Chip-based Ion Sensing

Trends in Micro Nano

5. Dec. 2013

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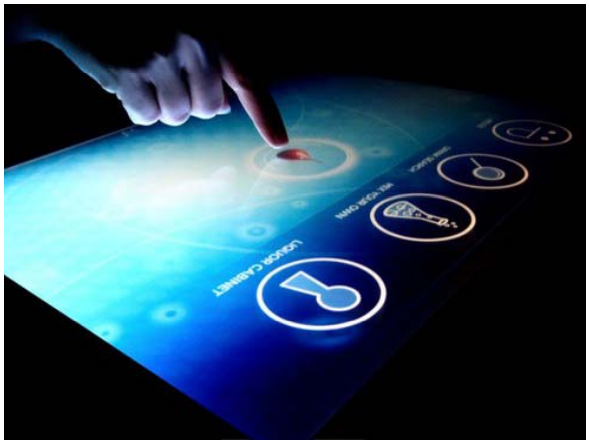
Sensor

Schönenberger group www.nanoelectronics.ch

wikipedia:

"A sensor (also called detector) **converts** a measured **physical quantity** into **a signal which can be read by an observer** or by an instrument. "



Sensor

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wikipedia:

A sensor (also called detector) **converts** a measured **physical & chemical quantity** into **a signal which can be read by an observer** or by an instrument.

GlucoWatch® Monitor

- fully integrated analytical systems
- portable diagnostic capabilities (early detection)
- personalized medicine

Sensor

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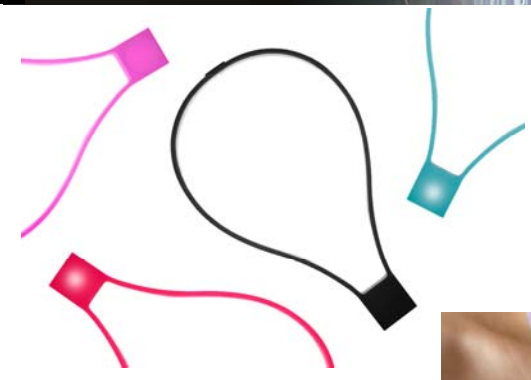
human's sensorics

- we can see
- we can hear
- we can smell
- we can taste
- we can feel
- we may have pain
- we can think (sensor ?)
- we have emotions (sensor ?)
- we have intuition (sensor ?)
- we may be frightened (sensor ?)



VIBE from Philips

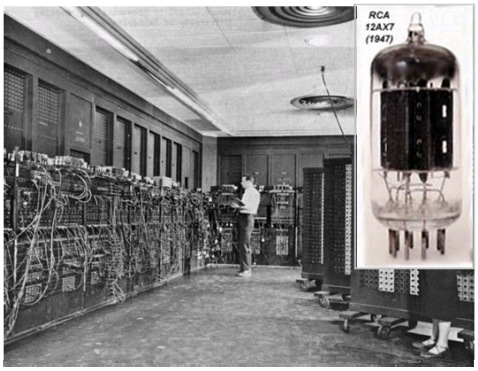
Q Sensor 2.0

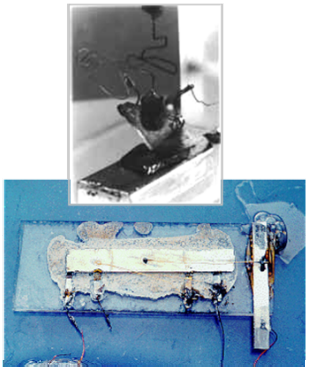
Measuring Emotion – Wirelessly and comfortably

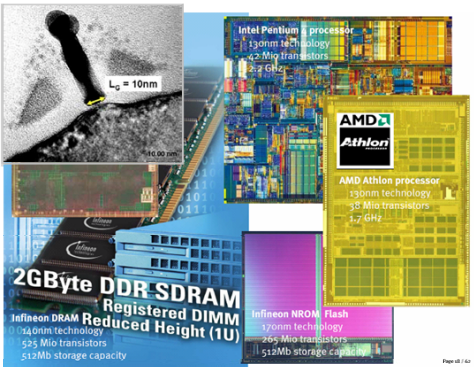
Which Q is right for you?

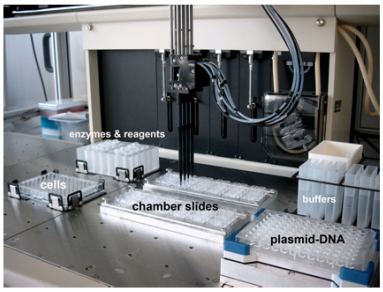
Download Software

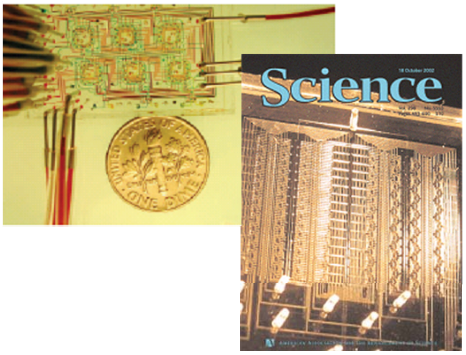
Chip-based sensing





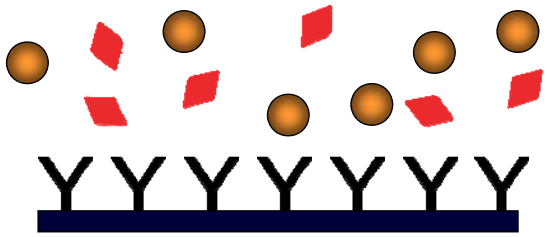






Bio- / chemical sensor

a device that can **detect molecules** with some **specificity**



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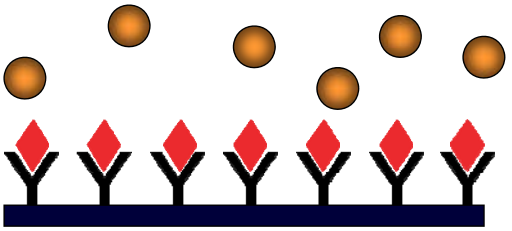

how can this information be read ?

Bio- / chemical sensor

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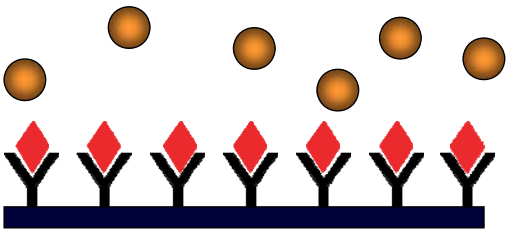


how can this information be read ?

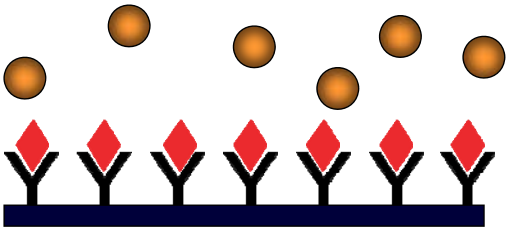
www.q-sense.com

<u>mechanically</u> a) mass change (QCM)

b) strain (cantilever)

Bio- / chemical sensor

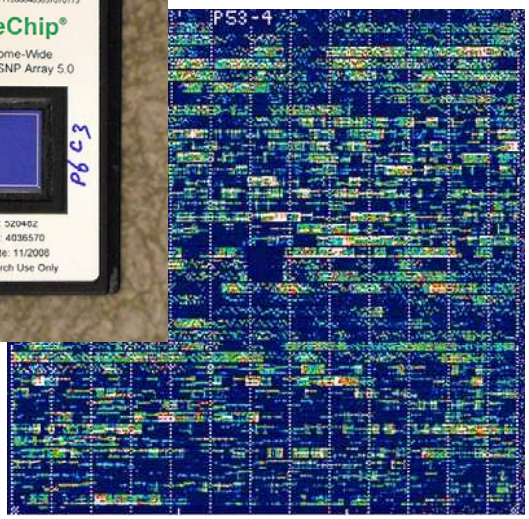
a device that can **detect molecules** with some **specificity**



mechanically a) mass change (QCM)
b) strain (cantilever)

optically a) labelled (DNA chip)

Affymetrix



Bio- / chemical sensor

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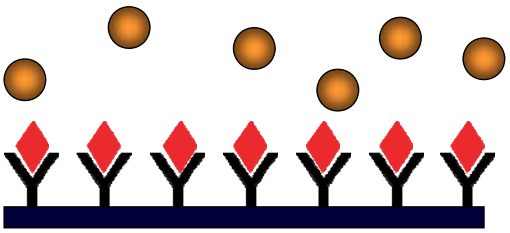
a device that can **detect molecules** with some **specificity**



