Ciência na Universidade do Algarve

Science at the University of The Algarve

P. Stallinga,
Universidade do Algarve (FCT, OptoEl, CEOT)
Amesterdão, 17 de Junho de 2005

Overview

Introduction to UAlg

OptoEl

CEOT

Cooperations

Research examples

- Organic Electronics
  - LEDs: admittance spectroscopy, DLTS
  - FETs
  - LEFETs
- DNA sensor
- TNT sensor
- Bio electronics

Universidade do Algarve (UAlg)

10,000 students, 5 Faculties, 4 campi, 700 profs., 60 courses.

Faculdade de Ciências e Tecnologia (FCT), 90 profs.

Departamento de Engenharia Electrónica e Informatica (DEEI), 20 profs.

3 Courses (ESI, EI and I)

Areas of ESI: Electrónica, Control, Signal Processing, Telecommunications

The university is the heart of The Algarve

Faro, 6 Oct. 2004; 26 ºC

OptoEl

OPTO-ELECTRONICS
UNIVERSIDADE DO ALGARVE

Opto-Electrónica Universidade do Algarve

Founded: 1997

2 members (PhD)

Prof. Henrique Leonel Gomes

Specialized in electronic characterization of organic electronic devices.

Sensitive equipment with custom made control software.

- DLTS (the only "organic" DLTS)
- Organics-specific FET measurement system
- Admittance spectroscopy
- Environment ideal for studying solar cells

Centro de Electrónica, Opto-Electrónica e Telecomunicações

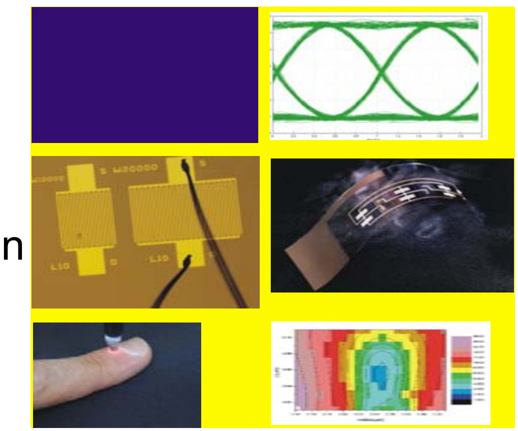
Founded in 2001

9 members (PhD)

Electronics (design of RF electronic circuits)

Opto-Electronics (characterization electronic materials, sensors)

Telecommunications. (Comm. protocols, network design, etc)



Centro de Electrónica,
Opto-Electrónica e
Telecomunicações

Founded in 2001

9 members (PhD)

€

In 2003, CEOT was evaluated by an external committee of FCT (Portuguese equivalent of FOM) as “very good” and received a 640 k€ equipment investment bonus in 2004 apart from the normal individual project grants.

OptoEl Cooperations in last 6 years

Electrical characterization of novel electronic materials

Sensors and actuators

Scientific instrumentation

Organic materials, a.k.a. "plastics"

The world is better with plastics ….

In may areas plastics have replaced traditional materials

Clothes

http://www.mischabarton.net/mbimages/misc/misc-nylon.jpg

Transportation

A plastic car, because of it's light weight can get more miles per gallon than a steel car

http://www.cnn.com/TECH/ptech/9902/25/plastic.cars/

Construction

http://www.solvayindupa.com.br/aplic/prod.htm

…. why not electronics ?

Electronics of the past

Electronics of the Future
“Ambient intelligence”

Applications

Cheap electronics:
Electronic barcodes
Low performance electronics (medicine)
Disposable electronics

Example: a computer of Si technology @ 3 GHz, a ring oscillator of organics @ 3 kHz.

but there are things you can do only with organics

Flexible electronics
Printed electronics

Printable electronics: electronics on paper

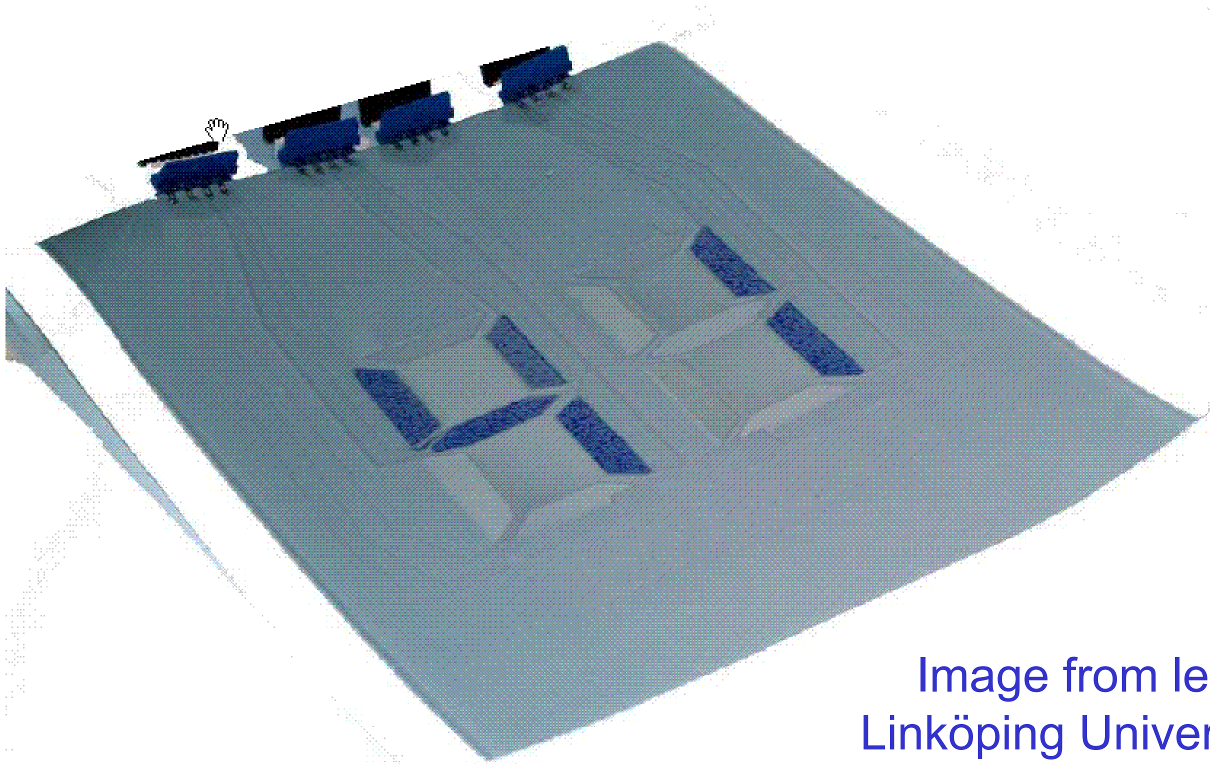
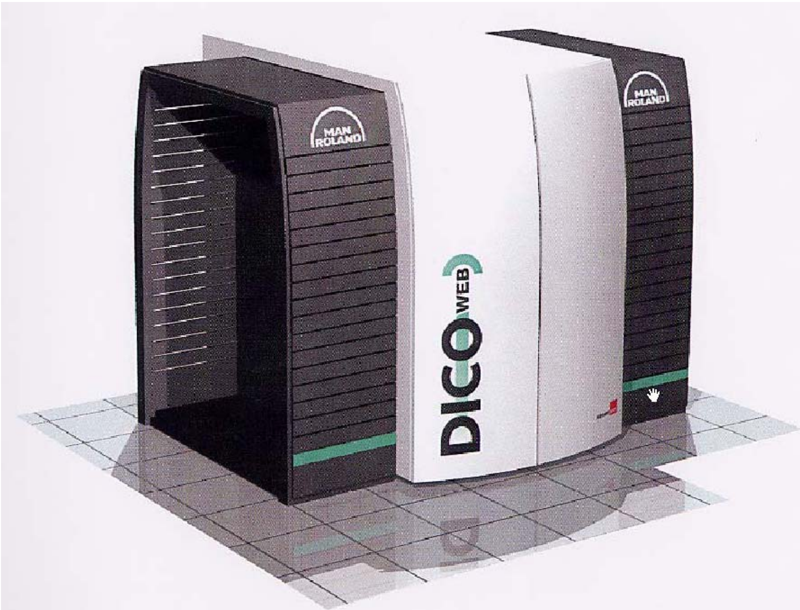


Image from lecture of Magnus Berggren, Linköping University at TPE04 (Rudolstadt)



MAN ROLAND

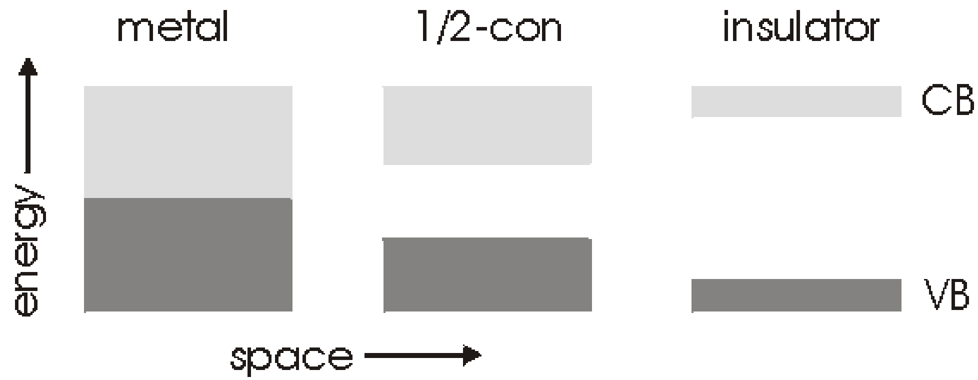
WE ARE PRINT.™

Using existing technologies (offset, gravure and flexo printing) to produce electronic circuits

… only organic electronics!

Reinhard Baumann,
MAN Roland Druckmaschinen AG, Germany

Semiconductor means "with electronic bandgap"



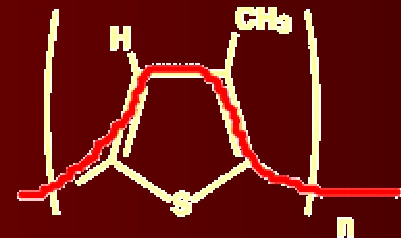
Material	Band gap
SiO_2	>10 eV
C (diamond)	5.47 eV
GaN	3.36 eV
Polymers	2.5 eV
GaAs	1.42 eV
Si	1.12 eV
Ge	0.66 eV

Organic semiconductors means "with conjugated backbone"

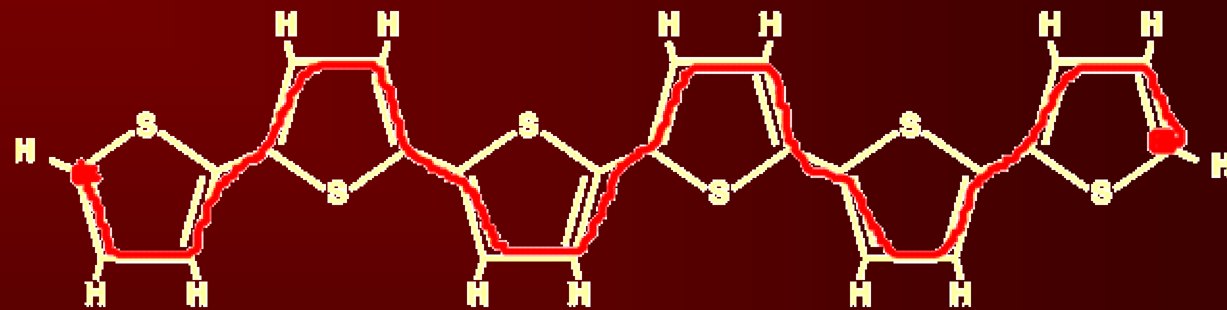
····-C=C–C=C–C=····

Examples

Conjugated organics have paths with alternating single and double bonds



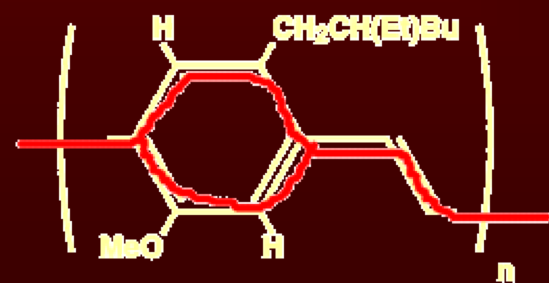
PMeT



αT6

Very good for FETs

Very good for LEDs



MEH-PPV

The metallic properties of organic materials were discovered by accident in a laboratory in Japan. New wave of organic electronics research.

Groups like Cambridge (Richard Friend) and Santa Barbara (Alan Heeger) focus(sed) on the LEDs.

Nobel prize in chemistry in 2000, Alan Heeger, Alan McDiarmid, Hideki Shirakawa.

Companies like Philips, Samsung and EPSON soon joined the wagon.

