Detection of explosive vapors using organic thin-film transistors

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Wien, 26 October 2004

OptoEl-CEOT in Faro

Opto-Electrónica
Univerisdade do Algarve

Centro de Electrónica,
Opto-Electrónica e
Telecomunicações

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

Faro, 6 Oct. 2004; 26 °C

Overview

Need for a reliable and cheap sensor.

… so many mines to be deleted from this planet.

Why an organic FET?

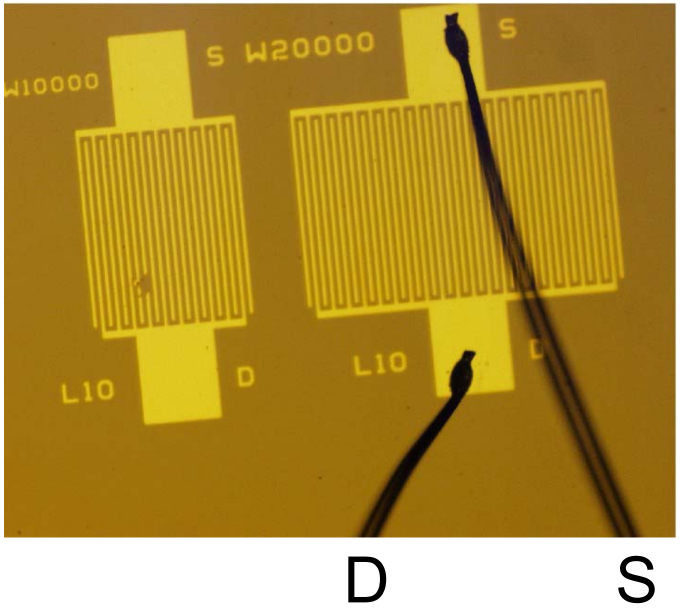
FETs are multi-parametric

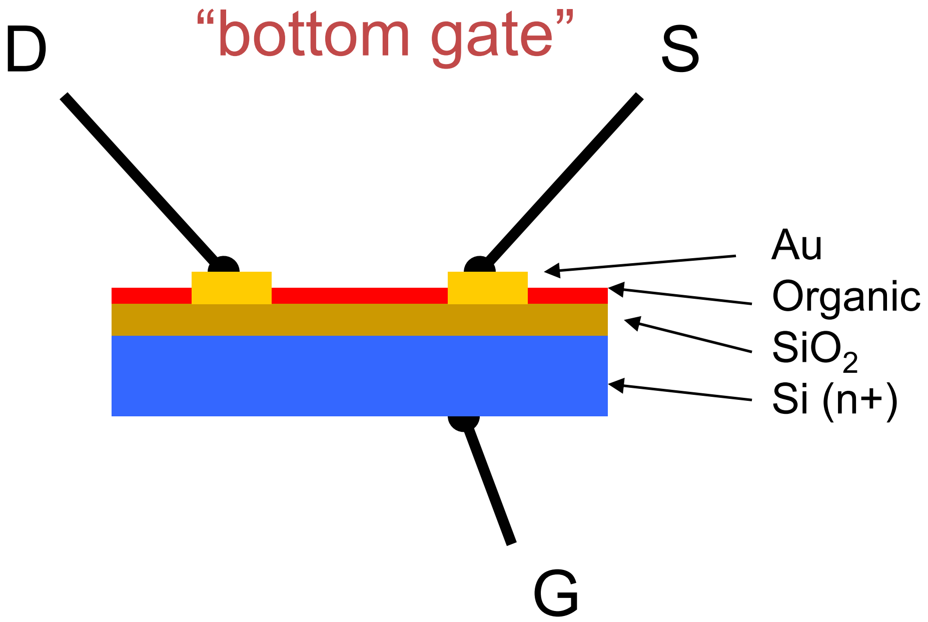
Organics can be functionalized easily

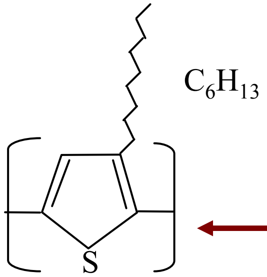
Organics are cheap to produce

Organic Electronics are our expertise

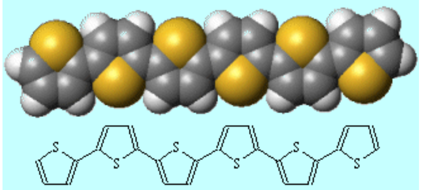
Devices

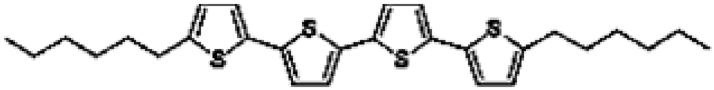




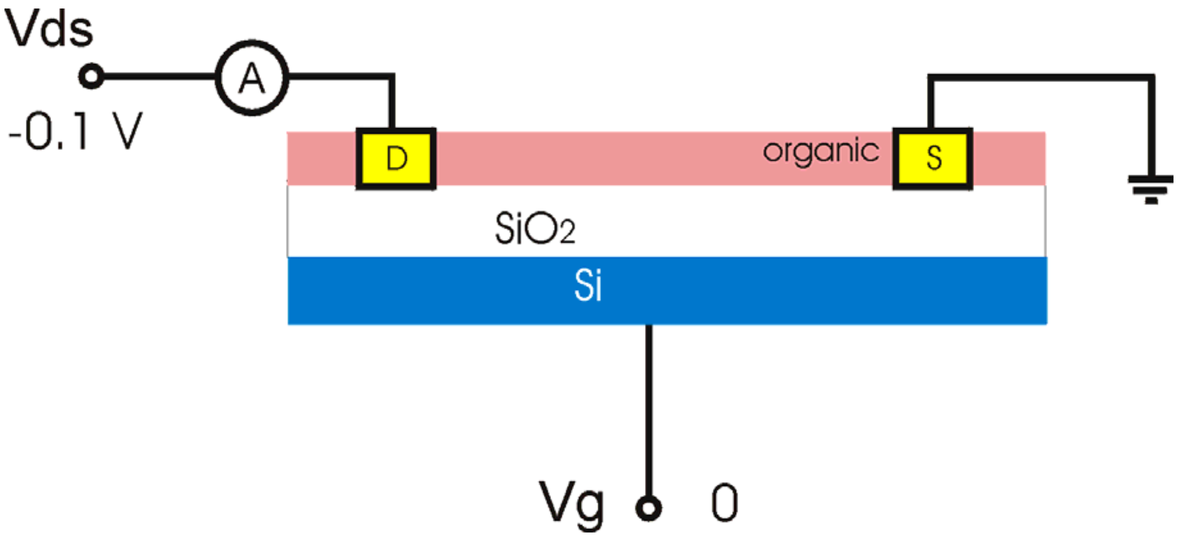


Organic layer:
sexithiophene (T6)
or PMeT or DH4T





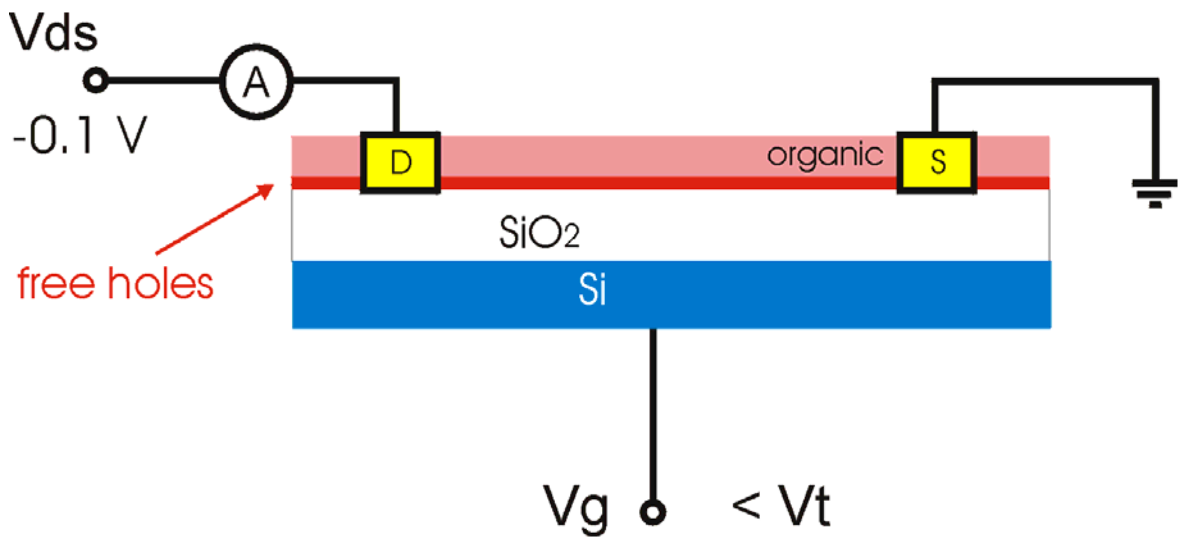
How does an FET work?



