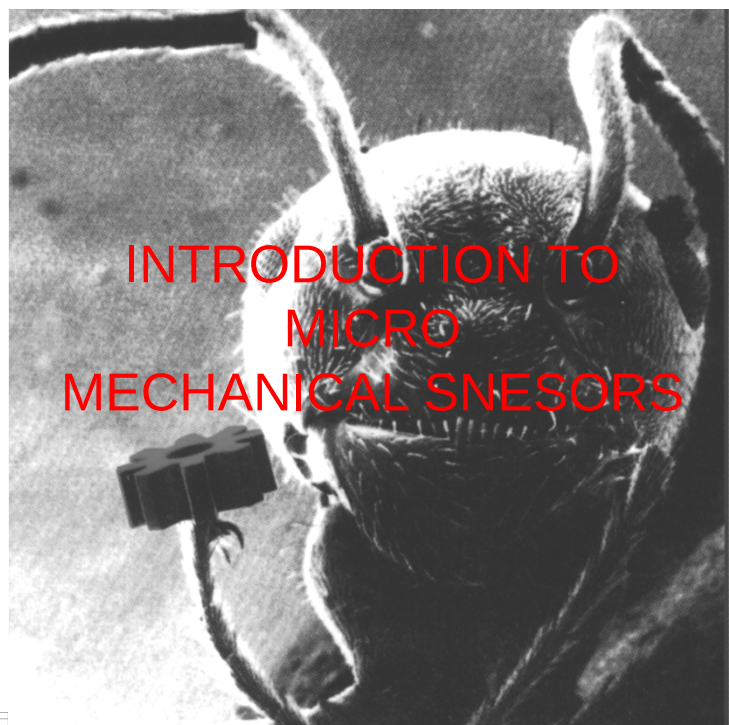




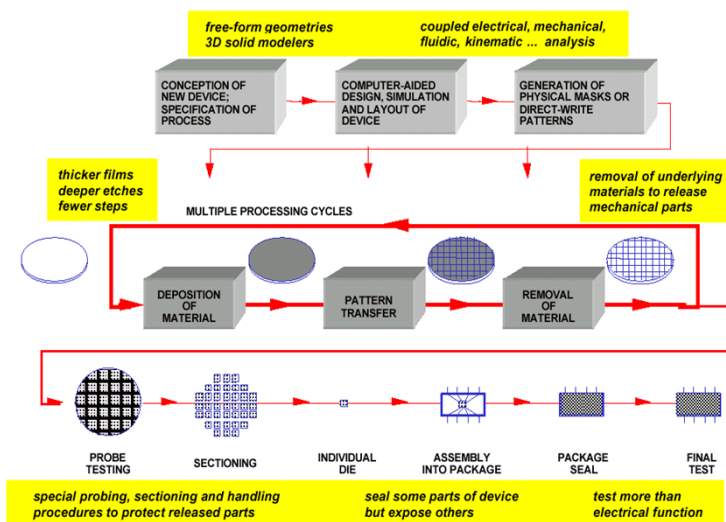
TU50235100

100年6月14日

周元昉

MEMS vs. IC process flow

NTU50235100



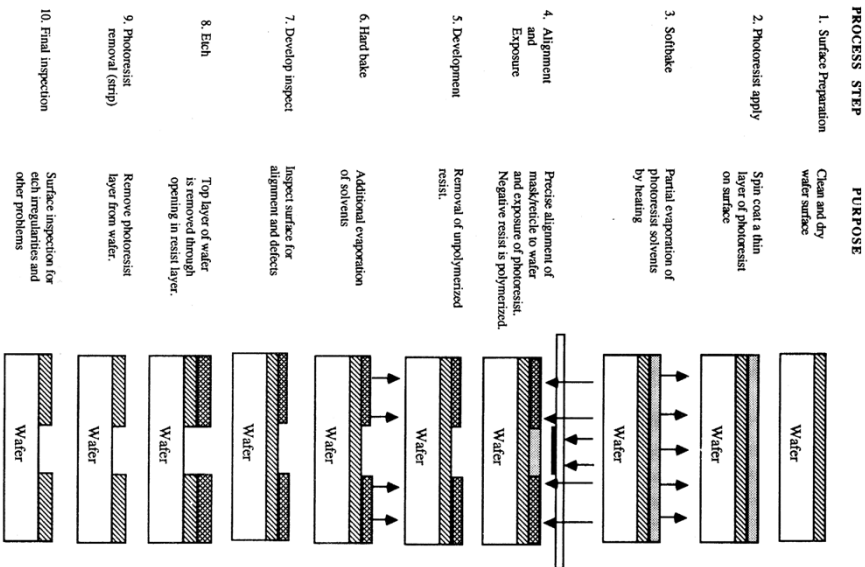
(Kaigham Gaberiel, CMU)

100年6月14日

周元昉

NTU50235100

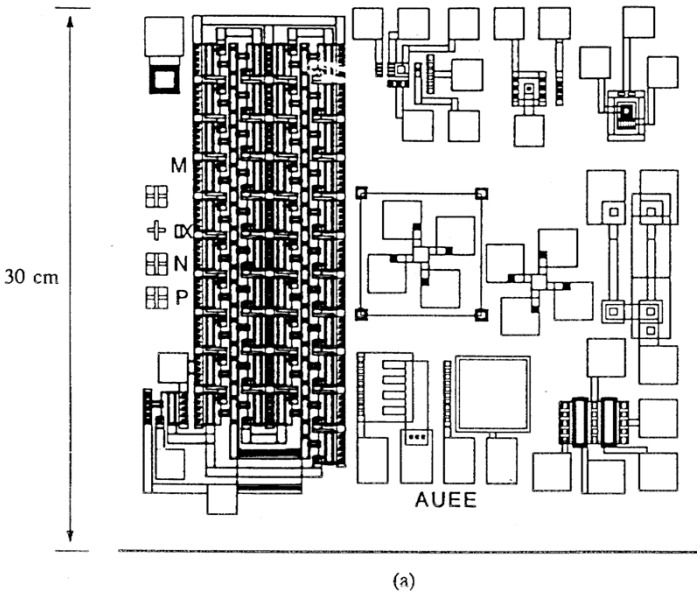
Lithography process



周元昉

100年6月14日

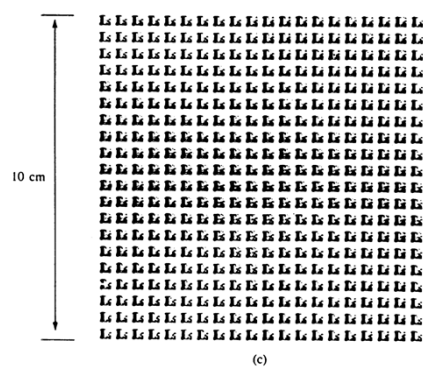
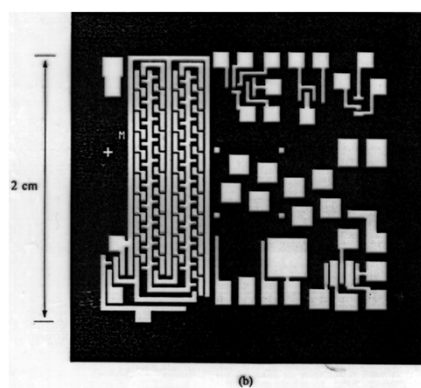
NTU50235100