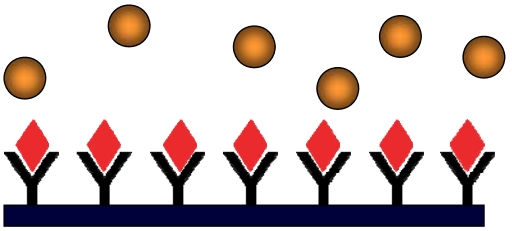
mechanically a) mass change (QCM)
b) strain (cantilever)

optically a) labelled (DNA chip)
b) refractive index
c) Plasmonics

OPTICAL WAVEGUIDE GRATING COUPLER SENSOR CHIP

Bio- / chemical sensor

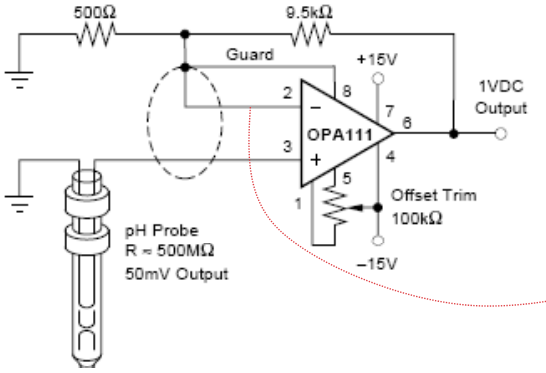
a device that can **detect molecules** with some **specificity**

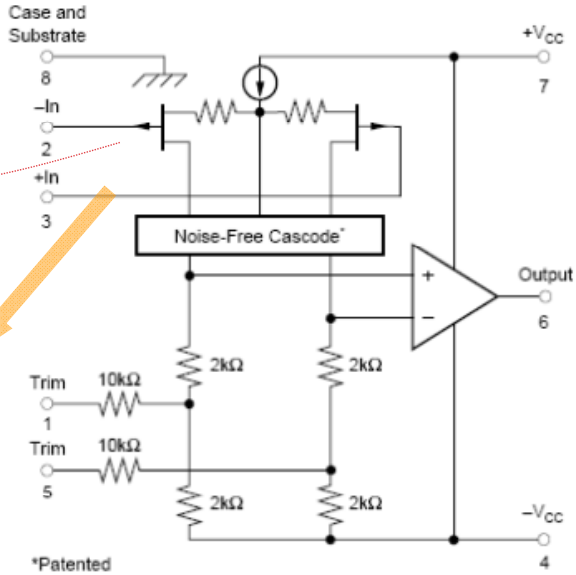


how can this information be read ?

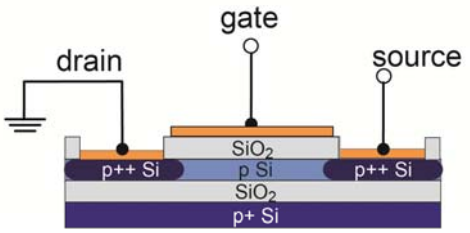
mechanically	a) mass change (QCM)
	b) strain (cantilever)
optically	a) labelled (DNA chip)
	b) refractive index
	c) Plasmonics
<u>electrically</u>	a) impedance spectroscopy
	b) CV spectroscopy
	c) potentiometric (e.g. zeta potential)

Potentiometric sensing

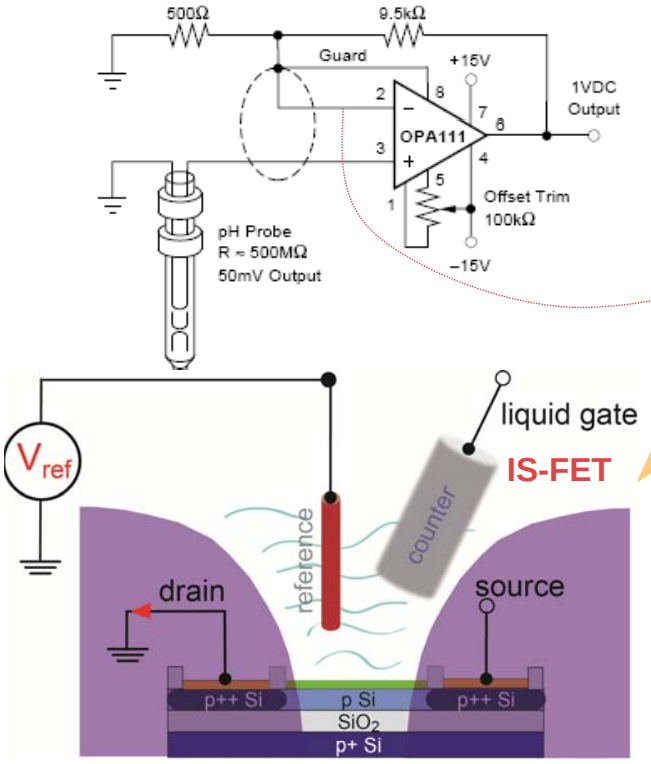


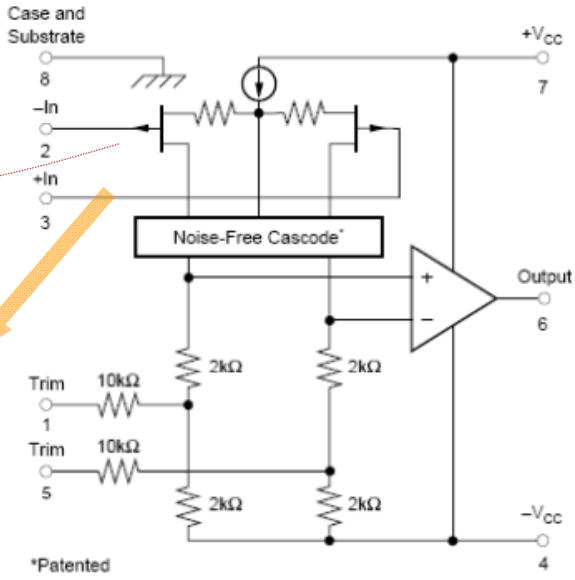


FET



Potentiometric sensing

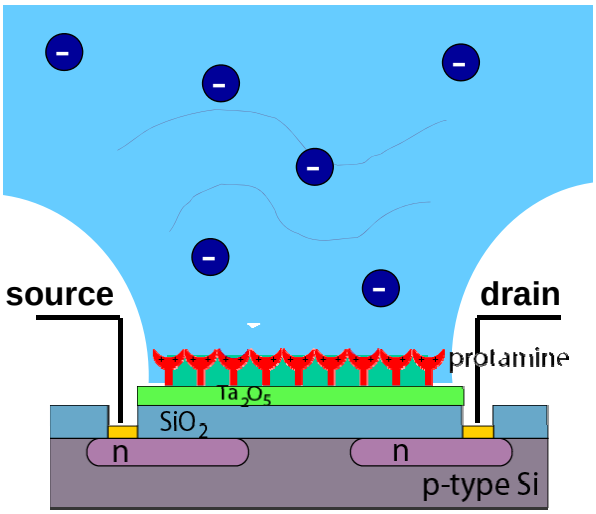




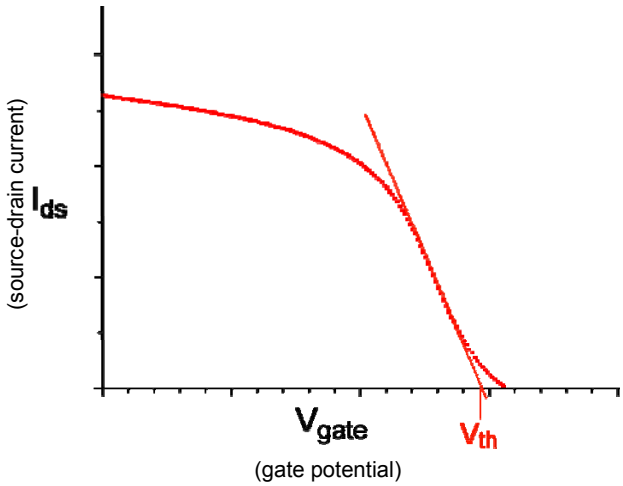
P. Bergveld / Sensors and Actuators B 88 1–20 (2003)

