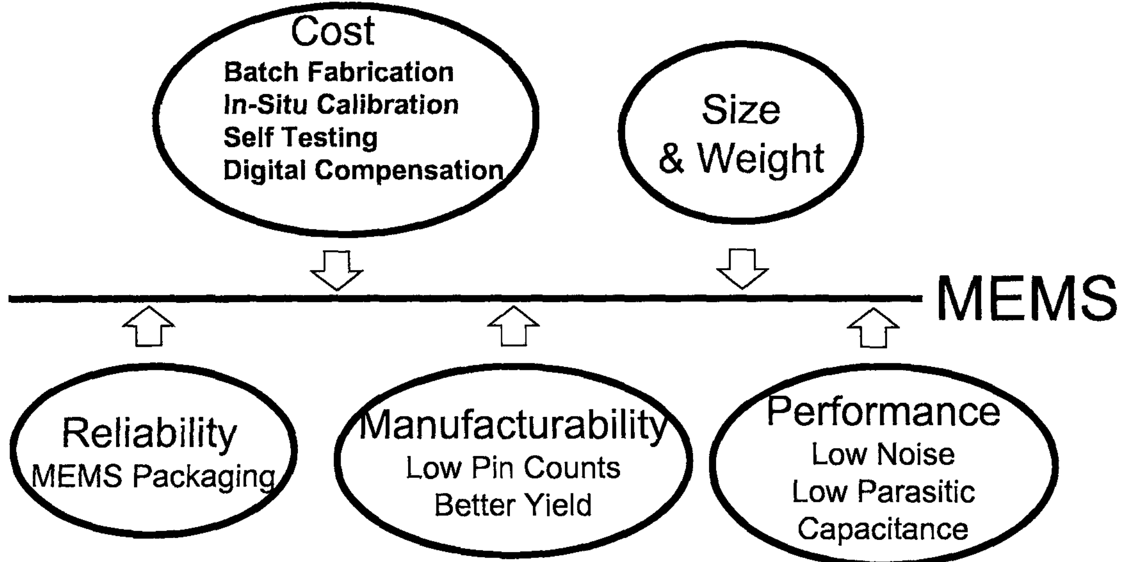
Sept. 2, 2000

Contents

- **What is MEMS ?**
- **Inertial Sensors Research activity in SAIT**
  - **Inertial measurement unit & application**
  - **Micro gyroscope**
  - **Micro accelerometer**
  - **MEMS packaging**
  - **Micro flux-gate Compass**
- **Summary**

Why MEMS ...?

A Micro-Electro-Mechanical System (MEMS) is a batch-fabricated miniature system that contains both electrical and mechanical components with characteristic sizes ranging from nanometers to millimeters



- In US: MEMS, Microdynamics, Micromachining
- In Europe: Micro Systems/Technology (MST)
- In Japan: Micromachines, MicroRobots

■ Application Areas

MEMS

Actuators
- new actuation principles,
- microactuators for small-scale machines
- concatenated microactuators for large-scale machines

Sensors
- devices detecting strain, force, pressure, flow, acceleration, position, temperature chemicals, etc.,
- sensing systems (environmental & intelligent sensors)

System Configurations
- distributed microsystems
- integration of microsensors and microactuators,
- interfacing of MEMS with the external world

Fluidic Systems
- pumps, valves, microchannels, mixers
- micro total analysis systems

Optical Systems
- microoptics,
- telecommunication적용
- measurement systems
- devices for the generation, modulation & detection of light

Data Storage
- disk storage
- Data Memory Device using AFM or STM

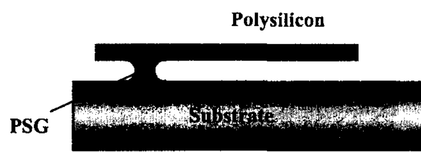
Medical Engineering
- surgical & electrical devices
- patient monitoring

Scientific Instruments
- chemical analysis
- probe microscopy
- biology 적용

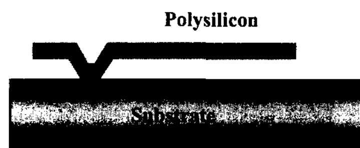
Industrial Applications
- switches & relays
- microrobots
- process monitoring & control devices
- RF MEMS
- Ink Jet Printer

Surface Micromachining

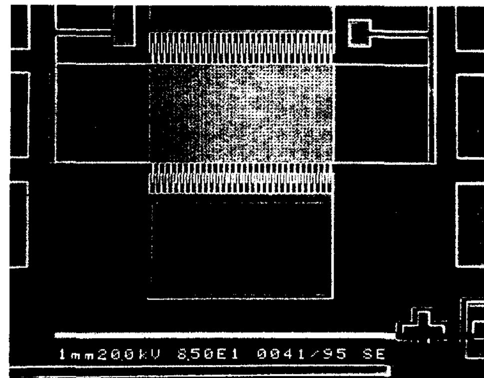
- Alternating structural (polysilicon) and sacrificial (PSG) layers are deposited on Si substrate
- Suspended (cantilevers, bridges,…) and movable structures (pin joints, rotors,…) are made by selectively etching the sacrificial layers (release etch)



- One-mask process

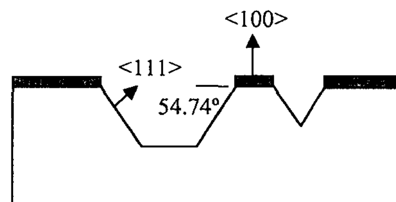


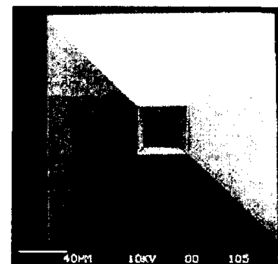
- Two-mask process

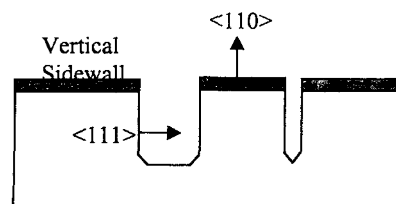


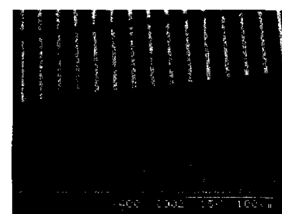
Bulk Micromachining (anisotropic etching)

- Sculpture of Si substrate by wet chemical etching (e.g. TMAH, KOH, EDP)
- <111> crystal planes has much slower etching rate than <100> and <110>, and are exposed after etching



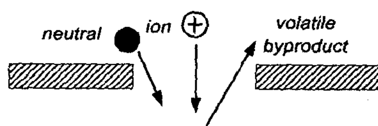






Silicon Deep Etching Micromachining

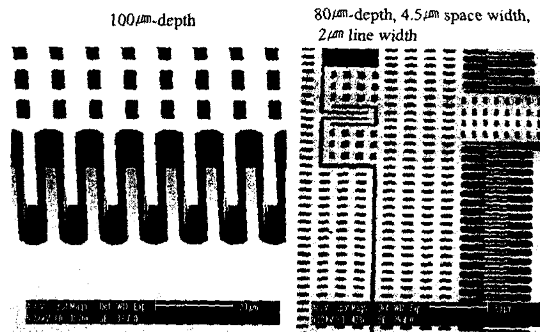
- ion-enhanced etch mechanism
- Etch rate: > 2.0 ㎛ /min
- Selectivity to Resist Mask: >75:1
- Selectivity to Oxide Mask: >150:1
- Sidewall Profile: 90°< ±1°
- Etch depth Capability: up to 500㎛



ion-enhanced energetic

100㎛-depth

80㎛-depth, 4.5㎛ space width, 2㎛ line width



Gyroscope

LIGA

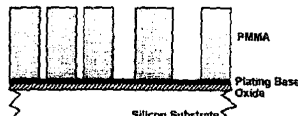


Fig. 1 Fabrication is done on a (100) silicon wafer with a 0.5μm oxide layer. A plating base is formed by sputtering 300nm of Ti and 5000A of Cu with a top layer of 300A Ti. The Ti and Cu also act as a release layer. Thick photoresist is applied and exposed using x-rays from a synchotron and developed with a solvent.

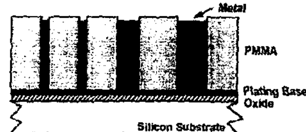


Fig. 2 The desired metal, in this case nickel, is electroplated onto the substrate, filling the voids in the PMMA.

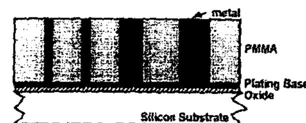
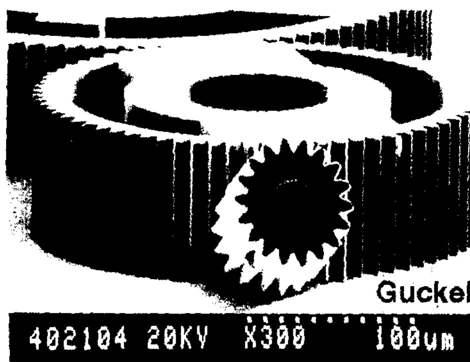


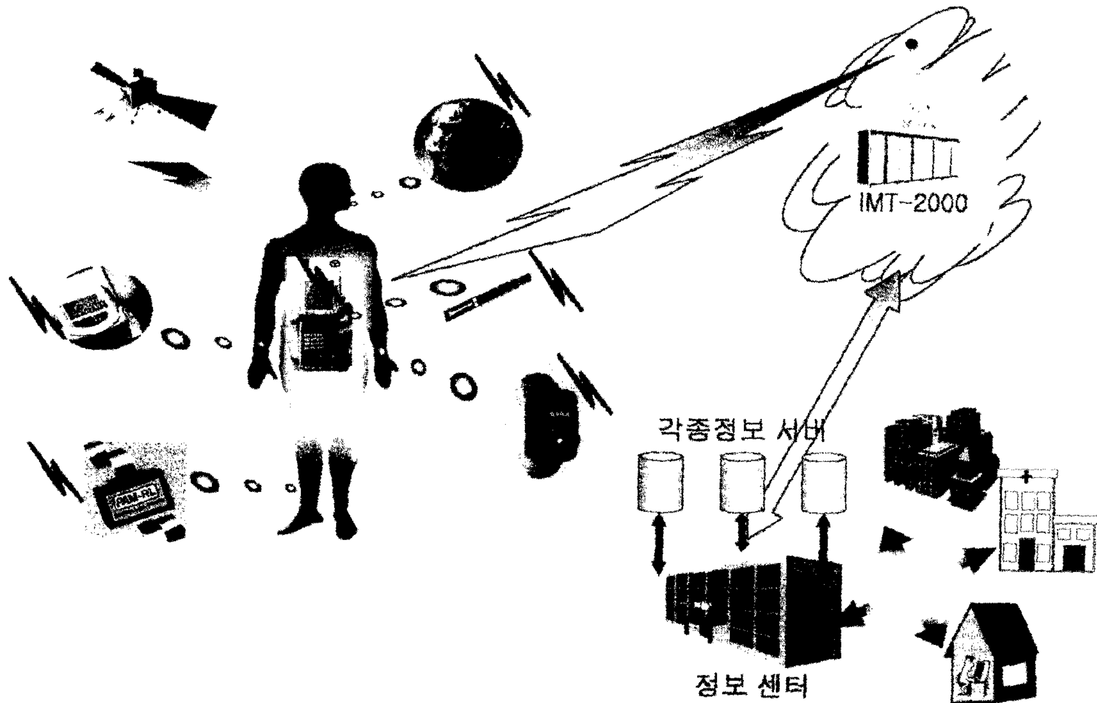
Fig. 3 The metal and PMMA are milled back to produce a uniform top surface.

Fig. 4 Finally, the PMMA is removed. If desired, the customer can release the structures from the substrate by etching away the plating base in an NH_4O_2/H_2O_2 solution.