For a “normally-off hole-channel FET”, the current is zero when the gate bias is off because there are no free holes in the channel.

$Vg = 0 \longrightarrow$ channel resistivity is infinite

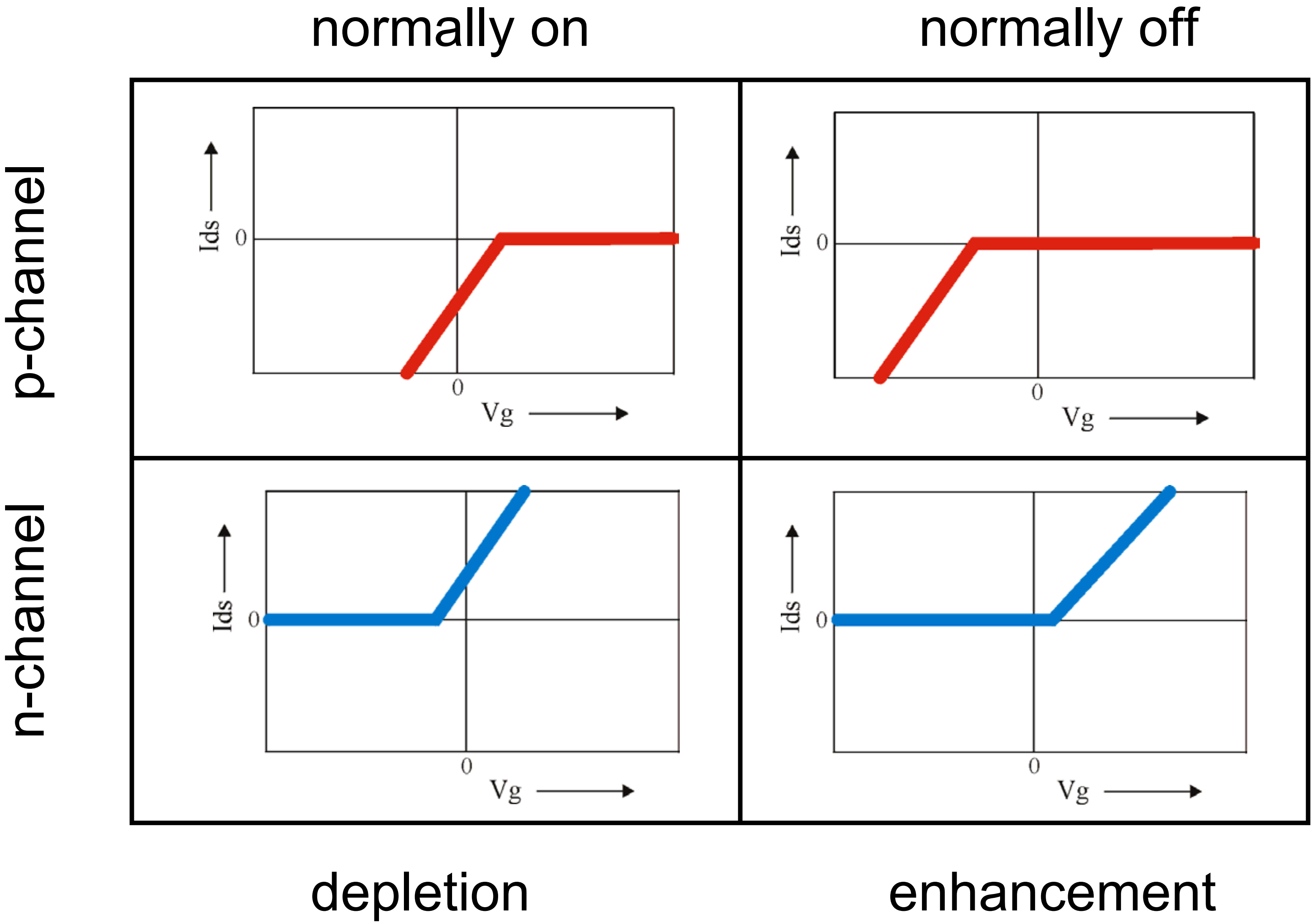
How does an FET work?



When the gate bias reaches a certain threshold voltage, a channel with free carriers is established and the channel resistivity is finite.

$$V_g > V_t \longrightarrow I_{ds} \neq 0$$

4 basic types of inversion channel FETs



normally on

normally off

p-channel

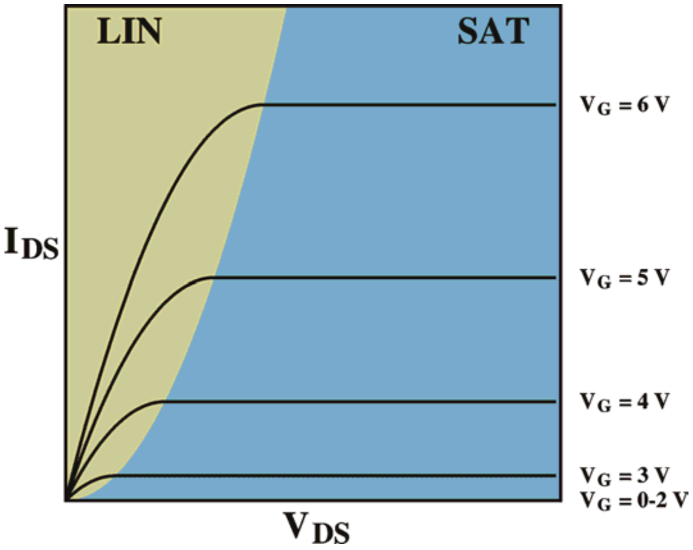
n-channel

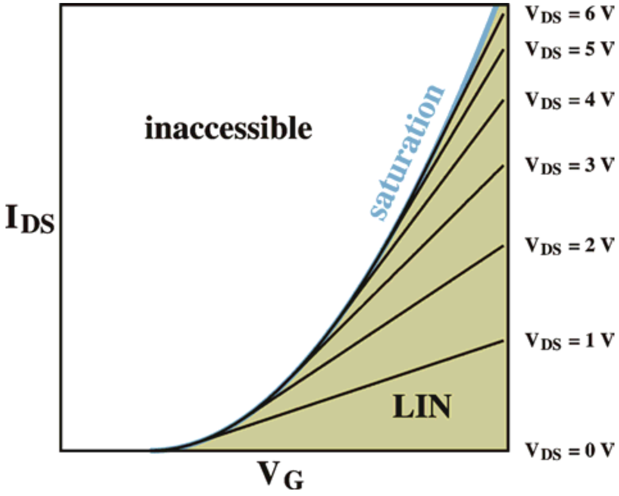
depletion

enhancement

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

Standard inversion channel FETs





LIN: 🟨 $I_{DS} = \mu(Z/L)\, C_{ox}\, [(V_G - V_T)V_{DS} - (1/2)V_{DS}^2]$

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

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

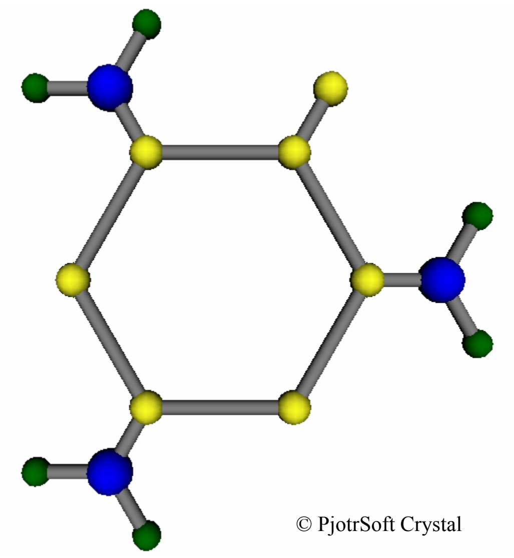
Organic FETs

Organic FETs are different:

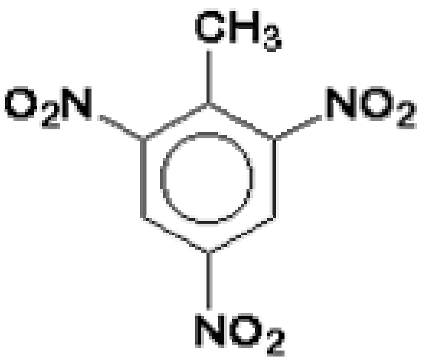
1) They are of accumulation type. $V_t = 0$.
(we cannot use textbook $V_t = V_{FB} + 2\psi_B + \sqrt{(2\varepsilon_s q N_A 2\psi_B)}/C_{ox}$)
2) Traps control the conduction processes (like in α-Si)
  a: mobility depends on in-plane field (Vds)
  b: mobility depends on transverse field (Vg)
  c: temperature activation of current (T)
  d: stressing; V_t depends on time t

our related works:
a,b,c: P. Stallinga *et al*., J. Appl. Phys., Nov. 2004.
c,d: H.L. Gomes *et al*., Appl. Phys. Lett. **84**, 3184 (2004).
b: P. Stallinga *et al*. submitted to Organic Electronics (2004)

The detection principle



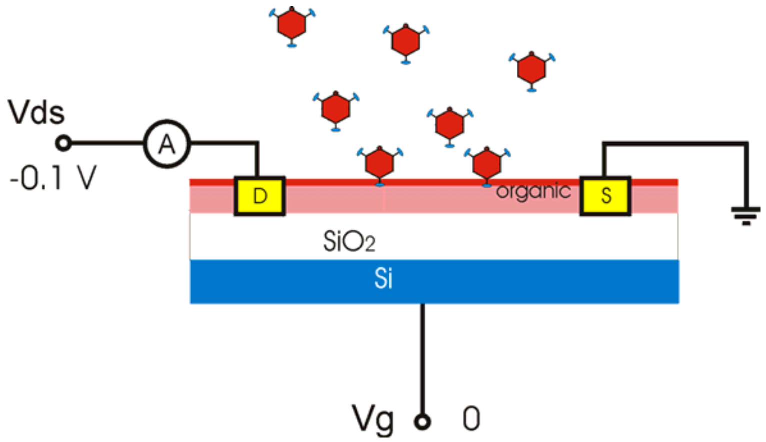
© PjotrSoft Crystal



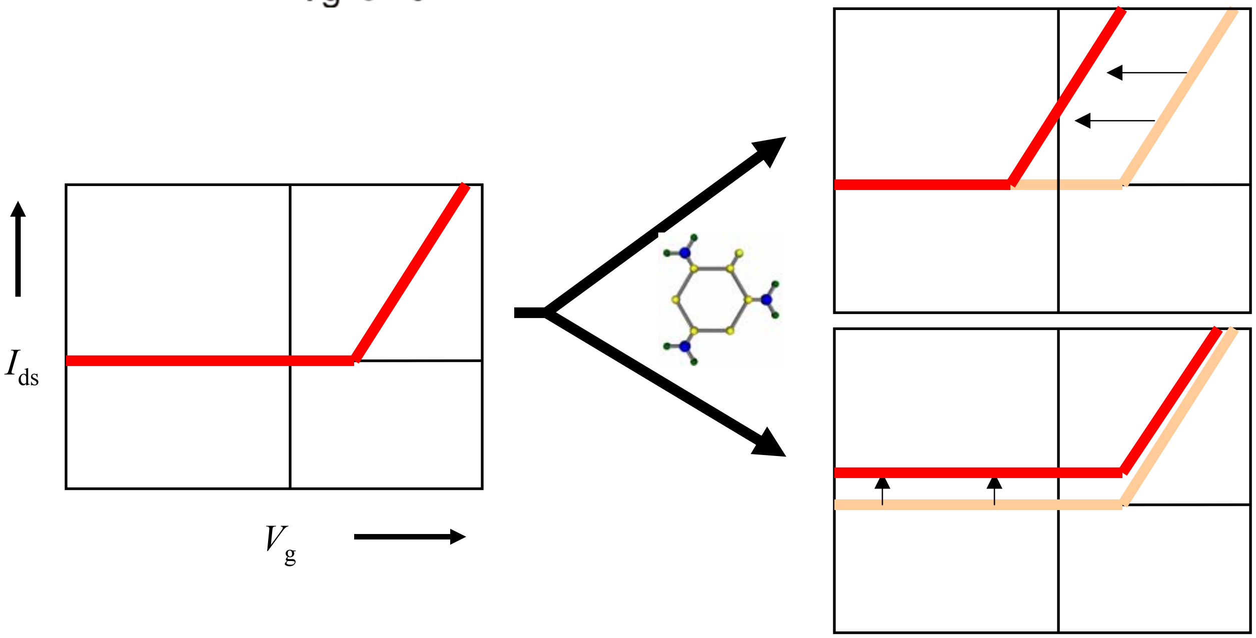
A TNT molecule is very reactive and can interact with the organic layer.

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

The detection principle

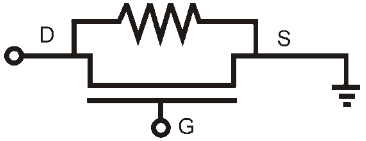


1) TNT molecules are acceptors and create new free holes in the active layer. Thus increasing the zero-bias conductivity of the channel.

