Organic field-effect transistor sensors for biomedical applications

Corso di Tecnologie e Dispositivi Elettronici Avanzati

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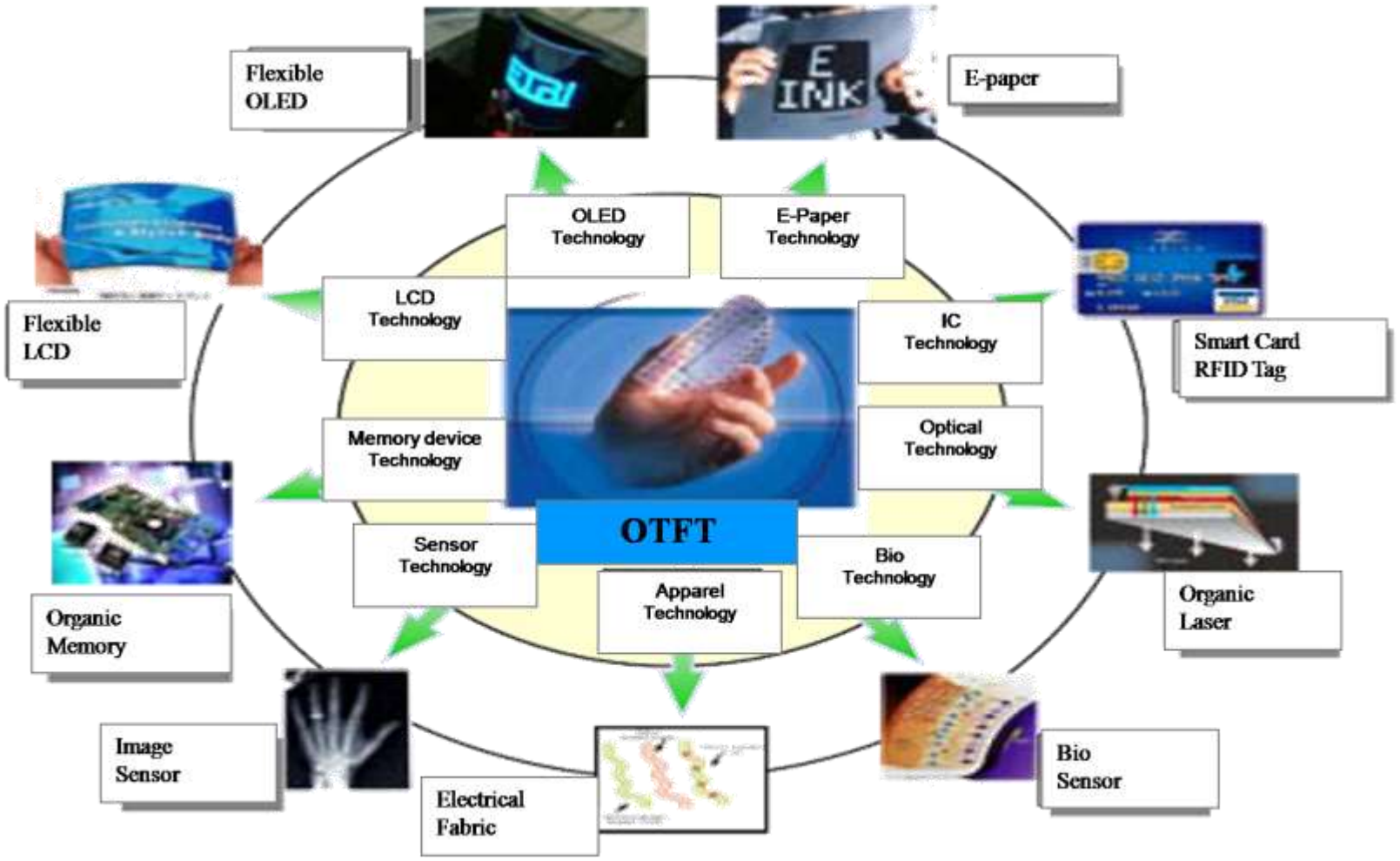
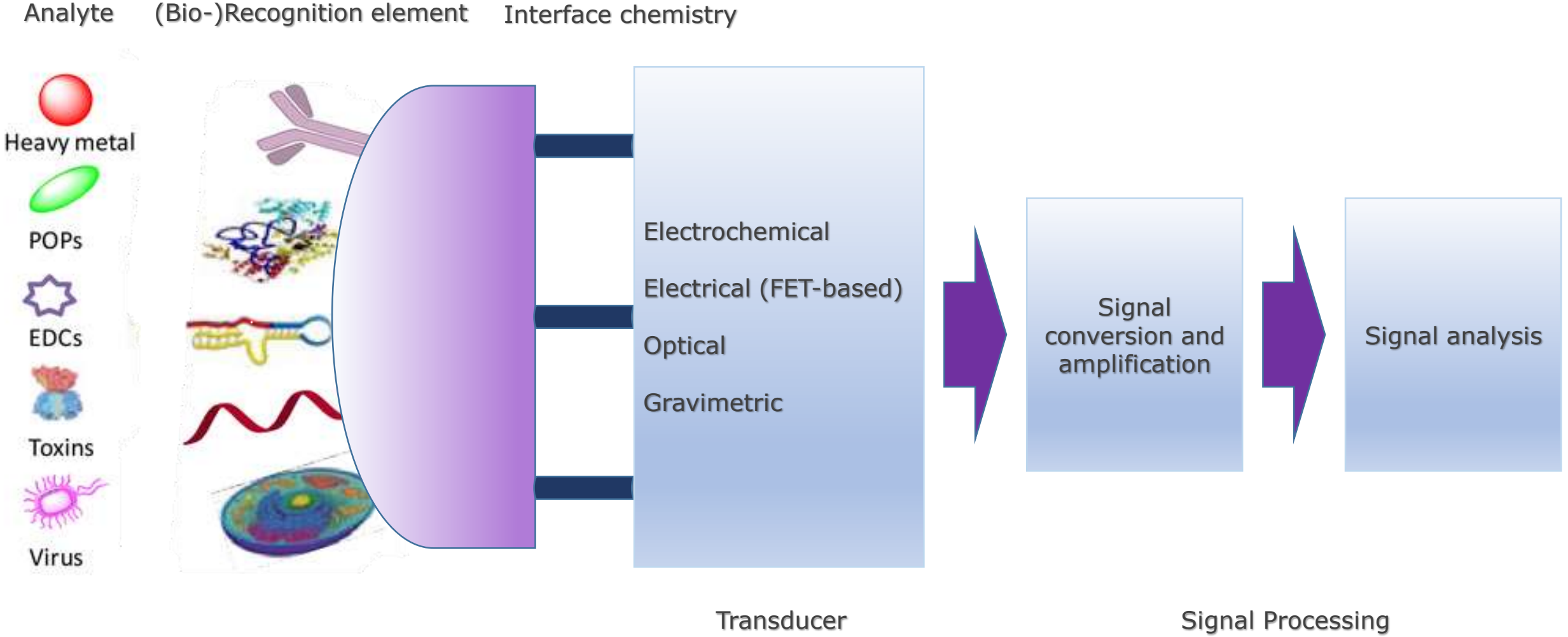
22nd December 2015

Applications



Biosensors


Analyte
(Bio-)Recognition element
Interface chemistry
Heavy metal
POPs
EDCs
Toxins
Virus
Electrochemical
Electrical (FET-based)
Optical
Gravimetric
Signal conversion and amplification
Signal analysis
Transducer
Signal Processing

Analytical figures of merit

- Selectivity
- Sensitivity
- Reversibility, hysteresis
- Long-term reliability and stability
- *Fast* response
- Dynamic and calibration range
- Linearity, precision and accuracy
- Recovery time
- SNR
- Limit of Detection (LOD)
- Limit of Quantitation (LOQ)

- Materials
- Physical/Chemical properties
- Measurement system
- Measurement environment

$$LOD = B_{mean} \pm k\sigma_B$$

B_{mean} : mean of at least ten independently prepared blank samples

σ_B : SD of B_{mean}

k : numerical factor dependent to the level of confidence required

Operatively, the LOQ is estimated by taking k = 10 in the LOD definition.

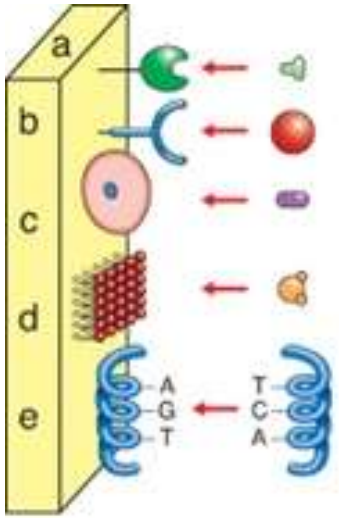
Selectivity

Def: ***Selectivity*** *of a method refers to the extent to which it can determine particular analytes under given conditions in mixtures or matrices, simple or complex, without interferences from other components.* (IUPAC)

Def: ***Specificity*** *is the ultimate of Selectivity* (IUPAC)