周元昉

100年6月14日

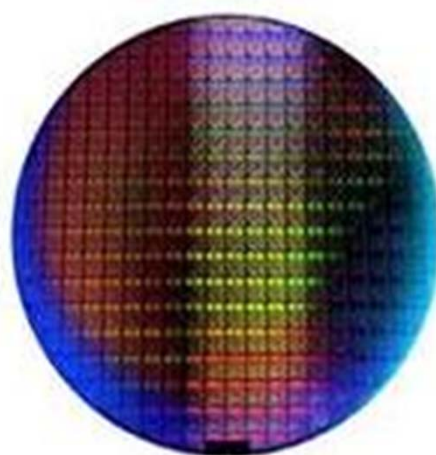
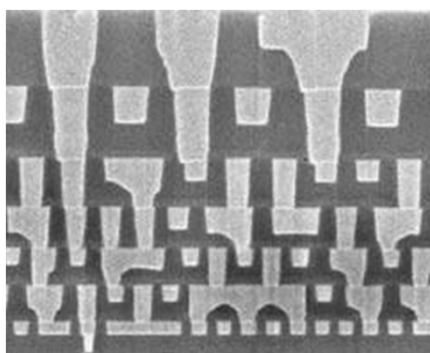
NTU50235100



100年6月14日

周元昉

NTU50235100

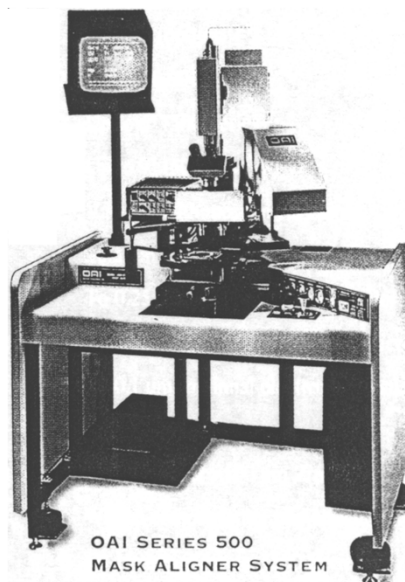


100年6月14日

周元昉

NTU50235100

Mask Aligner

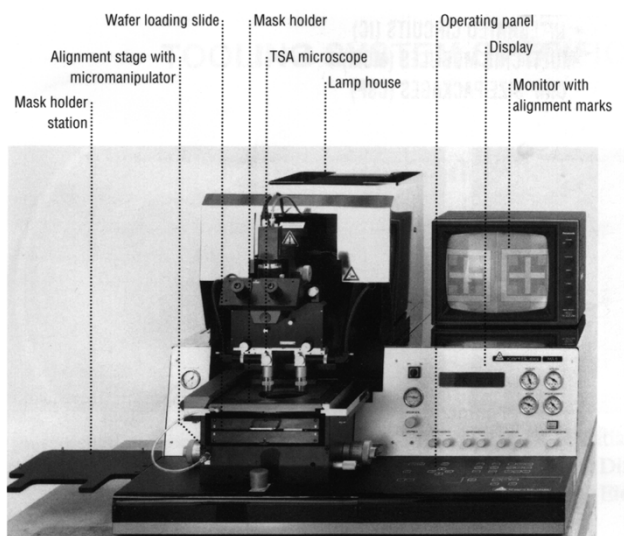


100年6月14日

周元昉

NTU50235100

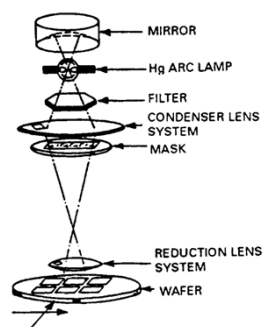
Mask aligner



100年6月14日

周元昉

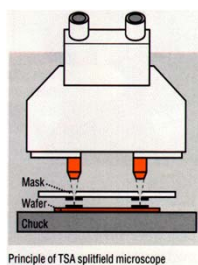
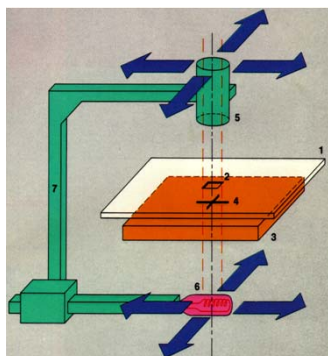
Stepper



NTU50235100

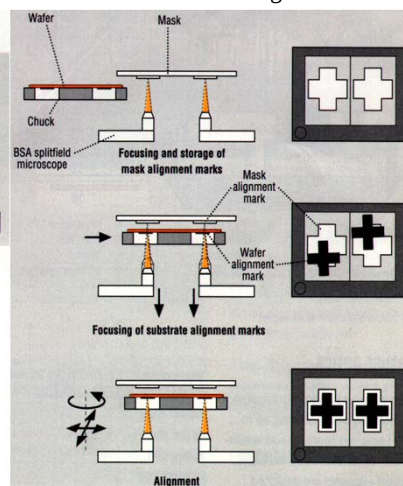
Double-side alignment

Infrared illumination



Principle of TSA splitfield microscope

Bottom side alignment

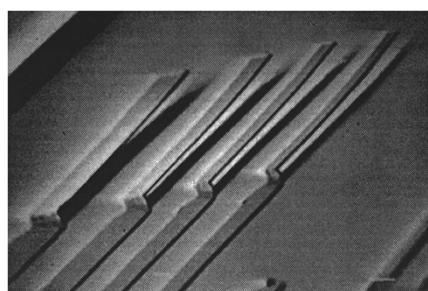
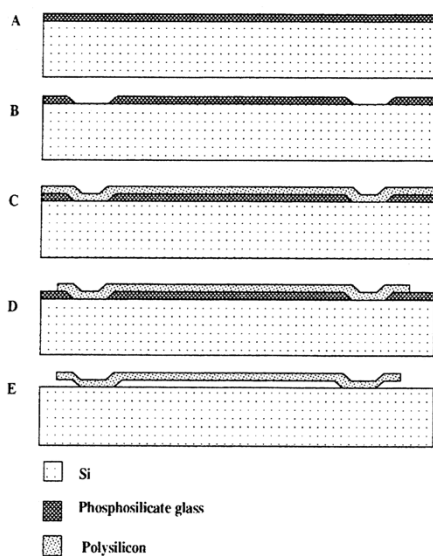


100年6月14日

周元昉

NTU50235100

Surface Micromachining



(Howe and Muller, 1982)

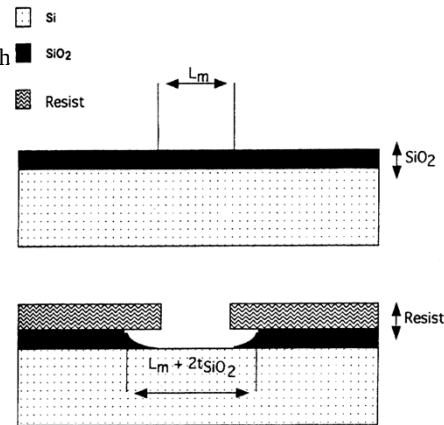
100年6月14日

周元昉

NTU50235100

Fabrication steps

- Pattern transfer to SiO_2 buffer/isolation layer
 - (- A blanket n^+ diffusion layer defining ground plane)
 - Buffer/isolation passivation layer: thermal oxide; LPCVD nitride etc.
 - Wet pattern transfer to SiO_2 film
 - * buffered HF (e.g., $\text{NH}_4\text{F}:\text{HF}=5:1$) isotropic etch (unbuffered HF attacks the photoresist)
 - * monitoring the color change or observing the hydrophobic/hydrophilic behavior
 - * strip resist in a piranha etch bath
 - * BHF dip
 - Pattern transfer to nitride/oxide film
 - * dry etch (e.g., SF_6 plasma) followed by a 5:1 BHF etch



