



微感測器 生化、熱流感測器

Microsensors 2

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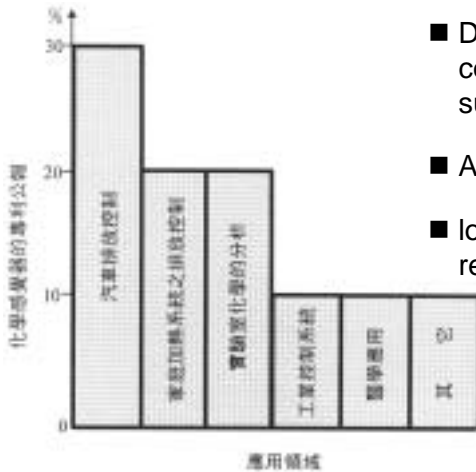
NKFUST

Chemical Sensors

CFD



Applications of Chemical Sensors



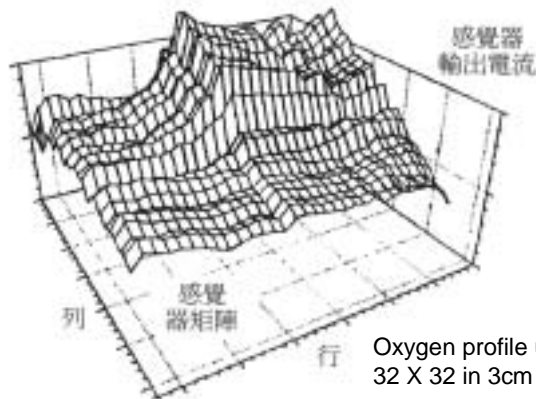
- Detect the presence or concentration of a chemical substance in a solution.
- About 60% are gas sensors.
- local measurement in a real-time environment.

圖 6.26 化學感測器的運用領域。數據 [Gron 93]。



Sensor Matrix

- Instead of the global detection in conventional methods, chemical micro system can analyze the chemical distribution over a domain.



Oxygen profile using sensor matrix
32 X 32 in 3cm X 3cm.





General Structure of a Chemical Sensor

- Major sensor principles:
 - ▶ Potentiometer principle in connection with field effect transistors (FET)
 - ▶ Acoustic sensors using the change of mass
 - ▶ Optical sensors

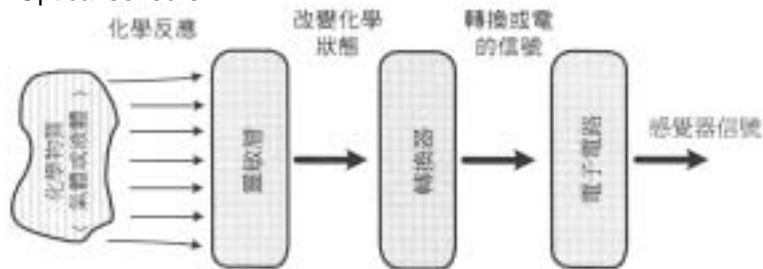
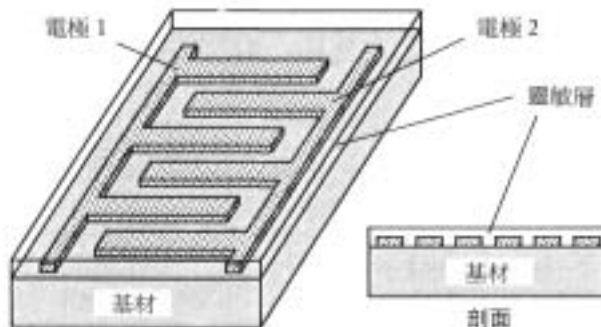


圖 6.28 化學感測器系統架構。



Interdigital Transducer (IDT) Sensor Principle

- The capacitance of IDT deviates due to the change of the dielectric properties of the sensitive layer (eg. SnO_2).
- Good for measuring humidity, concentration of sulfur dioxide or ethanol (乙醇).





Pellistor Sensor Principle

- Determine concentration of gases.
- Measure the increase of temperature due to a chemical reaction.
- When a gas is burnt, energies are released, that causes a temperature increase specific to the gas on the catalytical surface.
- High working temperatures of up to 700°C causes problems to silicon.