Ion Sensitive FET (IS-FET)

channel conductance (i.e. threshold) depends on **gate charge**

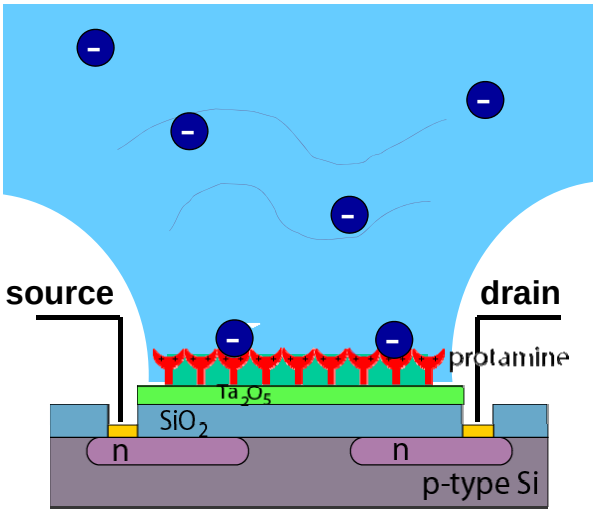


p-channel, sub-threshold regime

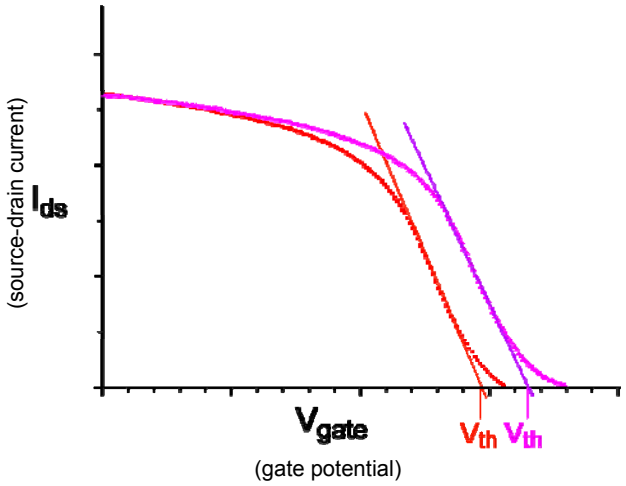


Ion Sensitive FET (IS-FET)

channel conductance (i.e. threshold)
depends on **gate charge**



p-channel, sub-threshold regime



Ion Sensitive FET (IS-FET)

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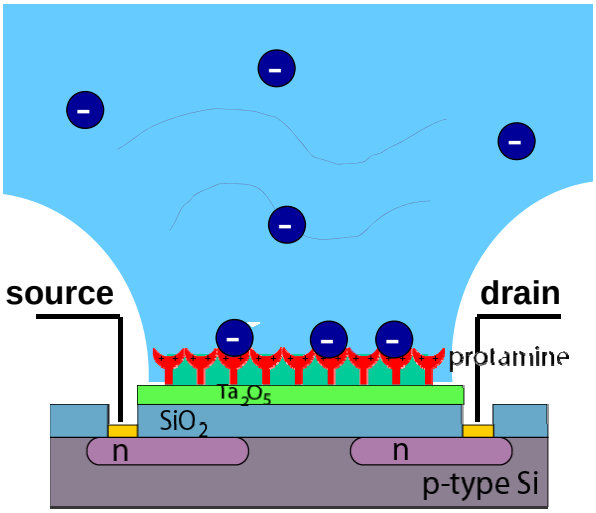
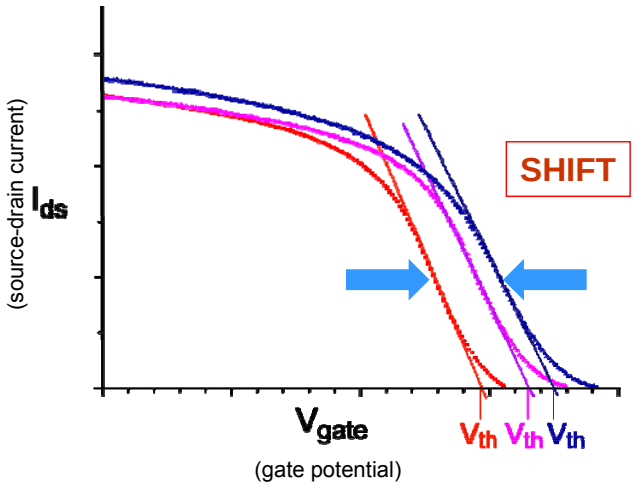
channel conductance (i.e. threshold)
depends on **gate charge**

e.g. heparime binding on protamie



p-channel, sub-threshold regime



IS FET for pH sensing

Honeywell: Durafet III

pH sensors

Endress+Hauser :CPS441 and CPS441D

taken from an application note

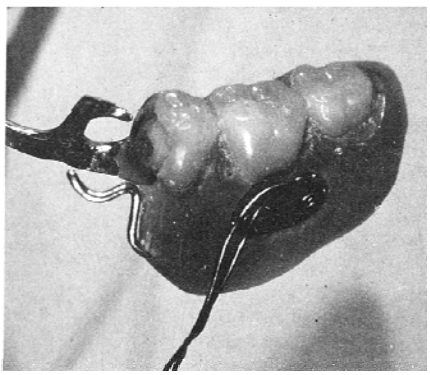
The measurement of pH in cheese

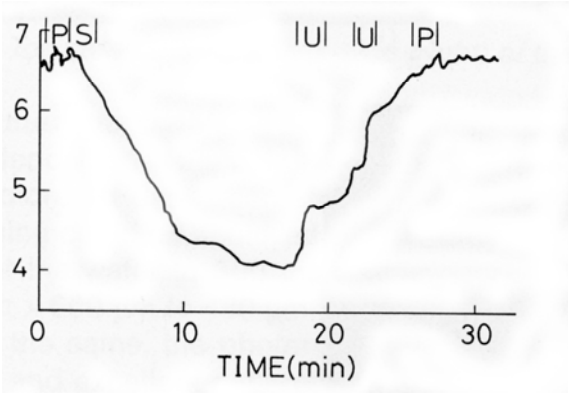
Sentron Europe BV
Postbus 125
9300 AC Roden
The Netherlands

*P. Bergveld / Sensors and Actuators B **88** 1–20 (2003)*

Dental Application

- Food components that lower pH of dental plaque cause caries





pH recording of dental plaque
P = paraffin chewing
S = rinse with sucrose 10%
U = rinse with urea 3 %

H. H. van den Vlekkert, Sensors and Actuators, Vol 14, p. 165 (1988)

ISFET pH catheter

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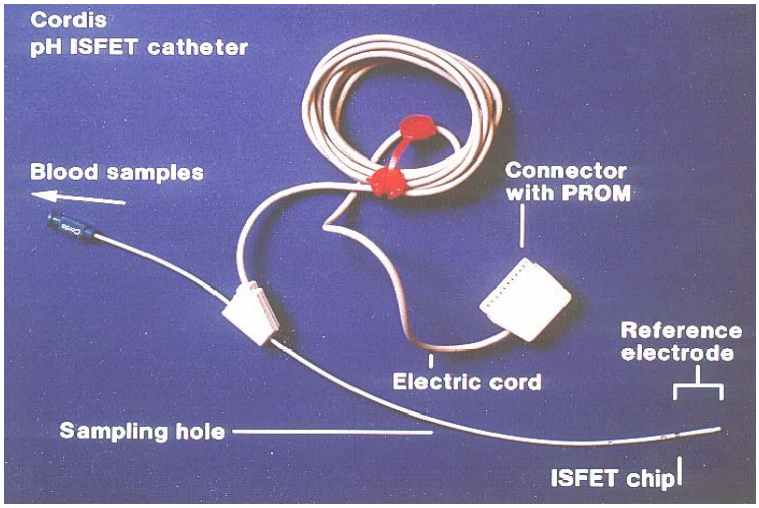
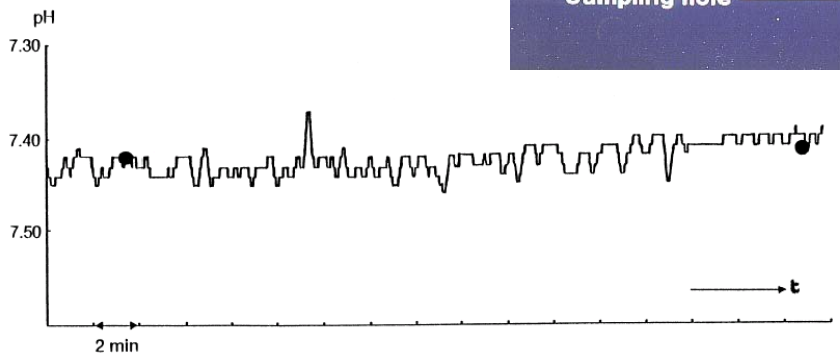
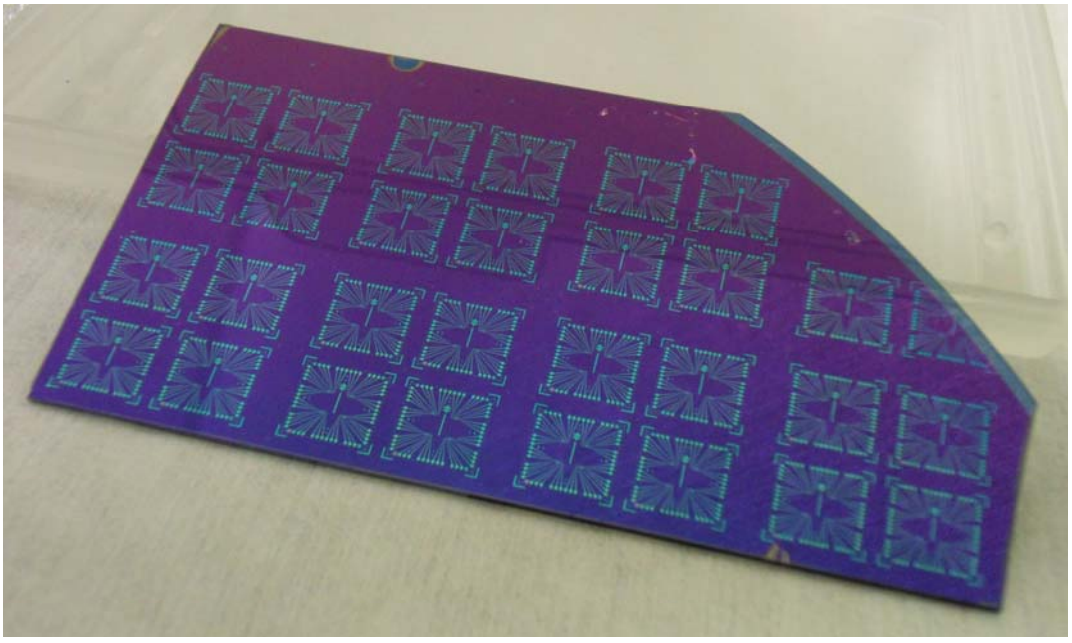