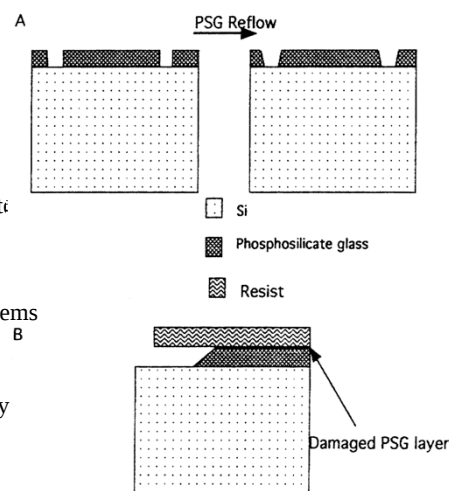
100年6月14日

周元昉

NTU50235100

• Base (spacer, sacrificial) layer deposition and etching

- LPCVD phosphosilicate glass (PSG) layer
 - * high etch rate in HF
 - * diffusion dopant source
 - * help to control window taper
- Densify PSG at 950 °C for 30 min to 1 hr in a wet oxygen ambient to obtain a uniform etch rate
- Windows in the base layer are used to make anchors onto the buffer/isolation layer
- Tapered window can minimize coverage problems
 - * plasma etching: introduce etch rate gradient
 - * reflow of the etched spacer
 - * ion implantation of PSG has created a rapidly etching, damaged PSG layer



A: taper by reflow; B: taper by ion implantation

100年6月14日

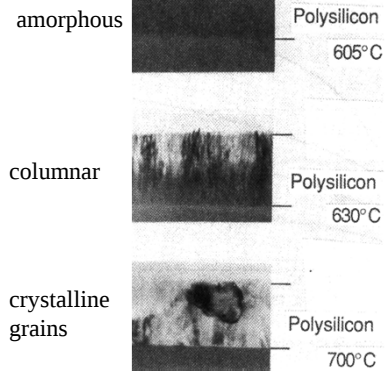
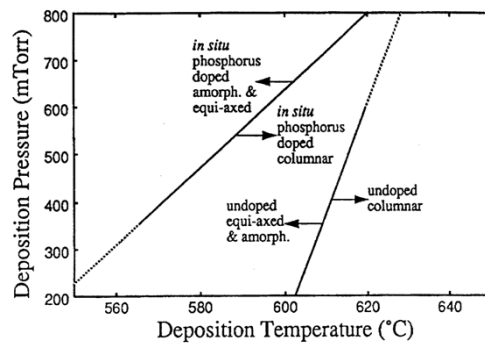
周元昉

NTU50235100

- Deposition of structural material
- CVD provides best coverage over the base window
- LPCVD polysilicon is the most widely used structural material

* structures

- . below 575 °C: amorphous
- . above 625 °C: columnar structured poly-Si
- . heat amorphous or columnar poly-Si : crystalline grains growth



100年6月14日

周元昉

NTU50235100

- Selective etching of spacer layer

R_m : etch rate of microstructural element
 R_s : etch rate of spacer layer
 R_i : etch rate of insulator layer

$$R_s \gg R_m \text{ and } R_s \gg R_i$$

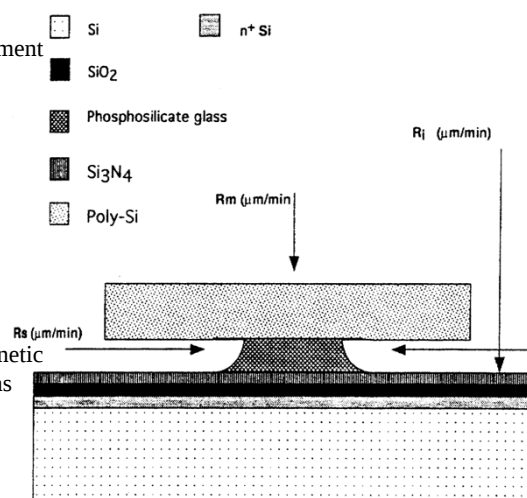
$$\text{HF:HCl}=1:1$$

$$R_{\text{SiO}_2}:R_{\text{Si}_3\text{N}_4}=310$$

$$\text{HF:H}_2\text{O}=1:1$$

$$R_{\text{SiO}_2}:R_{\text{Si}_3\text{N}_4}=91$$

- The etching reaction shifts from kinetic controlled to diffusion controlled as the etch channel becomes longer

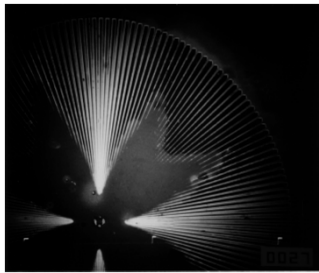
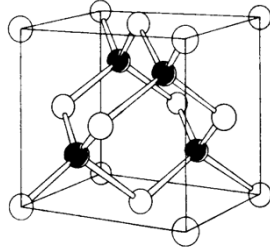


100年6月14日

周元昉

NTU50235100

Silicon Bulk Micromachining



Etching rate normal to [100] direction

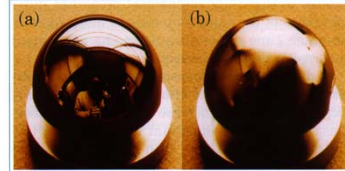


Fig. 1 Silicon test piece before and after etching

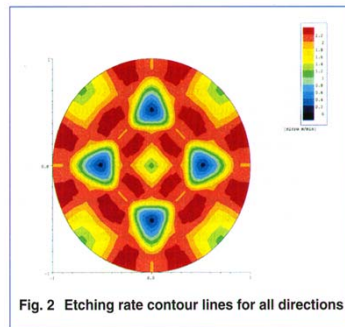


Fig. 2 Etching rate contour lines for all directions

Kazuo Sato, Nagoya University

周元昉

NTU50235100

Anisotropic etching of Si

Etchant/Diluent/Additives/ Temperature	Etch Stop	Etch Rate (100) ($\mu\text{m}/\text{min}$)	Etch Rate Ratio (100)/(111)	Remarks	Mask (Etch Rate)
KOH/water, isopropyl alcohol additive, 85°C	$B > 10^{20} \text{ cm}^{-3}$ reduces etch rate by 20	1.4	400 and 600 for (110)/(111)	IC incompatible, avoid eye contact, etches oxide fast, lots of H_2 bubbles	Photoresist (shallow etch at room temperature); Si_3N_4 (not attacked); SiO_2 (28 Å/min)
Ethylene diamine pyrocatechol (water), pyrazine additive, 115°C	$\geq 5 \times 10^{19} \text{ cm}^{-3}$ reduces the etch rate by 50	1.25	35	Toxic, ages fast, O_2 must be excluded, few H_2 bubbles, silicates may precipitate	SiO_2 (2–5 Å/min); Si_3N_4 (1 Å/min); Ta, Au, Cr, Ag, Cu
Tetramethyl ammonium hydroxide (TMAH) (water), 90°C	$> 4 \times 10^{20} \text{ cm}^{-3}$ reduces etch rate by 40	1	From 12.5 to 50	IC compatible, easy to handle, smooth surface finish, few studies	SiO_2 etch rate is 4 orders of magnitude lower than (100) Si LPCVD Si_3N_4
N_2H_4 (water), isopropyl alcohol, 115°C	$> 1.5 \times 10^{20} \text{ cm}^{-3}$ practically stops the etch	3.0	10	Toxic and explosive, okay at 50% water	SiO_2 (<2 Å/min) and most metallic films; does not attack Al according to some authors ¹⁰⁴

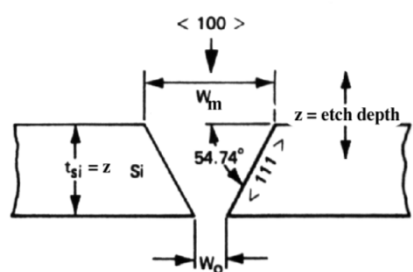
* Given the many possible variables, the data in the table are only typical examples.