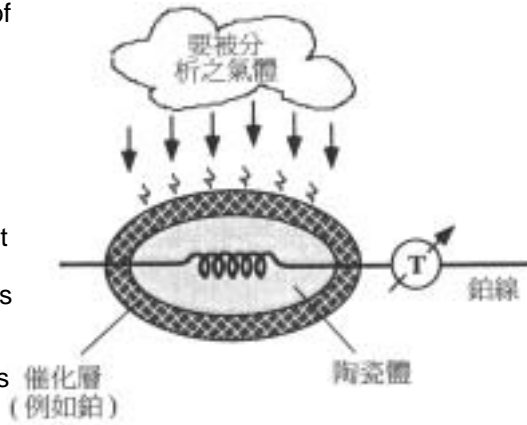


圖 6.30 使用於量測氣體濃度之彈丸原理



Optical Sensor Principle -1

- Interferometer
 - ▶ 經過待測介值之光路產生相位差，在與原入射光加成而產生干涉。
 - ▶ 加成之光電磁波的振幅受光相位差大小影響。
 - ▶ 光波能量強度與振幅的平方呈正比。
 - ▶ 光二極體 (Photodiodes) 測出合成光的強度

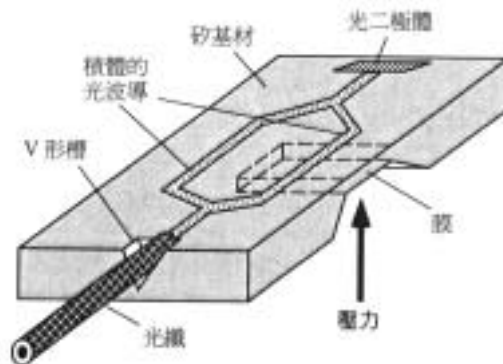


圖 6.8 馬赫切德干涉儀。根據 [Fisch 91]。





Optical Sensor Principle -2

■ Coupling Grid

- ▶ The substance has direct contact with the waveguide and changes its index of refraction.
- ▶ The amount of light striking the photodiode sensor is proportional to the concentration of the substance.

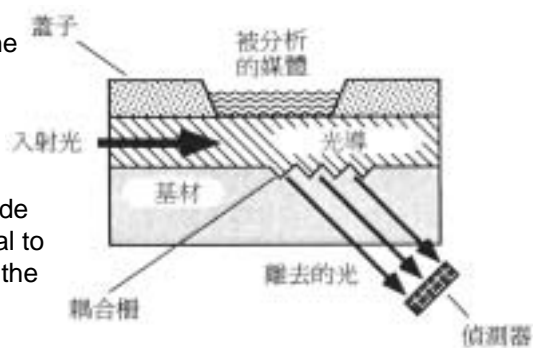


圖 6.31 耦合柵構造之功能。根據 [Krull 93]。



Microspectrometer

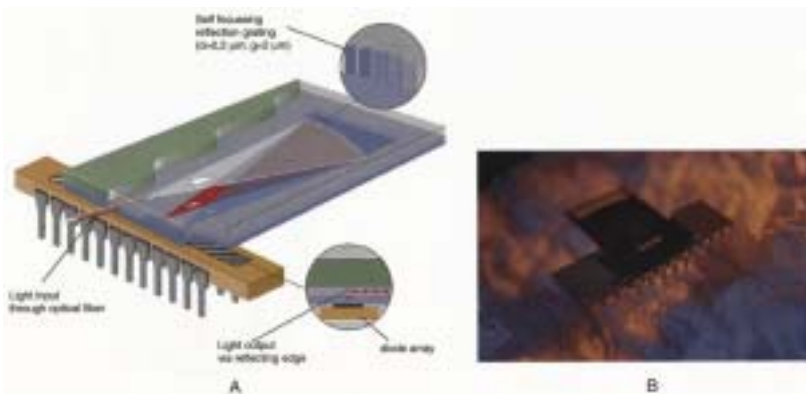


FIGURE 10.24 Microspectrometer from STEAG microParts.

Source: Fundamentals of Microfabrication - Madou



Field Effect Transistor Sensor Principle

- Ion-sensitive FET are used to measure the concentration of ions of various elements such as hydrogen, sodium, potassium or calcium.