chips



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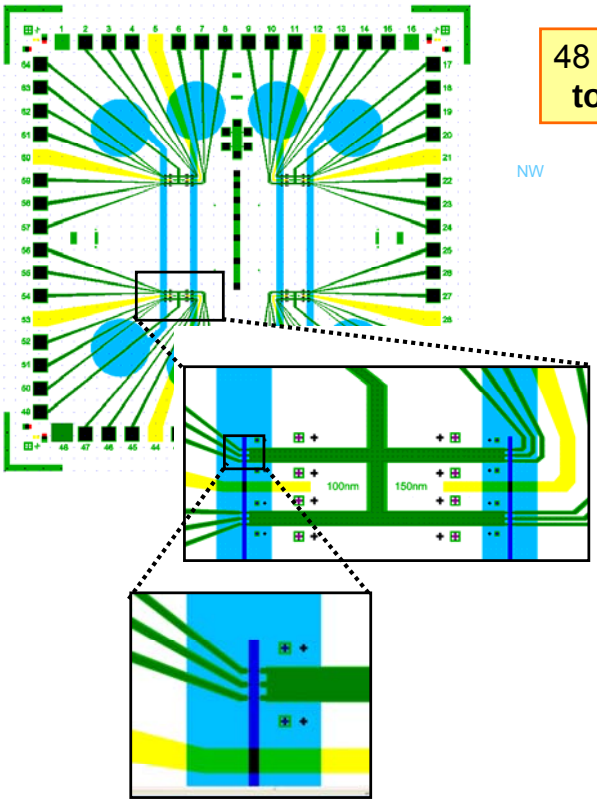
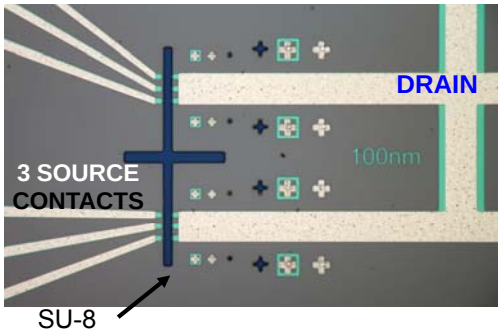
chip

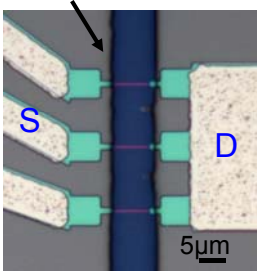


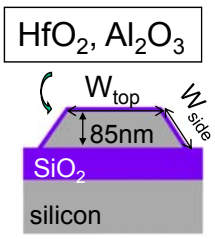
48 silicon nanowires/sample
top width: 100nm – 1µm

NW



SU-8 microchannel





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electrode fabrication

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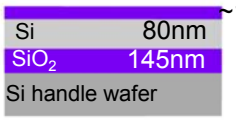
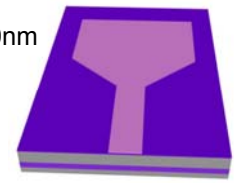
p-type (100) SOI

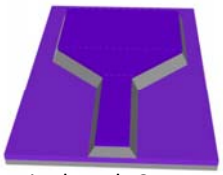


~10nm

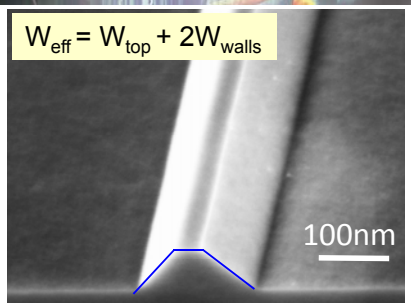
step 1.



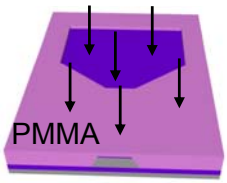
step 2.+3.



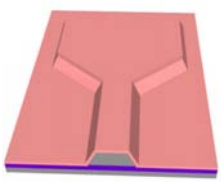
wire length:6um
width: 100nm-1um

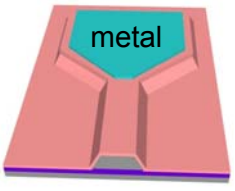


step 4.+5.

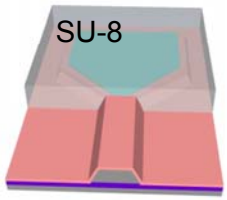


step 6.+7.

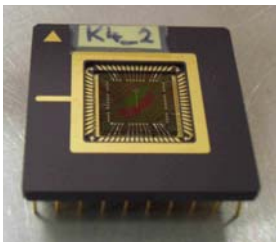


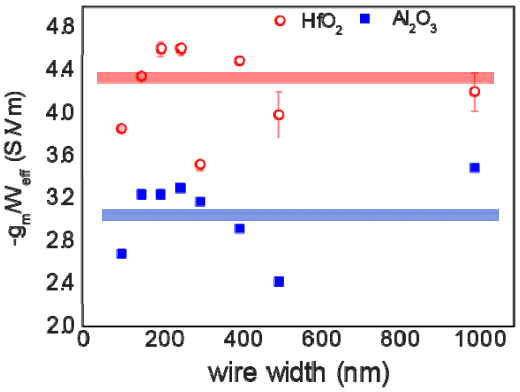


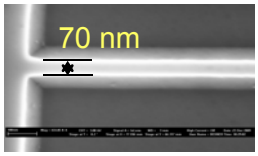
step 11.to14.