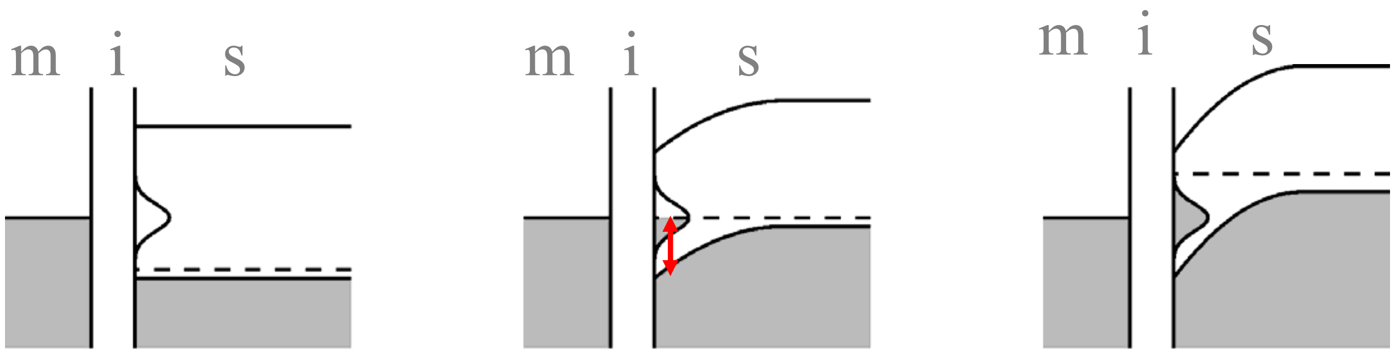
First commercial products are already on the market.

Next slides:

Some projects of OptoEl in Organic Electronics.

In 1997 the research group was formed and started with acquiring knowledge and building equipment for measuring organic electronics.
A continuation of the PhD work of Henrique Gomes in Bangor (Wales).

Admittance spectroscopy. Interface states in MIS diode



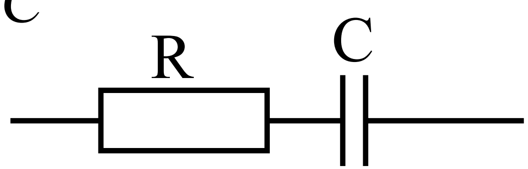
(a) forward (b) no bias (c) reverse

Filling and emptying of states with time constant

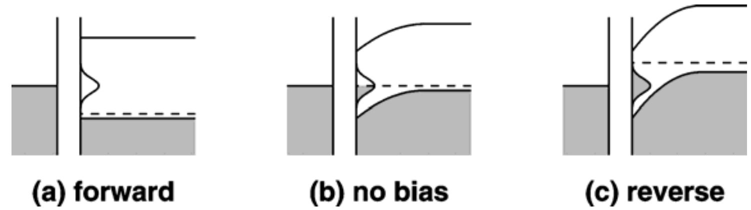
$\tau = \exp(E_T/kT)$

.. can be modeled by electronic circuit

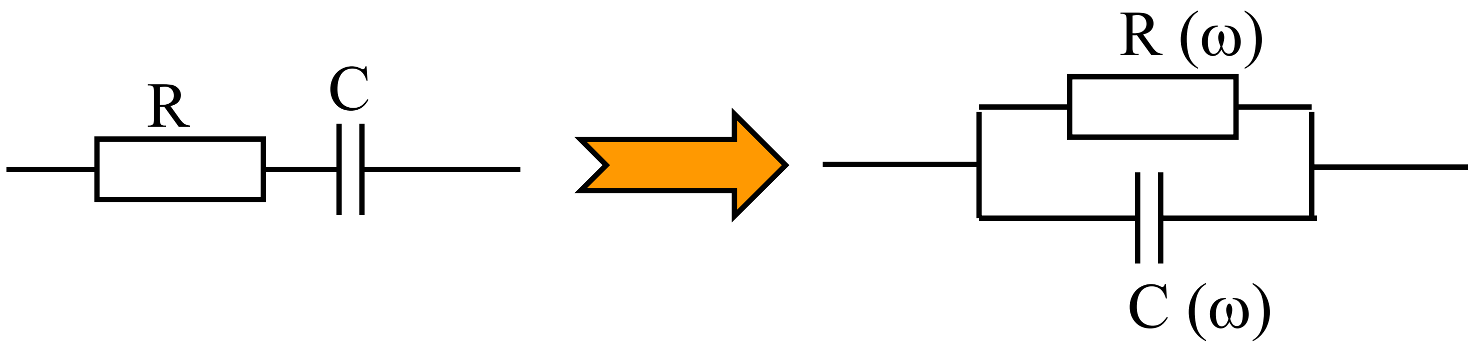
$\tau = RC$



Interface states



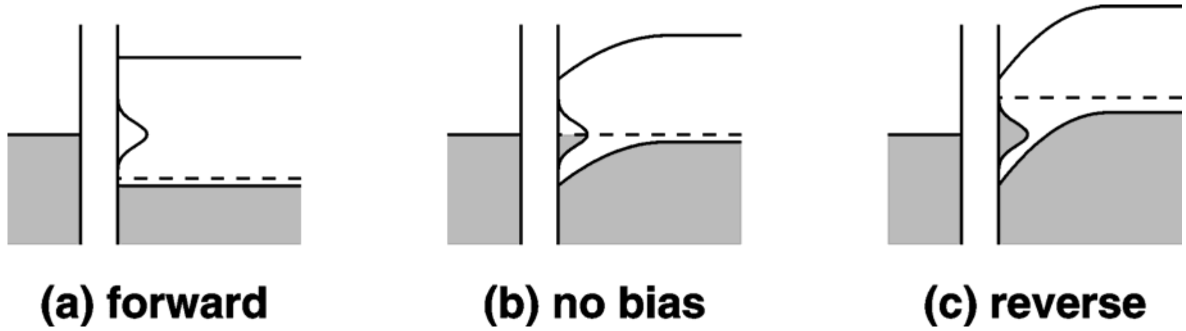
$\tau = \exp(E_T/kT) = RC$



The so-called Loss Tangent ($\tan\delta = 1/\omega RC$) has a peak at
$\omega_m = 1\backslash\tau = \omega_0\exp(-E_T/kT)$

Measuring ω_m as a function of T yields E_T

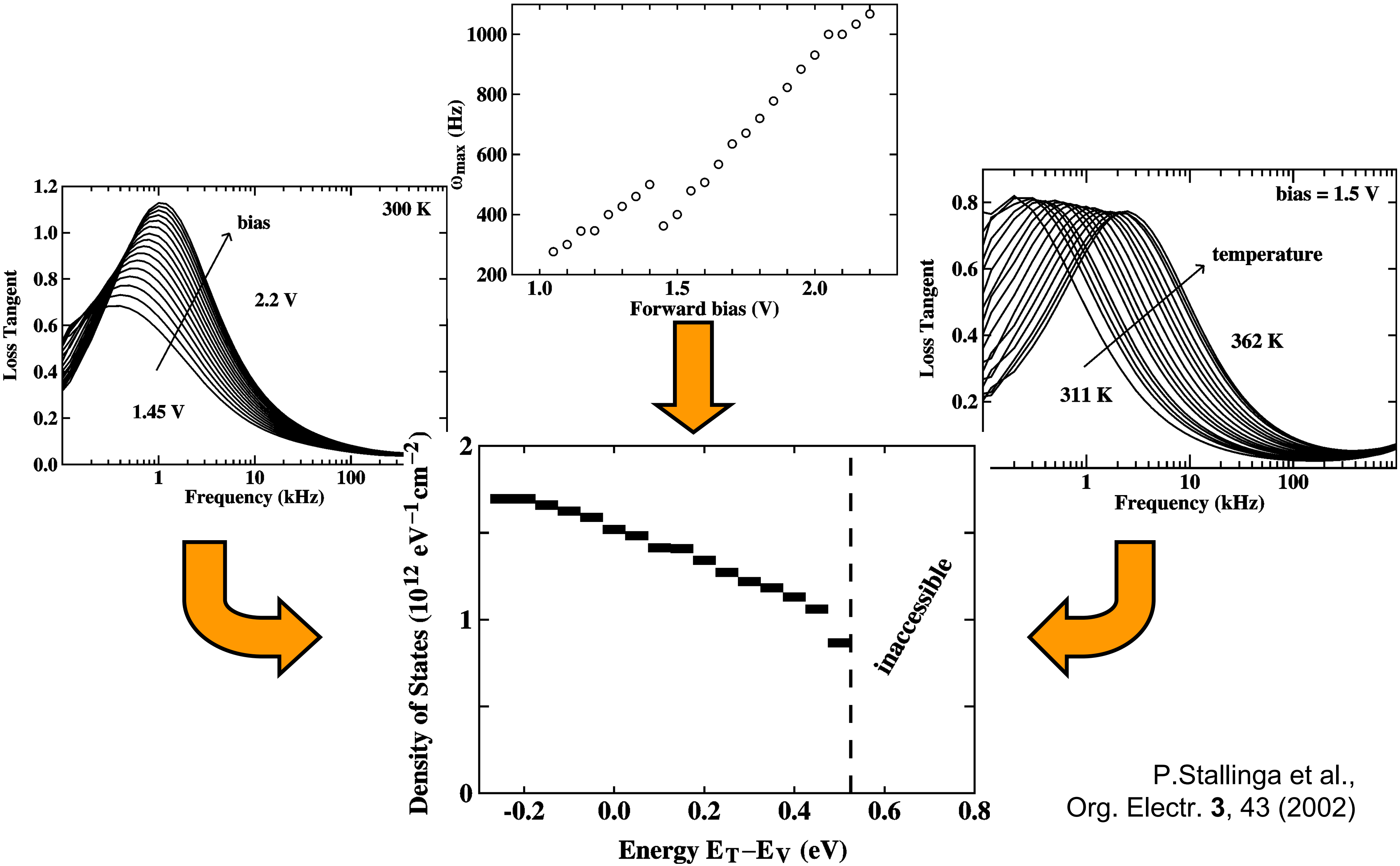
Interface states



For interface states, τ depends on bias:
  Reverse bias: deeper states, τ longer.
  Forward bias: shallower states, τ shorter.
For bulk states, τ doesn't depend on bias.

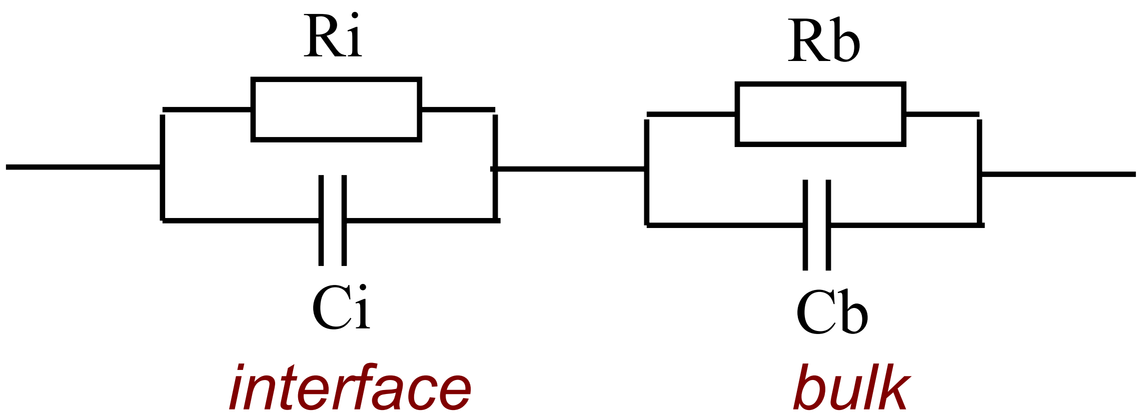
Intensity of peak in Loss ($L = 1/\omega R$) directly proportional to density of states.

Interface states



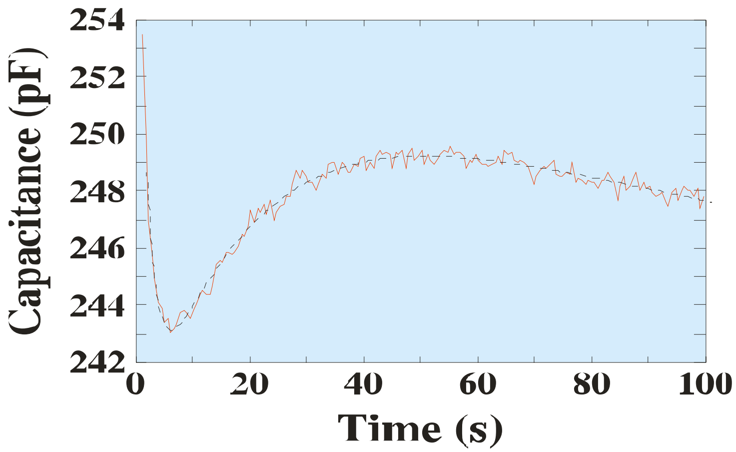
P.Stallinga et al.,
Org. Electr. **3**, 43 (2002)

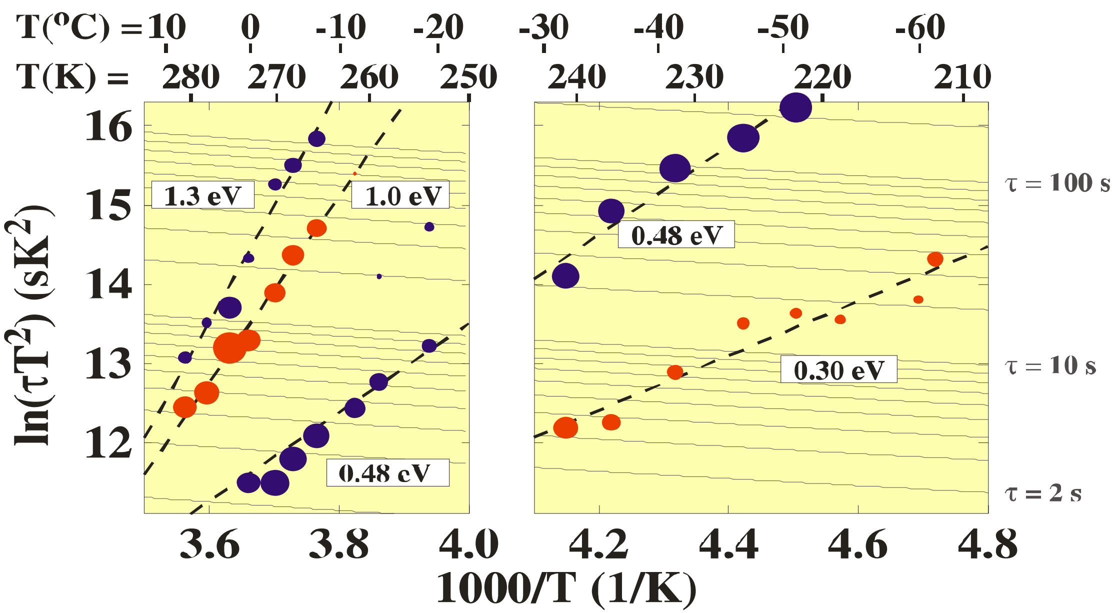
The problem of DLTS



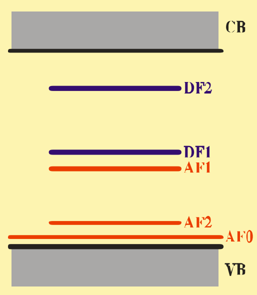
in a transient, C_i changes and contains the information. However, the bulk part filters everything off. Do not use commercial DLTS equipment (working at 1 MHz).

