ISFET-based Electronic Tongue System and Applications

鍾文耀教授

中原大學電子工程系/電子資訊技術研究中心

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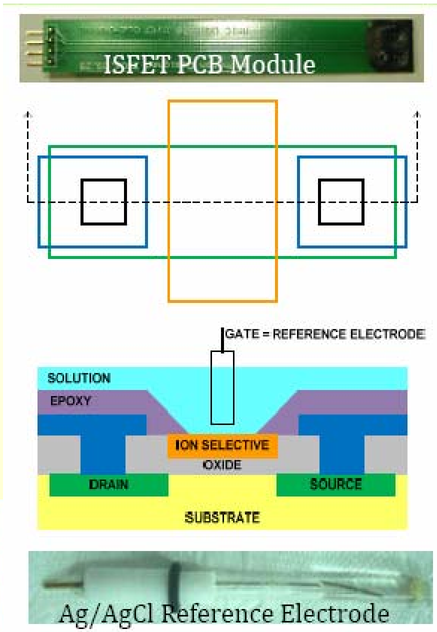
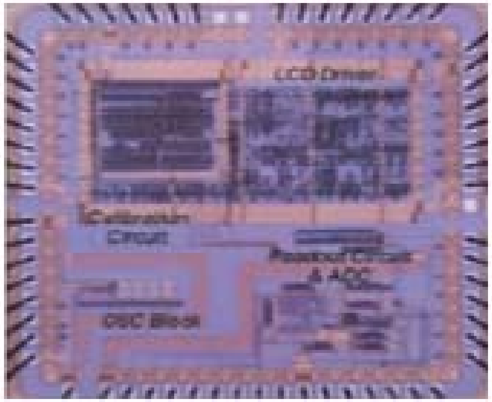
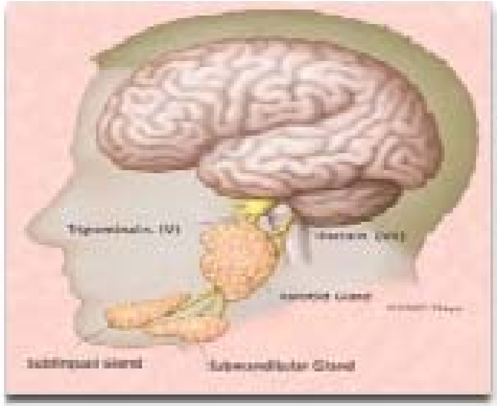


大綱

- 甚麼是電子舌
- 電子舌系統及應用
- 電子舌技術之挑戰 -
  感測器陣列與讀出電路研發
- 未來展望與參考文獻


電子舌系統導論

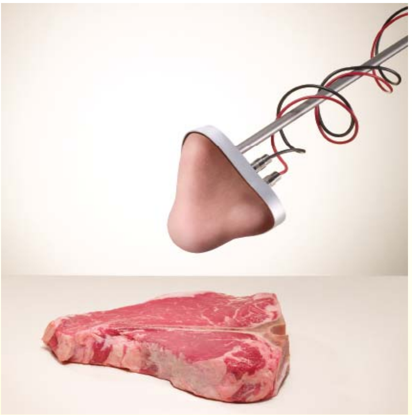


1.1 Electronic Sensing

Sensors Inspired by Nature

http://en.wikipedia.org/wiki/Wine_tasting

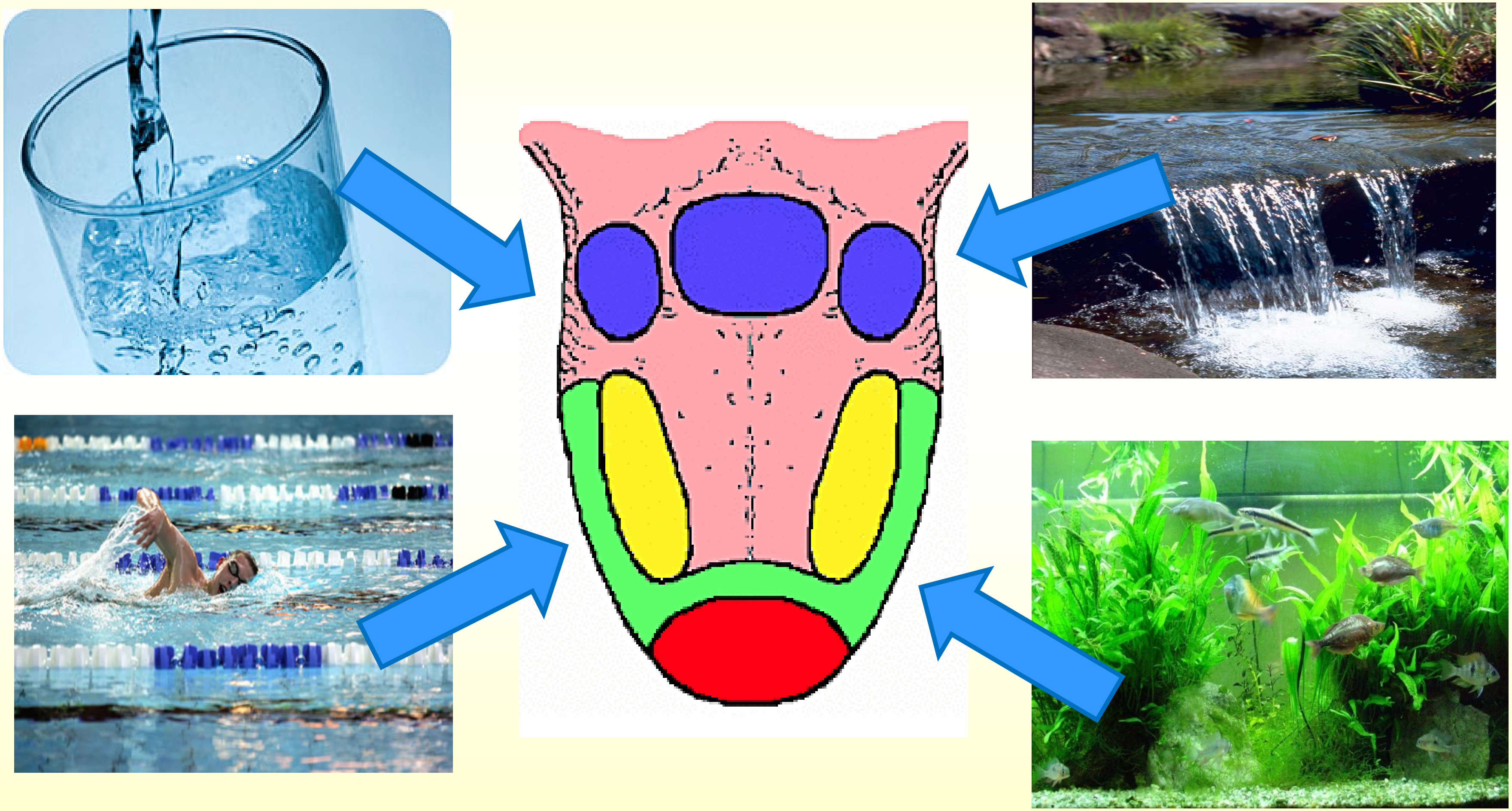
- Color View
- Flavor Taste
- Air, Water, Wine, Food,…



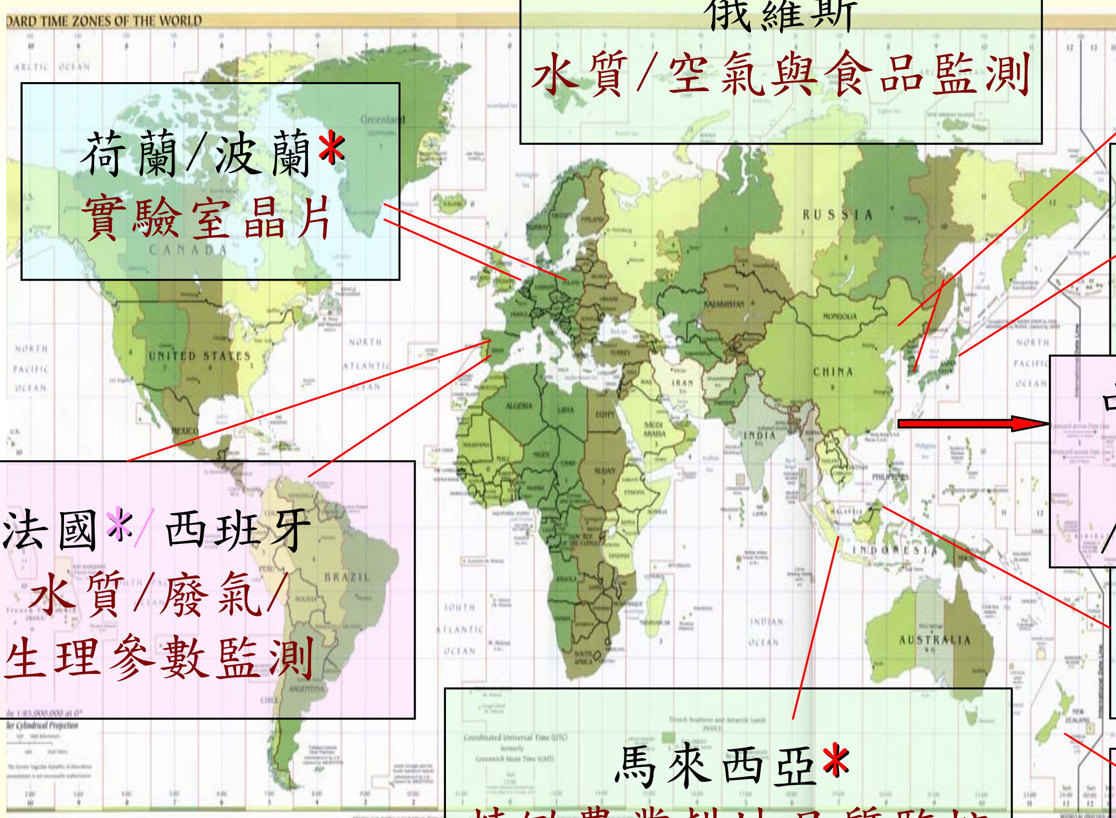
- Why biomimetic system?

Ref: Change, J.B. Subramanian, V., "Electronic Noses Sniff Success," **Spectrum, IEEE, pp. 50-56,** March 2008

1.2 Electronic Tasting



全球研究投入現況



俄羅斯
水質/空氣與食品監測

韓國/大陸
假酒測試

荷蘭/波蘭*
實驗室晶片

日本
水質與食品測試

中原大學*水質/廢氣/
生理參數監測
/清華大學與各校團隊

法國*/西班牙
水質/廢氣/
生理參數監測

新加坡
蛇毒血清研究

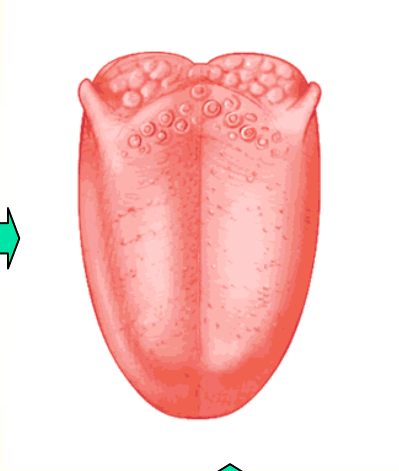
馬來西亞*
精緻農業耕地品質監控

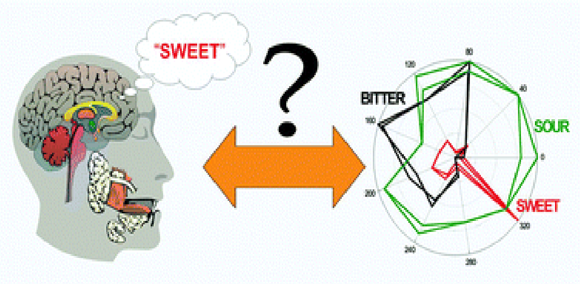
紐西蘭
青草毒物含量監測

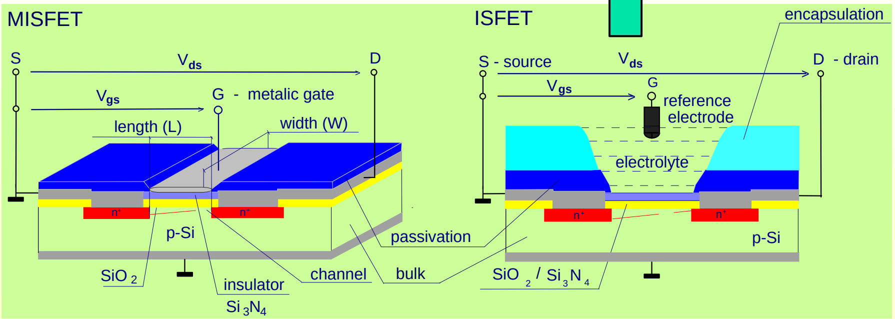
http://www.overseasstudy.cn/info_center/worldmaps/

Why Electronic Tongue System and ISFETs

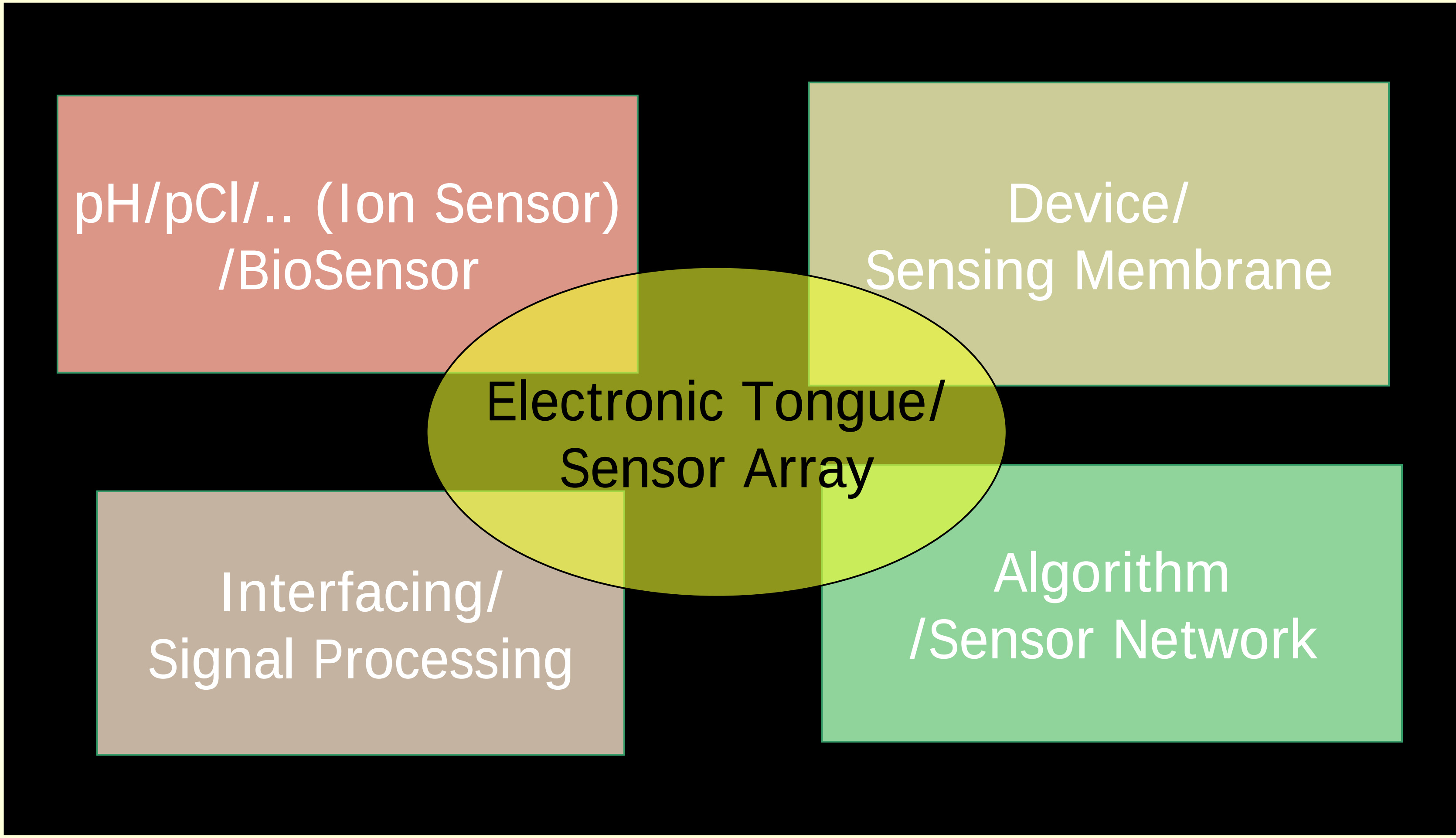
Liquid Environment / Potentiometric Sensors