Binding selectivity

Chemoselectivity



LBF, *Langmuir-Blodgett Film*

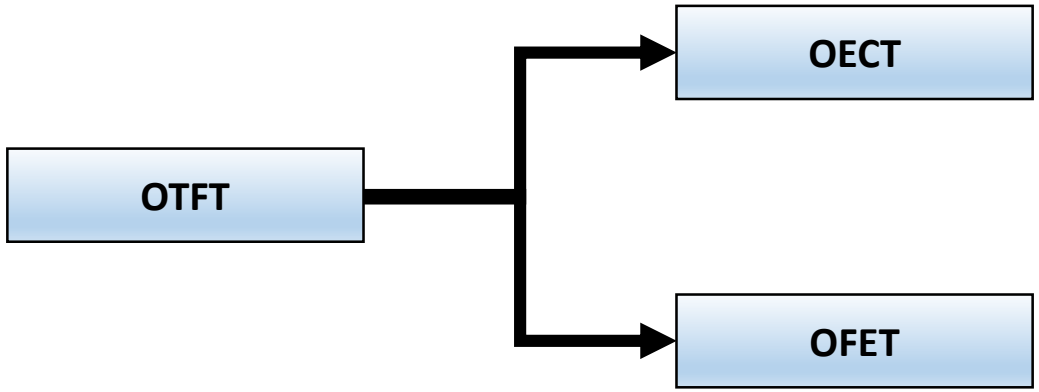
SAM, *Self-Assembled Monolayer*

Electrochemical

Organic Thin Film Transistor sensors

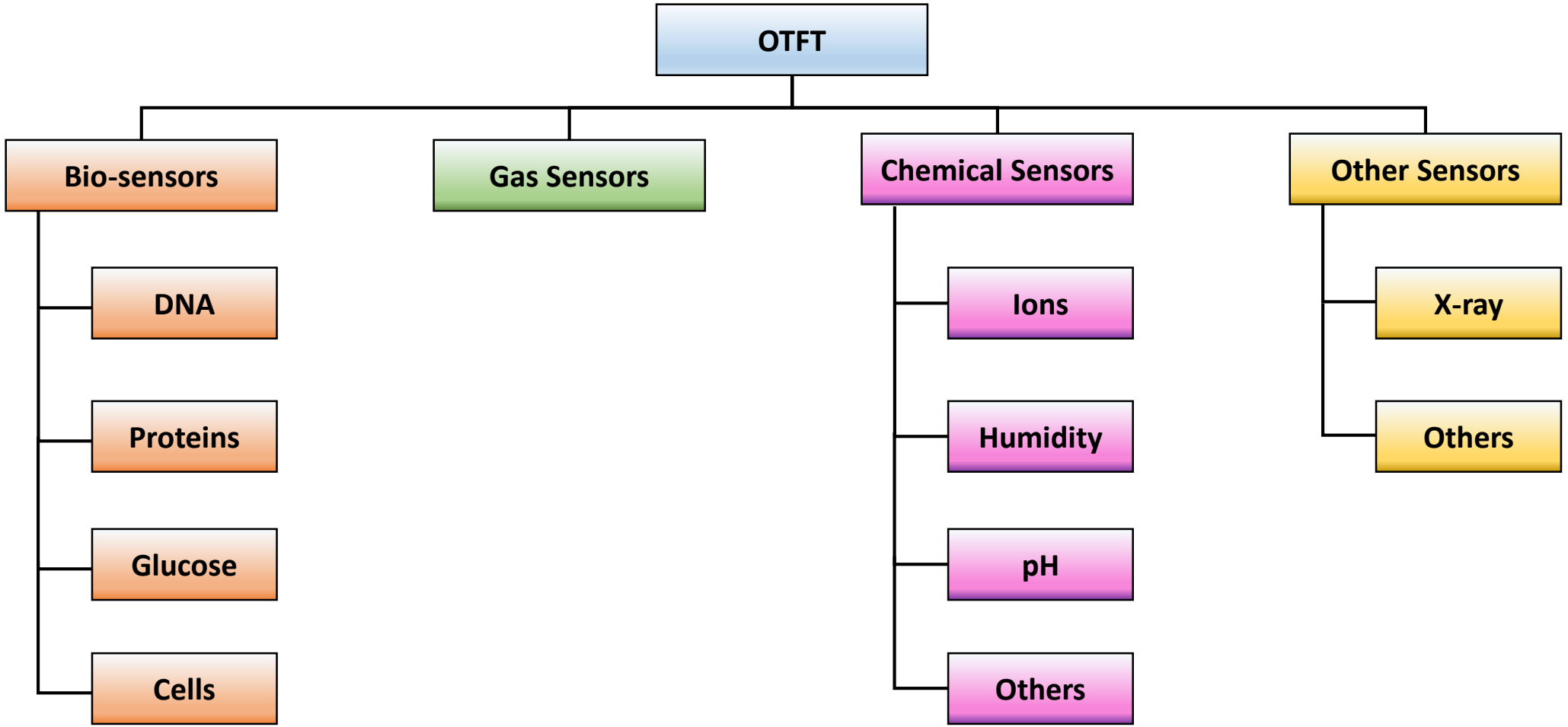
Why OTFT?

- FET structure:
  - ➢ Amplification
  - ➢ Label free

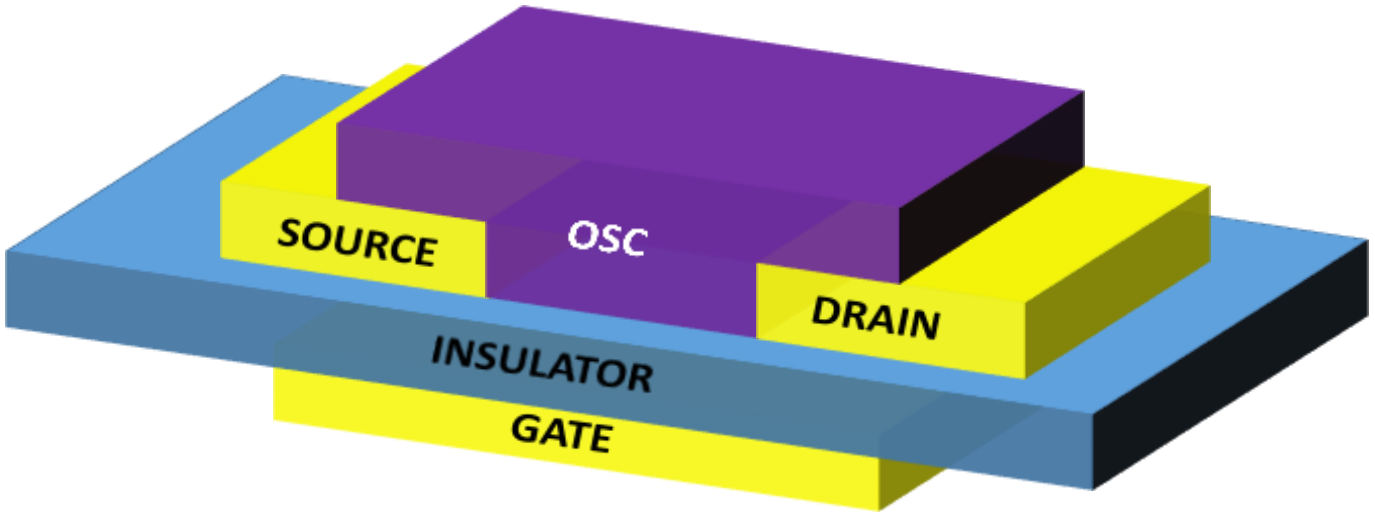


- Materials:
  - ❖ Biodegradable
  - ❖ Biocompatible
  - ❖ Flexible
  - ❖ Cost effective

OFET sensors



Sensing mechanism



Sensing area:

- Active semiconductor/electrolyte
- Gate/electrolyte
- Semiconductor
- Electrodes

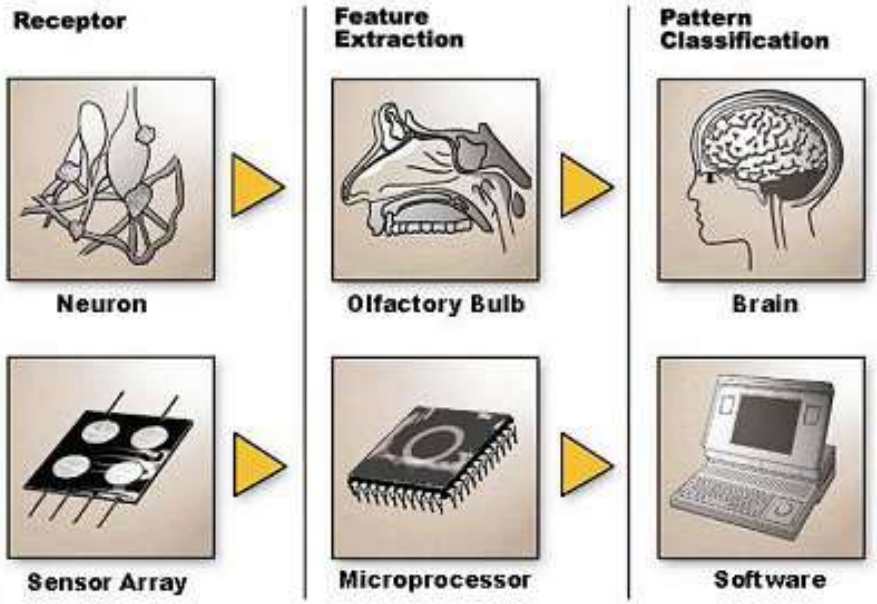
Sensing mechanism:

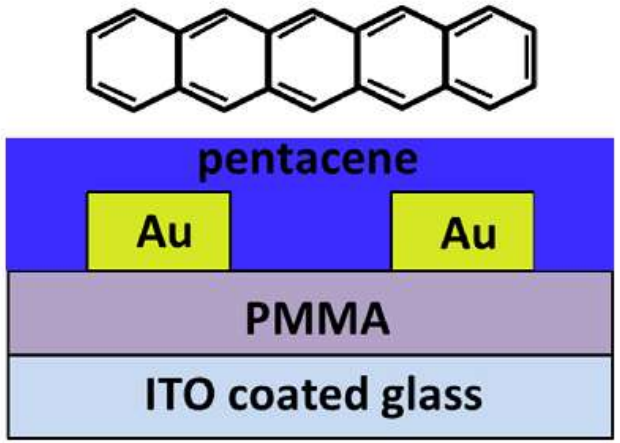
- Morphology variation
- Charge injection
- Field effect modulation

Gas sensors: an overview

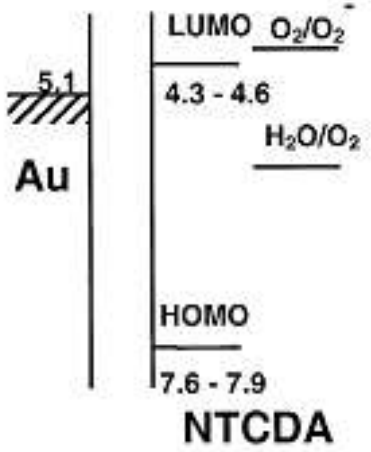
Applications

- Nose
- Tongue
- …





- OSC molecular structure
- Degree of crystallization
- Grain boundaries
- Surface roughness