DLTS





label	*type*	*activation energy*
AF0	acceptor	0.12 eV
AF1	majority	0.30 eV
DF1	minority	0.48 eV
AF2	majority	1.0 eV
DF2	minority	1.3 eV



P.Stallinga et al.,
J. Appl. Phys. **89**, 1713 (2001)

Three-terminal devices: thin-film FETs

Three-terminal devices are transistors (bipolar junction transistors or thin-film field-effect transistors)

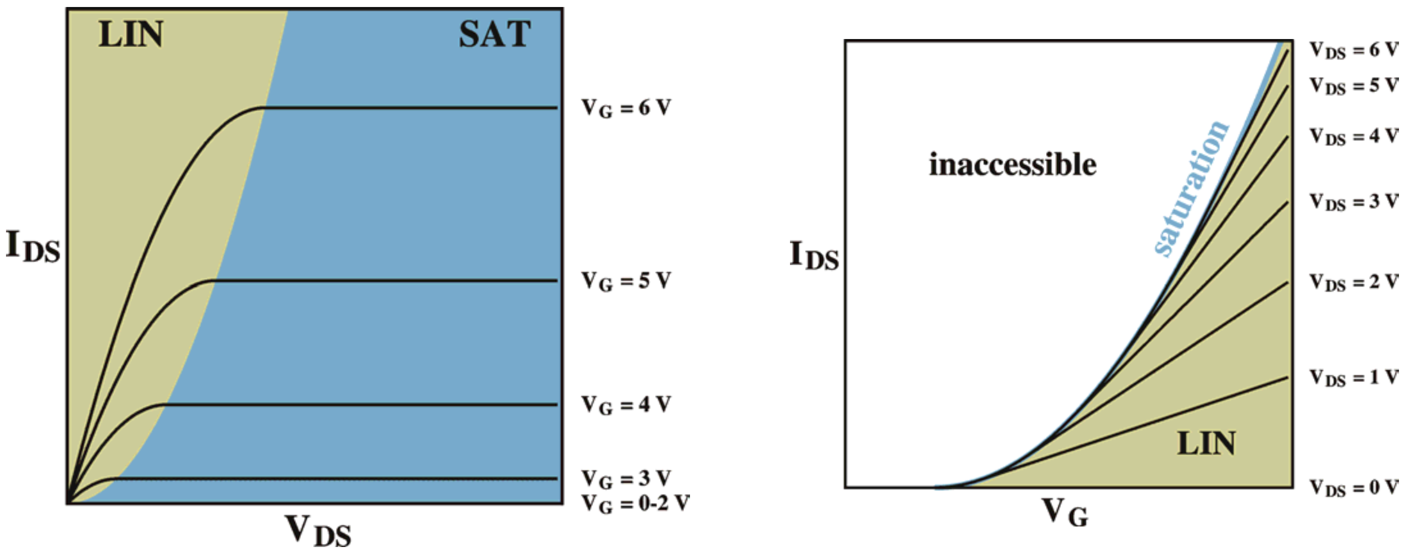
As an application, three-terminal devices are used to control the current in, for instance, active matrix displays.

As a research tool, they serve to measure the mobility, because (FET)

$$\text{LIN:} \quad I_{ds} = (W/L)\, C_{ox}\, \mu\, (V_g - V_t)\, V_{ds}$$

$$\text{SAT:} \quad I_{ds} = (W/L)\, C_{ox}\, \mu\, (V_g - V_t)^2$$

Standard inversion channel FETs

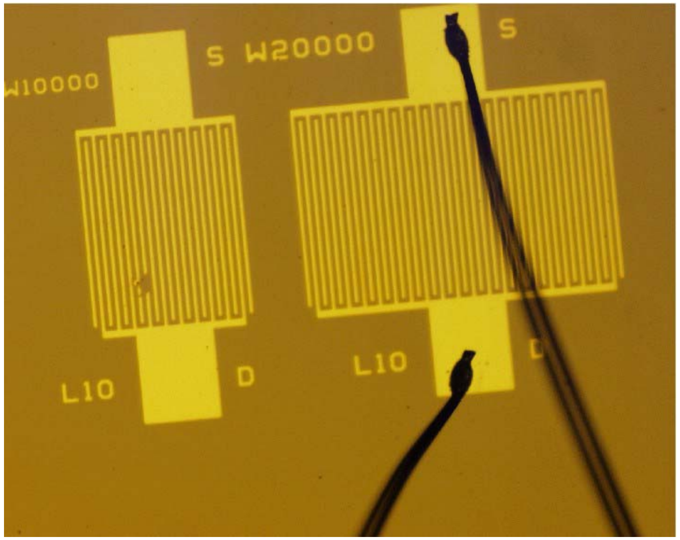


LIN: $I_{DS} = \mu(Z/L)\, C_{ox}\, (V_G - V_T) V_{DS}$

SAT: $I_{DS} = (1/2)\mu(Z/L)\, C_{ox}\, (V_G - V_T)^2$

http://www.ualg.pt/fct/adeec/optoel/theory/fet/

Three-terminal devices: thin-film FETs



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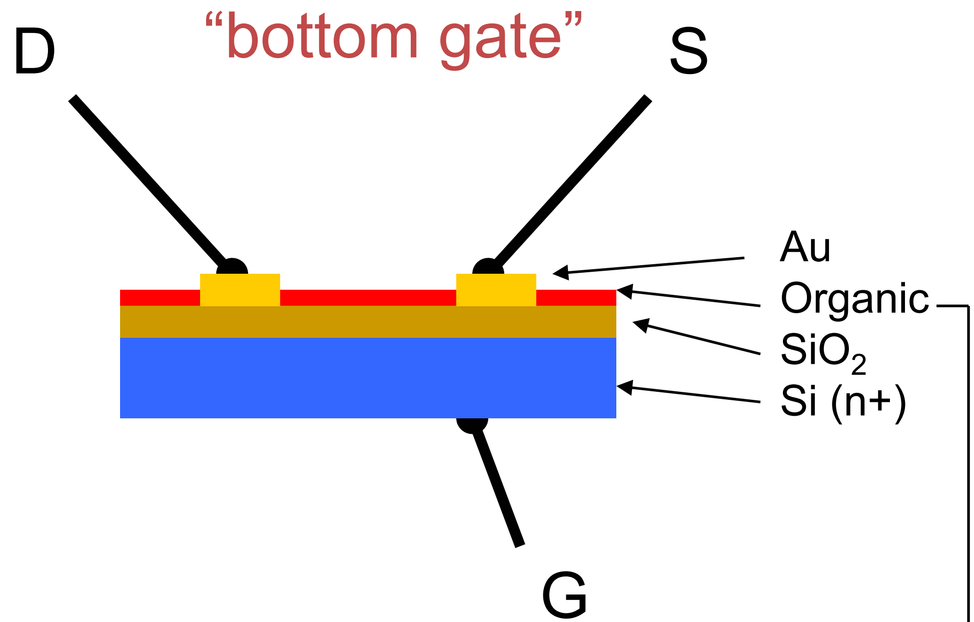
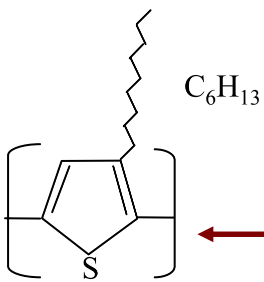
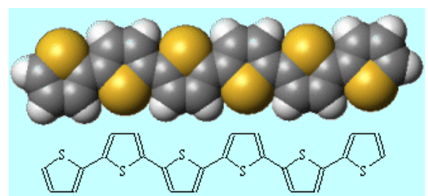
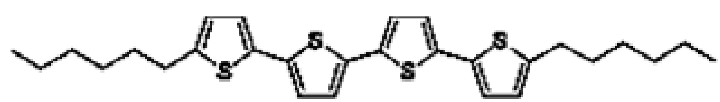




Organic layer:
sexithiophene (T6)
or PMeT or DH4T

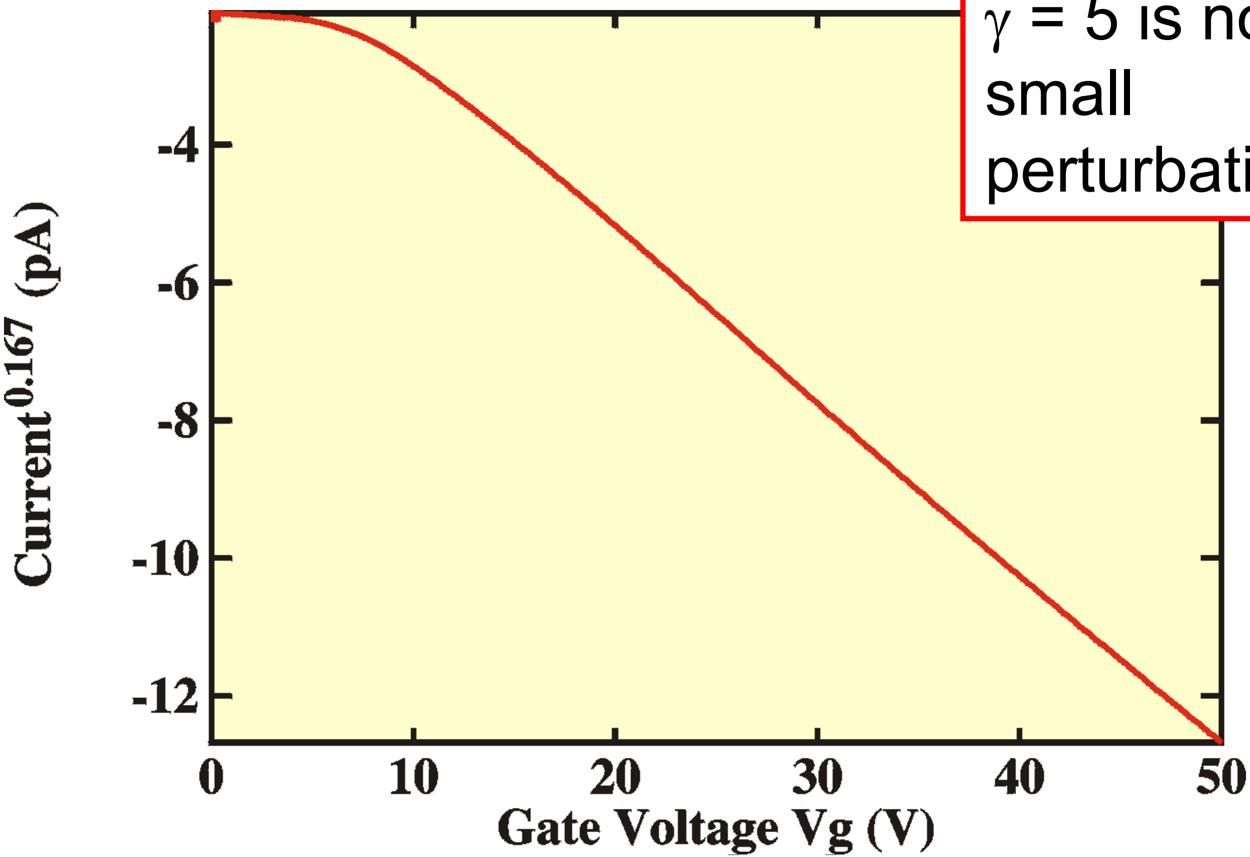




In the so-called linear region:

$$\text{LIN:} \quad I_{ds} = (W/L)\, C_{ox}\, \mu\, (V_g - V_t)^{1+\gamma}\, V_{ds}$$

γ = 5 is not a small perturbation!



