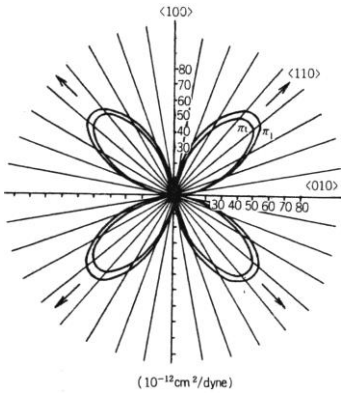
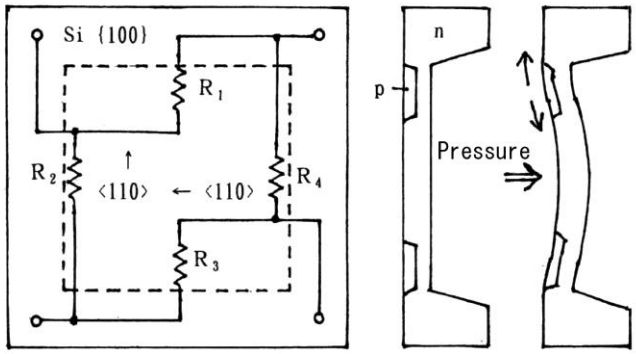
# B1 Piezoresistive pressure sensor

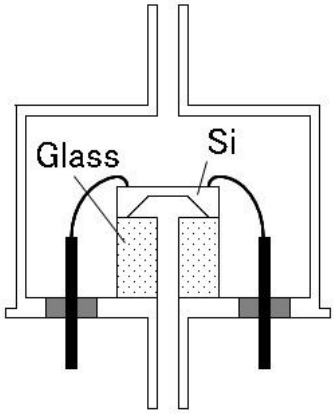
Dr. Isemi Igarashi
(Toyota Central Research Laboratory)



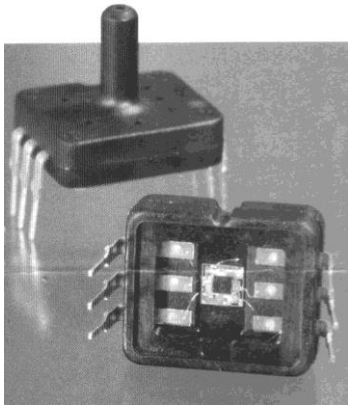

Piezoresistive coefficient on (100) p-Si
maximum in <110> direction



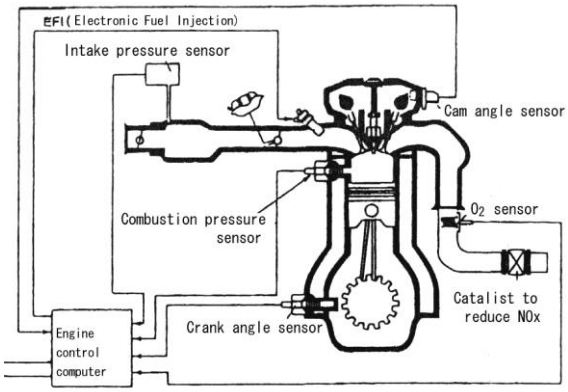

Piezoresistive Si diaphragm pressure sensor




Packaging of pressure sensor



Pressure by Fujikura Ltd.




Pressure sensor applied for engine control

Reference : I.Igarashi, Piezo-resistive Effect of Ge and Its Application to Strain Gages, Applied Physics, 29 (1960) pp.73-78
O.N.Tufle (Honeywell), Silicon Diffused-element Piezoresistive Diaphragms, J. of Applied Physics, 33 (1962) pp.3322-3327)

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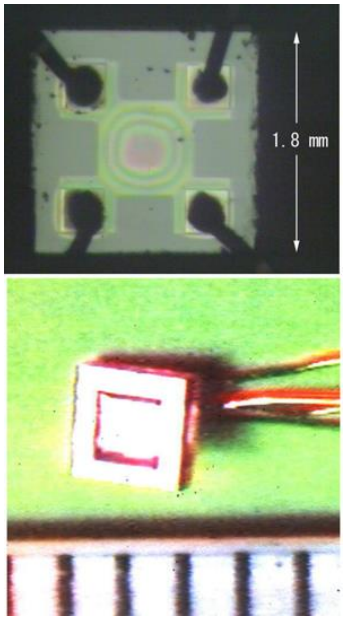
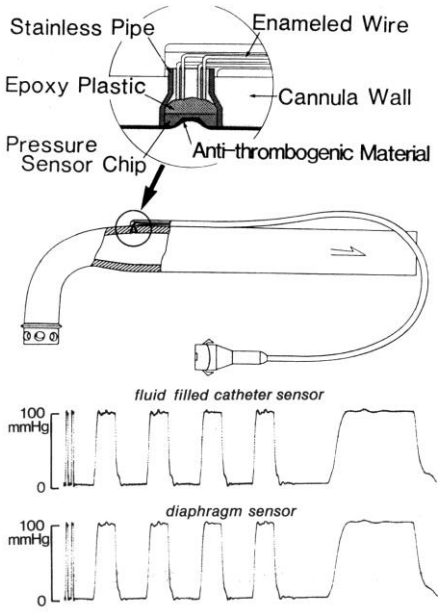
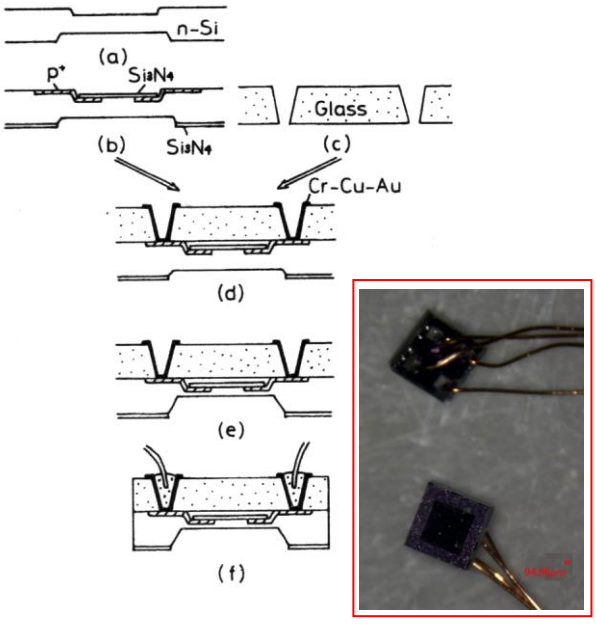
# Piezoresistive Absolute Pressure Sensor




Photograph



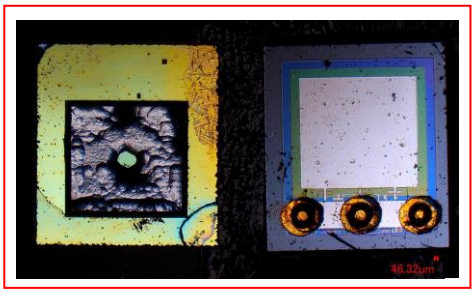

Blood pressure monitor in ventricular assist device

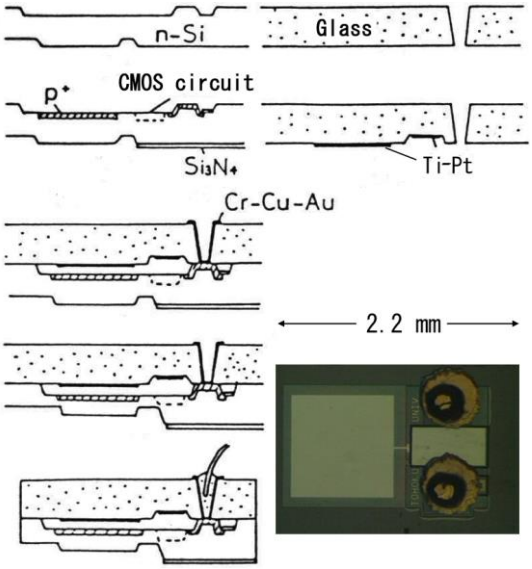



Fabrication process

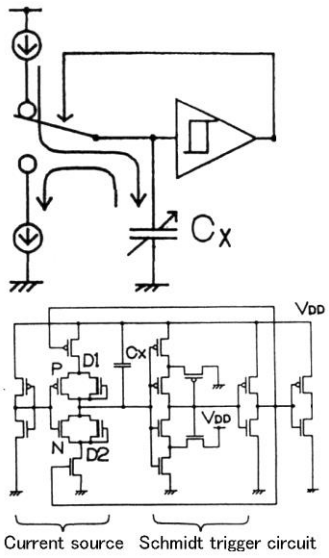
Reference : M.Esashi, Y.Matsumoto and S.Shoji, Absolute Pressure Sensors by Air-tight Electrical Feedthrough Structure, Sensors and Actuators, A21-A23 (1990) pp.1048-1052

## B2 Integrated capacitive pressure sensor

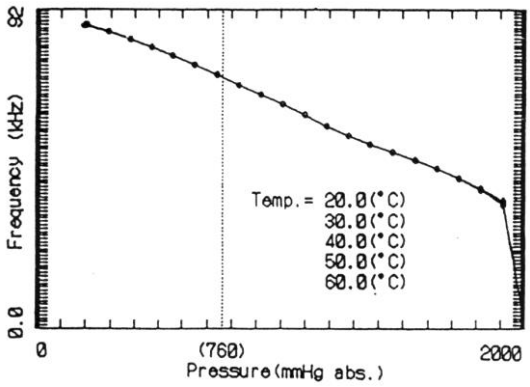




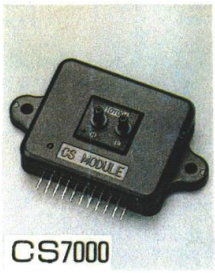

Fabrication process




Circuit




Characteristics




For low pressure measurement

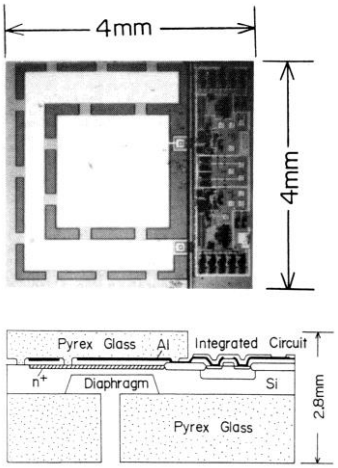
10mmH2O～300mmH2O

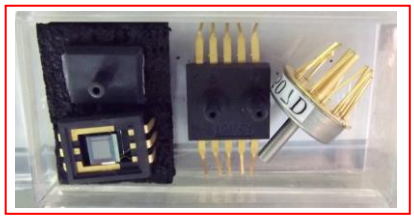
Frequency and analog output

TOYODA

Toyoda Machine Works, LTD.