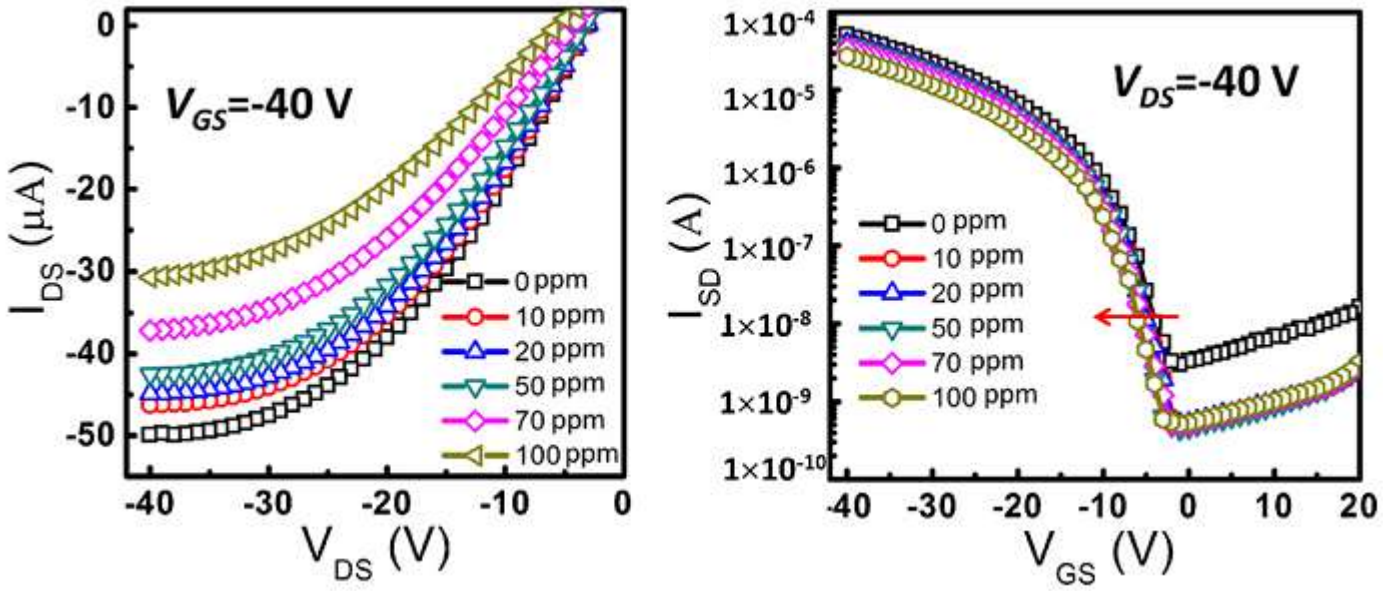


Changing parameters

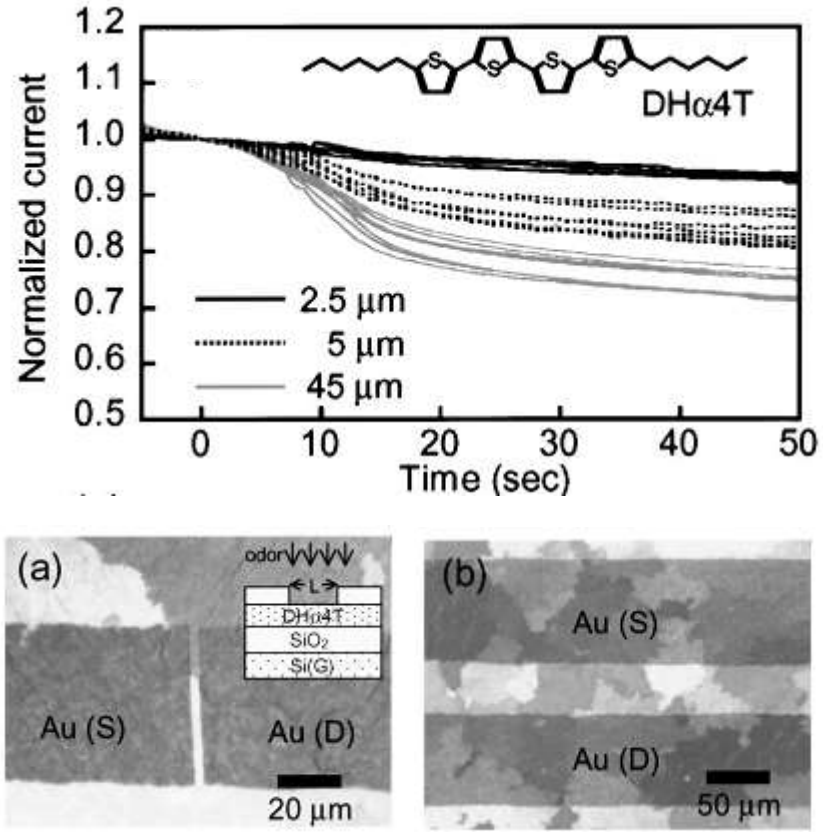
- Off state current
- V_{TH}
- μ

Multi-parameter gas sensors based on organic thin-film-transistors
L. Torsi, A. Dodabalapur, L. Sabbatini, P.G. Zambonin (2000)

Gas sensors



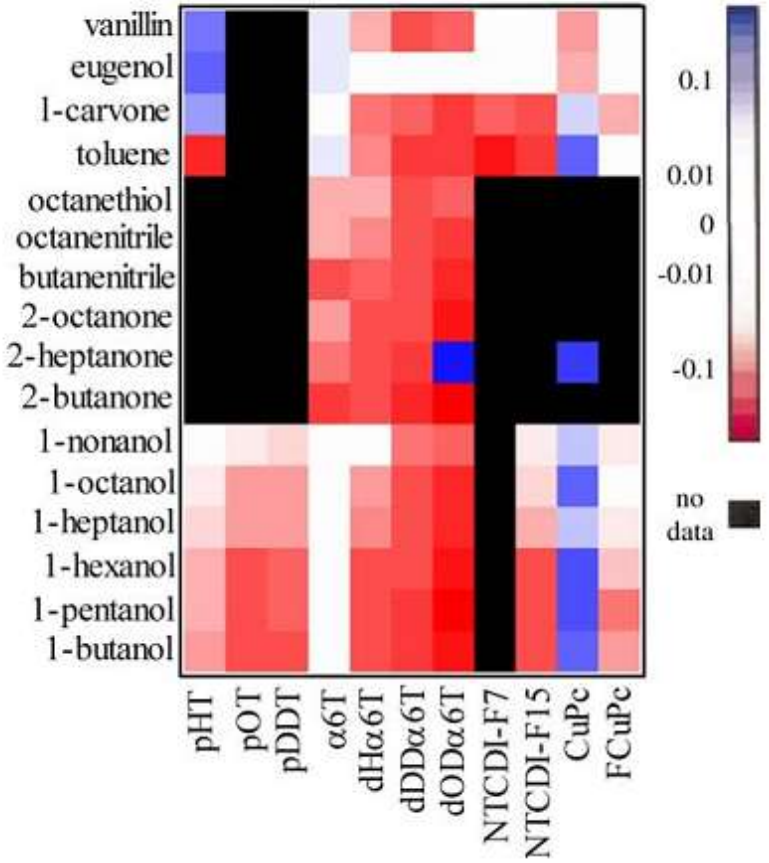
Ammonia gas sensor based on pentacene organic field-effect transistor
Junsheng Yu, Xinge Yu, Lin Zhang, Hongjuan Zeng (2015)



Vapor sensing with a,v-dihexylquarterthiophene field-effect transistors: The role of grain boundaries
Takao Someya, Howard E. Katz,Alan Gelperin, Andrew J. Lovinger, and Ananth Dodabalapur (2002)

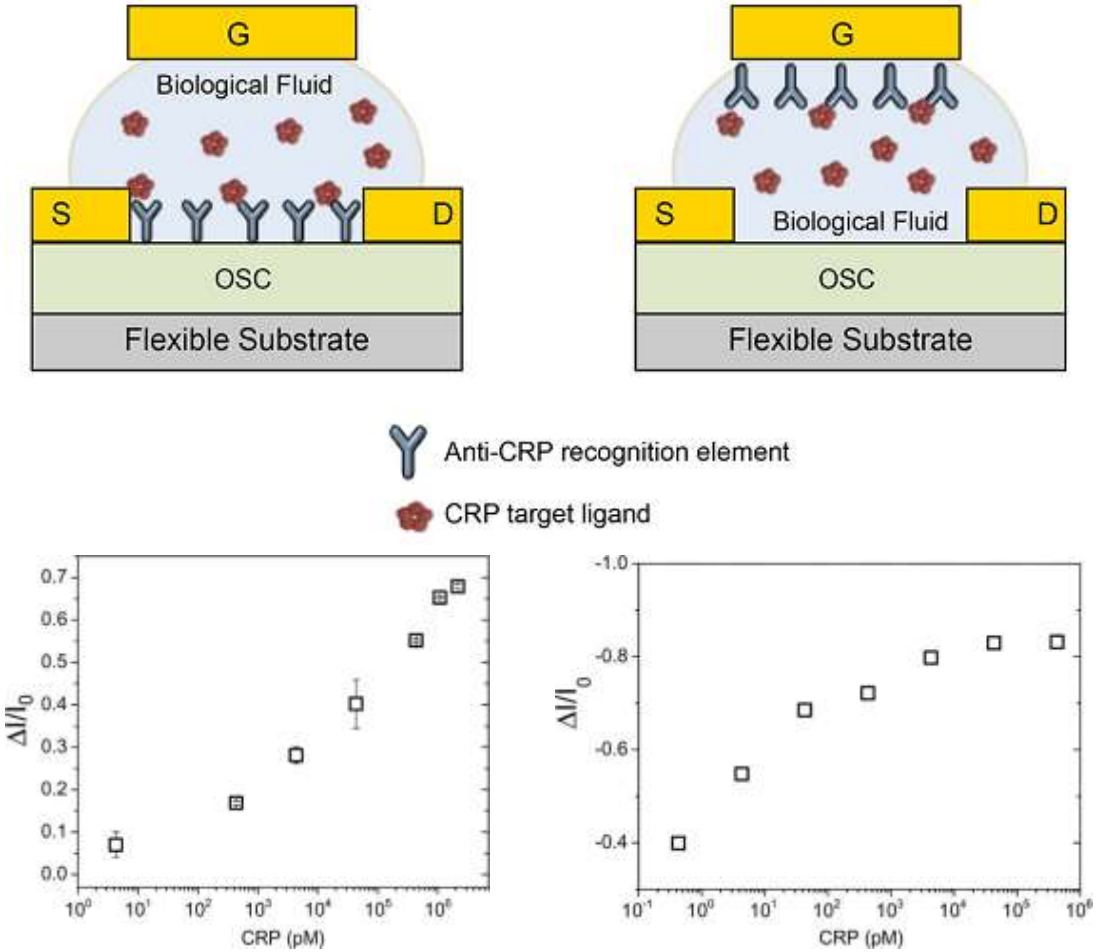
Gas sensors: selectivity

Active layer	Analyte
Phthalocyanine	Oxygen, Iodine, Bromine, NO2, Ozone, Alchools, Ketones, Thiols, Nitriles, Esters
Naphthalene tetracarboxylic dianhydride	Nitrogen, Oxygen, Alcohols, Ketones, Thiols, Nitriles, Esters
Pentacene	1-Pentanol, Aqueous analytics
Oligothiophenes	Alcoholes, Ketones, Thiols, Lactic acid, Glucose
Polythiophenes	Ammonia, Chloroform, Alcohols, Esters, Nitriles