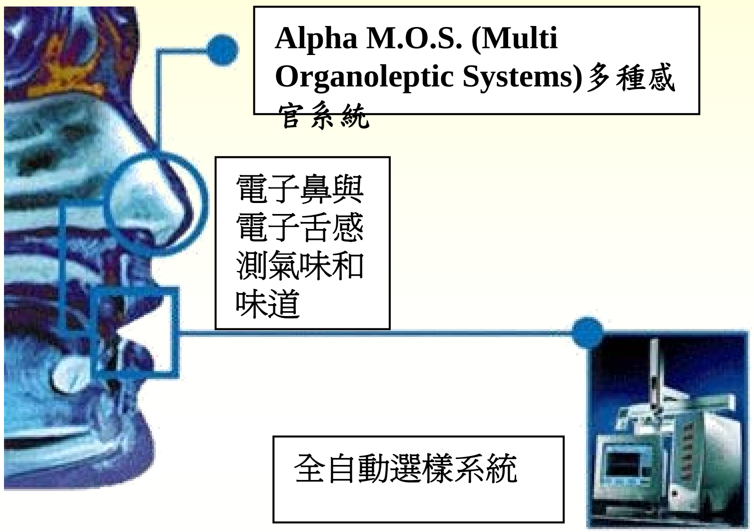


核心技術研究項目


pH/pCl/.. (Ion Sensor)
/BioSensor
Device/
Sensing Membrane
Electronic Tongue/
Sensor Array
Interfacing/
Signal Processing
Algorithm
/Sensor Network

感官仿生技術研究

http://www.alpha-mos.com/cn/index.php



-仿生物感測器是一種整合性的裝置功能是將待測物(如生物訊號)轉換成可量化之電子訊號，以便進行資料分析及輸出處理

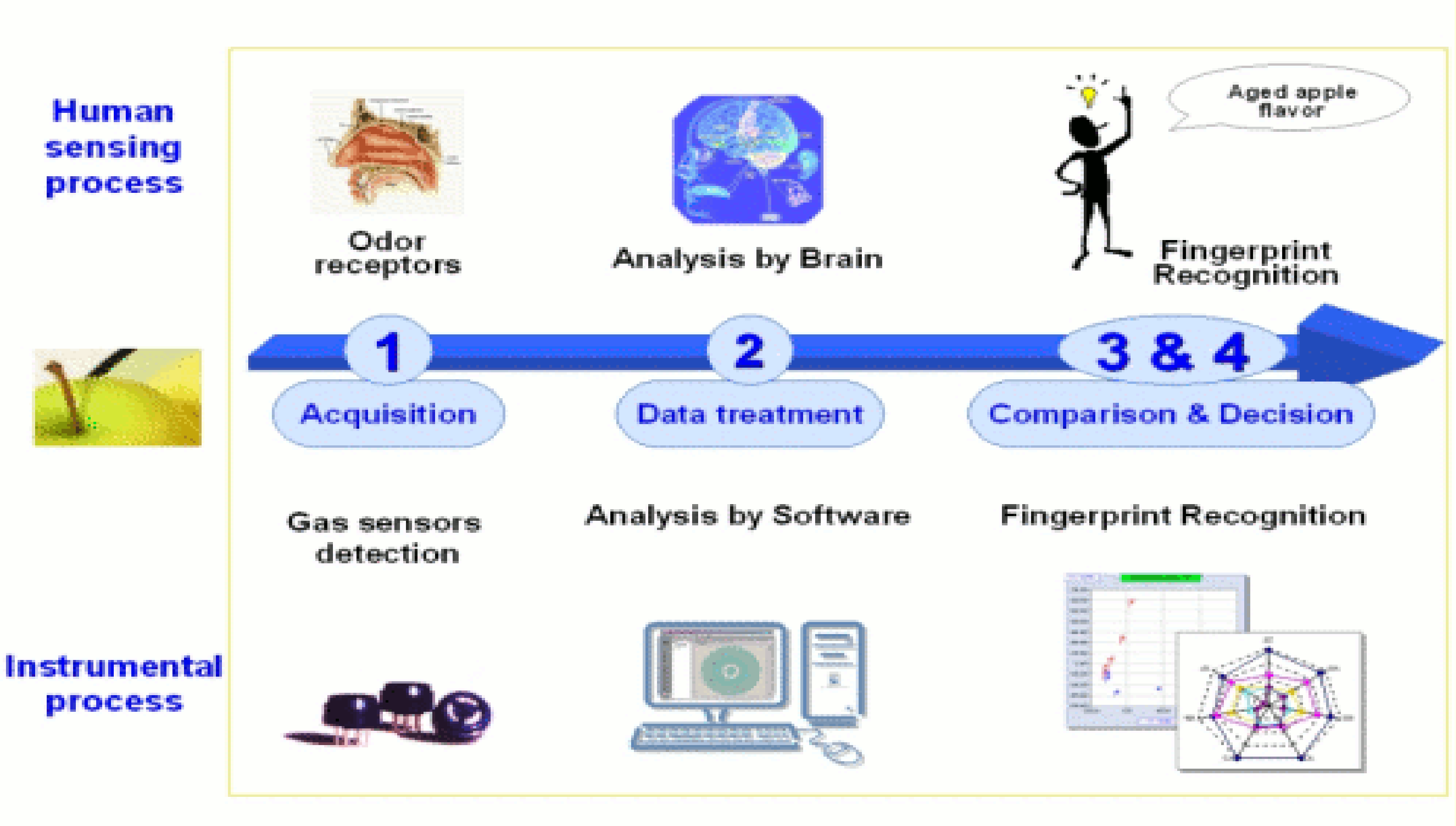
-近年來，電子鼻與電子舌系統激起大量研究者的興趣

-1990初 電子鼻商品化產品
-工研院生醫中心與中國醫藥學院，電子鼻診斷系統，
經由呼出的氣體可檢測尿毒症及肝硬化，其準確率約有85%及94%

- Tongue function

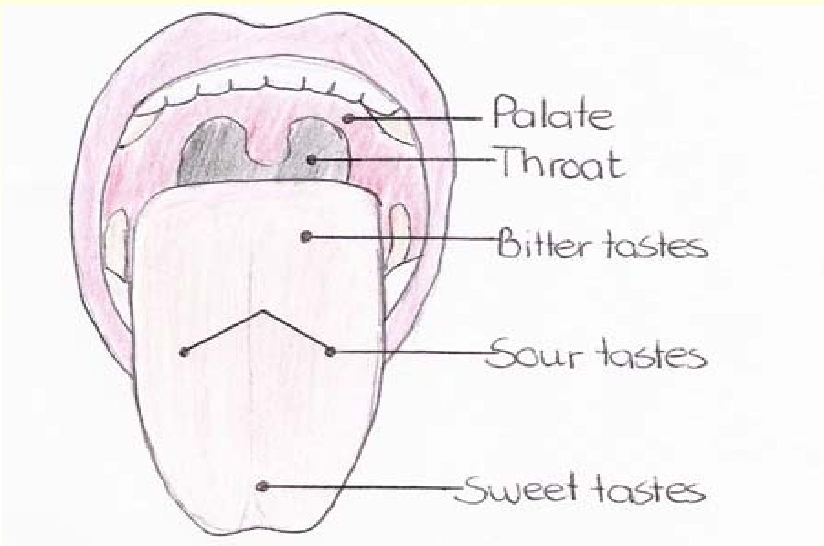
人類感官與仿生儀器比較

http://www.alpha-mos.com/index.php



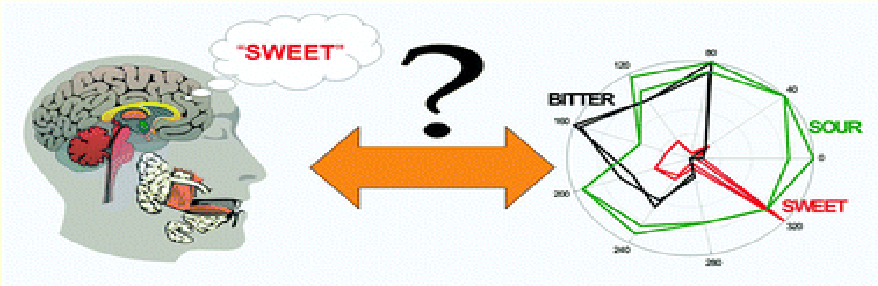
電子舌的工作原理和電子鼻一樣。主要的區別在於分析的樣品是液體，所有感測器直接浸入液體中。

甚麼是電子舌?



http://library.thinkquest.org/05aug/00386/taste/index.htm

- 電子舌 – 一種感測元件可以用來辨識（含確認、分類、判析過程）並能定性或定量地進行溶液中多成份的分析；並以人為之方式評估各種溶液之味道與鮮美程度

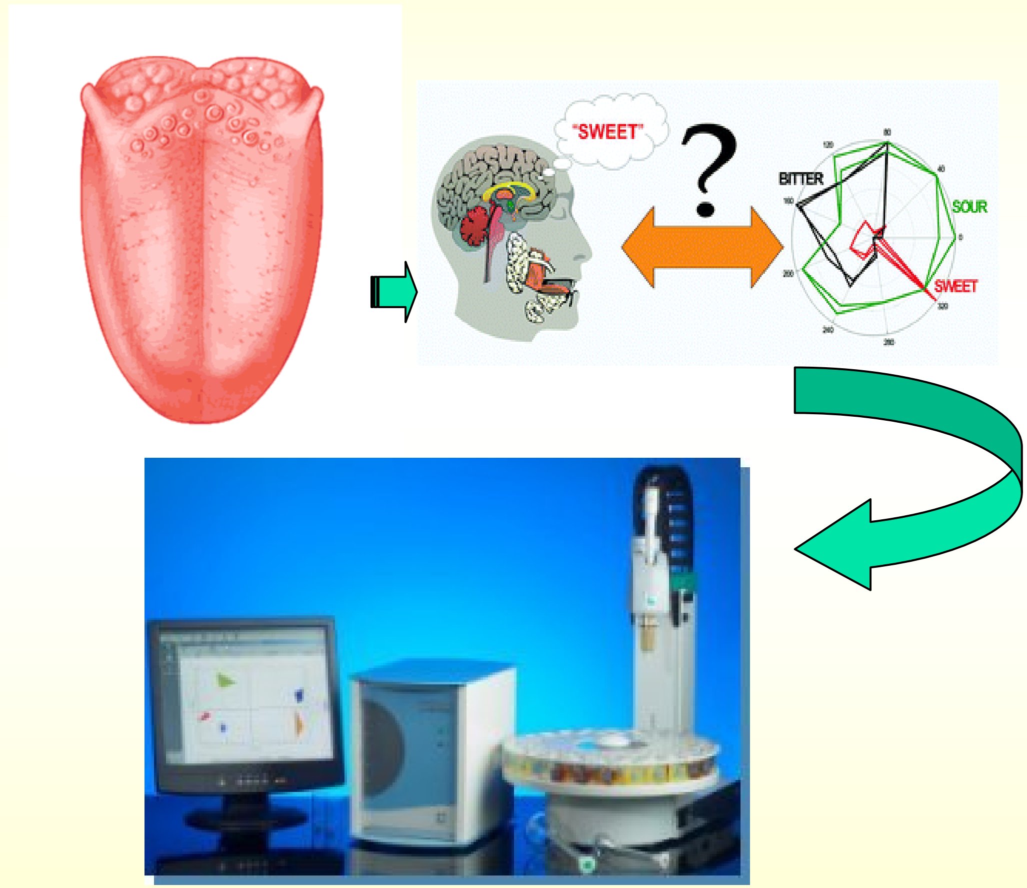


Patrycja Ciosek and Wojciech Wróblewski,

The Analyst, 2007, 132, 963 - 978

電子舌之基礎內涵

- 一種模仿生物體的味覺系統
- 快速分辨酸、甜、苦、鹹、鮮美等於液體中味道的儀器
- 其訊號檢測最常見的是電化學式的方法
- 辨識原理則為模仿生物體味覺系統之圖譜辨識
- 延伸之定義與應用-其他物種或離子監測



http://www.alpha-mos.com/cn/index.php

電子舌廣義應用研究之價值

水安全監控

休閒設施、工業、及飲用水H+, Cl- 濃度應用

建康指標之判斷

生物醫學應用, 氯濃度測試(Chloride Test)可用於糖尿病代謝之酮酸中毒(diabetic ketoacidosis)檢測

pH(酸鹼值) – 環境監控

- 低成本ISFET 酸鹼度儀 (pH meter)
- 可更換之感測頭(sensor tip)
- 食品、土壤、廢水、泳池與其他樣本之快速酸鹼度讀取

標準之檢測頭(sensor tip)可進行微量檢體(20ul)之酸鹼度偵測

http://www.topac.com

http://www.deltatrak.com/24003.pdf

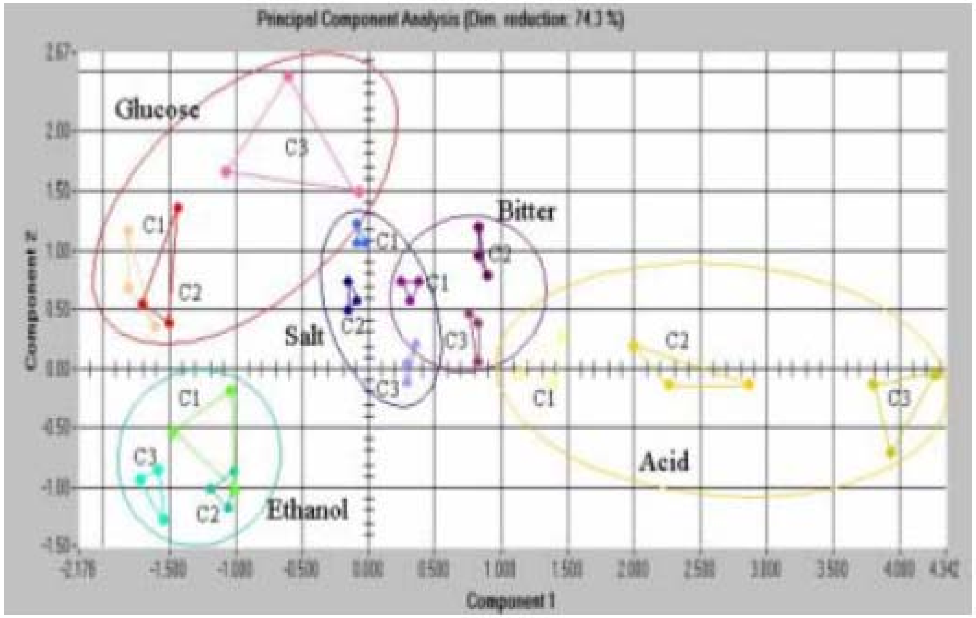
Chloride (氯離子)–水質監測與應用

- 氯化作用(Chlorination)
  - 氯與水反應所形成的酸可殺細菌與藻類(algae)
  - 衛生(Sanitation)、消毒(disinfectant)
  - 適當之氯離子濃度Cl^- (0.1 – 1 ppm)