This can be explained by assuming high density of trap states, as in the model of Shur and Hack for α-Si

Other effects explained by trap states:

Non-exponential current transients: $I_{ds} = I_0 \exp(-(t/\tau)^{\alpha})$

Stressing: V_t increases with time

Thermally activated current: $I_{ds} = I_0 \exp(-E_T/kT)$

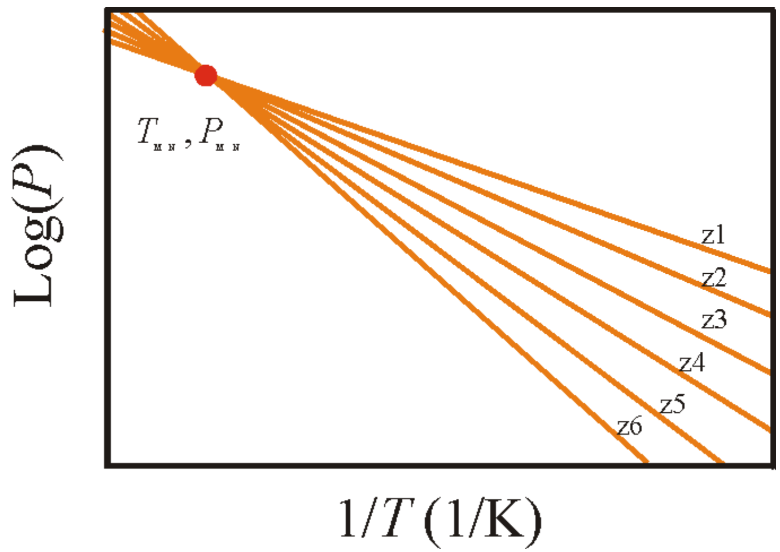
Meyer-Neldel Rule

P. Stallinga *et al.*, J. Appl. Phys. **96**, 5277 (2004).
H.L. Gomes et al. Appl. Phys. Lett. **84**, 3184 (2004)

Observation without explanation*

The thermal activation energy of a process (P) depends on a certain parameter (z).

There exists a temperature (T_{MN}) where the dependence of P on z disappears.



$$P = P_0 \exp(-E_A/kT)$$

$$P_0 = P_{MN} \exp(E_A/kT_{MN})$$

* Original article: W. Meyer and H. Neldel, Z. Techn. **18**, 588 (1937).

Examples of the Meyer-Neldel Rule

Processes	Parameters	Devices/materials
current	gas concentration	α-Si
diffusion*	pressure	organic ½cons
ionic currents	electrical bias	gas detectors
		High-Tc supercons
		glasses
		liquid ½cons
		polycryst. Si
		CCDs

Cross disciplinary!

* Here the MNR is called the Compensation Effect.

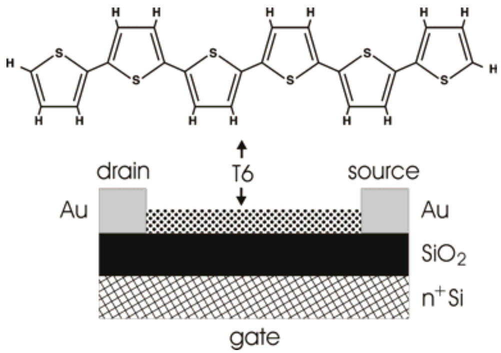
Examples of the Meyer-Neldel Rule

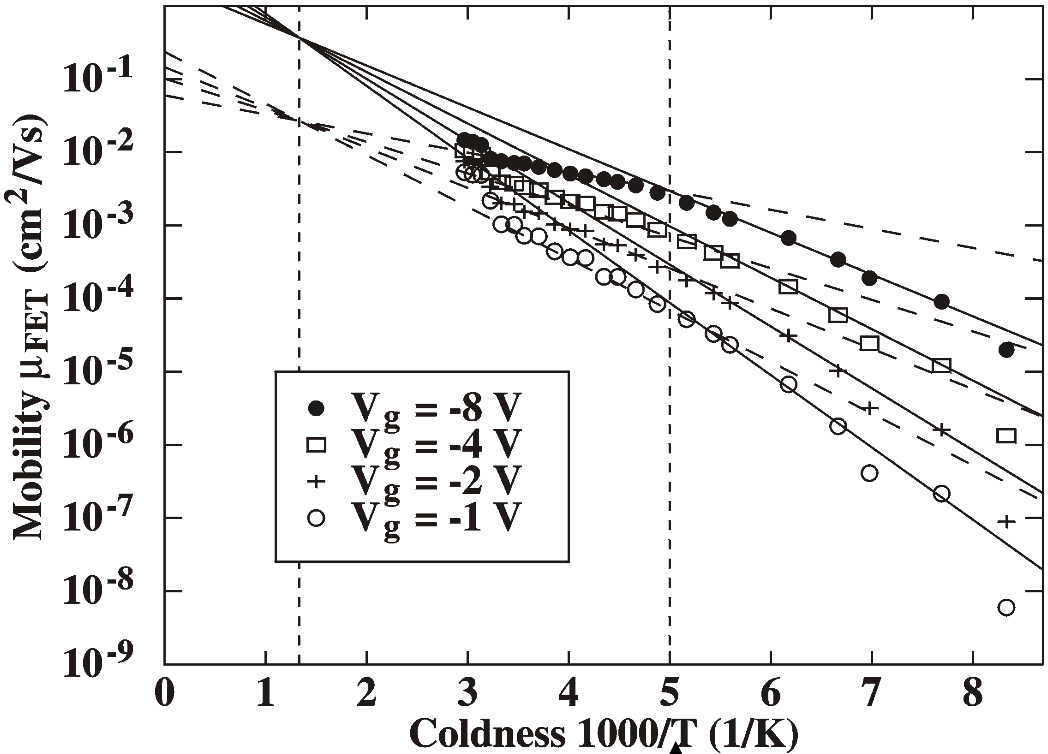
Processes	Parameter	Devices/materials
current	gas concentration	α-Si
diffusion*	pressure	organic ½cons
ionic currents	electrical bias	gas detectors
		High-Tc supercons
		glasses
		liquid ½cons
		polycryst. Si
		CCDs

All less-than-perfect-crystalline materials

* Here the MNR is called the Compensation Effect.

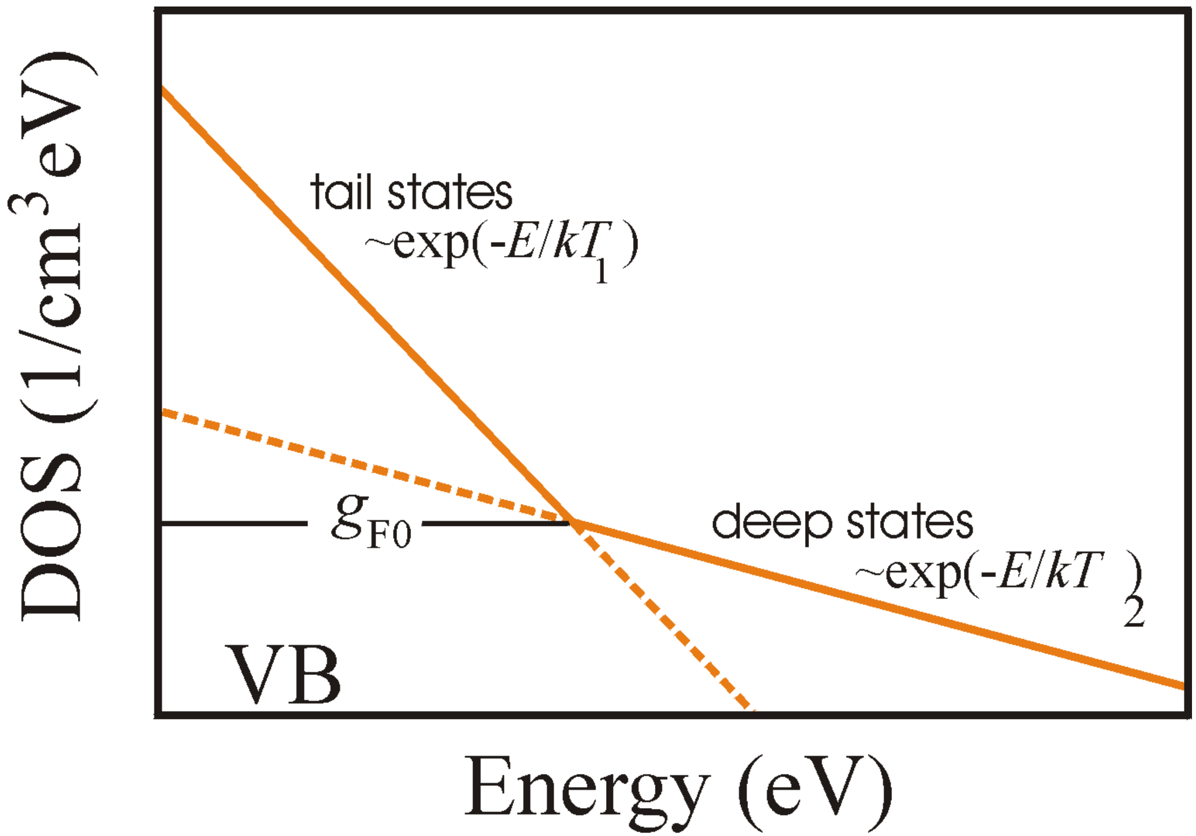
Meyer-Neldel Rule in T6 TFT





Phase transition (?) at 200 K

Amorphous silicon: Shur & Hack



* Original article: M. Shur and M. Hack, J. Appl. Phys. **55**, 3831 (1984).

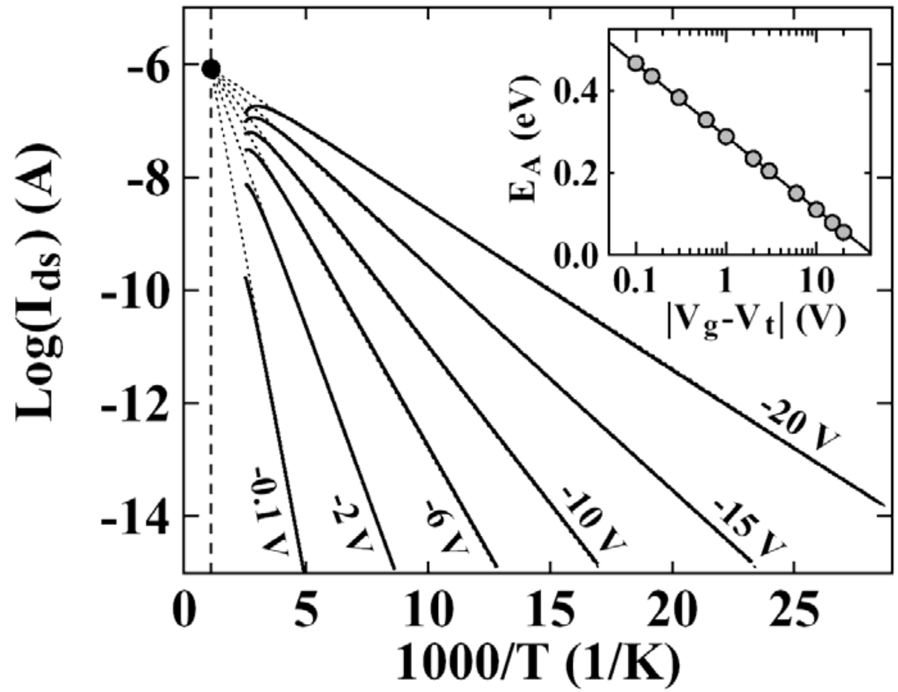
Shur & Hack

$$I_{\rm ds} = \frac{q\mu_0 W}{L} f\left(T,T_2\right)\left[C_{\rm ox}\left(|V_{\rm g}-V_t|\right)\right]^{\left(\frac{2T_2}{T}-1\right)} V_{\rm ds} \qquad (53)$$

$$f(T,T_2) = N_{\rm V}\exp\left(\frac{-E_{F0}}{kT}\right)\frac{kT\epsilon}{q}\left(\frac{\sin(\pi T/T_2)}{2\pi\epsilon T_2 kT g_{F0}}\right)^{T_2/T} \qquad (51)$$

