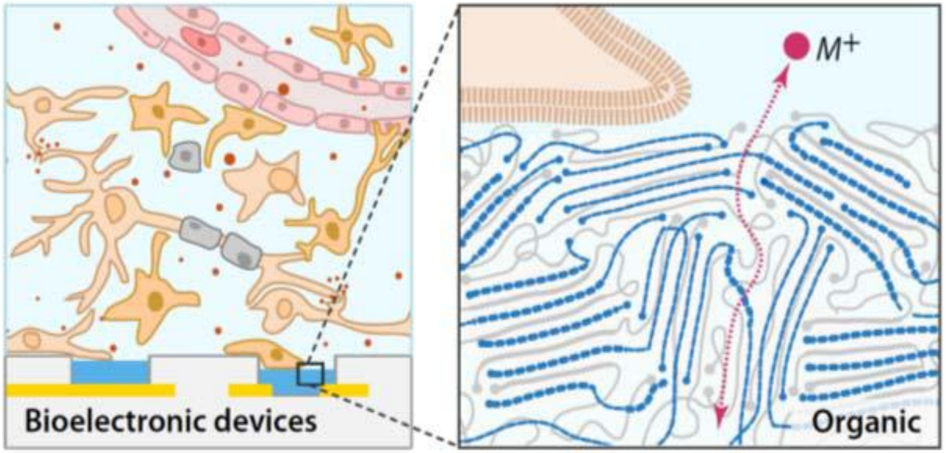
Novel concepts for biosensors: focus on OECT

MINES Saint-Étienne



Organic electronics at the interface with biology

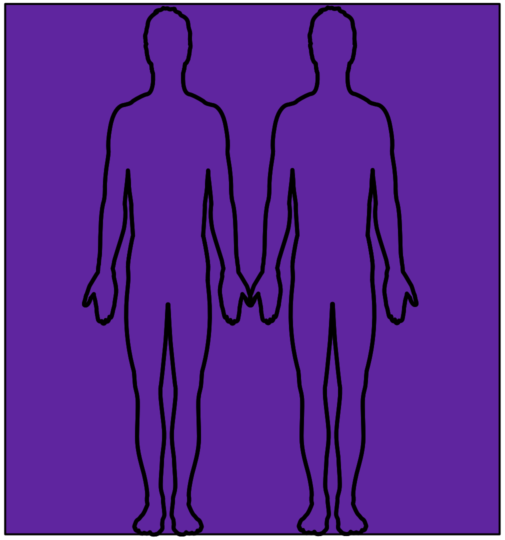
Róisín M. Owens (*owens@emse.fr*)

Outline

- **Part I:**
  - Why do we want to interface with biology?
  - Why use organic electronic materials for interfacing with biological systems?
  - What are the levels of complexity of biological systems?
    - Examples of biorecognition elements showcasing interface with organic electronics
- **Part II:**
  - Organic bioelectronics for tissue monitoring
- **Future perspectives**

Why do we want to interface with biology?

Reasons for interfacing with biology



Health

?

The Environment

Fundamentals **Diagnostics** **Treatment**

Why use organic electronic materials for interfacing with biological systems?

Why do we want to do electronic monitoring

- **Electronic monitoring provides continuous, dynamic readouts**

- **Can be compatible with optical imaging if necessary**
  - Organic electronic materials can be transparent

- **Electronic monitoring is label free – doesn't rely on chromophores or labels necessary for optical techniques**
  - Can be very sensitive, yielding results beyond optical resolution of Ernst Abbe

Traditional applications for organic electronics

Light emitting diodes

Samsung

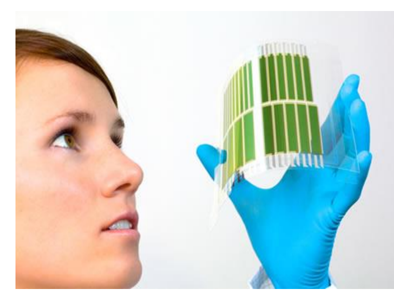
Astron FIAMM

Thin film transistors

DuPont

Someya Lab

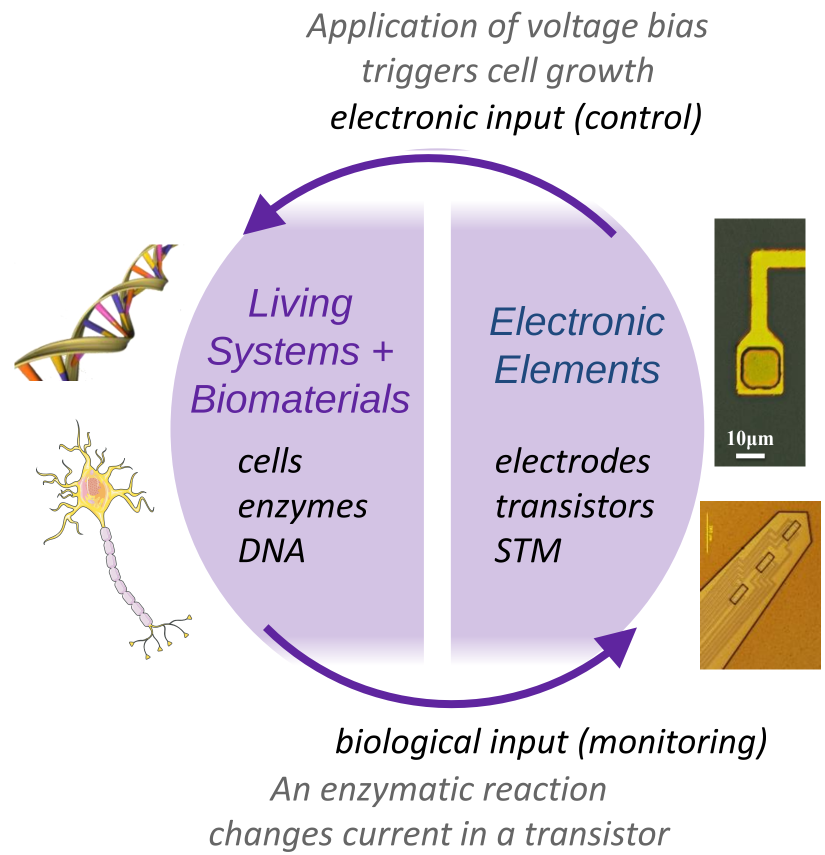
Photovoltaics



Heliatek

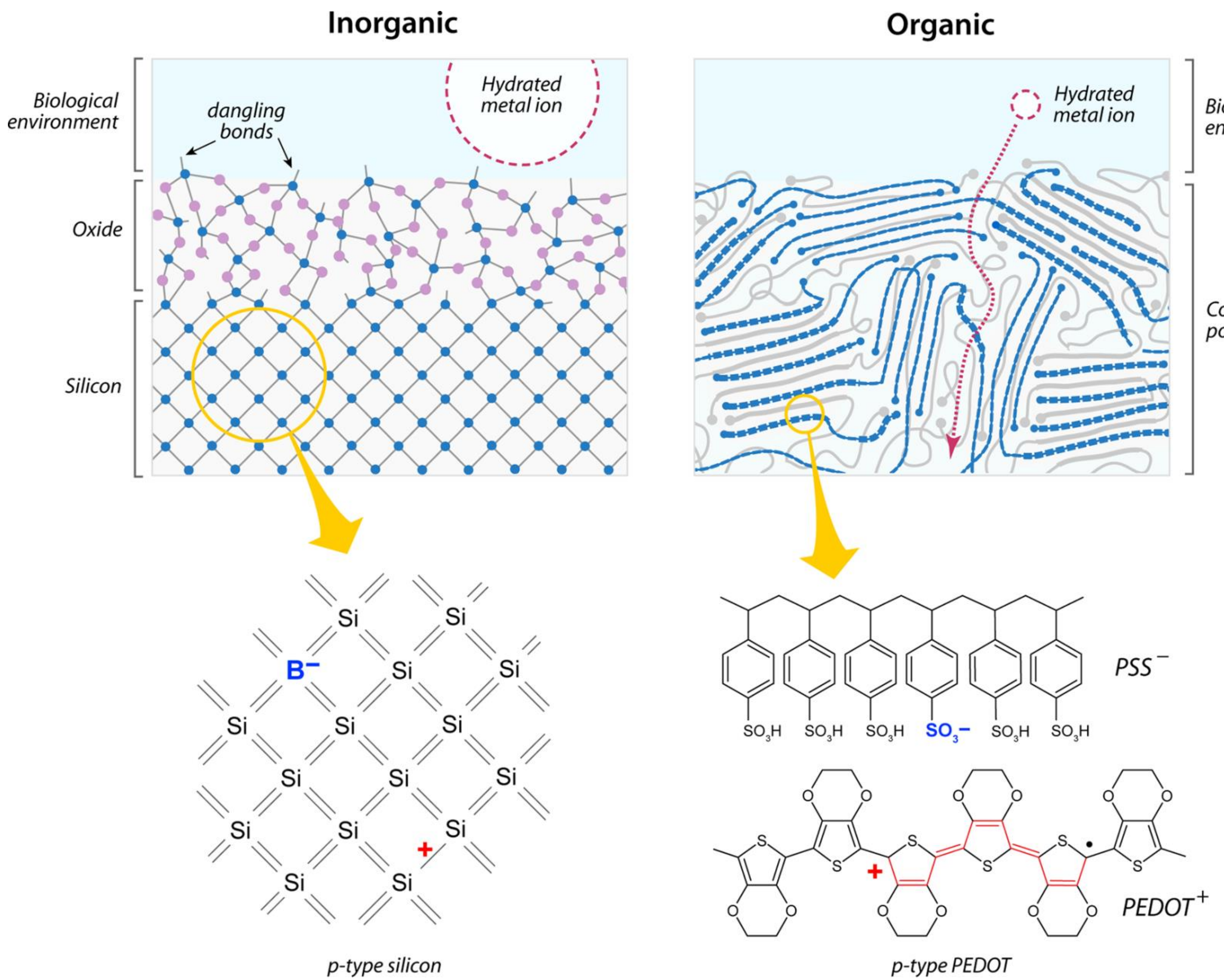
Organic electronics offer unique opportunities

- **Mechanical Properties**: *Similar to tissue, improved implant stability*
- **Ideal surfaces/interfaces**: *high sensitivity, low noise*
- **Ionic conductivity**: *electrical interfacing with biological systems*
- **Processing**: *low cost fabrication, disposable devices*
- **Tunability of electronic properties**: *tailor for specific applications*



Organic electronic materials provide a new toolbox for interfacing with biology

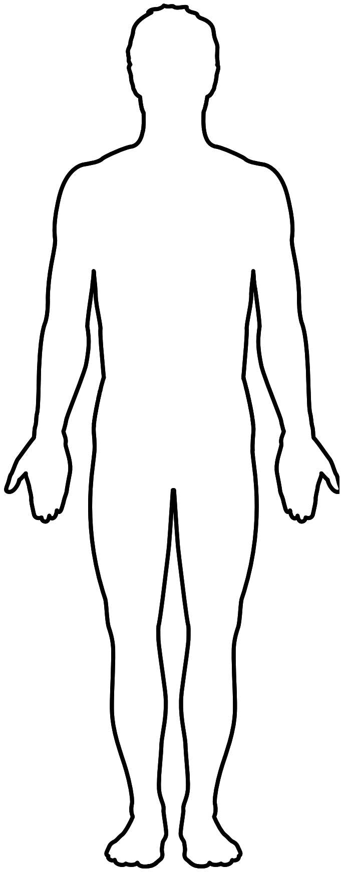
Comparison of inorganic and organic materials

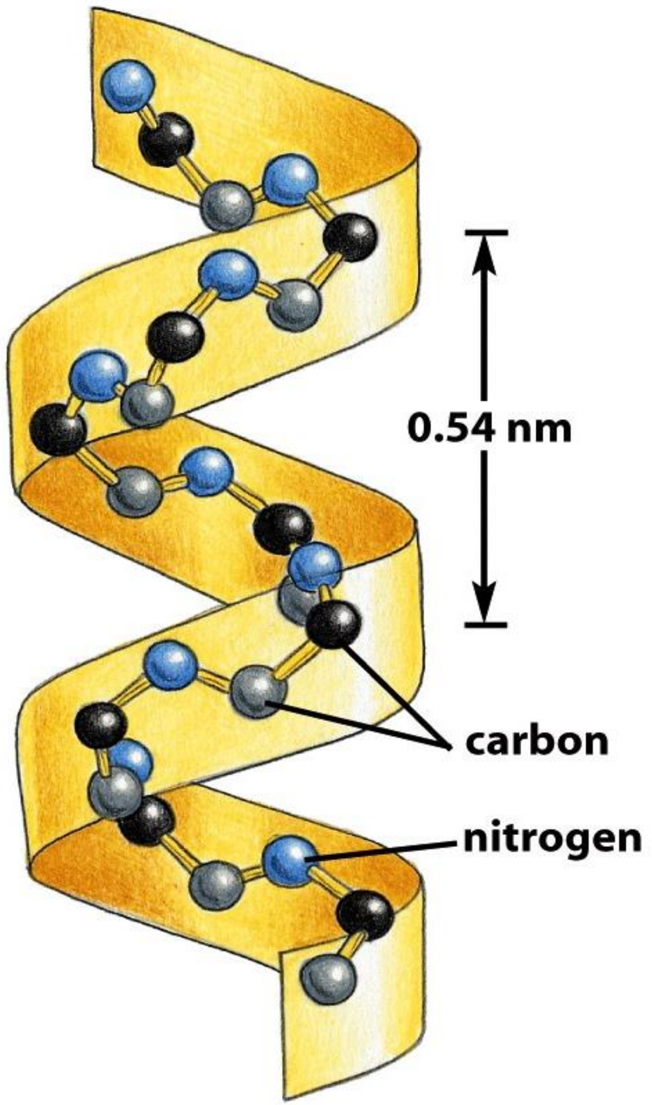


What are the levels of complexity of biological systems?

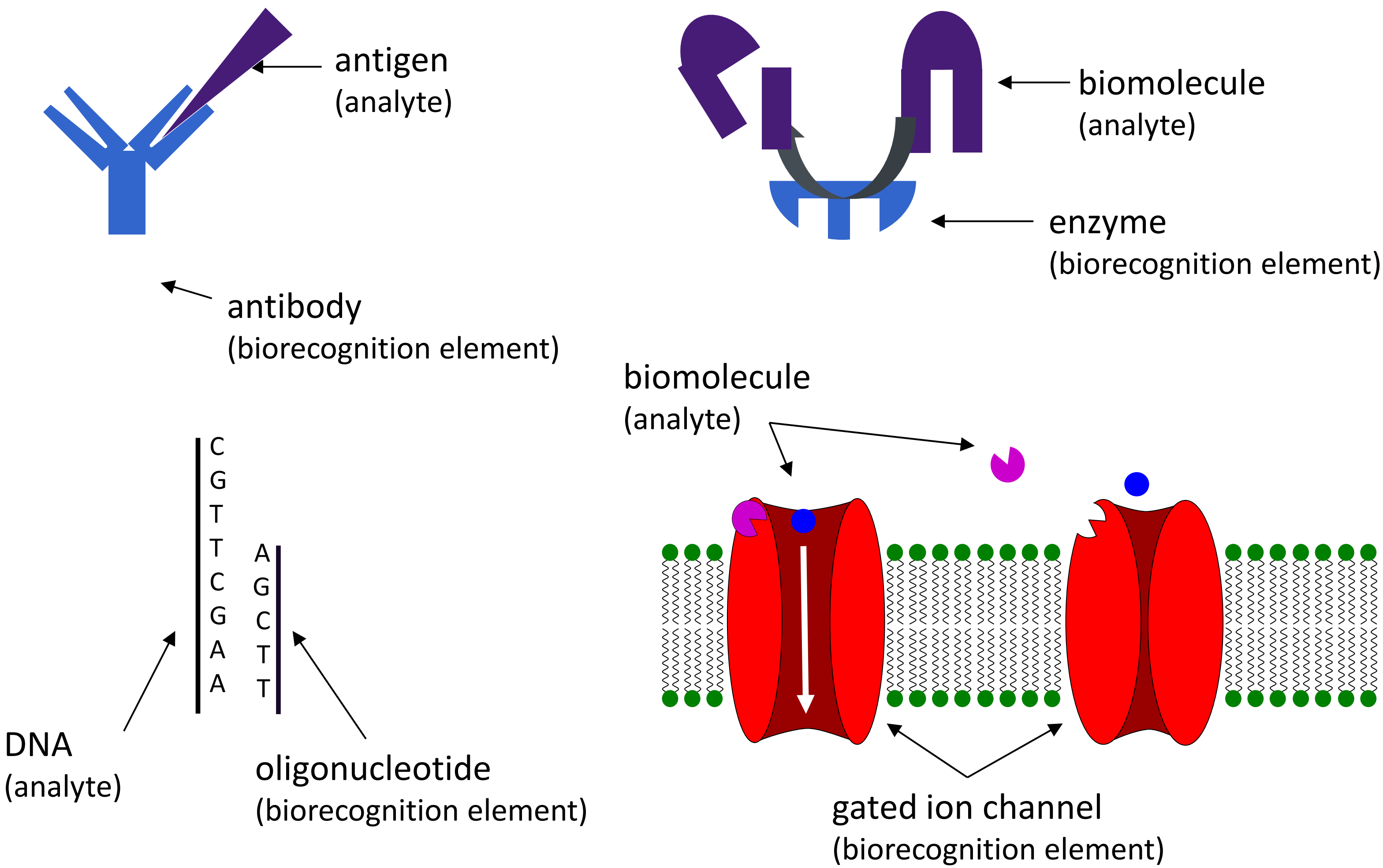
On what level can we integrate organic electronics to biological systems?