電子舌系統發展之需要性

- 老年化人口，居家照護
- 優質生活
- 家園安全

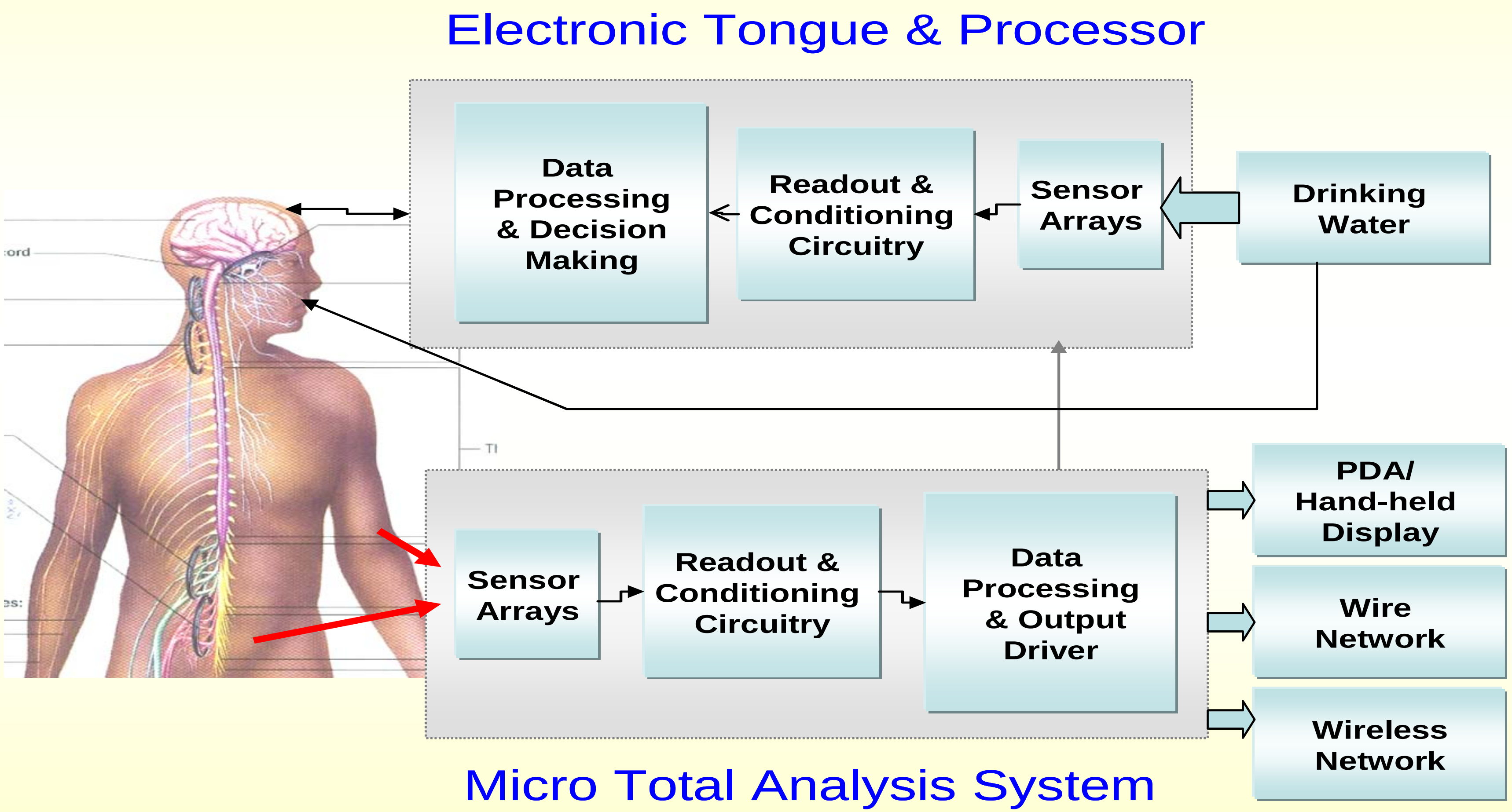
聚合物塗佈之感測器
(polymer coated sensor)



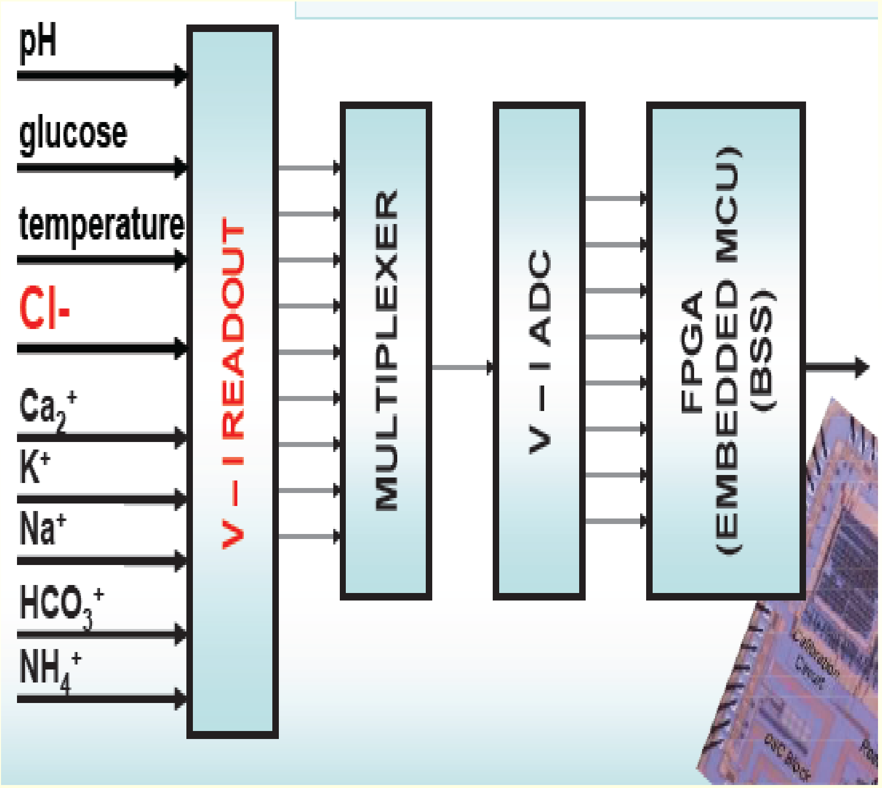
Discrimination result of 5 tastes using PCA
Analyzing impendence data of sensor array

Ref: 2005 IEEE EMB proceeding, pp.259-262

本研究擬進行之電子舌系統方塊



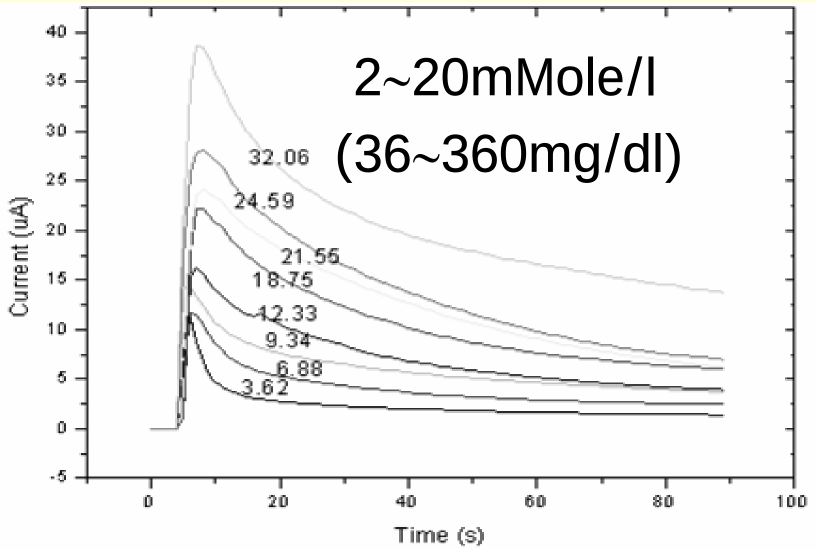
多離子/參數感測



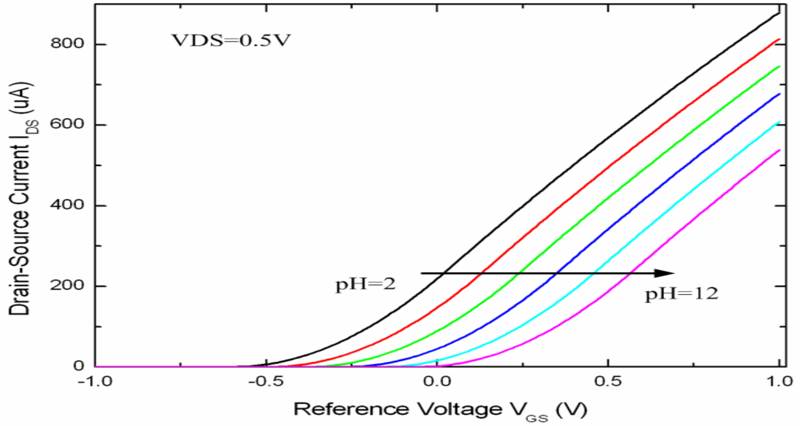
- 感測器特性分析
- 感測器陣列設計
- 訊號讀取與處理電路
- 非理想效應補償校正
- 辨識處理演算法開發

化學感測

- 電流式化學感測
- 利用電極上生化分子與血液中葡萄糖進行反應,由電極測得產生電子所造成的電流變化量可以換算得到血液中葡萄糖濃度.



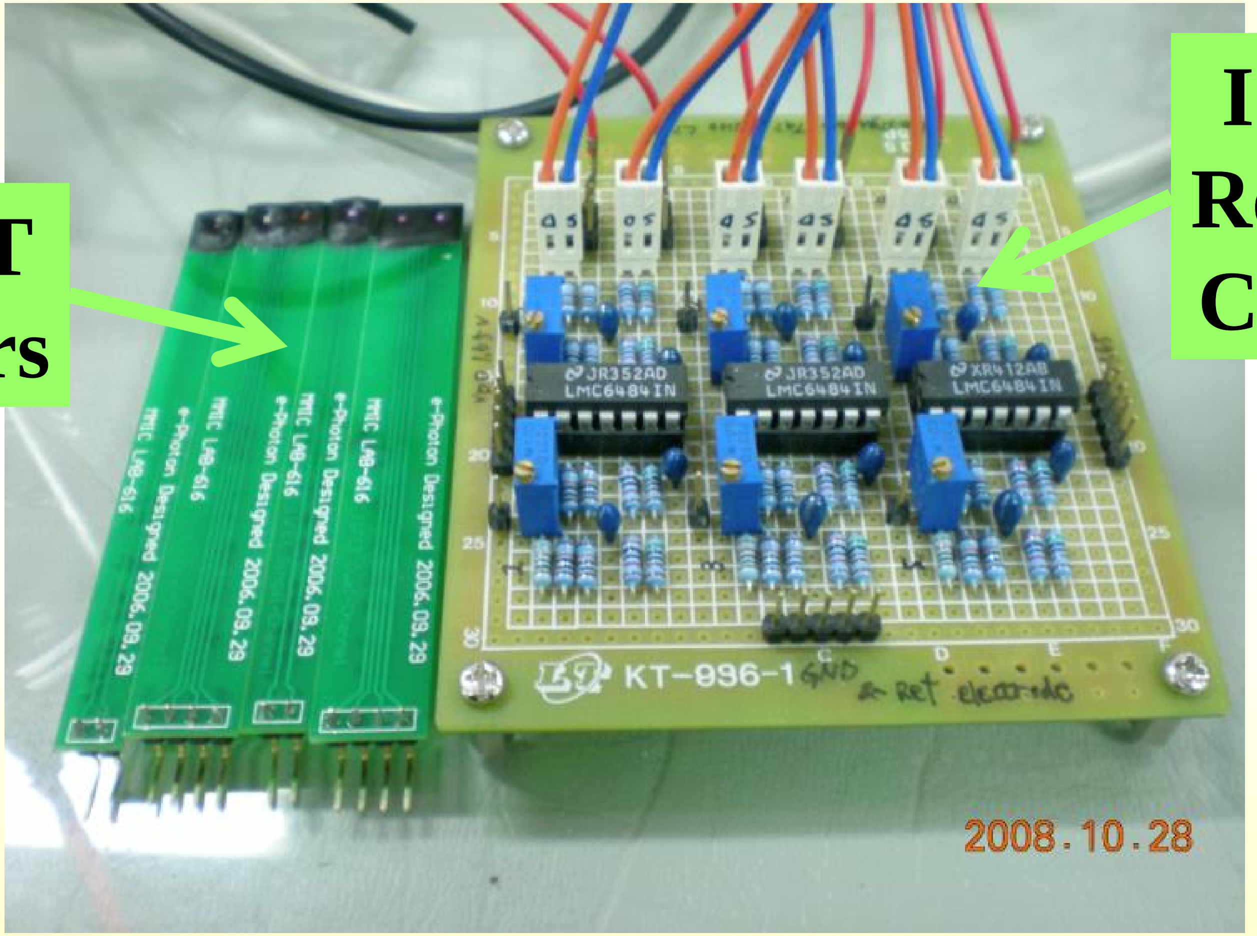
- 電位式化學感測
- 利用電位大小及相對的變化以換算所測得之物種或離子濃度
- 離子敏感型場效電晶體



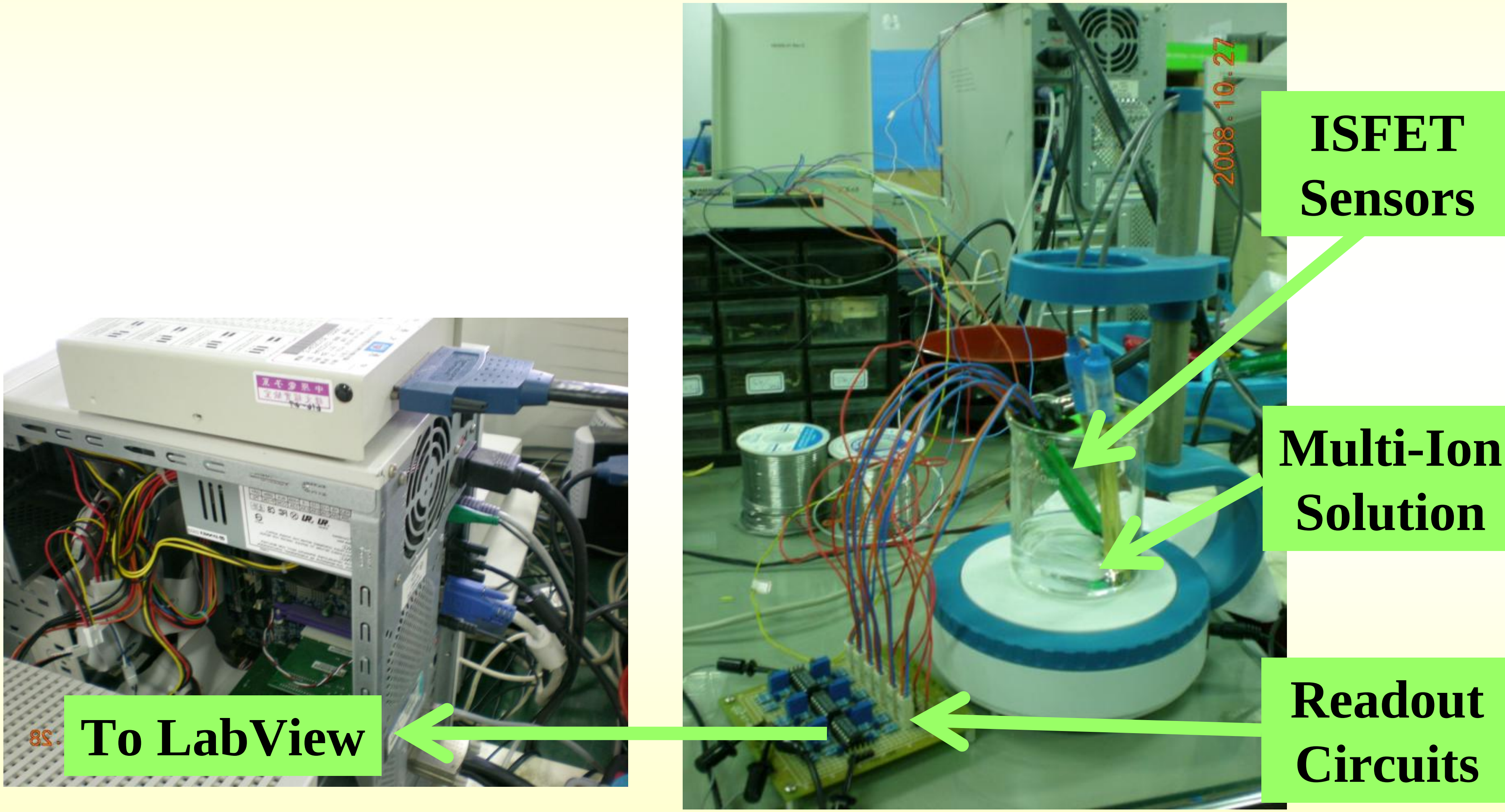
1.3 ISFET Electronic Tongue for Multi Ions