Monolithic capacitive pressure sensor



Wafer level packaged integrated capacitive pressure sensor (Tohoku Univ. — Toyda Machine Works)

(This sensor was used for filter clogging detection of air conditioner for about 20 years)

Reference : Y.Matsumoto, S.Shoji and M.Esashi, A Miniature Integrated Capacitive Pressure Sensor, Extended Abstracts of the 22nd International Conference on Solid State Devices and Materials (1990) pp.701-704

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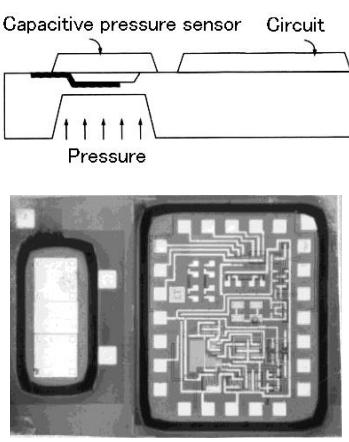
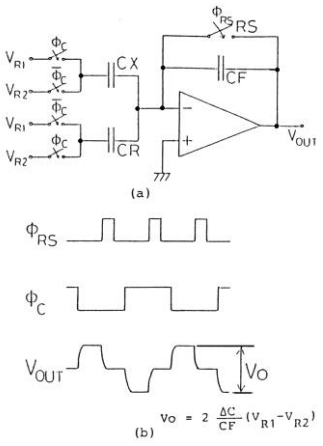


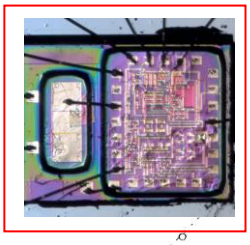
Structure and photograph

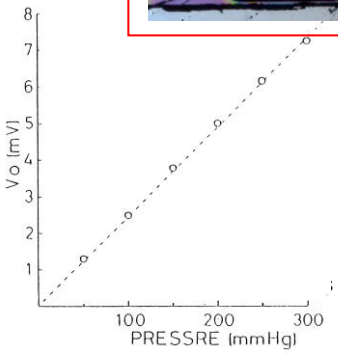



Fabrication




Circuit

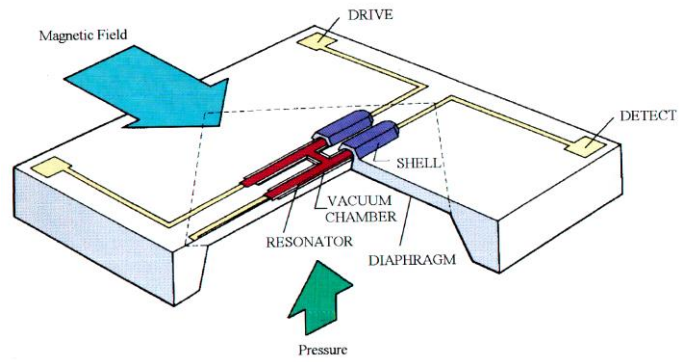




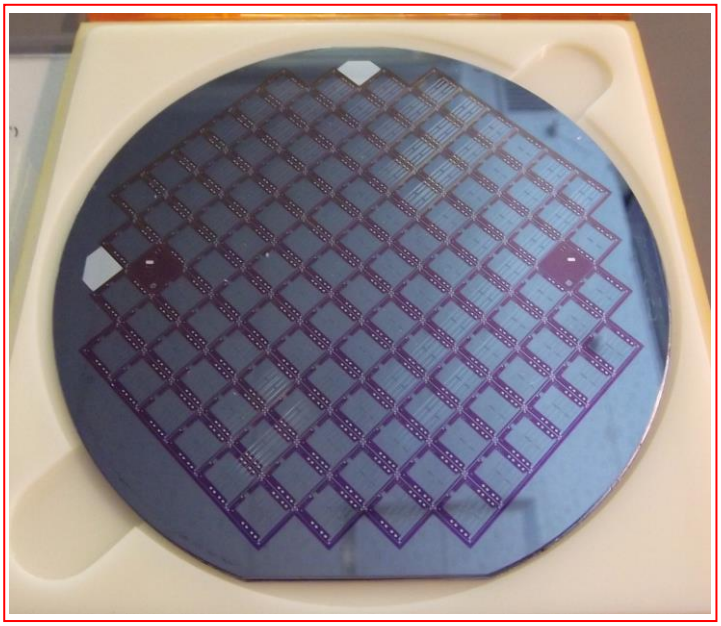

Integrated Capacitive Pressure Sensor by Si Direct Bonding

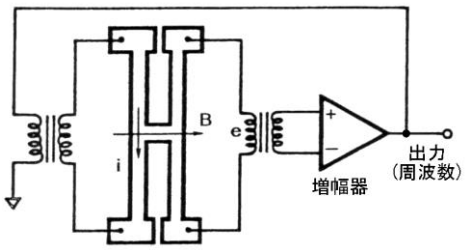
Reference : S.Shoji, T.Nisase, M.Esashi and T.Matsuo, Fabrication of an Implantable Capacitive Type Pressure Sensor, The 4th Int. Conf. on Solid State Sensors and Actuators (transducers' 87), (1987) pp.305-308

## B3 Resonant pressure sensor (Yokogawa Electric Work)

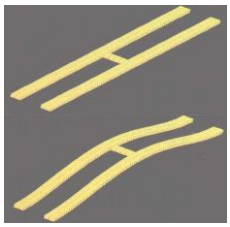



Principle

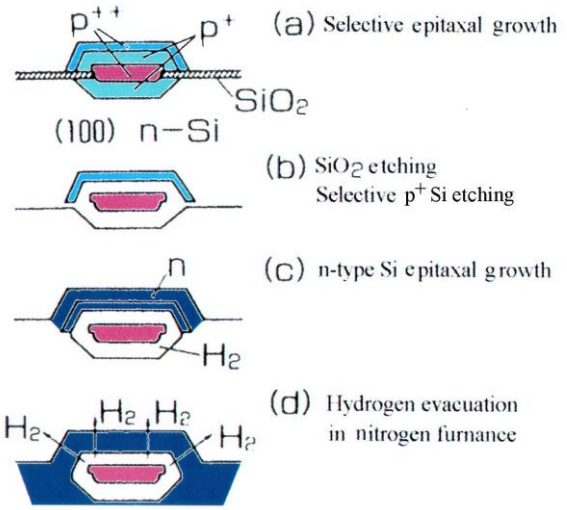




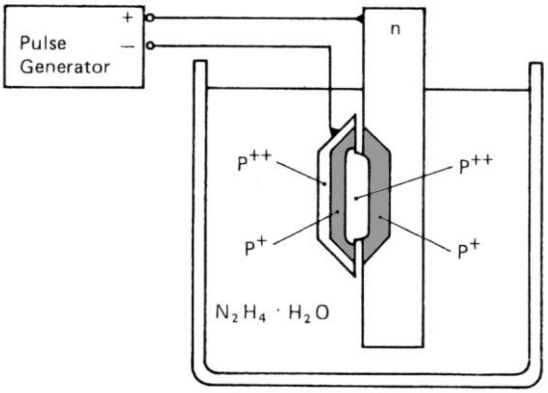

Circuit



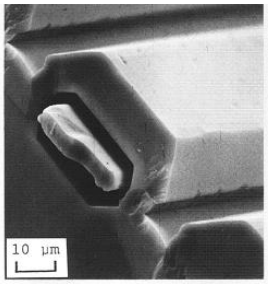
Resonant mode



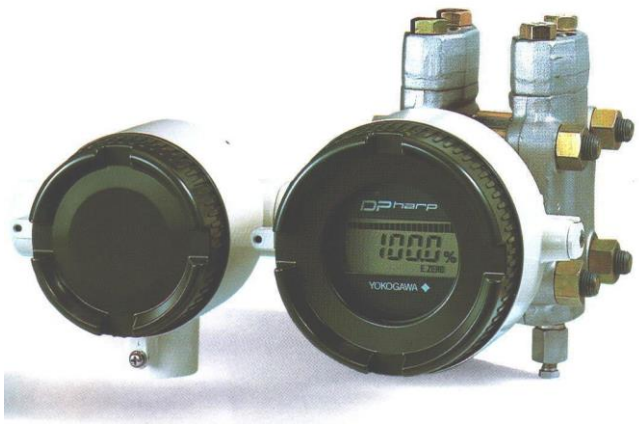

Fabrication process

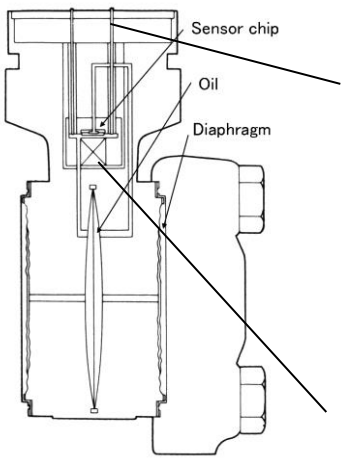


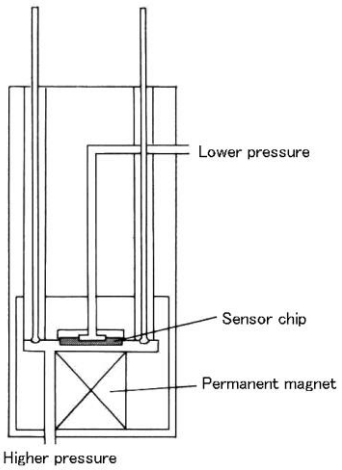

Etching apparatus in process (b)




Cross section of resonator



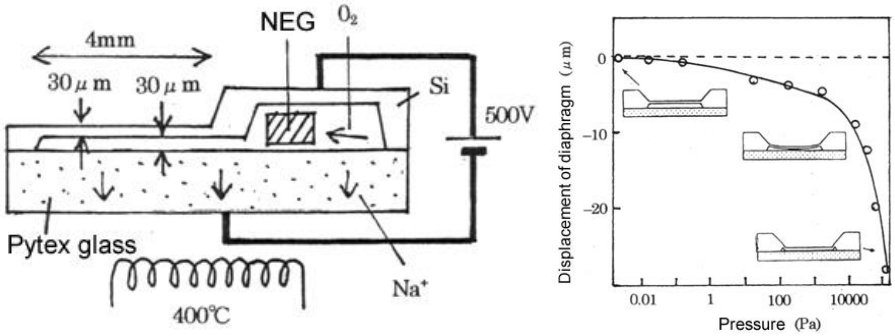



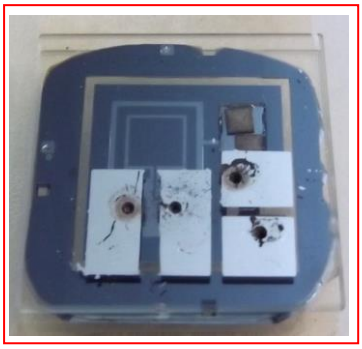




Differential pressure transmitter (DP harp)

Reference : K.Ikeda, H.Kuwayama, T.Kobayashi, T.Watanabe, T.Nishikawa and T.Yoshida, Silicon Pressure Sensor with Resonant Strain Gages Built into Diaphragm, Tech. Digests of the 7th Sensor Symposium (1988) pp.55-58