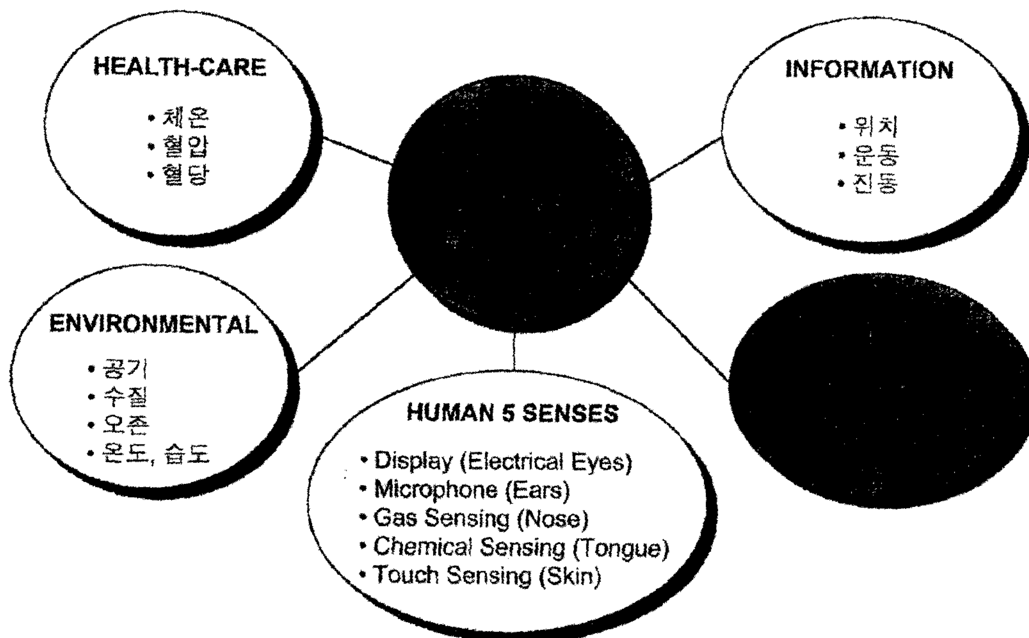
- Lithography & Electroplating & Molding
- Tall structures with high aspect ratio and fine features are made by X-ray lithography and electroplating
- Mass production through injection molding



차세대 정보통신 복합단말기

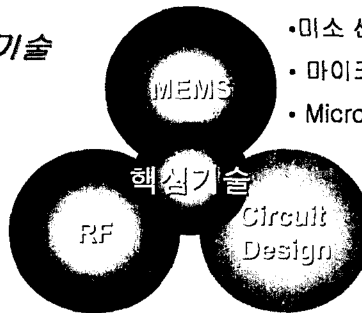


요구기능



핵심/기반/관련 기술

■ 핵심기술/기반기술/관련기술



- 미소 센서 집적 설계/제작 기술
- 마이크로머시닝 기술
- Microsystem Package기술

- RF MEMS 소자 제작기술
- RF소자 설계/집적 기술

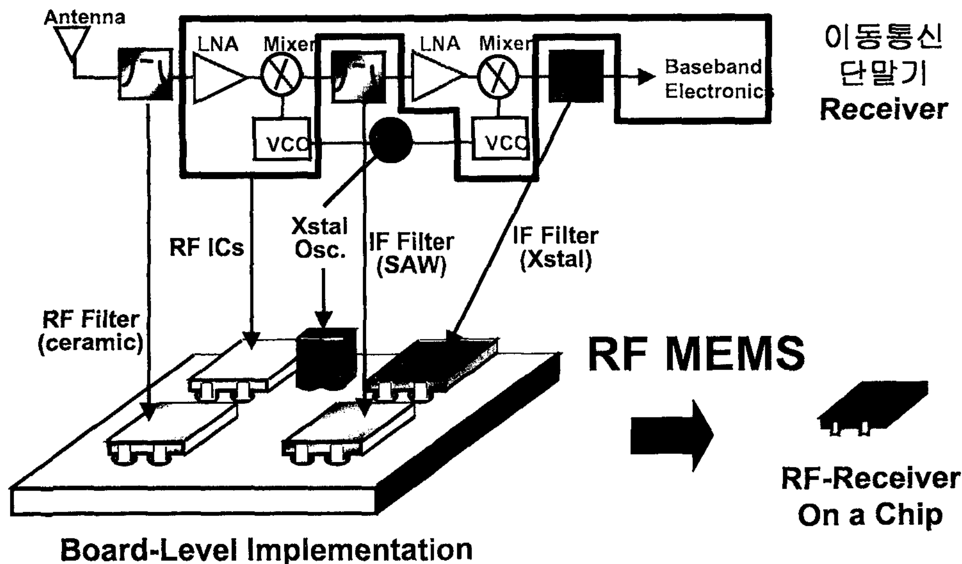
- 미소 구동 제어 기술
- 저전력회로 설계 기술

기반기술
- 물리량 및 생체 신호 센싱 기 술
- 미소 구조체의 특성 분석 기술

관련기술
- 반도체 설계 제작 기술
- 고주파 통신기술
- Telemetry 기술

Communication : RF-Transceiver On Chip (TOC)

- 초소형 무선 송수신 모듈



이동통신 단말기 Receiver

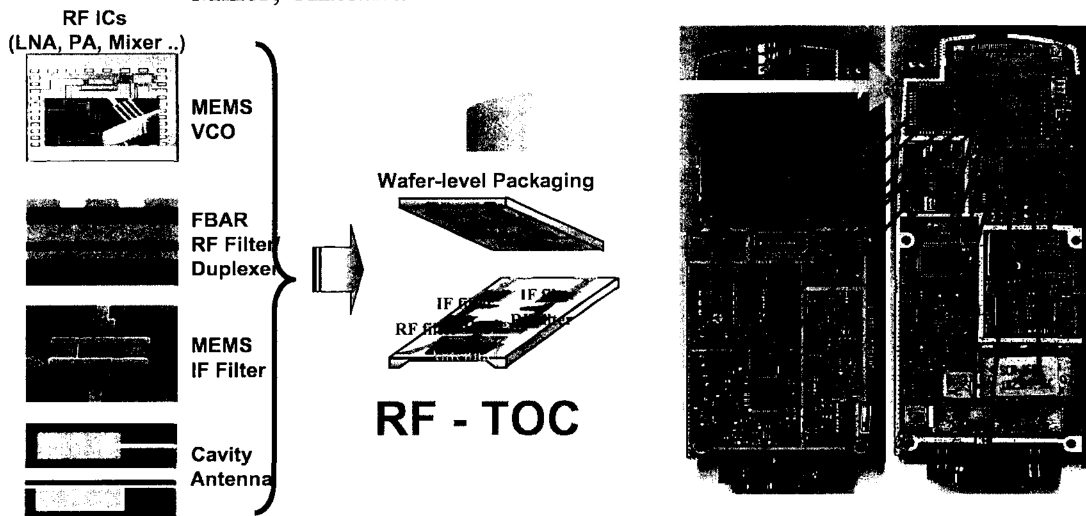
RF MEMS

RF-Receiver On a Chip

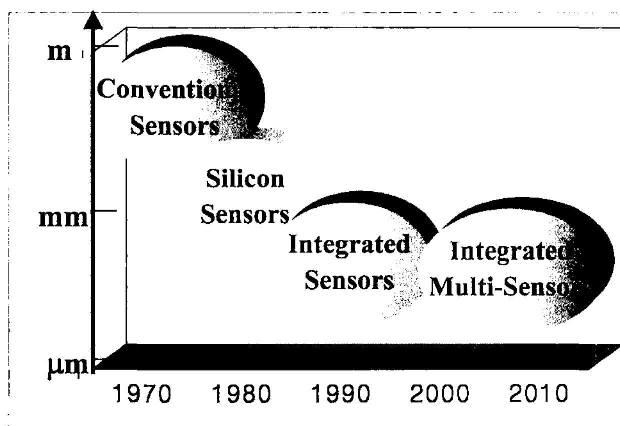
(Ref: C. Nguyen, U of Michigan, MTT-S Workshop, 1999)

Communication : RF-Tranceiver On Chip (TOC)

- MEMS 및 MMICs기술을 이용하여 제작한 RF 수동/능동소자들을 MCM-D기술을 이용하여 Single Package에 집적
  - RF 소자: Switch, IF/RF filter/Duplexer, VCO, Power Amp, LNA, Mixer, Antenna



센서의 발전방향



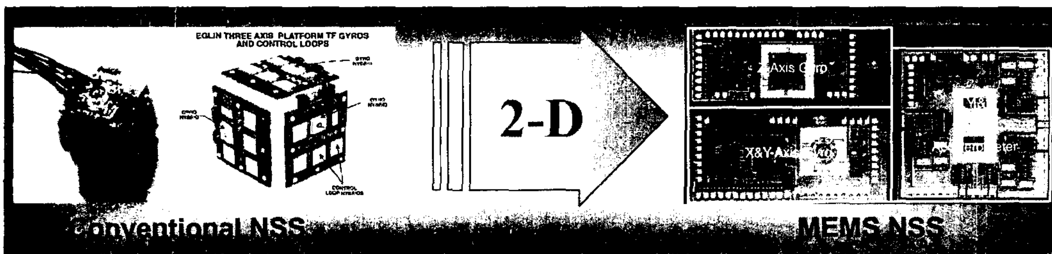
정 보 화
지 능 화
휴 대 화

- High Performance
- Small Volume
- Light Weight
- Mass Production
- Low-cost
- Low-power

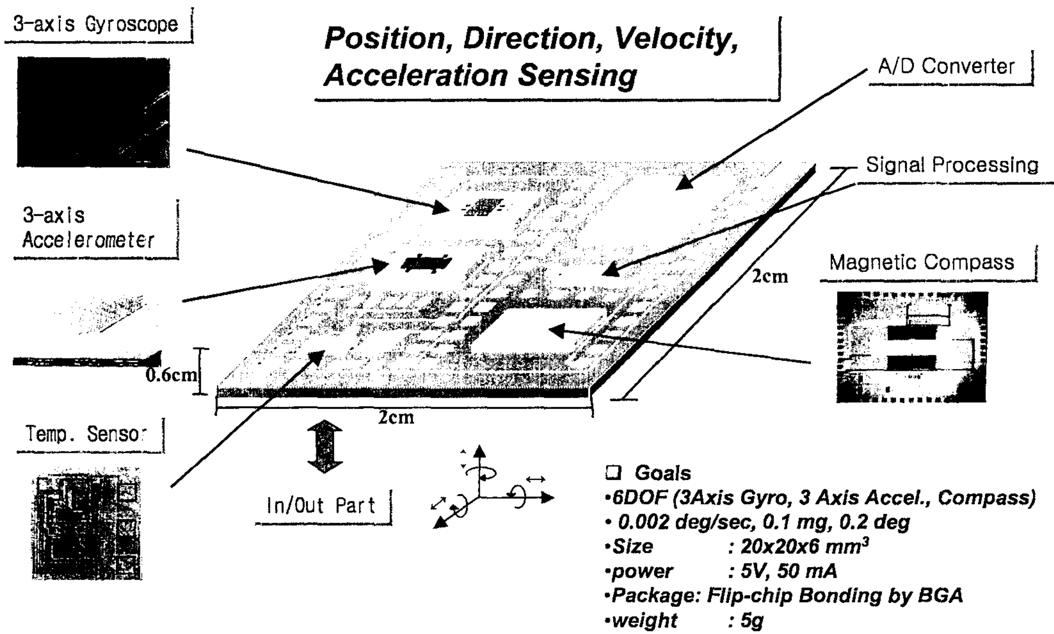
MEMS-based Silicon Technology

Navigation Sensor System 기술동향

1970	1980	1990	2000
Mass : 17kg Size : 280x300x330mm Power : ~22Watts Rate : 2deg/sec(max) Drift : 0.003deg/hr	Mass : 5kg Size : 280x200x100mm Power : ~18Watts Rate : 10deg/sec(max) Drift : 0.01deg/hr	Mass : <250gram Size: ~80x60x70mm Power : <4Watts Rate : 360deg/sec(max) Drift : 0.01deg/hr	Mass : <10gram Size: <30x30x10mm Power : <50mWatts Rate : >360deg/sec Drift : 10deg/hr (goal: 0.1deg/hr)