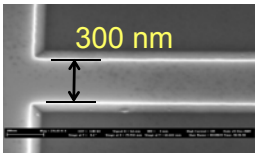


- silicon
- silicon oxide
- ALD oxide
- resist
- metal
- epoxy









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UNI BASEL

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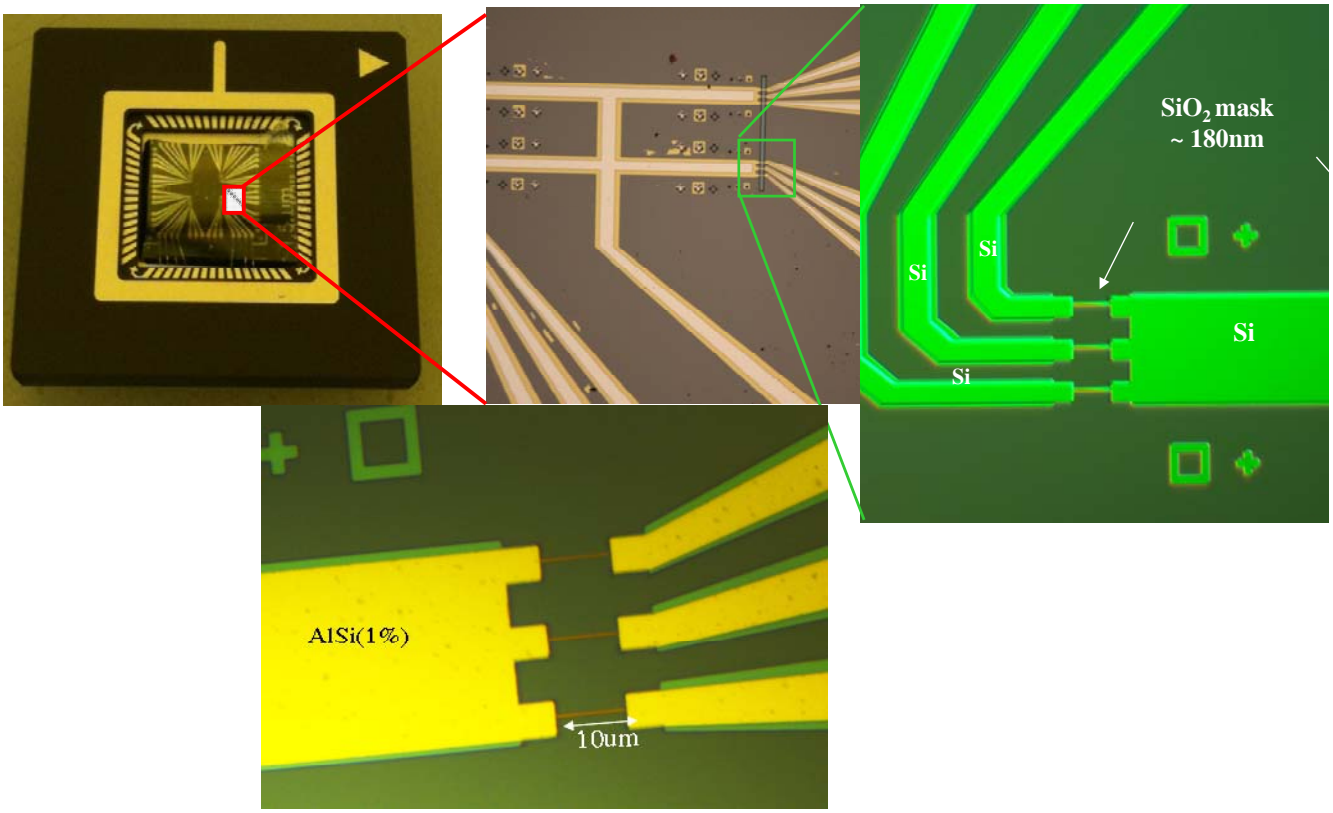
up-scaling



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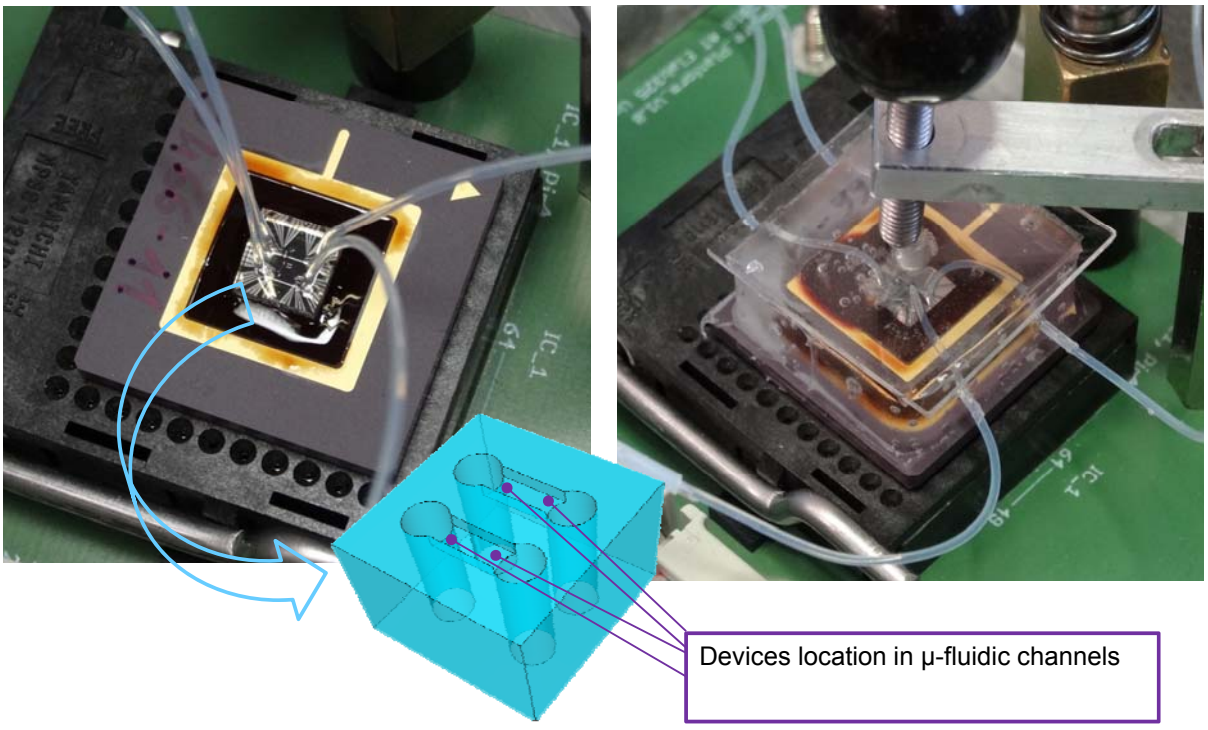
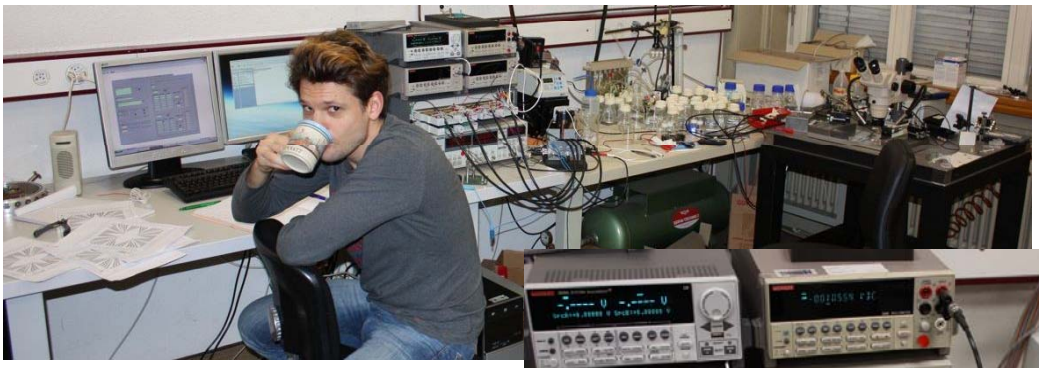
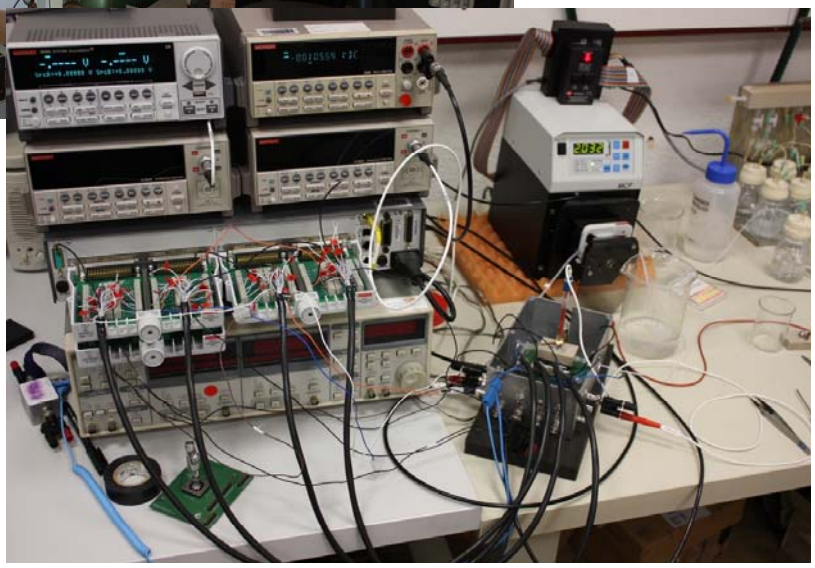
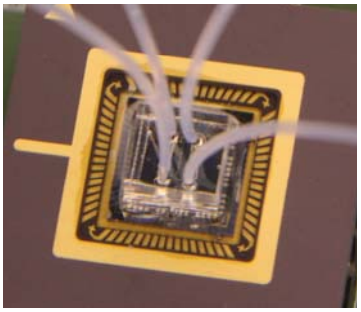
Microfluidics