ISFET Sensors

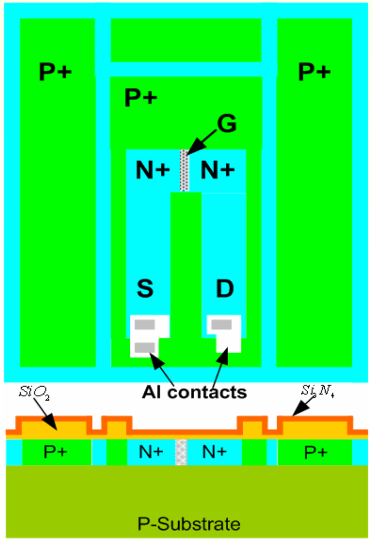
ISFET Readout Circuits

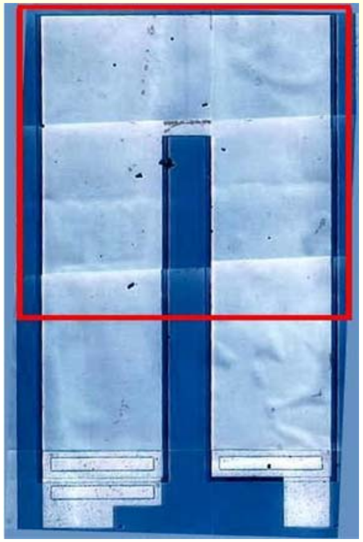


1.3 ISFET Electronic Tongue for Multi Ions



感測器設計與特性分析
- MOSFET, ISFET, EGFET

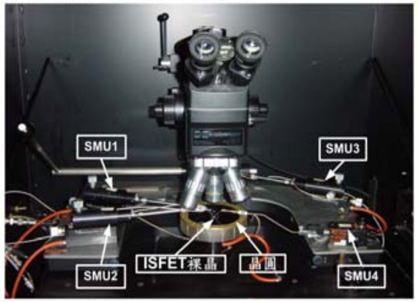




(a)ISFET基本結構與剖面圖(b)ISFET微照相

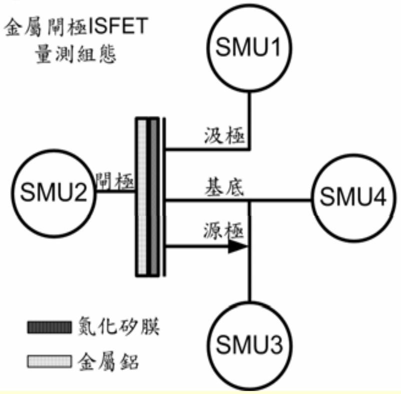
HP4155C半導體參數量測儀

量測探針座



①量測參數、使用者定義函式與訊號源設定
②訊號源掃瞄範圍、間距與固定值設定
③選擇顯示/儲存參數與圖形顯示範圍設定
④量測結果圖形顯示與數據列表
⑤訊號輸入源掃瞄
⑥1.44MB FDD 數據儲存

金屬閘極ISFET
量測組態



I.汲源極電流對閘源極電壓特性曲線量測環境設定
MEASUREMENT MODE SWEEP
CHANNELS

MEASURE				
UNIT	VNAME	INAME	MODE	FCTN
SMU1	VD	ID	V	CONST
SMU2	VG	IG	V	VAR1
SMU3	VS	IS	COMMON	CONST
SMU4	VB	IB	COMMON	CONST

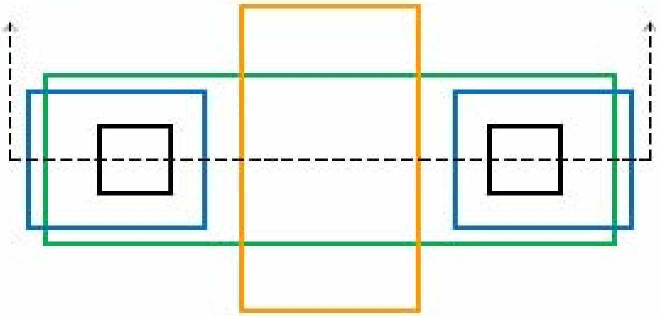
II.使用者定義函式設定
USER FUNCTION

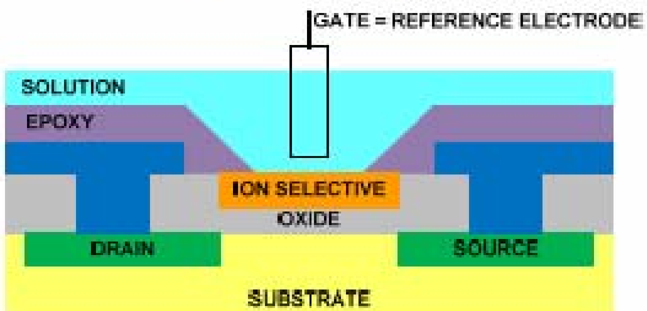
NAME	UNIT	DEFINITION	
GM		DIFF(ID,VG)	GM曲線量測
SQID		SQRT(ID)	將電流軸取根號

III.汲源極電流對汲源極電壓特性曲線量測環境設定
MEASUREMENT MODE SWEEP
CHANNELS

MEASURE				
UNIT	VNAME	INAME	MODE	FCTN
SMU1	VD	ID	V	VAR1
SMU2	VG	IG	V	VAR2
SMU3	VS	IS	COMMON	CONST
SMU4	VB	IB	COMMON	CONST

金氧半場效電晶體(MOSFET) 與離子敏感型場效電晶體(ISFET)之發明





EMF = electrochemically induced voltage

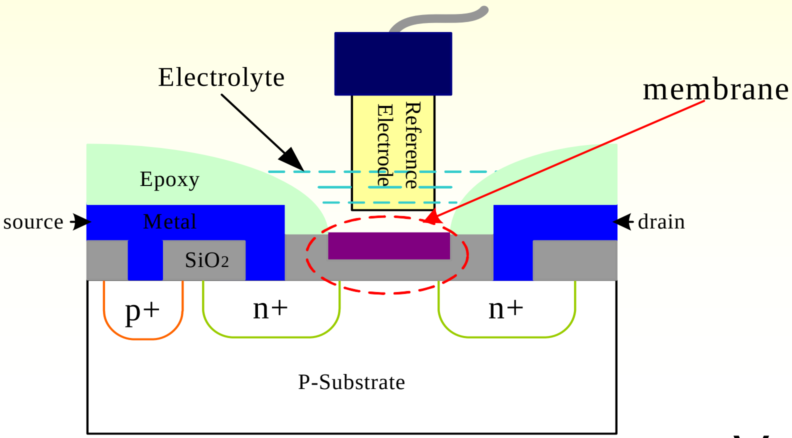
$$V_{T(ISFET)} = V_{T(MOSFET)} + EMF$$

$$I_{DS} = \mu C_{ox} \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^{2}\right]$$

$$V_{GS} = V_T + \frac{\dfrac{I_D}{\mu C_{ox}\dfrac{W}{L}} + \dfrac{1}{2}V_{DS}^{2}}{V_{DS}} = V_T + k$$

Linear region, Constant VDS & Constant ID

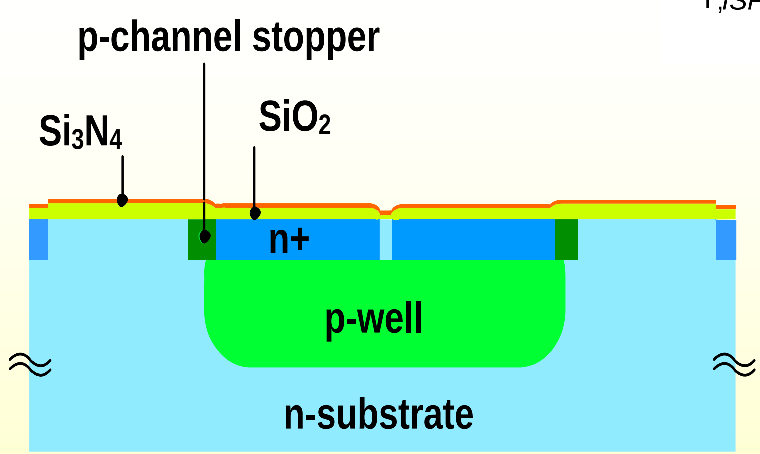
離子敏感型場效電晶體(ISFET) 工作機制



- **For ISFET in Triode region**

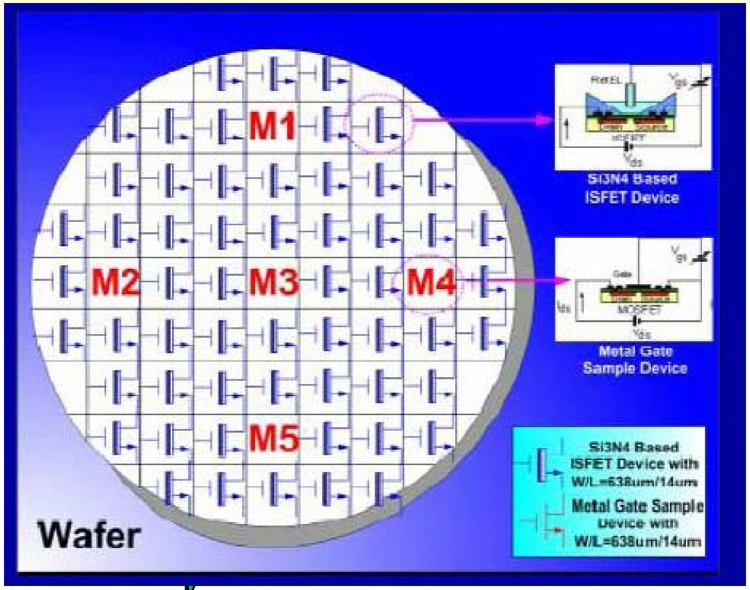
$$I_{DS} = K_p[(V_{GS} - V_{TH}^{*}) - \frac{V_{DS}}{2}]V_{DS}$$

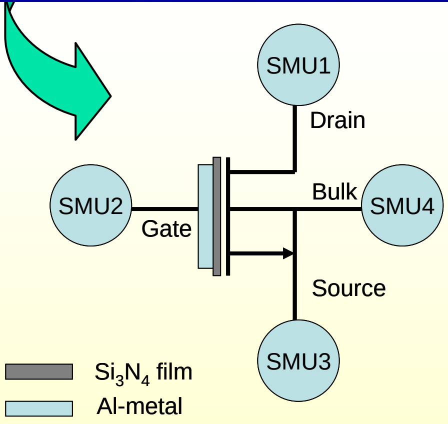
$$V_{T,ISFET} = \left(E_{REF} - \phi_{eo} + \phi_{CS} - \frac{\Phi_{Si}}{q} - \frac{Q_{OX} + Q_{SS} + Q_{B}}{C_{OX}} + 2\phi_f \right)$$



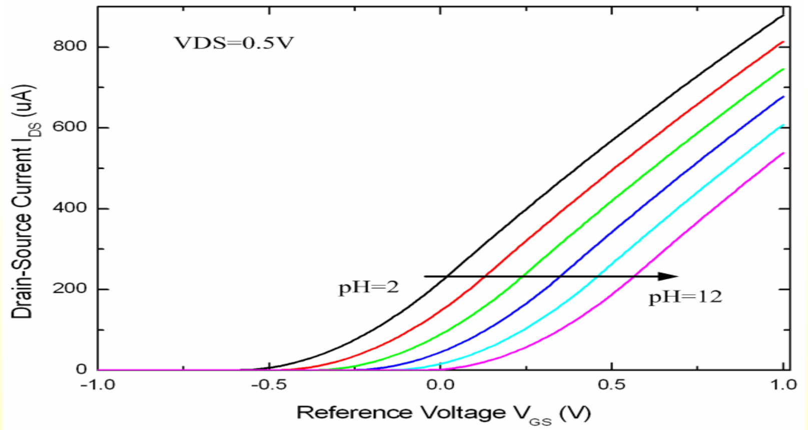
感測膜材質	SiO_2	Si_3N_4	Al_2O_3	Ta_2O_5
pH量測範圍	4~10	1~13	1~13	1~13
靈敏度(mV/pH)	23~25(pH > 7) 37~48(pH < 7)	46~56	53~57	56~57
時漂(mV/hour)	不穩定	1.0	0.1~0.2	0.1~0.2
遲滯(mV)	不穩定	3.0	0.8	0.2

ISFET 直流特性探討(DC Characterization)





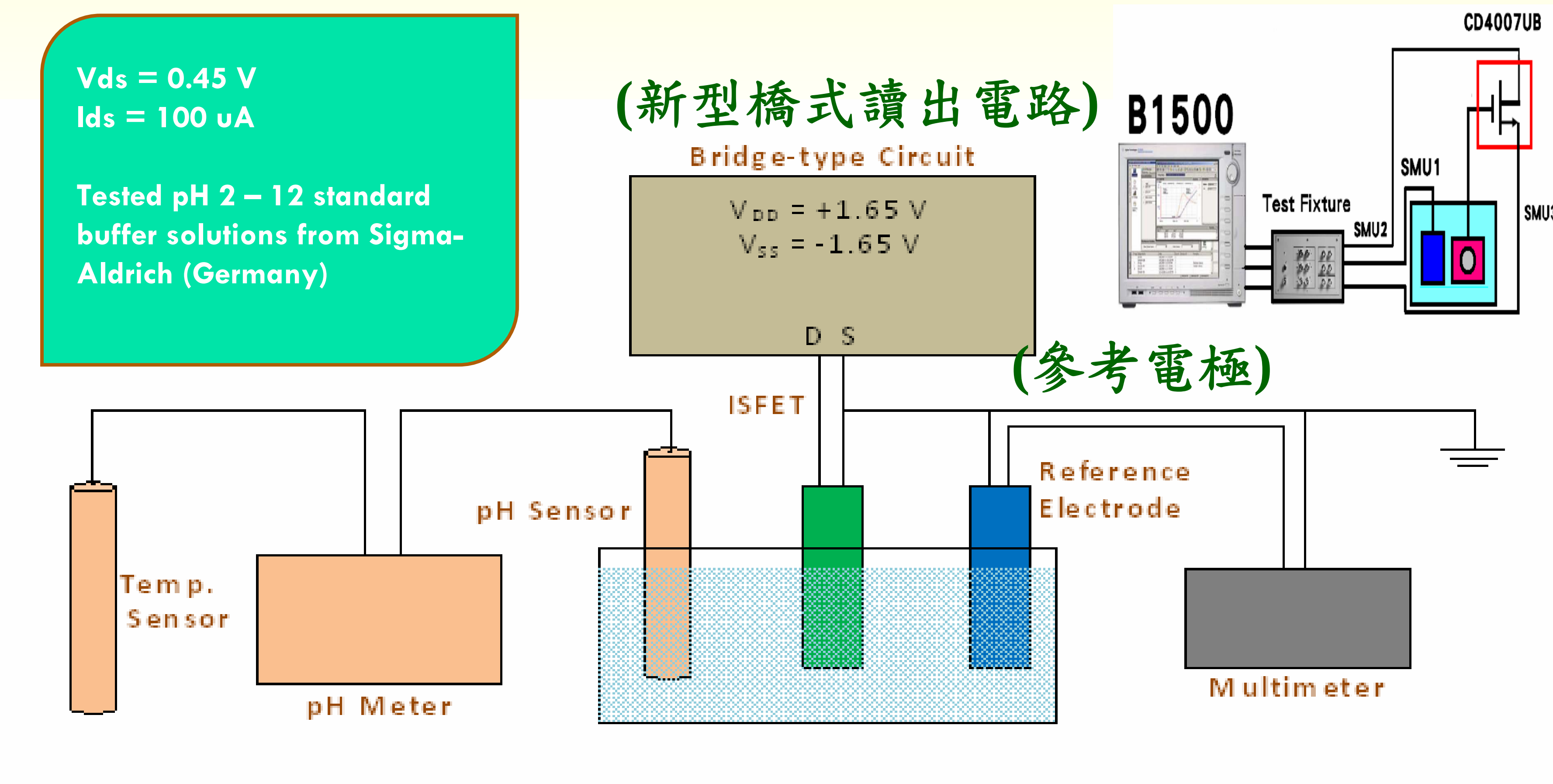
- 使用四激勵與測量裝置 (Stimulus and measurement units, SMU)
- 用於取出氫離子濃度與反應電壓之相對關係