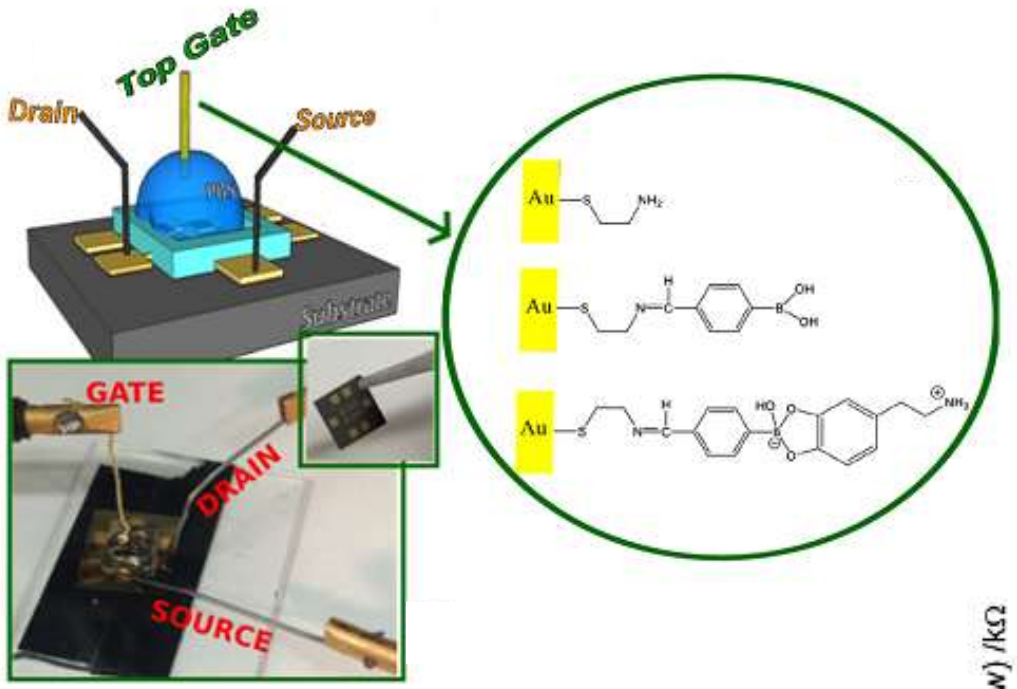
POC biosensors: EGOFET

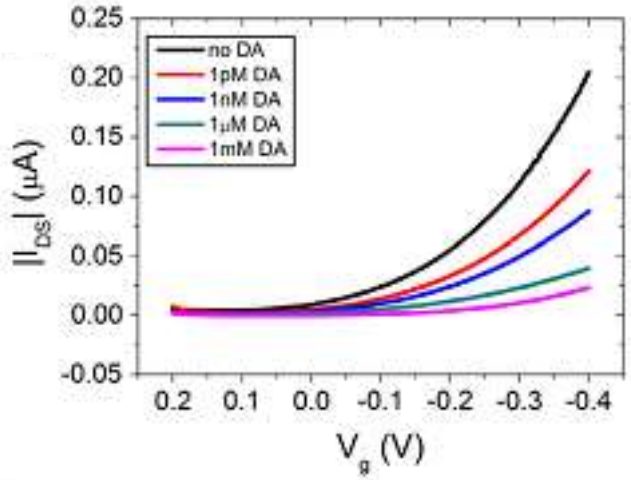
Point-of-care (**POC**) biosensors are integrated diagnostic devices that allow the detection of clinically relevant biomarkers in biological fluids (blood, urine, saliva, sweat, and tears) outside conventional laboratories.

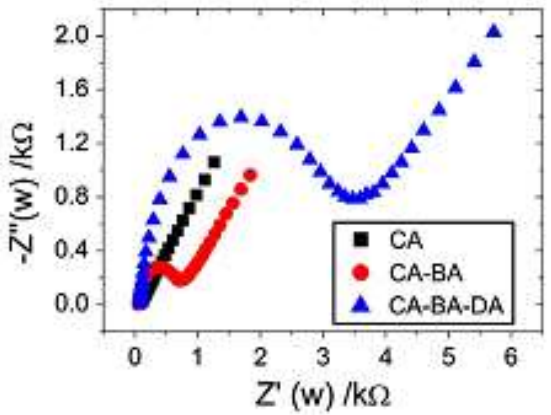


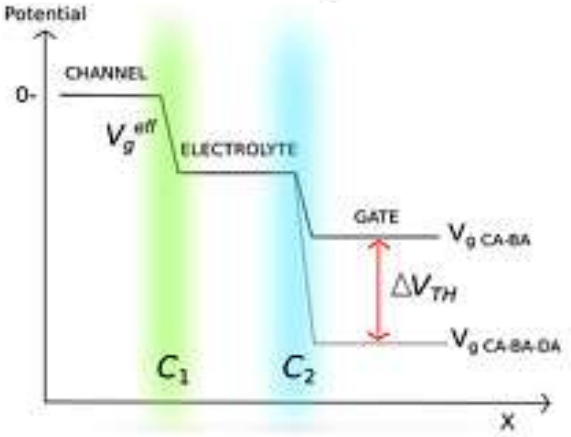
Ultrasensitive printable biosensors for point-of-care applications
*Maria Magliulo, Mohammad Yusuf Mulla, Kyriaki Manoli, Donato De Tullio, Preethi Seshadri, Gaetano Scamarcio, Gerardo Palazzo and Luisa Torsi (*2012)

POC biosensors: dopamine



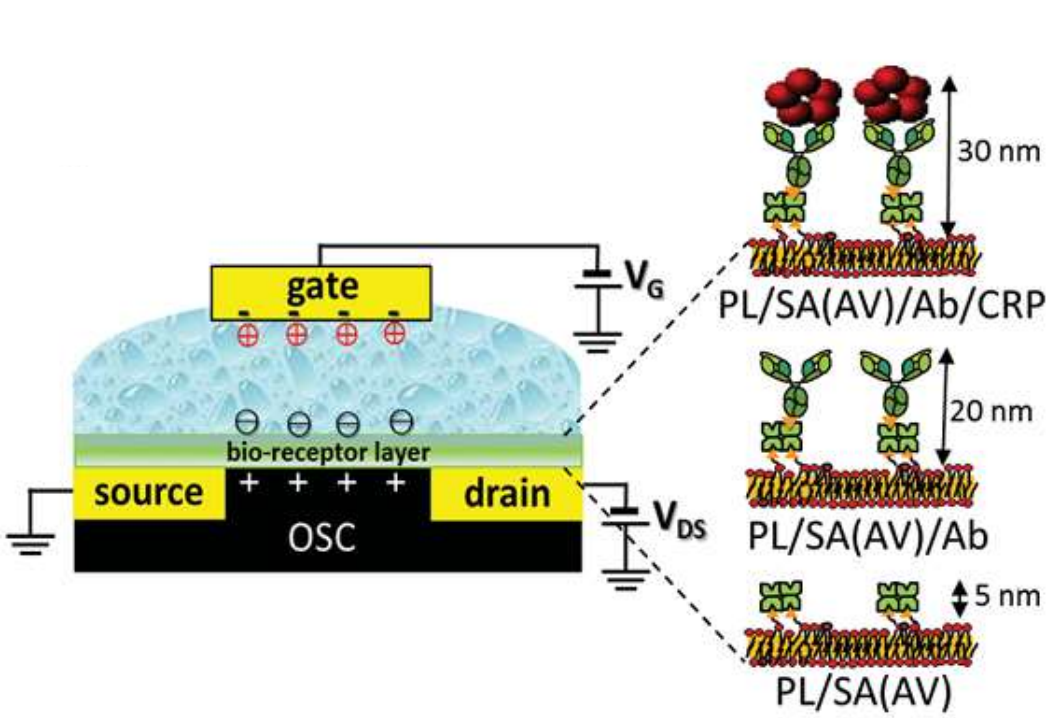


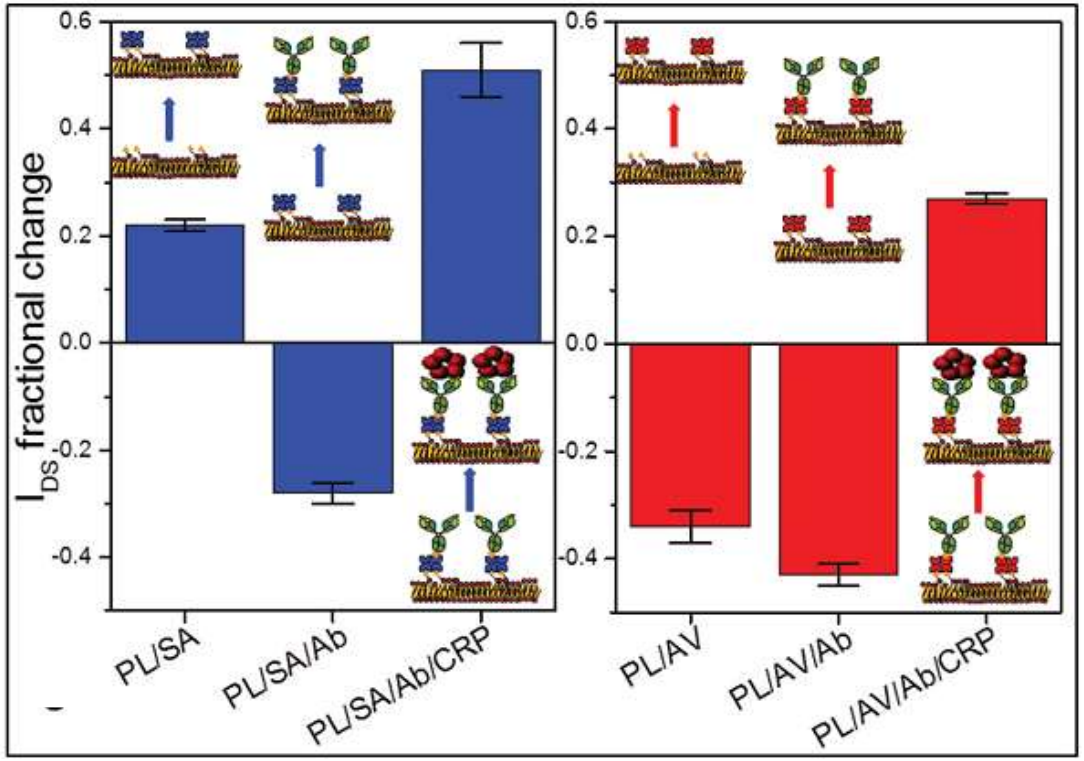




Organic field-effect transistor for label-free dopamine sensing
S. Casalini, F. Leonardi, T. Cramer, F. Biscarini (2013)