Simulation FET+traps

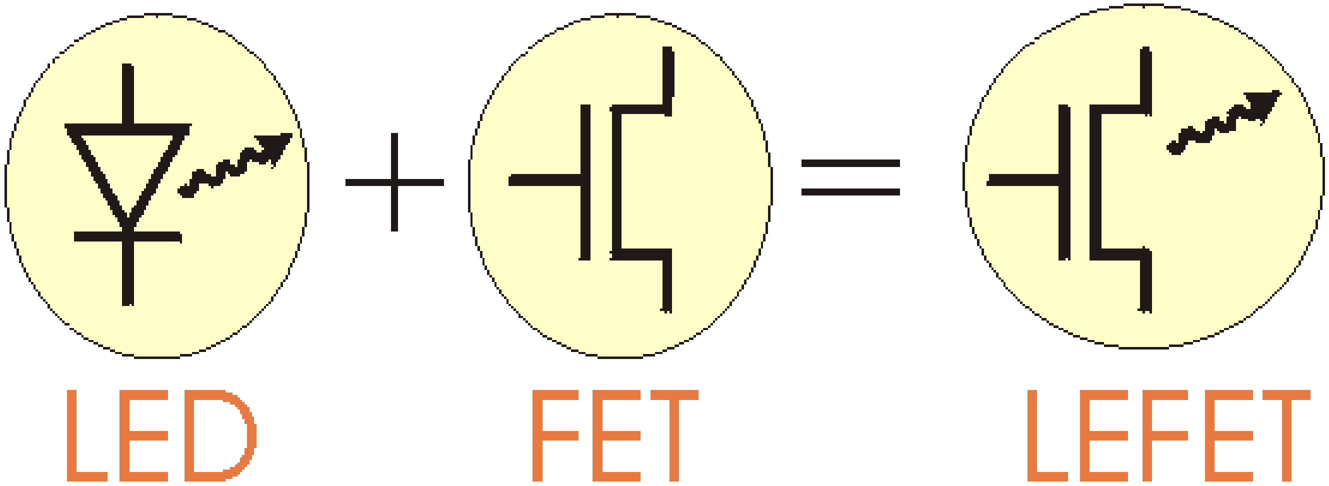
Parameter	value	unit
N_V	10^{19}	cm^{-3}
C_{ox}	$1.92\ 10^{-4}$	F/m^2
E_{F0}	484	meV
V_{ds}	-0.1	V
g_{F0}	10^{16}	$cm^{-3}eV^{-1}$
T_2	450	K
W	1	cm
L	30	μm
μ_0	3	$cm^2V^{-1}s^{-1}$
ϵ	$5\epsilon_0$	



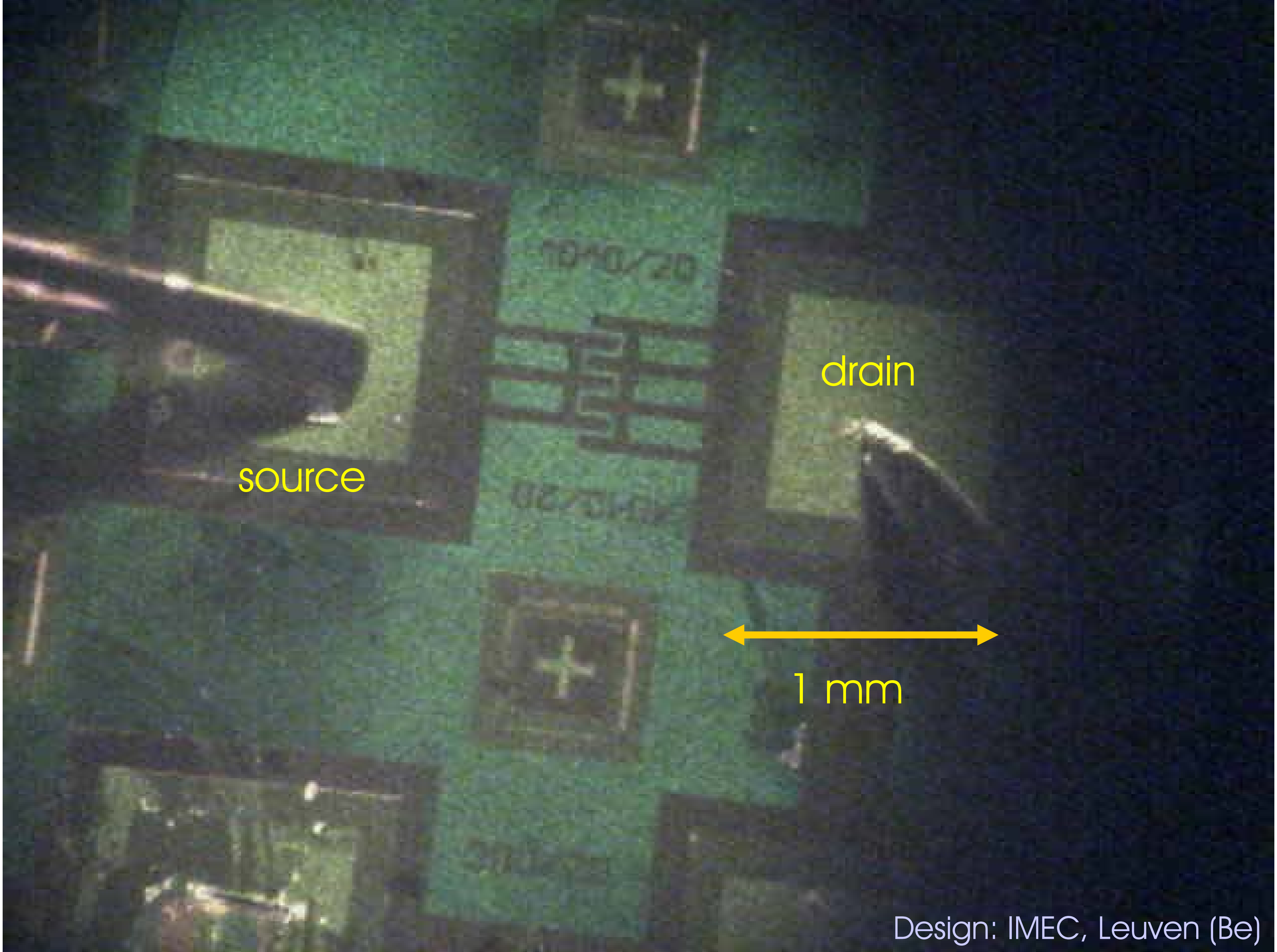
Note: No measurements possible at/close to T_2 (currents drop and diverge).

P.Stallinga, H.L. Gomes, accepted Org. Electr. (2005)

Light-emitting FET



A light-emitting field-effect transistor would be useful. It would eliminate the need for a separate LED and thus reduce the number of processing steps in the fabrication of an active-matrix display.


drain
source
1 mm
Design: IMEC, Leuven (Be)

You are looking at the first picture ever taken showing light coming out of an FET … (Bologna, 2003)

C. Santato *et al.*, Synth. Metals **146**, 329 (2004)

OptoEl Projects

Electrical characterization of novel electronic materials

Sensors and actuators

Scientific instrumentation

Need for a reliable and cheap sensor.

… so many mines to be deleted from this planet.

Why use an organic FET for a TNT sensor?

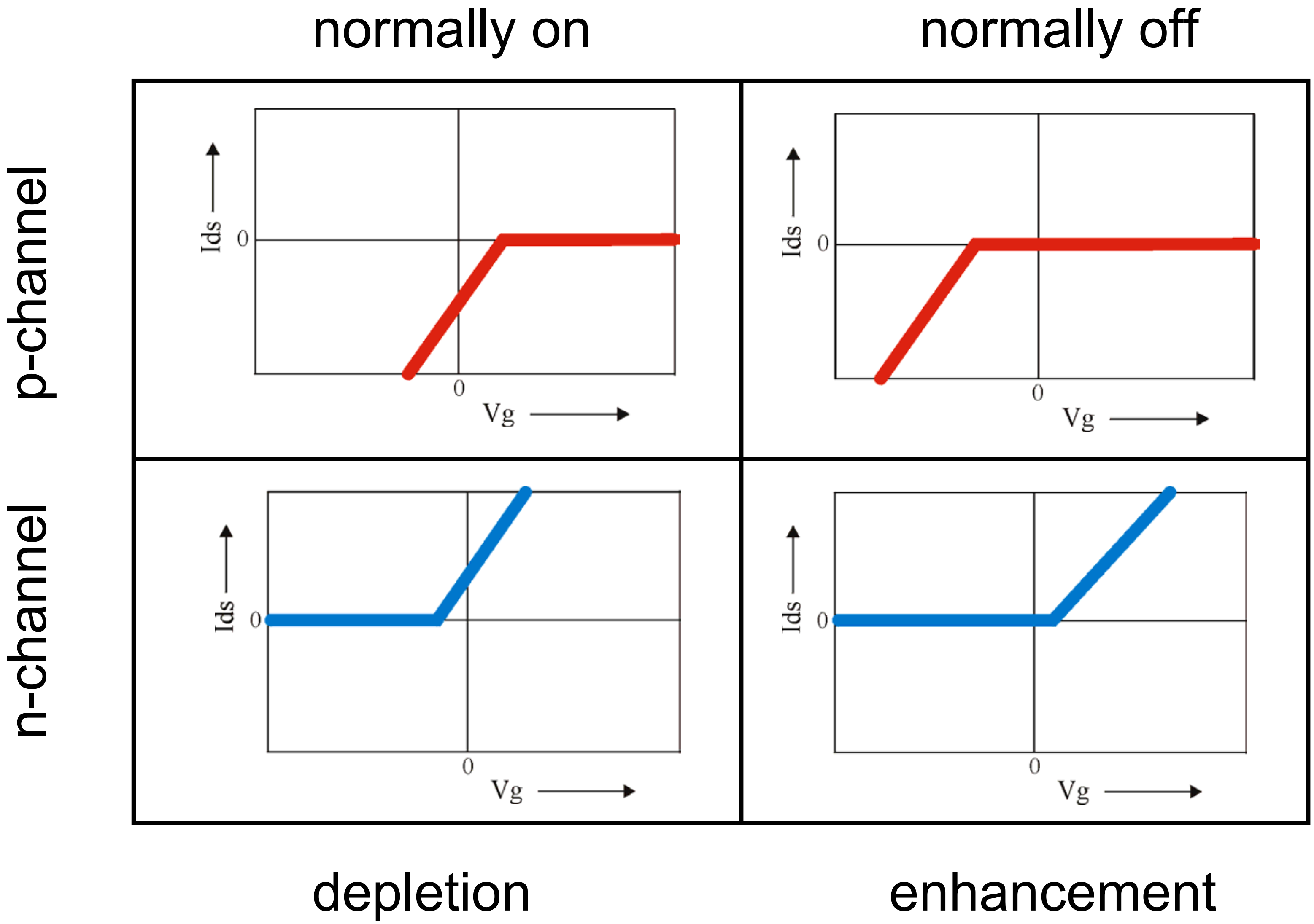
FETs are multi-parametric

Organics can be functionalized easily

Organics are cheap to produce

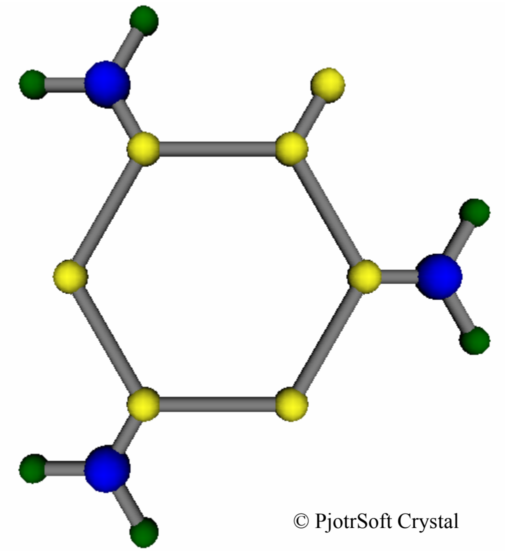
Organic Electronics are our expertise

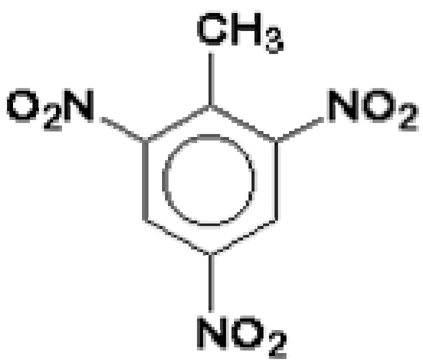
4 basic types of inversion channel FETs



S.M. Sze, Physics of semiconductor devices, p.455

The detection principle

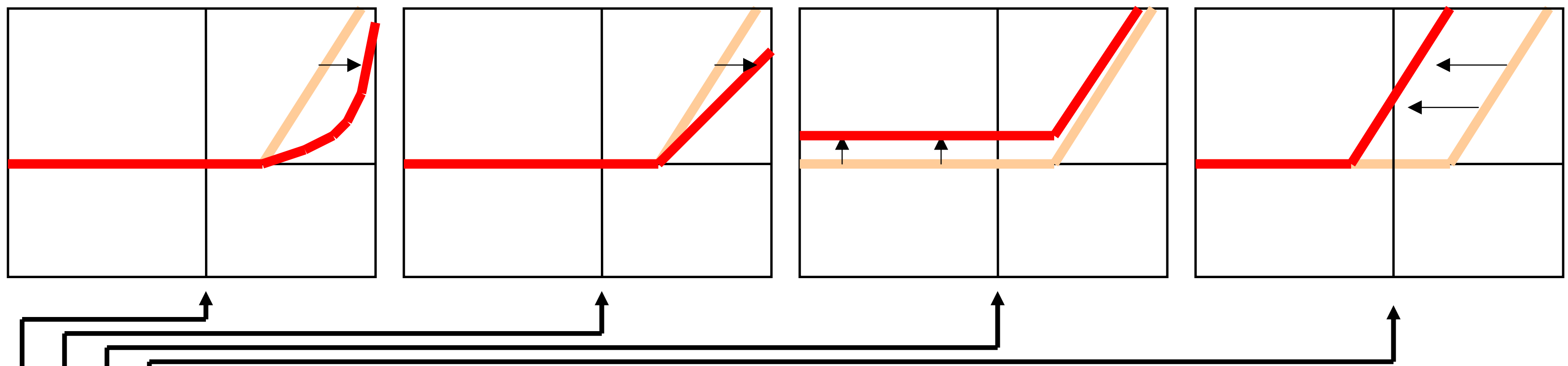




A TNT molecule is very reactive and can interact with the organic layer.

for example:
(1) stealing electrons (acceptor) or
(2) introducing deep traps or
(3) changing the charge mobility.