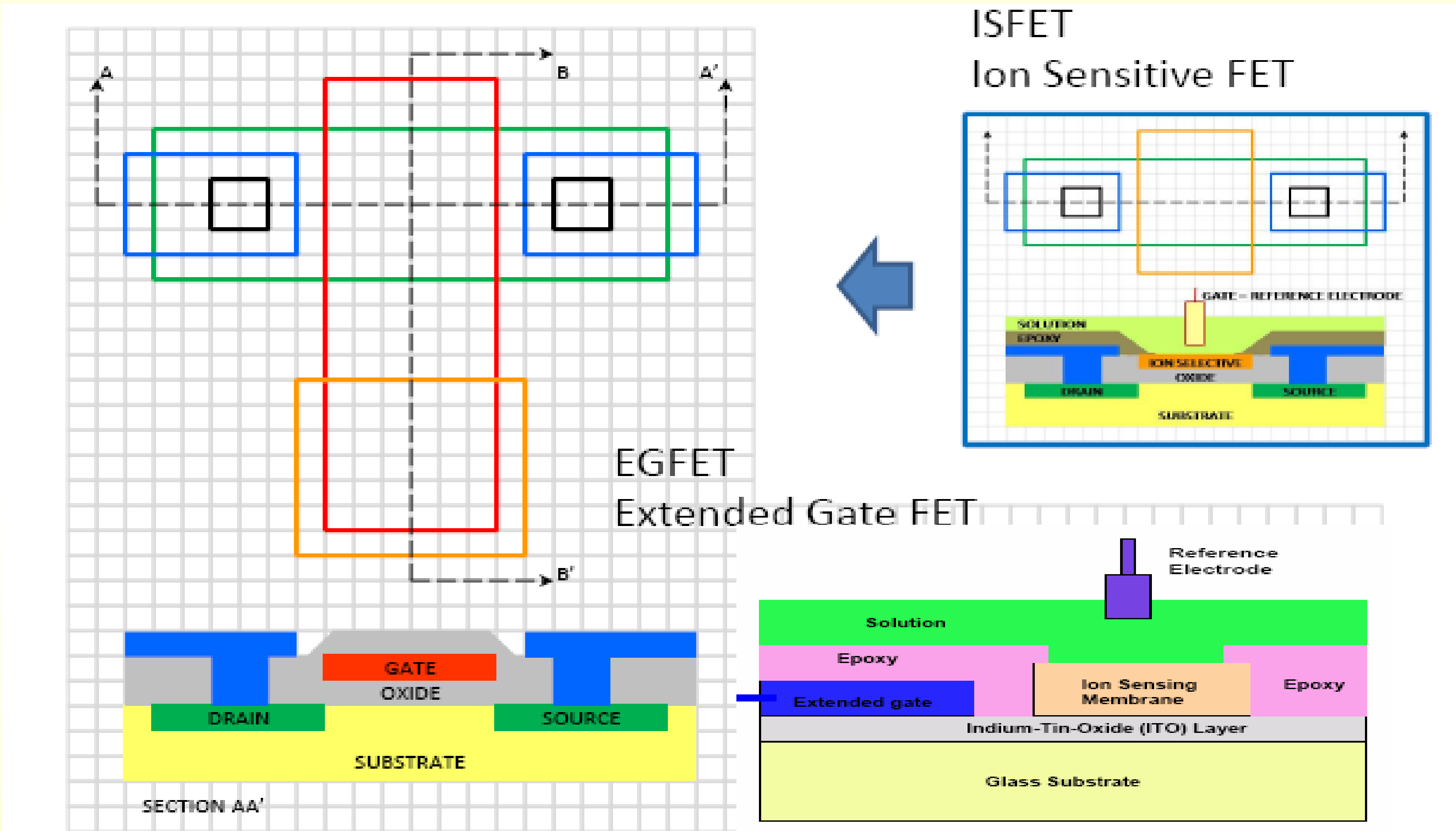
離子敏感型場效電晶體之實驗建置

Vds = 0.45 V
Ids = 100 uA

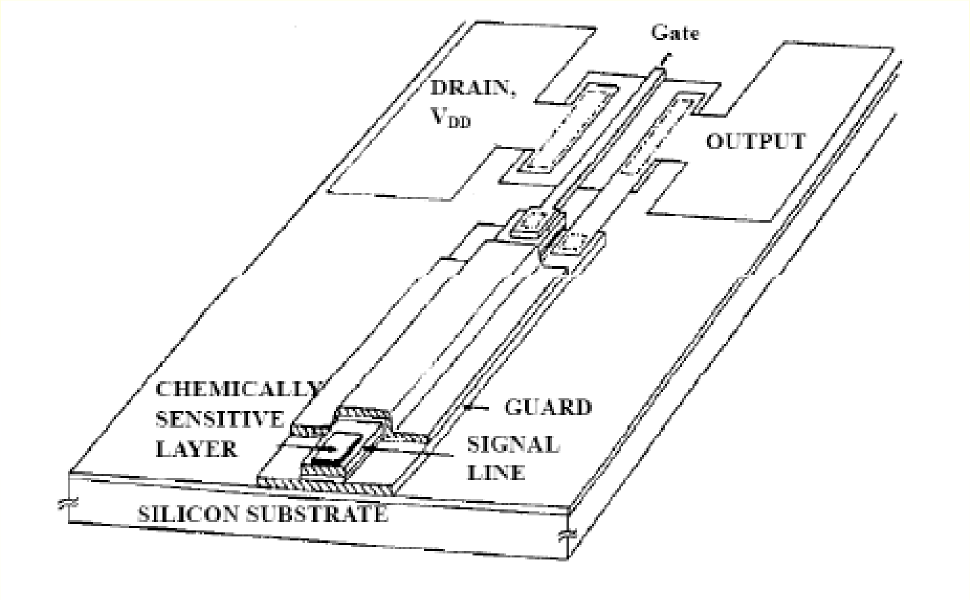
Tested pH 2 – 12 standard buffer solutions from Sigma-Aldrich (Germany)

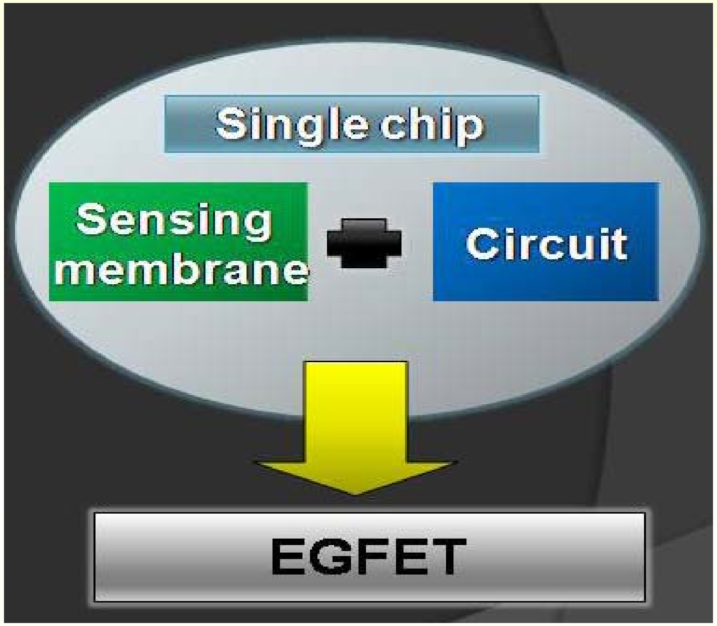


離子敏感型場效電晶體(ISFET)與延伸式ISFET(EGFET)之發明



第一個 EGFET結構(1983)

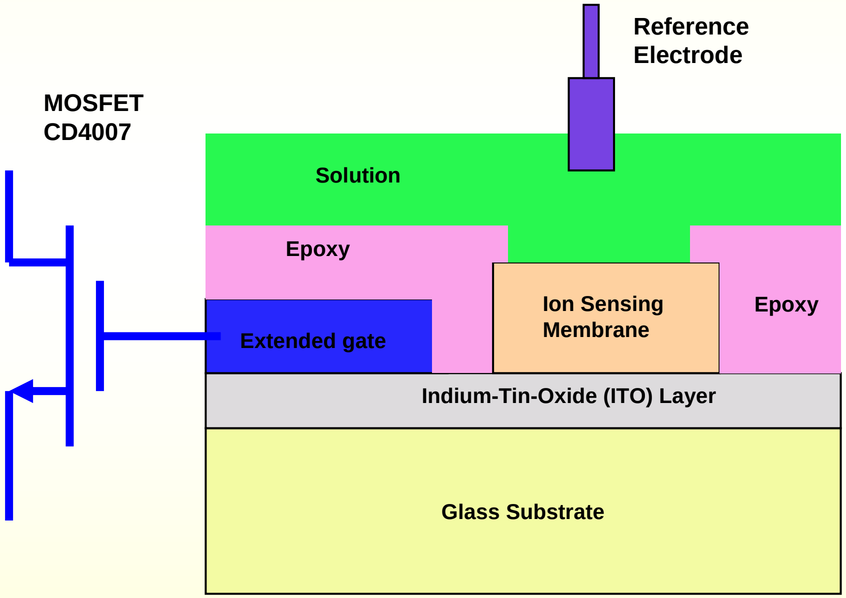




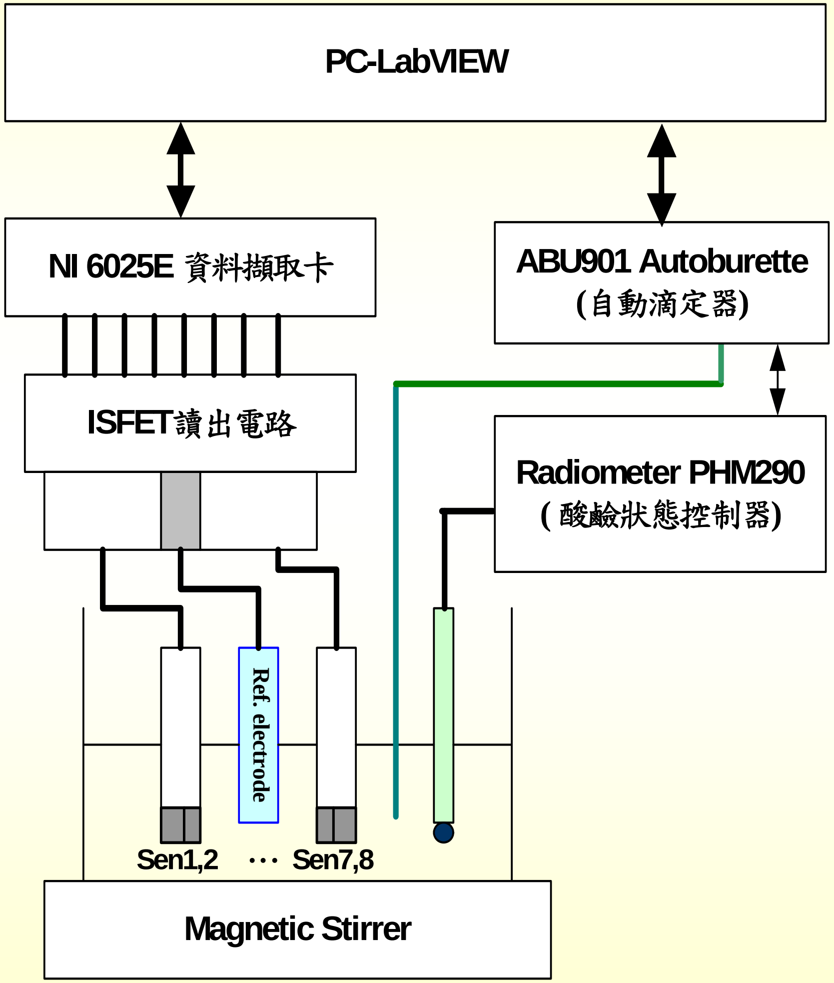
J. Vander Spiegel, I. Lauks, P. Chan, D. Babic; The Extended Gate Chemically Sensitive Field Effect Transistor as Multi-Species Microprobe; Sensors and Actuators,Vol.4, pp.291-298;1983

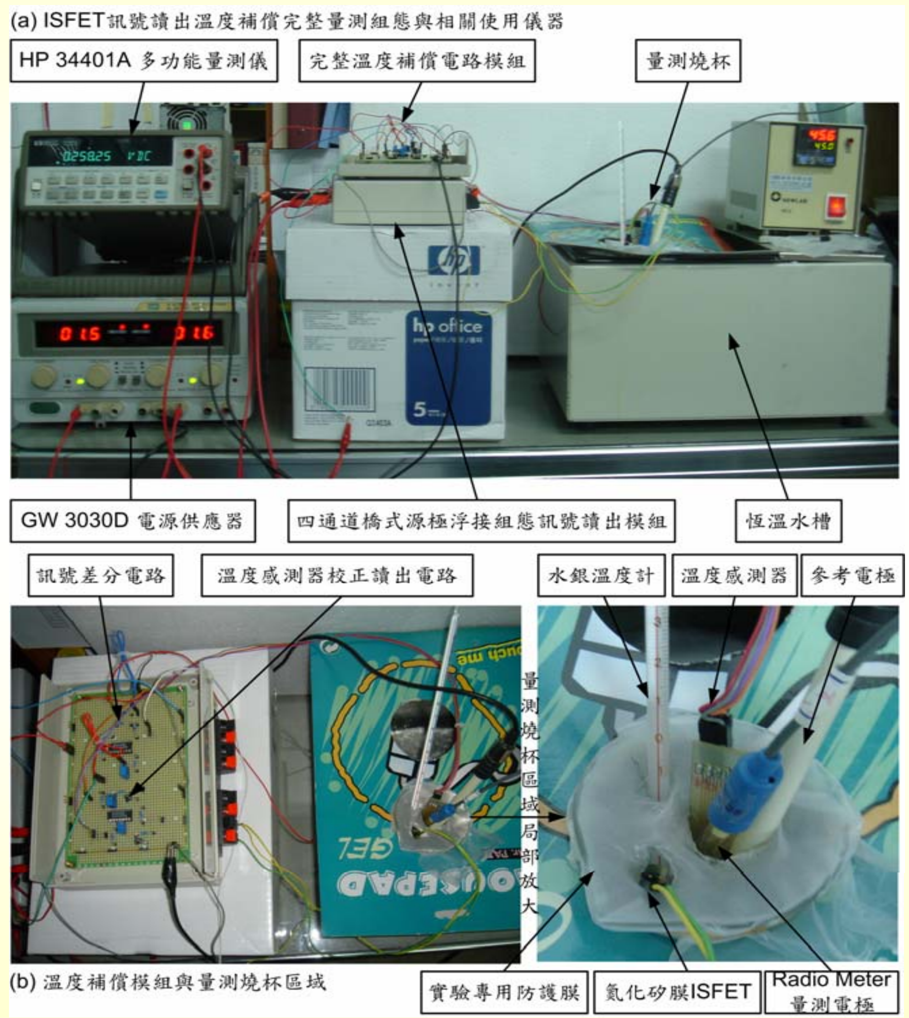
延伸式EGFET之剖面圖與優勢

- 可拋棄式感測頭
- 低成本玻璃基片
- 較低之光敏感性 (light-sensitivity)
- 可重複使用之訊號讀出系統與訊號處理器

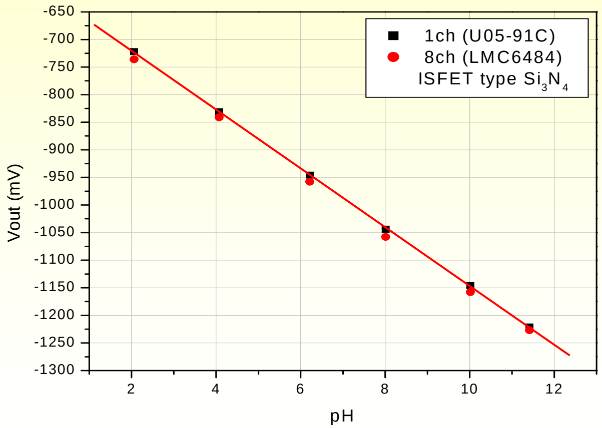


自動化多通道測試環境設計

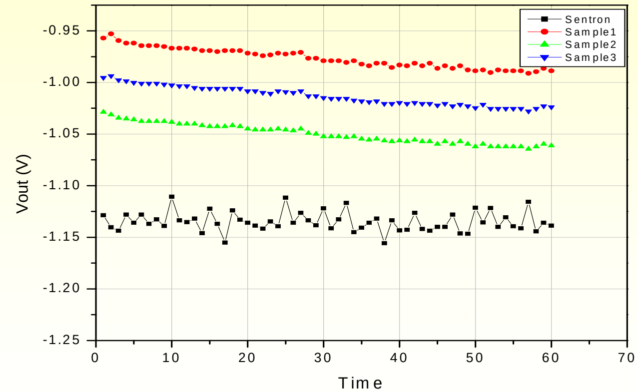




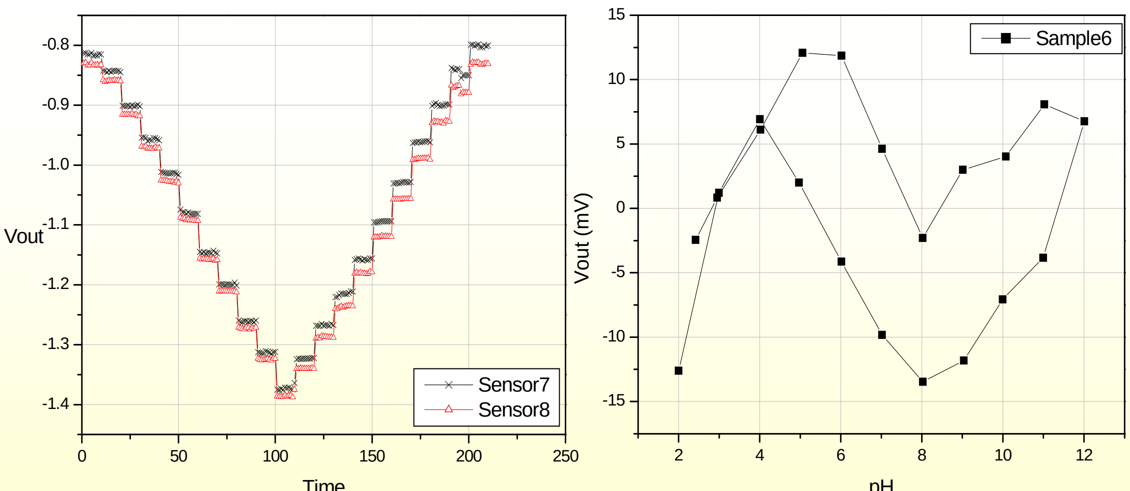
感測器效能參數量測



pH 敏感度



時漂效應Time Drift (16 hours)