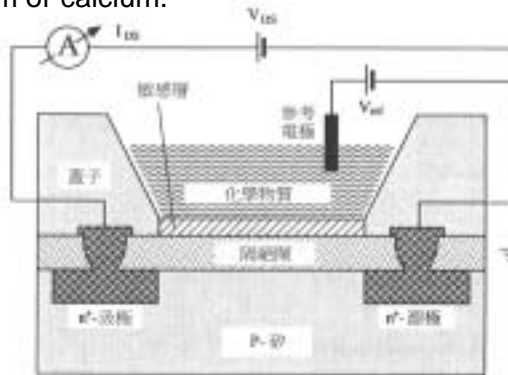


圖 6.32 基於一離子敏感場效電晶體的化學感測器。

FET Sensor Principle

- The ion-sensitive layer deposited on the gate area of the transistor.
- V_{GS} changes by the ions in the chemical substance.
- The change of V_{GS} is detected by adjusting V_{ref} .
- $I_{DS} = k(V_{GS} - V_T)^2$

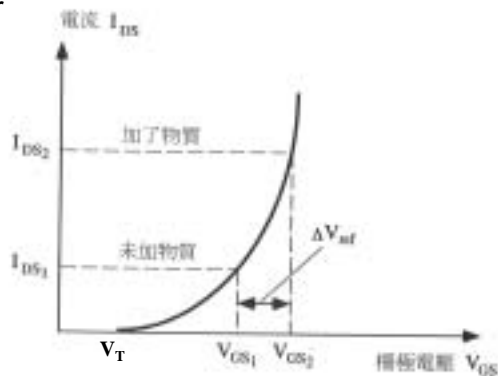
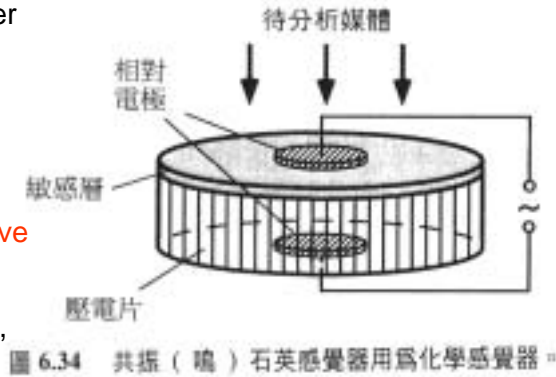


圖 6.33 基於離子敏感 FET 之化學感測器中電流 I_{DS} 是電壓 V_{GS} 的函數。



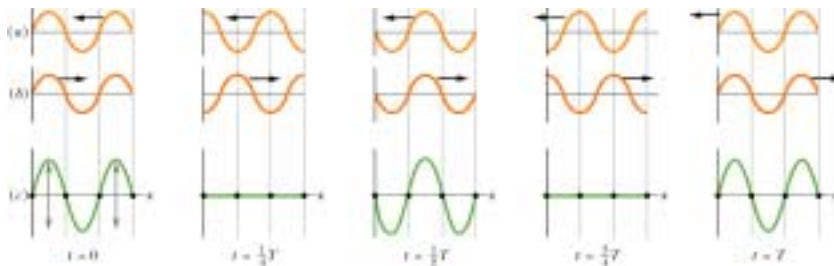
Resonance Quartz Sensor Principle

- The chemical reaction between the substance and the sensitive layer changes the sensor mass.
- The mass change affects the resonant frequency of the a **standing acoustic wave** in a mechanical structure such as a membrane, cantilever, or solid.



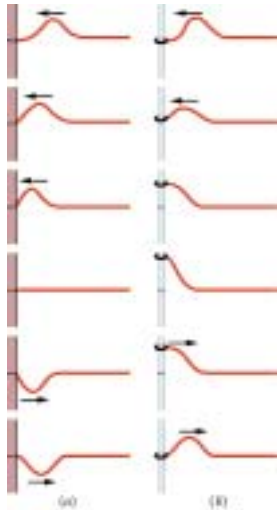
Principle of Standing Waves

- If two sinusoidal waves of the same **amplitude** and **wavelength** travel in opposite directions along a stretched string, their **interference** with each other produces a standing wave.