B4 Capacitive vacuum sensor

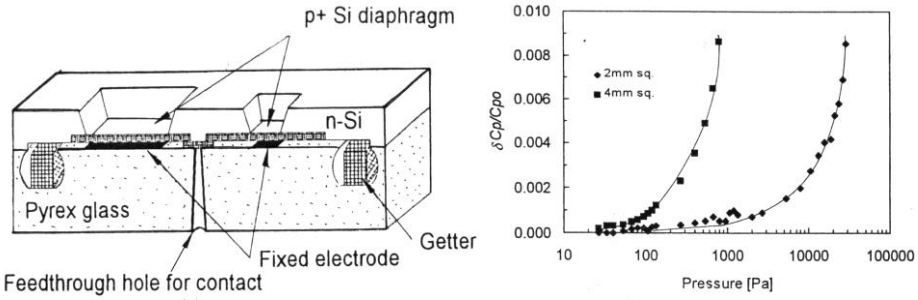


Vacuum encapsulation by anodic bonding with getter

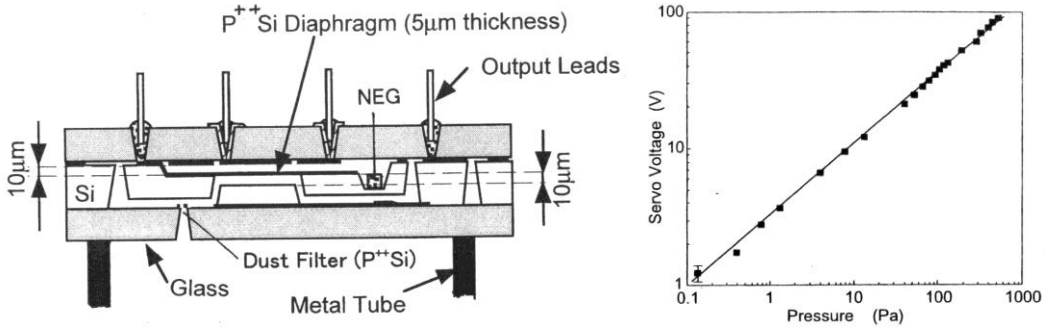
Reference : M.Esashi, S.Sugiyama, K.Ikeda, Y.Wang and H.Miyashita, Vacuum-Sealed Silicon Micromachined Pressure Sensors, Proc. of the IEEE, 86 (1998) pp.1627-1639

Reference : H.Henmi, S.Shoji, Y.Shoji, K.Yoshimi and M.Esashi, Vacuum Packaging for Micro-sensors by Glass-Silicon Anodic Bonding,, Sensors and Actuators A, 43 (1994) pp.243-248



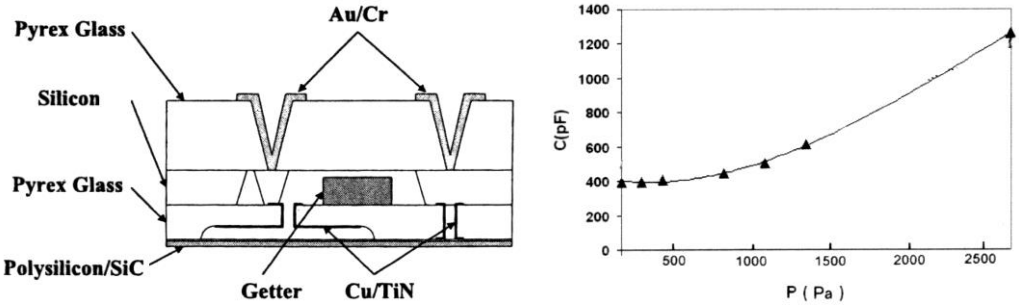

Dual diaphragm vacuum sensor

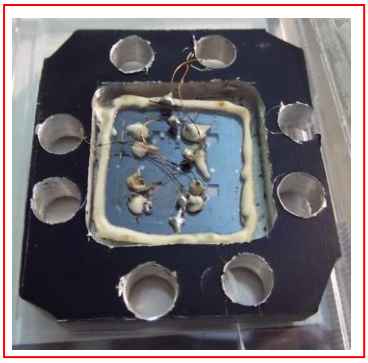
Reference : K.Hatanaka, D.Y.Sim, K.Minami and M.Esashi, Silicon Diaphragm Capacitive Vacuum Sensor, Tech. Digest of the 13th Sensor Symp.,(1995) pp.37-40




Electrostatic servo vacuum sensor

Reference : H.Miyashita and M.Esashi : Wide Dynamic Range Silicon Diaphragm Vacuum Sensor by Electrostatic Servo System, J. Vac. Sci. Technology, B18, (2000) pp.2692-2697



SiC diaphragm anti-corrosive vacuum sensor

Reference : B.Larangot, S.Tanaka and M.Esashi, Fabrication of Anti-Corrosive Capacitive Vacuum Sensors with a Silicon Carbide/Polysilicon Bi-Layer Diaphragm and Electrical Through-Hole Connections on the Opposite Side, Trans. IEE of Japan, 128-E (2008) pp.331-336

# B5 Capacitive vacuum sensor products (Canon ANELVA, Daiavac)


ANELVA

キャパシタンスゲージ
M-340DG

●概要

マイクロマシン技術による、小型、高性能キャパシタンスゲージ

絶対圧測定を可能とするキャパシタンスゲージ（静電容量型隔膜真空計）をマイクロマシン（MEMS）技術を用いて作製し、小型化、高性能、低価格を実現した画期的な真空計です。

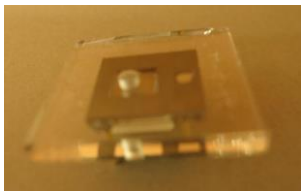
●特長

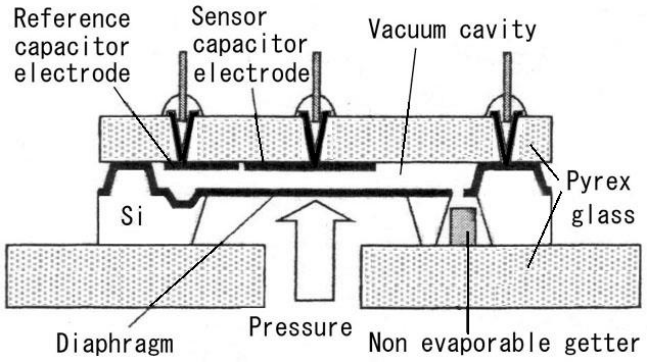
- コンパクト、低価格
  マイクロマシン（MEMS）技術を用いて、小型化、低価格（量産化）を実現
- 測定レンジ5タイプをラインナップ
  33Pa、133Pa、1.33kPa、13.3kPa、133kPaの5タイプ
- 高感度、高再現性
  単結晶シリコンダイヤフラムの採用により、高感度、高再現性を実現
- メンテナンスコスト低減
  センサチップのみの交換が可能※
- 優れた対震動ノイズ性
  小型・軽量ダイヤフラムのため、機械震動ノイズを受けにくい
- 取付け方向を選ばない
  垂直、水平、逆さ、どの取付け方向においても正確な測定が可能

●用途

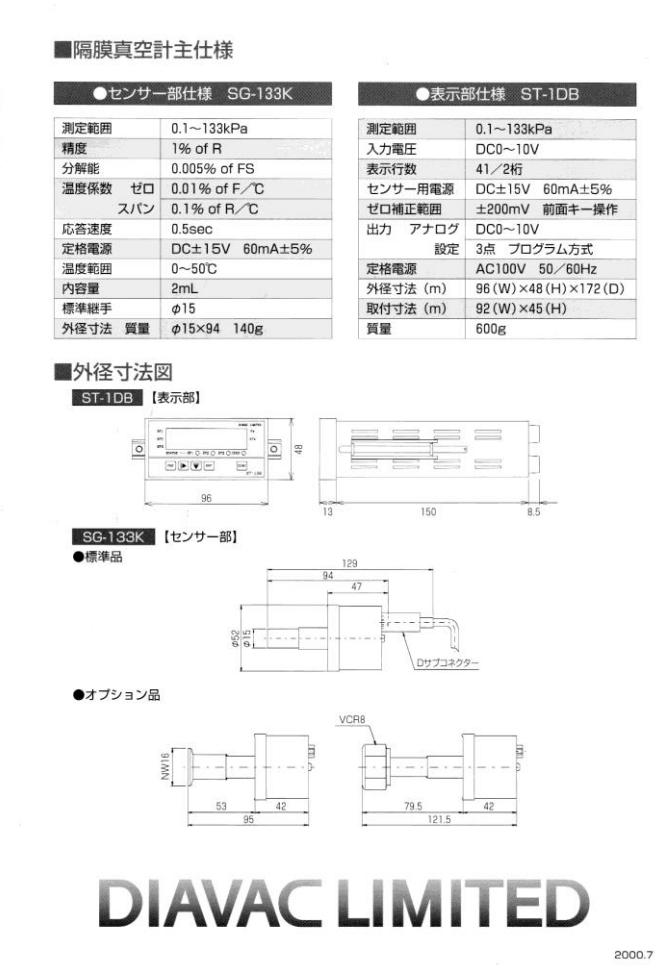
- スパッタリング装置のプロセス圧力測定
- ロードロックチャンバの圧力測定
- ガス分析装置の圧力測定
- 真空乾燥装置の圧力測定
- ランプのガス封入プロセス圧力測定
- 正確な大気圧測定

※メーカでのチップ交換・調整作業が必要です。




Reference : H. Miyashita, Y. Kitamura, Micromachined Capacitive Diaphragm Gauge, Anelva Technical Report, 11 (2005) pp.37–41 (in Japanese)


■隔膜真空計主仕様

●センサー部仕様　SG-133K

| | |
|---|---|
| 測定範囲 | 0.1～133kPa |
| 精度 | 1% of R |
| 分解能 | 0.005% of FS |
| 温度係数　ゼロ | 0.01% of F／℃ |
| スパン | 0.1% of R／℃ |
| 応答速度 | 0.5sec |
| 定格電源 | DC±15V　60mA±5% |
| 温度範囲 | 0～50℃ |
| 内容量 | 2mL |
| 標準継手 | φ15 |
| 外径寸法　質量 | φ15×94　140g |

●表示部仕様　ST-1DB

| | |
|---|---|
| 測定範囲 | 0.1～133kPa |
| 入力電圧 | DC0～10V |
| 表示行数 | 41／2桁 |
| センサー用電源 | DC±15V　60mA±5% |
| ゼロ補正範囲 | ±200mV　前面キー操作 |
| 出力　アナログ | DC0～10V |
| 設定 | 3点　プログラム方式 |
| 定格電源 | AC100V　50／60Hz |
| 外径寸法（m） | 96（W）×48（H）×172（D） |
| 取付寸法（m） | 92（W）×45（H） |
| 質量 | 600g |

■外径寸法図

ST-1DB【表示部】



SG-133K【センサー部】

●標準品



●オプション品



DIAVAC LIMITED

2000.7


DIAVAC LIMITED

Diaphragm Vacuum Gauge
ST-1DB
シリコン隔膜真空計

●相対圧から絶対圧へ！

センサー部にシリコンダイヤフラムを採用した小型で絶対圧力測定の隔膜真空計です。表示部にはオートゼロ機能を有し、外部出力3点、更にアナログ出力として0～10Vを標準装備しています。小型で使い易さを追求した真空計です。