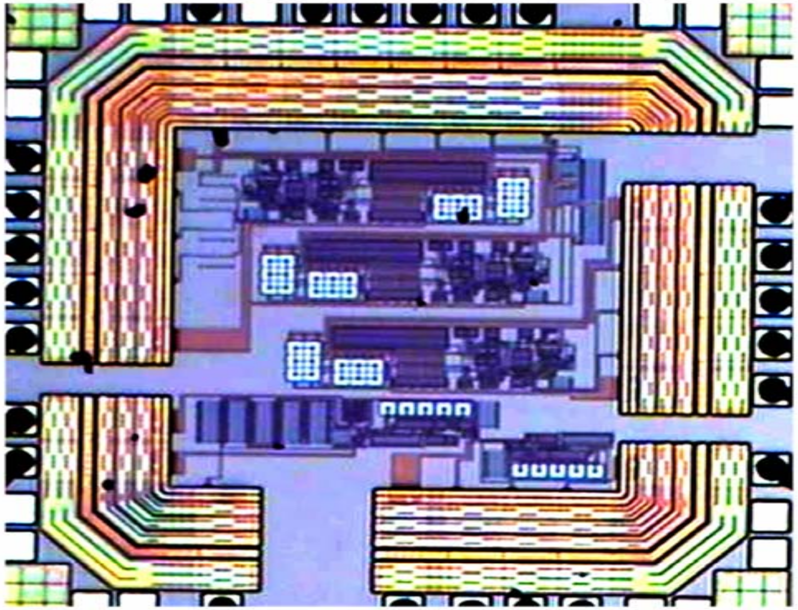


遲滯效應(Hysteresis)

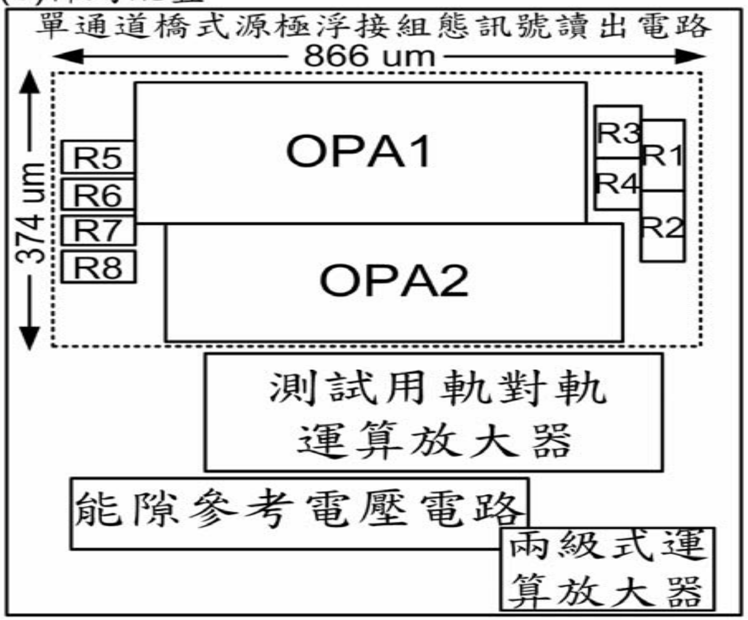
- ISFET
  - Si_3N_4 **x7**
- **pH -range**
  - (Sab)pH2~pH12
  - (Sba)pH12~pH2
- Record -
  - pH 10min
  - 1 record/1min

感測器介面 – 讀出與處理電路

(a)晶片微照相　　晶片編號:D35-92C-24b



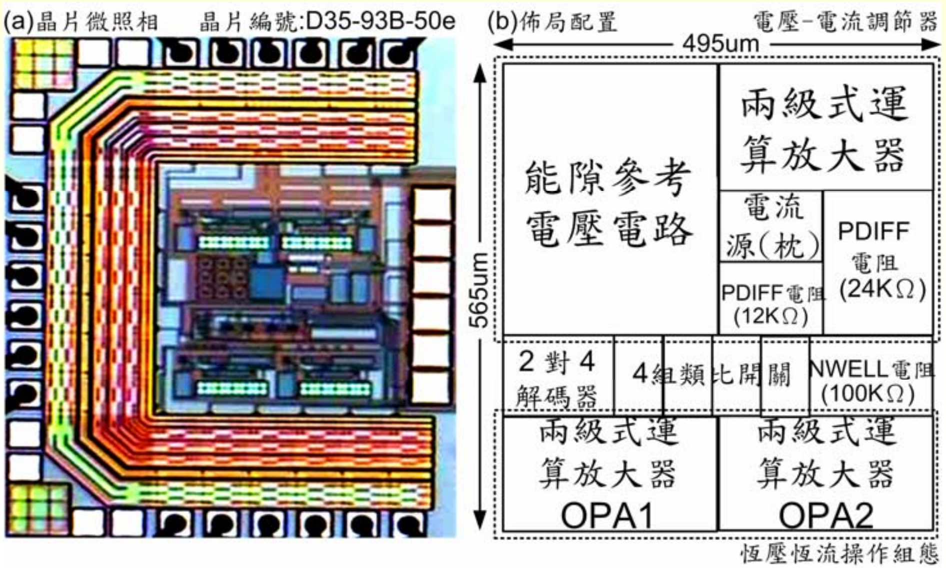
(b)佈局配置



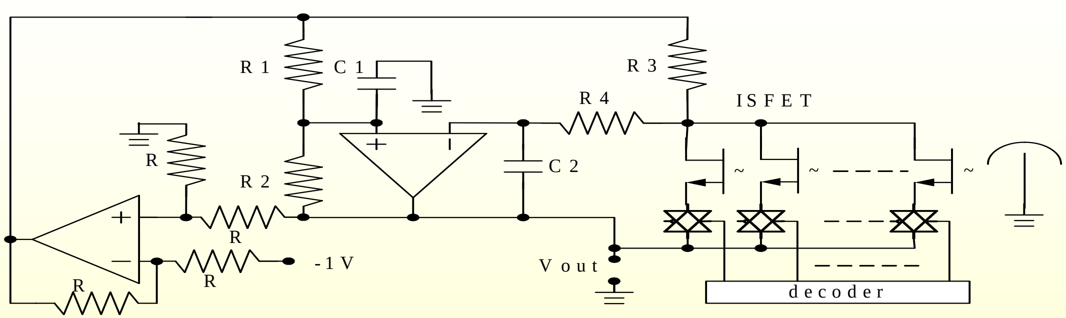
(c)使用元件規格列表

對應電路編號	規格	佈局方式	對應電路編號	規格	佈局方式	對應電路編號	規格	佈局方式
OPA1-OPA2	軌對軌	--------	R4	5KΩ	PDIFF	R8	50KΩ	NWELL
R1	15KΩ	PDIFF	R5	50KΩ	NWELL	C1	1 μF	外接
R2	15KΩ	PDIFF	R6	50KΩ	NWELL	C2	1 μF	外接
R3	5KΩ	PDIFF	R7	50KΩ				

ISFET 感測陣列之新型讀出電路



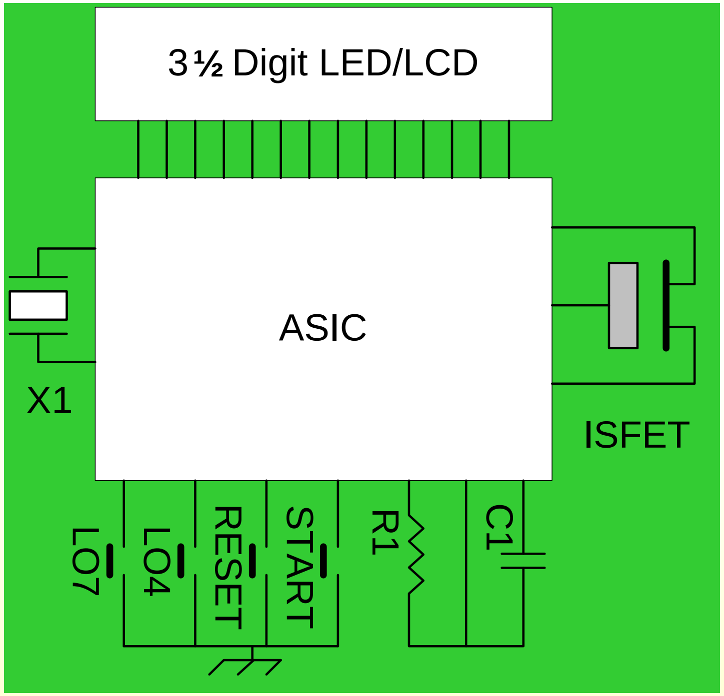
- 定電壓/定電流電路
- 類比開關反應時間與線性度
- 低頻雜訊濾波



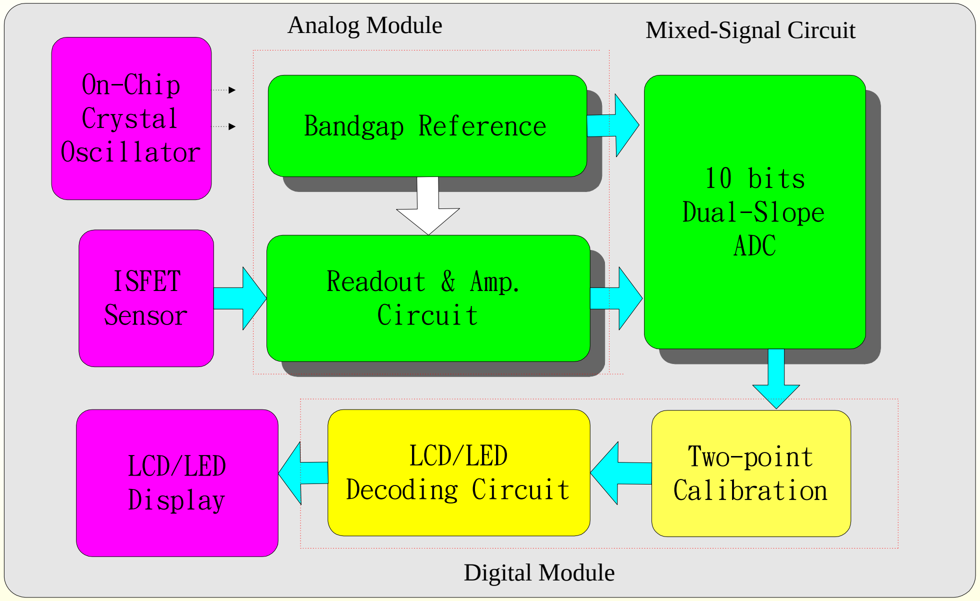
Prof. Chung's Lab. (2005)「離子感測電路」中華民國發明專利I 235236

ISFET pH meter 單晶片設計

•The proposed ISFET-based pH meter by using a single ASIC chip with peripheral interface



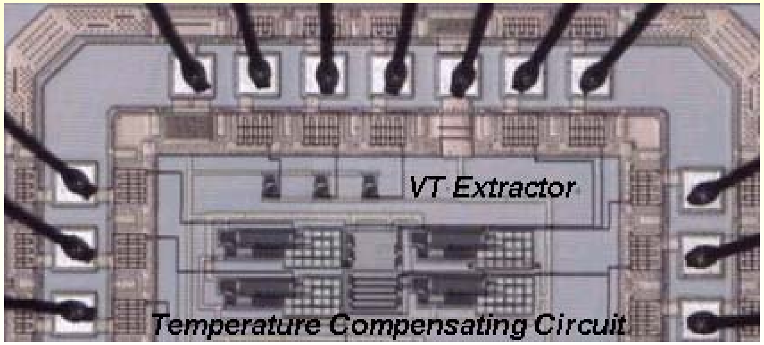
•Key building blocks of an ISFET-based pH meter



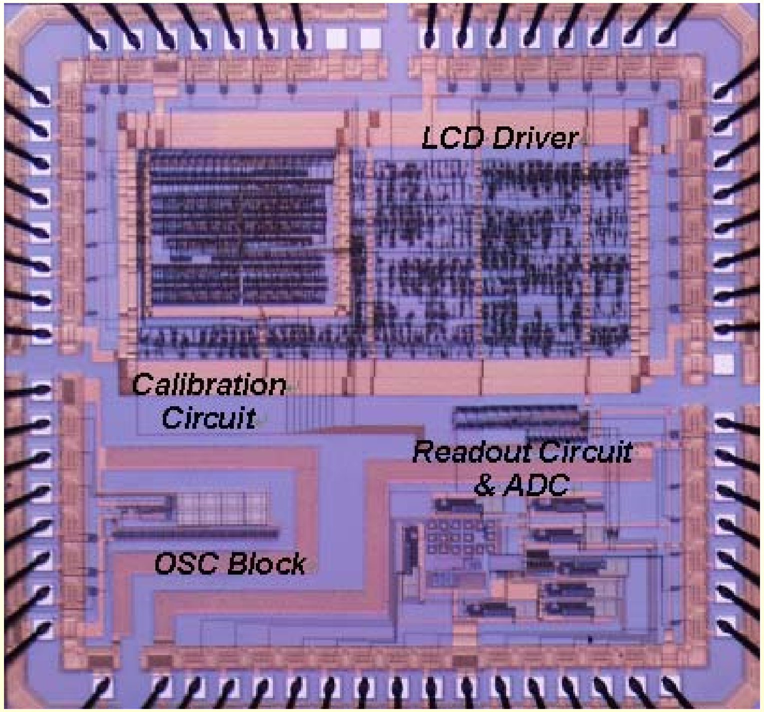
Prof. Chung's Lab (2004) Microelectronic Journal

晶片實現與原型機驗證

- VT extractor & 溫度補償電路 (Temperature compensating circuit)