Reflections at a Boundary

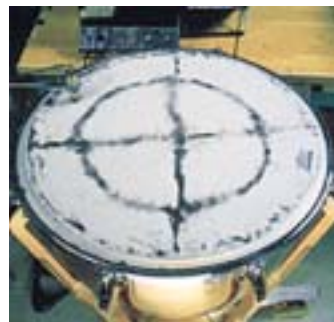
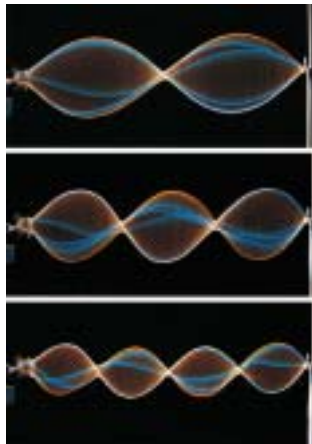


- When the string is tied to a **wall** (a), the reflected pulse is **inverted** from the incident pulse.
- When the string is tied to a **ring** (b), the pulse is **not inverted** by the reflection.
- We can set up a **standing wave** in a stretched string by allowing a traveling wave to be reflected from the far end of the string.



Standing Waves and Resonance

- Standing waves pattern on a string and on a membrane .





Waveguide Sensor Principle

- The sensitive layer interacts with the analyzed substance and the wave transmission changes due to damping.

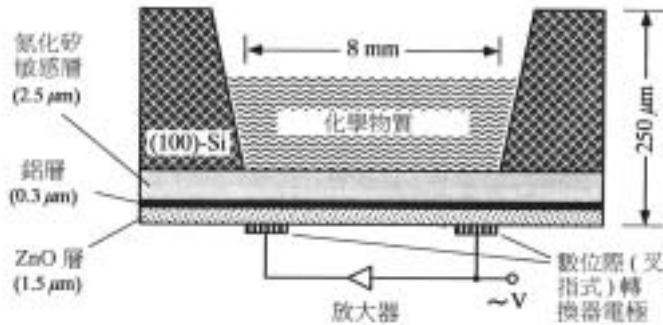
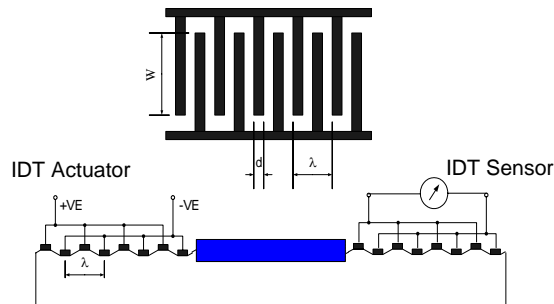


圖 6.35 表面聲波感測器 - 根據 [Gies 92]。



Acoustic Waves Transducers

- Principle of Acoustic Wave
 - ▶ Interdigital Transducer (IDT) over a piezoelectric layer.
 - ▶ Using IDT as actuator and sensor.
 - ▶ Sensitive layer, interacting with the chemical substance, changes the phase or the resonance frequency of SAW.

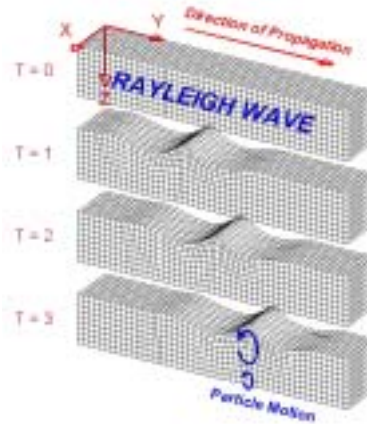




Raleigh Waves

■ Raleigh waves (瑞利波)

- ▶ 沿著平滑半無限厚彈性體表面傳播的波 (Surface Acoustic Wave, SAW)。
- ▶ 能量集中在表面下一個波長的深度傳遞。

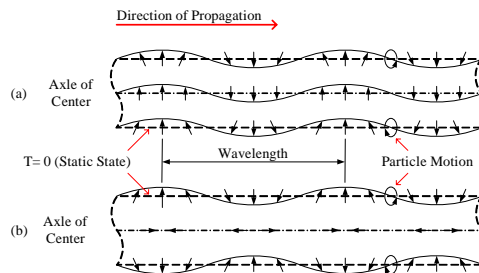


Lamb Waves

■ Lamb waves

- ▶ 在薄板中傳遞的彈性波 (Flexural Plate Wave, FPW), 波長大於板厚。

▶ 反對稱型



▶ 對稱型



Ion Sensitive FET Sensor

- Continuous measurement of the gases in blood (like pO_2 or pCO_2) and of the pH value are very important in surgery.
- Use ion-sensitive field effect transistors.