Levels of organisation in animal physiology

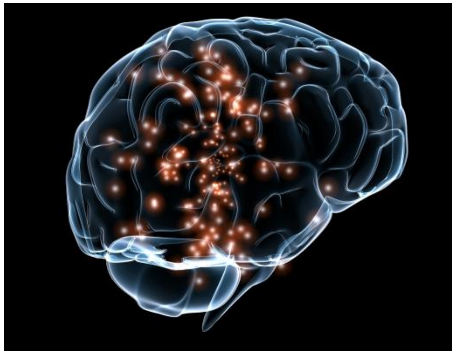




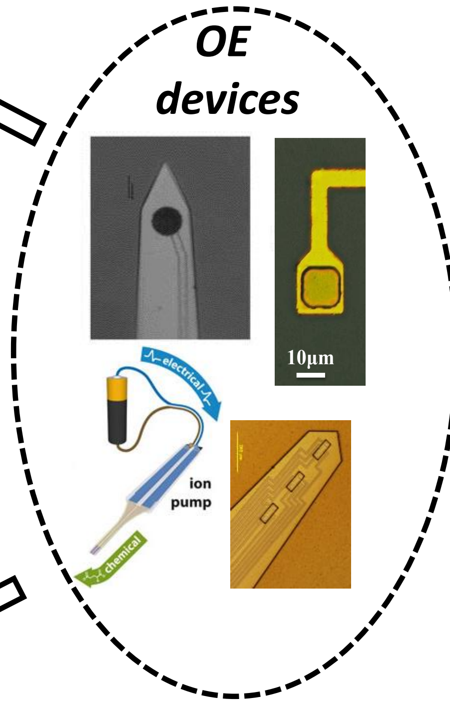
Biorecognition elements



Interfacing organic electronics with organs



Kim *et al, Frontiers in Neuroengineering* (2007)
Khodagholy *et al*, Nature comm; 4, 1575 (2013)



Simon *et al*, *Nat Materials ; 8 (9)* (2009)

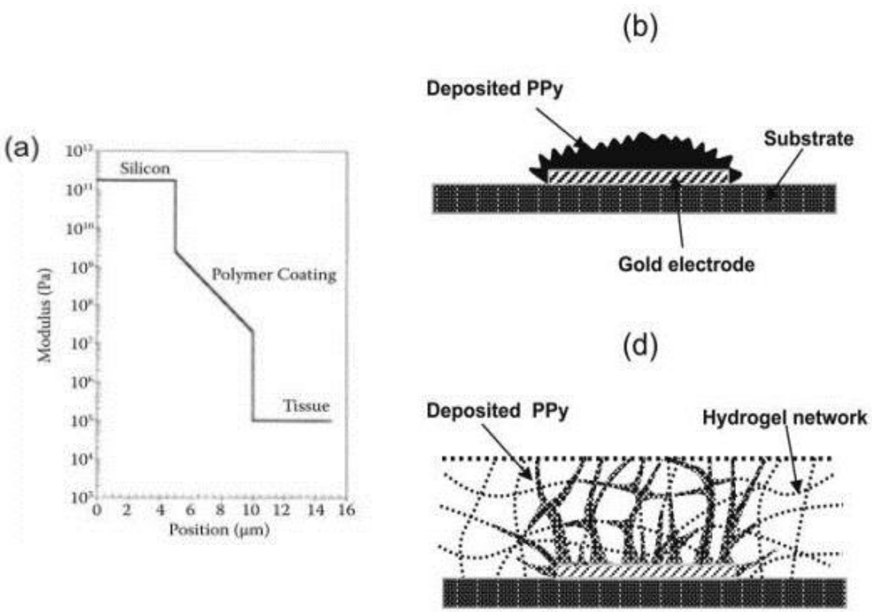
Leleux *et al*, *AHM;* (2014)
Campana *et al*, *Adv Mat;26 (23)* (2014)

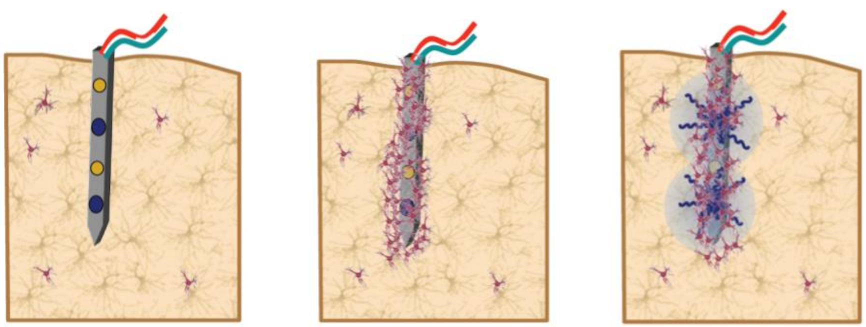
Ghezzi *et al*, *Nat Comm ; 8 (9)* (2011)

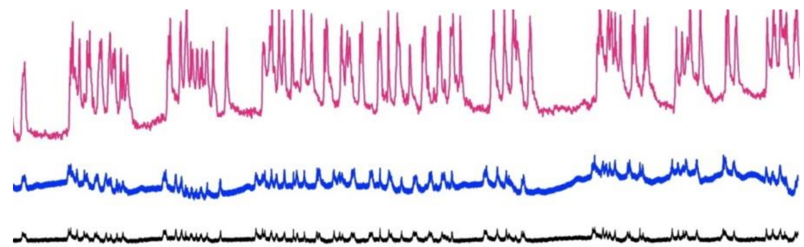
Improving brain: electrode interface with CPs

Better mechanical matching

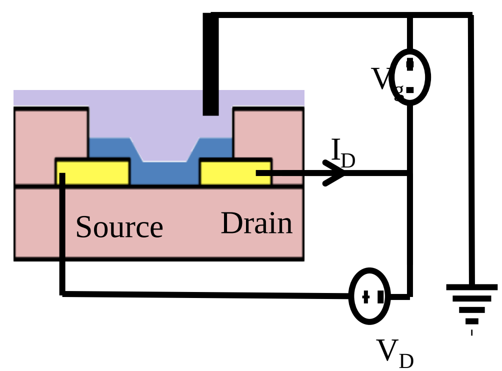
Improved signal transduction

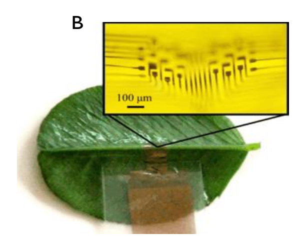






OECT: more sensitive, less invasive

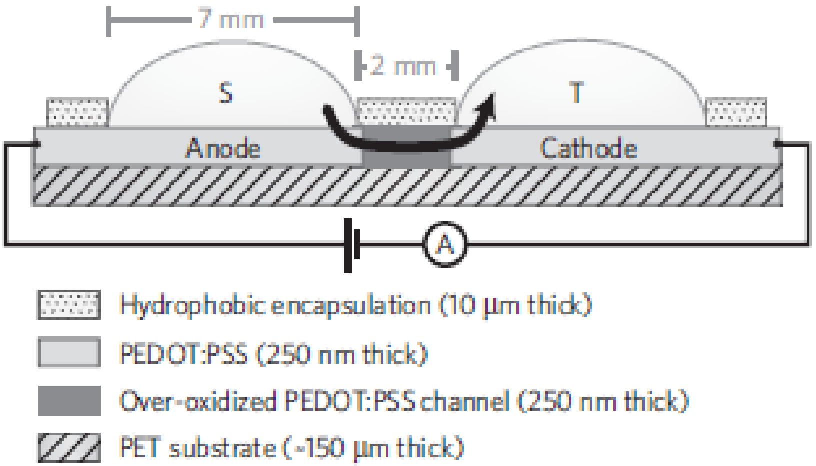


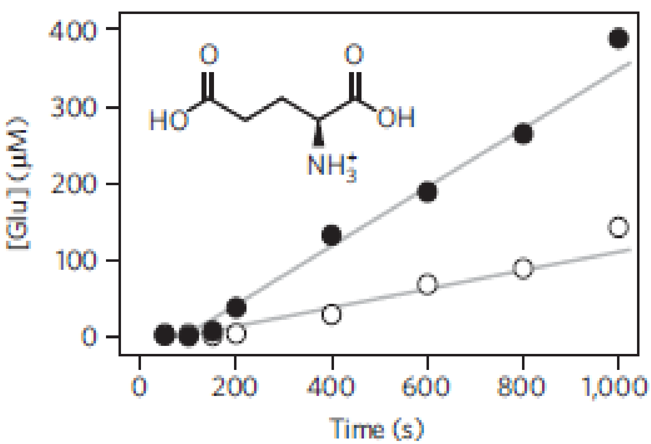


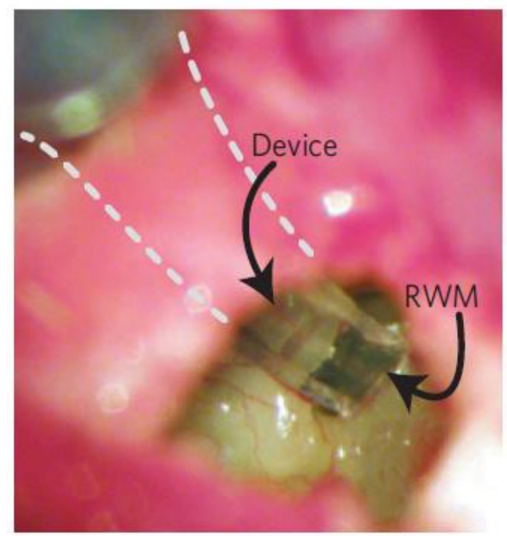
Kim *et al*, *Frontiers in Neuroengineering* (2007)

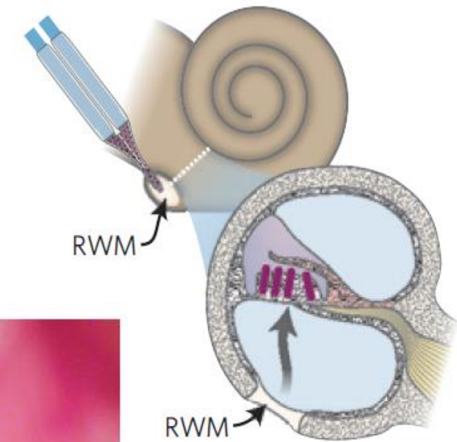
Delivery of neurotransmitters with organic ions pumps

Spatial control of delivery





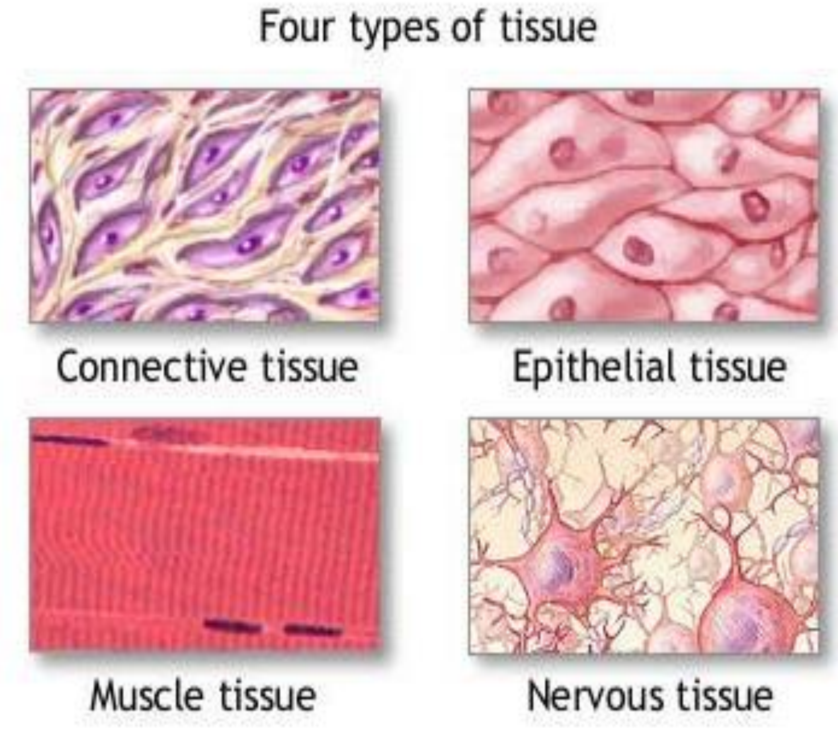




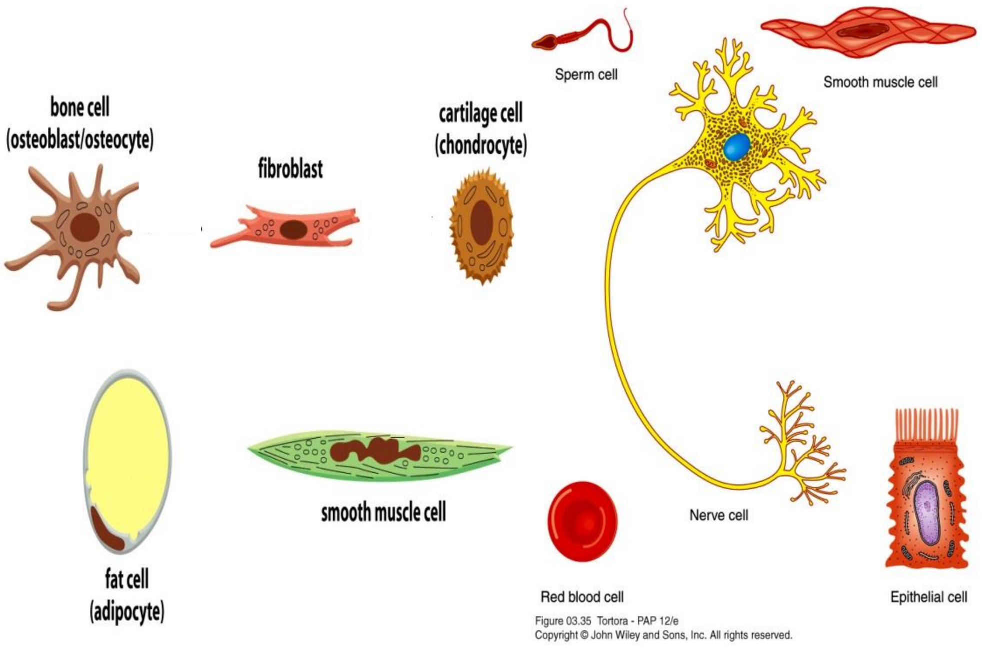
Simon *et al*, *Nat Materials ; 8 (9)* (2009)

Interfacing organic electronics with tissues/cells

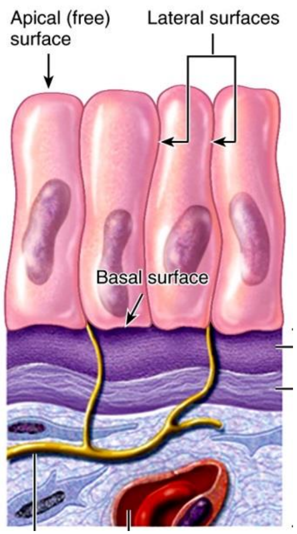
Four types of tissue in animals



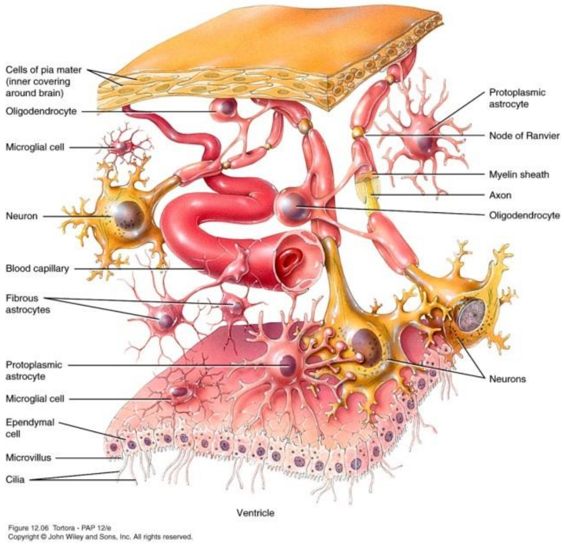
Over 200 types of cells



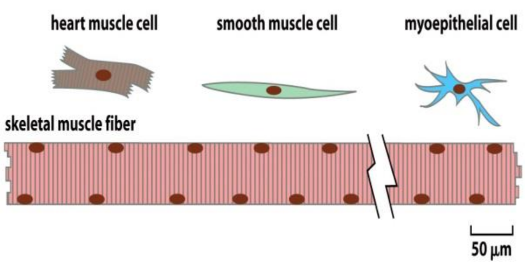
Interfacing organic electronics with tissue/cells



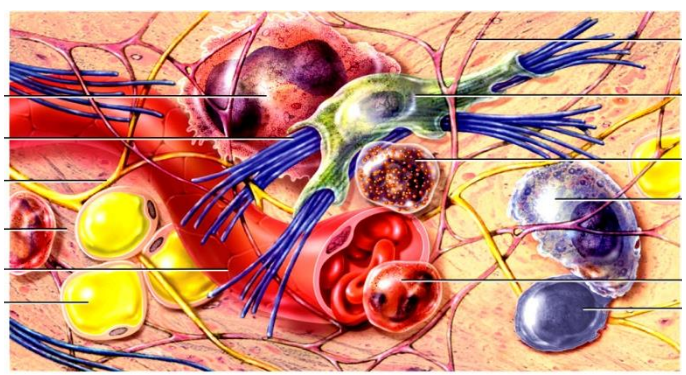
Yao et al*, Adv Mater* (2013)
Jimison, L.H., et al. *Adv Mat* 24 (44) *2012*



Lee *et al, Biomaterials* (2009)