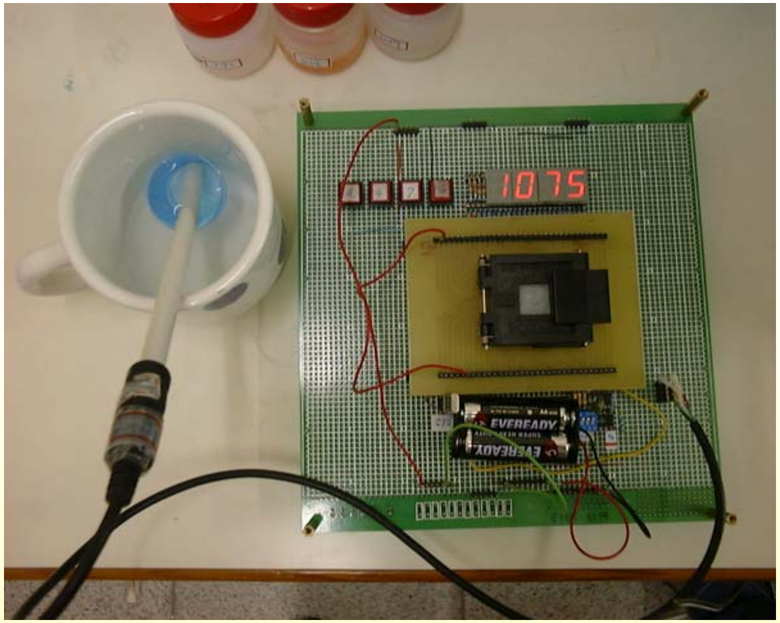


- pH meter ASIC 單晶片設計

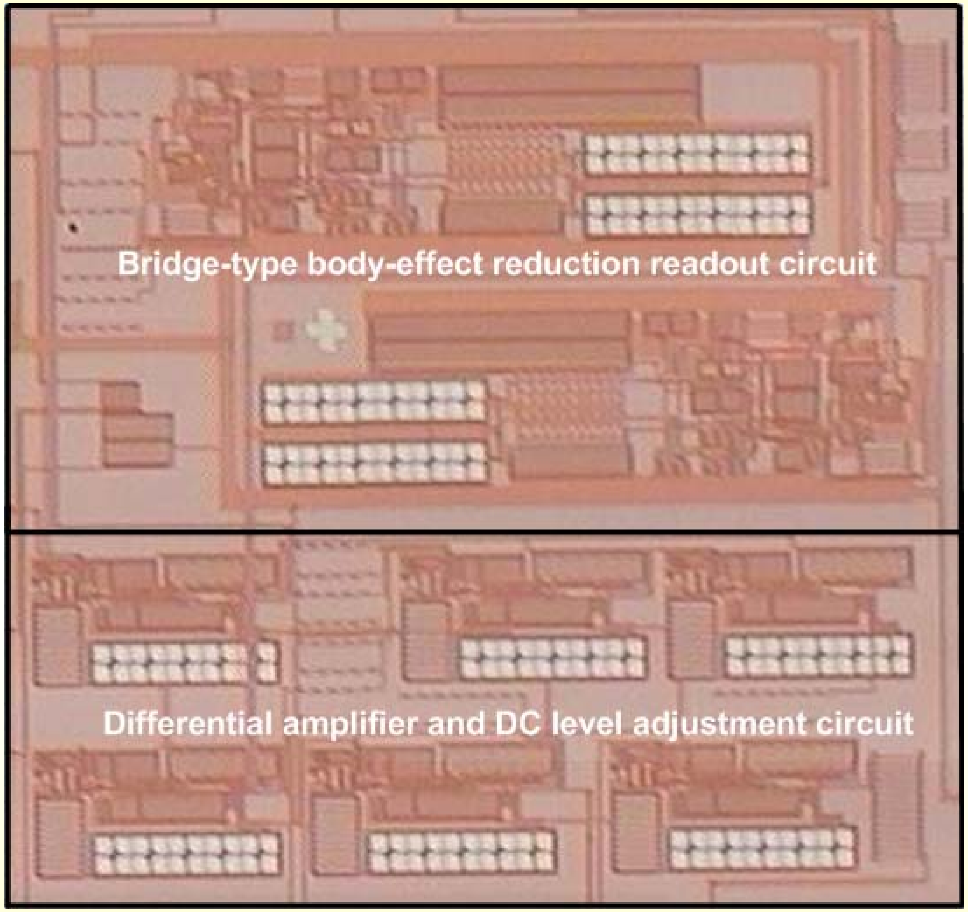


Prof. Chung's Lab (2004) Microelectronic Journal

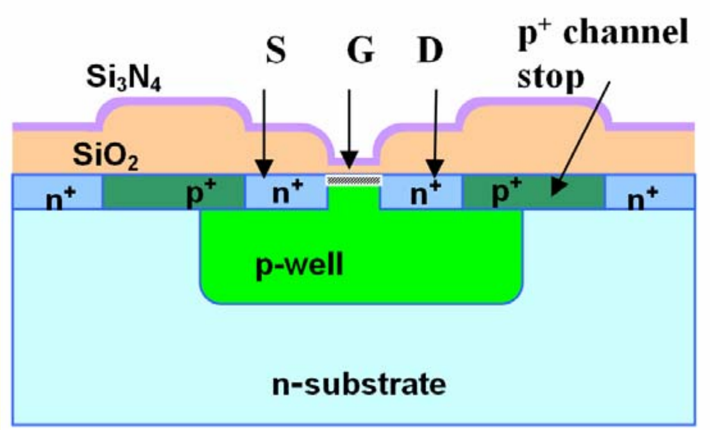
- On-board prototyping



基體效應改善電路及 P-well ISFET

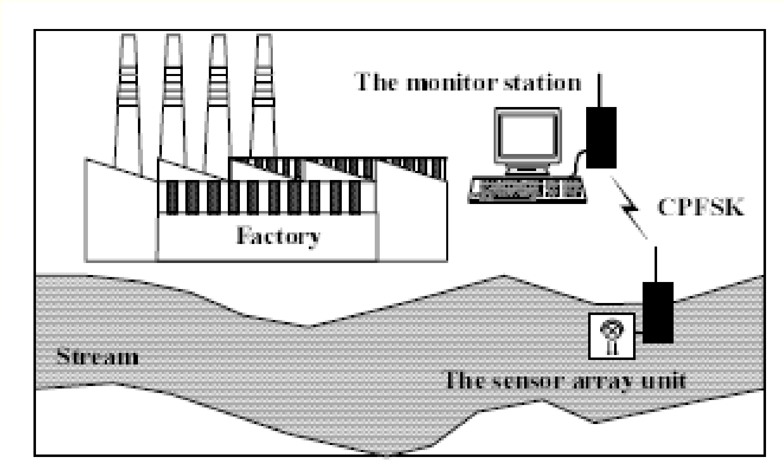


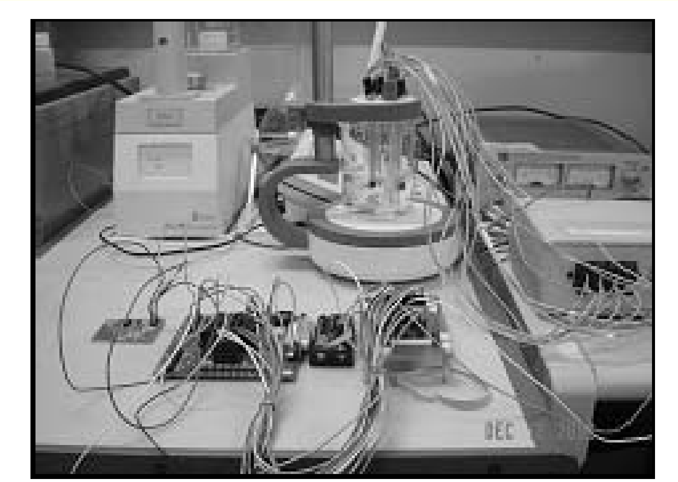
- 台積電製程
- TSMC 0.35μm 2P4M CMOS process.
- 晶片面積 9.1×9.1 mm^2

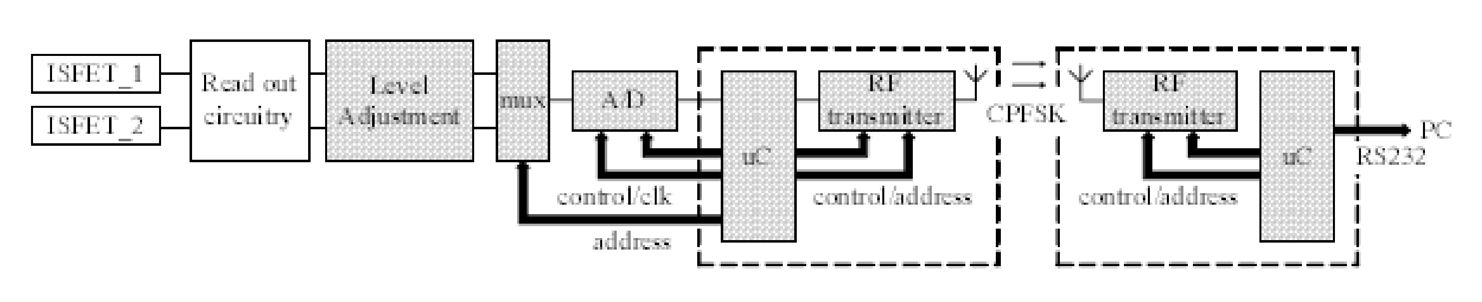


Prof. Chung's Lab. (2008/04) 「降低基體效應之離子感測電路」美國/中華民國發明專利

動態量測與應用

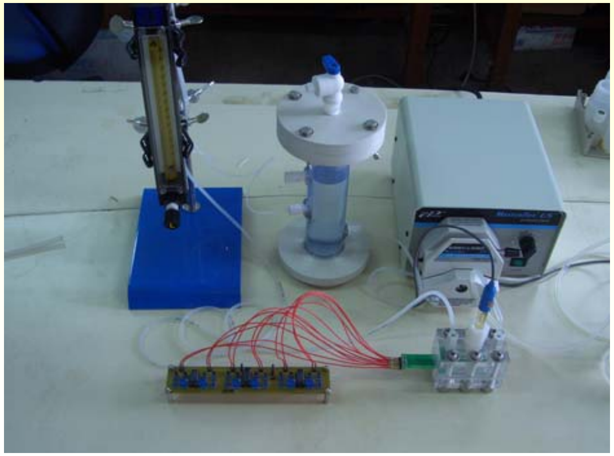


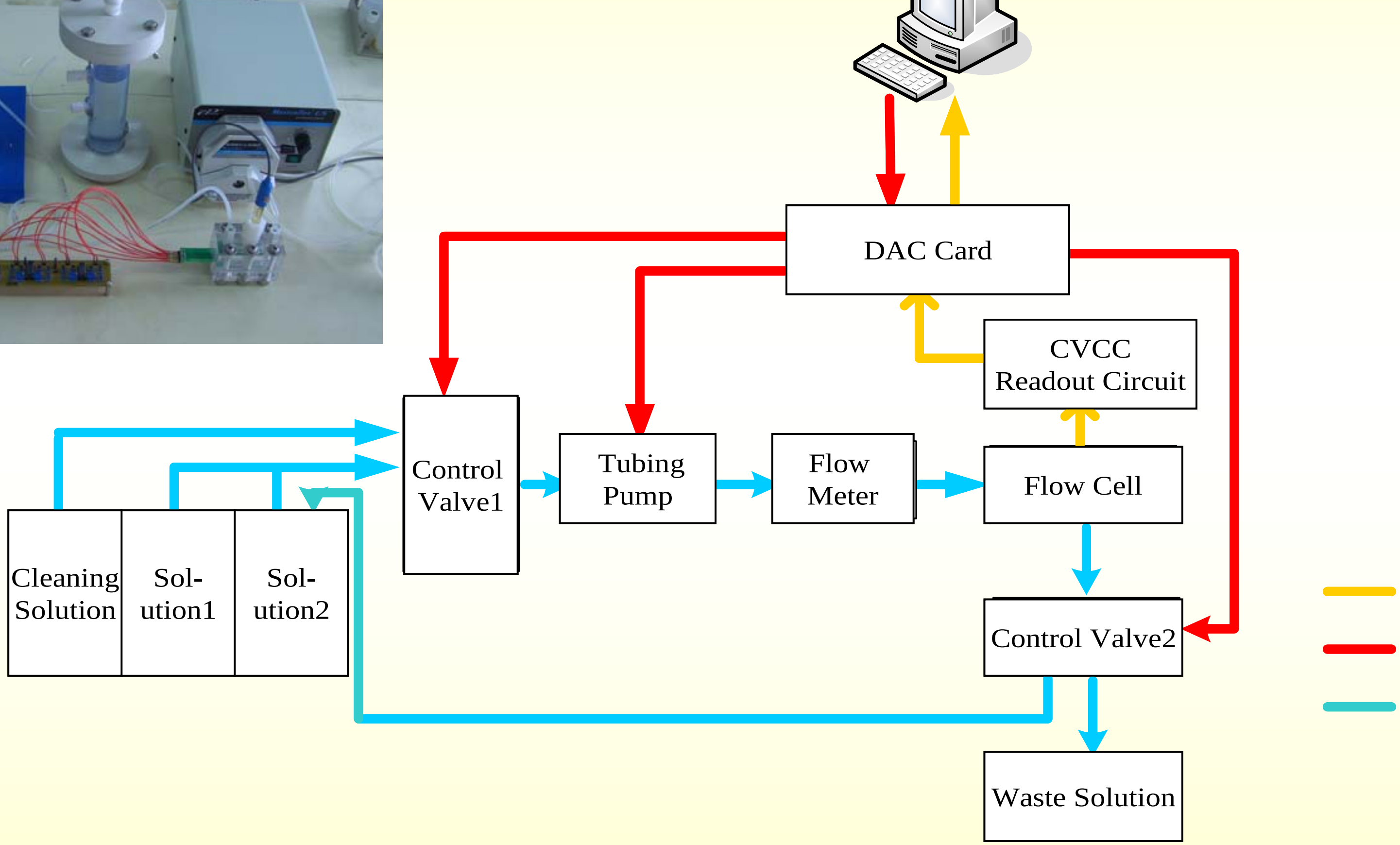




Prof. Chung's Lab (2003) European Conference on Circuit Theory and Design, Cracow, Poland.