100年6月14日

周元昉

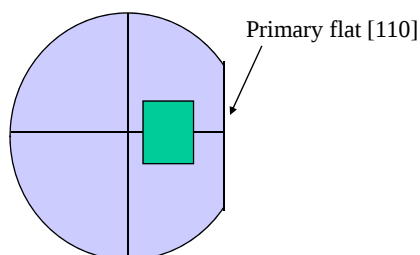
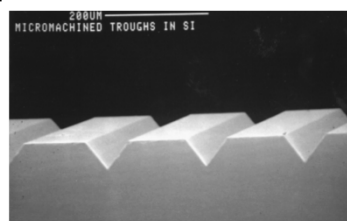
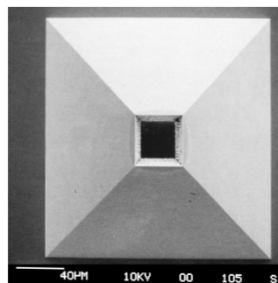
NTU50235100

• Anisotropic etching of (100) Si



ANISOTROPIC ETCHING OF <100> SILICON

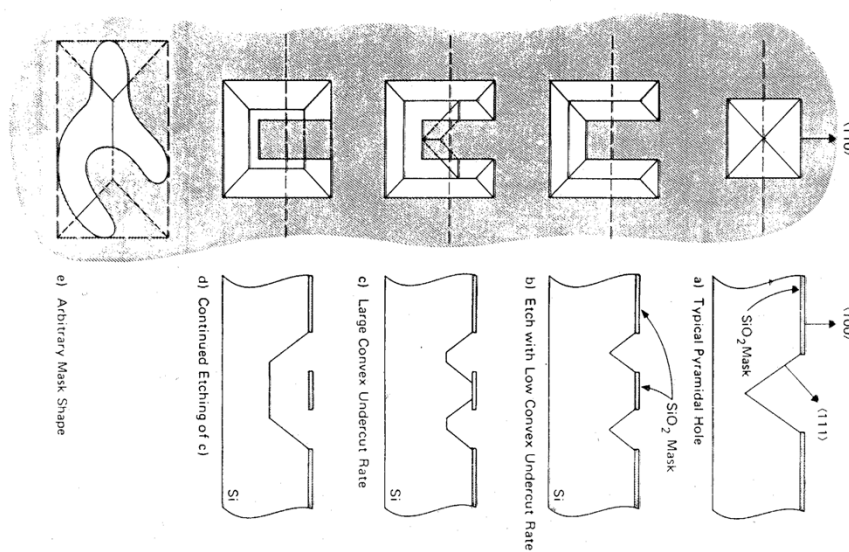
$$W_o = W_m - 2z / \tan(54.74^\circ)$$



100年6月14日

周元昉

NTU50235100

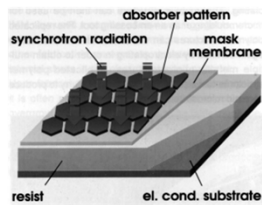


100年6月14日

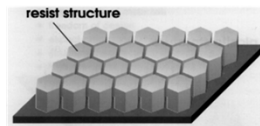
周元昉

NTU50235100

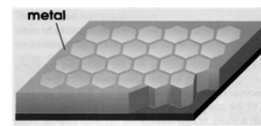
LIGA Fabrication process



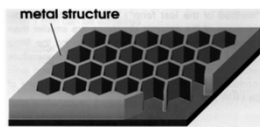
(1) 壓克力在X光下曝光



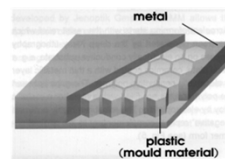
(2) 將曝光部分去除得一壓克力模



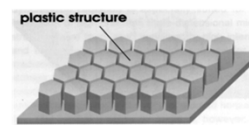
(3) 以電鍍方式填滿模穴



(4) 溶掉壓克力後得一金屬模



(5) 此金屬模可作為塑膠成形模



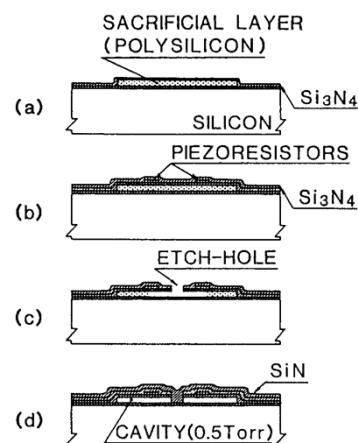
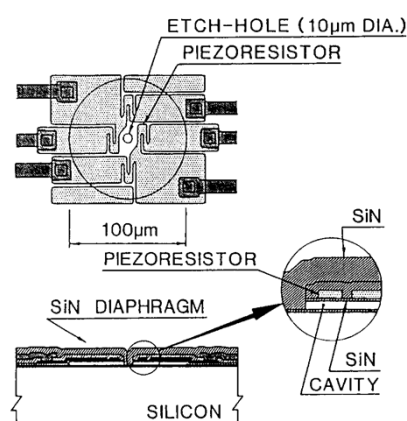
(6) 翻製的塑膠結構

100年6月14日

周元昉

NTU50235100

Micro Pressure Sensors



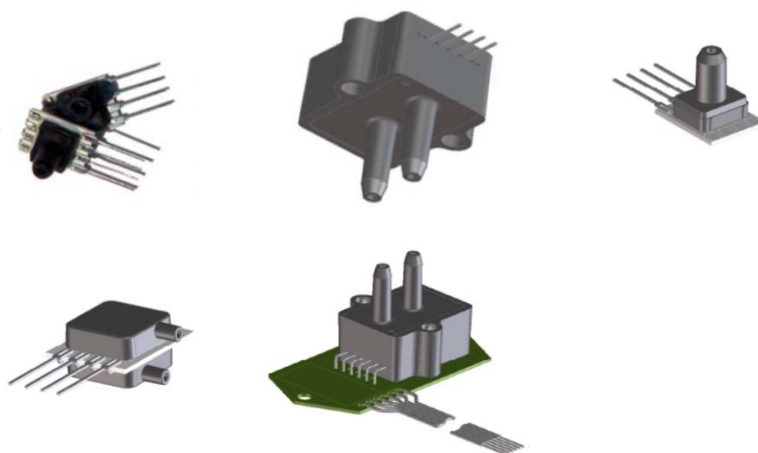
(S. Sugiyama, K. Shimaoka, and O. Tabata, 1991)

100年6月14日

周元昉

NTU50235100

ALL SENSORS



100年6月14日

周元昉

NTU50235100

PX40

**Miniature Voltage Output Pressure Sensors,
Fully Temperature Compensated**

\$ 60.00



Operating Temp.: -45 to 125°C
(-49 to 257°F)

Compensated Temp.: 0 to 70°C
(32 to 158°F); (0 to 50°C for mmHg)

Overpressure:
±50 mmHg ±170 mmHg

0-15 45 psi

0-100 200 psi

0-150 300 psi

0-250 500 psi

Response Time: 1 ms

Gage Type: Silicon

Media Compatibility: Limited to those media which will not attack invar, copper, silicon, stainless steel, glass and solder: i.e. air, water, refrigerants, engine fuel

Weight: 5 g (.18 oz)

100年6月14日

周元昉

NTU50235100

PX305

**General Purpose Current Output Pressure Transmitter,
Available in Gage, Absolute and Vacuum Ranges**

\$ 260.00

Accuracy: 0.25% FS (linearity, hysteresis, repeatability)

Long Term Stability: $\pm 0.5\%$ FS

Operating Temperature:

0 to 160°F (-18 to 71°C)

Compensated Temperature:

30 to 160°F (-1 to 71°C)

Total Thermal Effects: 1% FS max over compensated range

Proof Pressure: 200% or 13000 psi max, whichever is less

Gage Type: Stainless steel diaphragm, silicone oil filled semiconductor sensor

Shock: 50 g @ 11ms

Vibration: 15 g, 10-2000 Hz

Wetted Parts: 17-4 PH and 300 Series Stainless Steel

Weight: 9.4 oz max (266 grams)

100年6月14日

周元昉

NTU50235100

High Temperature Pressure Transducers**PX1004 \$ 1,850.00****PX1009 \$ 2,500.00**

Sensing Element:

4 active-arm bridge using sputter deposited thin film elements.