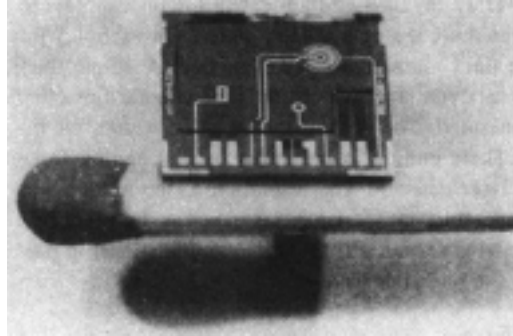


圖6.36 血液氣體/pH感測器



Bimetal Sensor

- A chemical reaction is transformed into mechanical motions by using the bimetal effect.
- Array of 400 μm long silicon cantilevers made of ($0.4 \mu\text{m}$ Pt catalytic layer) / ($0.4 \mu\text{m}$ Al) / ($1.5 \mu\text{m}$ silicon).
- The reaction heat causes the bimetal cantilevers to bend.
- Displacement measured by a scanning force microscope with an optical laser detector.

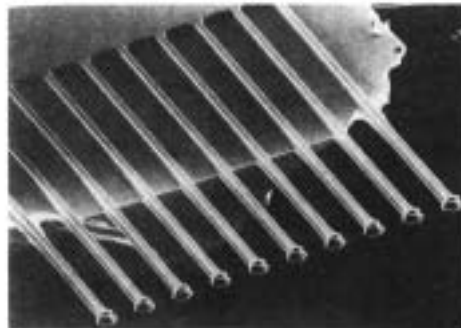


圖 6.37 化學雙金屬感測器之原型 - 感謝 the IBM Research Division (Zürich Research Laboratory) and of the University of Neuchâtel (Institute of Microtechnology) -

Sensor resolution: 0.01 nm, (ie. 10^{-5}°C)





Sensors Based on a Zigzag IDT Capacitance

- The concentrations Of CO₂ in a fluid is measured with AMO/PTMS whose dielectric properties is changed with the CO₂.
- Zigzag design has better capacitive properties.
- NiCrAu capacitor, Zigzag width varies between 2.5~15 μm.
- AMO/PTMS thickness varies between 0.9~1.2 μm.

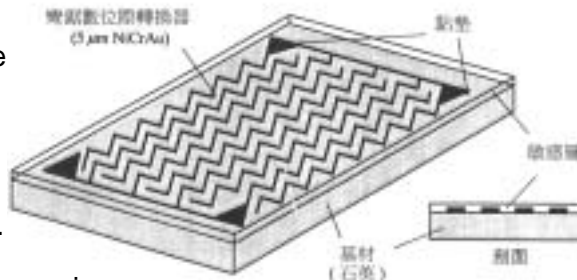


圖 6.38 CO₂ 濃度感測器。根據 [Hinz 92]。



Sensors Based on IDT Capacitance

- Another interdigital transducer sensor for detecting CO, CO₂, NO₂ and water concentrations.
- The sensitivity and selectivity of SnO₂ can easily be enhanced by a catalyst.

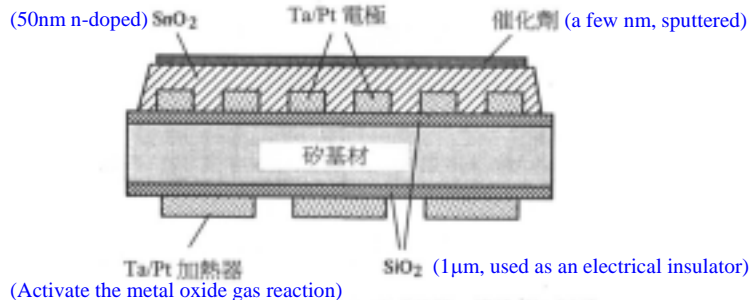


圖 6.39 具數位感測器之氣體感測器。根據 [Steil 94]。



BioSensors



Sensing Principles

- Similar principles as chemical sensors.
- The biologically sensitive elements such as enzymes, receptors and antibodies are integrated with the sensor.
- In many molecular interactions, gases are either released or consumed, that can be detected by a chemical sensor.
- Major difficulties
 - ▶ Produce only short-lived sensors because the proteins are not very stable for a very long time.
 - ▶ Immobilization (固定) of the proteins.
- Biosensors are divided into metabolism sensors (代謝型) and immuno-sensors (免疫型).