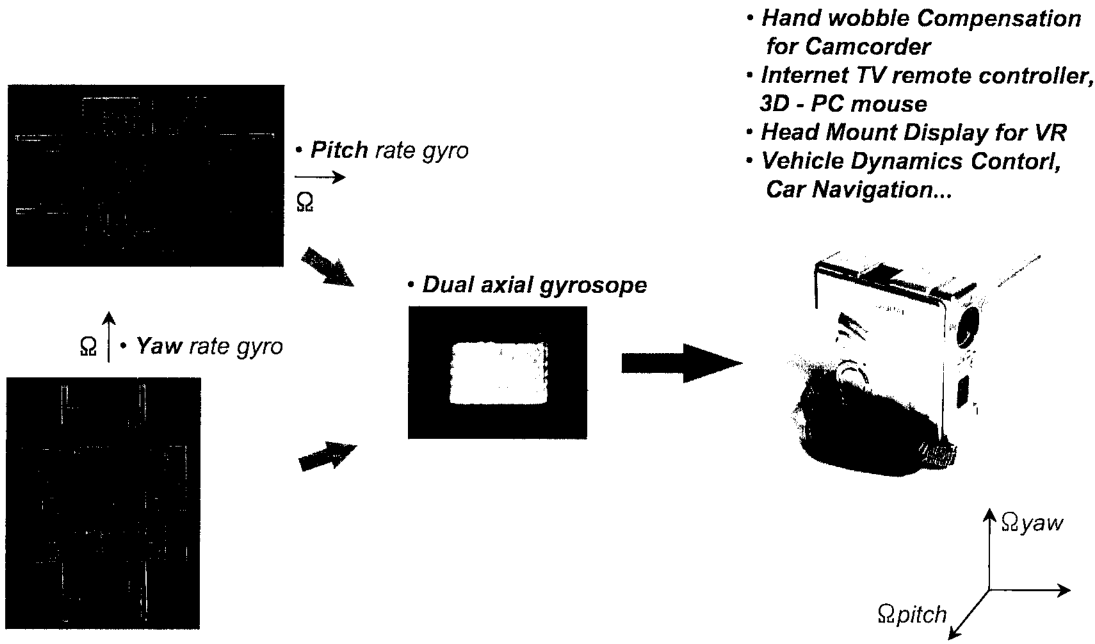


Inertia Measurement Module



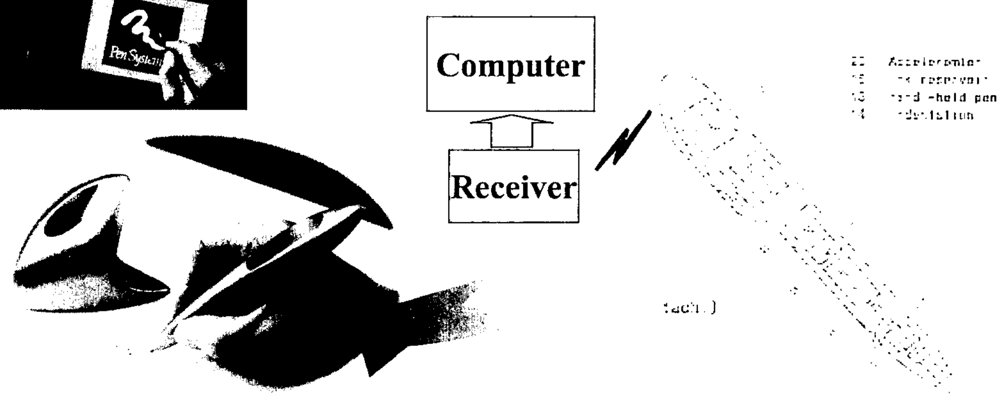
❑ Goals
- *6DOF (3Axis Gyro, 3 Axis Accel., Compass)*
- *0.002 deg/sec, 0.1 mg, 0.2 deg*
- *Size : 20x20x6 mm^3*
- *power : 5V, 50 mA*
- *Package: Flip-chip Bonding by BGA*
- *weight : 5g*

Dual axial micro-gyroscope

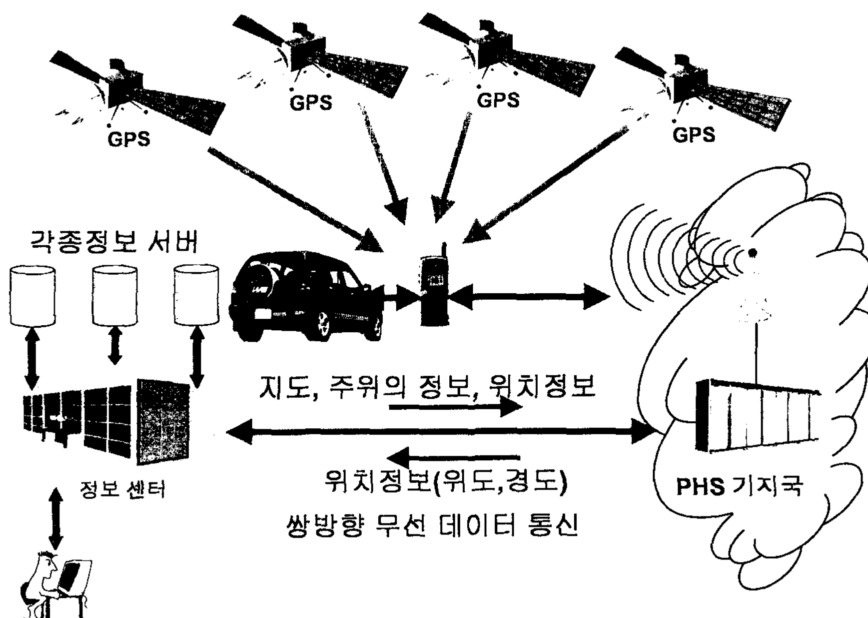


Electronic Pen System

The touchpad converts to a digitizer tablet with the touch of a button. Presentations are conveniently annotated to underscore important points. Notes, drawings and signatures can be added to on-screen documents. A variety of FreedomWriter pen tools is available.



Portable Navigation System



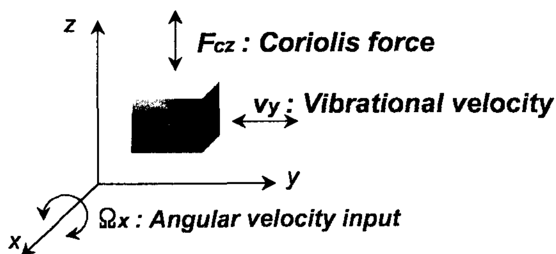
Inertia Sensor Application ROADMAP

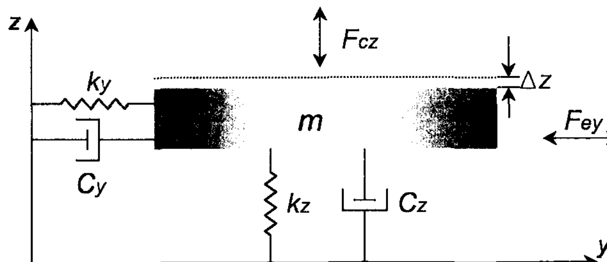
Navigation
- GPS assisted: 1~10°/hr
- Tactical: 1°/hr
- Strategic: <0.01°/hr

Automobile control
- **Roll Over: 1-10°/sec**
- **Ride Adjust: 1°/sec**
- **Skid Control: 1°/sec**

Pointing
- **Camcorder: 1~10°/sec**
- **3D Mouse : 1°/sec**

Principle of Vibratory Gyroscope





$$F_{cz} = 2mv_y \times \Omega_x$$

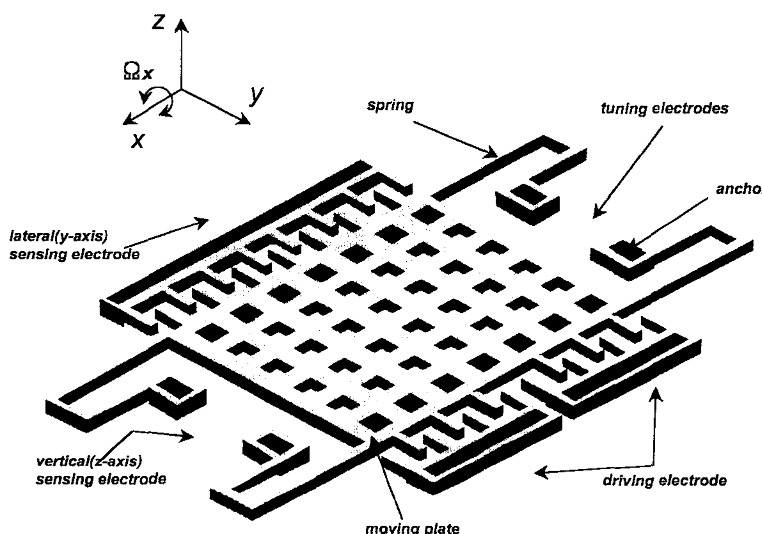
$$\frac{\Delta z}{\Omega_x} = \frac{F_{ey}}{m}\frac{Q_y}{\omega_{ry}}\frac{2}{\sqrt{\left(\omega_{ry}^2 - \omega_{rz}^2\right)^2 + \left(\frac{\omega_{ry}\omega_{rz}}{Q_z}\right)^2}}$$

- *Electrostatic driving(F_{ey} ⇔ v_y)*
- *Capacitive detection(F_{cz} ⇔ Δz)*

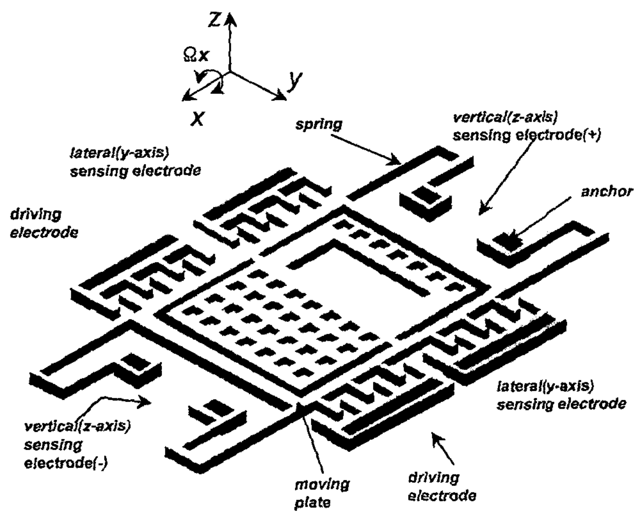
Δz : Displacement due to the Coriolis Force
F_{ey} : Electrostatic force
Q : Quality factor
ω_r : Resonant frequency
k : Stiffness

Vibratory Micro Gyroscope (Z-axis)

<Features>
•Capacitance detection
•Vertical direction sensing
•Electric stiffness control
•Differential driving
•Closed loop driving
<Surface micromaching>
•Thick poly-Si



Decoupled Vertical Gyroscope



<Features>

- Capacitance detection
- Vertical direction sensing
- Electric stiffness control
- Differential driving/Sensing
- Closed loop driving

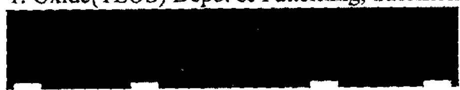
<Deep etching micromaching>

- Thick single Si
- SOI(Silicon-on-Insulator)
- SOG(Silicon-on-Glass)

** Note: $Qx=2000$, $Qy=1000$*

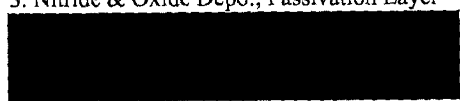
Reverse Micromachining using Single Silicon(Surface+Deep Etching)