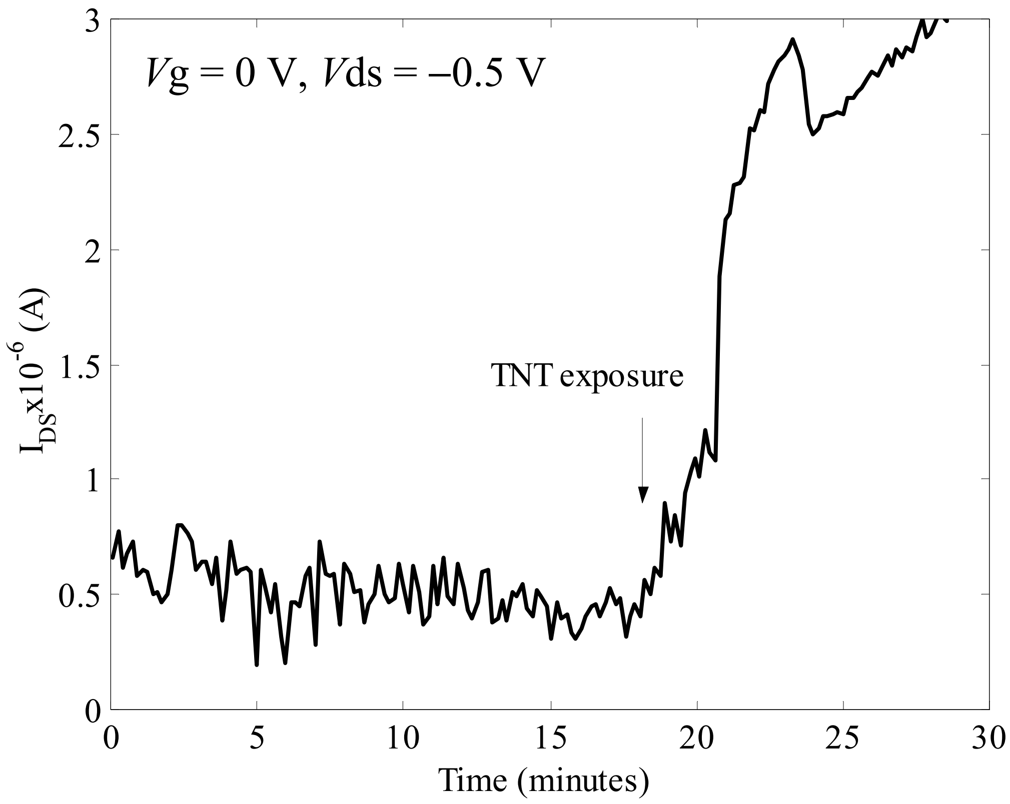
The detection principle using transfer curves



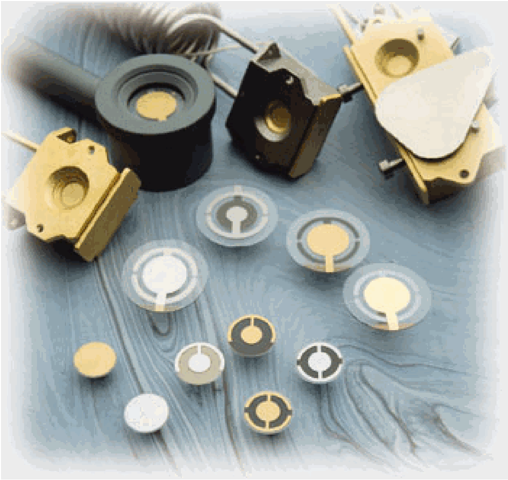
Thus, the detection is multi-parametric:

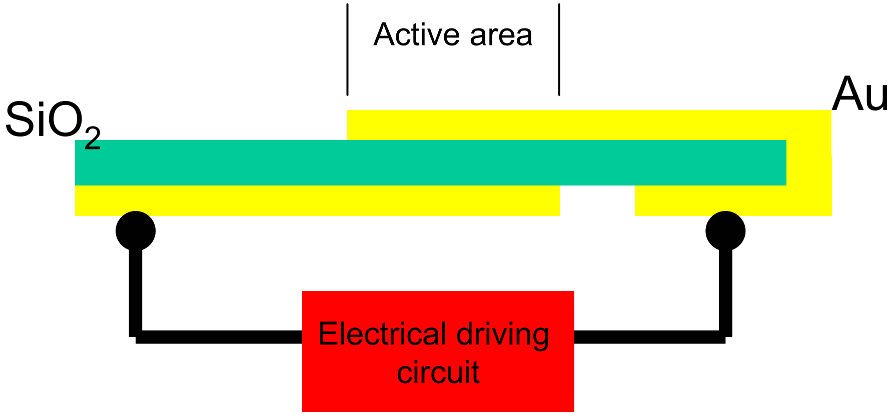
- changes in V_t
- changes in leakage current
- changes in mobility
- changes in conduction model (band conduction to hopping conduction)

Response to TNT



Organic active layer: DH4T





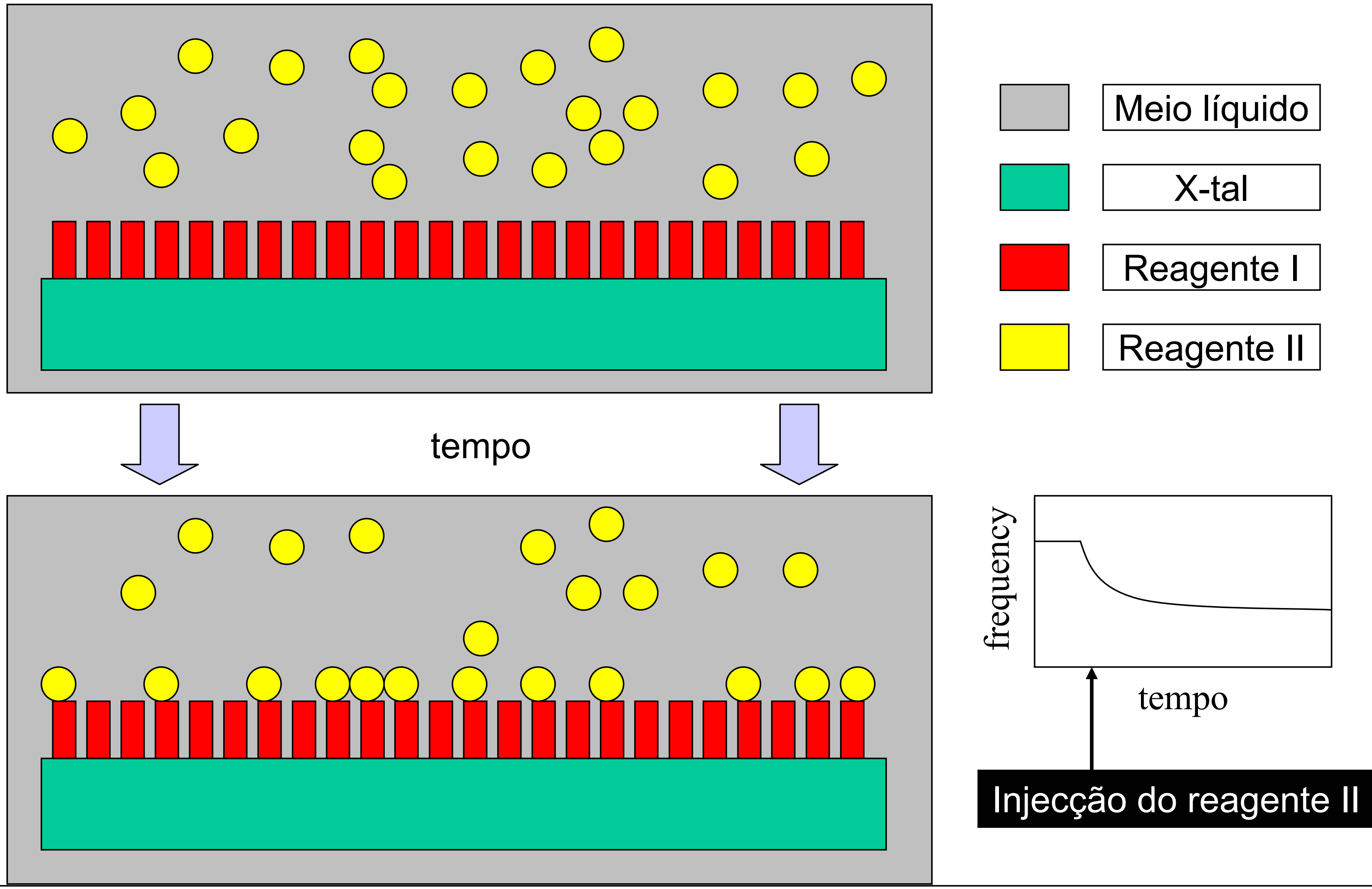
O QCM é um detector de massa. A frequência de ressonância de oscilação é uma função da massa depositada em cima do cristal. Sauerbrey:

$$\Delta f = -K\,\Delta m \qquad K = 2f_0^2 / A(\rho\mu)^{1/2}$$

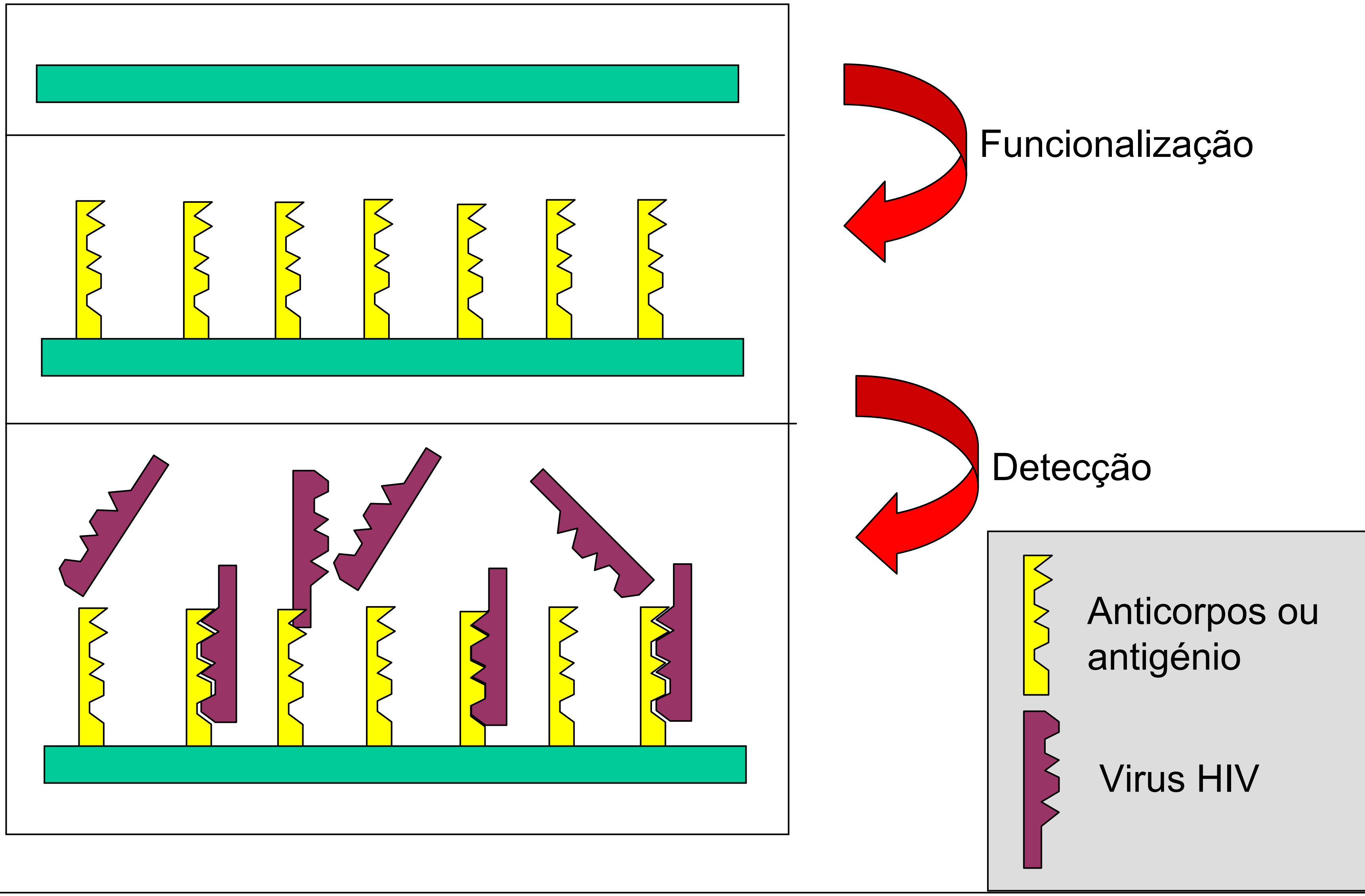
Por isso, é muito usado em medições de espessura de films, etc.