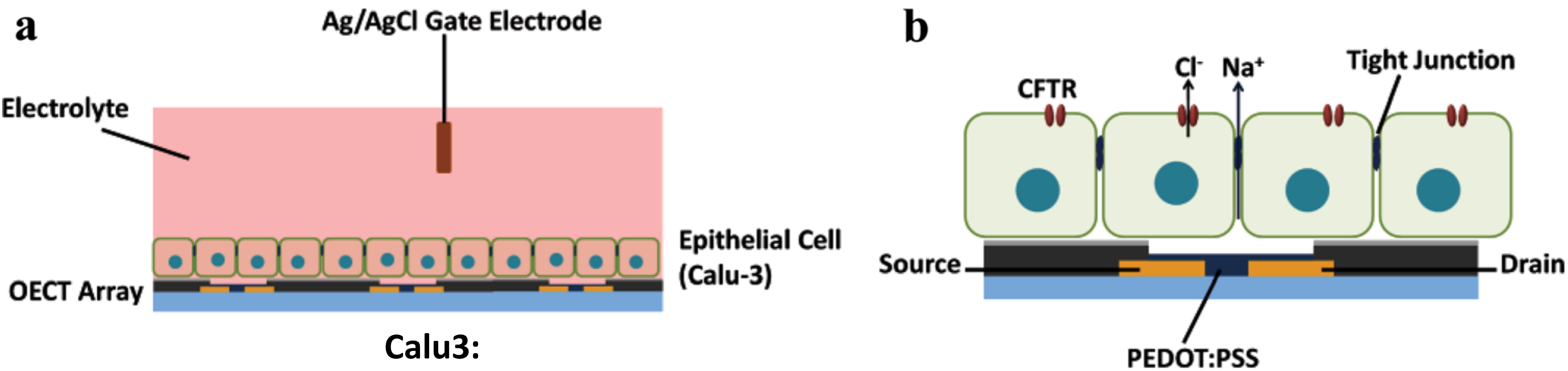


Breukers *et al, J. Bio. Mat Res Part A* (2010)

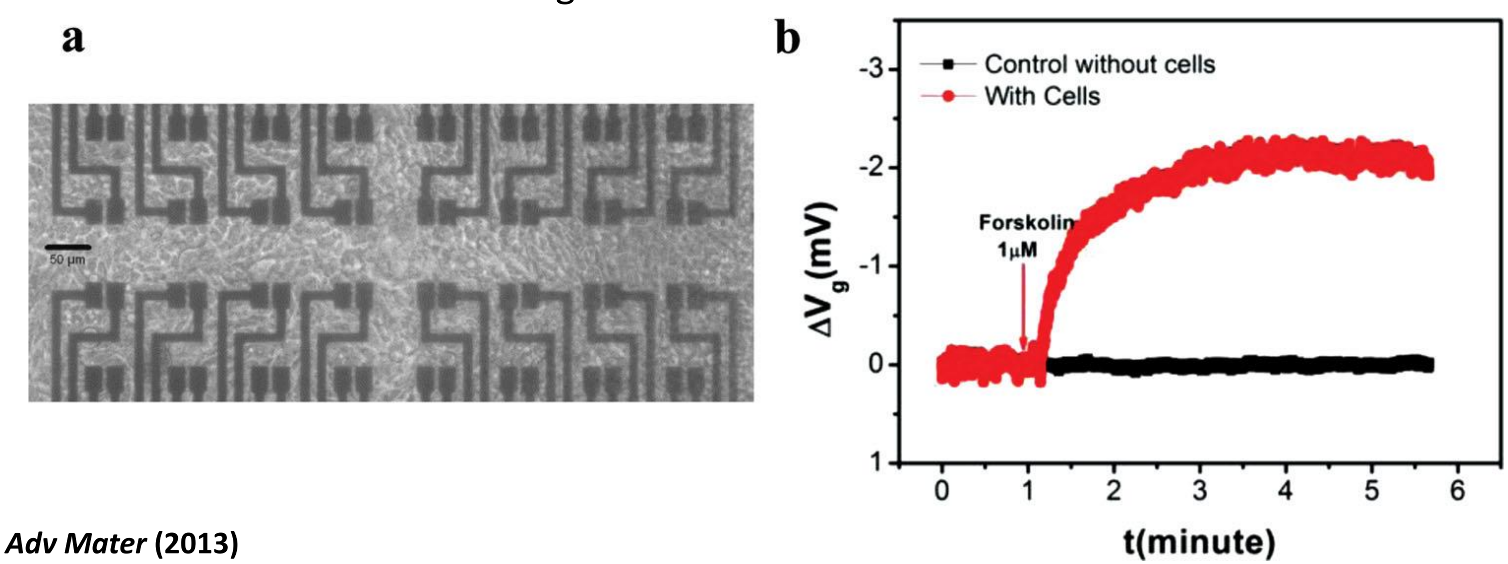


Interfacing with epithelial tissue: OECTs

Improved signal transduction



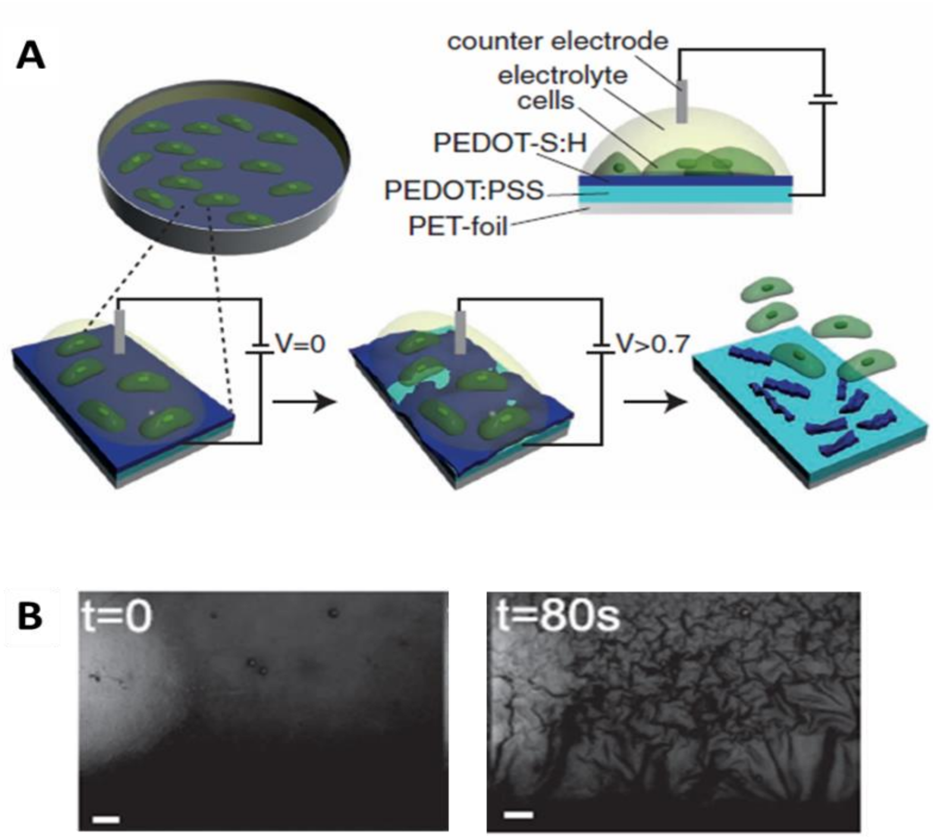
Calu3:
in vitro model for the lung



Yao et al*, Adv Mater* (2013)

Organic electronic materials designed for function

Tunable chemistry



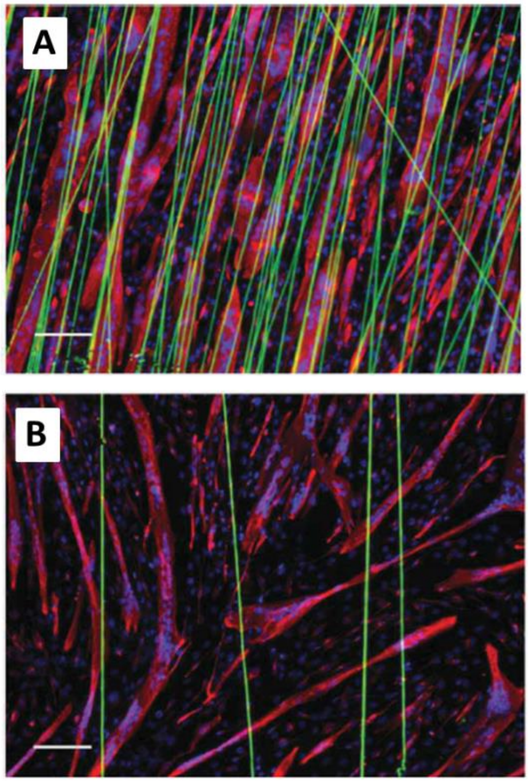
OE material provides advantage for tissue engineering

Persson *et al, Adv Mater* (2011)

Controlling cell migration/proliferation with OE

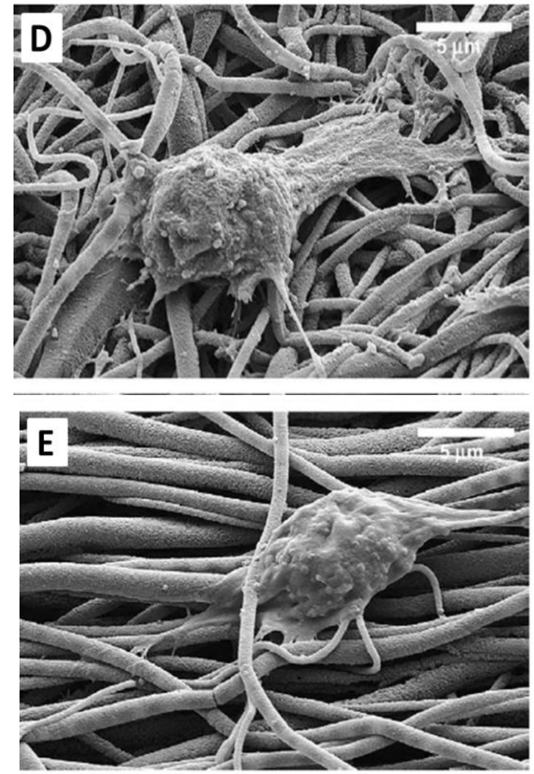
Tunable chemistry; mixed ionic/electronic signals

Muscle cells



Breukers *et al, J. Bio. Mat Res Part A* (2010)

Neurons

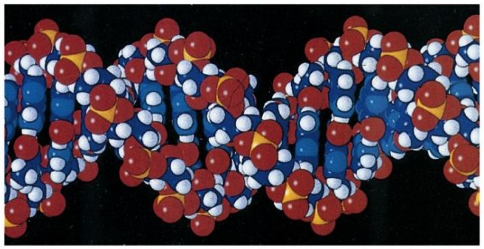


Lee *et al, Biomaterials* (2009)

OE materials combine topographical and electrical stimuli

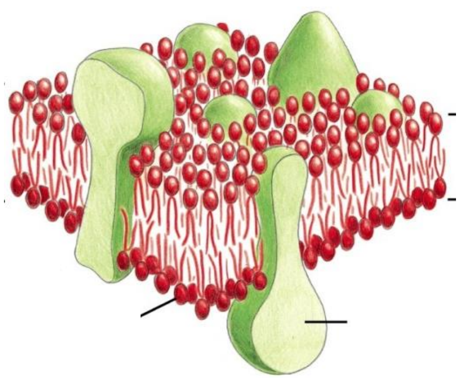
Integration at the level of macromolecules

Nucleic acid



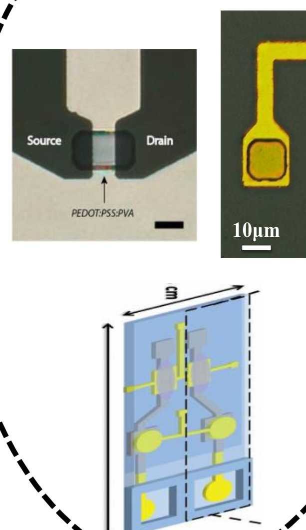
Lai *et al*, *Adv Mat 25* (2013)
Lin *et al*, *Adv Mat 23* (2011)

Lipids



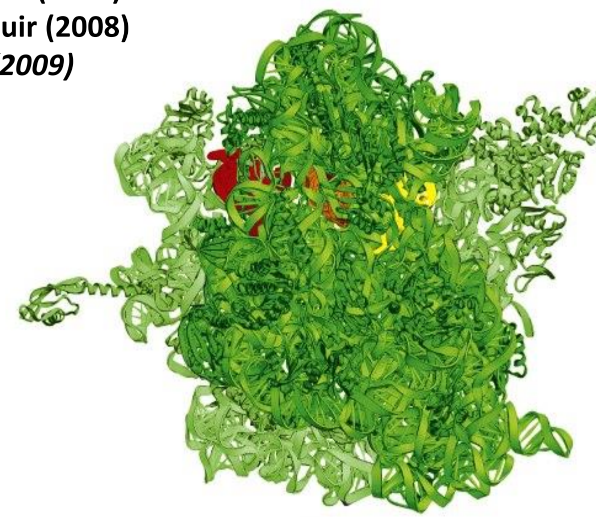
Angione *et al*, PNAS (2012)
Bernards *et al,* APL (2006)

OE devices

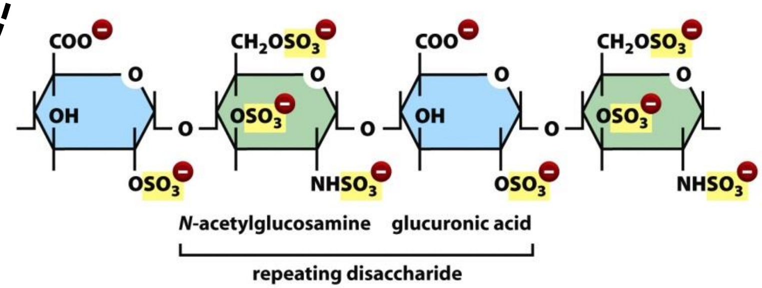


Wan *et al*, Adv Mat (2011)
Salto *et al* Langmuir (2008)
Shim *et al LOAC (2009)*
….

Proteins



Polysaccharides

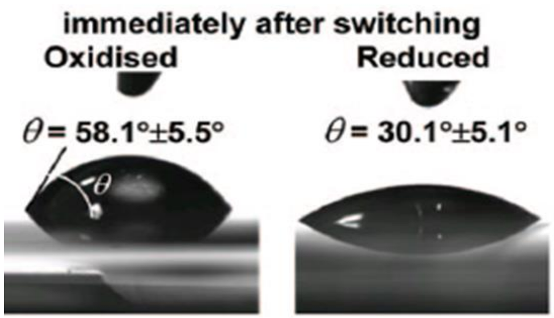


Irimia Vladu et al *Adv F Mat* 23 (2010)
Zhong *et al* Nat Comm 2 (2011)

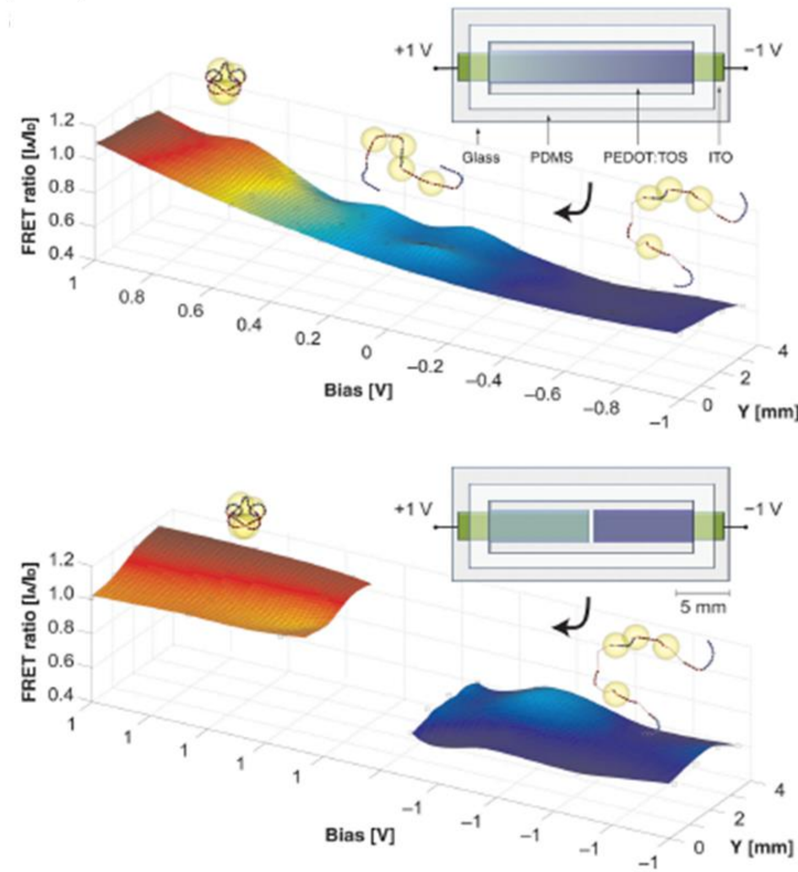
Electrical control of protein conformation with OE devices

Tunable chemistry; mixed ionic/electronic signals

$$\mathrm{PEDOT^{+}:PSS^{-}} + \mathrm{M^{+}} + e^{-} \rightleftharpoons \mathrm{PEDOT^{0}} + \mathrm{PSS^{-}:M^{+}}$$