1. Oxide(TEOS) Depo. & Patterning; Sacrificial Layer

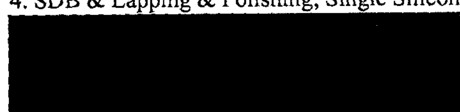


2. Poly Depo. & patterning; Bottom Electrode

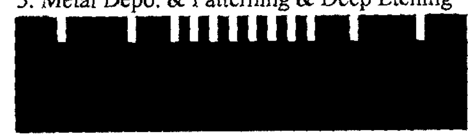
3. Nitride & Oxide Depo.; Passivation Layer



4. SDB & Lapping & Polishing; Single Silicon Structure

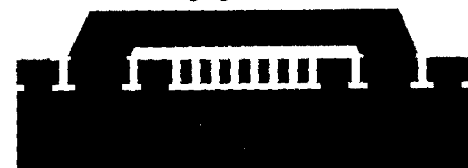


5. Metal Depo. & Patterning & Deep Etching

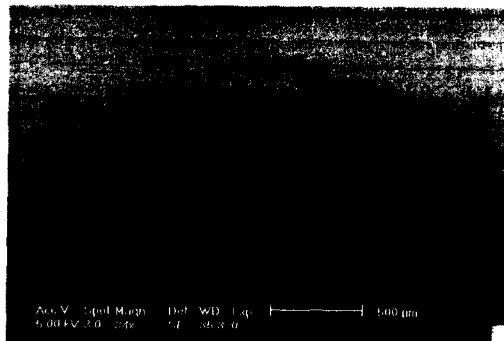


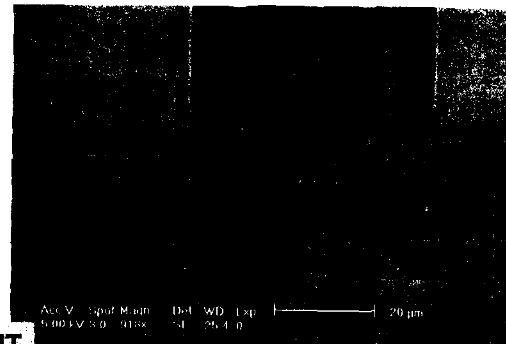
6. Oxide Remove

7. Vacuum Packaging



Decoupled Vertical Gyroscope SEM Photographs





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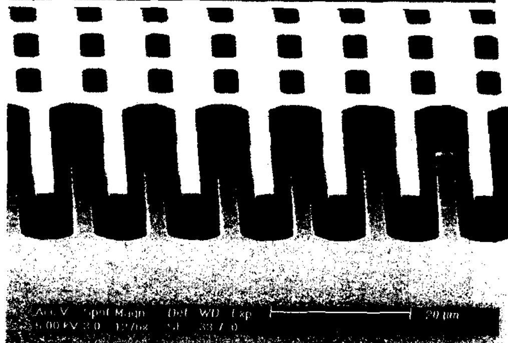
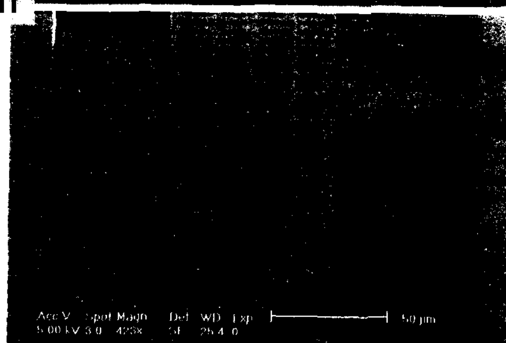
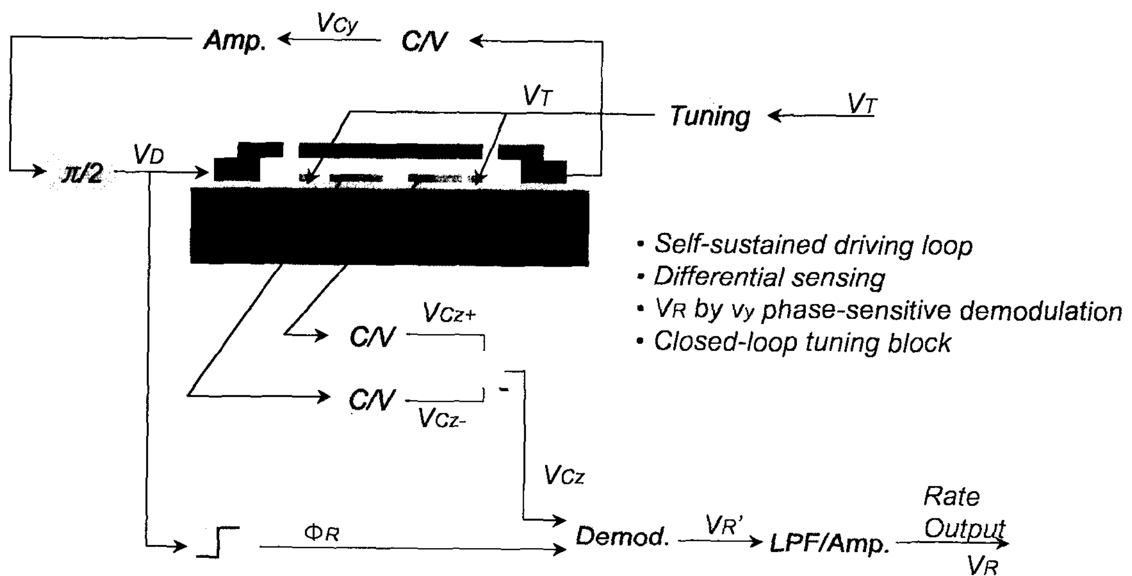




Signal Processing of Micro-gyroscope :

Closed-loop Tuning Control

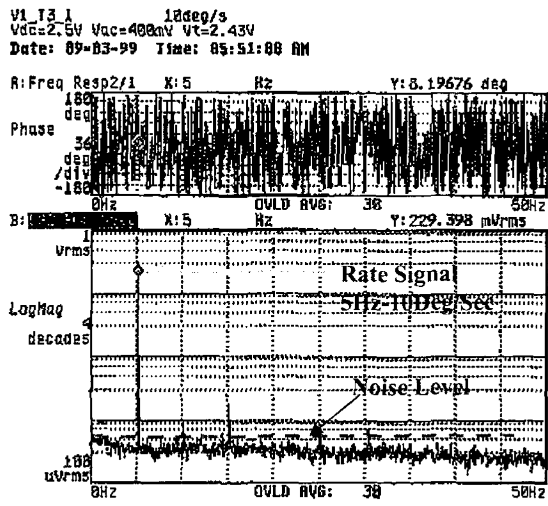


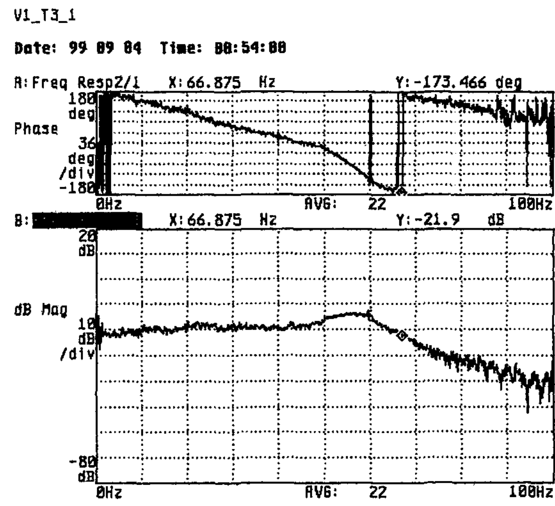
Test Results(Rate Output)

Circuit Noise : 8nV/ (@100Hz)

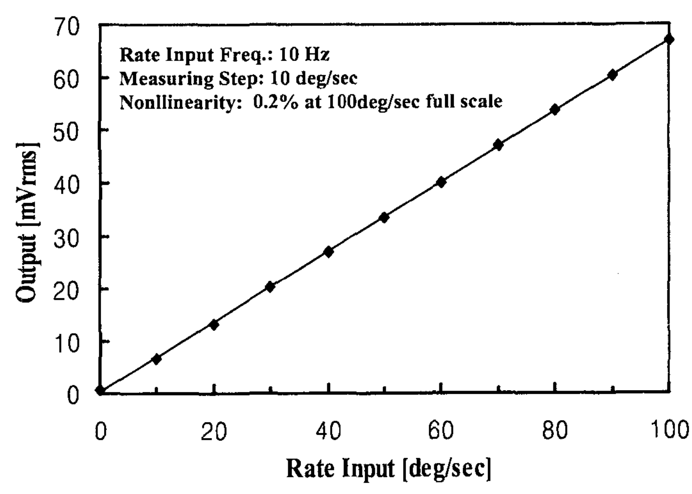
10deg/sec pk, 5Hz Angular Rate
- Demodulated Rate Output
→ Noise Equivalent Resoluble Rate
≒ 0.013deg/sec/√Hz (@5Hz)

• *@0~100[Hz] random rate input*
Bandwidth ≒ 60[Hz]

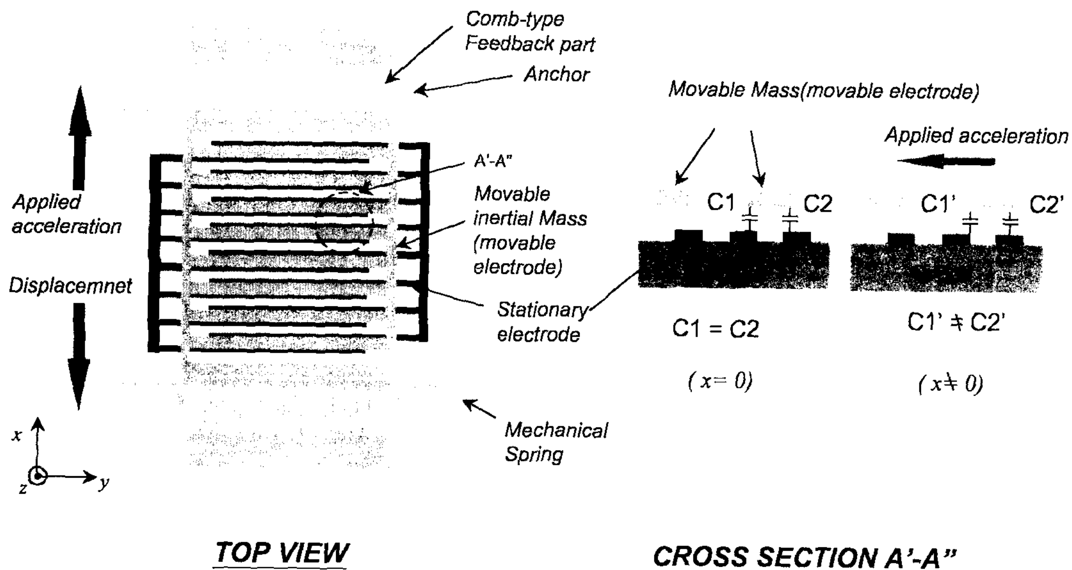




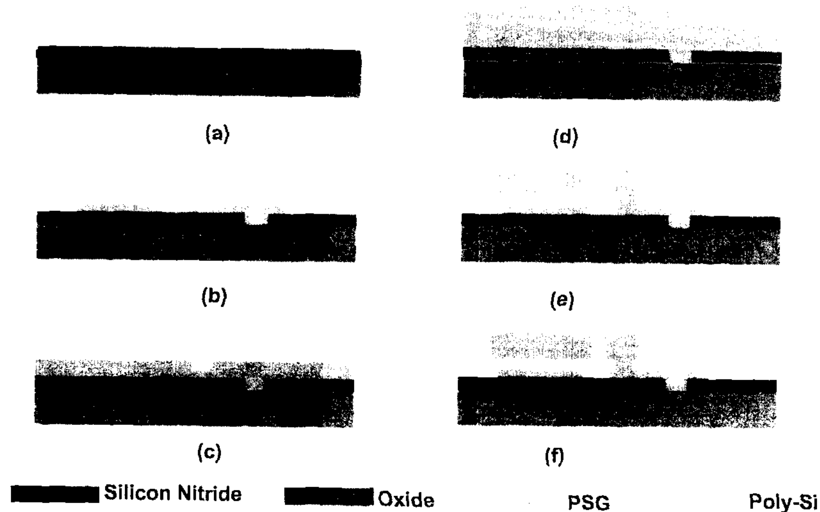
Test Results(Linearity)