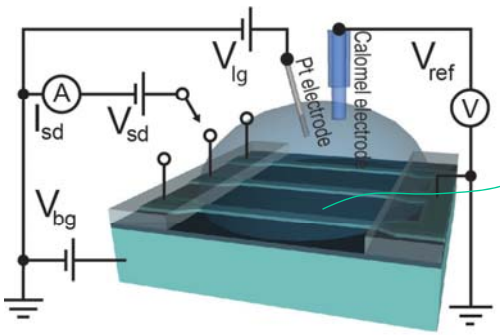
in the lab in operation





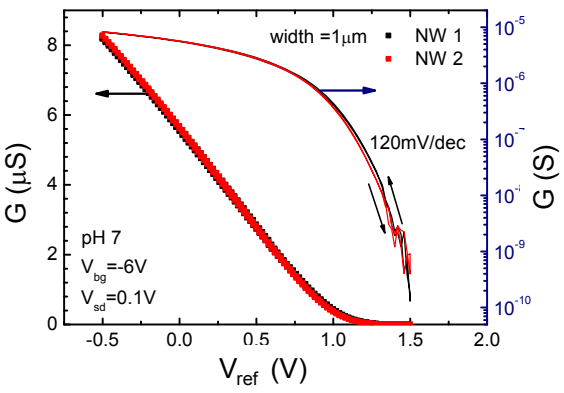


NW-ISFET “quality”

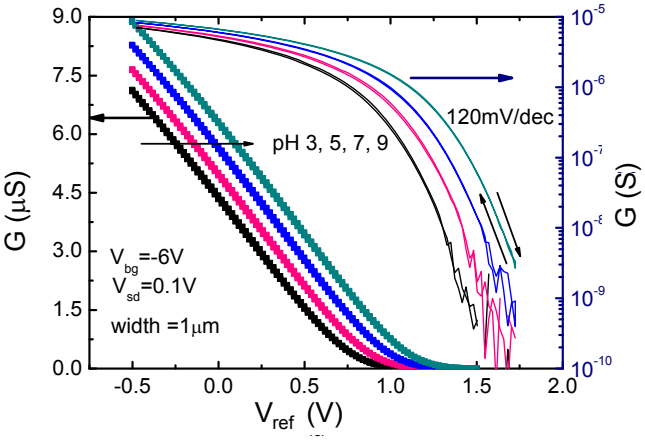


(low p-doped wires in accumulation with p+-implanted and alloyed contacts)

reproducibility

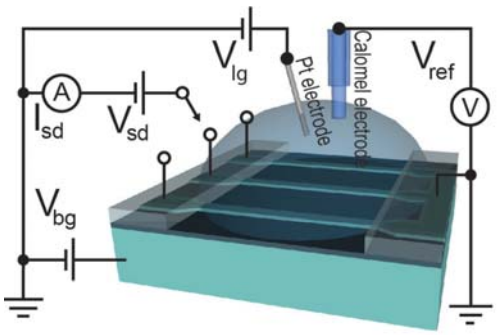


pH response & sensitivity

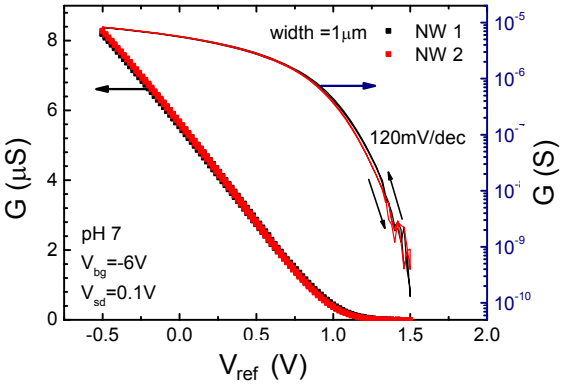


with good ALD oxides, HfO_2 and Al_2O_3 always reach **maximum sensitivity** of ~ 60 mV/pH

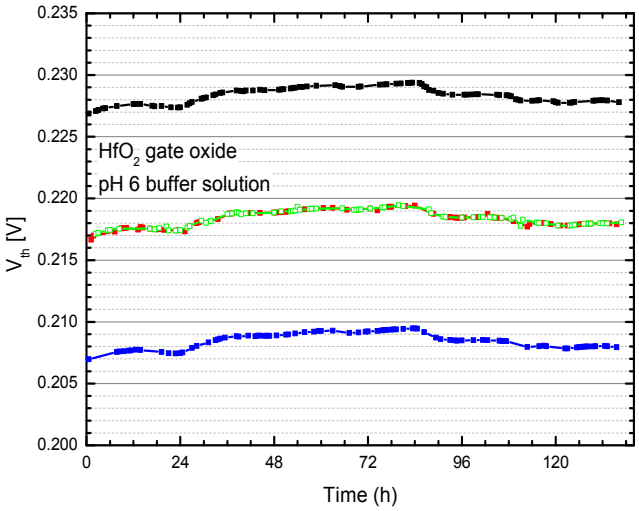
NW-ISFET “quality”



reproducibility



Stability measurements 5.5 days



FinFET sample (EPFL) 8nm HfO_2 gate ox
pH6 buffer solution

- 4 different nanowires
- Max. Drift ~2mV/day
- differential drift ~ 0mV

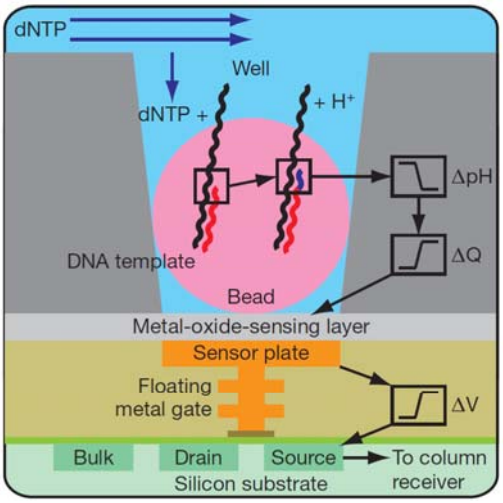
S. Rigante et al.

Genome sequencing

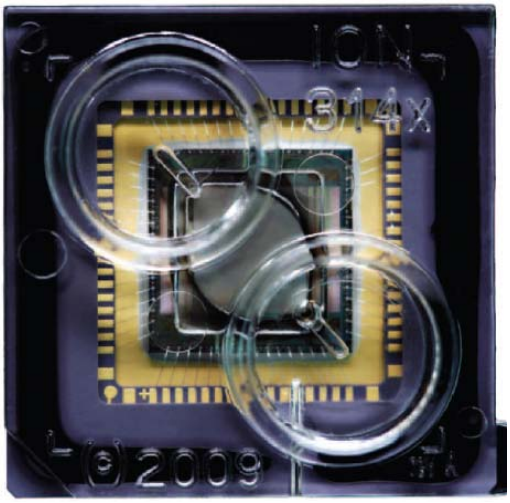
An integrated semiconductor device enabling non-optical genome sequencing

348 | NATURE | VOL 475 | 21 JULY 2011

Jonathan M. Rothberg[1], Wolfgang Hinz[1], Todd M. Rearick[1], Jonathan Schultz[1], William Mileski[1], Mel Davey[1], John H. Leamon[1], Kim Johnson[1], Mark J. Milgrew[1], Matthew Edwards[1], Jeremy Hoon[1], Jan F. Simons[1], David Marran[1], Jason W. Myers[1], John F. Davidson[1], Annika Branting[1], John R. Nobile[1], Bernard P. Puc[1], David Light[1], Travis A. Clark[1], Martin Huber[1], Jeffrey T. Branciforte[1], Isaac B. Stoner[1], Simon E. Cawley[1], Michael Lyons[1], Yutao Fu[1], Nils Homer[1], Marina Sedova[1], Xin Miao[1], Brian Reed[1], Jeffrey Sabina[1], Erika Feierstein[1], Michelle Schorn[1], Mohammad Alanjary[1], Eileen Dimalanta[1], Devin Dressman[1], Rachel Kasinskas[1], Tanya Sokolsky[1], Jacqueline A. Fidanza[1], Eugeni Namsaraev[1], Kevin J. McKernan[1], Alan Williams[1], G. Thomas Roth[1] & James Bustillo[1]