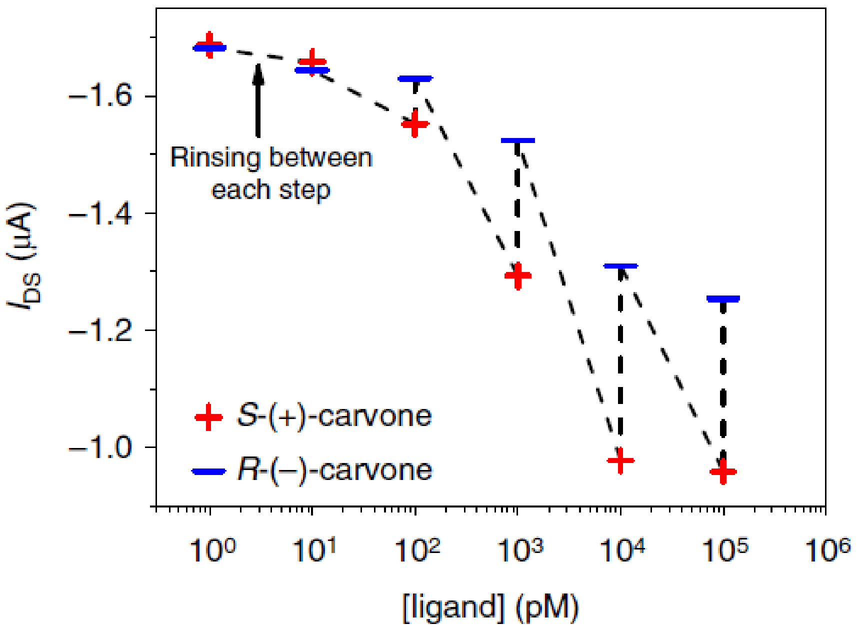


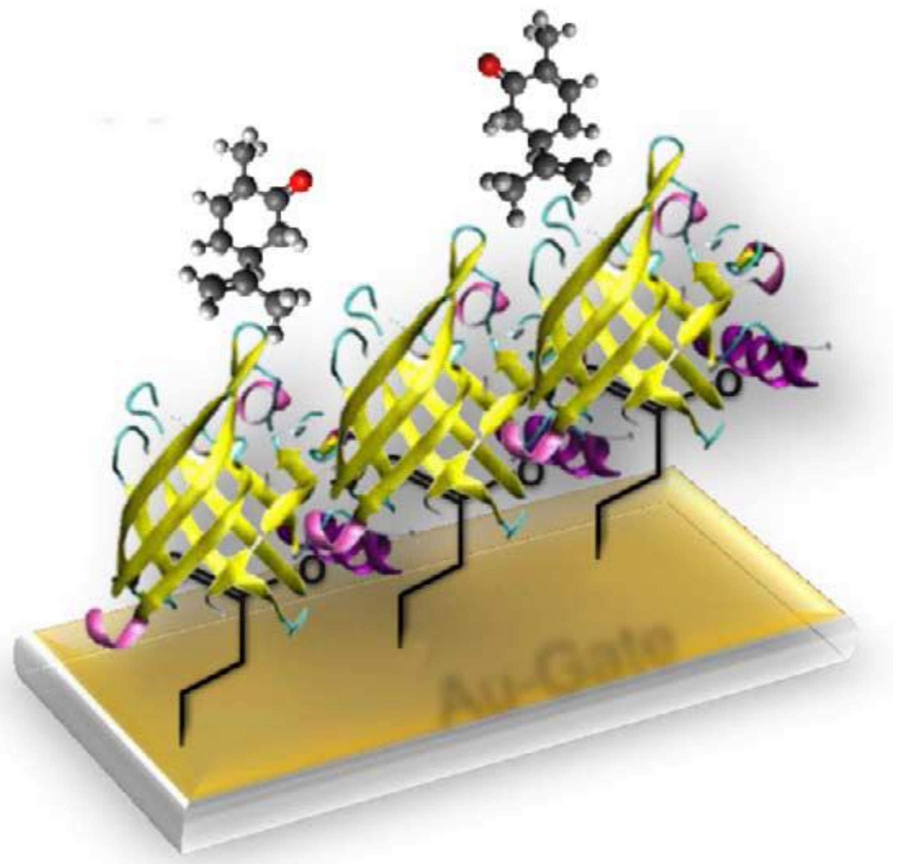
Salto *et al*, *Langmuir* (2008)



Wan *et al*, Adv Mat (2011)

Integration of organic electronics with proteins





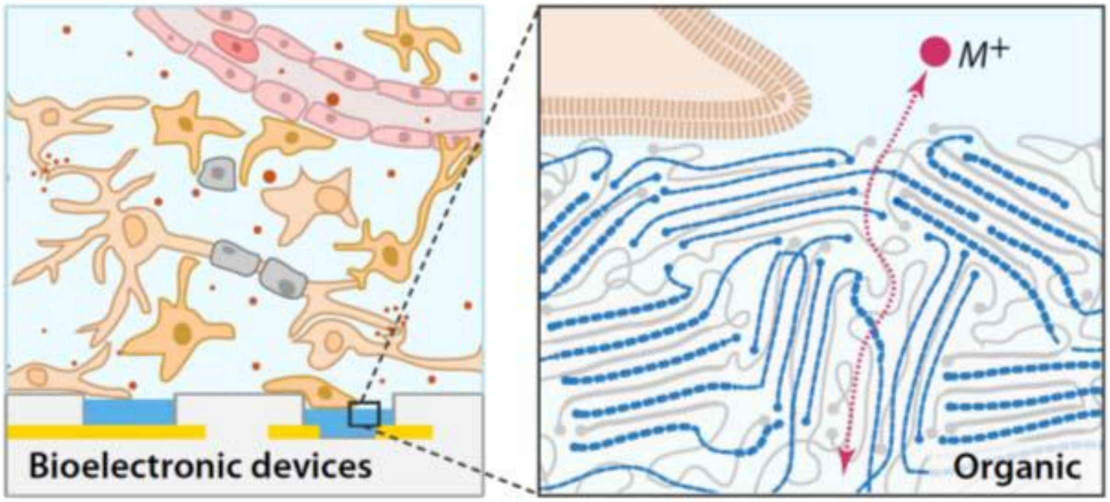
Detection of noncharged molecules and discrimination between enantiomers possible

Torsi et al, *Nat Comm* 2015

Outline

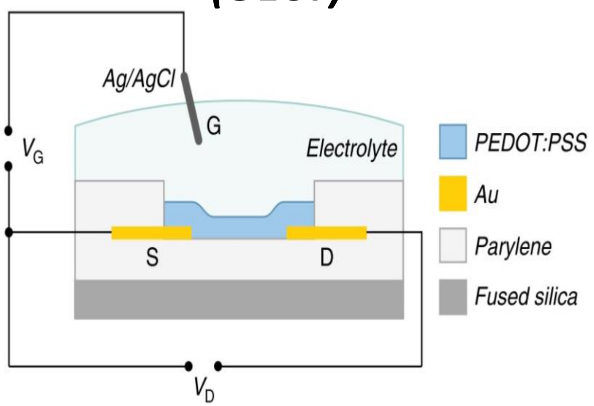
- **Part I:**
  - Why do we want to interface with biology?
  - Why use organic electronic materials for interfacing with biological systems?
  - What are the levels of complexity of biological systems?
    - Examples of biorecognition elements showcasing interface with organic electronics
- **Part II:**
  - The Organic electrochemical transistor for biomedical applications
- **Future perspectives**

Interfacing organic electronic devices with biology:

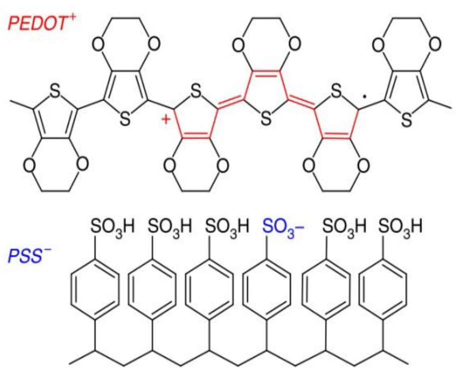


- **Mixed conductivity**: *signal transduction*
- **Processing**: *disposable devices*
- **Mechanical Properties**: *improved stability, flexible, hydrogel-like*
- **Chemistry**: *application specific*
- **Ideal interfaces:** *no oxides, sensitive*
- **Optical transparency:** *high res. images*

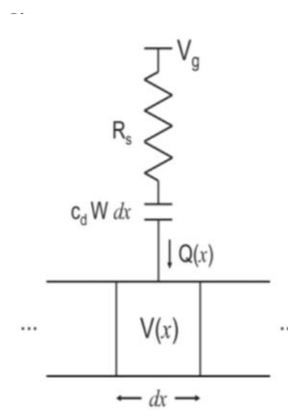
Organic electrochemical tranistor (OECT)



PEDOT:PSS

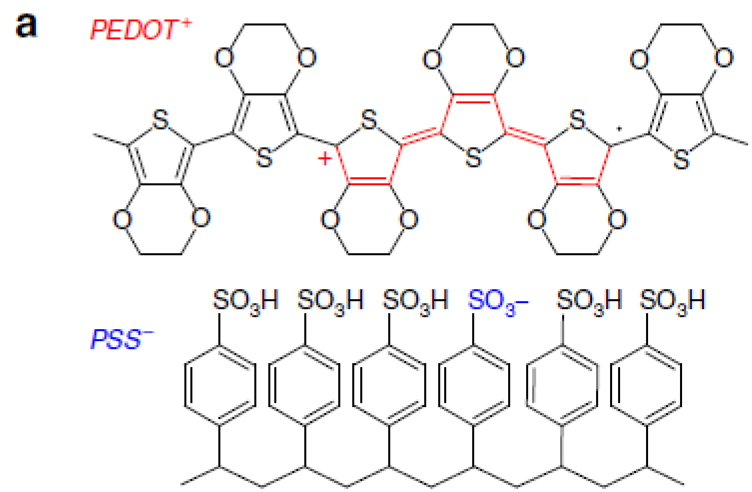


Electronic and Ionic circuits



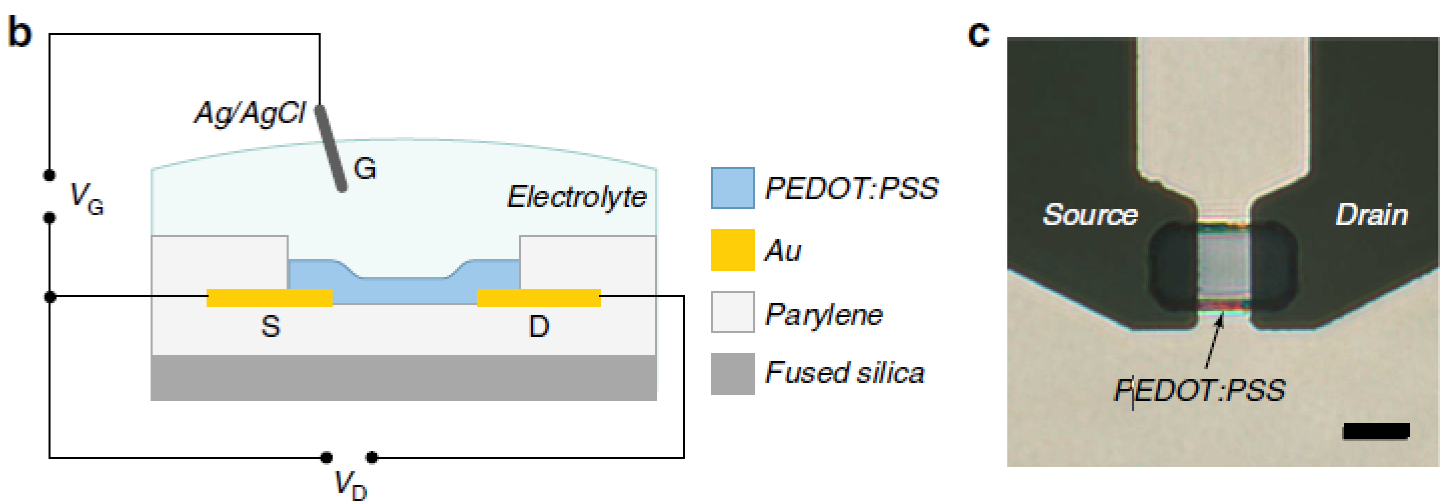
Rivnay, J., Owens, R.M, Malliaras, G. *Chem. Mater.*, 26 (1), 2014

The Organic Electrochemical Transistor (OECT)



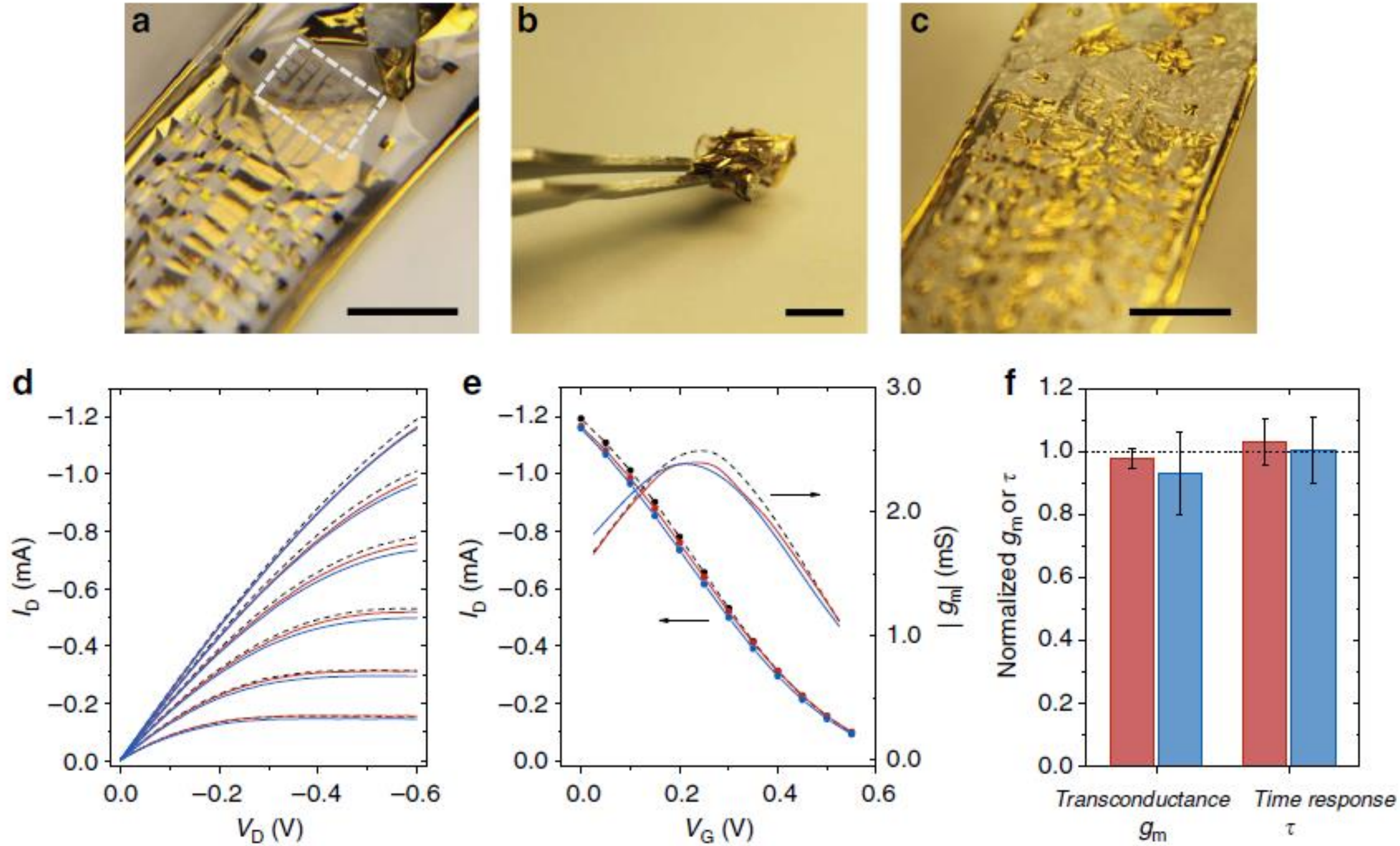
$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$$

PEDOT:PSS= 4.2 mS
Graphene = 0.420 mS
Silicon = 0.015 mS



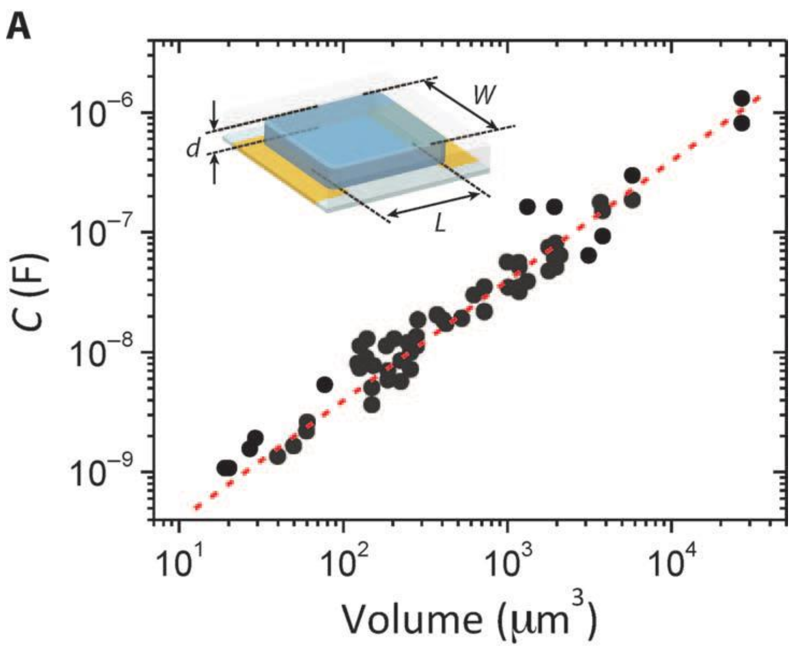
Rivnay *et al, Nature Communications* (2013)

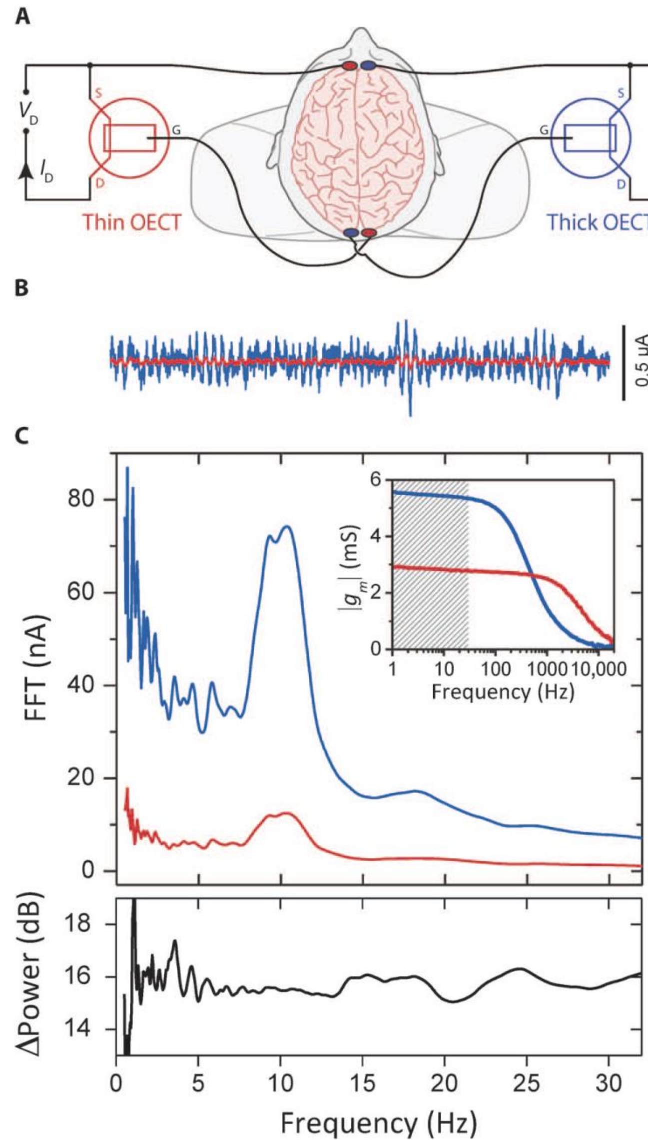
Rugged, high transconductance devices



Rivnay *et al, Nature Communications* (2013)