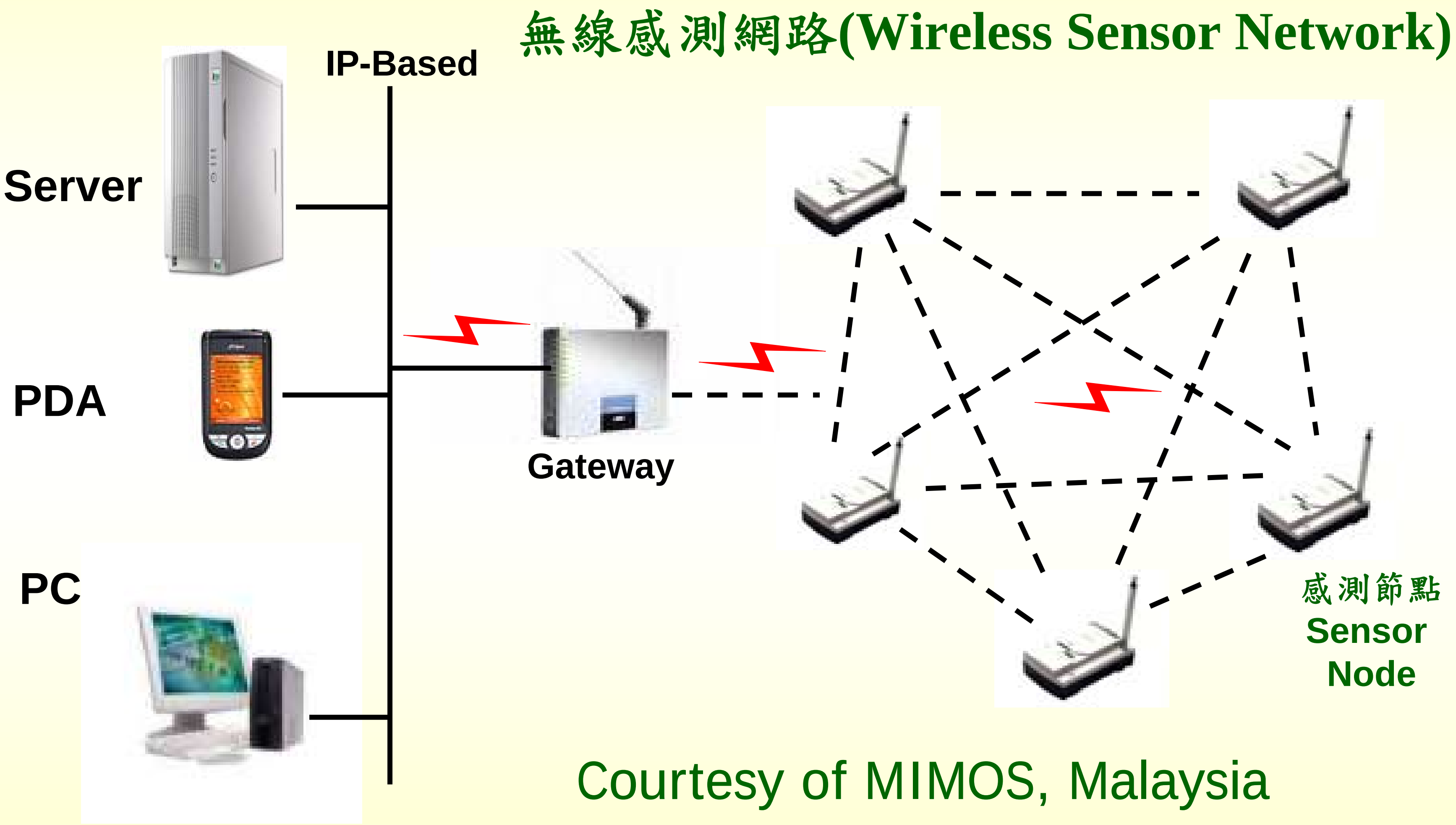
流體注入與流體單元系統





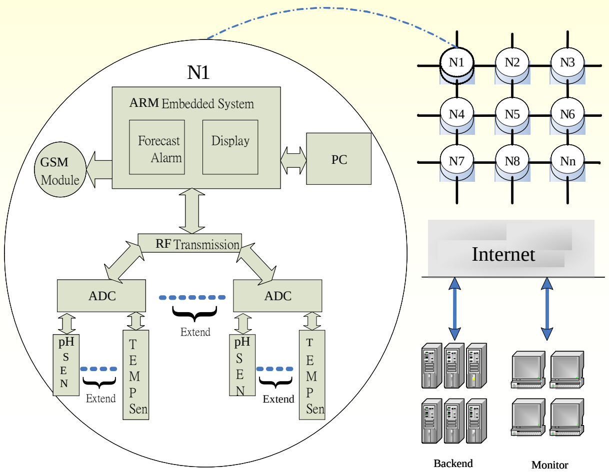
Prof. Chung’s lab. (2007) SPIE, Orlando, Florida, USA

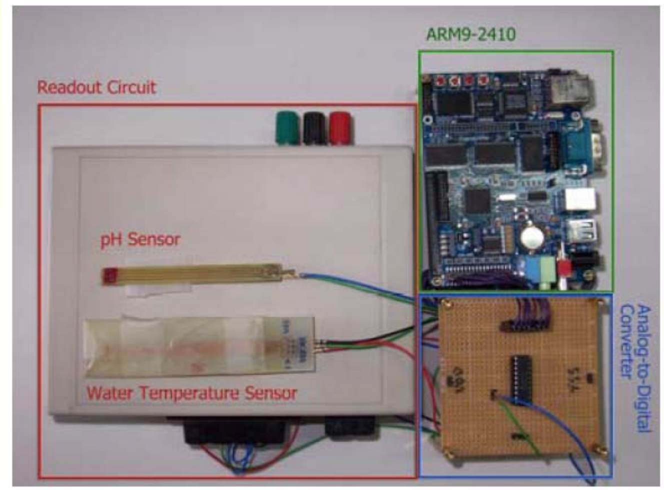
微機電技術整合之無線感測存取及網路系統

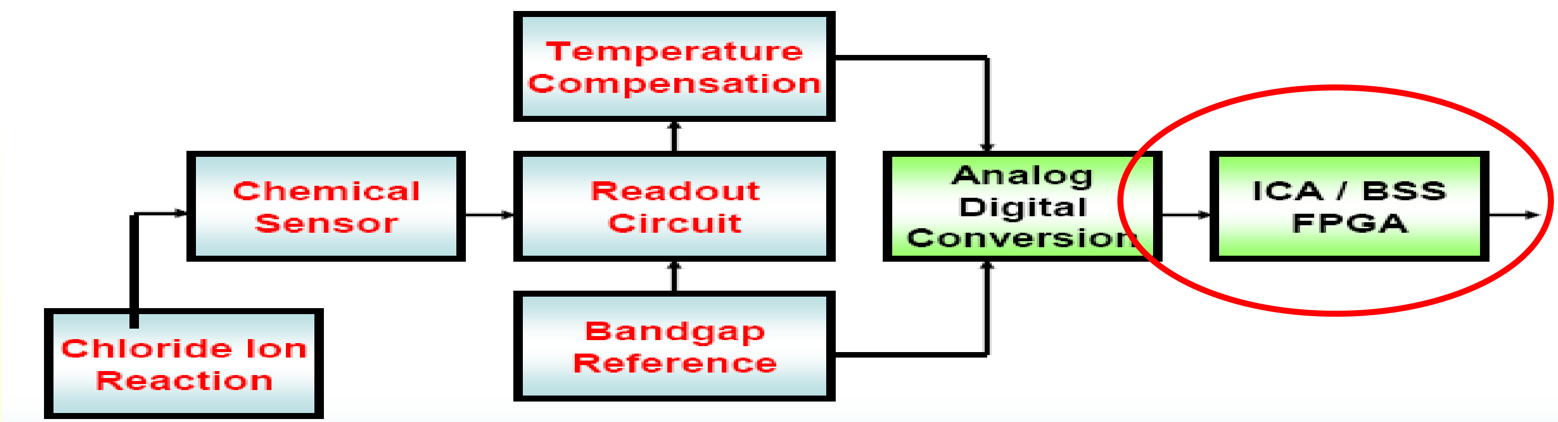


Courtesy of MIMOS, Malaysia

自動化多感測器水值預測系統

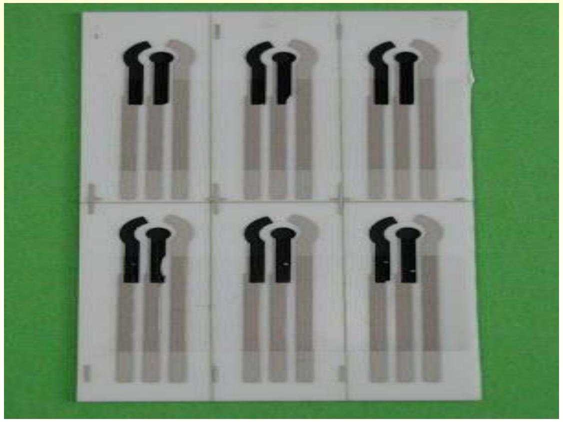


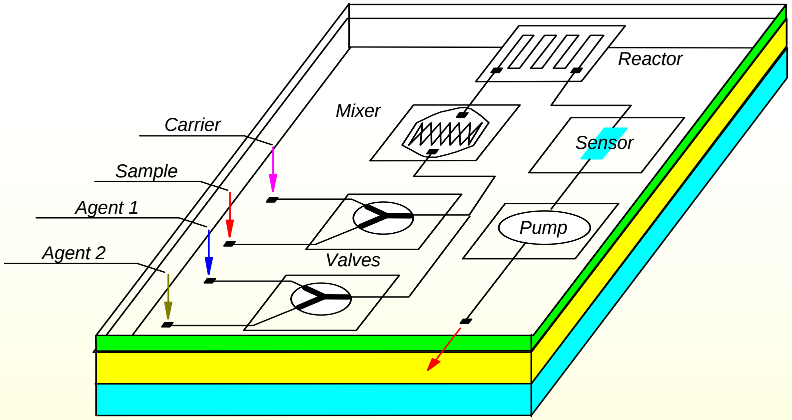




未來展望

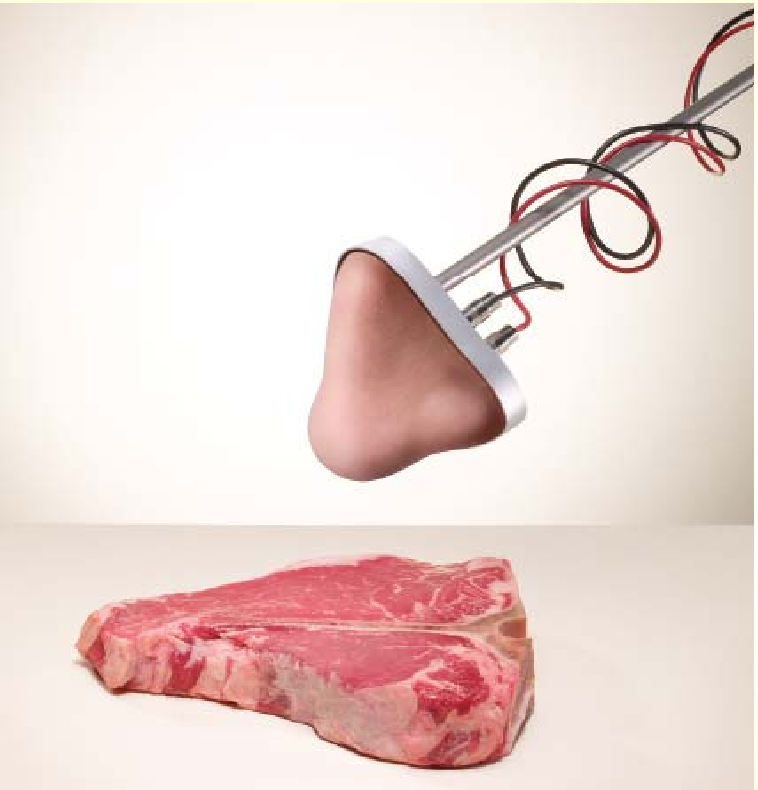
- 生醫福祉工程
  BioMedical Wellness (BMW) Engineering
- 電子舌與優質生活
  Electronic Tongue System Design for Smart-living Space
- 實驗室晶片
  uTAS/Lab-on-a-chip





Micro Total Analysis Systems, μTAS

我的未來不是夢!



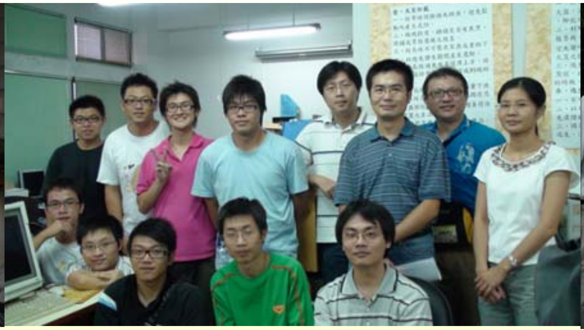
Ref: Change, J.B.   Subramanian, V., "Electronic Noses Sniff Success,"
Spectrum, IEEE, pp. 50-56, March 2008

Acknowledgement
-International Team Members

Harold Szu[1,a,b], Wen-Yaw Chung[a], Febus Reidj G. Cruz[a], Dorota G. Pijanowska[c], Marek Dawgul[c], Wladyslaw Torbicz[c], Pitor B. Grabiec[d], Bohdan Jarosewicz[d], Jung-Lung Chiang[e], Kuo-Chung Chang[a], Cheanyeh Cheng[a], Wei-Po Ho[a]

[1]Research Physicist, US Army NVESD, VA, USA
[a]Chung Yuan Christian University, Chung-Li City, Taiwan R.O.C.
[b]George Washington University, Washington DC, USA
[c]Polish Academy of Sciences, Warsaw, Poland
[d]Institute of Electron Technology, Warsaw, Poland
[e]Chung-Chou Institute of Technology, Changhua County, Taiwan R.O.C.






電子舌團隊研究人員 in 2008/2009

Wen-Yaw Chung[a], Kuo-Chung Chang[b], Da-You Hong[a], Cheanyeh Cheng[b], Febus Cruza[a], Tai Sung Liu[a]
Electronic Engineering[a], and Chemistry[b] Departments
Chung-Yuan Christian University
Chung-Li City, Taiwan, R.O.C.
eldanny@cycu.edu.tw

Chung Huang Yang
Electronic Engineering Department
Vanung University of Technology
Chung-Li City, Taiwan, R.O.C.

Jung-Lung Chiang
Electronic Engineering Department
Chung-Chou Institute of Technology
Changhua County, Taiwan, R.O.C.

Dorota G. Pijanowska, Marek Dawgul, Wladyslaw Torbicz
Institute of Biocybernetics and Biomedical Engineering
Polish Academy of Sciences
Warsaw, Poland

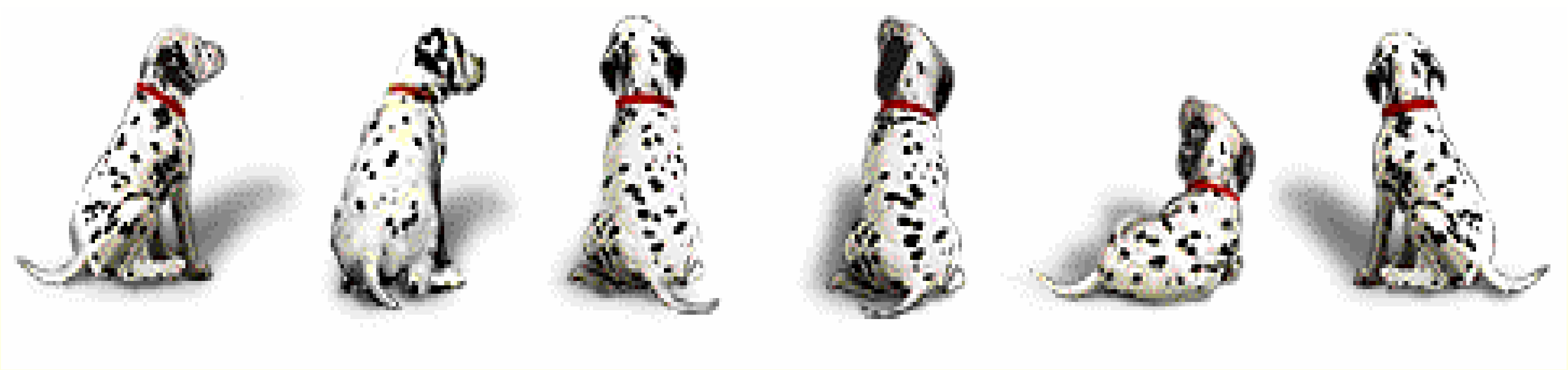
Pitor B. Grabiec, Bohdan Jarosewicz
Department of Silicon Microsystem and Nanostructure Technology
Institute of Electron Technology
Warsaw, Poland

Lewa Galilee Semblante, Mark Andrew Mateo

Ateneo De Manila University, Manila, Philippines

Thank you for your attention

Q & A section



參考文獻(References)

[1] F. Winquist, E. Rydberg, S. Holmin, C. Krantz-Rülcker, I. Lundström, “Flow injection analysis applied to a voltammetric electronic tongue,” Analytica Chimica Acta, 471, pp. 159–172, 2002.
[2] D.G. Pijanowska, A.J. Sprenkels, W. Olthuis, P. Bergveld, “A flow-through amperometric sensor for micro-analytical systems,” Sensors and Actuators B 91, pp.98–102, 2003.
[3] F. Winquist, R. Bjorklund, C. Krantz-R¨ulcker, I. Lundstro¨m, K. O¨ stergren, T. Skoglund, “An electronic tongue in the dairy industry,” Sensors and Actuators B 111–112, pp.299–304, 2005.
[4] Ramón Mart´ınez-Máñez, Juan Soto, Eduardo Garcia-Breijo, Luis Gil, Javier Ibáñez, Eduard Llobet, “An “electronic tongue” design for the qualitative analysis of natural waters,” Sensors and Actuators B 104 pp.302–307, 2005.
[5] Patrycja Ciosek, Zbigniew Brz´ozka, Wojciech Wr´oblewski, “Electronic tongue for flow-through analysis of beverages,” Sensors and Actuators B 118, pp.454–460, 2006.
[6] Boyko Iliev, Malin Lindquist, Linn Robertsson, PeterWide, “A fuzzy technique for food- and water quality assessment with an electronic tongue,” Fuzzy Sets and Systems 157, pp.1155 – 1168, 2006.