Metabolism Sensors

- Biosensitive enzymes (酵素) as biocatalysts (生物催化劑) to detect molecules in a substance and to catalyze a chemical reaction.
- The analyzed substance is chemically transformed and the course of a reaction can be detected by a chemical sensor.
- For instance, Phosphate (磷酸鹽) concentration can be determined from the amount of oxygen consumed.

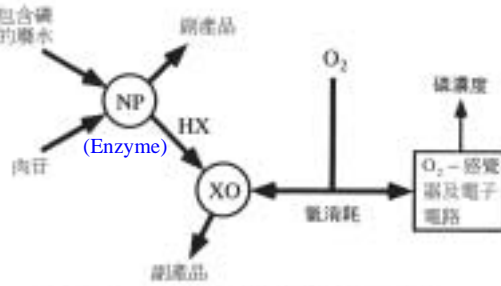


圖 6.40 以同化感測器之磷的量測。根據 [Nest 92]。

Immuno-sensors

- To detect chemically inactive molecules in a substance.
- Immobilized antibody molecules ("lock") on the sensor surface bond with an antigen molecule "key" in the substance.

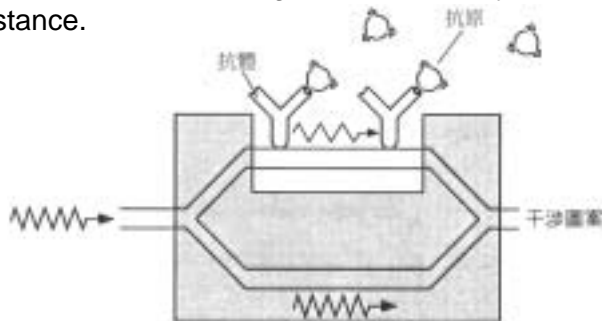


圖 6.41 使用光學轉機器之免疫偵測。根據 [Gopel 94]。

Immuno-Sensor with IDT

- 結構包括小室本體、具格柵狀結構之流體室（固定珠狀免疫蛋白）、入口管、出口管、轉換器（四對Ti/Pt指狀電極，70支手指，每支900 μm，寬度1 3.2 μm，相鄰手指間隙186-800 nm）

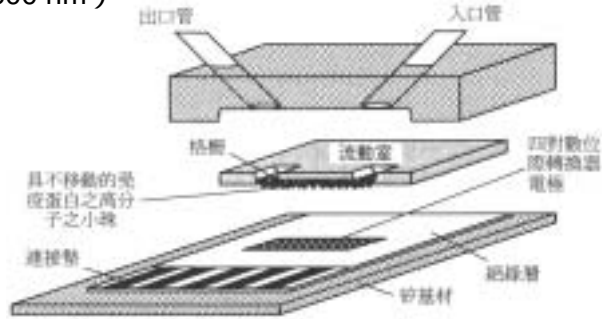


圖 6.42 生物感測器之設計示意圖。根據 [Hirn 94]。

Immuno-sensor with IDT

- 當與IDT接觸的免疫蛋白與抗原產生去氧反應（Redox），該去氧反應為可逆，而去氧反應時持續的氧氣消耗與形成，造成IDT電流增加30倍。

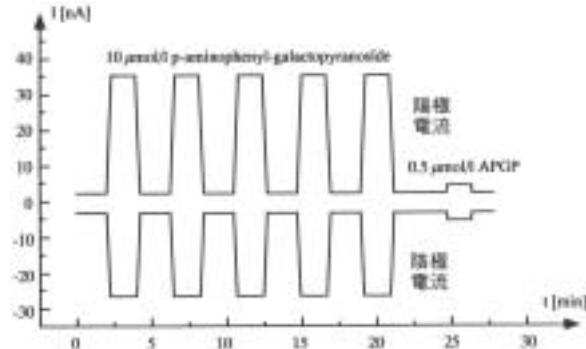


圖 6.43 注入 APGP 之感覺器反應。根據 [Hirn 94]。



Single Channel Metabolism Sensors

- Several thermal metabolism sensors can be installed in one sensor system.
- Thermistors (熱量計) are made by doping and etching the quartz chip.