OECTs display volumetric capacitance





Rivnay *et al, Science Advances* (2015)

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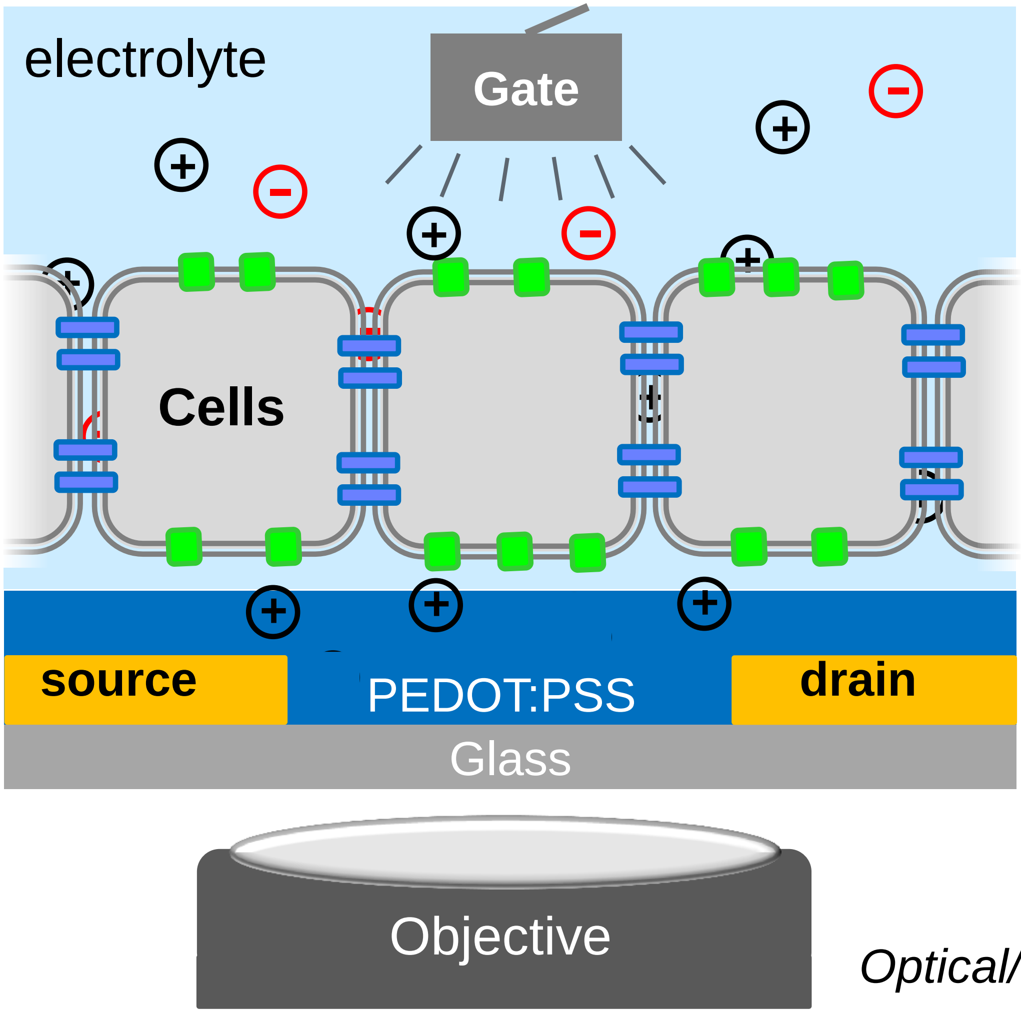
OECT application 1: Interfacing with live cells



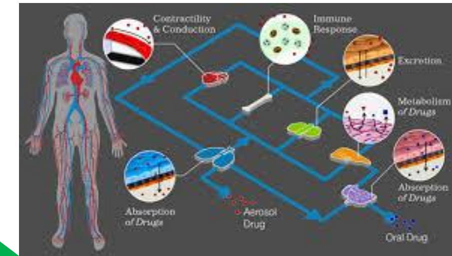
- *Integrated, robust device platform*
- *Fast response times*
- *Dynamic information captured*
- *Transparent for real time optical monitoring*

Optical/fluoroscence imaging

L.H. Jimison, et al., Adv. Mater. (2012)

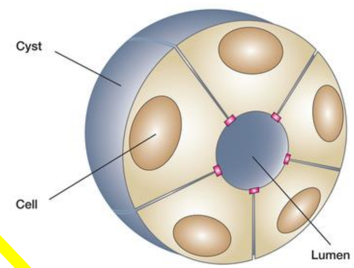
Cell growth *in vitro:* monitoring should adapt

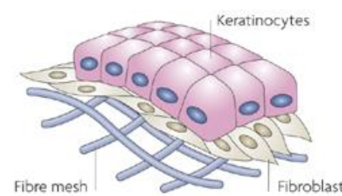
Cell culture systems should be:
- ***Suitable for long-term measurements***
- ***Preferably multiple (human) cell types***
- ***Recreate physiological niche***
- ***Take into account physical and chemical cues***
- ***Should be multi-parameter!!!***

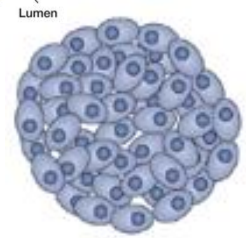


Organoids
Organ-on-chip
Body-on-chip

3D cell cultures

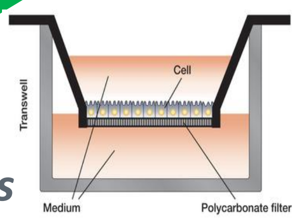


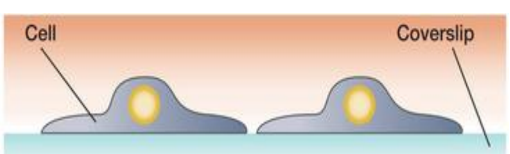




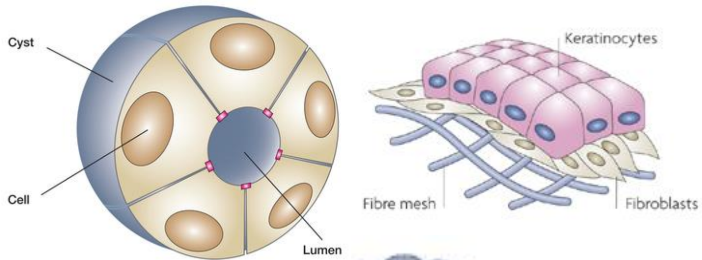
Co-cultures
Layered cultures
Cysts
Spheroids

2D cell cultures

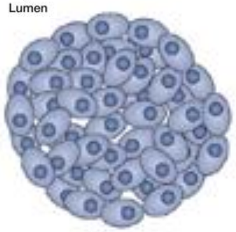




Cells *in vitro:* what can we monitor electrically?



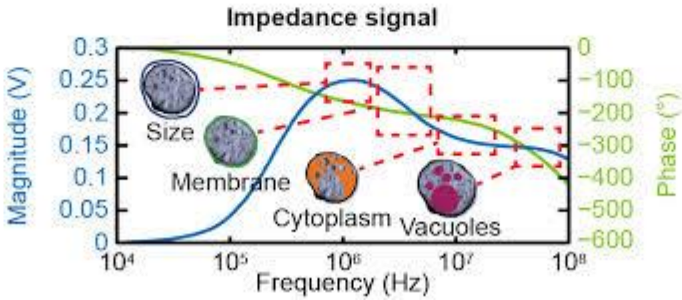
3D cell cultures



Non-electrogenic cells

Electrical impedance spectroscopy:

- Coverage
- Differentiation
- Barrier properties



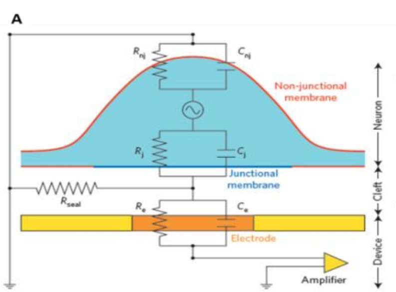
Electrogenic cells

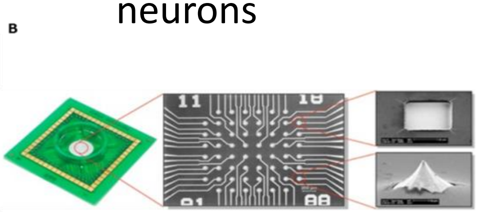
Patch clamp:

- Monitoring action potentials
- Ion channel activity

Micro-electrode arrays:

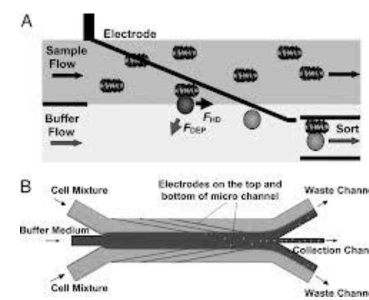
- Activity of single neurons
- Activity of groups of neurons





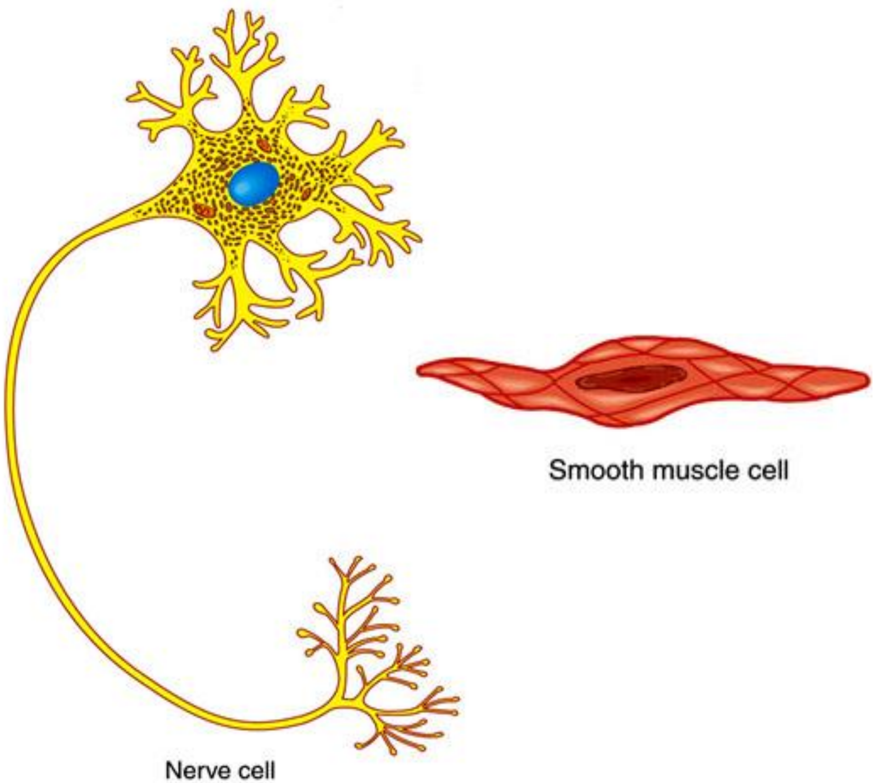
Dielectrophoresis (DEP):

- separation of live and dead cells
- Cancer cells from blood
- Red and white blood cells

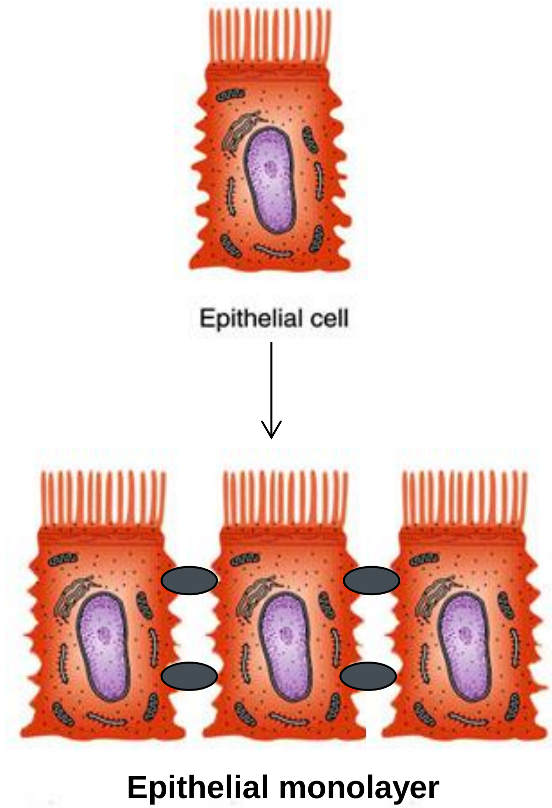


Different types of mammalian cells

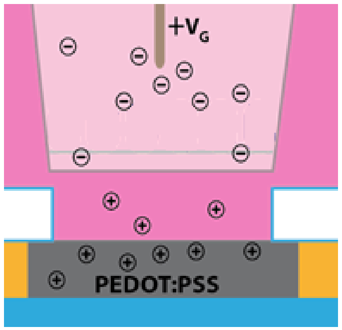
Electrogenic cells



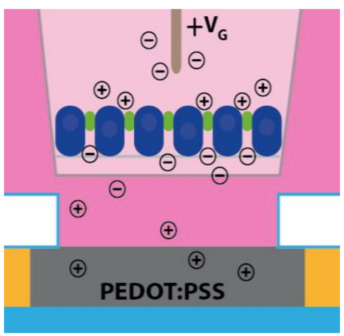
Non electrogenic cells



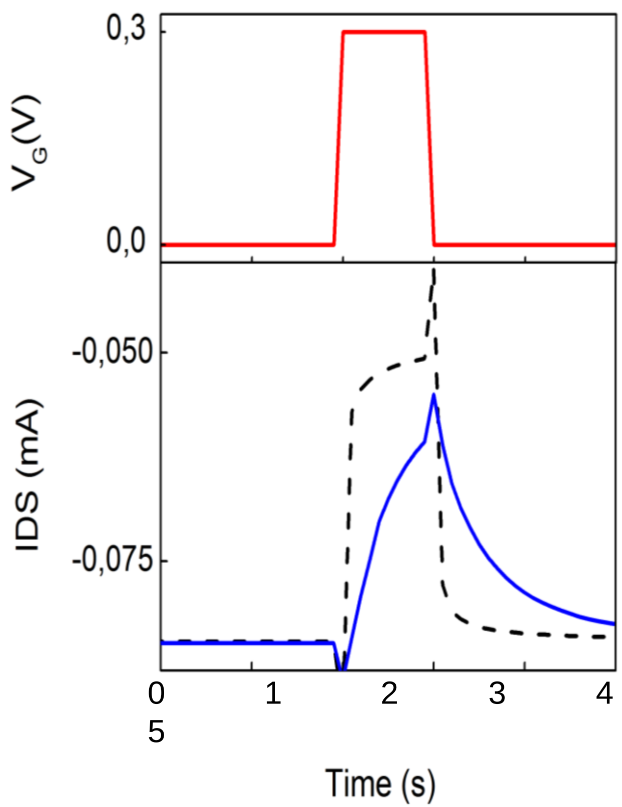
Cell layers modify OECT transient response



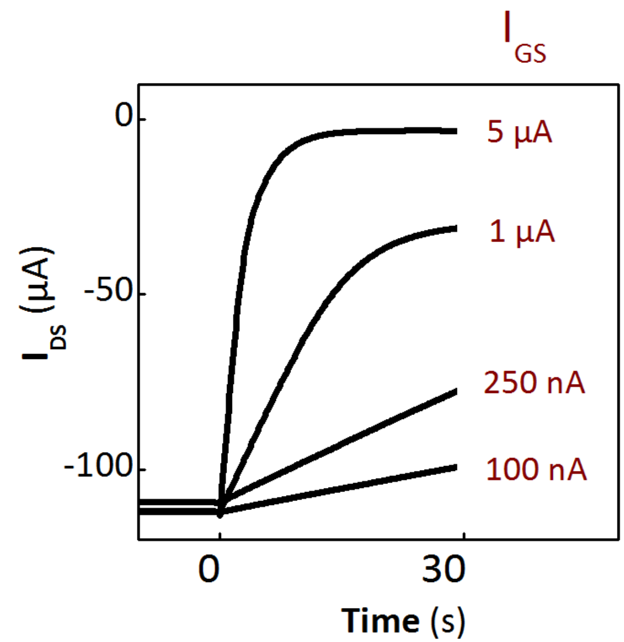
No cells



Healthy epithelium



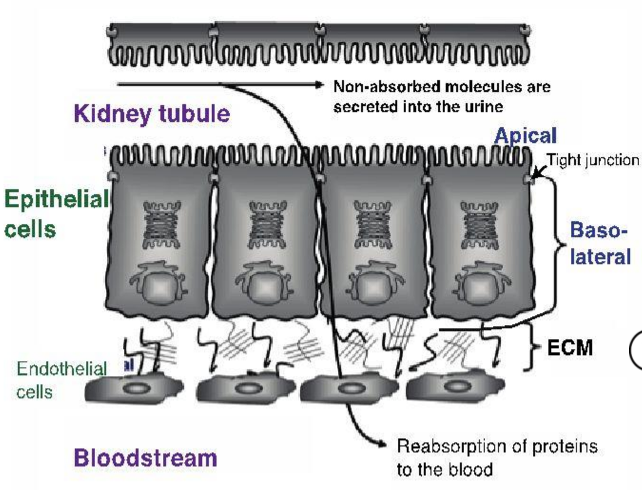
V_G 0.3 V
V_D -0.1 V



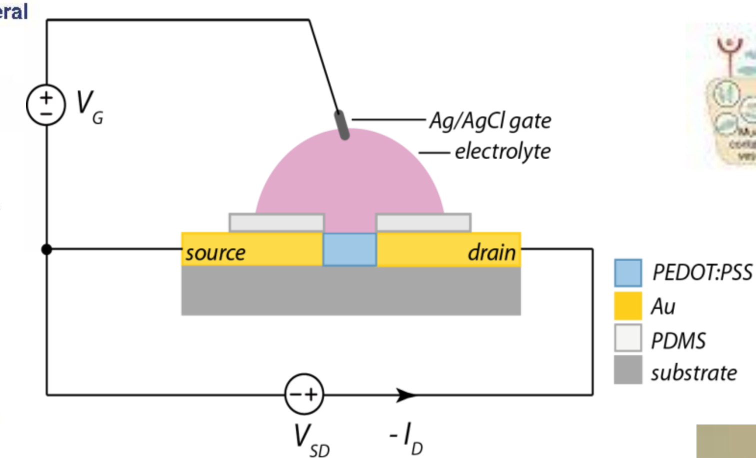
Jimison, L.H., et al. *Adv Mat* 24 (44) *2012*