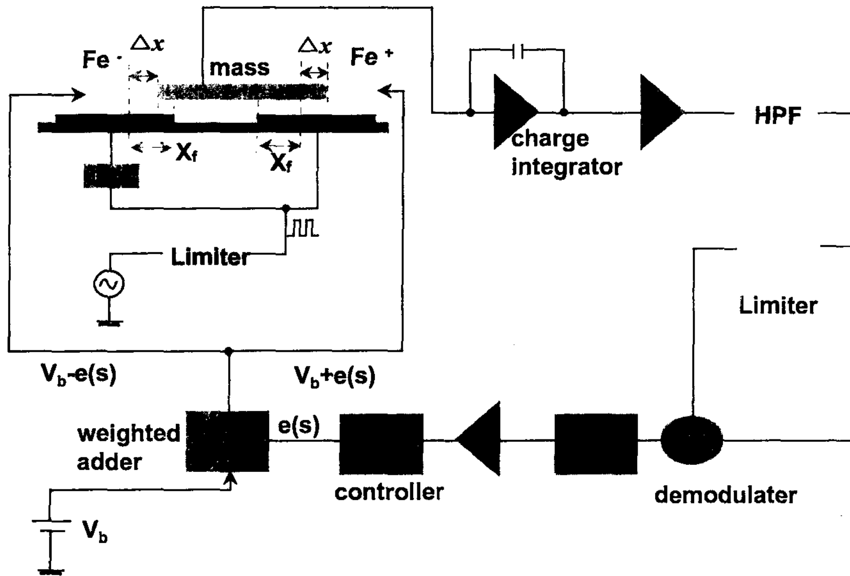
Area Variable Capacitive Microaccelerometer



Fabrication(Surface Micromaching)

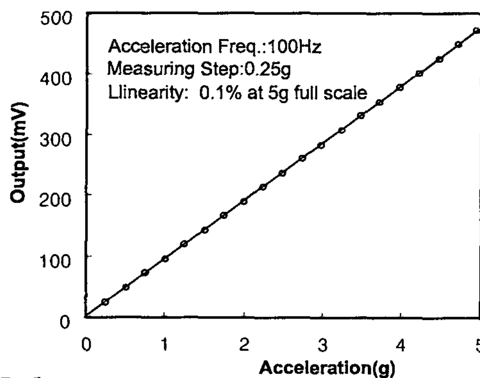


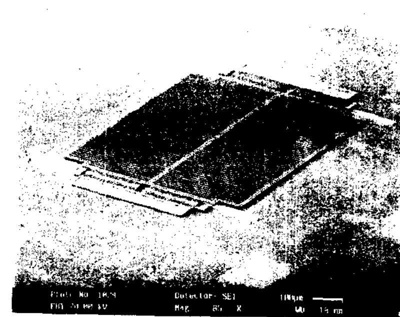
Signal Processing Circuits

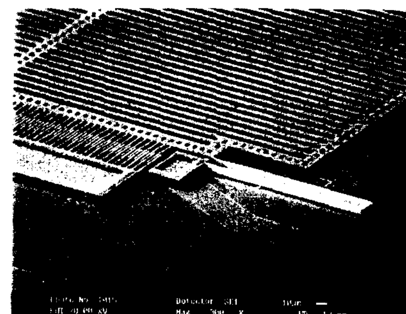


Test Results of Microaccelerometer

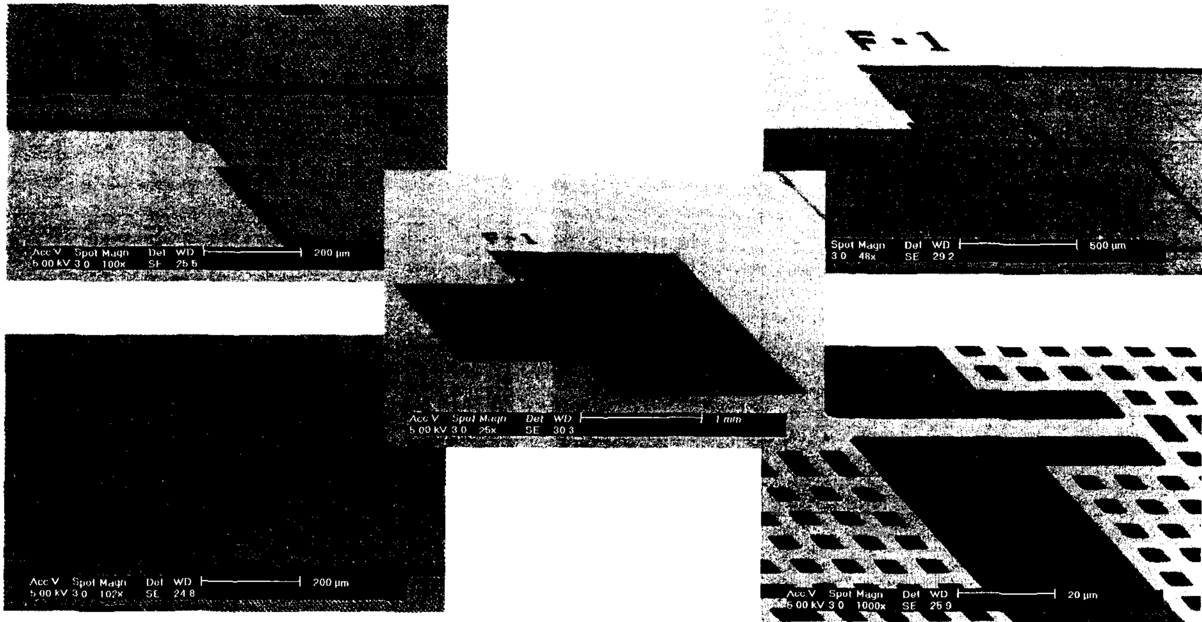
- *Area variable capacitive*
  - *7μm thick poly-Si technology*
  - *force rebalancing loop*
  - *new structure(interdigital rib-type electrodes)*
- *Performance*
  - *resolution: 3mg, bandwidth: 0~1kHz,*
  - *sensitivity: 95mV/g, dynamic range: ±5g,*
  - *linearity: 0.1% (F.S.)*



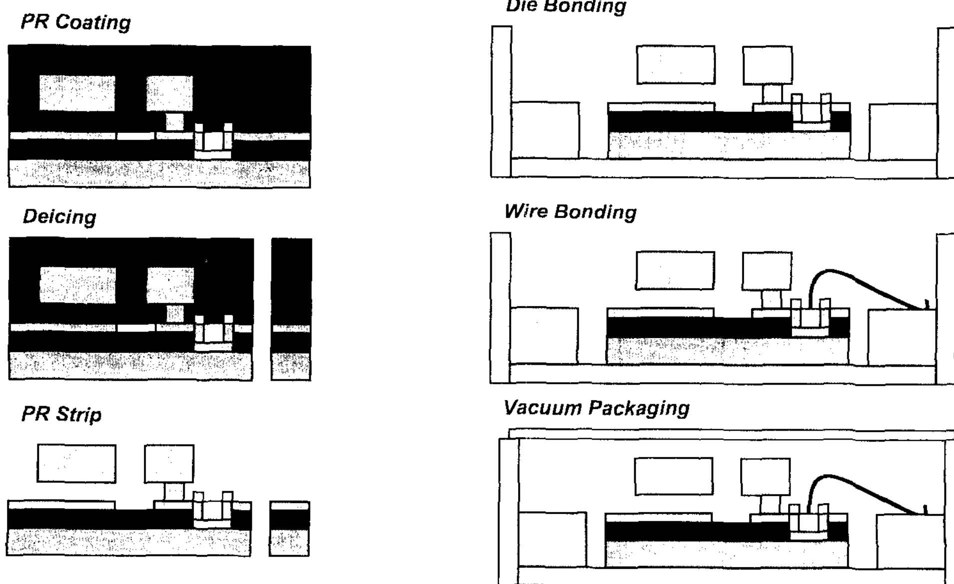




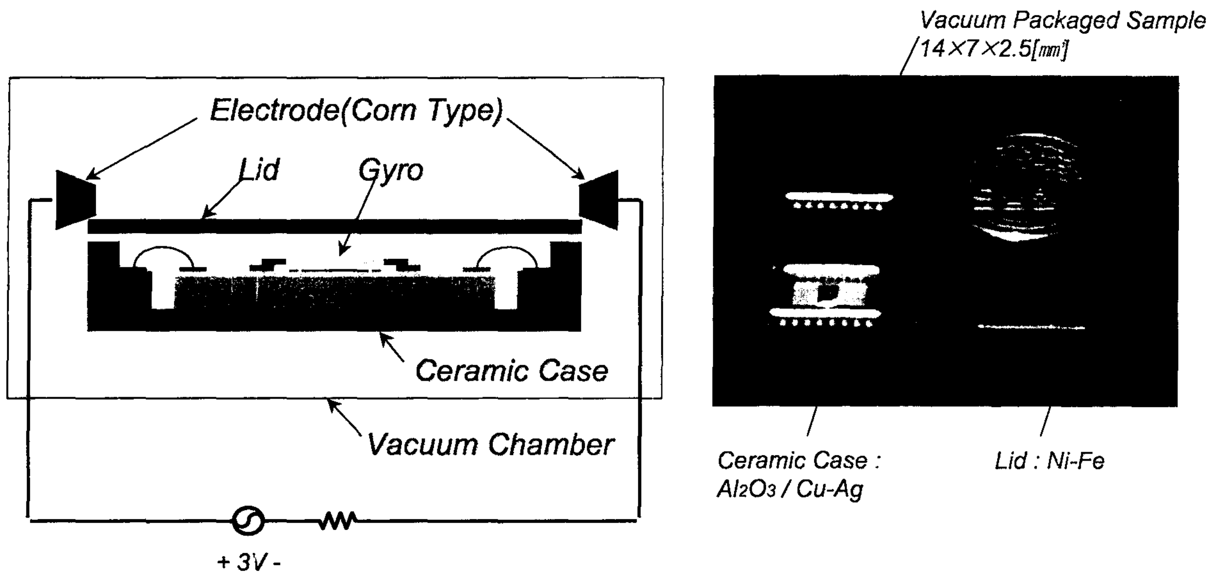
차동형 공진형 가속도계



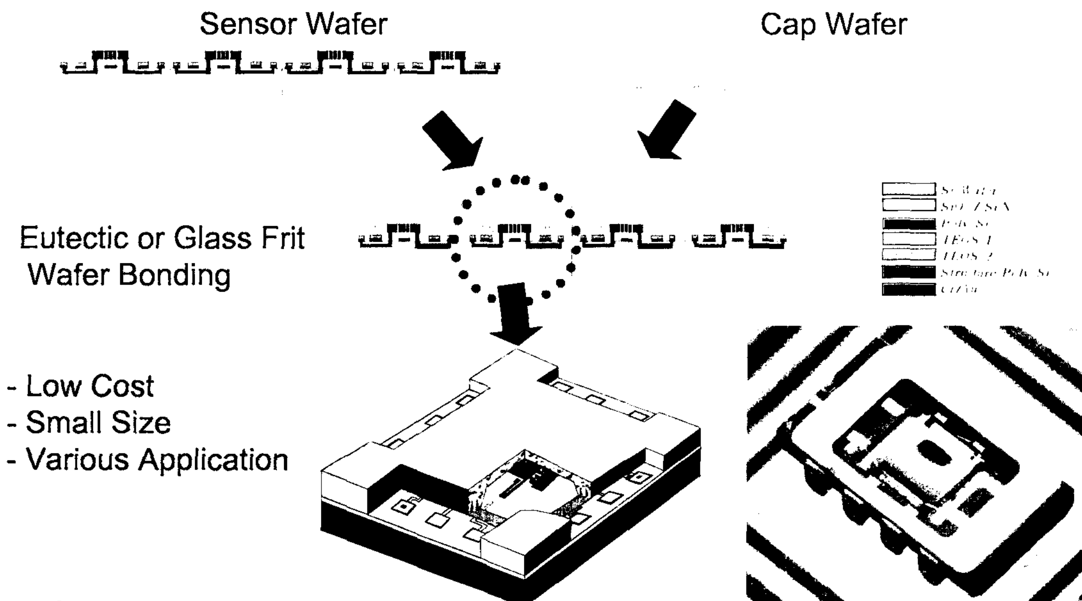
4-2. 제작공정(후공정)



4-4. 제작공정(Vacuum Packaging)

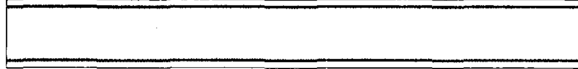


Micro Packaging ; SAIT (Wafer Level Vacuum Packaging)

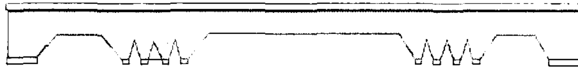


Cap Wafer Fabrication Process

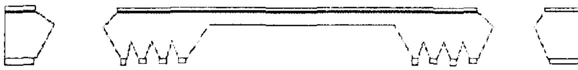
1. SiO_2 Depo.