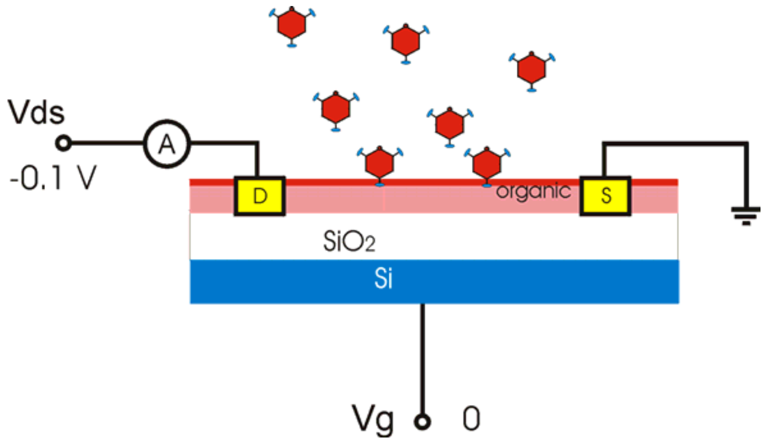


change of V_t

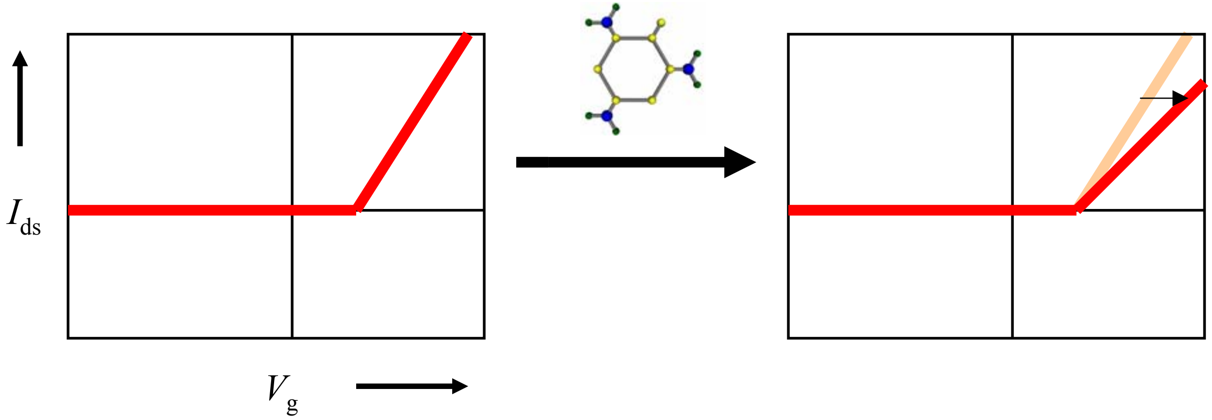
parallel conductance



The detection principle

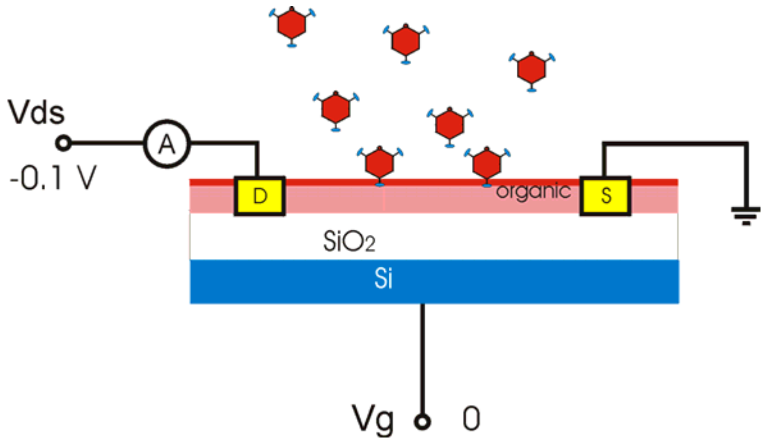


2) TNT molecules create scattering centers, thus reducing the carrier mobility μ.

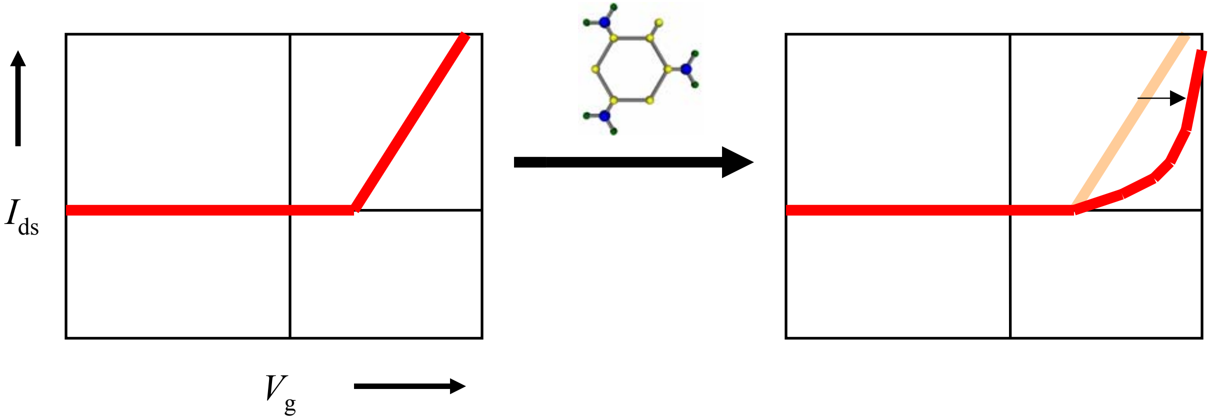


change of μ

The detection principle

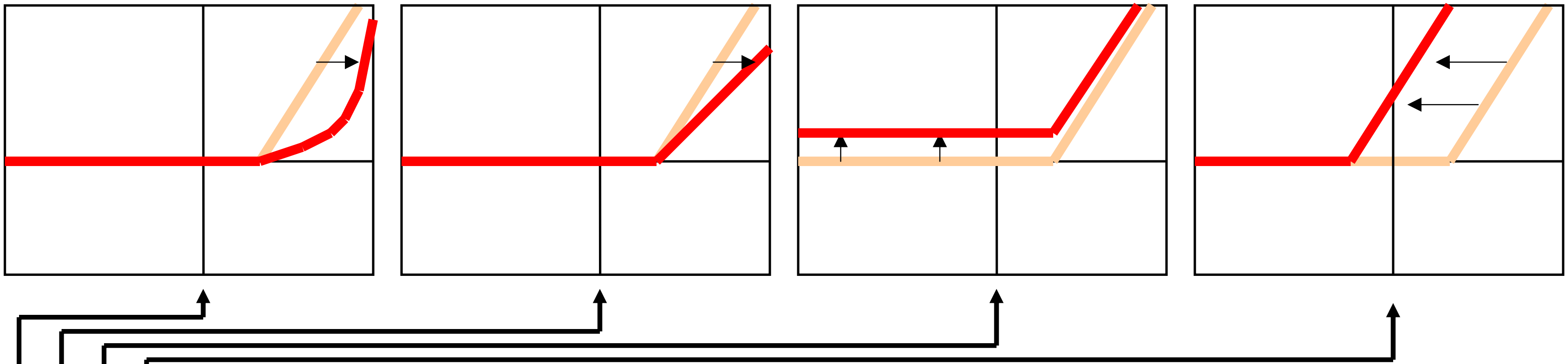


3) TNT molecules create deep traps, thus changing the conduction mechanism.



change of conduction mechanism (trap conduction)

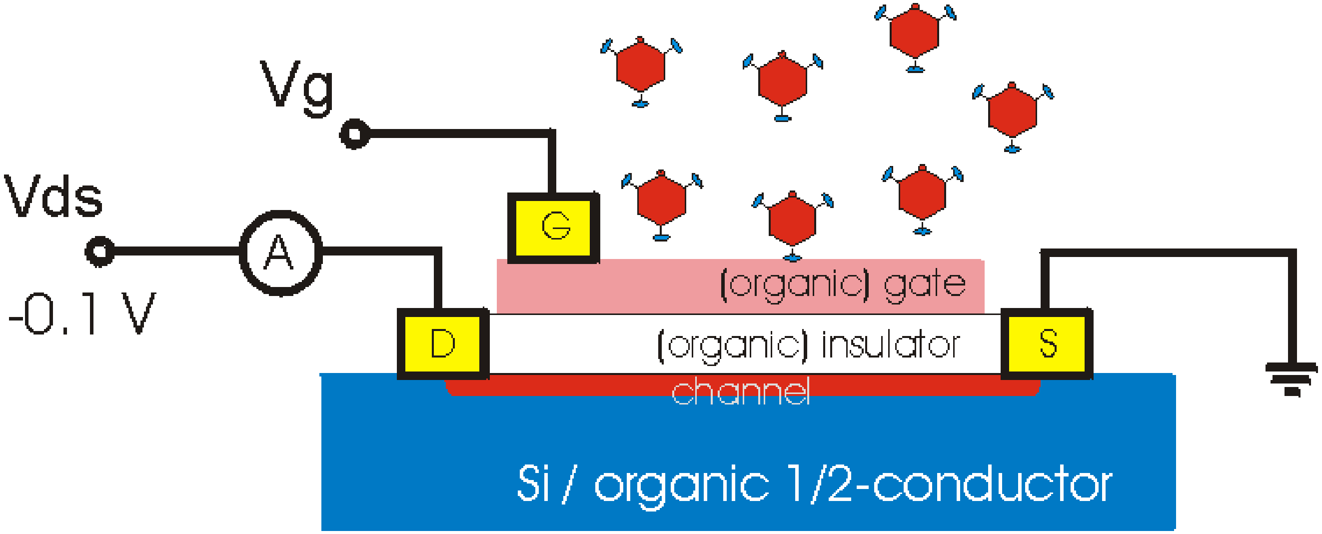
The detection principle



Thus, the detection is multi-parametric:

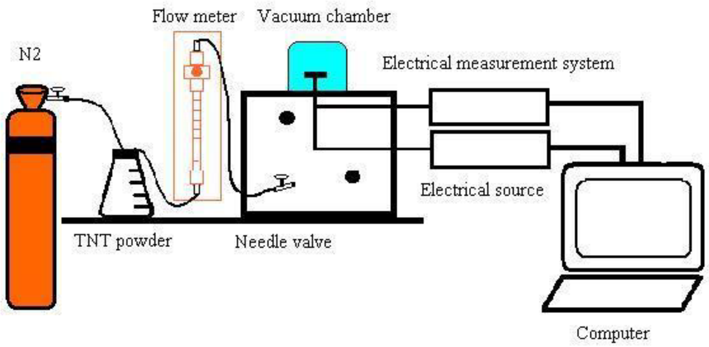
- changes in V_t
- changes in leakage current
- changes in mobility
- changes in conduction model (band conduction to hopping conduction)

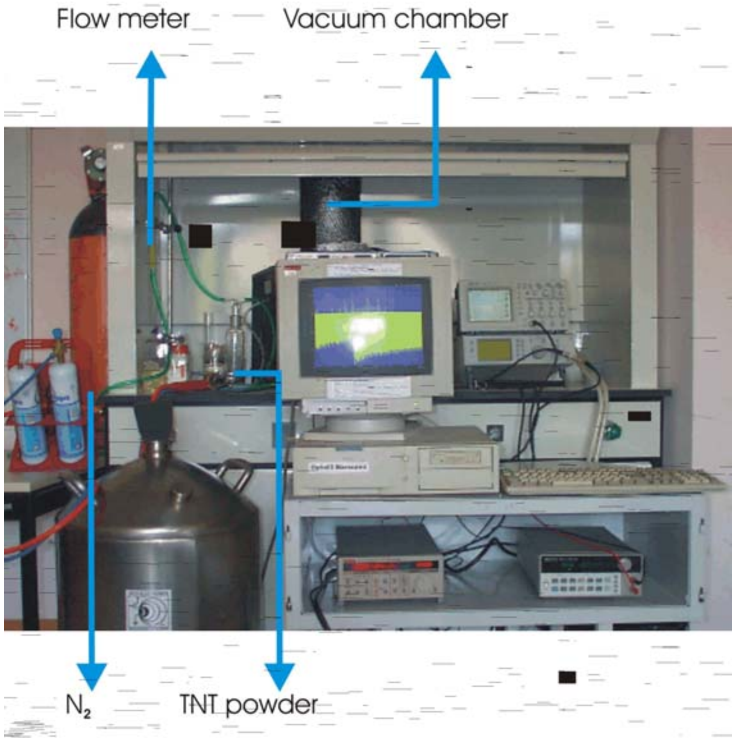
Alternative FET design



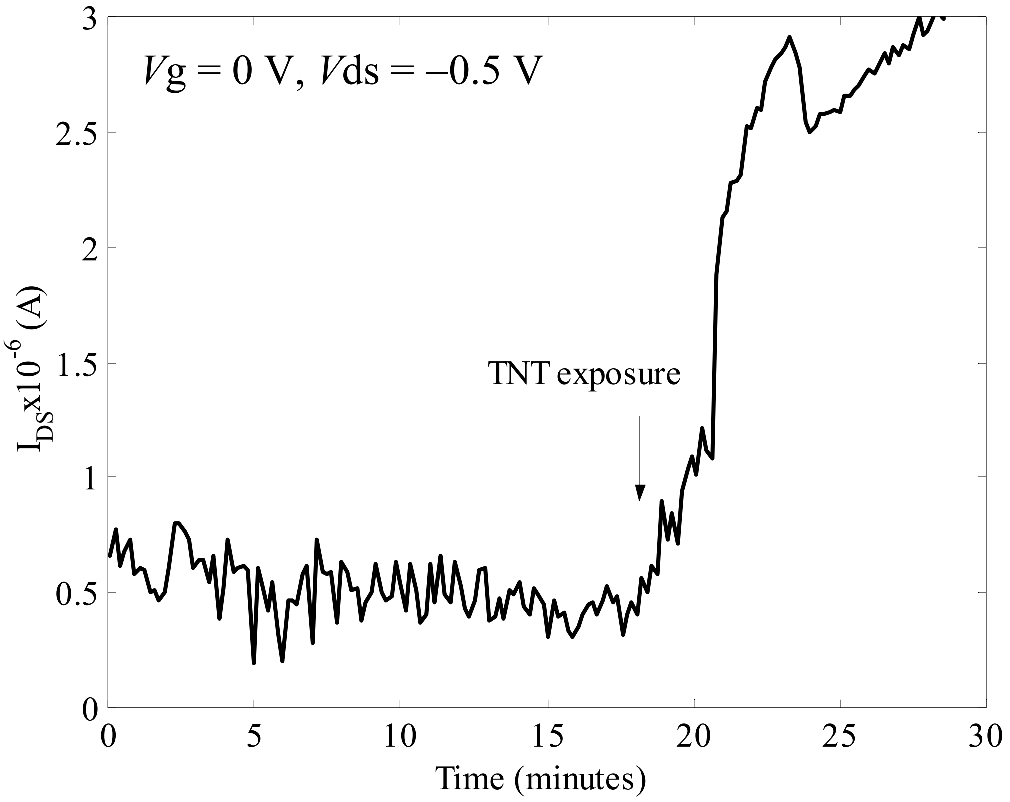
A top-gate FET design is not a good detector for neutral molecules. Poisson's equation, $E(x) = \int \rho(x)\, dx$, tells us that the field at the interface will not increase because of neutral charges. No effect on current.