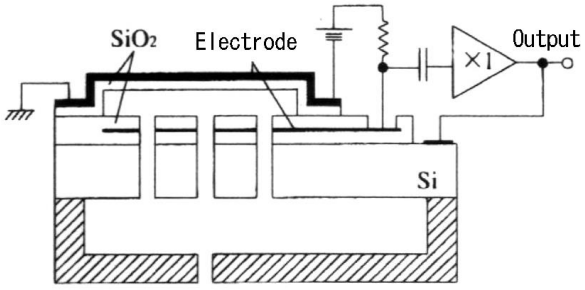
- 気体の圧力を力として検出しますので気体の種類に関係なく測定ができます。但し、強腐食性気体を除く。
- ダイヤフラムにシリコンチップを採用することにより小型で再現性に優れています。
- 検出回路は静電容量方式ですので安定して低圧力まで測定出来ます。
- 表示部はシンプル機能とし、小型で使い易さを実現しました。

DIAVAC LIMITED

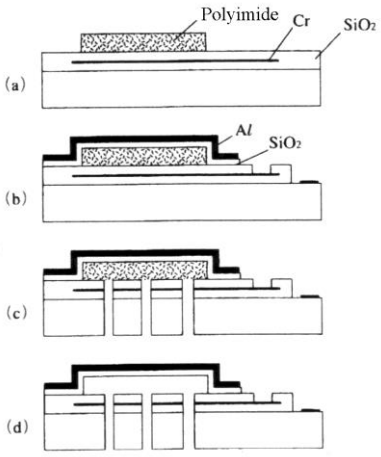
大亜真空株式会社
DIAVAC LIMITED

TEL 047(459)7628
TEL 06(6396)1771

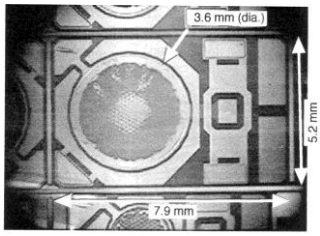
# B6 MEMS microphone




Structure



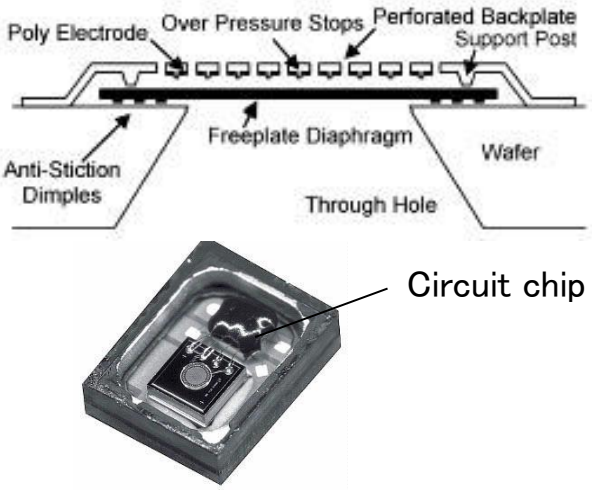

Fabrication process



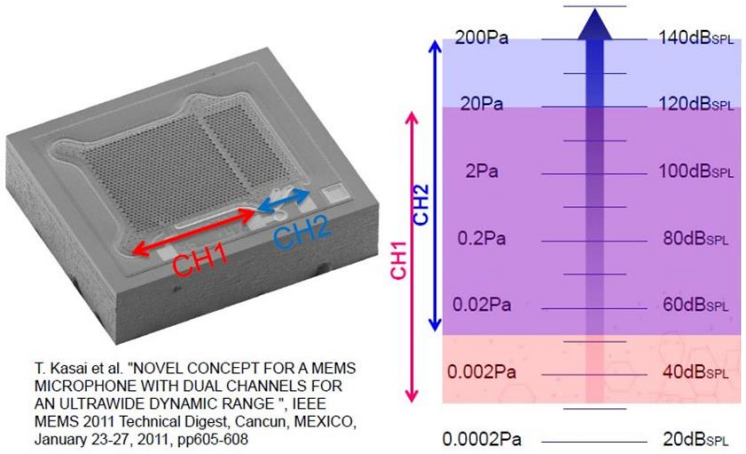

Photograph

Driven Shield MEMS Microphone (Tohoku Univ. – Matsushita Communication Industry)

Reference : M.Ikeda, N.Shimizu and M.Esashi, Surface Micromachined Driven Shielded Condenser Microphone with a Sacrificial Layer Etched from the Backside, Tech. Digest of the Transducers' 99, (1999) pp.1070–1073

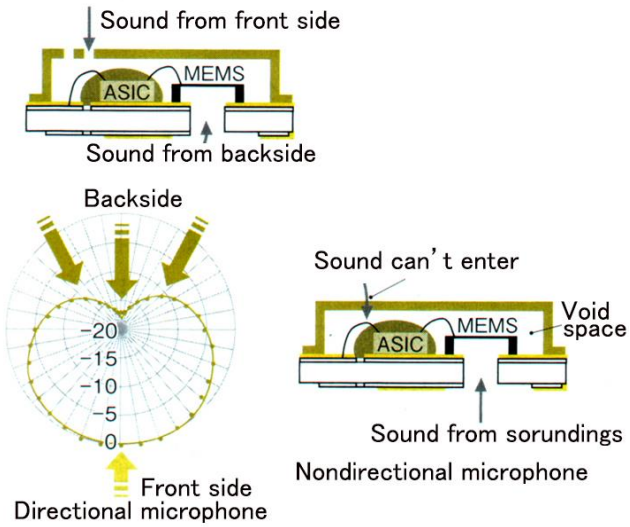



MEMS microphone used for smartphone (Knowles)

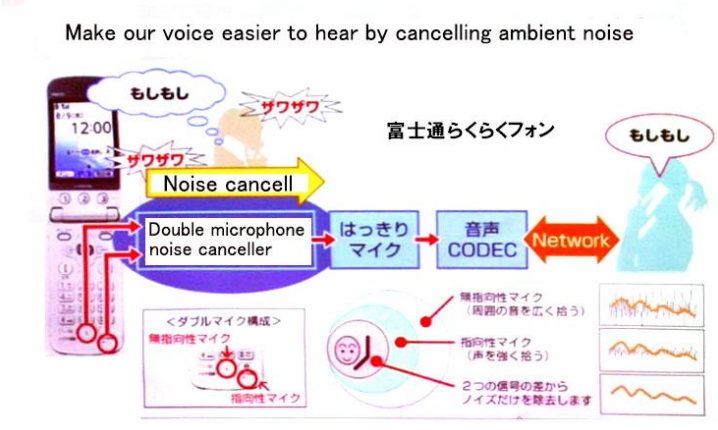



Wide dynamic range MEMS microphone (Omron)

Reference : Nikkei Micro Device, 248 (2006/2) p.38) in Japanese

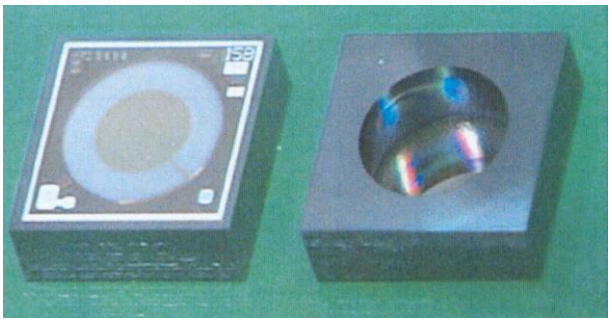



Principle of cancelling ambient noise by double microphone

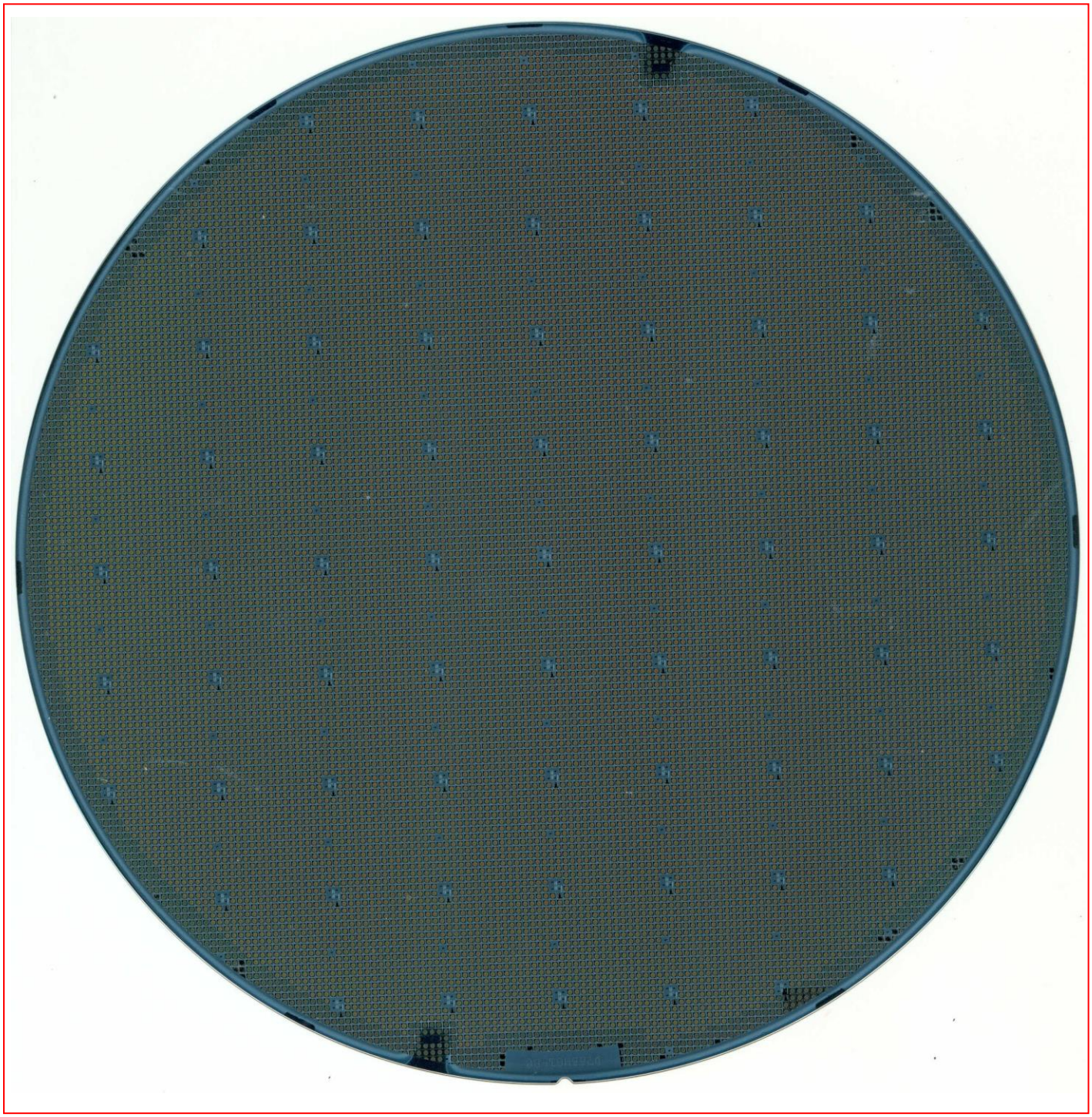



Noise cancell by double microphones

B7 # MEMS microphone wafer (Nisshinbo Micro Devices)