ion-torrent



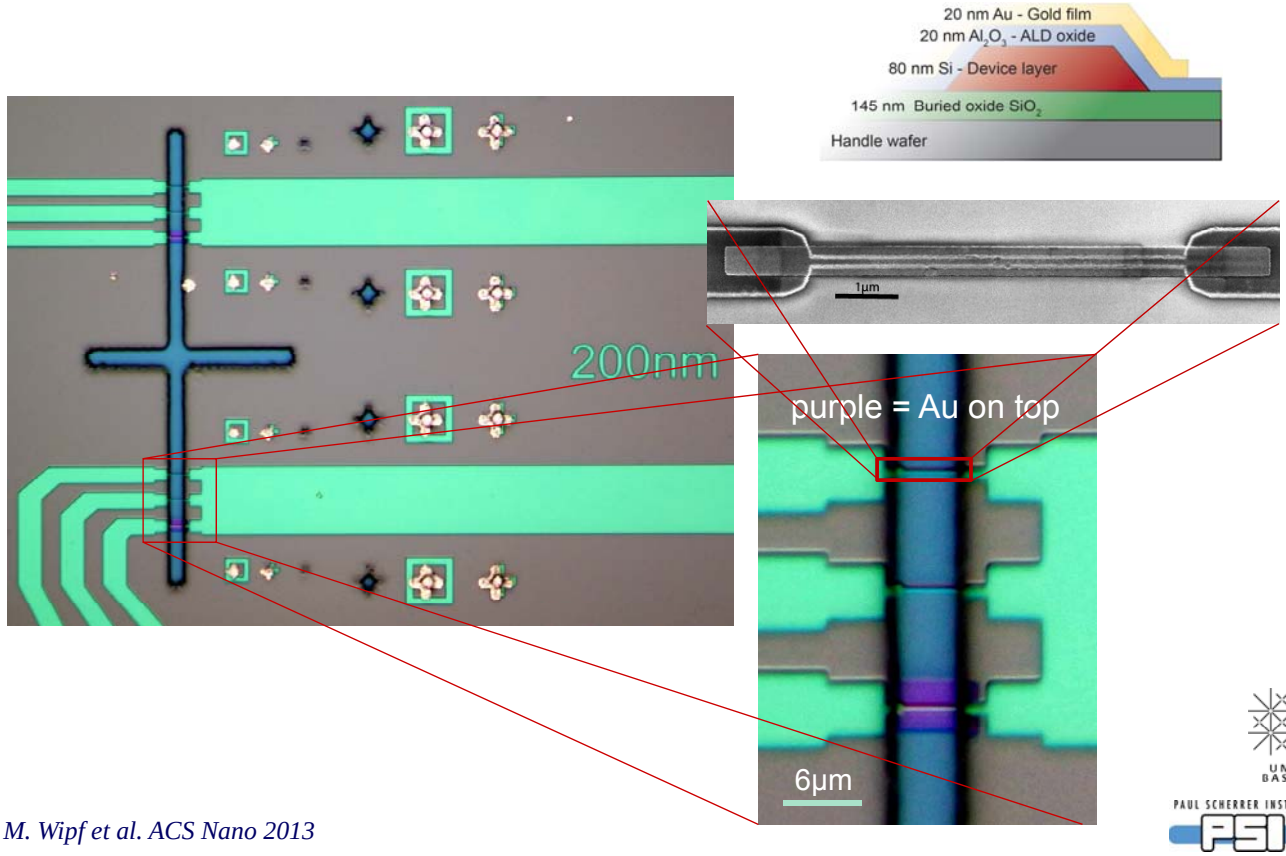
can one measure something else ?

oxide surface highly sensitive to protons → Nernst limit

sensitivity to other ions is usually very small !

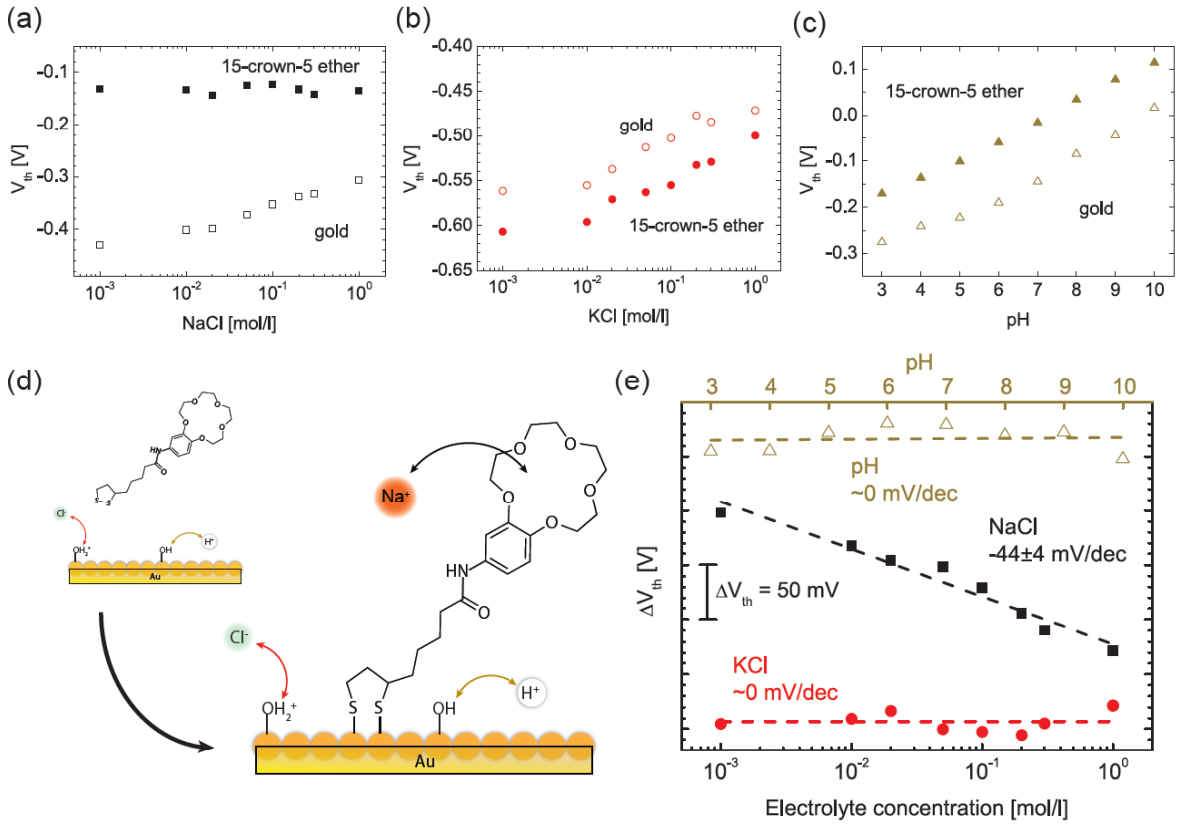
if there are other reactions on the surface that can compete with the de-protonation and proton addition at OH sites, the pH sensitivity may be reduced

NW with floating gate



M. Wipf et al. ACS Nano 2013

Au coated NW: Selective Sodium



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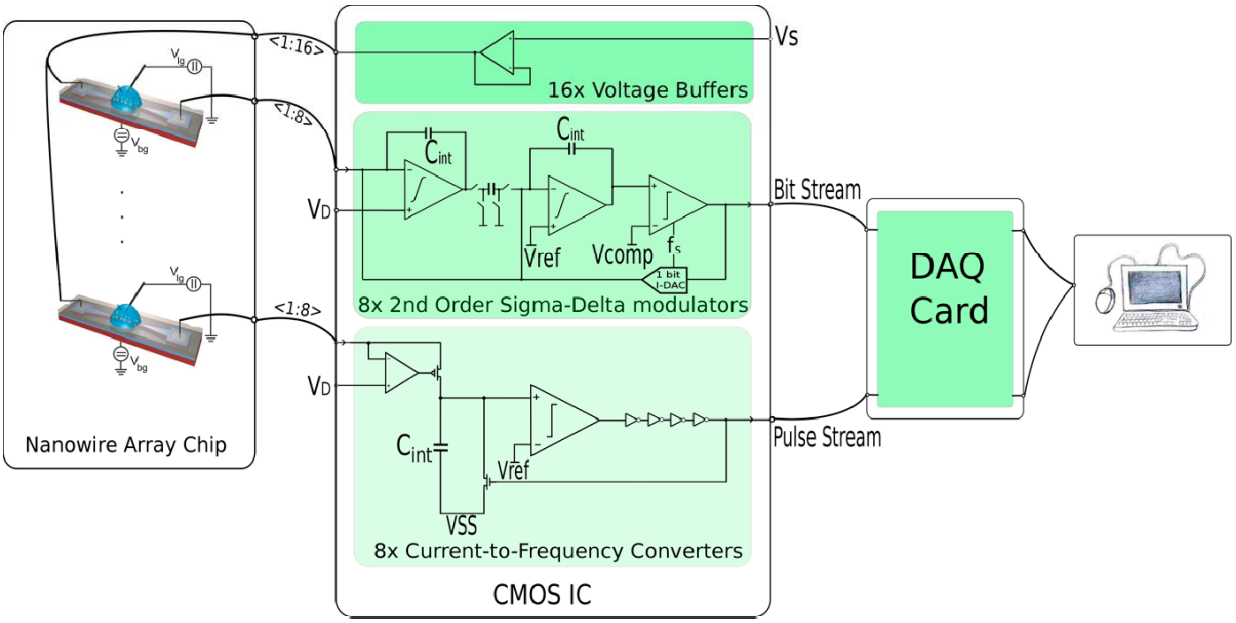
Results