Muito sensível (exemplo standard 5 MHz cristal, 1 Hz ruido):

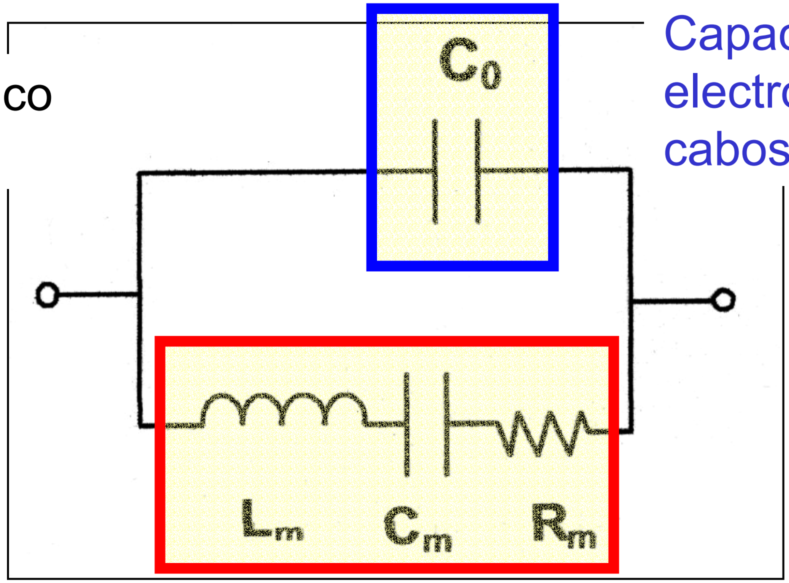
17.6 ng ou $1.77\ 10^{-7}$ kg/m^2 ou 0.35 Å ou 0.1 ML


Meio líquido
X-tal
Reagente I
Reagente II
tempo
frequency
tempo
Injecção do reagente II

II: Detector HIV



Modelo electrónico do cristal

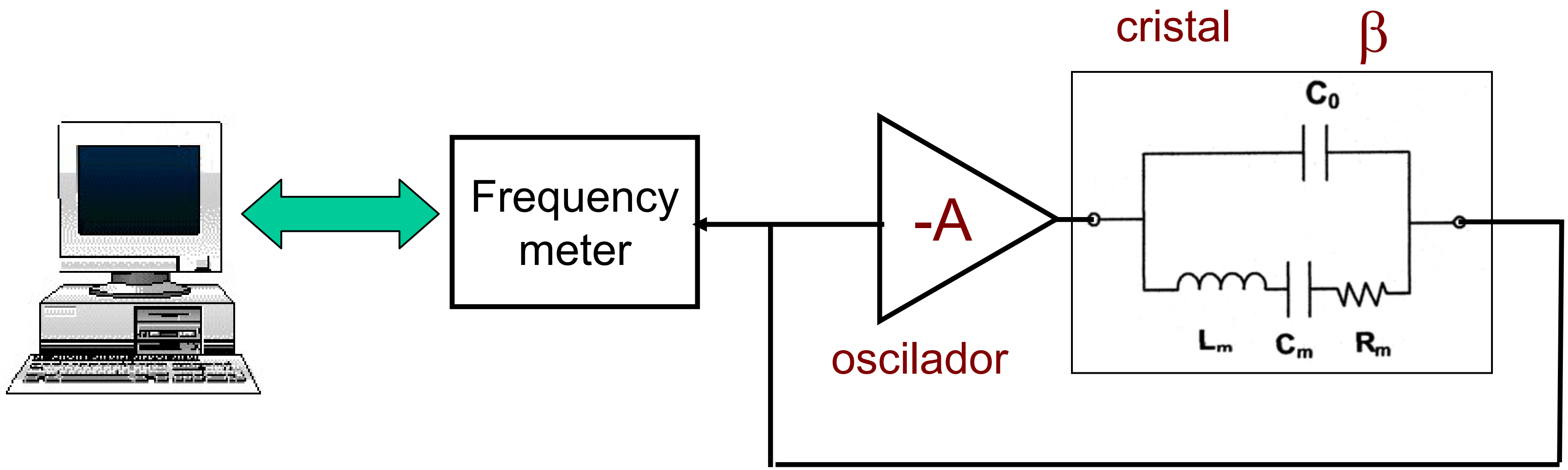


Capacitância dos electrodes paralelos e cabos

Modelo das oscilações mecánicas

Acoplamento: Piëzo-eléctrico

C_0 tem nada a ver com os processos de interesse (oscilações mecánicas) e tem de ser compensado.



Barkhausen critério: ressonância quando a fase $A\beta$ = 180º (parte imaginária 0)

$$Z(\omega) = \left(i\omega C_0 + \frac{1}{R_m + i(\omega L_m - \frac{1}{\omega C_m})} \right)^{-1}$$

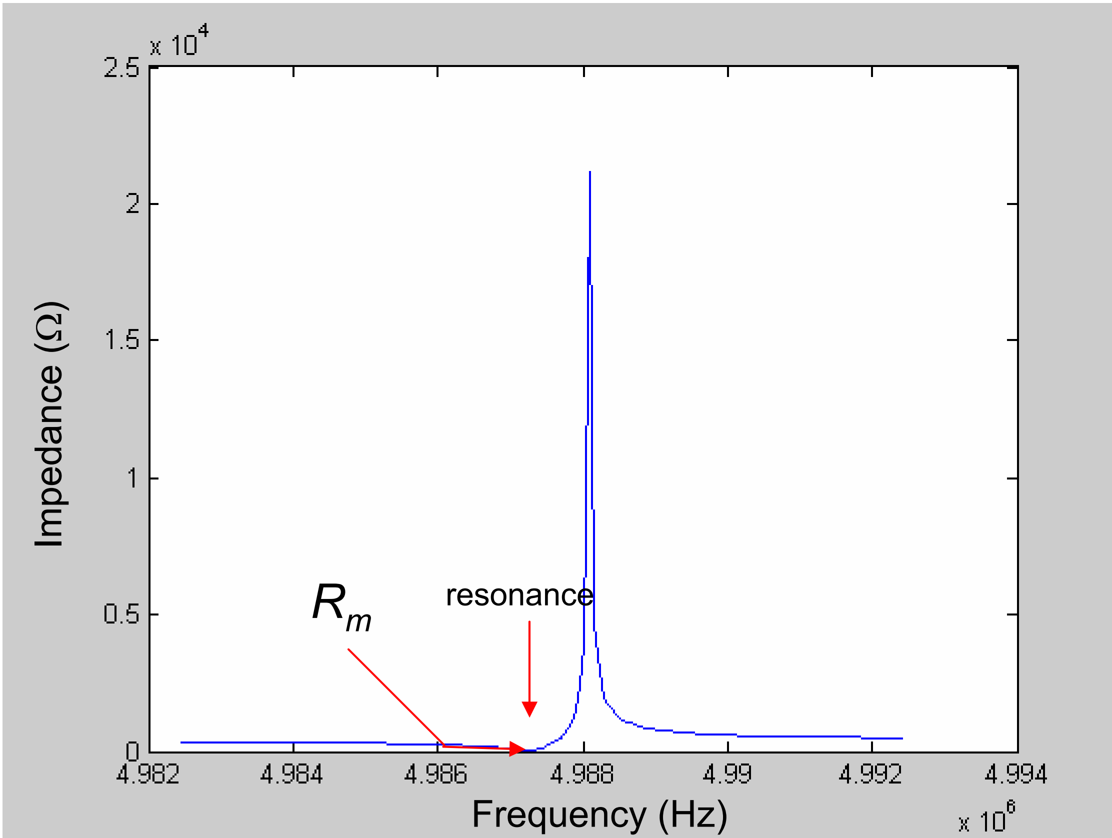
C_0 tem de ser compensado!
Neste caso:

$\omega_r = 1 / (L_m C_m)^{1/2}$

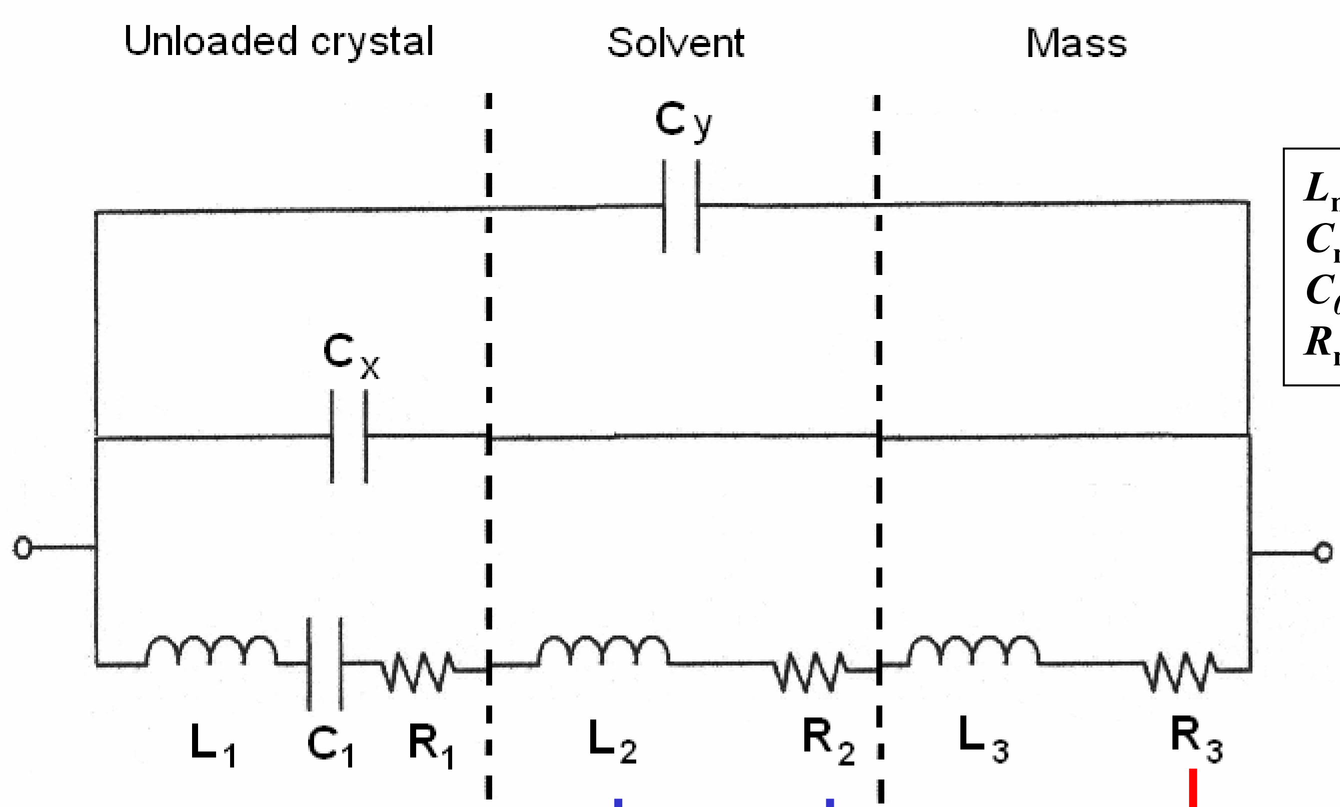
$Z_r = R_m$

Usar apenas um oscilador e um frequencímetro perda informação

Spectro do cristal obtido pelo *network analyzer*:



O uso do *network analyzer* pode dar informação suplementar



$L_m = L_1 + L_2 + L_3$
$C_m = C_1$
$C_0 = C_x + C_y$
$R_m = R_1 + R_2 + R_3$

Newtonian fluids:

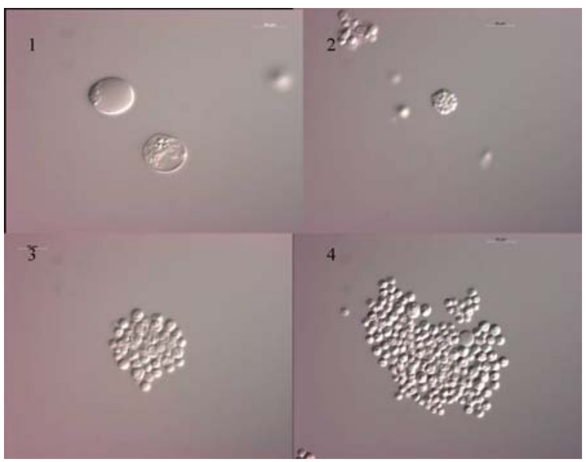
$\omega L_2 = R_2$

Rigid films

$R_3 = 0$

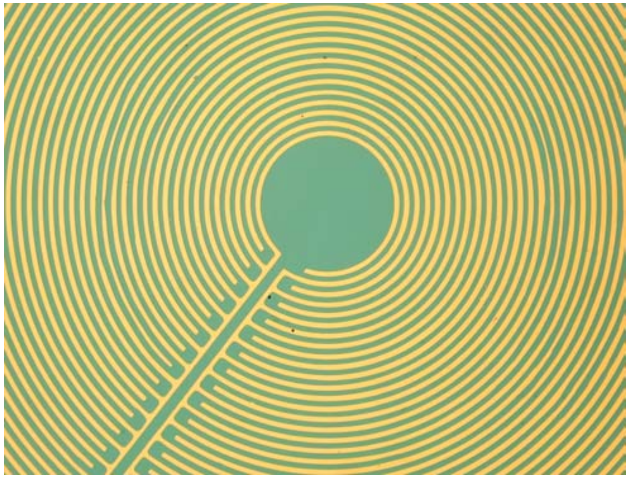
Detection of interaction of living cells