POC biosensors: CRP

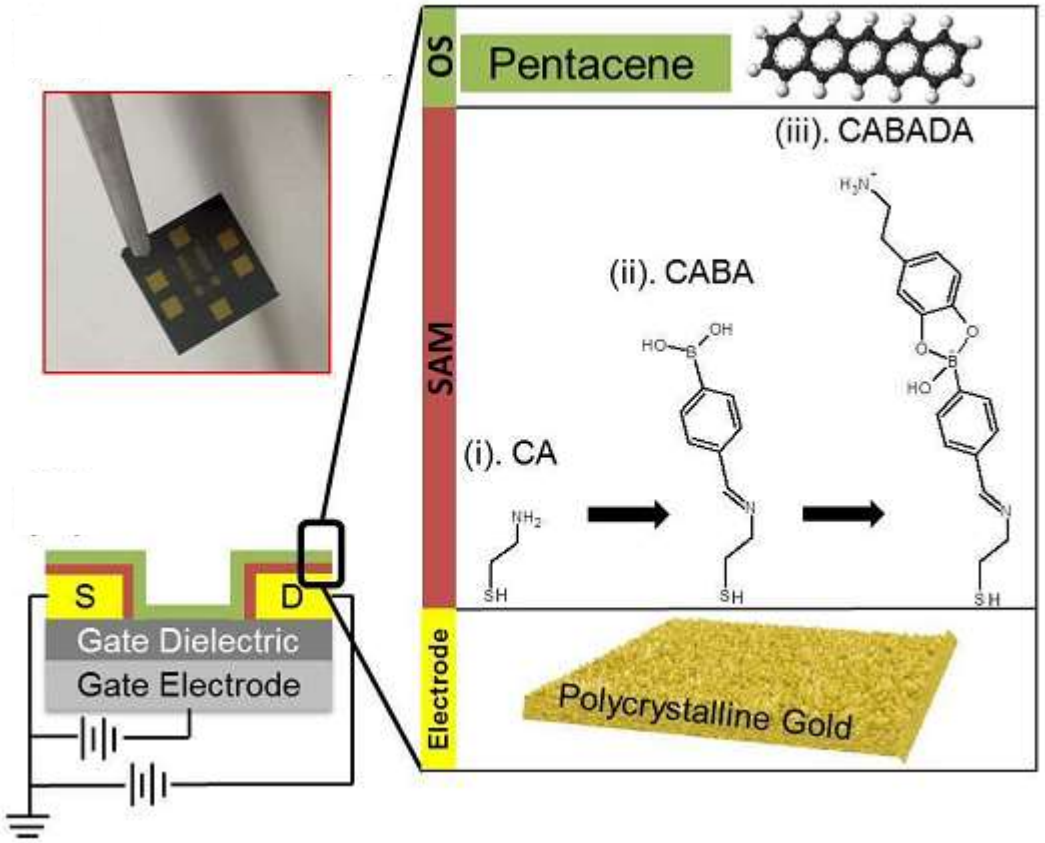


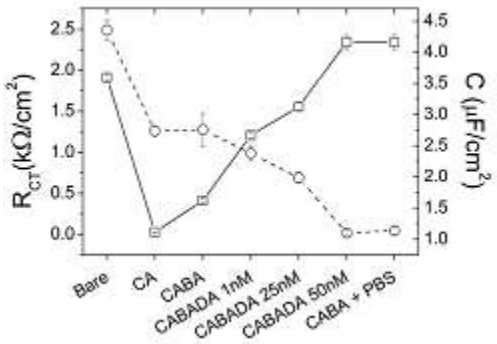


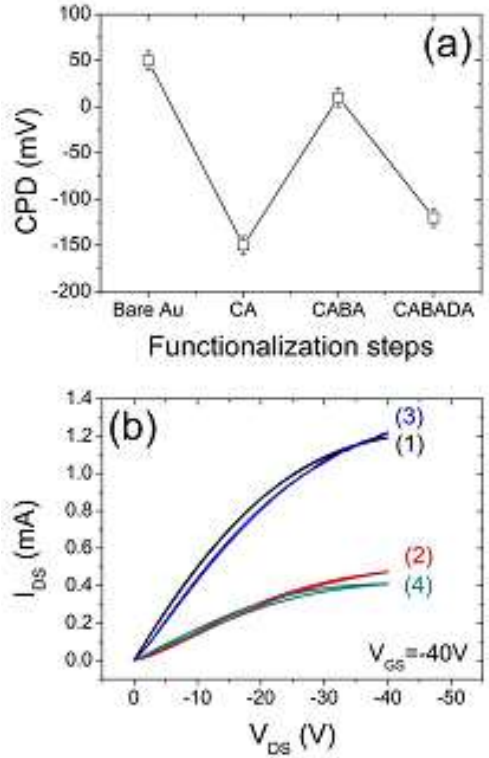
Detection Beyond Debye's Length with an Electrolyte-Gated Organic Field-Effect Transistor

*Gerardo Palazzo , * Donato De Tullio , Maria Magliulo , Antonia Mallardi , Francesca Intranuovo, Mohammad Yusuf Mulla , Pietro Favia , Inger Vikholm-Lundin , and Luisa Torsi* (2015)

Charge injection modulation

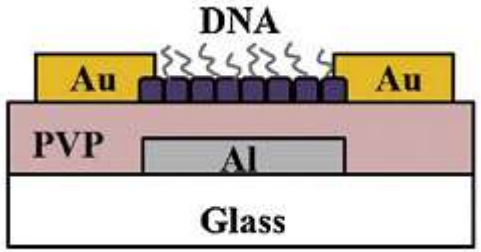




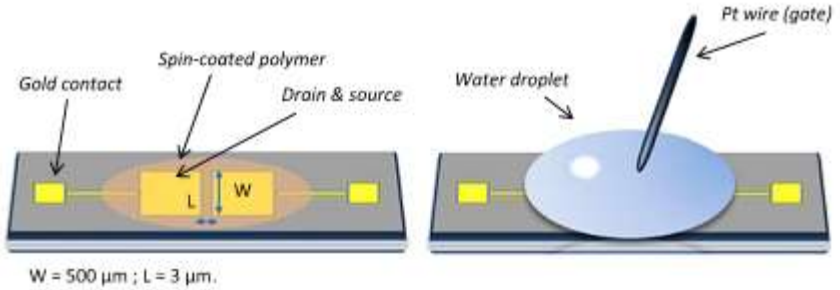


Charge-Injection Organic Gauges to Detect Dopamine Down to the Nanomolar Scale
Francesca Leonardi, Stefano Casalini, Cristiano Albonetti, Alessandro Kovtun, Andrea Liscio, and Fabio Biscarini (2015)

DNA hybridization

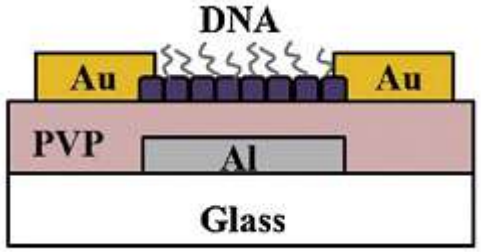


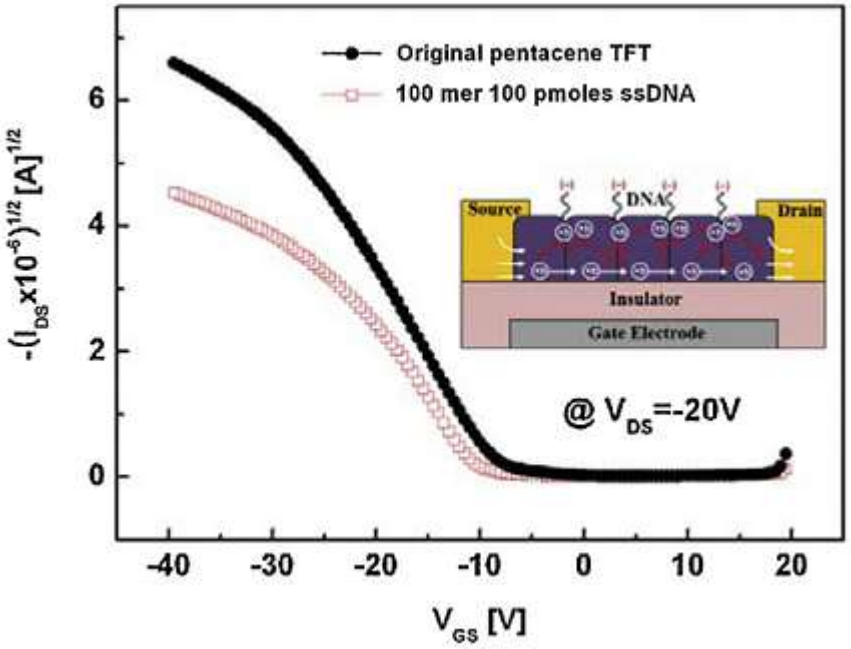
DNA hybridization sensor based on pentacene thin film transistor
Jung-Min Kim, Sandeep Kumar Jha, Rohit Chand, Dong-Hoon Lee, Yong-Sang Kim (2011)

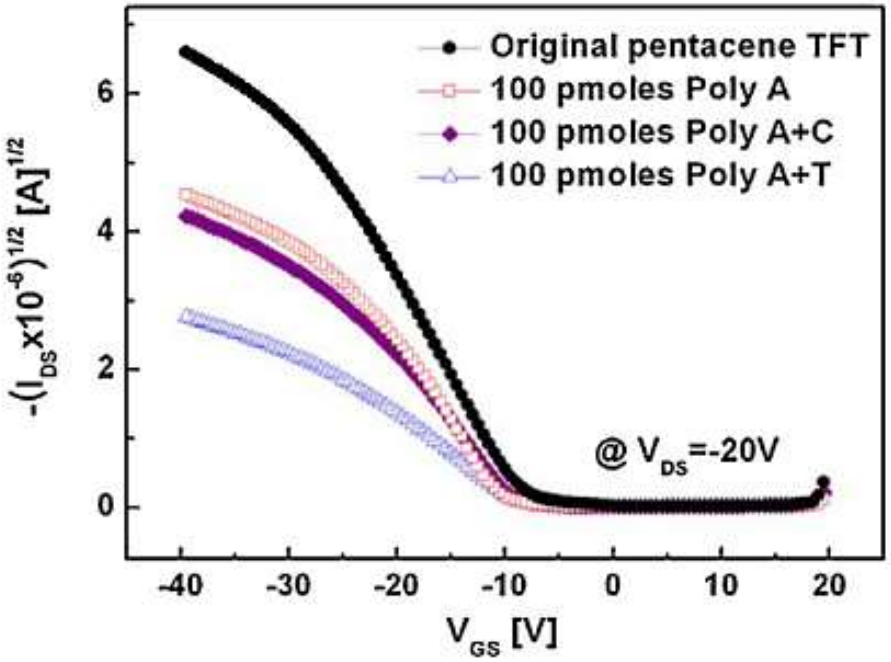


DNA detection with a water-gated organic field-effect transistor
Loig Kergoat, Benoît Piro , Magnus Berggren, Minh-Chau Pham, Abderrahim Yassar, Gilles Horowitz (2012)

DNA hybridization







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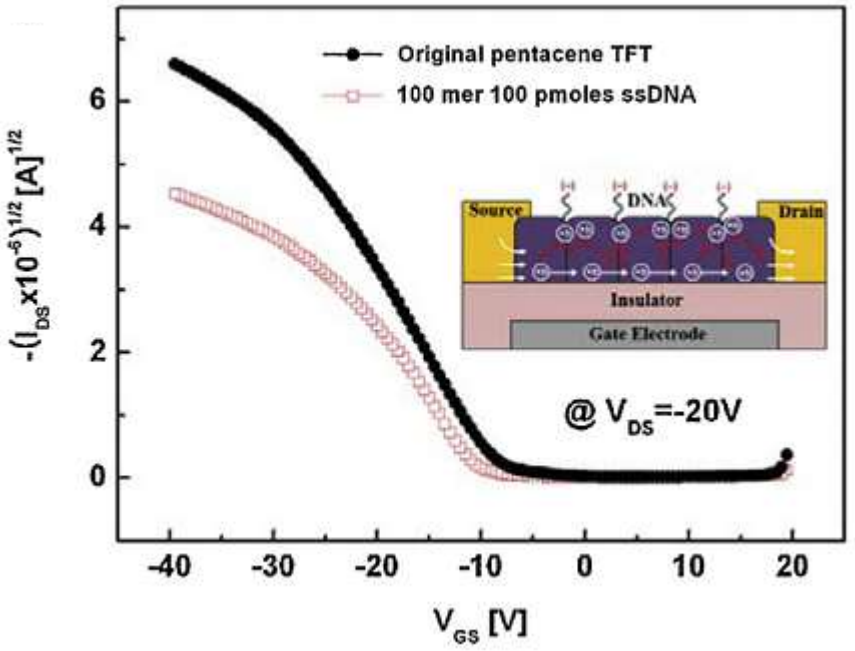
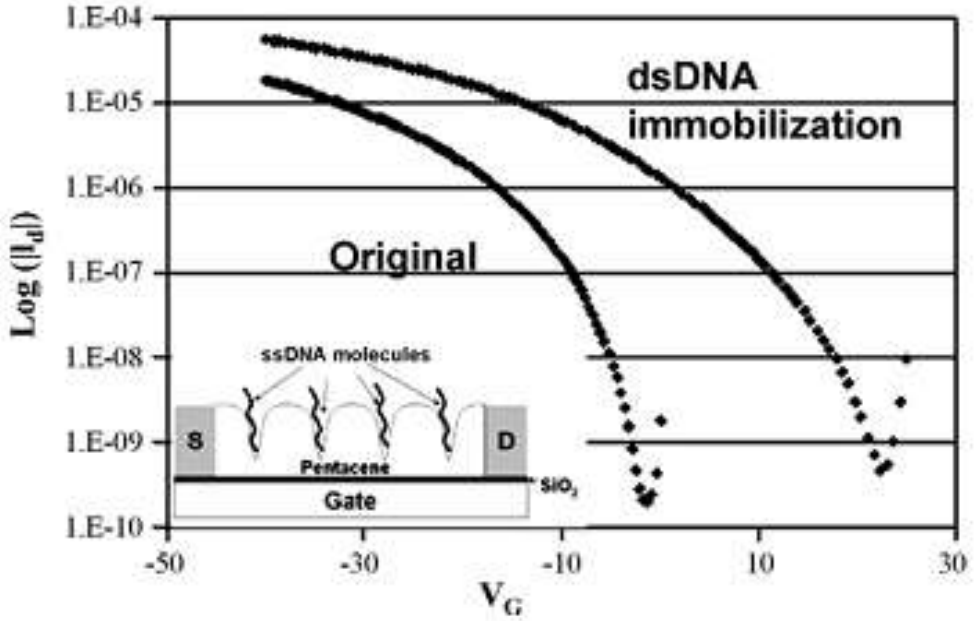
DNA hybridization