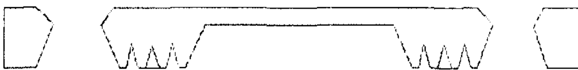
2. Si Wet Etching



3. Back Side Si Etching



4. Metal Layer Depo.

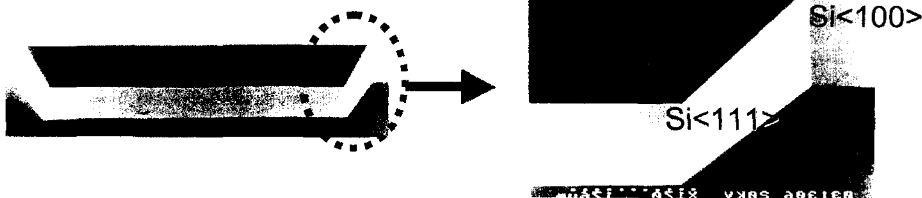


Si Bulk Etching Process Development

- Anisotropic Etching Aspect

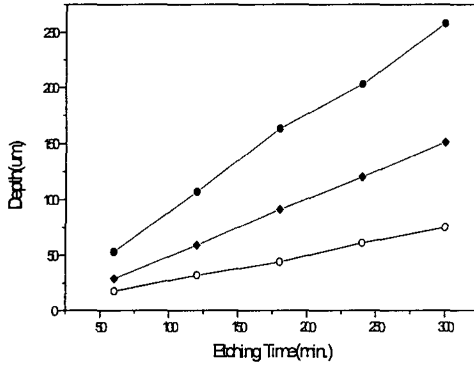
- Etching Condition
  - TMAH 20wt.%
  - Temperature : 90℃
  - Surface Roughness of <100> orientation : 0.1um (Etching Depth : 460um)

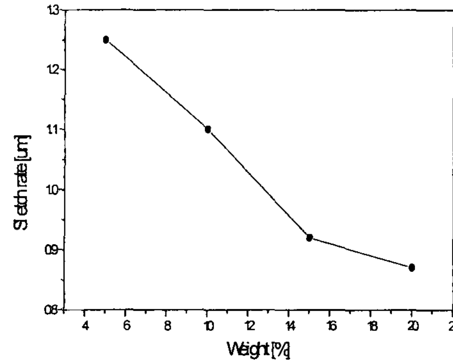
- SEM Views of Etched Si Surface



Si Etch Rate in TMAH

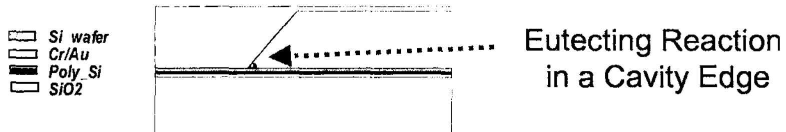
- Temperature Dependence
- TMAH Concentration Dependence

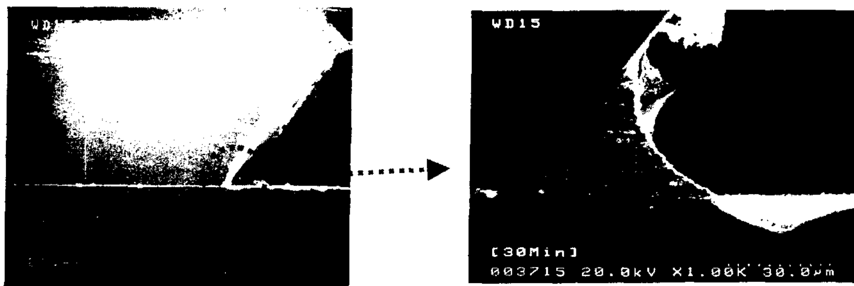




- The Higher Temperature, The Faster Etch Rate.
- The Higher Concentration, The Slower Etch Rate.
- Si <111> vs Si <100> Etch Ratio ~ 1 : 20
- Si vs SiO_2 Etch Ratio ~ 1 : 20 ~ 4600 : 1

Au/Si Eutectic Vacuum Sealing Technology



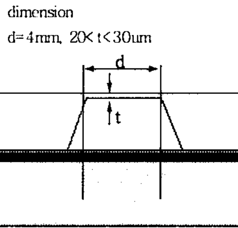


SEM EDS Analysis of Edge Accumulated Material : Au/Si Alloy

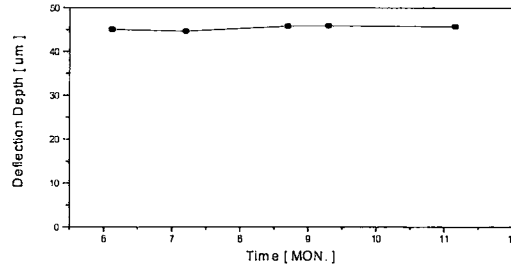
→ Main Contribution of Vacuum Sealing

Vacuum Monitoring(Laser Interferometer; 98. 6.12~)

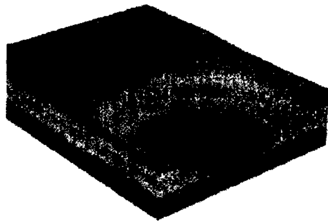
- Vacuum Cavity

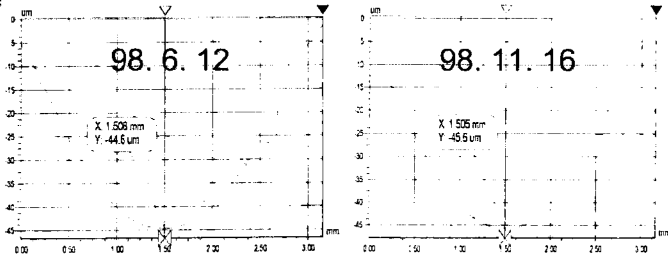


- Life-timeTest of Au/Si Bonded Vacuum Cavity



- Laser Interferometer Image





Diaphragm Depth Profiles

Vacuum Packaging Process Using Glass Frit

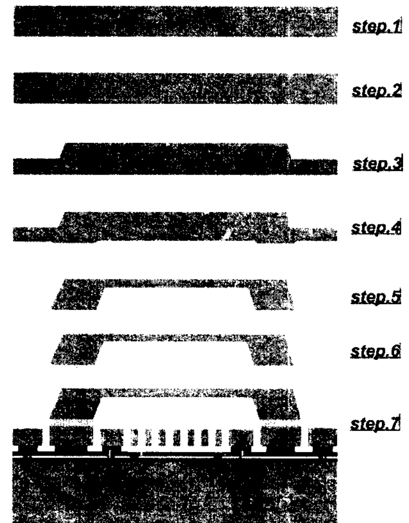
Cap Wafer 설계 및 공정(Step.1 ~ 5)
- Bulk Si etching
- Vacuum Monitoring용 다이아프램
- Feedthrough

◆ Glass Frit의 장점
- 절연체
- Interconnection 용이
- 공정이 간단함
- 공정비가 저렴
- step coverage 문제 없음

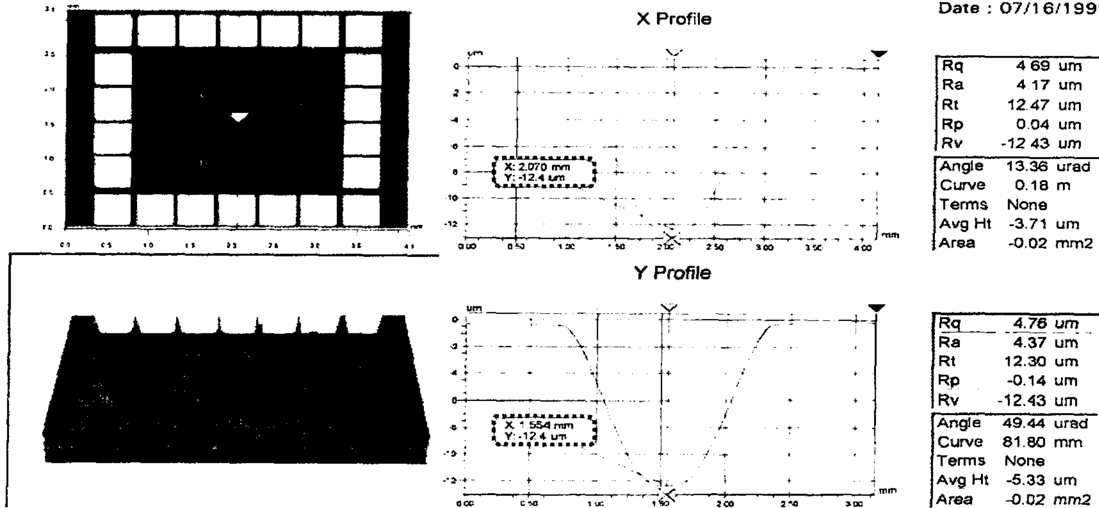
Glass Frit Paste 개발
- 목적: MEMS 공정 가능한 paste 제조
- 고려인자: 입자크기, 점도, 조성, 열팽창계수, 용융온도 등
- 제조: 대주정밀화학
- Proto명:DHG-5420

Glass Frit Depo(Step.6)
- Glass FritDepo.(20μm thick) by ScreenPrinting
- 유기용제 제거(100℃)

진공 용융접합(Step.7)
- 2단계 용융접합개발
  - 1차 용융: outgasing 제거 430℃, 30분, vacuum
  - align: sensor wafer + Cap wafer
  - 2차 용융: 진공접합 430℃, 20분, vacuum, >1psi 압력
- 진공도: 150 mTorr