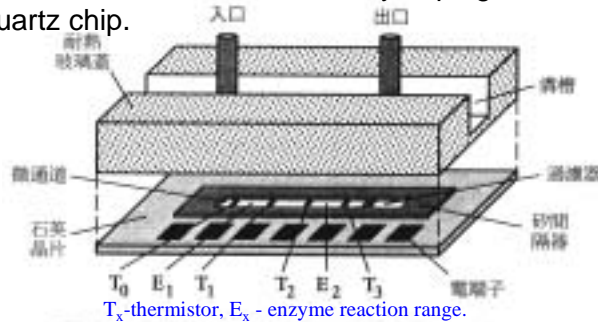


圖 6.44 生物感測器的設計原理。(感測器分為上下兩半以利觀察) - 根據 [Xie 94] =



Single Channel Metabolism Sensors

- The thermistors T_0 and T_1 , are responsible for measuring the enzyme located in the reaction range E_1 .
- The reaction between the enzymes E_i with the substances marked as S_i generates heat that is registered by the thermister.

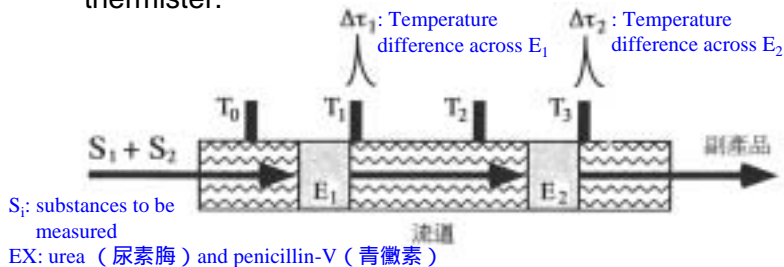


圖 6.45 生物感測器之基本原理 - 根據 [Xie 94] =





Temperature Sensors



Fiber- Optical Thermometer

- The multi-modal glass fiber is made of materials that have different temperature coefficients in the core and the mantle.
- Temperature variation in the sensor surrounding changes the local index of refraction in the fiber, that results in an optical light attenuation.
- Measure temperatures of up to 90°C with in accuracy of 0.1°C.

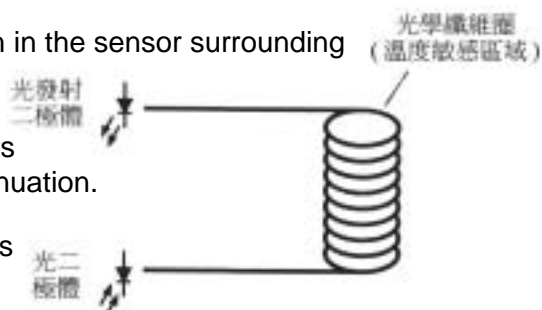
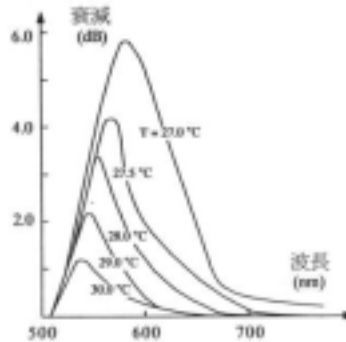
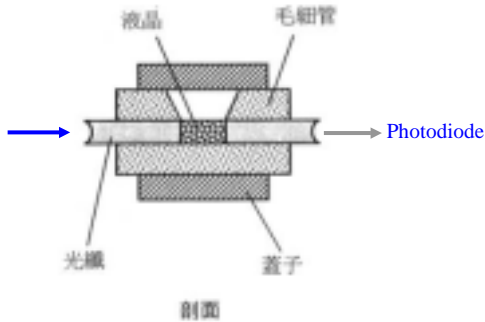


圖 6.46 光纖溫度計示意圖。根據 [Ecke 93] =



Liquid Crystal Thermometer

- The thermotropic liquid crystals can be used for measuring temperature since their optical properties are determined by the molecular alignment, which is temperature-dependent.