Accuracy: Combined Linearity, Hysteresis and Repeatability: $\pm 0.25\%$

Operating Temp Range:

PX1004: -54 to 232°C (-65 to 450°F)

PX1009: -54 to 343°C (-65 to 650°F)

Compensated Temp Range:

PX1004: +24 to 204°C (+75 to 400°F)

PX1009: +24 to 316°C (+75 to 600°F)

Thermal Effects:

Span: $\pm 0.01\%$ FSO/°F

Zero: $\pm 0.01\%$ FSO/°F

Natural Frequency:

50 kHz at 5000 psi decreasing logarithmically 5 kHz at 15 psi

Shock: 100g, 11 msec half sine wave without calibration shift or damage

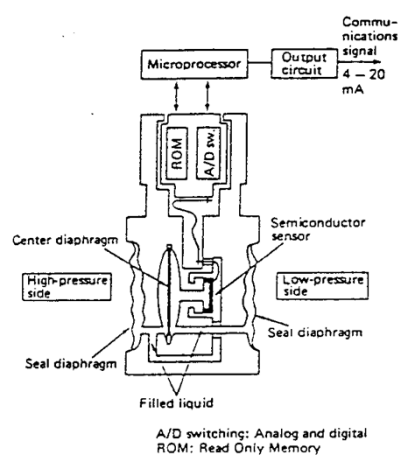
100年6月14日

周元昉

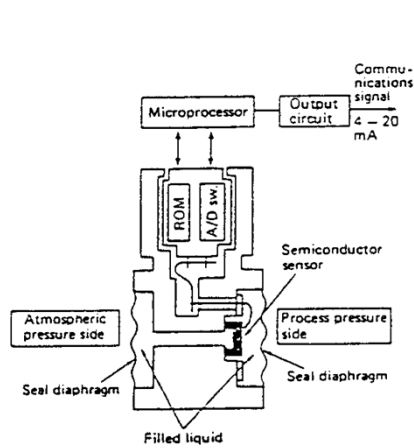
NTU50235100

Hitachi Naka Electronics

Differential transmitter



Pressure transmitter

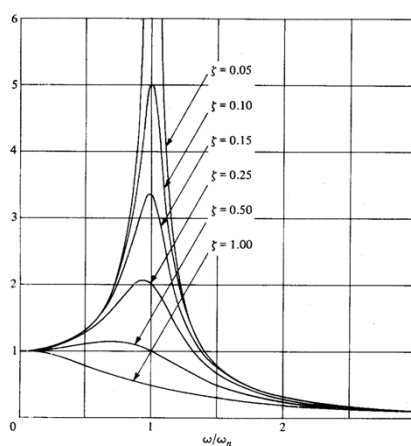
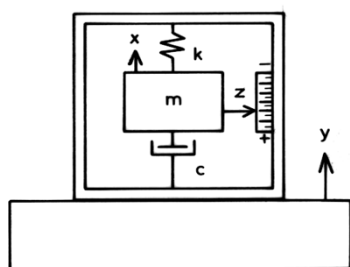


100年6月14日

周元昉

NTU50235100

Micro Accelerometers



100年6月14日

周元昉

NTU50235100

Silicon piezoresistive accelerometers

(Roylance, 1979)

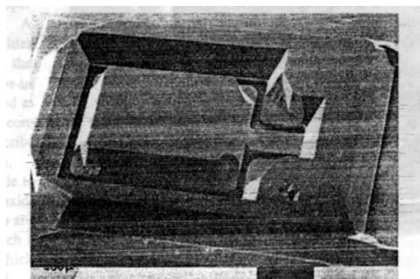
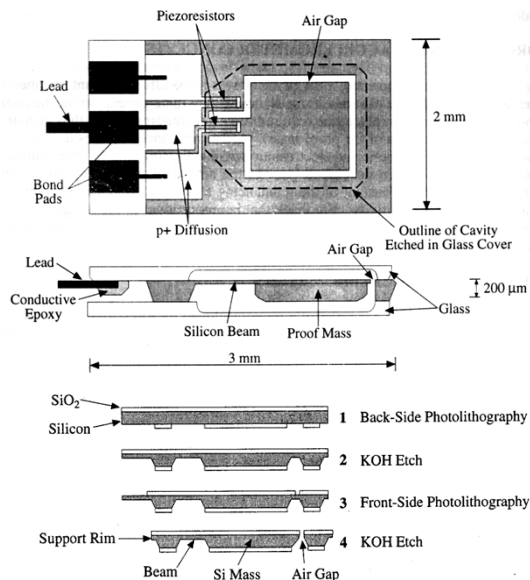
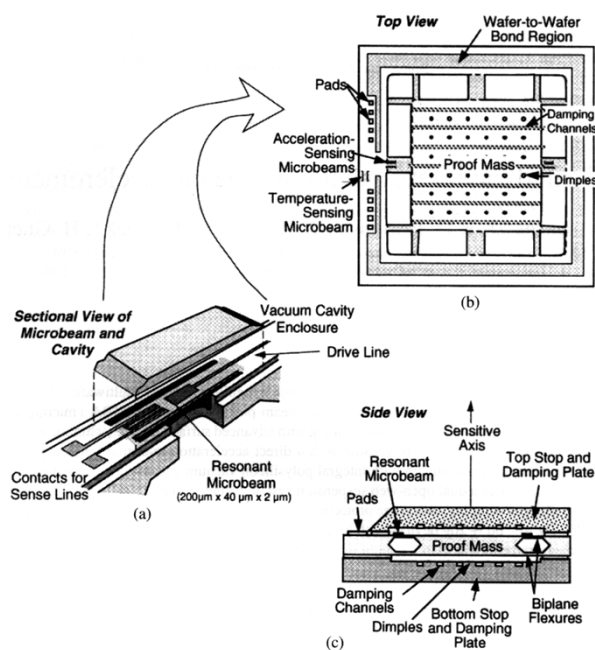


Fig. 2. SEM of backside of the accelerometer with a silicon mass after KOH etch.