1. **maximum sensitivity** (Nernst limit) can be achieved (Al_2O_3 and HfO_2)
2. oxide surfaces (Al_2O_3 and HfO_2) can be **highly selective** to protons
   (yielding ideal pH sensor up to buffer conc. of 10 mM)
3. **maximum sensitivity** also for the **narrowest nanowires**
4. **highest resolution in concentration** best for **wide wires**
5. **differntial measurement greatly improves stability**
6. **full passivation** possible → "ideal" **reference electrode**
7. **good sensitivity with high selectivity to other ions** can be achieved
8. **multi-ion sensing is promissing**

System Architecture



- 16 nanowires can be interfaced in parallel
- voltage across each nanowire is kept constant, and the current flowing through is measured
- Two different analog-to-digital converter architectures are used (12 bits resolution)
- Current range: 1 nA to 5 µA

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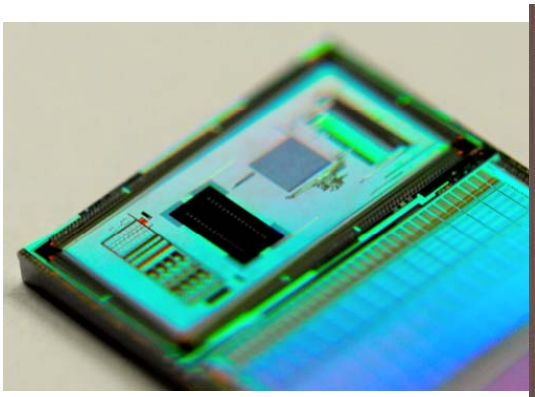
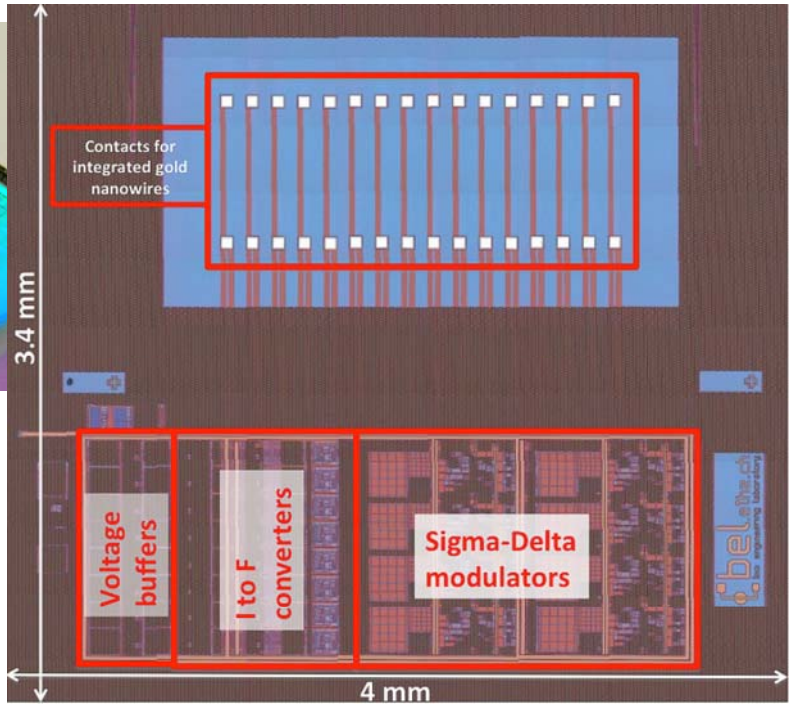
CMOS readout





- Power consumption: 35 mW
- I2F resolution:
  - 8 bits (50 pA -1 µA range)
  - 10 bits (10 nA - 400 nA range)
- Sigma-Delta resolution:
  - 12 bits in the range ±2 µA

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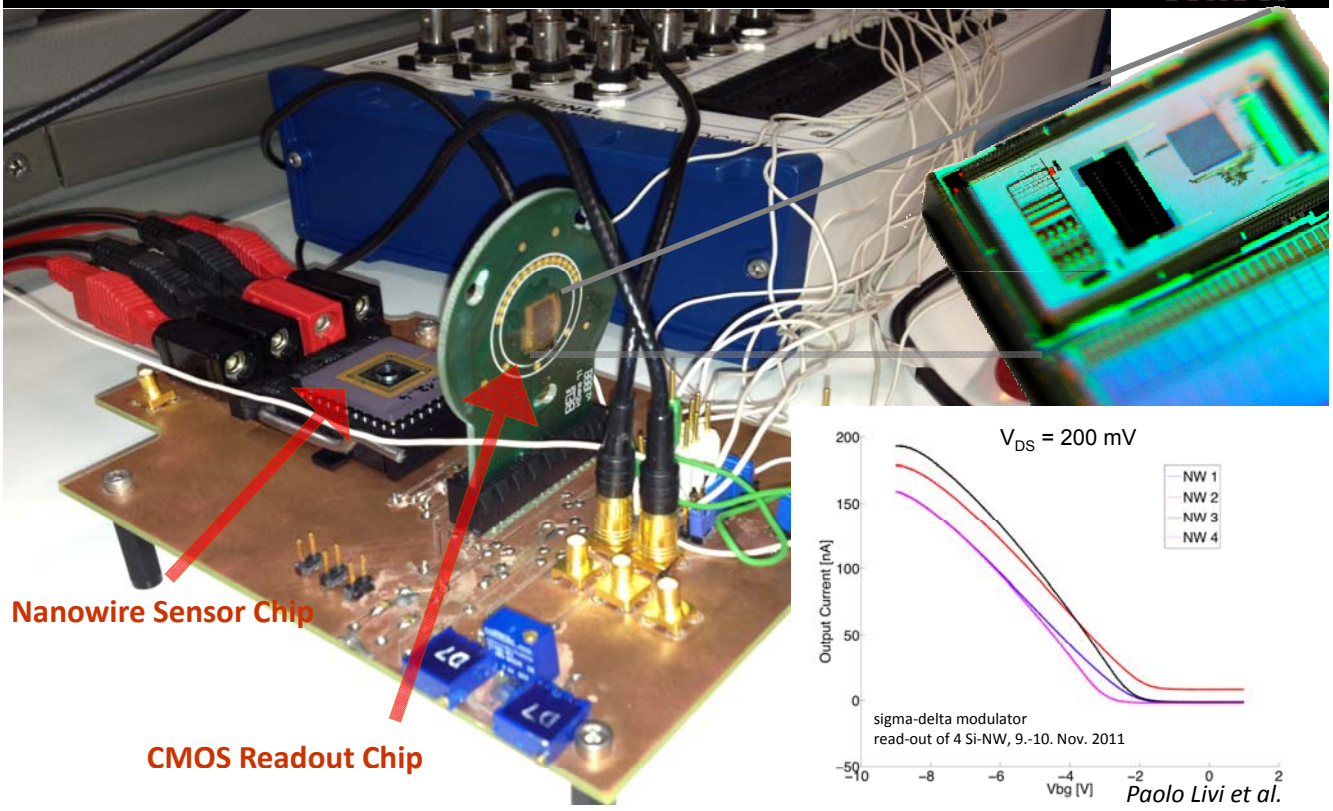
System Architecture



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Thanks to....

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Ralph Stoop

EPFL


Adrian Ionescu


Mohammad Najmzadeh


Sara Rigante

PSI


Jens Gobrecht


Kristine Bedner


Birgit Päivänranta


Vitaliy Guzenko


Christian David


Renato Minamisawa

ETHZ


Janos Vörös


Bernd Dielacher


Robert MacKenzie

UniBas pharma


Beat Ernst


Arjan Odedra


Floriian Binder


Uwe Pieles


Jolanta Kurz

D-BSSE


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Paolo Livi


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Sensirion


Matthias Sreiff

FHNW