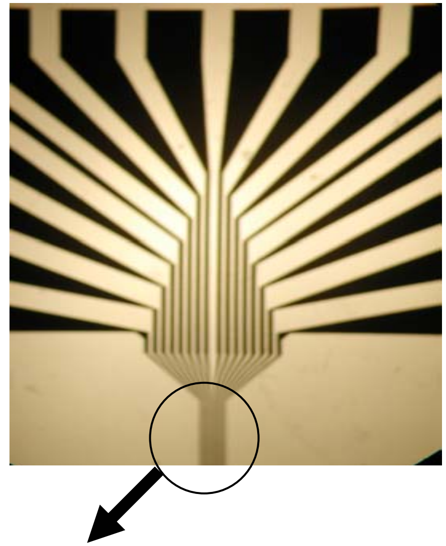
Oysters

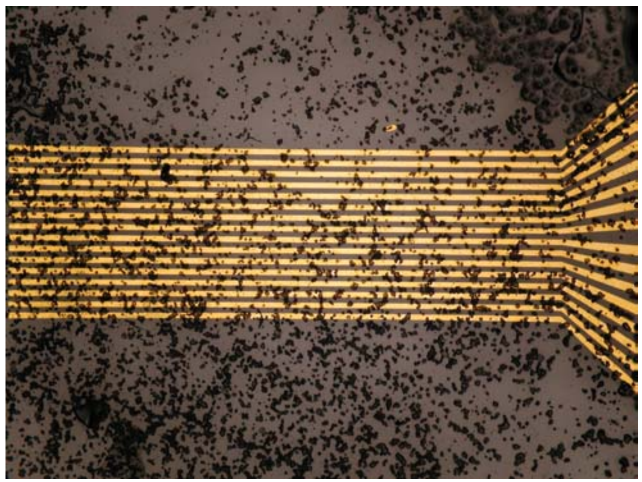


Parasites

Microelectrode array structures used





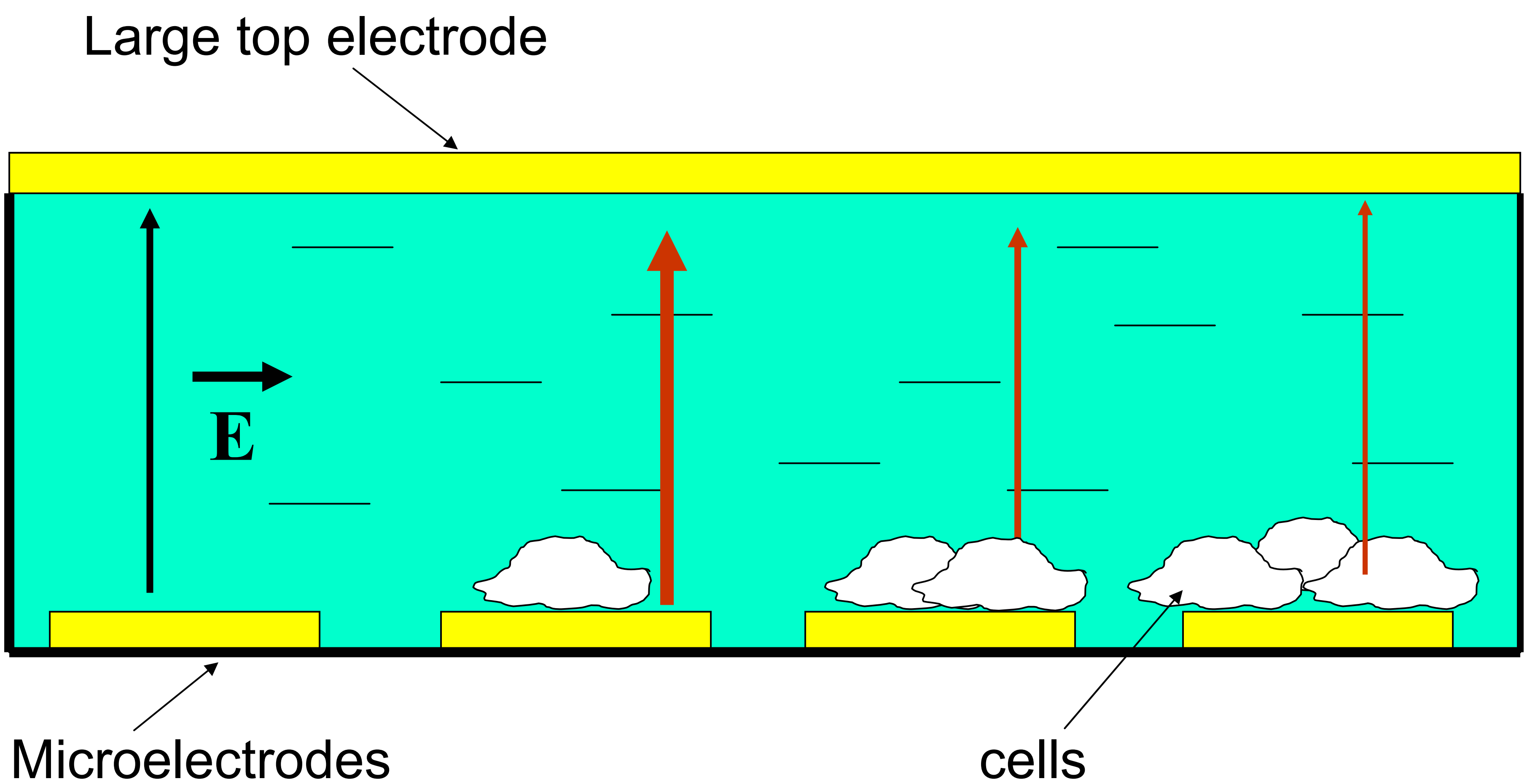


L = 2 mm

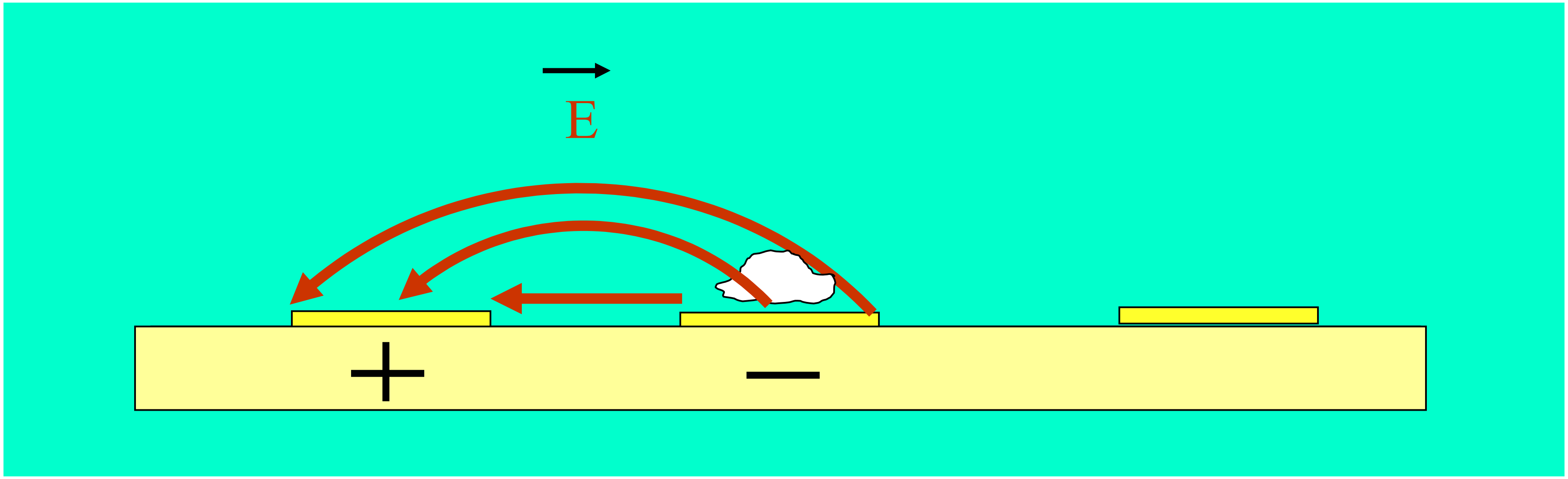
W =10-20 μm

Gap = 10-20 μm

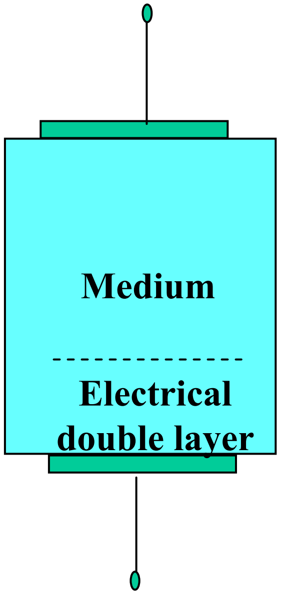
Detecting cells by measuring the impedance

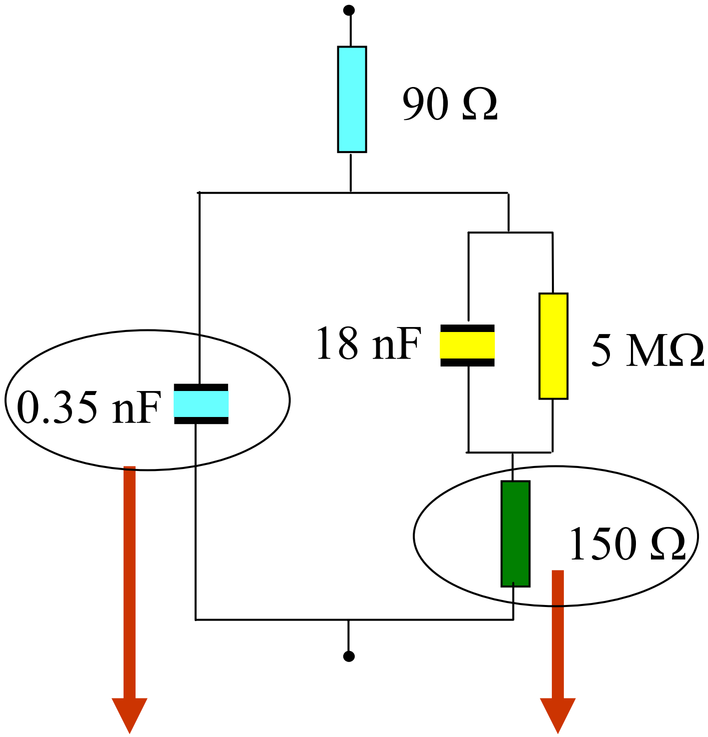


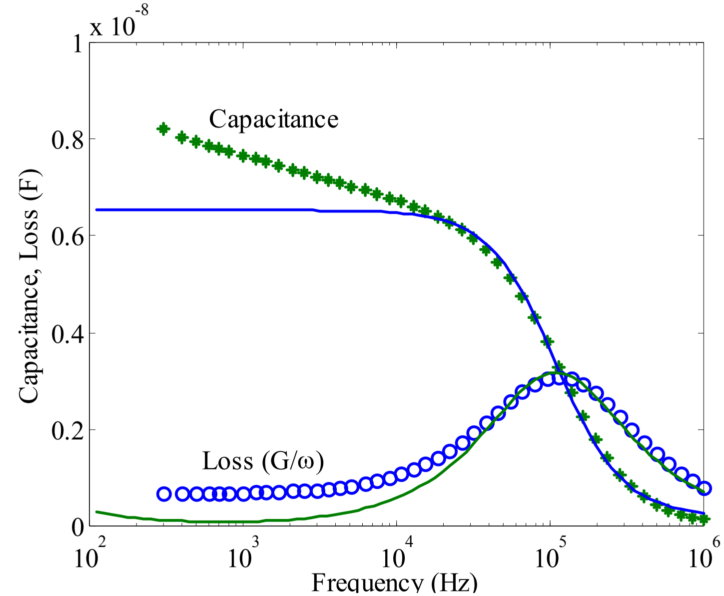
Measurements between two adjacent electrodes

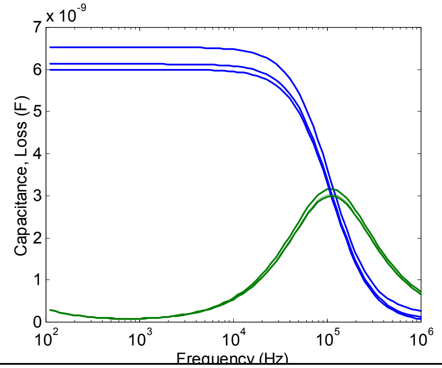


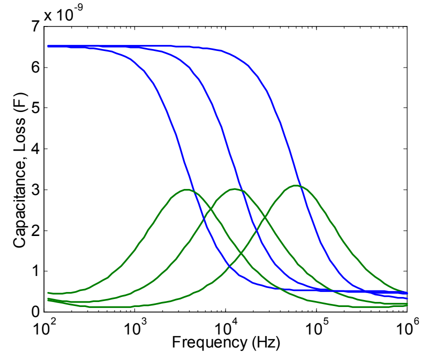
The equivalent circuit











Summary

Electrical measurements:

characterizing novel materials

characterizing novel devices

sensors

instrumentation

signal processing, modelling, etc.

Thanks to all people in the various cooperations over Europe and in Portugal.
Special thanks to Prof. Henrique Gomes, eng. Eduardo Bentes and eng. João Encarnação