100年6月14日

NTU50235100

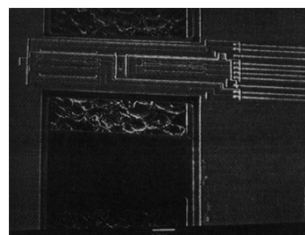
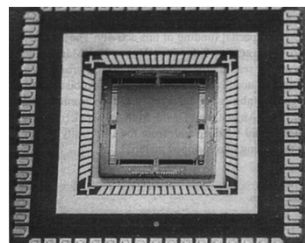
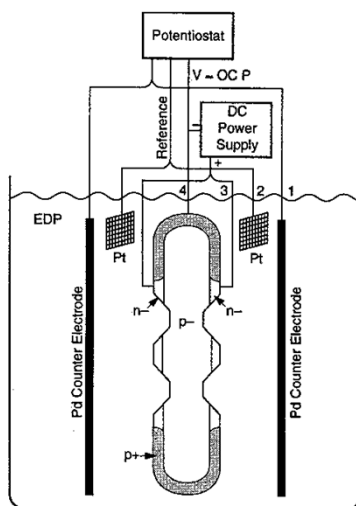


100年6月14日

(Burns, Horning, Herb, Zook, and Guckel, 1996)

周元昉

NTU50235100

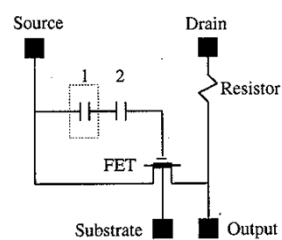
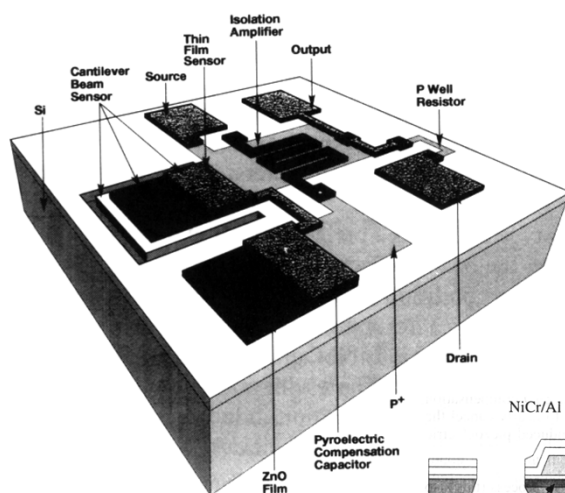


100年6月14日

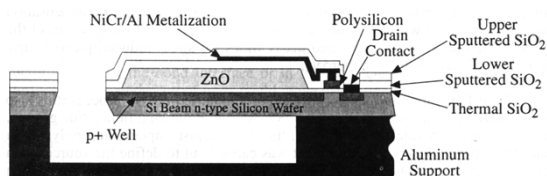
周元昉

NTU50235100

Piezoelectric accelerometers



Piezoelectric thin film capacitors:
1 - Strained capacitor on beam
2 - Unstrained compensation capacitor



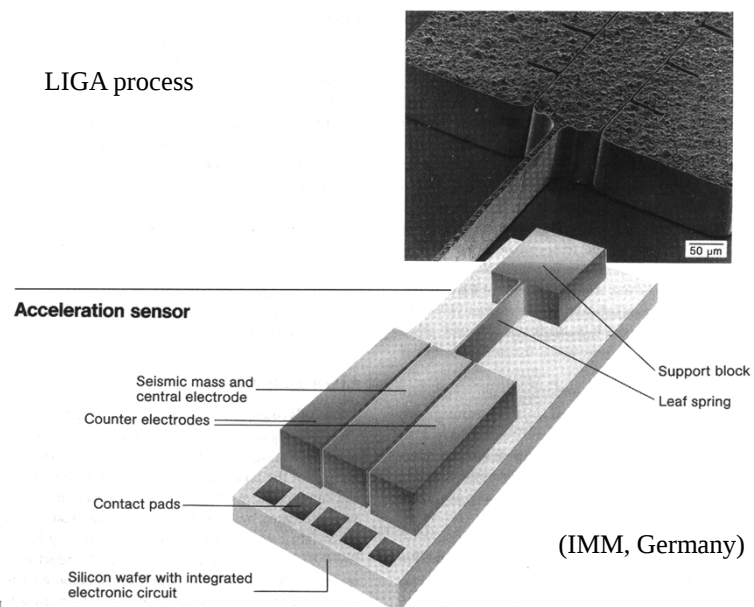
100年6月14日

周元昉

NTU50235100

Capacitive accelerometers

LIGA process



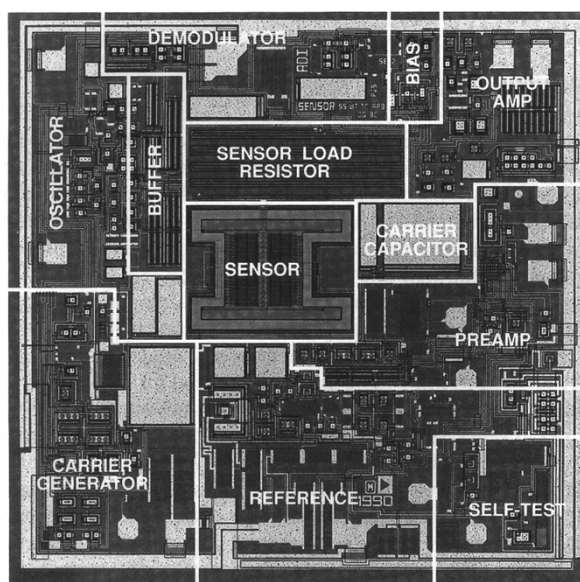
(IMM, Germany)

100年6月14日

周元昉

NTU50235100

Analog Devices ADXL50

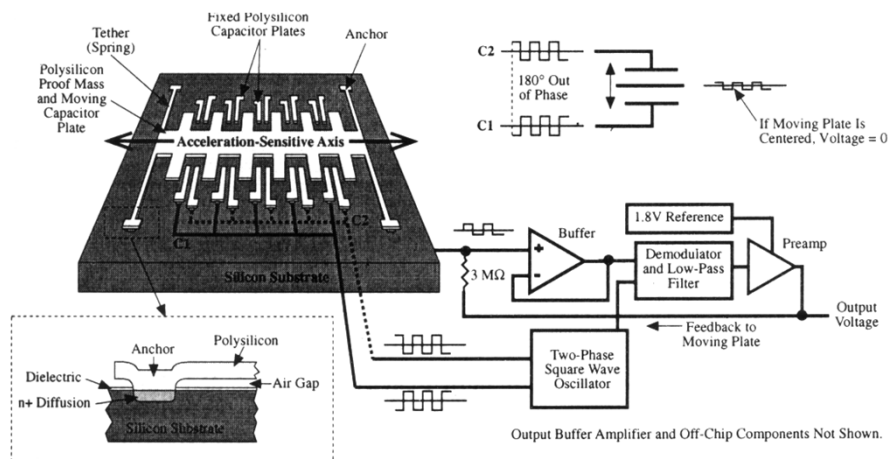


Analog Devices' ADXL-50, the industry's first surface micromachined accelerometer, includes signal conditioning on chip.