DNA hybridization detection with organic thin film transistors: Toward fast and disposable DNA microarray chips
Qintao Zhang, Vivek Subramanian (2007)



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Jung-Min Kim, Sandeep Kumar Jha, Rohit Chand, Dong-Hoon Lee, Yong-Sang Kim (2011)

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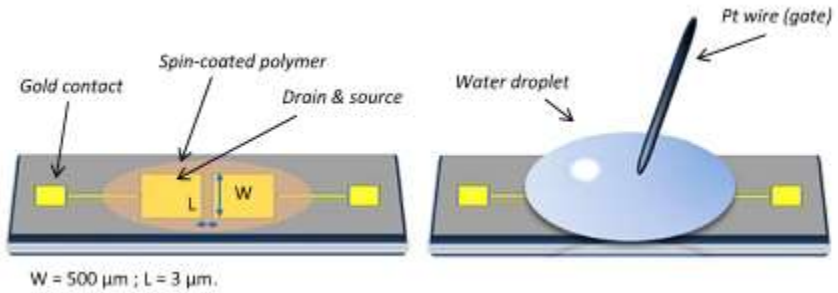
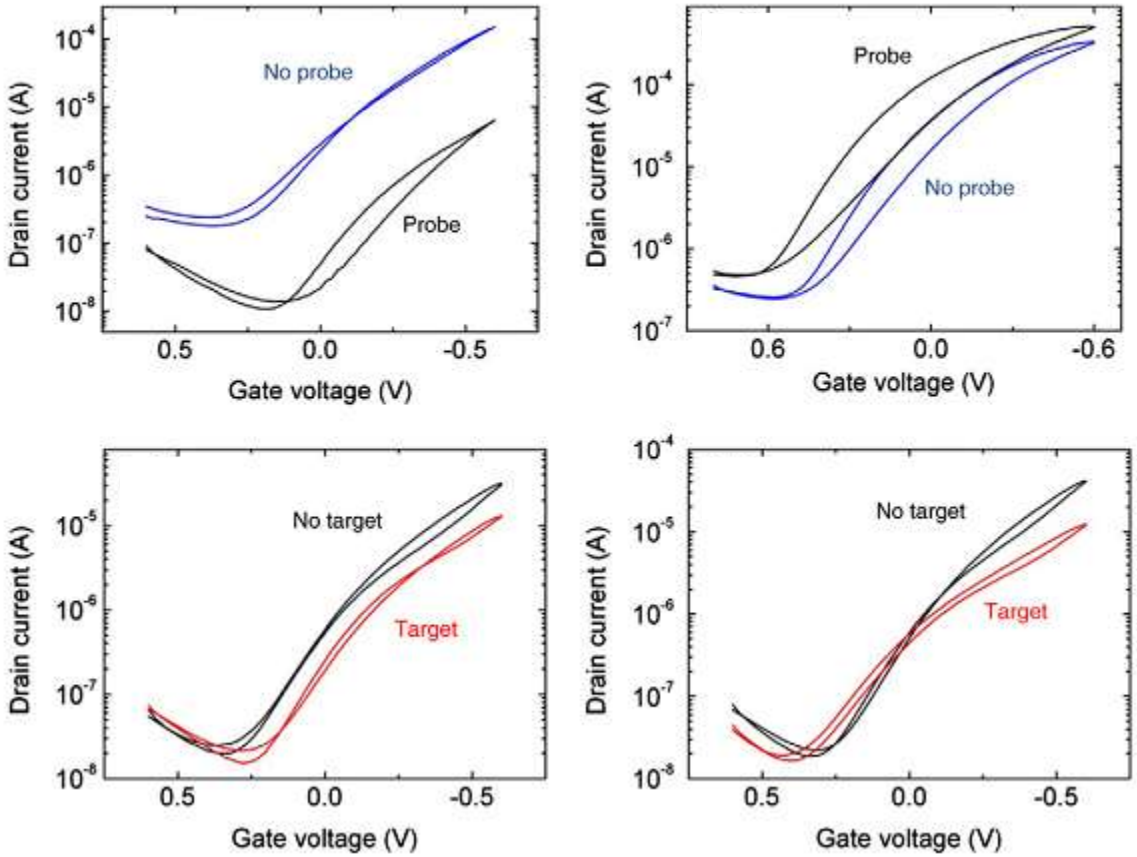
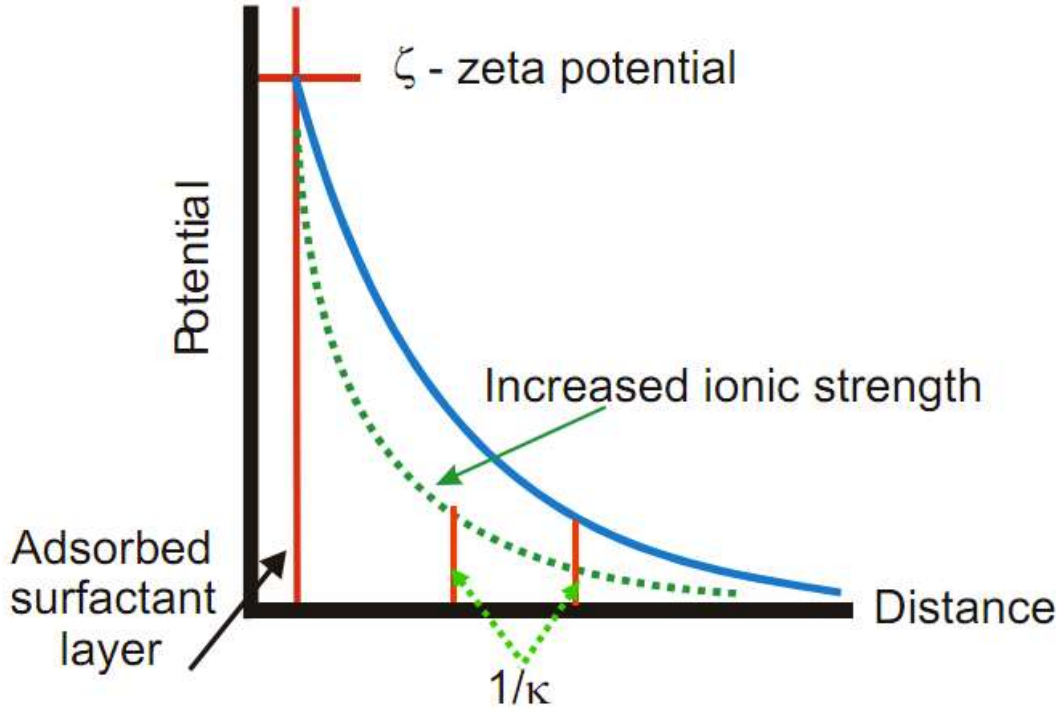
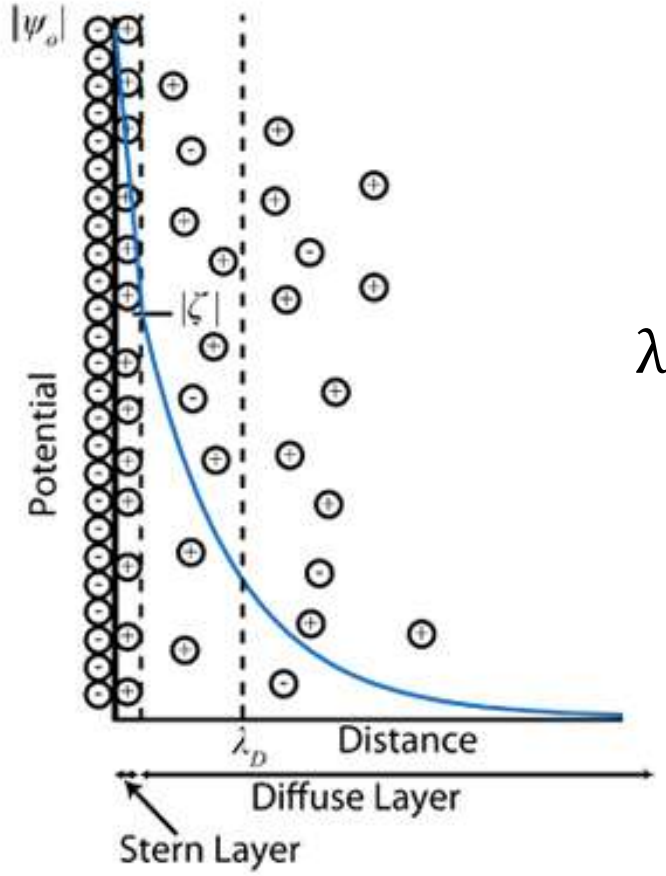




DNA detection with a water-gated organic field-effect transistor
Loig Kergoat, Benoît Piro , Magnus Berggren, Minh-Chau Pham, Abderrahim Yassar, Gilles Horowitz (2012)