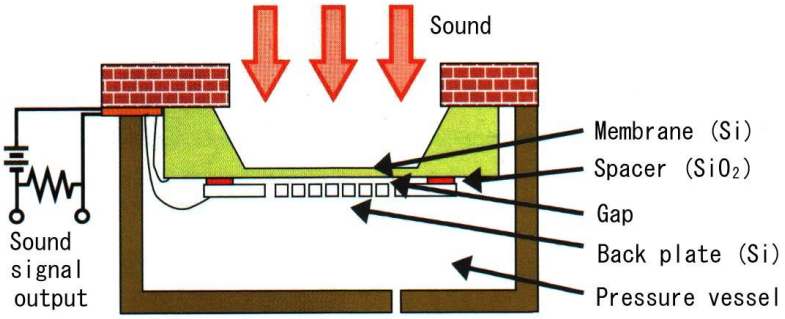


Capacitive MEMS microphone chip (New Japan Radio)



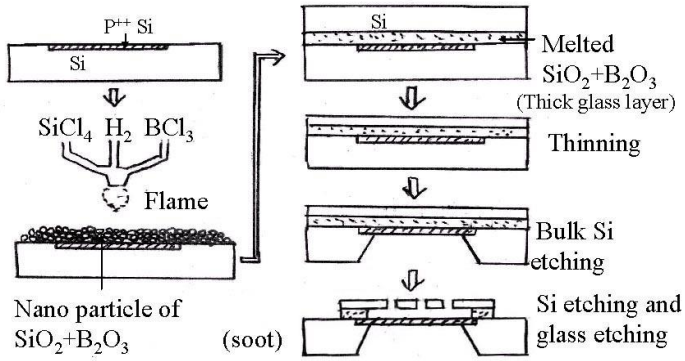
MEMS microphone chips on a 8 inch wafer (20 cm in diameter) (20,000 chips)

## B8 MEMS microphone for humid environment

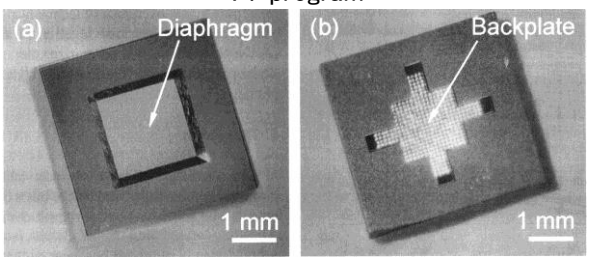



Structure


TV program




Fabrication process

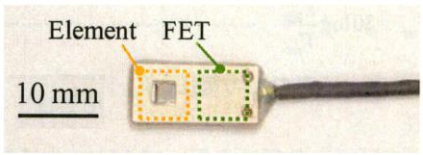


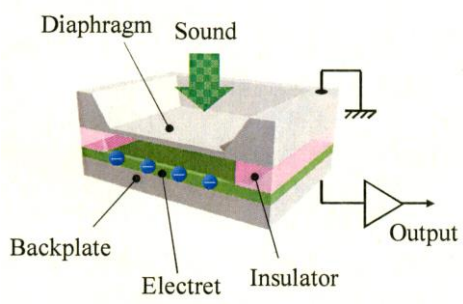

Photograph of chip

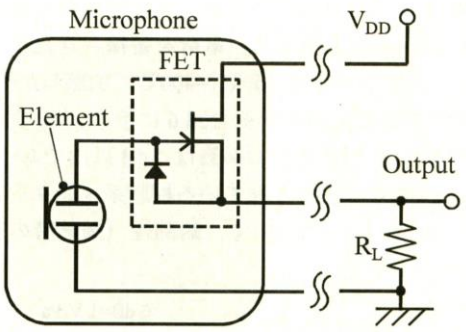
Used in TV for swimming game in Beijing Olympic game etc

MEMS microphone for broadcasting (NHK – Tohoku Univ. – Panasonic)

Reference : T.Tajima, T.Nishiguchi, S.Chiba, A.Morita, M.Abe, K.Tanioka, N.Saito and M.Esashi, High-performance Ultra-small Single Crystalline Silicon Microphone of an Integrated Structure, Microelectronic Engineering, 67-68 (2003) pp.508-519



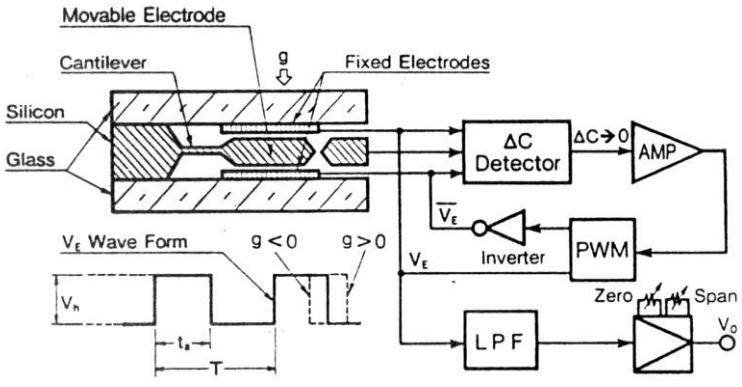



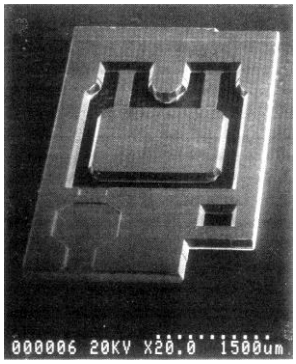


Si microphone using inorganic electret for humid environment (NHK, Kobayashi Inst. of Physical Research, Rion) (Hands-on-Access Fab. Was used)

Reference : M.Goto et.al, Si electret condenser microphone with inorganic electret、IEEJ Trans. 132-E (2012) 309-315)

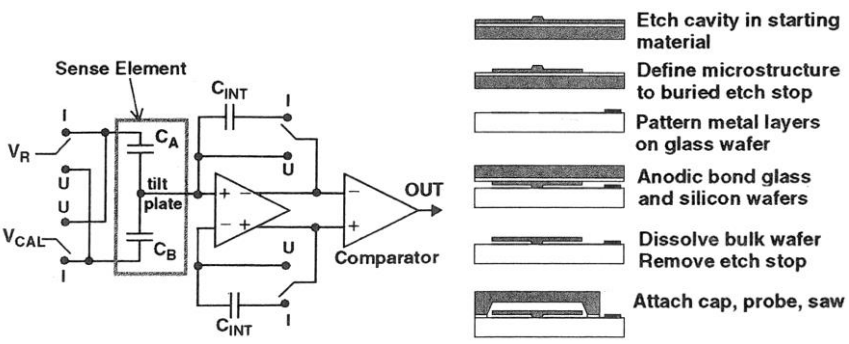
# B9 Capacitive accelerometer for automobile

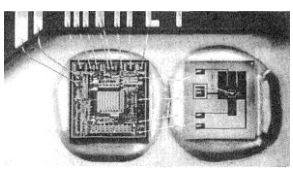




Accelerometer with electrostatic servo controller (Hitachi)

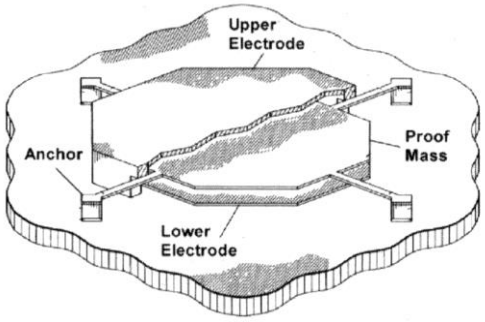
Reference: S.Suzuki, S.Tuchitani, K.Sato, Y.Yokota, M.Sato and M.Esashi : Semiconductor capacitance type accelerometer with electrostatic servo controller, Sensors and Actuators, A21–23, (1990) 316–319

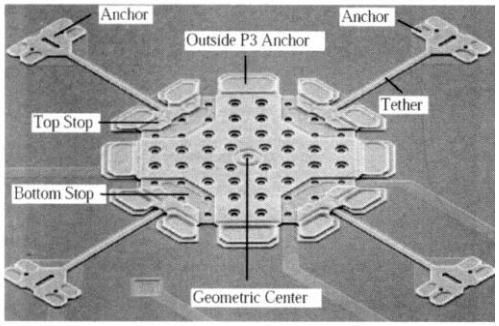


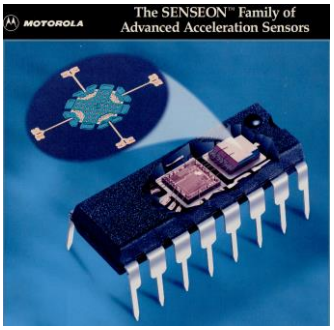




Accelerometer with ΔΣmodulation (Ford motor, USA)

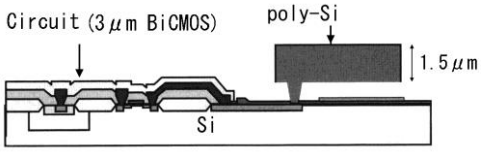
Reference : L.(Chip) Spangler and C.J.Kemp, ISAAC—Integrated Silicon Automobile Accelerometer, Transducers' 95 (1995) pp.585–588

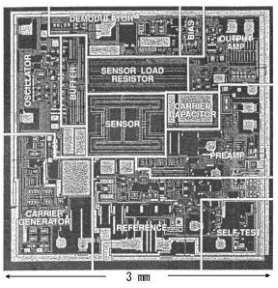


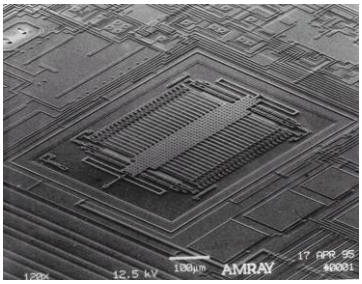



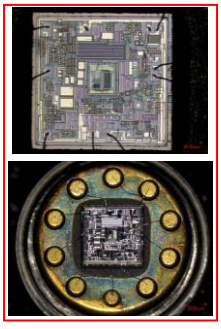




Z axis two-chip accelerometer by surface micromachining (Motorola, USA)