100年6月14日

周元昉

NTU50235100

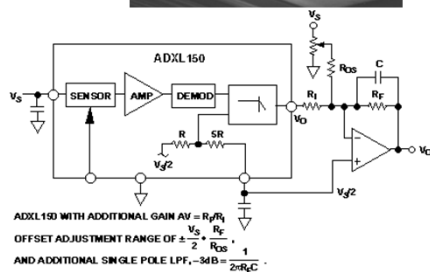
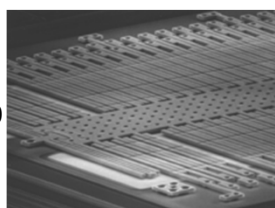


100年6月14日

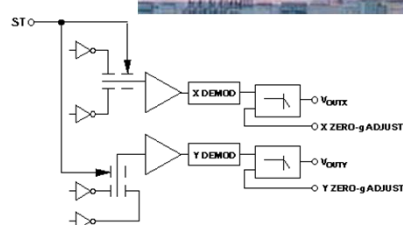
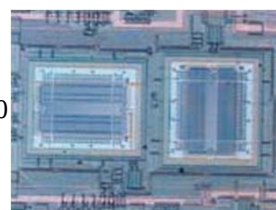
周元昉

NTU50235100

ADXL150



ADXL250



Model	Status	Package Description	Pin Count	Temperature Range	Price* (100-499)
ADXL250AQC	PRODUCTION	CERPAK(HERM CER SURF MOUNT)	14	COMMERCIAL	\$24.94
ADXL250EB	PRODUCTION	CERPAK(HERM CER SURF MOUNT)	14	COMMERCIAL	\$29.95
ADXL250JQC	PRODUCTION	CERPAK(HERM CER SURF MOUNT)	14	COMMERCIAL	\$19.95

100年6月14日

周元昉

NTU50235100

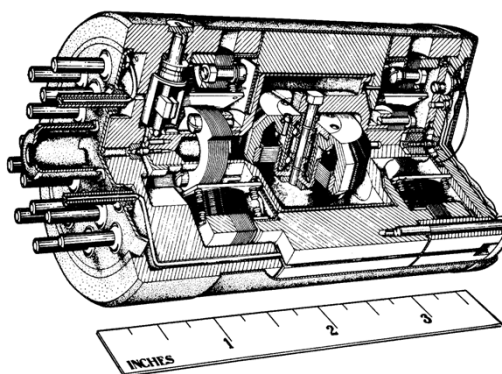
Micro Gyroscope

Tops



(<http://content.edu.tw/local/tainan/kunhwa/tolo.htm>)

Gyroscopes



(Wrigley, Hollister, and Denhard, 1969)

100年6月14日

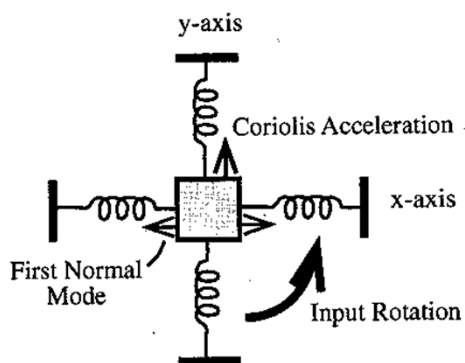
周元昉

NTU50235100

Resonator Gyroscopes

Coriolis force

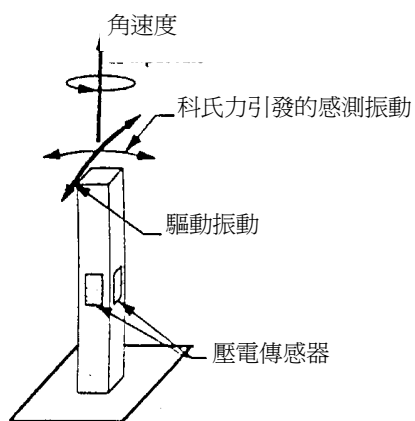
$$F_c = -2m\omega \times \mathbf{v}_r$$



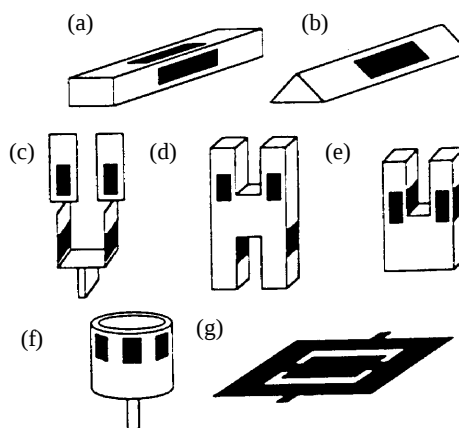
100年6月14日

周元昉

NTU50235100



(Putty and Najafi, 1994)

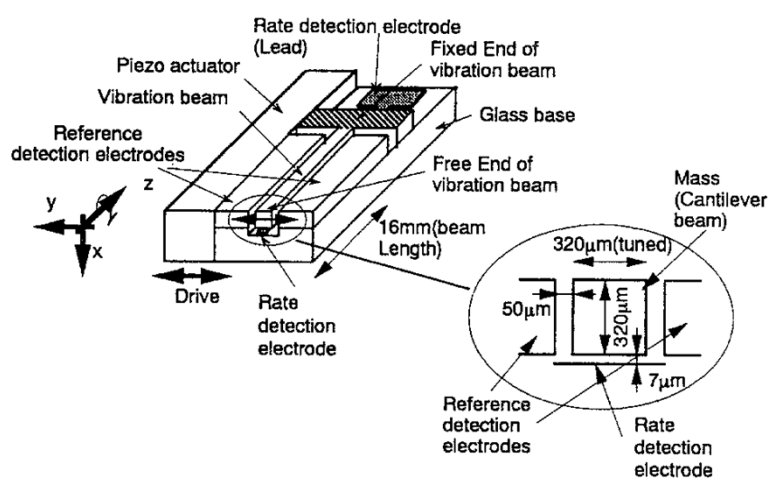


(Soderkvist and Jan, 1994)

100年6月14日

周元昉

NTU50235100



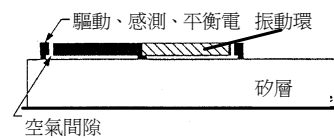
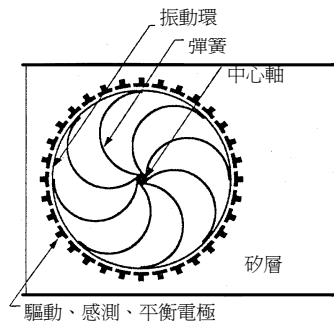
(Maenaka, Fujita, Konishi, and Maeda, 1996)

100年6月14日

周元昉

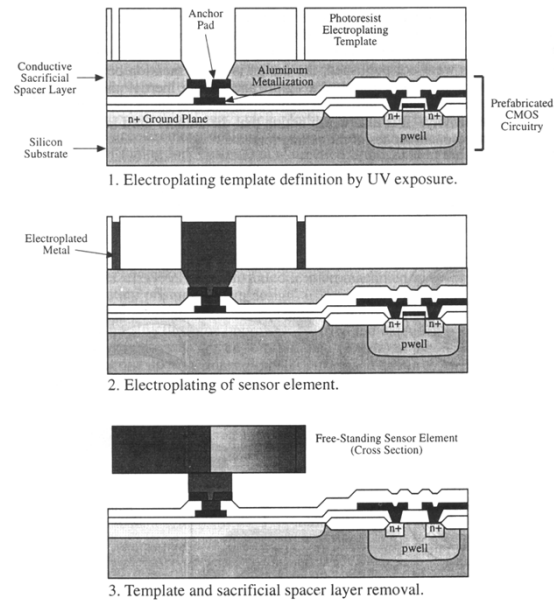
NTU50235100

Ring gyro



(Putty and Najafi, 1994)

100年6月14日



周元昉

NTU50235100

Silicon Sensing Systems Japan, Ltd.

Silicon Sensing Systems Japan

Rate Gyroscope CRS03

is an angular velocity sensor.

With the supply voltage of 5Vdc, it outputs analog DC voltage proportional to the angular velocity, centered at approx. 2.5V dc.



CRS03

Sensors Expo Award Winner

The CRS03 is known for its good performance under severe vibration/shock and temperature change. This product uses Silicon MEMs technology.