JOVE video of OECT fabrication

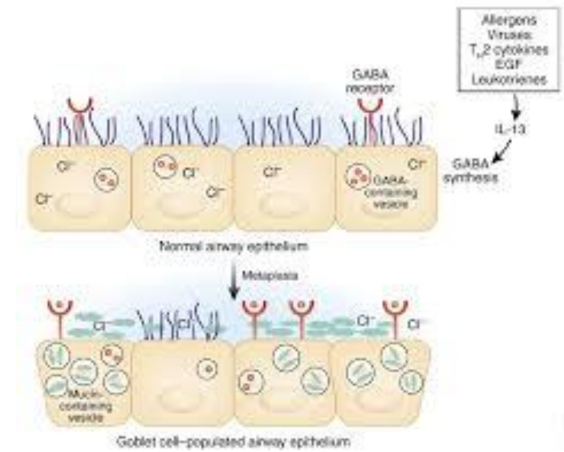
Integration of OECT with other *in vitro* models



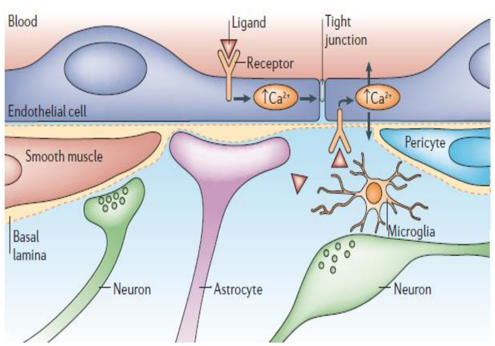
kidney tubule



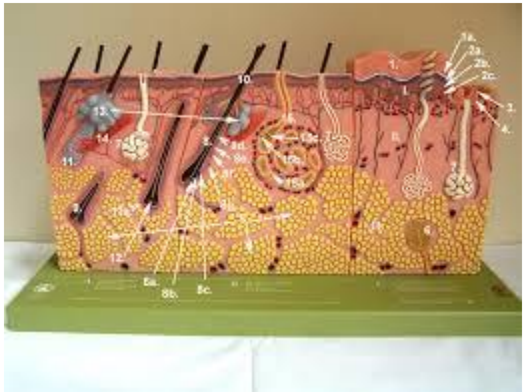
OECT



Airway



blood brain barrier (Abbott)



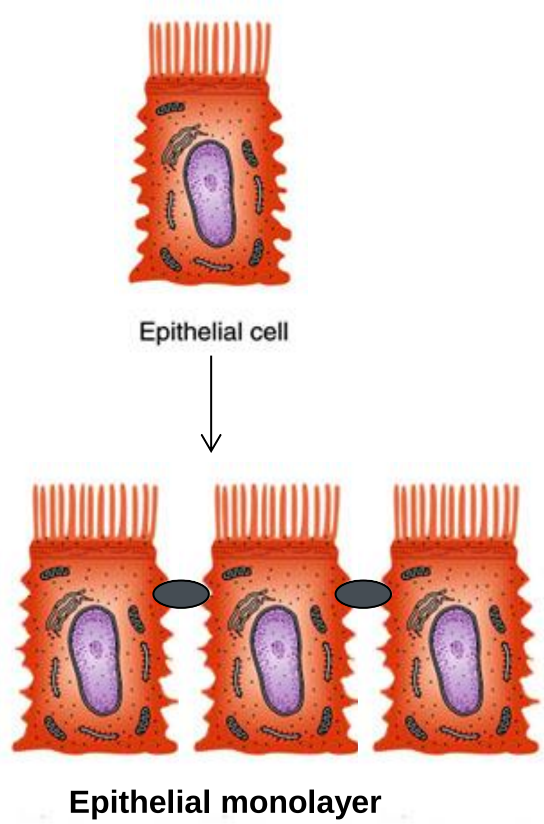
Skin

Monitoring of leaky adherent cell layers?

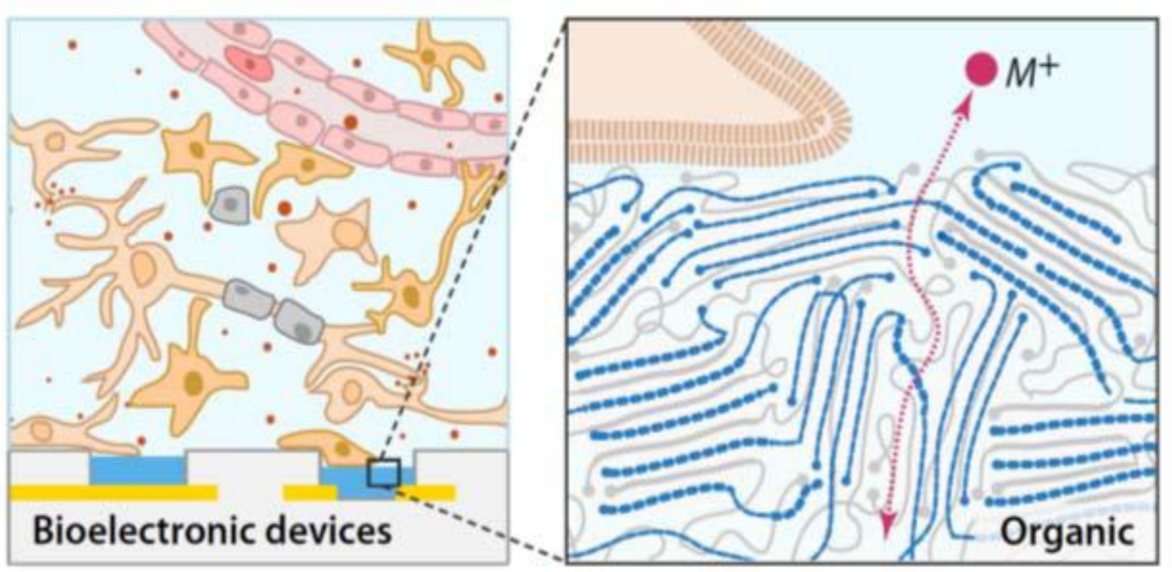
Can we be sensitive to cell layers with low resistance?

Tissue	Species	Rpara ($\Omega.cm^2$)
Proximal tubule	dog	6–7
Gallbladder	rabbit	21
Duodenum	rat	98
Jejunum	rat	51
Ileum	rabbit	100
Distal colon	rabbit	385
Urinary bladder	rabbit	300000

Epithelial cells



Interfacing organic electronic devices with live cells: *advantages of planar device*

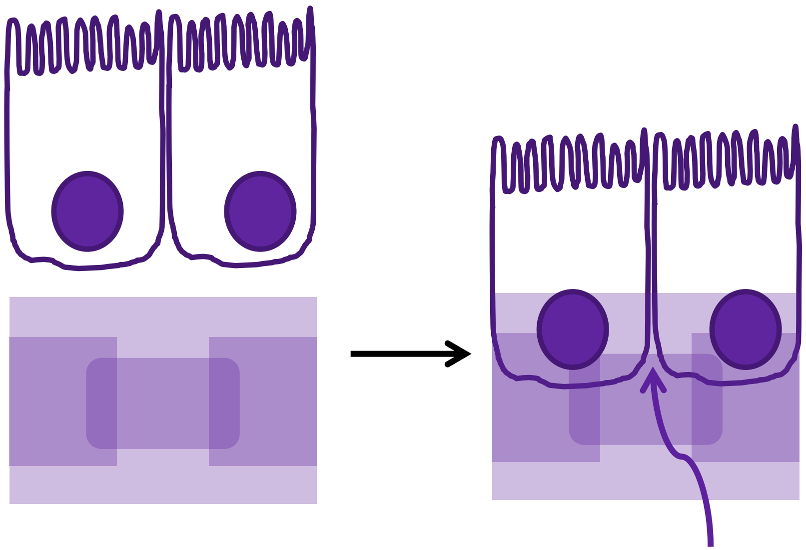


- **Mixed conductivity**: *signal transduction*
- **Processing**: *disposable devices*
- **Mechanical Properties**: *improved stability, flexible*
- **Chemistry**: *application specific*
- **Ideal interfaces:** *no oxides, sensitive*
- **Optical transparency:** *high resolution images*

Ionic to electronic conversion: efficient transduction

Rivnay, J. *et al. Chem. Mater.*, 26 (1), 2014

The biological target: ion flow through tissues



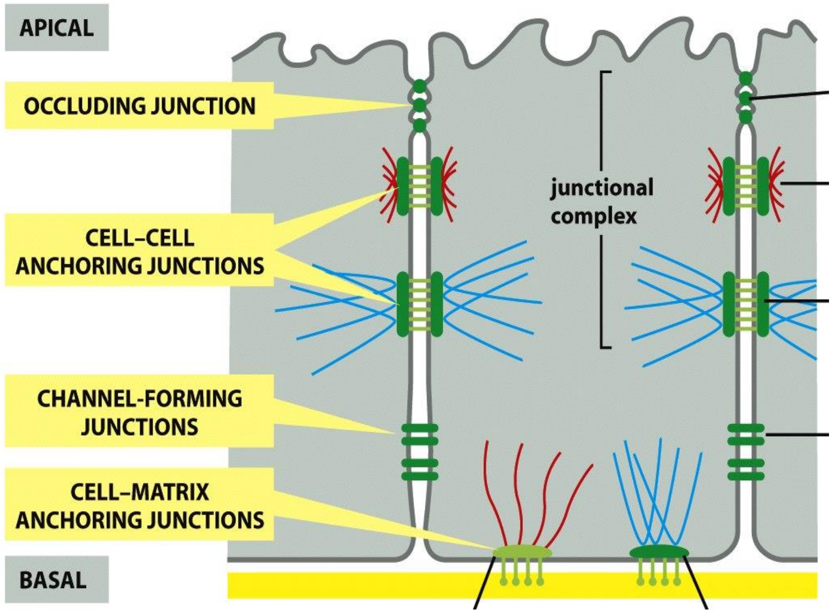
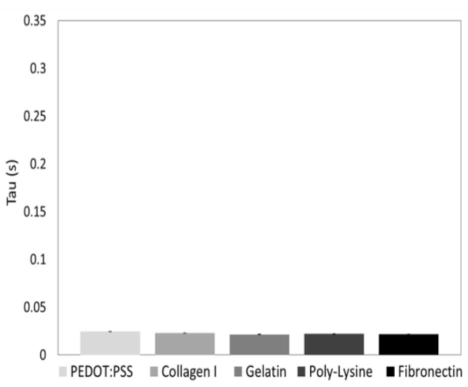
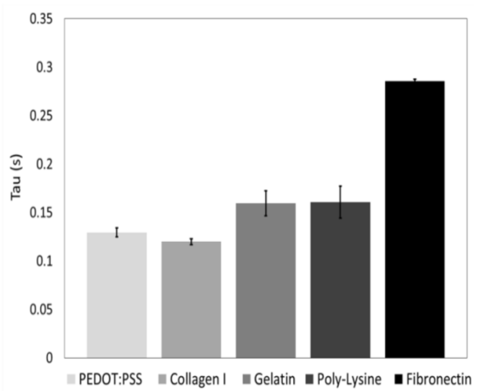


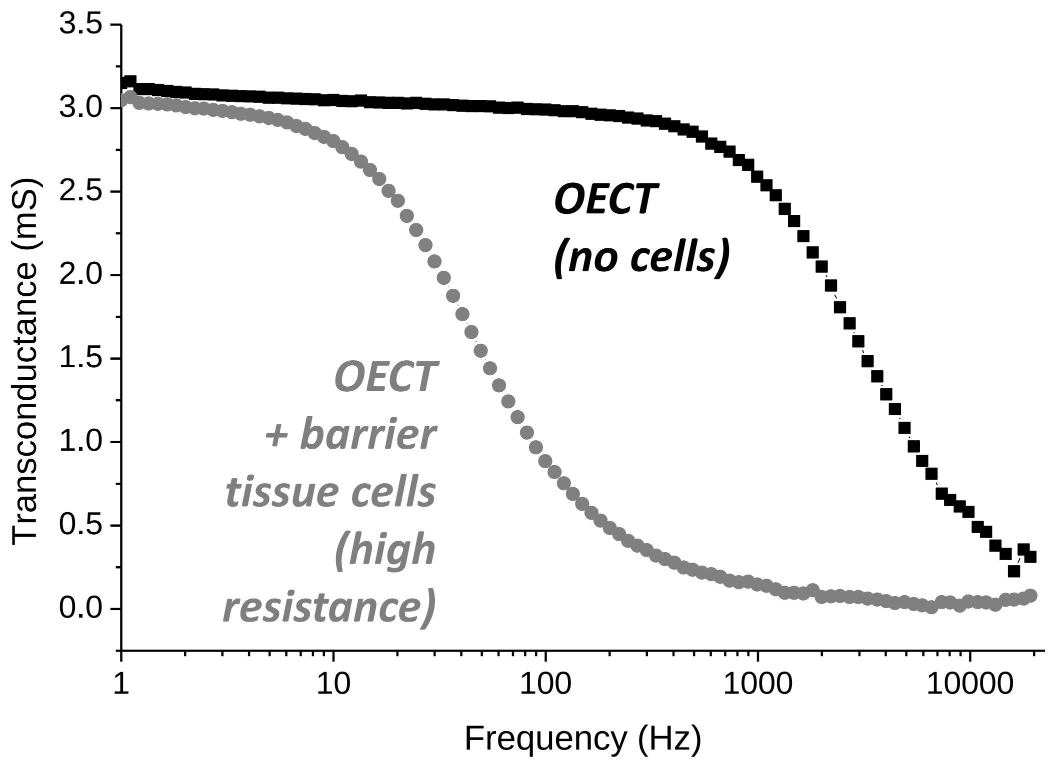
Figure 19-3 *Molecular Biology of the Cell* (© Garland Science 2008)

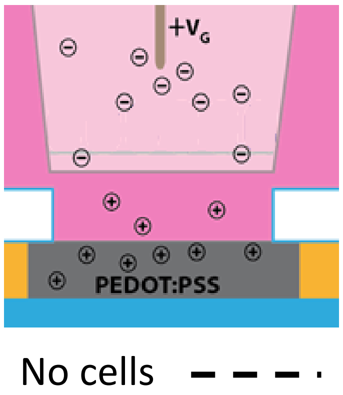


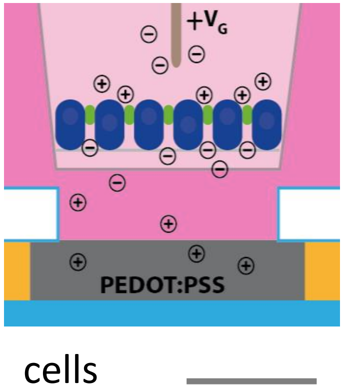


Ramuz.M, et al. chemphyschem in press **(2015)**

The OECT for monitoring cells: figure of merit

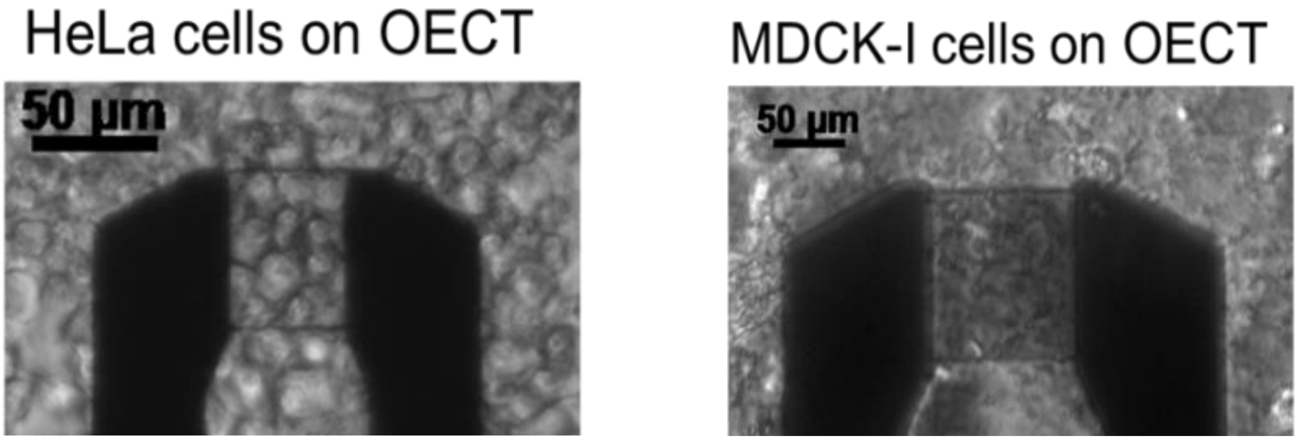


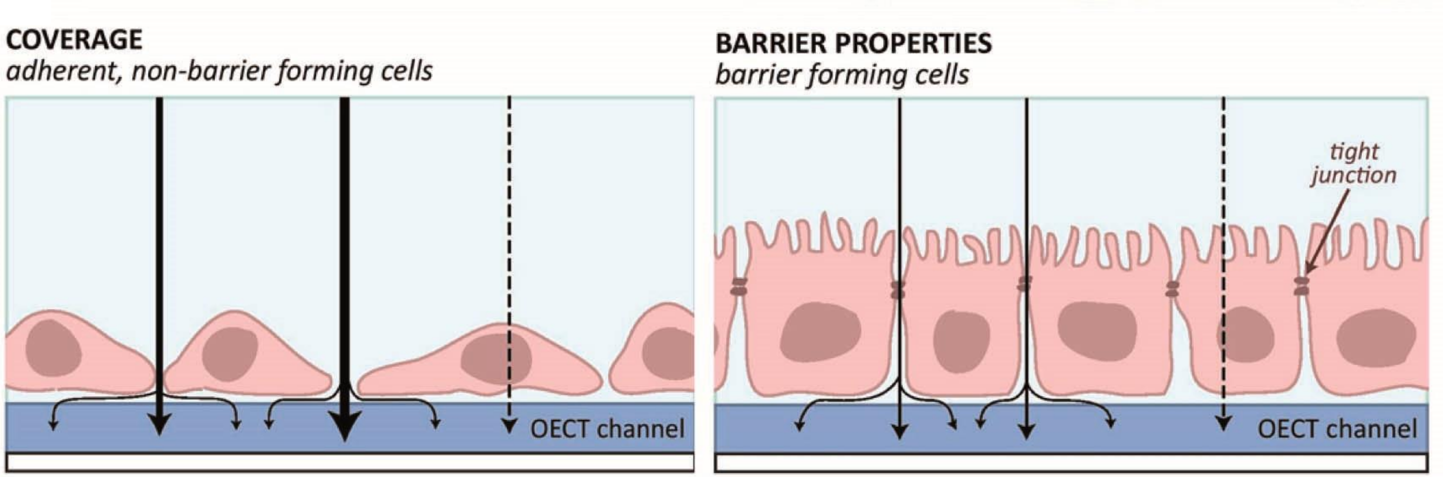




V_{GS} = 0.01 sin (wt)
Transconductance: $g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$