Experimental set-up



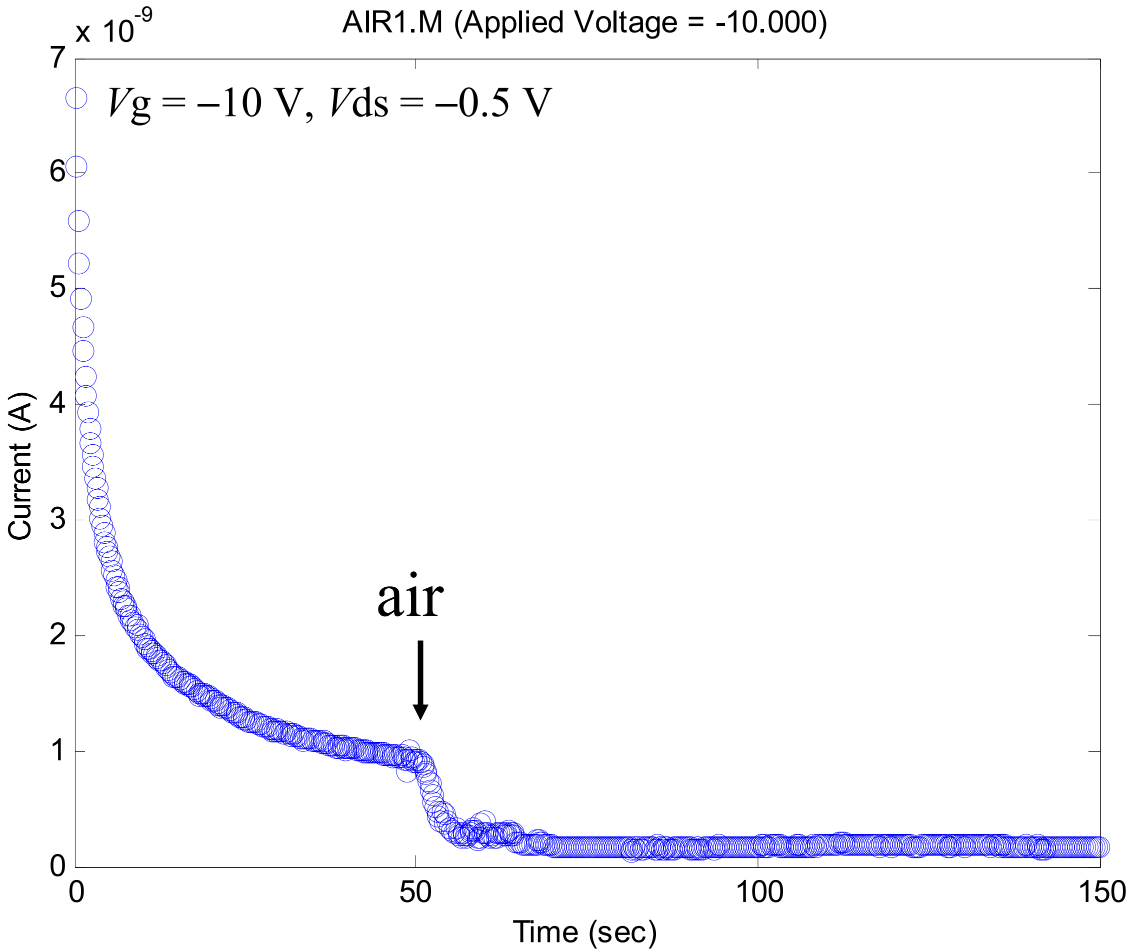


Response to TNT

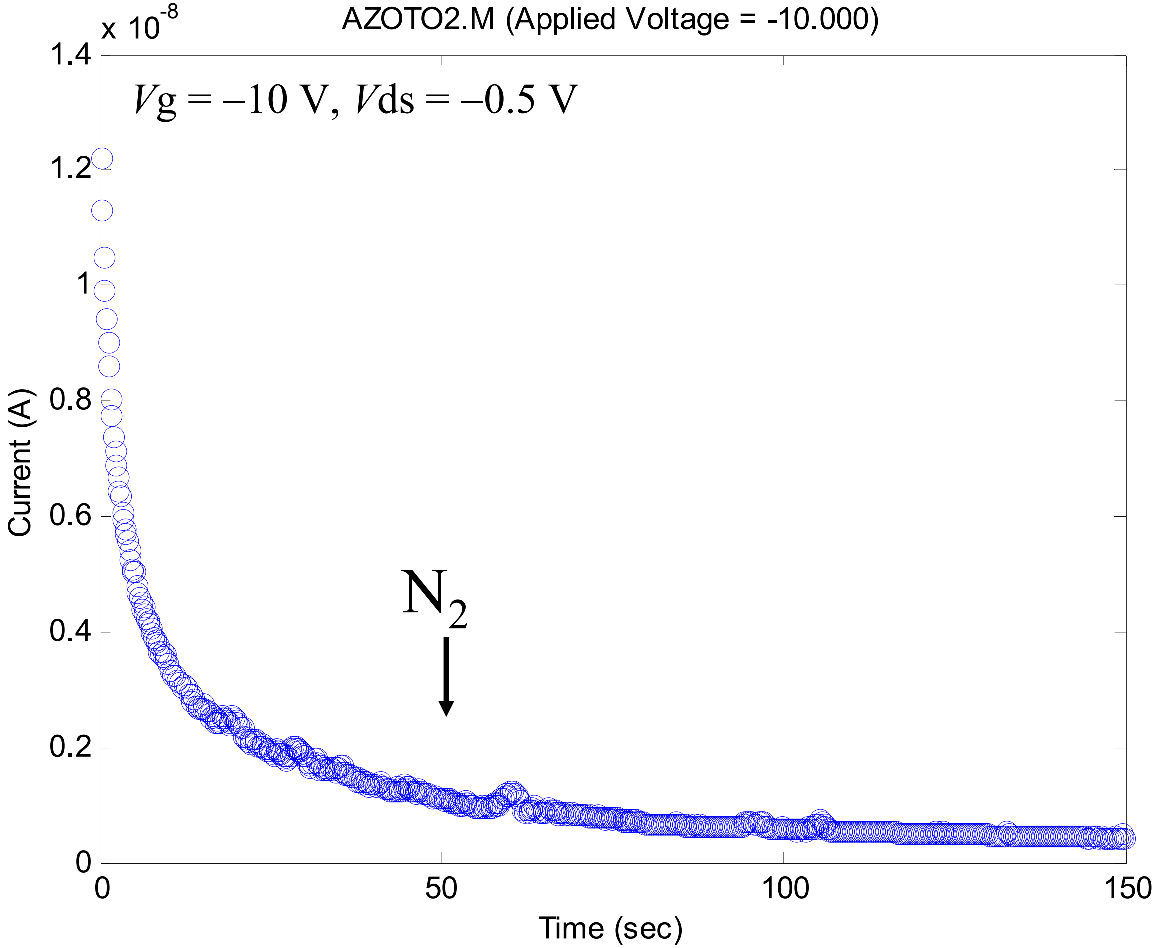


Organic active layer: DH4T

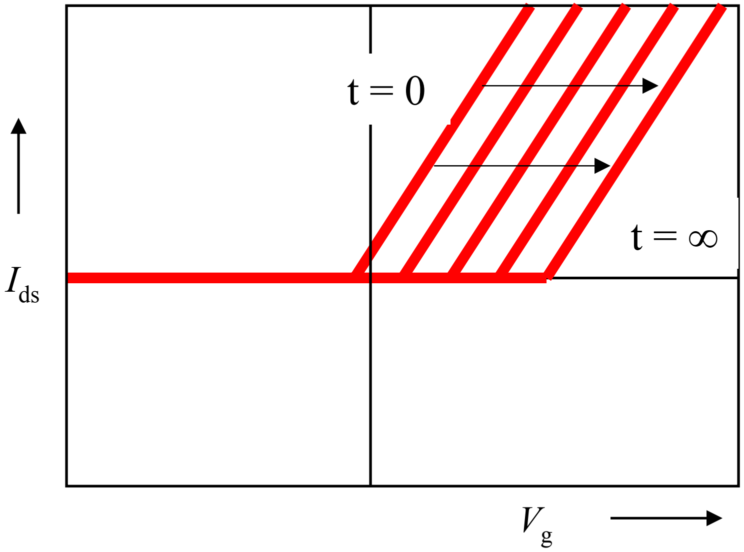
Response to air



Response to N_2

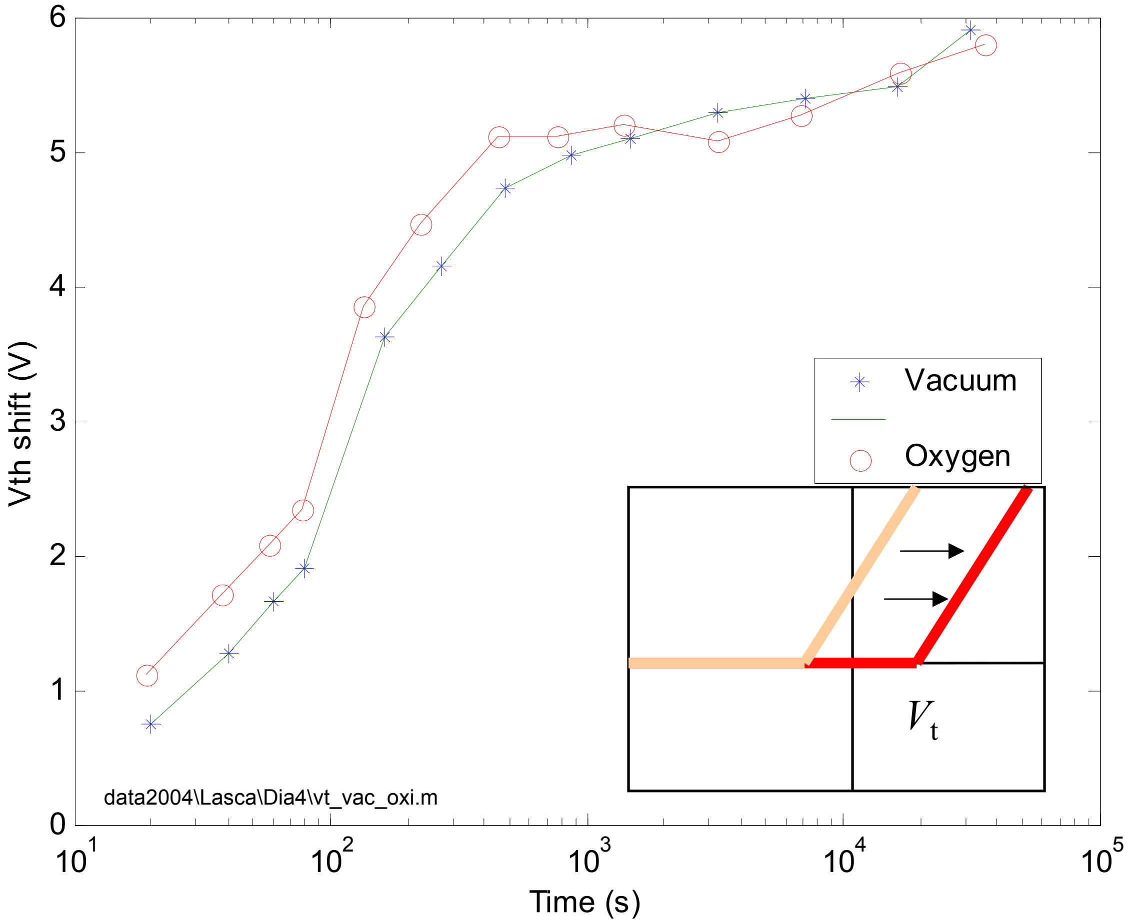


Stress



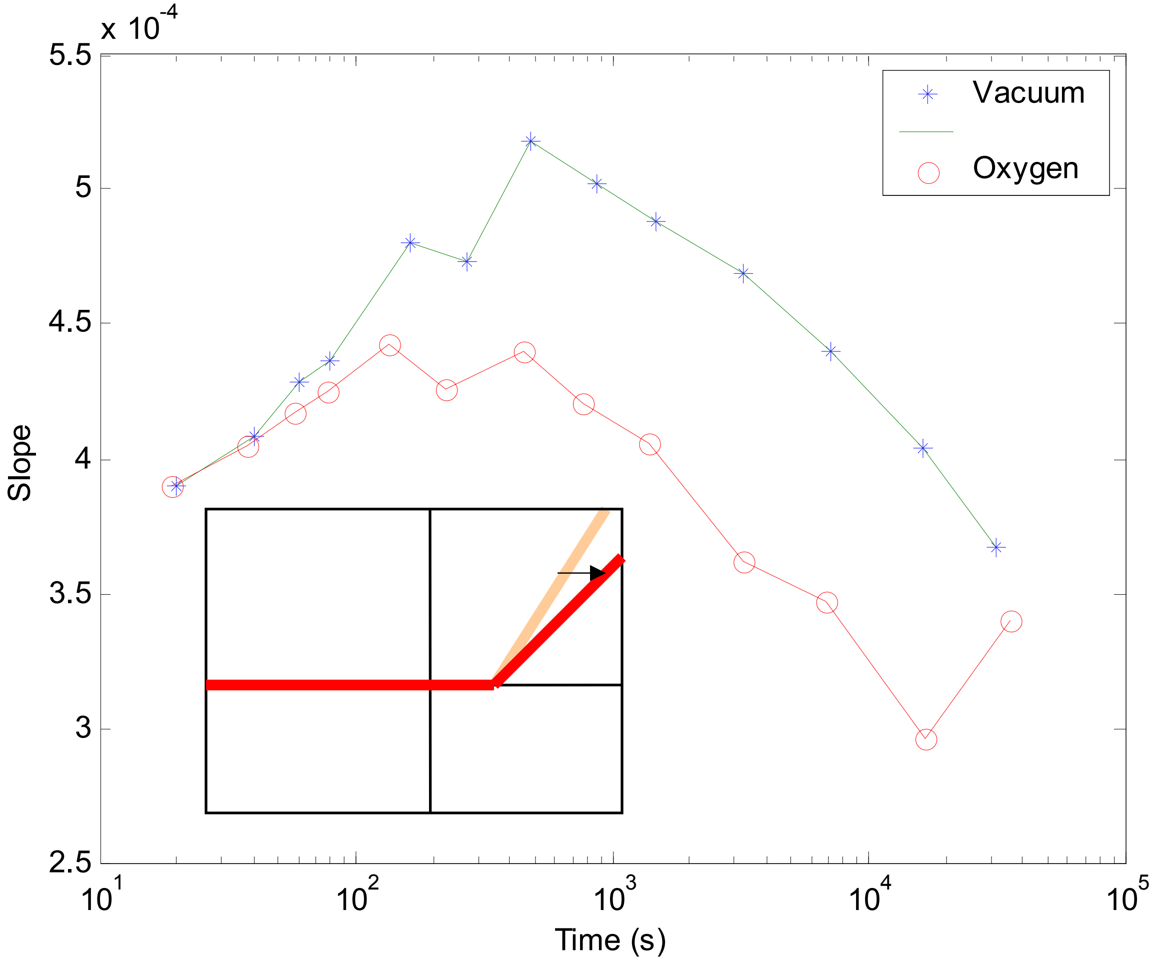
Organic FETs suffer from a phenomenon known as “stress”; a gradual increase of threshold voltage over time when (gate) bias is applied.