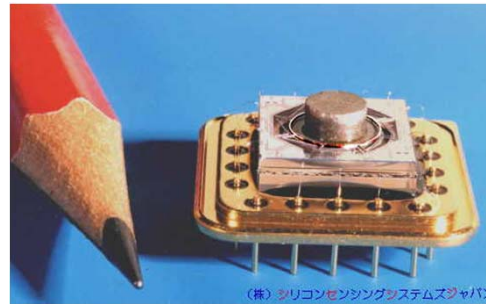
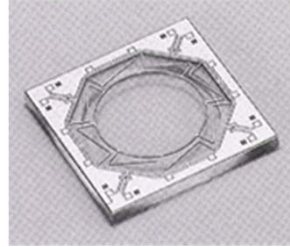
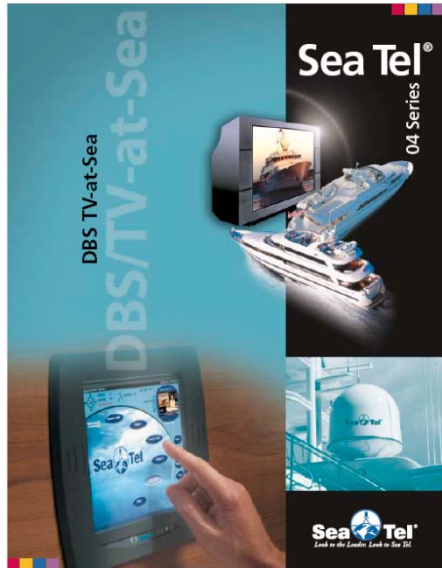
Current Users:

- Automotive Vehicle Stability Control (ESP)
- GPS aided direction controllers
- Antenna Stabilizers (3 mfrs in U.S., 2 mfrs in Japan)
- RC helicopter (major market share as Active Control System)
- Autonomous Guided Vehicles
- Marine auto-pilots
- Inertial (Control) Units
- Bipedal robots
- Telematics

100年6月14日

周元昉

NTU50235100

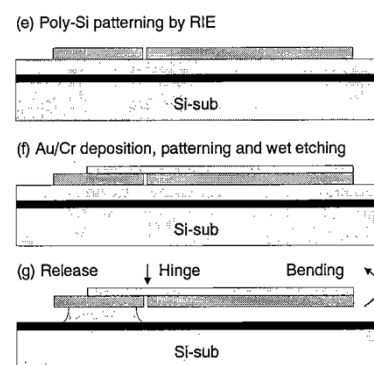
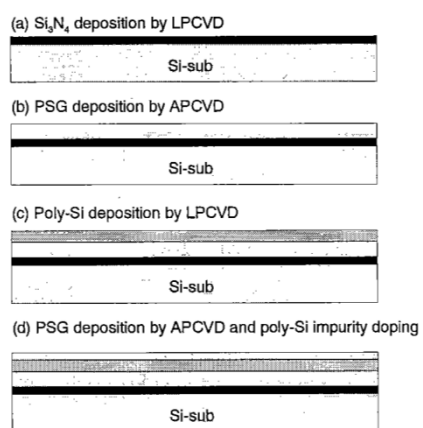


100年6月14日

周元昉

NTU50235100

Thermopile

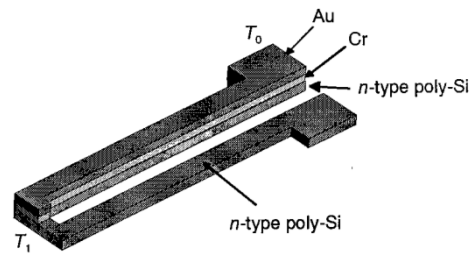
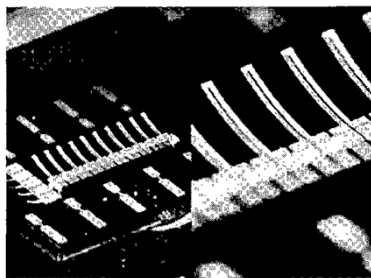
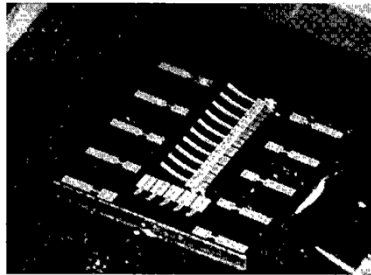


(M. Yajima, et. al., "Self-standing Polysilicon-metal Thermopile for Micro Power Generator," 2002.)

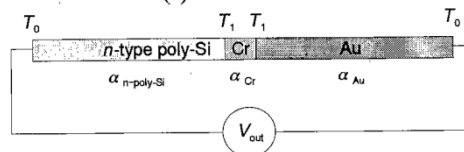
100年6月14日

周元昉

NTU50235100



(a) Structure



$$V_{out} = \alpha_{n-poly-Si} (T_0 - T_1) + \alpha_{Cr} (T_1 - T_1) + \alpha_{Au} (T_1 - T_0)$$

$$= (\alpha_{Au} - \alpha_{n-poly-Si}) (T_1 - T_0)$$

(b) Equivalent circuit

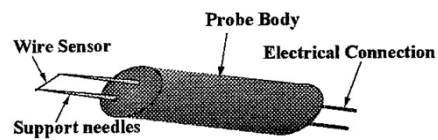
100年6月14日

周元昉

NTU50235100

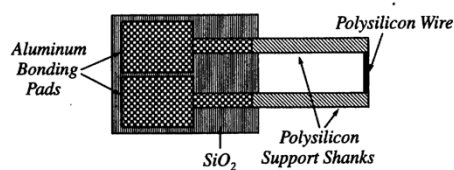
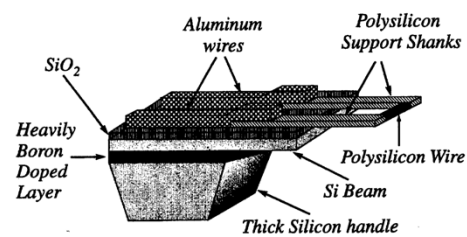
Micro hot wire

Conventional hot wire



Micro hot wire

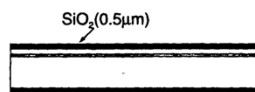
(F. Jing et. al., "A micromachined polysilicon Hot-Wire Anemometer," 1994.)



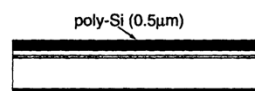
100年6月14日

周元昉

NTU50235100



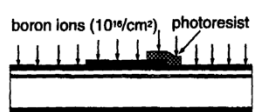
Thermal oxidation of silicon substrate at 1100°C which has highly-boron doped buried etch-stop layer



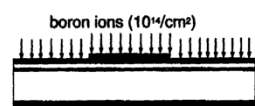
Low-Pressure Chemical Vapor Deposition (LPCVD) of polysilicon at about 560°C.



Patterning of polysilicon to form the resistor (heater & sensor) as well as interconnection lanes (supports)



High-dose boron implantation of polysilicon for interconnection lanes only. Photoresist PR mask for resistor part.

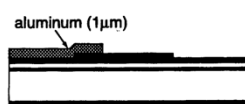


Low-dose boron implantation of polysilicon including resistor part

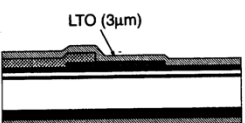
100年6月14日

周元昉

NTU50235100



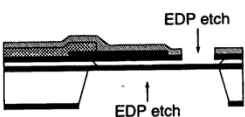
Aluminum metallization to contact interconnection lanes



LPCVD of low temperature oxide (LTO) to protect structures on frontside of the silicon substrate



Patterning of: LTO and thermal oxide on frontside, polysilicon and thermal oxide on backside of the wafer



Anisotropic etching of the silicon substrate releasing the sandwich polysilicon cantilever



Isotropic etching of silicon to remove the highly-boron doped etch-stop layer

100年6月14日

周元昉