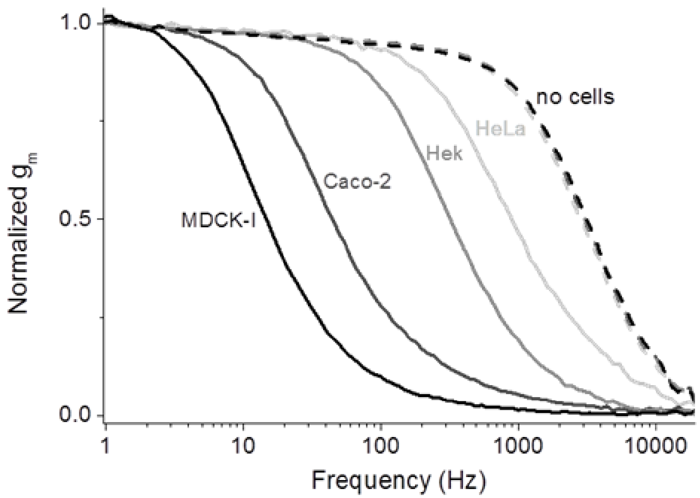
Differentiation of barrier and adhesion properties





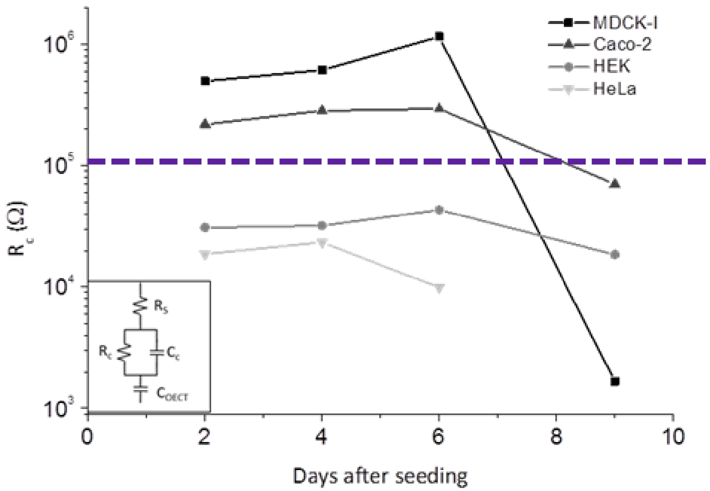
Ramuz.,M et al. JMC B, 2015, 3, 5971

Differentiation of barrier and adhesion properties



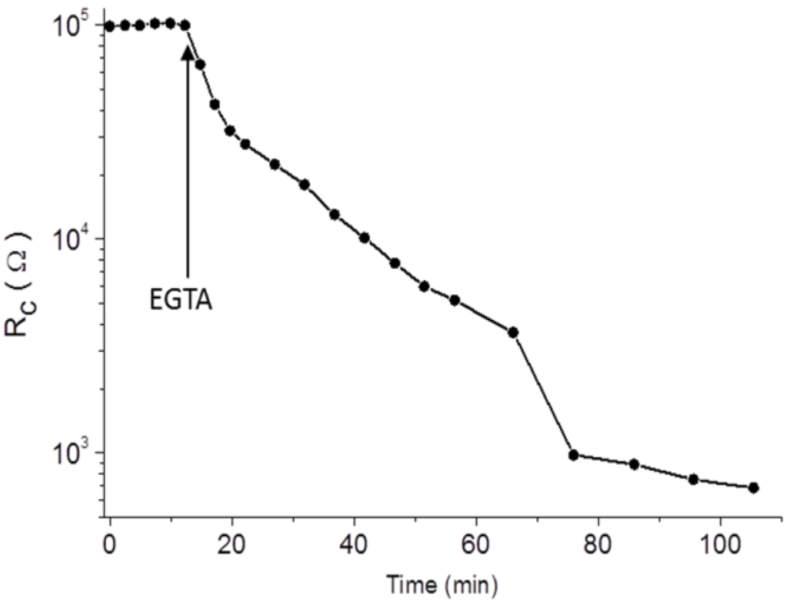
V_{GS} = 0.01 sin (wt)
Transconductance:

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$$

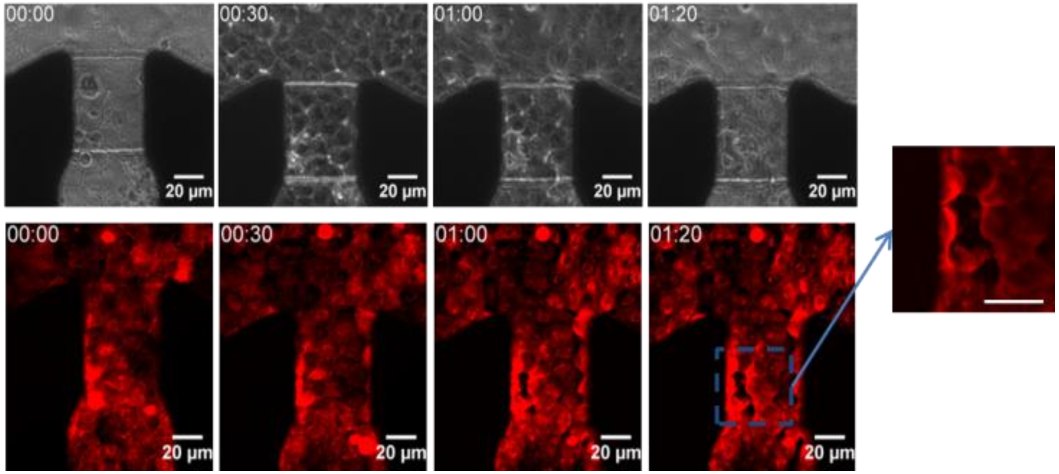


Ramuz.,M et al. JMC B, 2015, 3, 5971

Taking advantage of optical transparency



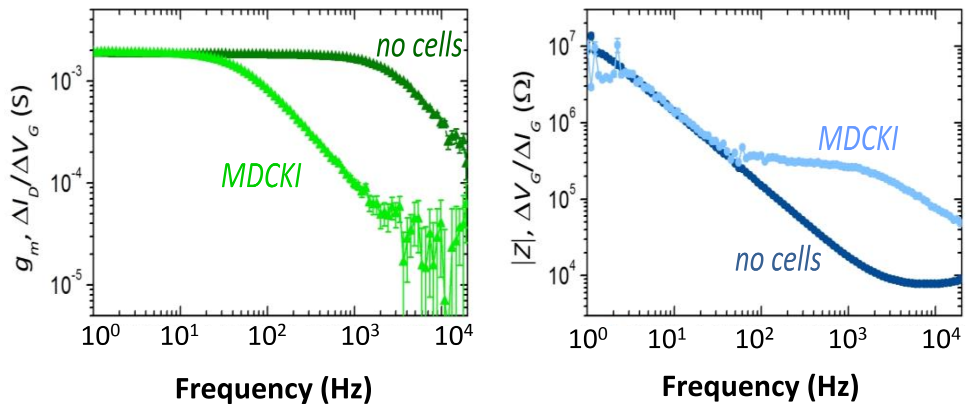
Addition of EGTA will eventually dissociate cells from surface

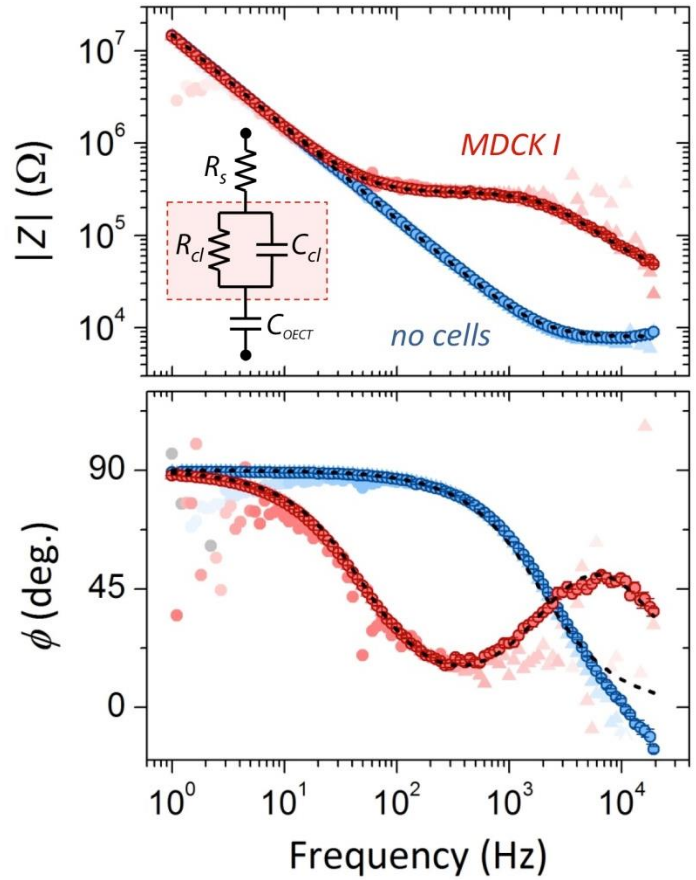


Tranfection of cells with fluorescent markers for specific proteins (e.g. actin allows following processes at the molecular level

Ramuz.,M et al. JMC B, 2015, 3, 5971

Generation of complex impedance traces using OECT





OECT

R_{cell} = 825 Ω cm^2 and C_{cell} = 544 nF/cm^2

CellZscope

R_{cell} = 730 +/-101 Ω cm^2 and C_{cell} = 1µF/cm^{2*}

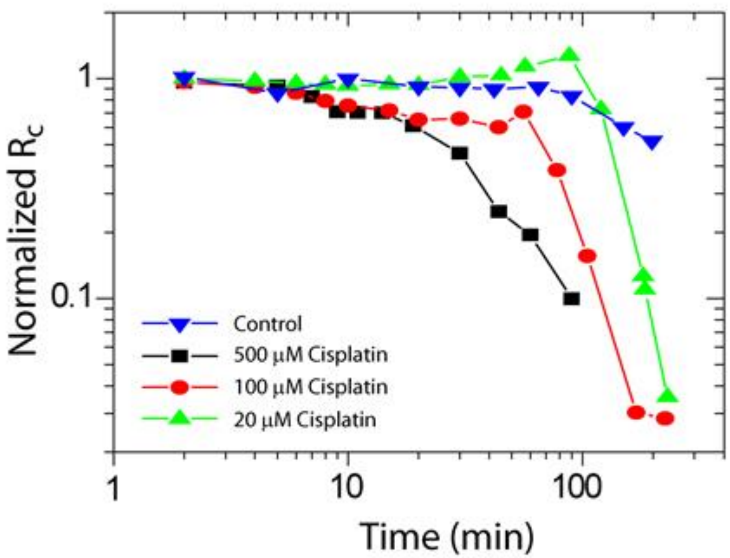
*literature

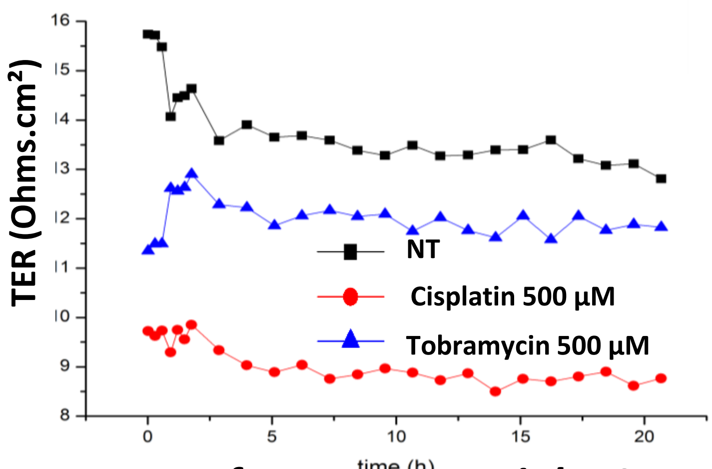
- ***Stitching both sets of data gives broad band frequency coverage with high confidence***

Rivnay et al, APL, 2015

OECTs for monitoring nephrotoxicology (primary cells)