液態晶體之特色

- 與固態晶體的比較
 - ▶ 具有一般晶體之方向性同時又具有液體之可流動性
 - ▶ 經由溫度、電場或磁場來控制改變方向性
 - ▶ 液晶分子示意圖

固態	液晶	液態
排列整齊	排列整齊中帶有不整齊	排列不整齊



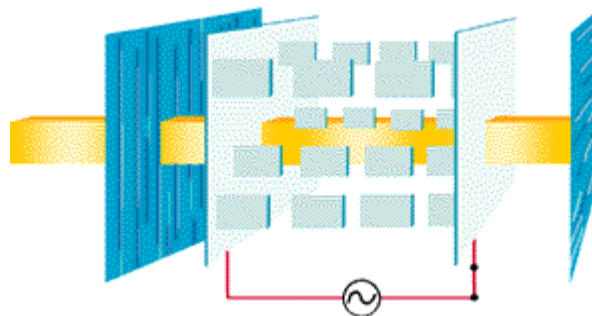
薄膜電晶體液晶顯示器

- 未加電壓時，偏極化後的光經液晶旋轉後會穿過正交的另一道偏極板，因此會亮。



薄膜電晶體液晶顯示器

- 加電壓時液晶順向，使得光不會偏轉，因此被第二道正交的偏極板擋住，因而變暗。

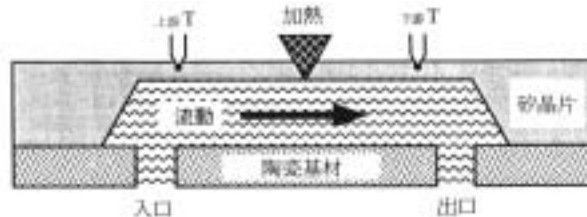


Flow Sensors

Two-mode Flow Sensor

■ Two modes:

- ▶ Elapsed time of the locally heated flow medium: A 5 Hz signal was applied to the heater and the time was measured until the temperature rise is recorded by the 2nd sensor.
- ▶ Thermal dilution: the heater supplies constant energy, and measure the temperature difference between the upstream and downstream sensors.

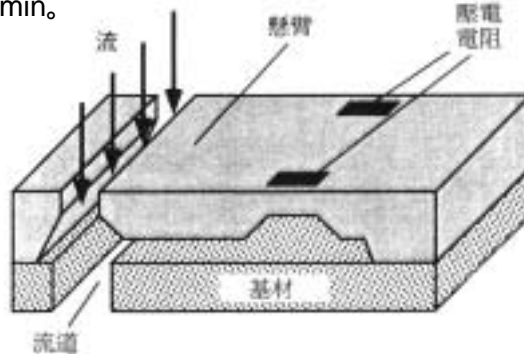


入口 Sensitivity: 0.05~0.2 ml/min. 出口
圖 6.48 微流動感測器 - 根據 [Bran 91]



Force-Measuring Flow Sensor

- 以壓阻原理量測物體在流體中所受的力，以計算流體流量
- 懸臂長3mm寬1mm厚30 μm ，以表面與體型微細加工矽晶圓製成。操作範圍5~500 ml/min，對水的敏感度為 4.3 $\mu\text{V/V}$ per $\mu\text{l/min}$ 。



Thermal Flow Sensor

- Consist of a circular silicon disc, an implanted heating resistor, a ring-like silicon dioxide layer (thermal insulation) around the disc, and a 3 μm thick polyimide film as chip cover.

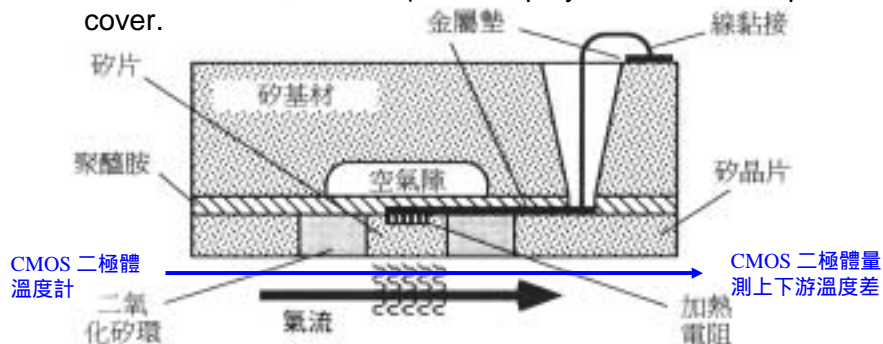


圖 6.50 氣流感覺器之剖面。根據 [Domi 93]。