Response to O_2



Threshold voltage shift equal in O_2 and vacuum

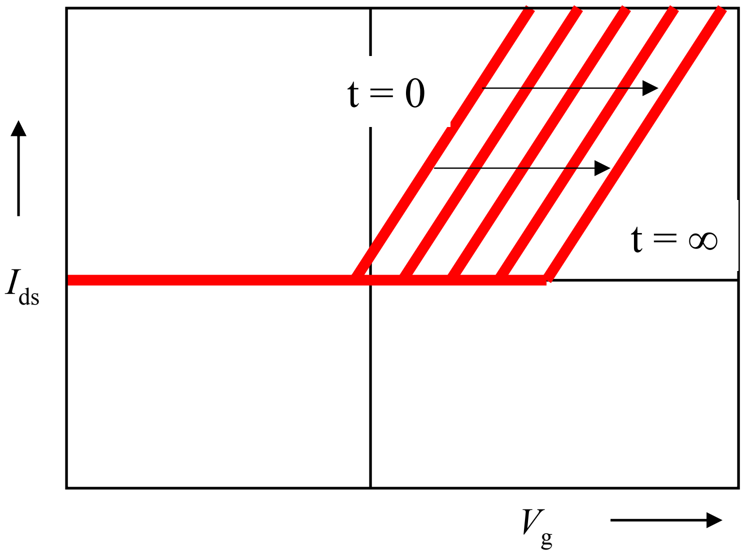
Response to O_2



Mobility change similar in O_2 and vacuum

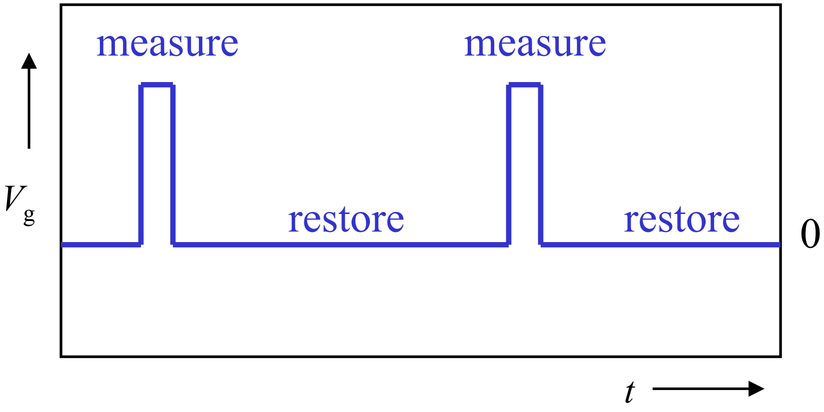
data2004\Lasca\Dia4\slope_vac_oxi.m

Stress

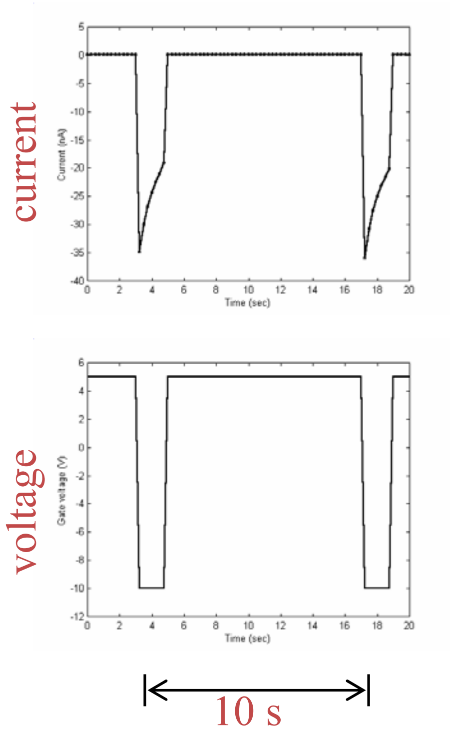


Organic FETs suffer from a phenomenon known as “stress”; a gradual increase of threshold voltage over time when (gate) bias is applied.