Debye length

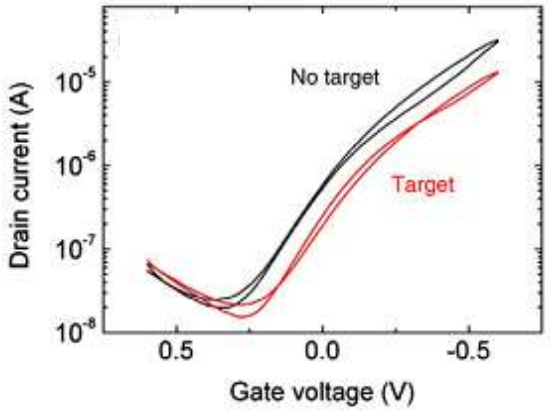




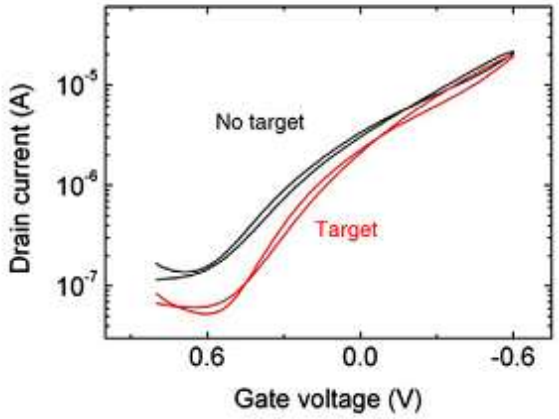
$$\lambda_D = \frac{1}{k}$$

Field effect modulation: Debye length

PBS



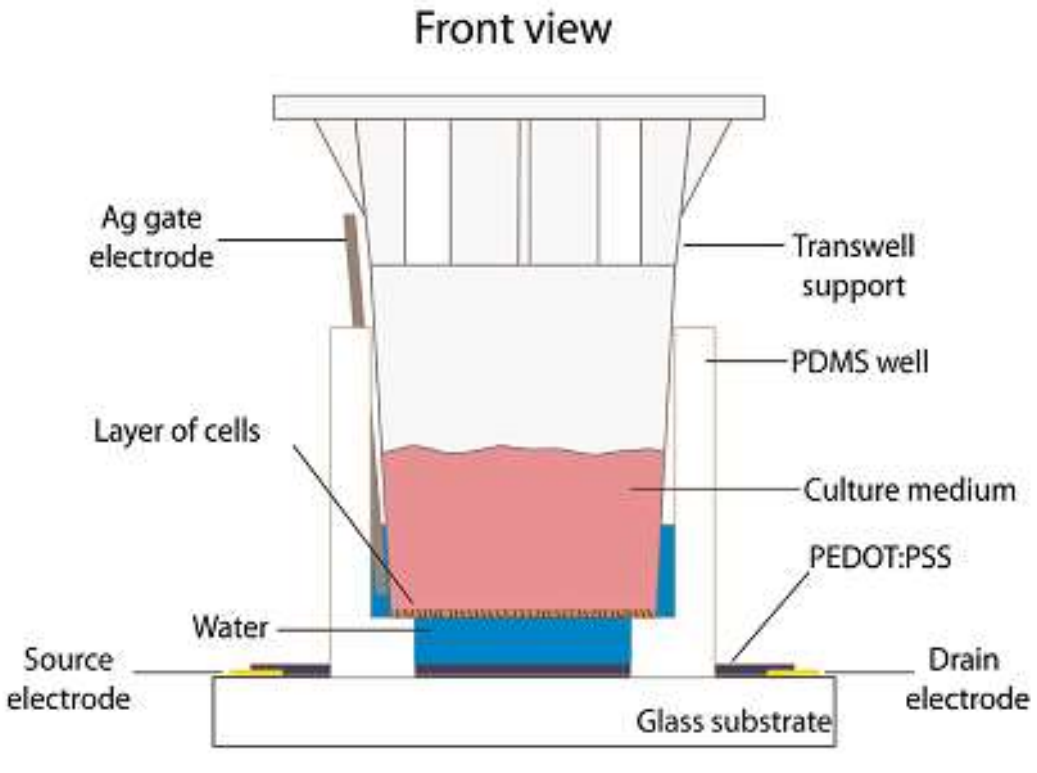
H_2O

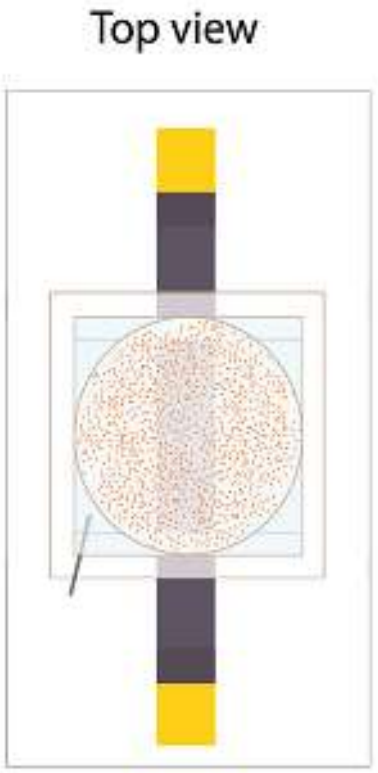


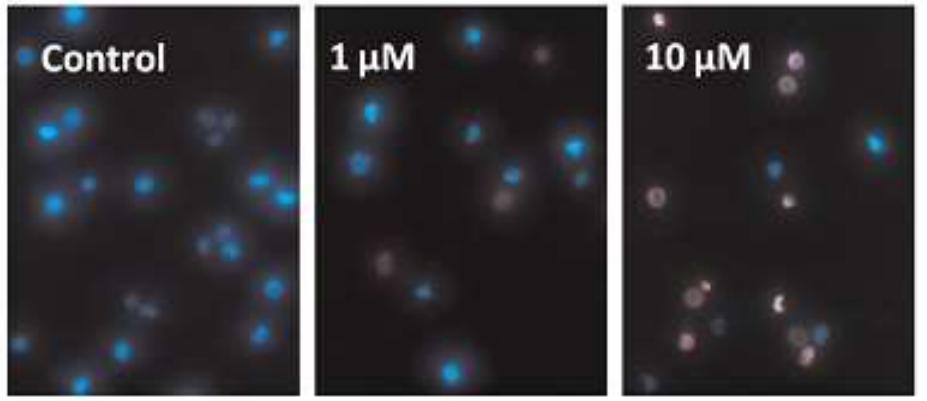
ODN grafting (Fig. 3a and b)	
ODN probe	$I_{off\ (bare\ film)}/I_{off\ (probe\text{-}modified\ film)}$
Yes	11.1 ± 3.7
No	0.5 ± 0.12
DNA hybrid. in PBS (Fig. 3c and d)	
ODN target	$I_{off\ (probe\text{-}modified\ film)}/I_{off\ (hybridization)}$
HIV	1.7 ± 0.45
RAND	1.3 ± 0.28
DNA hybrid. in H_2O (Fig. 3e and f)	
ODN probe	$I_{off\ (probe\text{-}modified\ film)}/I_{off\ (hybridization)}$
HIV	3.4 ± 1.5
RAND	1.04 ± 0.04

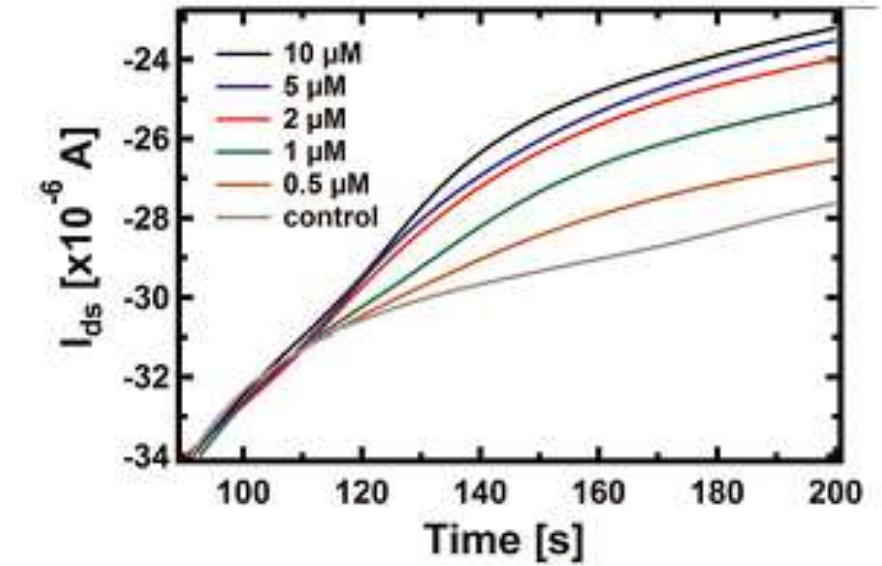
DNA detection with a water-gated organic field-effect transistor
Loig Kergoat, Benoît Piro , Magnus Berggren, Minh-Chau Pham, Abderrahim Yassar, Gilles Horowitz (2012)

Cells death monitoring





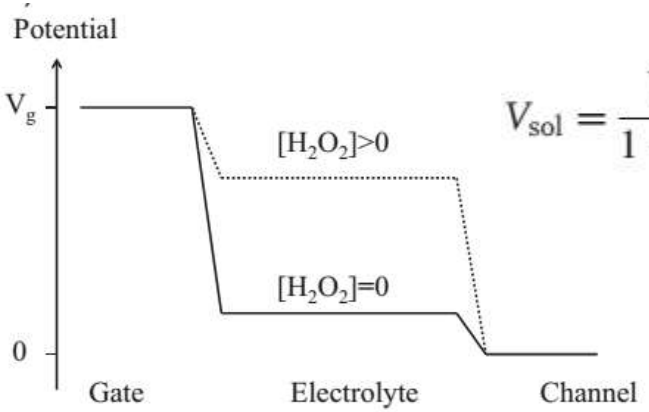




Drug-induced cellular death dynamics monitored by a highly sensitive organic electrochemical system
Agostino Romeo, Giuseppe Tarabella, Pasquale D'Angelo, Cristina Caffarra, Daniele Cretella, Roberta Alfieri, Pier Giorgio Petronini, Salvatore Iannotta (2015)