Vacuum Packaged Sample Using Glass Frit

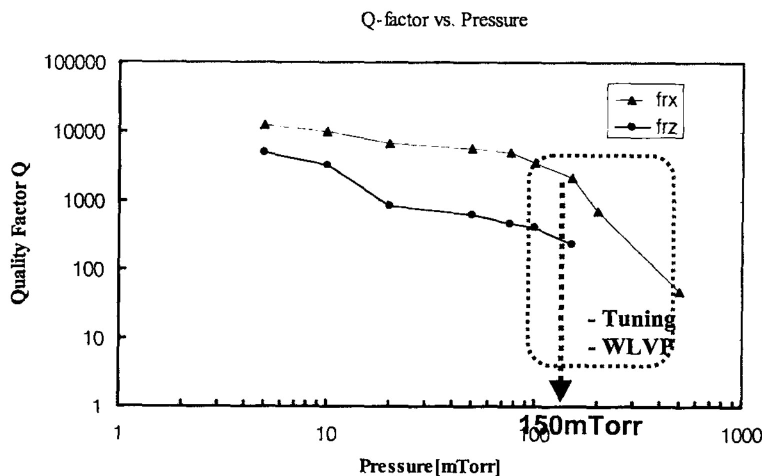


Title: B2

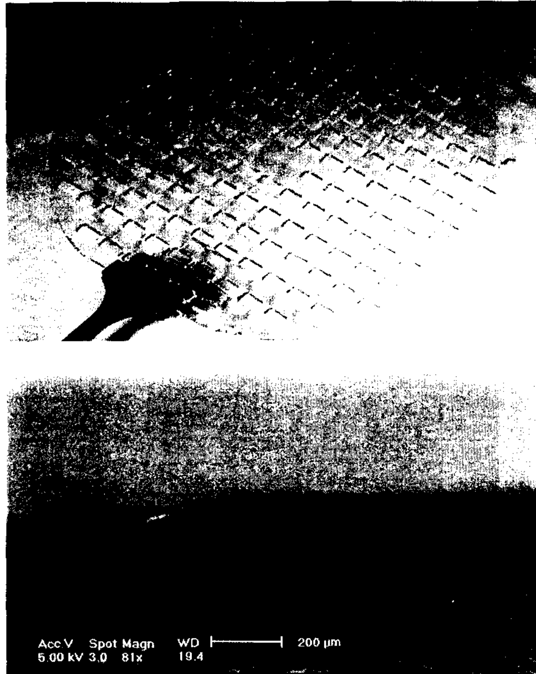
6개월 진공 유지중

Test Results(Q-factor)

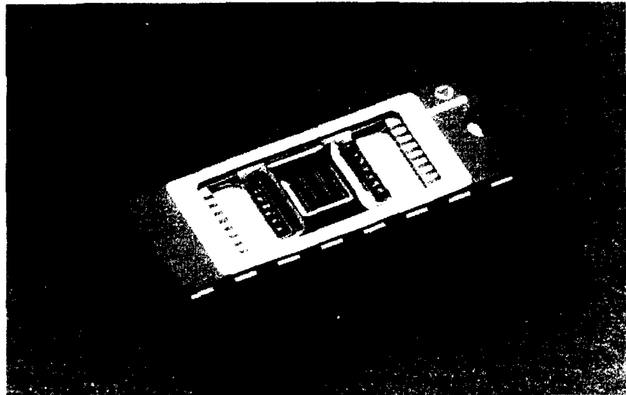
Q-Factor = $(kM)^{1/2}/C$



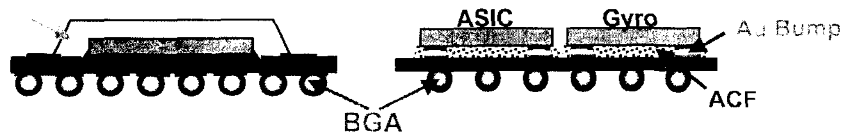
차동형 공진형 가속도계(진공 실장 결과)



- 최종 실장된 시편 외관
  - 내부 진공도 ~200mTorr



Flip-chip Package For IMU

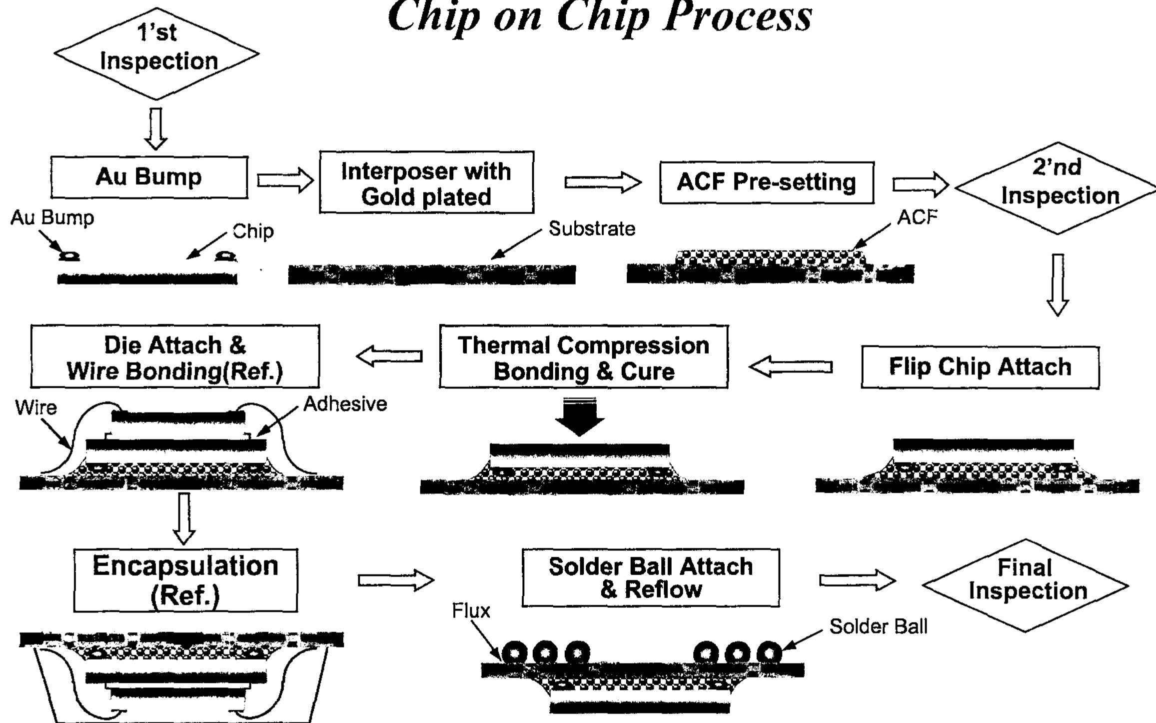


• Process	BGA (Reference)	ACF MCP (New Development)
Substrate	PCB	PCB
Adhesive	Epoxy	ACF
Interconnection	Wire Bond	Flip Chip Bond
Encapsulation	Transfer Mold	Potting / Transfer Mold
Package Thickness	Max 2.5 mm	Max 1.0 mm(Max 1.5)

• Advantage

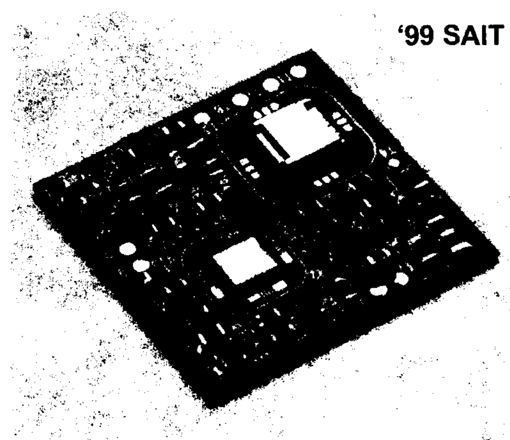
- Thinnest PKG Height : 1.5㎜t Max.
- Flip Chip Process ⇒ Thin Substrate(0.1㎜)를 이용한 Assembly 공정기술 확보
- 다른 Device의 MCP / MCM Application 가능
- High Performance(Low Noise) & Cost Effective

Chip on Chip Process

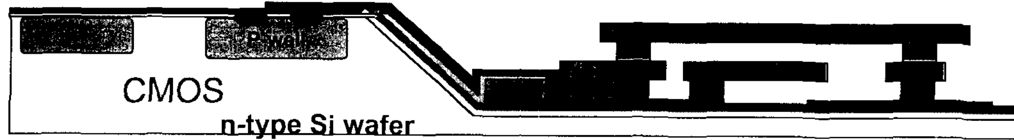


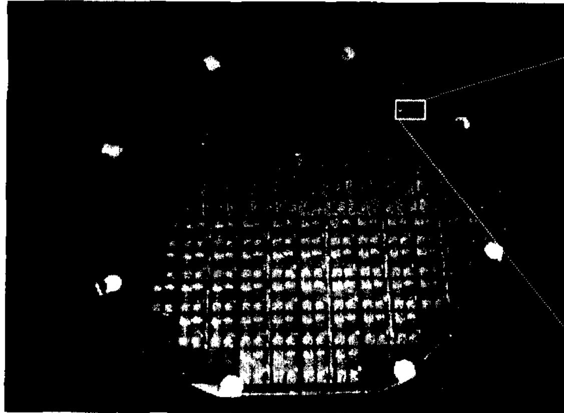
Test Results

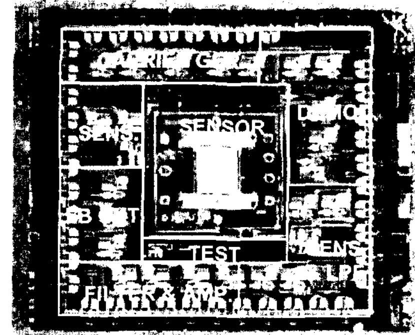
Spec.	Value
Electric Power	5 Volt single
Vacuum	150 mtorr
Bandwidth	0 - 60Hz
Nonlinearity	0.2%
Noise Equiv. Level	0.013 deg/s



Integrated MEMS

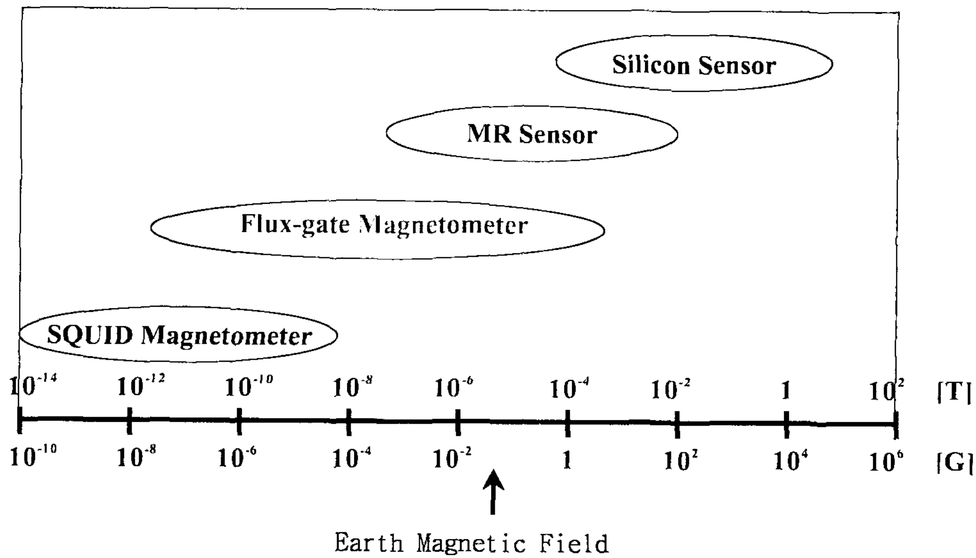






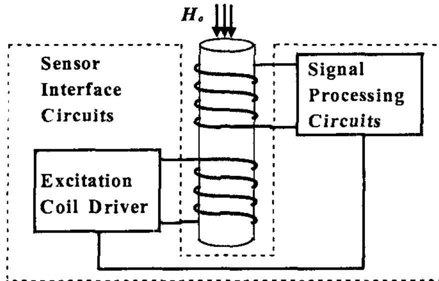
'98.3 Samsung/ Michigan Univ.