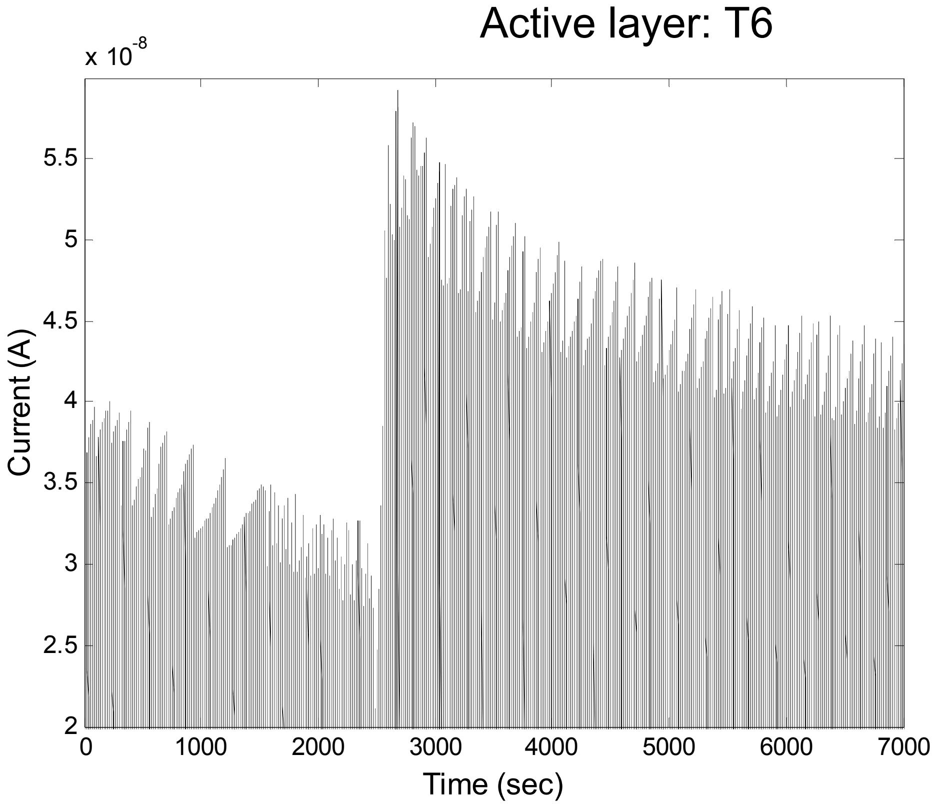
This can be reduced by using pulsed mode; ex. 99% of time at zero bias; 1% of time in measuring mode.



Pulsed mode; response to TNT



$V_{on} = -10$ V; $V_{off} = +5$ V



Reduced effect of stressing

Changes caused by ambient

Changes caused by bias in vacuum and N_2 are fully reversible and can be reduced by pulsed mode

Changes in O_2 are reversible when not in presence of UV

Changes caused by TNT are permanent

The big advantage of organic FETs

One of the advantages of organic materials, apart from being very cheap to produce is that they can be functionalized to react only with certain agents.

This is future work.

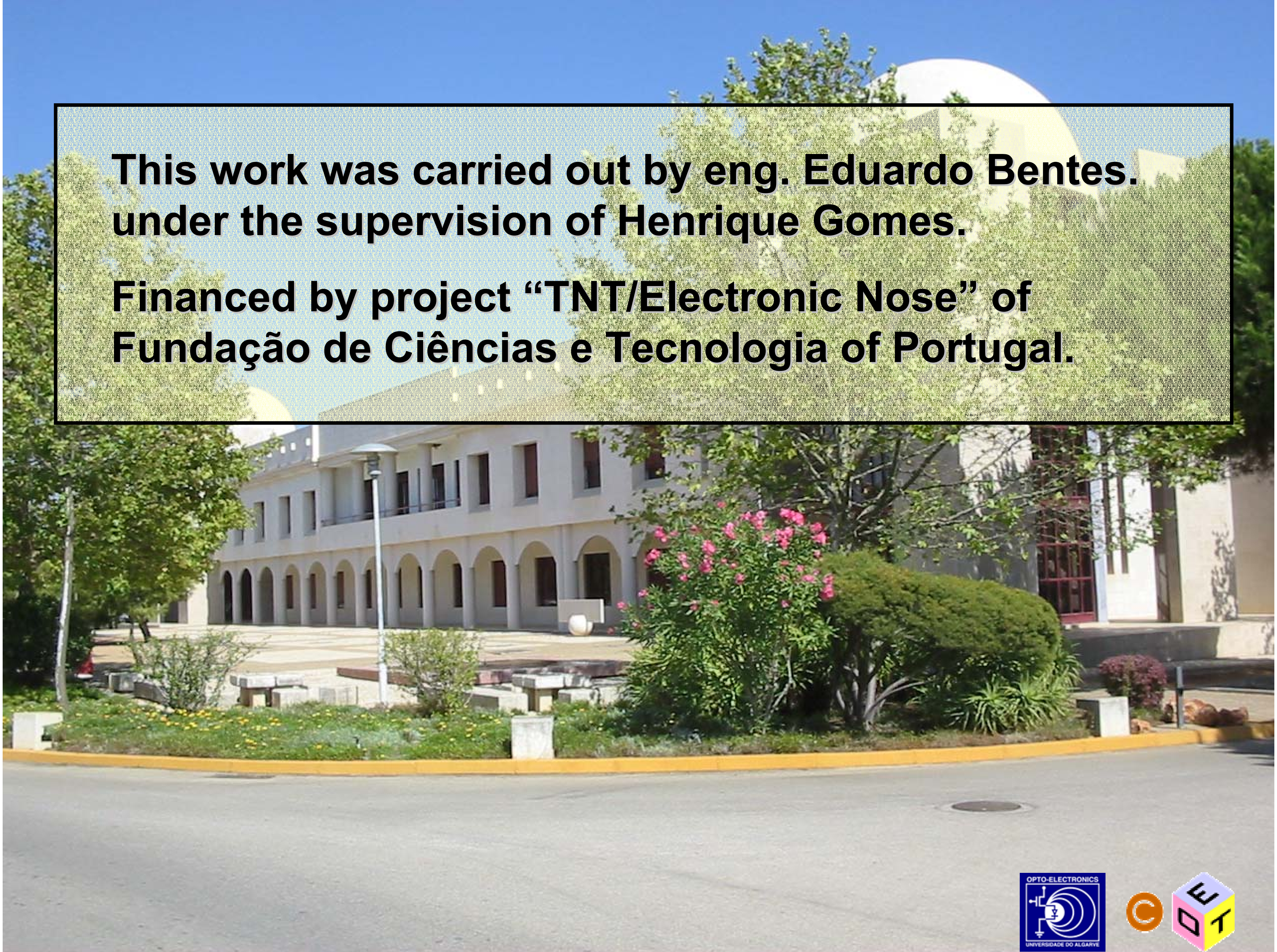
Summary

Successful fabrication of a TNT FET sensor

- Sensitive to TNT
- Selective: response to N_2 is zero, to O_2 is less
- In pulsed mode the stressing is reduced

Future work:

- Increase selectivity by functionalizing
- Reduce duty cycle in pulsed mode
- Calibrate sensitivity
- Verify dependence on film thickness
- Implement in ready-to-use device (electronics)



This work was carried out by eng. Eduardo Bentes. under the supervision of Henrique Gomes.

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