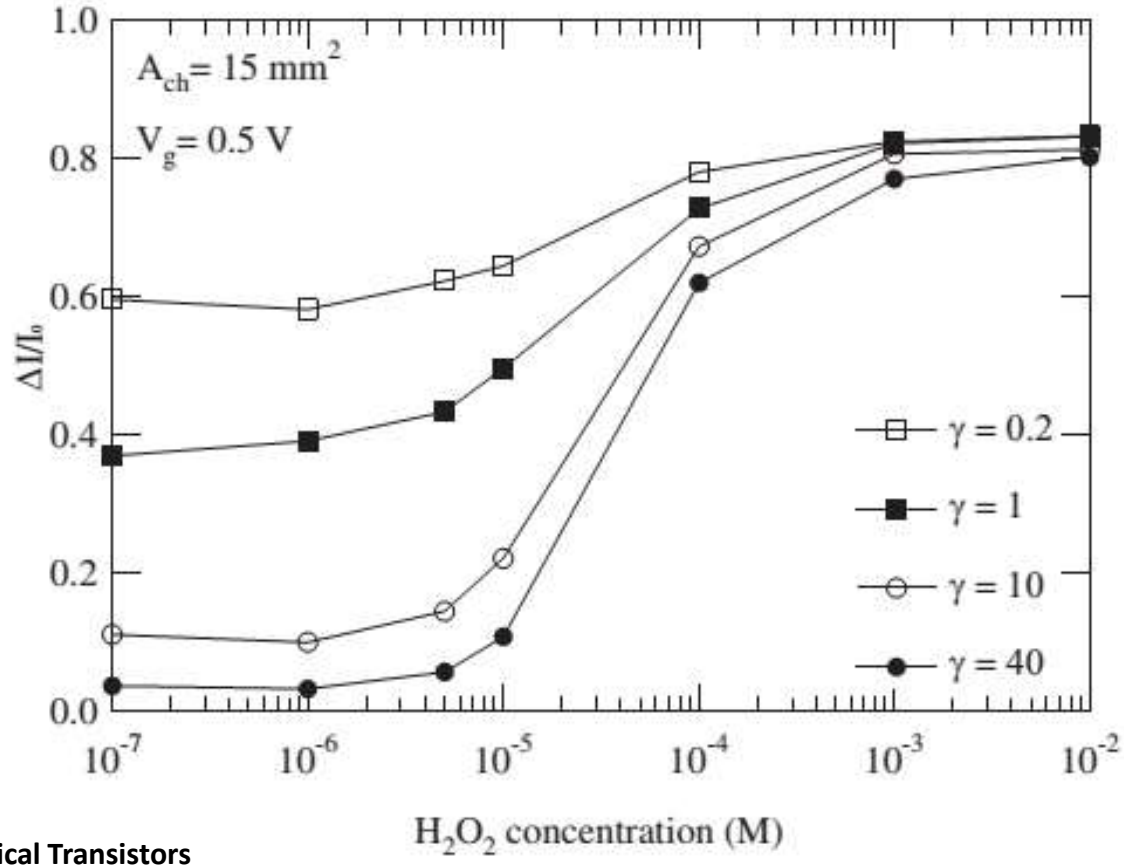
OECT sensitivity tuning – device geometry

$$\gamma = A_{ch}/A_g$$



$$V_{sol} = \frac{V_g}{1+\gamma} + \frac{kT}{2e^-} \ln[H_2O_2] + const$$

$$H_2O_2 \rightleftarrows O_2 + 2H^+ + 2e^-$$

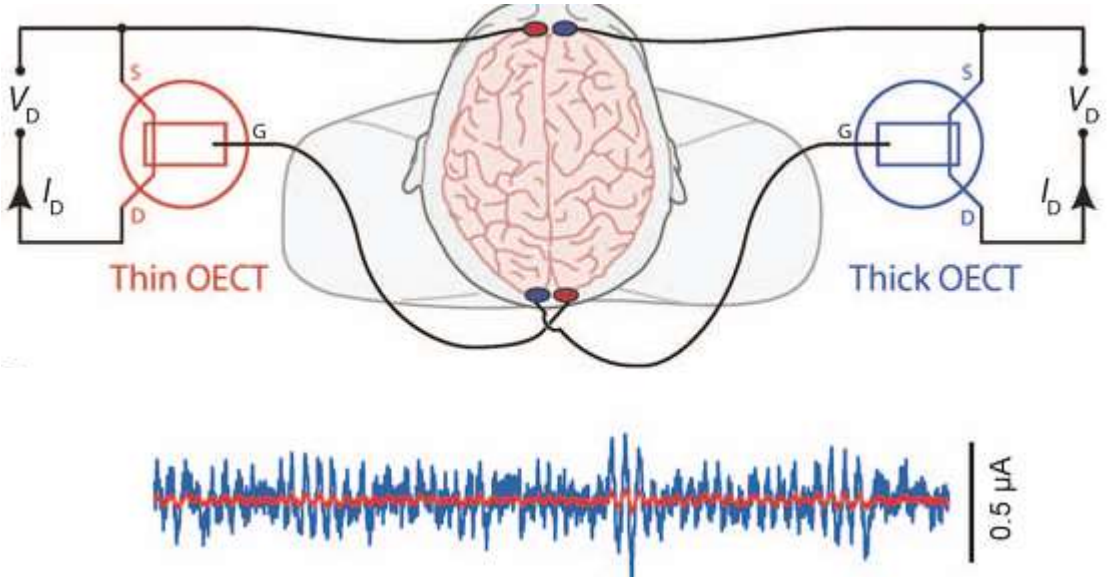


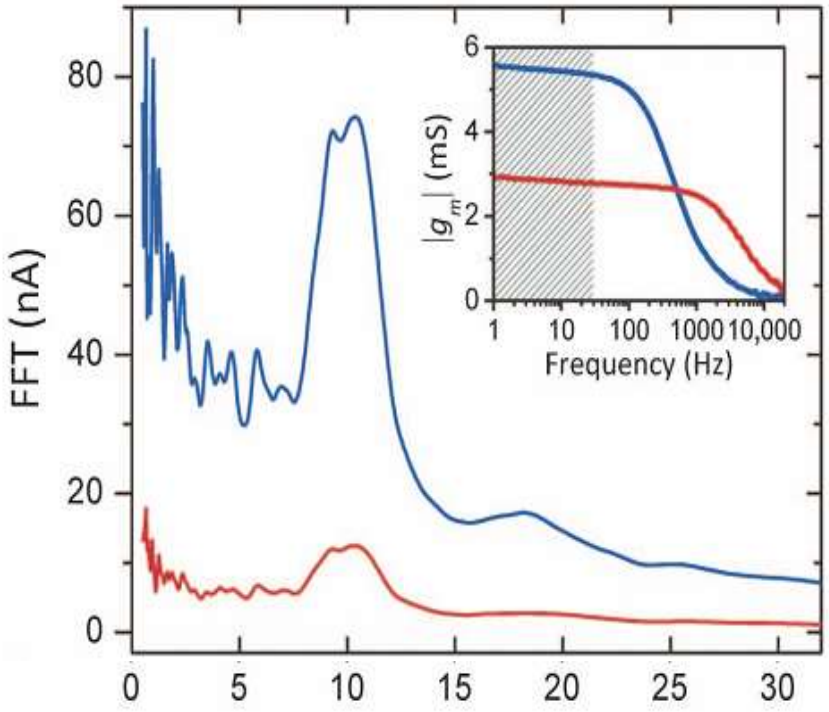
Influence of Device Geometry on Sensor Characteristics of Planar Organic Electrochemical Transistors
Fabio Cicoira, Michele Sessolo, Omid Yaghmazadeh, John A. DeFranco, Sang Yoon Yang, and George G. Malliaras (2012)

OECT sensitivity tuning – channel thickness

230 nm

870 nm

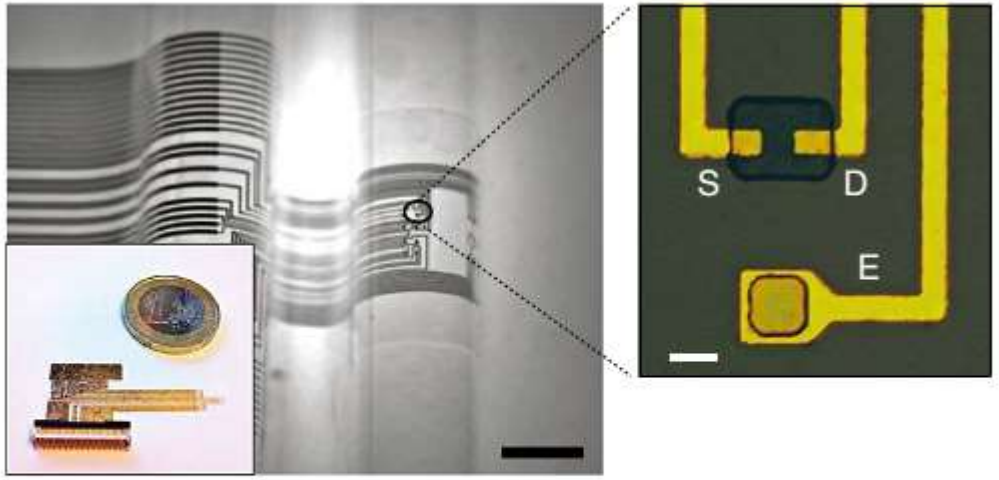


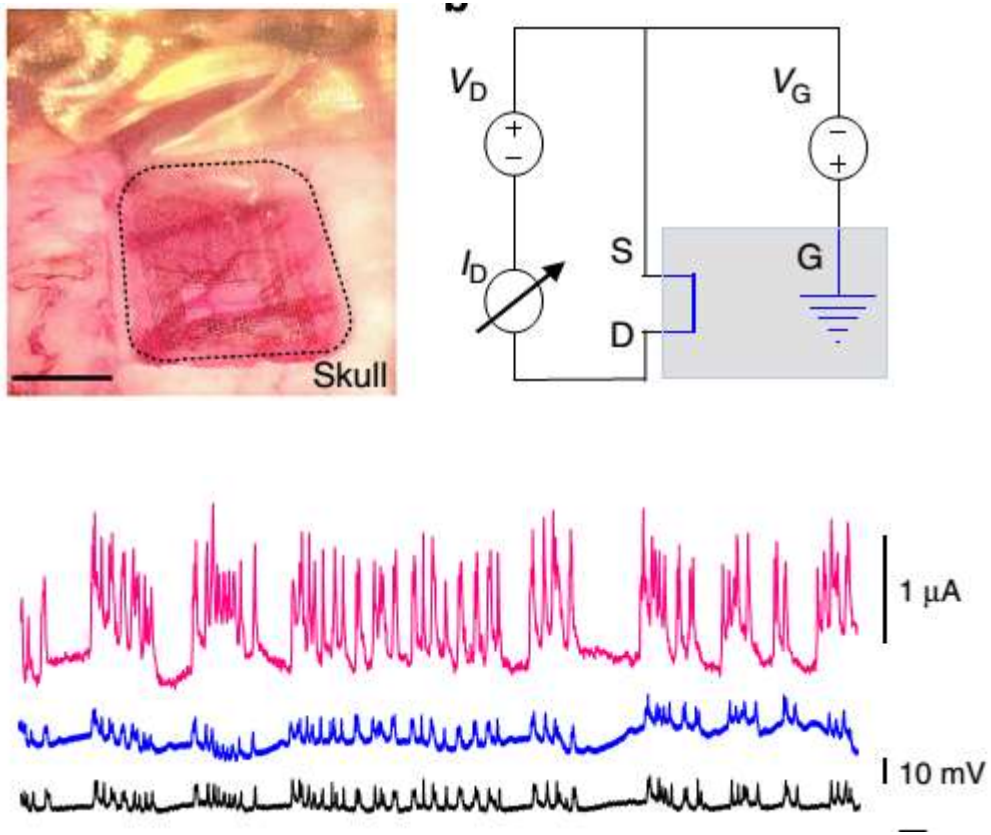


High-performance transistors for bioelectronics through tuning of channel thickness

Jonathan Rivnay, Pierre Leleux, Marc Ferro, Michele Sessolo, Adam Williamson, Dimitrios A. Koutsouras, Dion Khodagholy, Marc Ramuz, Xenofon Strakosas, Roisin M. Owens, Christian Benar, Jean-Michel Badier, Christophe Bernard,George G. Malliaras (2012)

Recordings of brain activity





Summary

- Sensing area:
  - Active semiconductor/electrolyte
  - Gate/electrolyte
  - Semiconductor
  - Electrodes
- Sensing mechanism:
  - Morphology variation
  - Charge injection
  - Field effect modulation
- Structures:
  - OECT
  - EGOFET
  - OFET