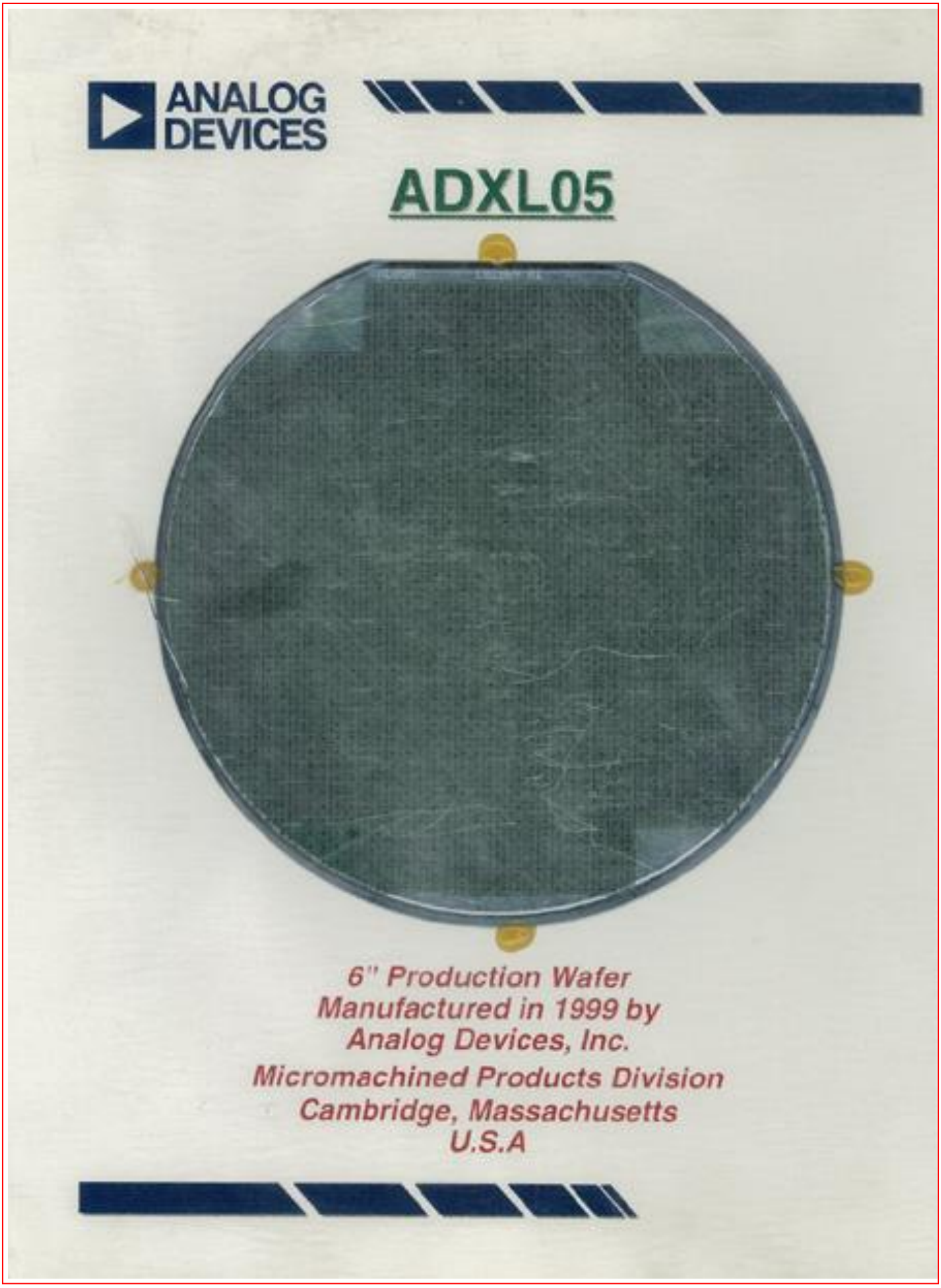



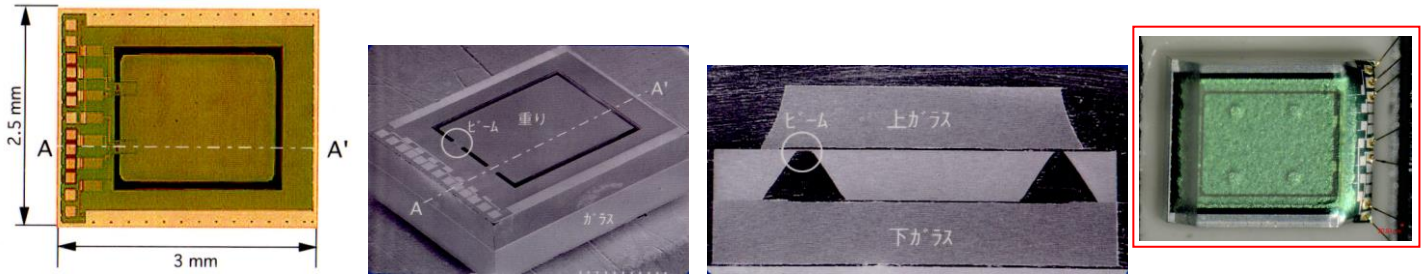
Monolithic integrated accelerometer (Analog Devices, USA) (Wafer and chips are in A12)

Reference : K.H.-L..Chau, S.R.Lewis, Y.Zhao, R.T.Howe. S.F.Bart and R.G.Marcheselli, An Integrated Force-Balanced Capacitive Accelerometer for Low-G Applications, Transducers' 95 (1995) pp.563–596

B10 Wafer of accelerometer by surface micromachining (Analog Devices USA)

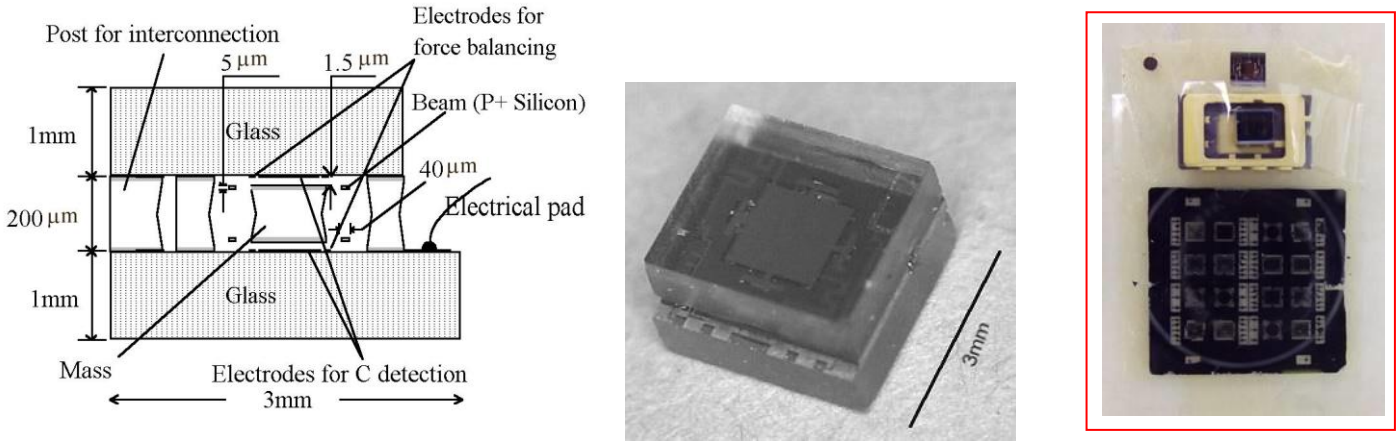


# B11 Various accelerometers



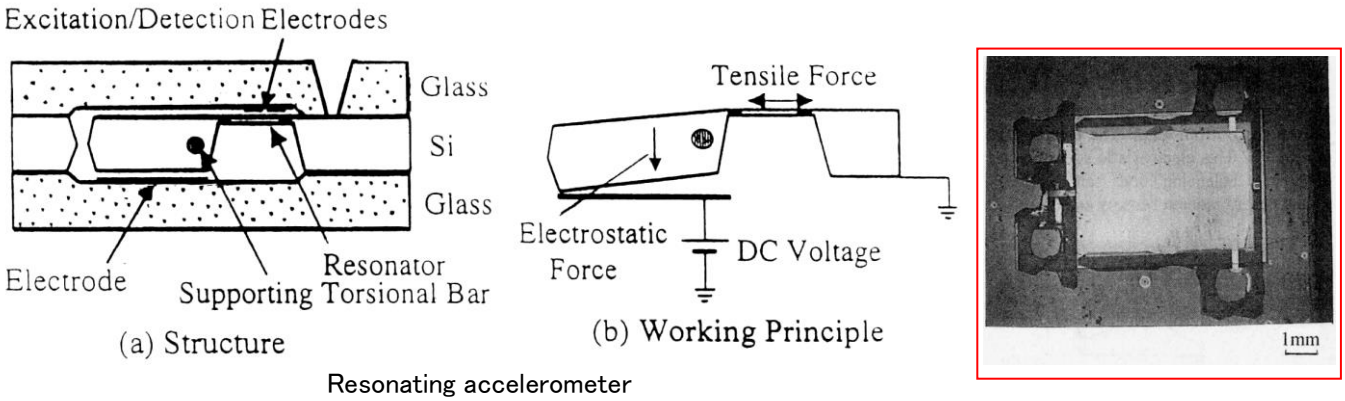

Piezoresistive accelerometer (Panasonic Electric Works)

Reference : High-accuracy high-reliability MEMS accelerometer, Technical Report of Panasonic Electric Works (Nov.2003) pp.15-21



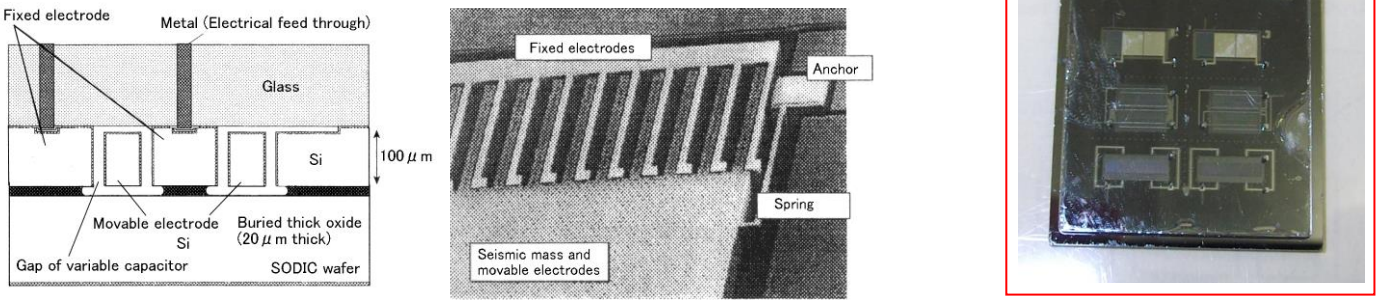

Narrow gap capacitive servo accelerometer (Tohoku Univ. – Samsung)

Reference : G.Lim, S.Baek and M.Esashi : A New Bulk-Micromachining Using Deep RIE and Wet Etching for an Accelerometer, Trans. IEE of Japan, 118-E (1998) pp.420-424