Dynamic Range of Magnetic Sensors



Flux-gate Magnetic Sensor

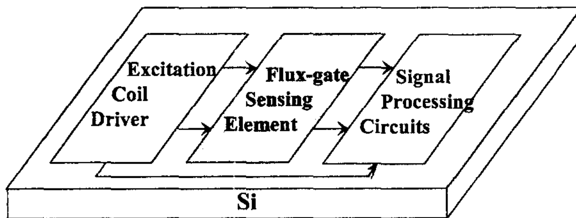
• **Conventional Flux-gate**



- High Sensitivity
- High Resolution at Room Temperature

- Large Volume, Weight
- High Fabrication Cost

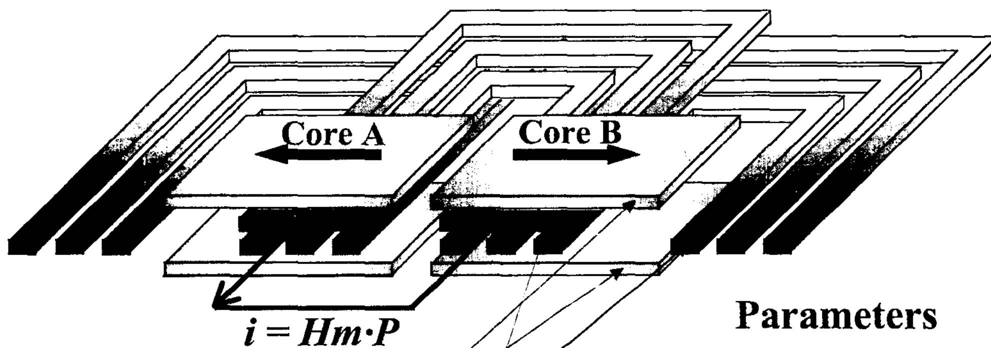
• **Monolithic Silicon Flux-gate**



• **Magnetic Thin Film + Micro Coil**
• **Silicon Process Technology**

- Possibility of high Frequency Excitation (L, C : Small)
  ➡ Wide Frequency Dynamic Range
- Small Size, Light Weight, Low Cost, High Sensitivity, High Resolution
  ➡ Various Fascinating Application

Sensing Element Structure



$i = Hm \cdot P$

★ **Basic Structure**

Sandwich Core

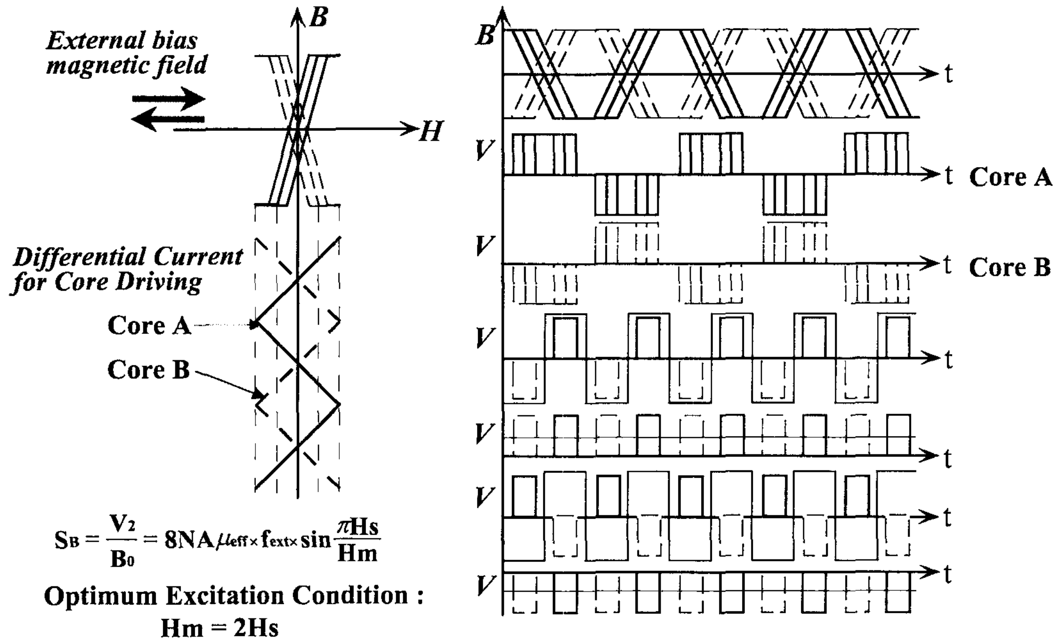
Differential Drive Coil

Pick-up Coil

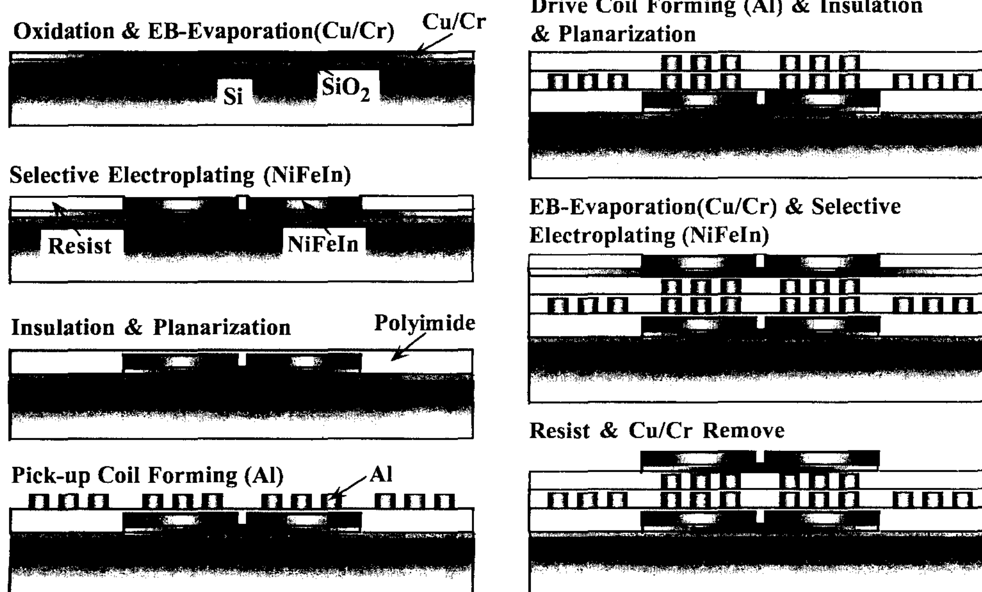
Parameters

Core	Length	1200μm
	Width	600μm
	Thickness	2μm
Coil	Pitch	20μm
	Turns(Exc./Pick-up)	40/40
	R(Exc./Pick-up)	113/226
Iexc.	Exc. Current	40mA

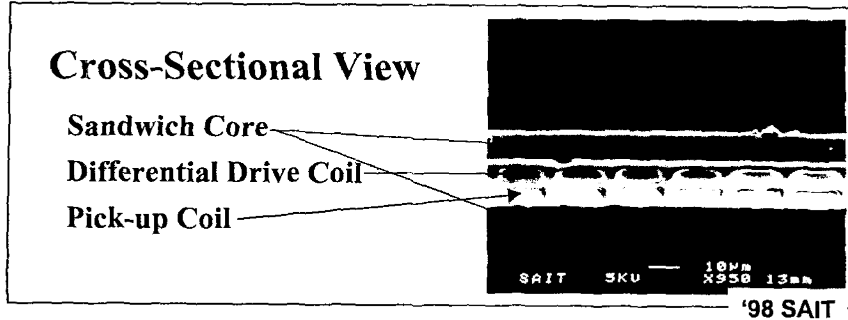
Sensing Principle

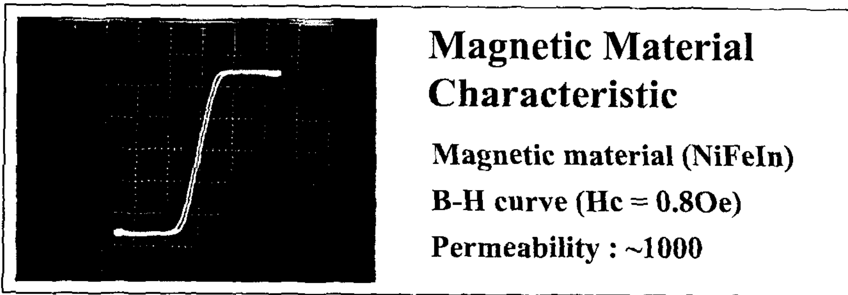


Fabrication Process



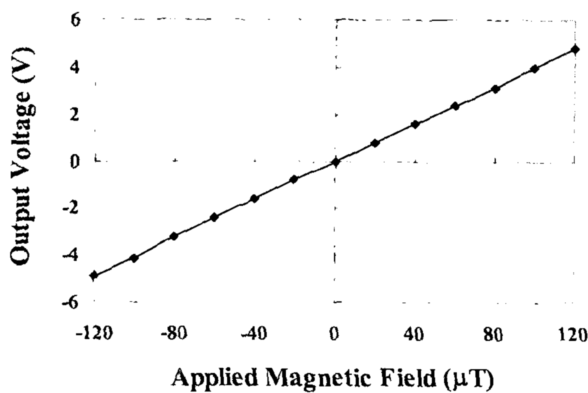
Fabricated Sensing Element Chip

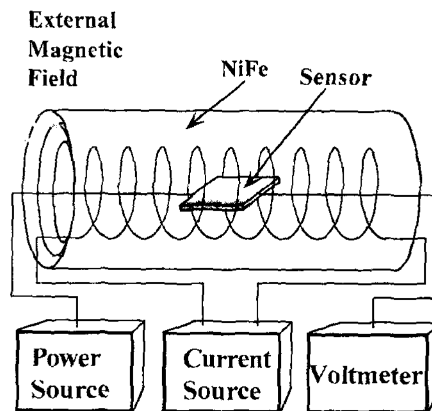




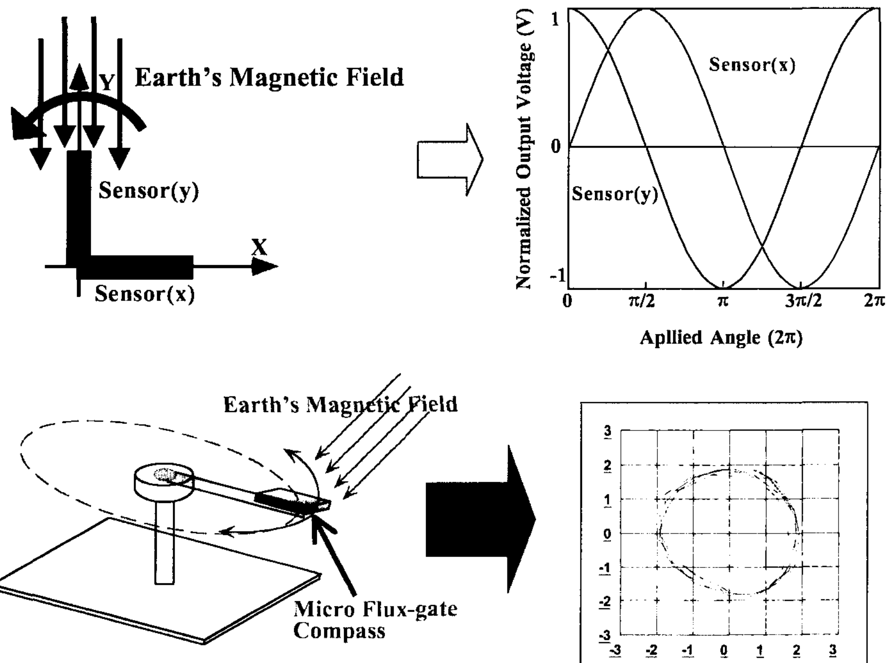
Test Results(Linearity)

- Performance
  - System Sensitivity: 40000V/T
    (Sensing Element Sensitivity : 280V/T, Driving Frequency :1MHz)
  - Dynamic Range: ± 120mT
  - Linearity: 0.6% (F.S.)





Tracking Using Direction Data



Summary

- MEMS(Micro Electro Mechanical System) technology
- MEMS Inertial Sensors promise a new wide market for many areas
  - Challenge
    - significant cost reduction by wafer level packaging and testing
    - decreasing of power consumption by miniaturization
    - enhancing of performance and reliability
    - on-chip integration for multiplicity
- MEMS is newly emerging technology