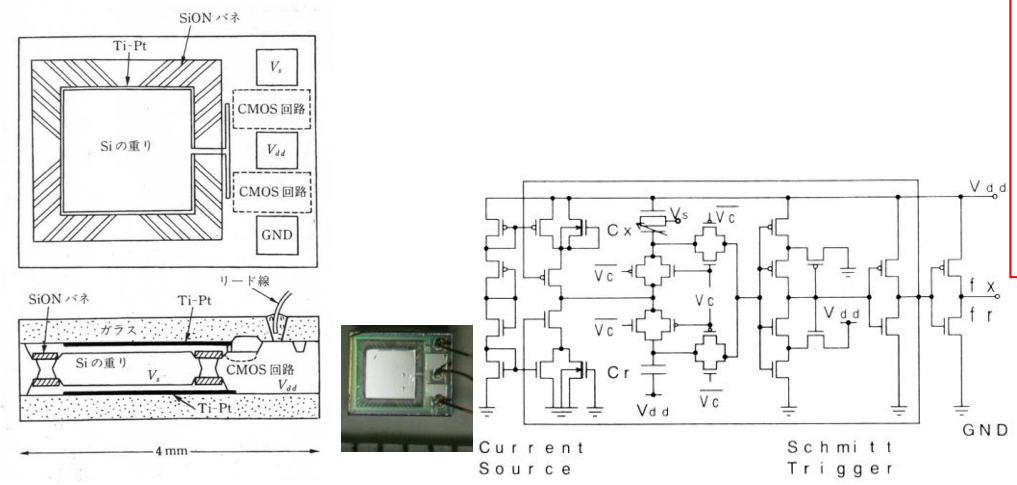

Resonating accelerometer

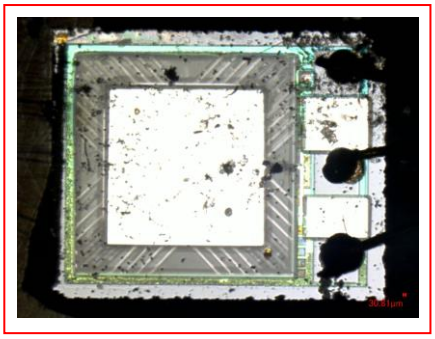
Reference : H.Hashimoto, K.Minami and M.Esashi, Silicon Resonant Accelerometer, Technical Digest of the 13th Sensor Symposium (1995) pp.181-184




Capacitive accelerometer using deep RIE of SOI wafer with thick buried oxide (Tohoku Univ. – Daimler-Chrysler)

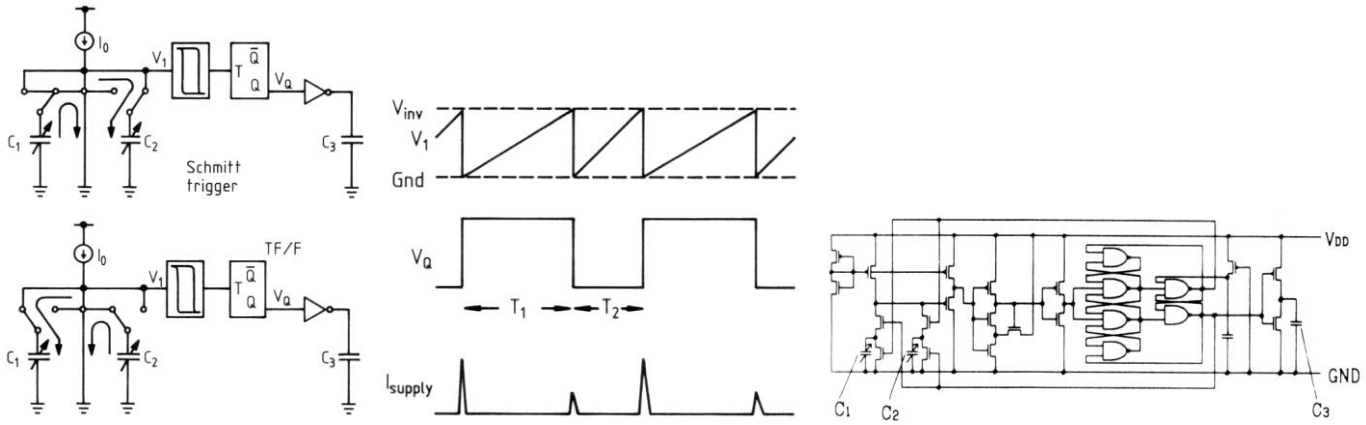
# B12 Integrated capacitive accelerometer



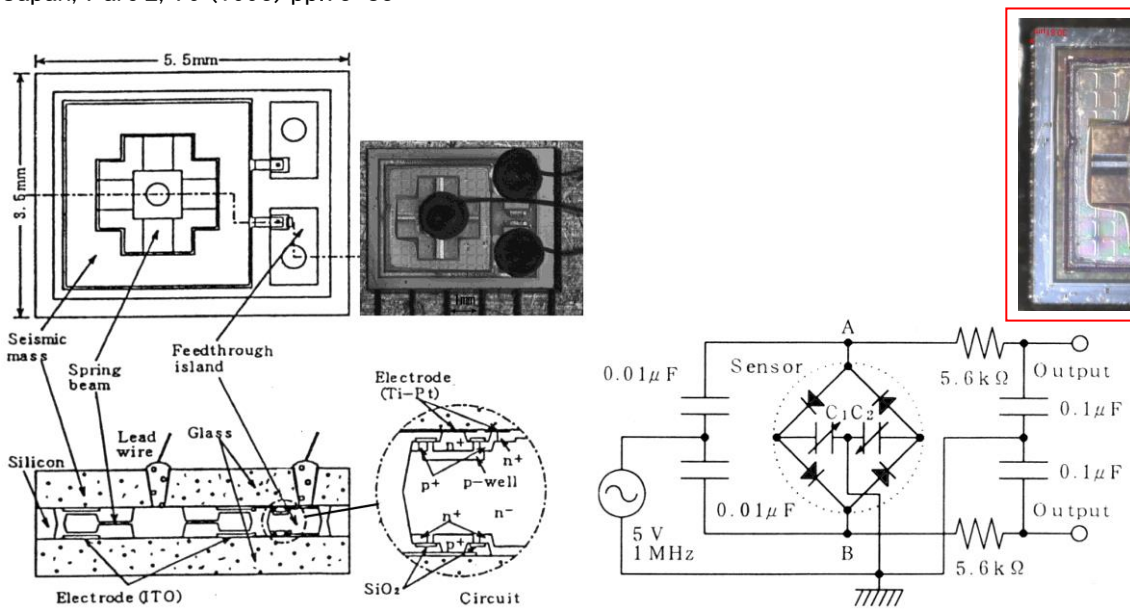
Integrated Capacitive Accelerometer

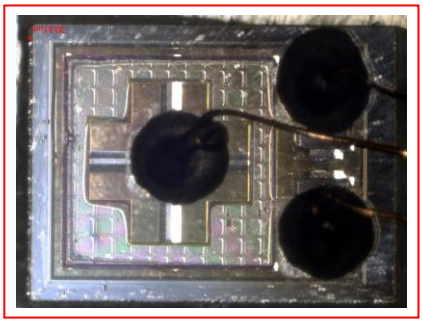
Reference : Y.Matsumoto and M.Esashi, Integrated Silicon Capacitive Accelerometer with PLL Servo Technique, Sensors and Actuators A, 39 (1993) pp.209-217




Differential capacitance two-wire accelerometer temperature sensor

Reference : T.Shirai, M.Esashi and N.Ura, A Two-Wire Silicon Capacitive Accelerometer, Electronics and Communications in Japan, Part 2, 76 (1993) pp.73-83

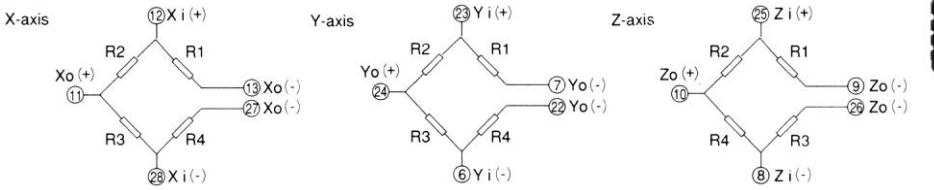


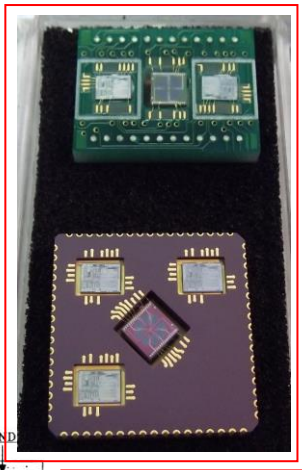
Diode bridge Integrated capacitive accelerometer

Reference : Y.Shoji, M.Yoshida, K.Minami and M.Esashi, Diode Integrated Capacitive Accelerometer with Reduced Structural Distortion, Transducers'95 (1995) pp.581-584

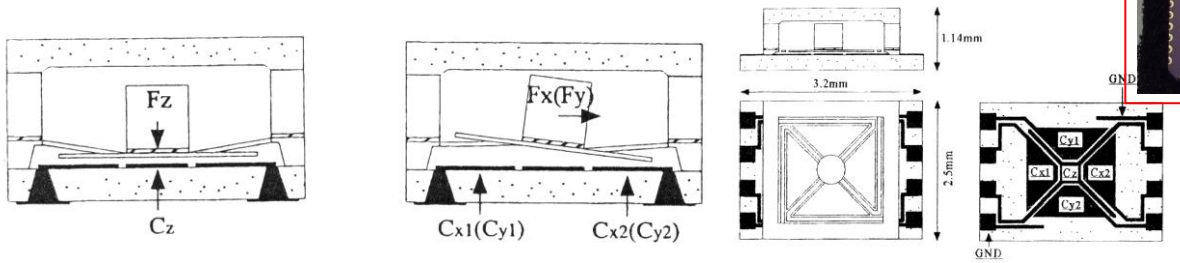
# B13 3-axis accelerometer

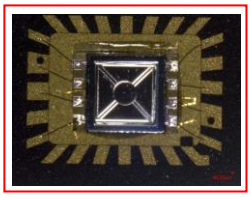






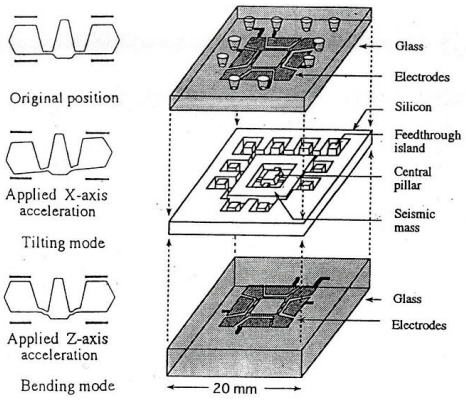
Piezoresistive 3-axis accelerometer (Fujikura)

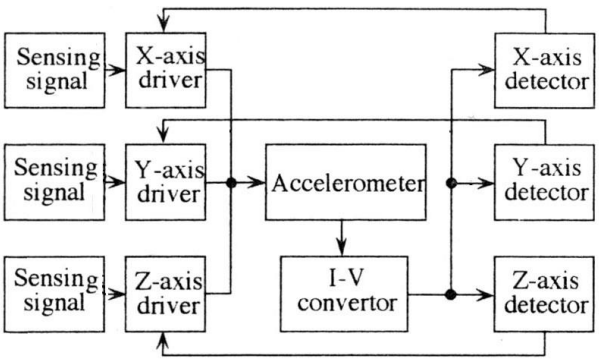


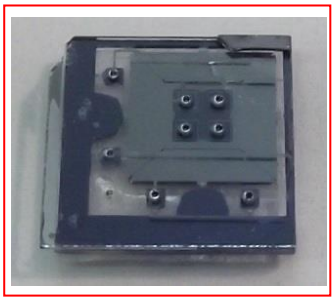



Capacitive 3-axis accelerometer (Tohoku Univ. – Tateyama Kagaku)

Reference : M.Mizusima and M.Esashi : Capacitive 3-axis Accelerometer Using SOI Wafer, Technical Digest of the 17th Sensor Symposium, (2000) pp.225-230

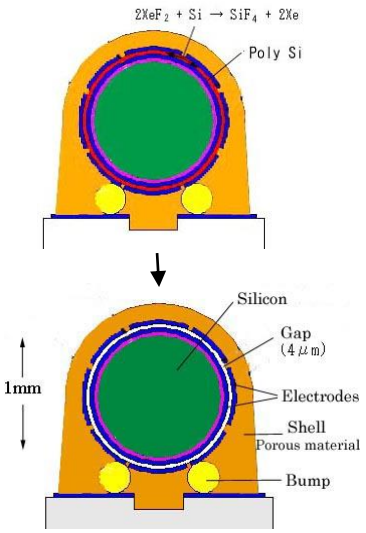


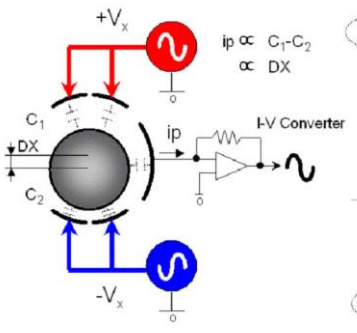



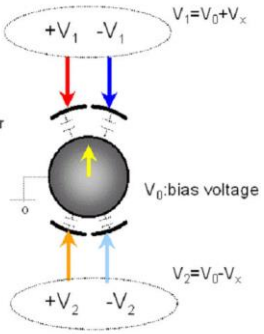



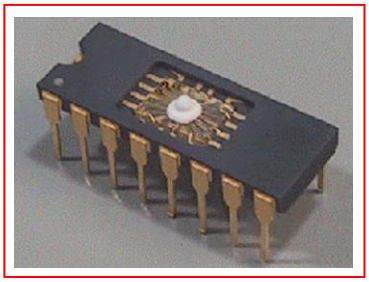
Capacitive 3-axis servo accelerometer (Tohoku Univ. – Kobe Steel)

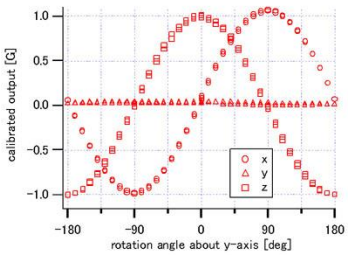
Reference : K.Jono, K.Minami and M.Esashi, Electrostatic Servo Type Three-axis Silicon Accelerometer, Measurement Science and Technology, 6 (1995) pp.11-15






Electrostatically levitated spherical 3-axis accelerometer (Ball Semiconductor – Tohoku Univ.)

Reference : R.Toda, N.Takeda, T.Murakoshi, S.Nakamura and M.Esashi : Electrostatically Levitated Spherical 3-Axis Accelerometer, Technical Digest MEMS'2002 (2002) pp.710-713

# B14 Electrostatically levitated rotational gyroscope

## The Electric Vacuum Gyro

H.W. Knoebel : "*The Electric Vacuum Gyro*", Control Engng, 11, 2, p 70, (Feb. 1964).

The Electric Vacuum Gyro Is a high precision 2-axis gyro for inertia navigation systems. A metal spherical rotor is levitated by high electric field in high vacuum ($10^{-8}$ – $10^{-9}$ mmHg) and rotated. The friction by mechanical supports are eliminated and hence high precision and low drift are achieved. This method was invented by Prof. A.Nordsieck in University of Illinois during his research on the inertia navigation systems for Polaris submarine.

Pinpoint for Polaris Launching

0.0001 deg per hr

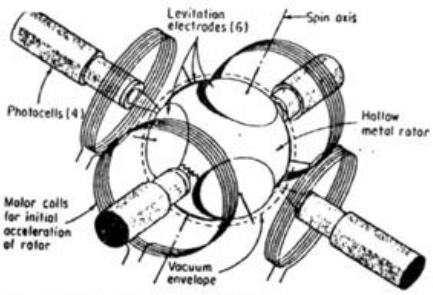



FIG. 1. Basic elements of the electric vacuum gyro include hollow rotor and levitation electrodes.

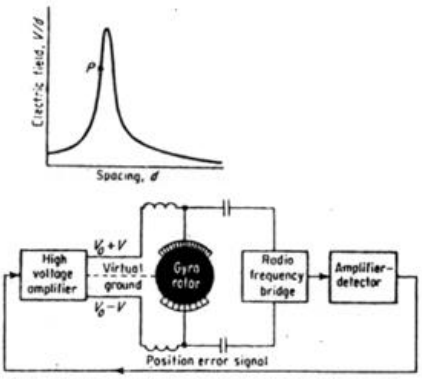
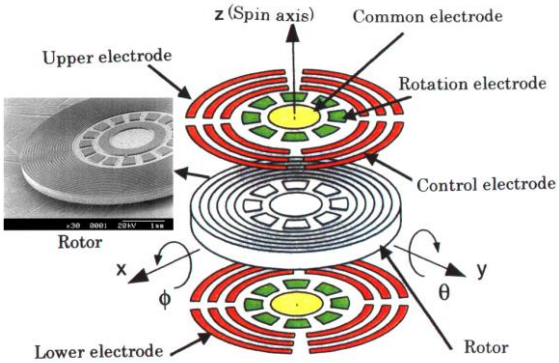
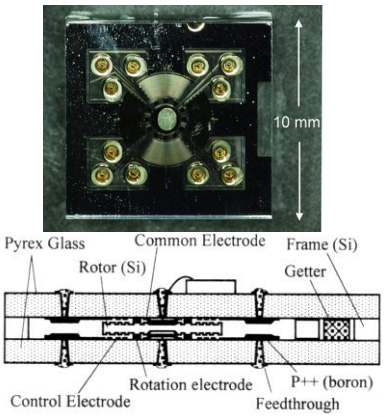


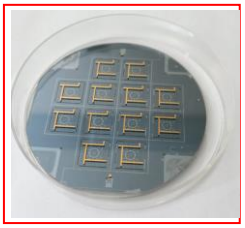

FIG. 6. Electronic levitation servo can be used to support rotor centrally in gap between electrodes (single axis).



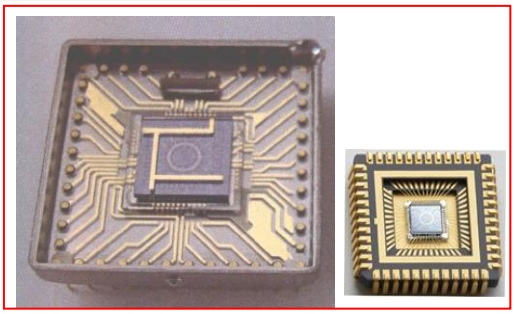




Electrostatically levitated disk rotor type rotational gyro (Tohoku University – Tokimec (at present Tokyo Keiki))

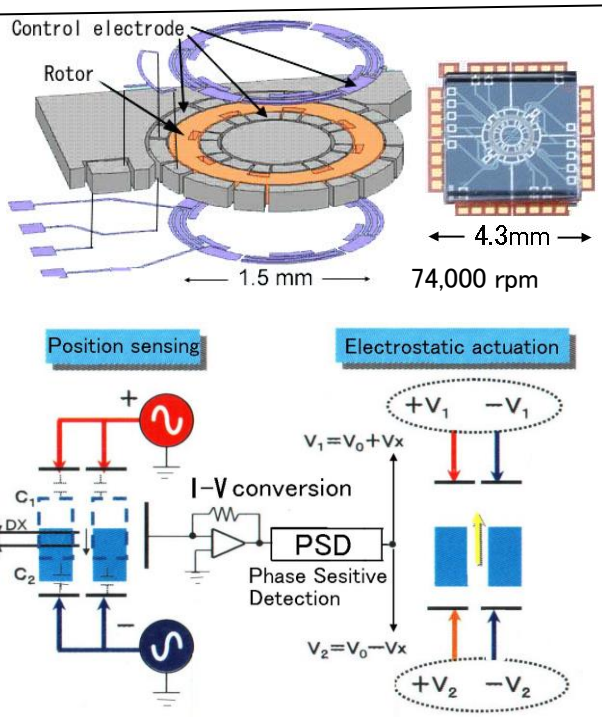
Ref. : K.Fukatsu, T.Murakoshi and M.Esashi, Electrostatically Levitated Micro Motor for Inertia Measurement System, Tech. Digest of the Transducers' 99 (1999) p.1558



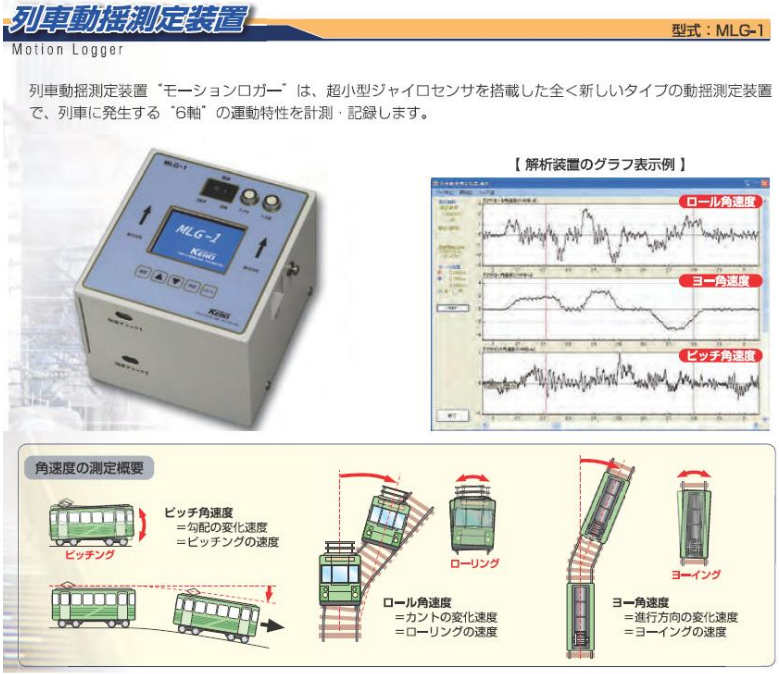
Wafer for electrostatically levitated ring rotor type rotational gyro (large ring type)



Electrostatically levitated ring rotor type rotational gyro (large ring & small ring type)




Electrostatically levitated ring rotor type rotational gyro (2 axis rotation and 3 axis acceleration) (Tohoku University – Tokimec (at present Tokyo Keiki))




Application to motion logger used for subway in Tokyo

Reference : T.Murakoshi, Y.Endo, K.Sigeru, S.Nakamura and M.Esashi: Electrostatically levitated ring-shaped rotational-gyro/accelerometer, Jpn. J. Appli. Phys., 42, Part1 (2003) 2468-2472