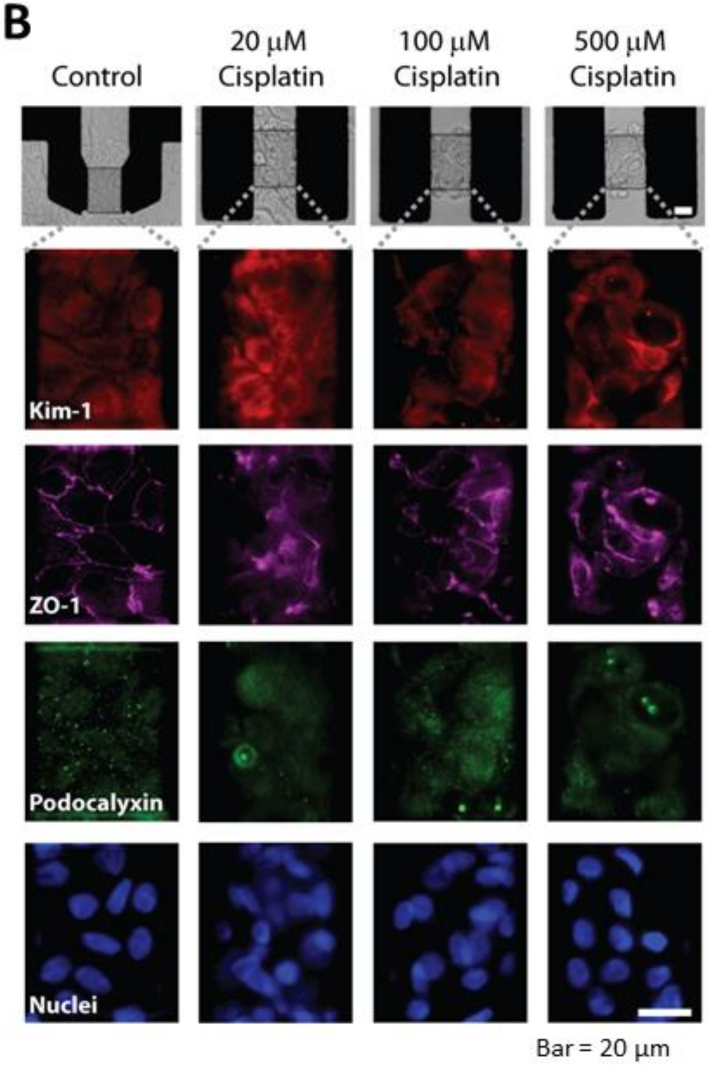
A





Data from commercial EIS

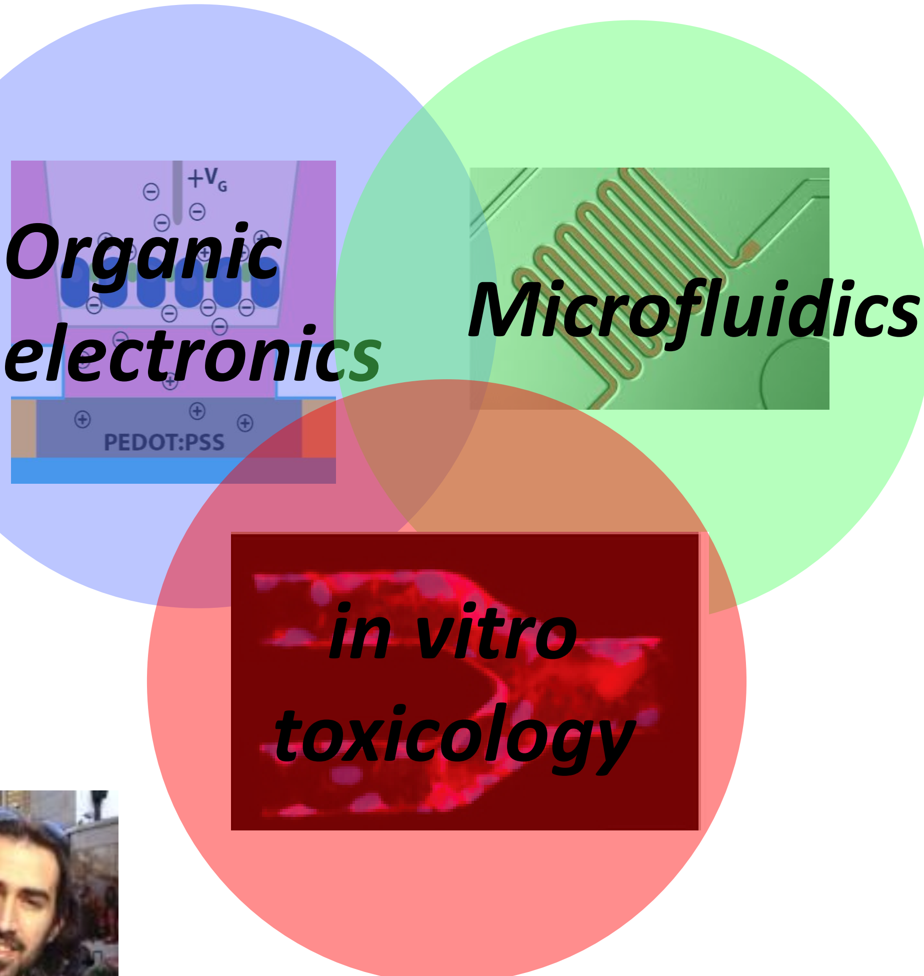
B

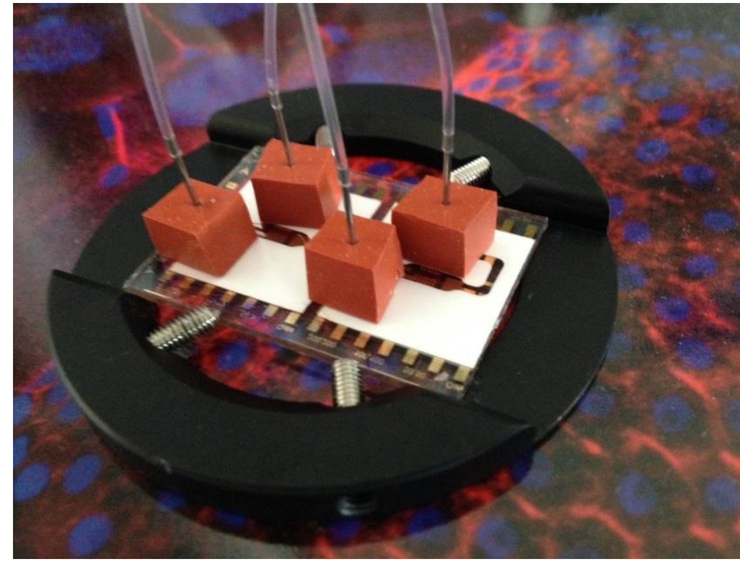


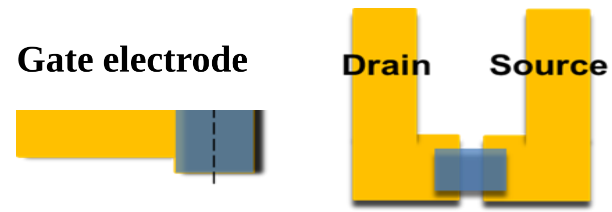
HRPTEC thanks to Biopredic

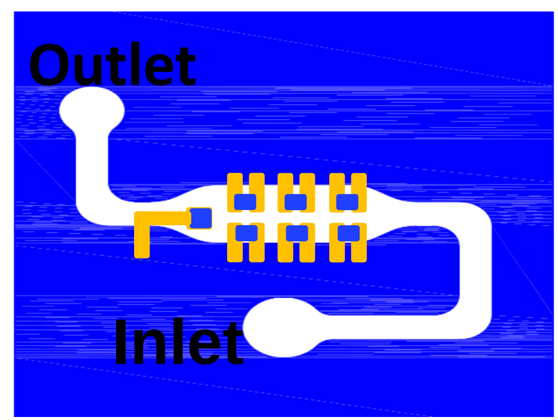
M. Huerta et al Submitted ATIV

Integration of microfluidics with the OECT



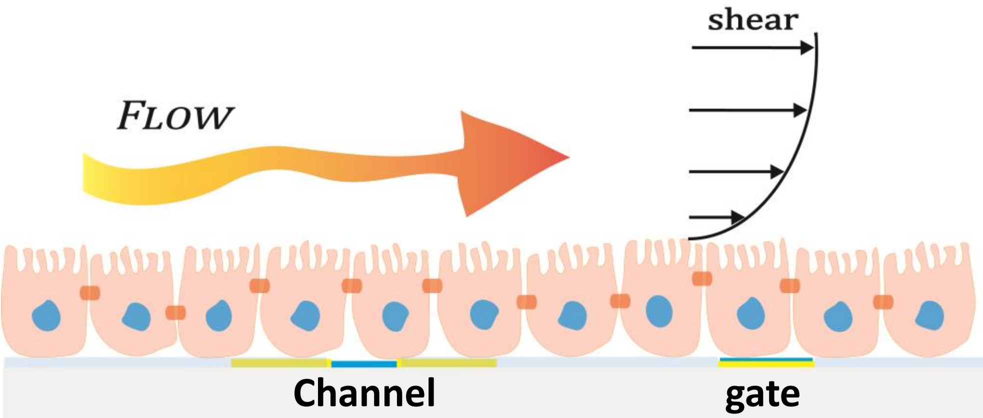






V. Curto

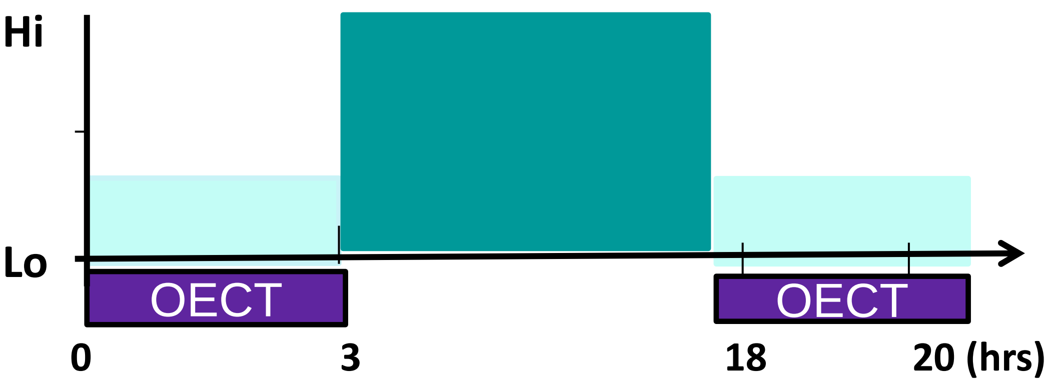
Integration of microfluidics with the OECT

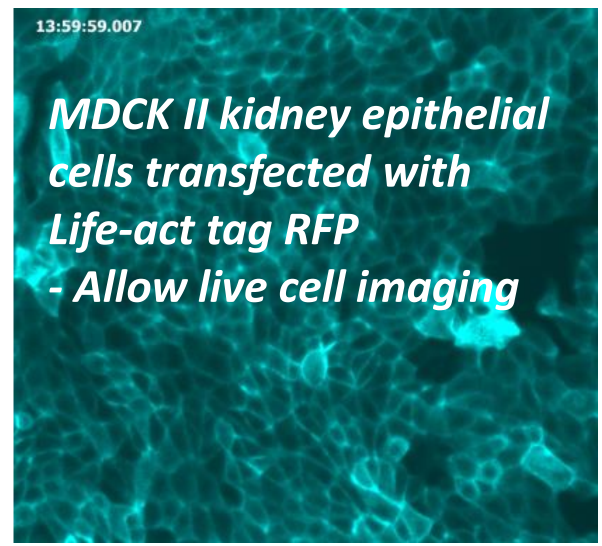


OECT Tool box:

- *Impedance monitoring*
  - *Capacitance*
  - *Resistance*
- *Quantitative image analysis*
- *Metabolite Monitoring*
- *Wound Healing Assay*

Shear stress induced by high flow rate over cells

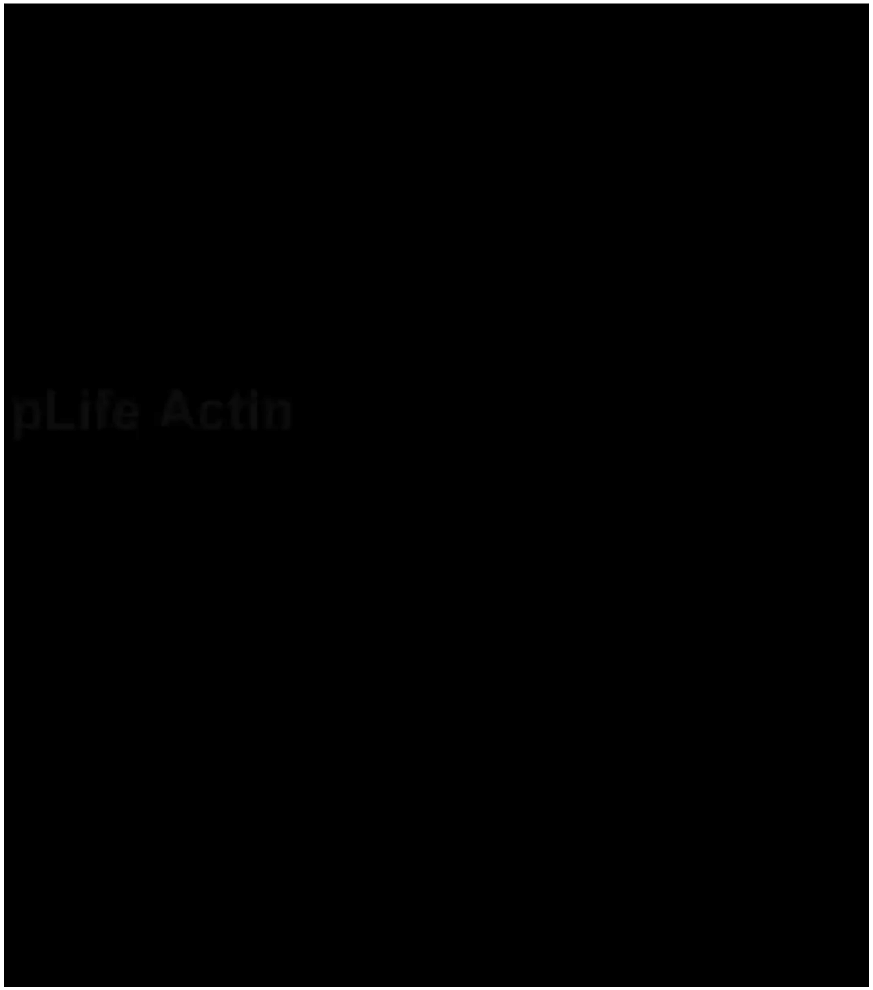


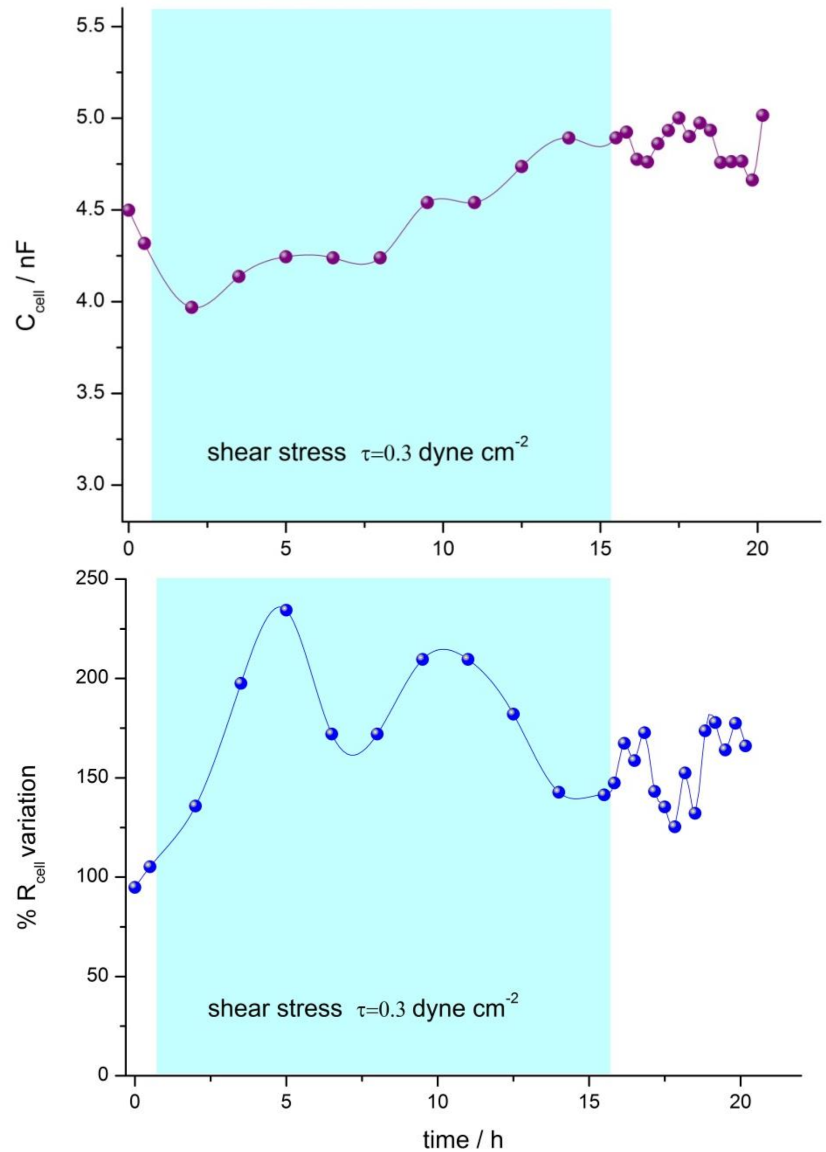


Curto.,V et al. In preparation

Impedance monitoring with microfluidics

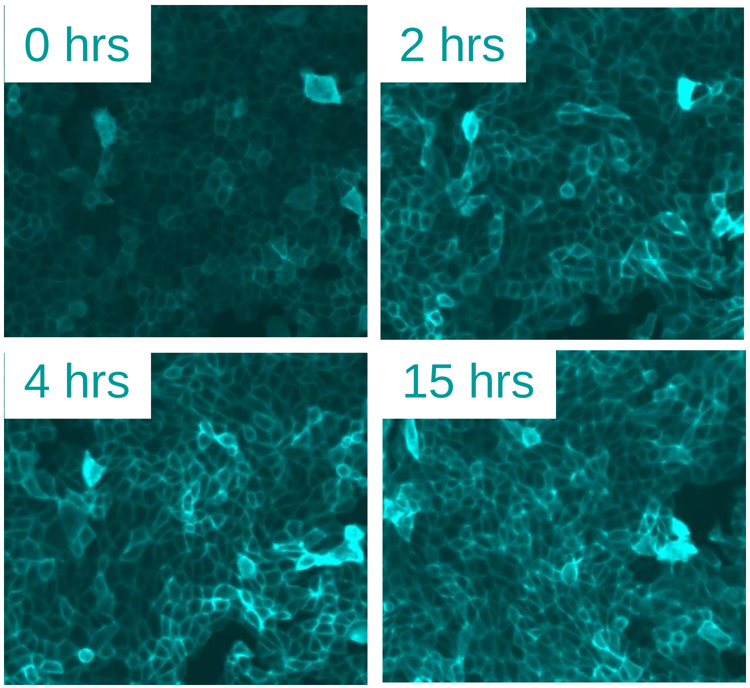
Time lapse video of Life act MDCK II cells on OECT

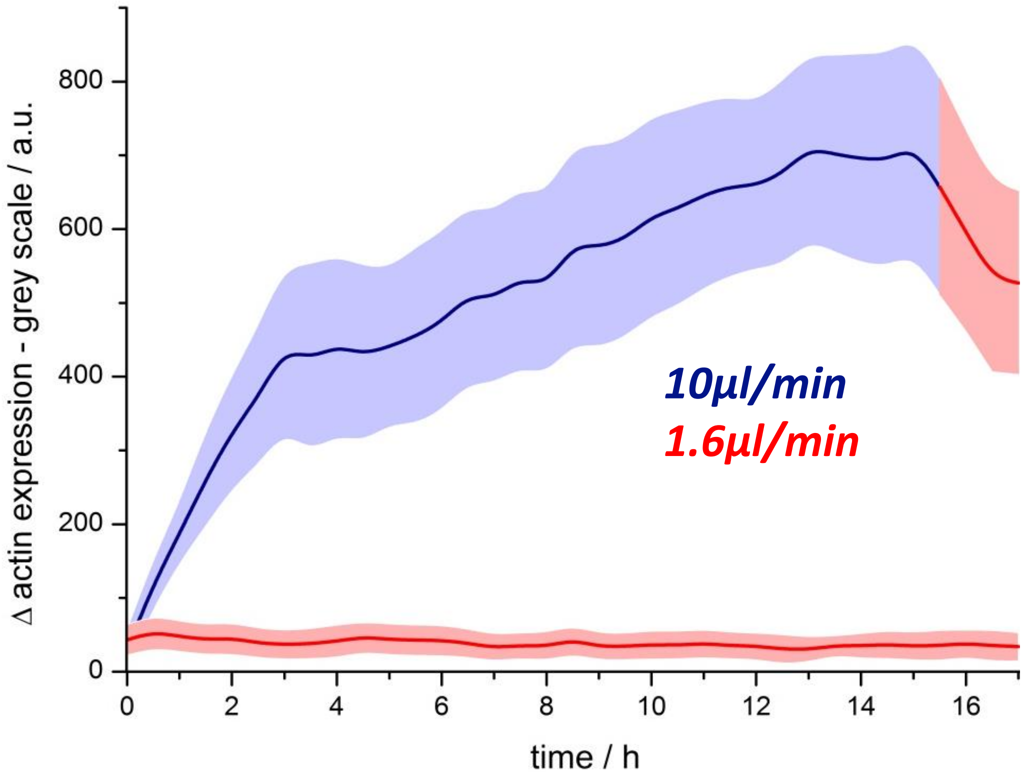




Curto.,V et al. In preparation

Physiological flow induces additional differentiation

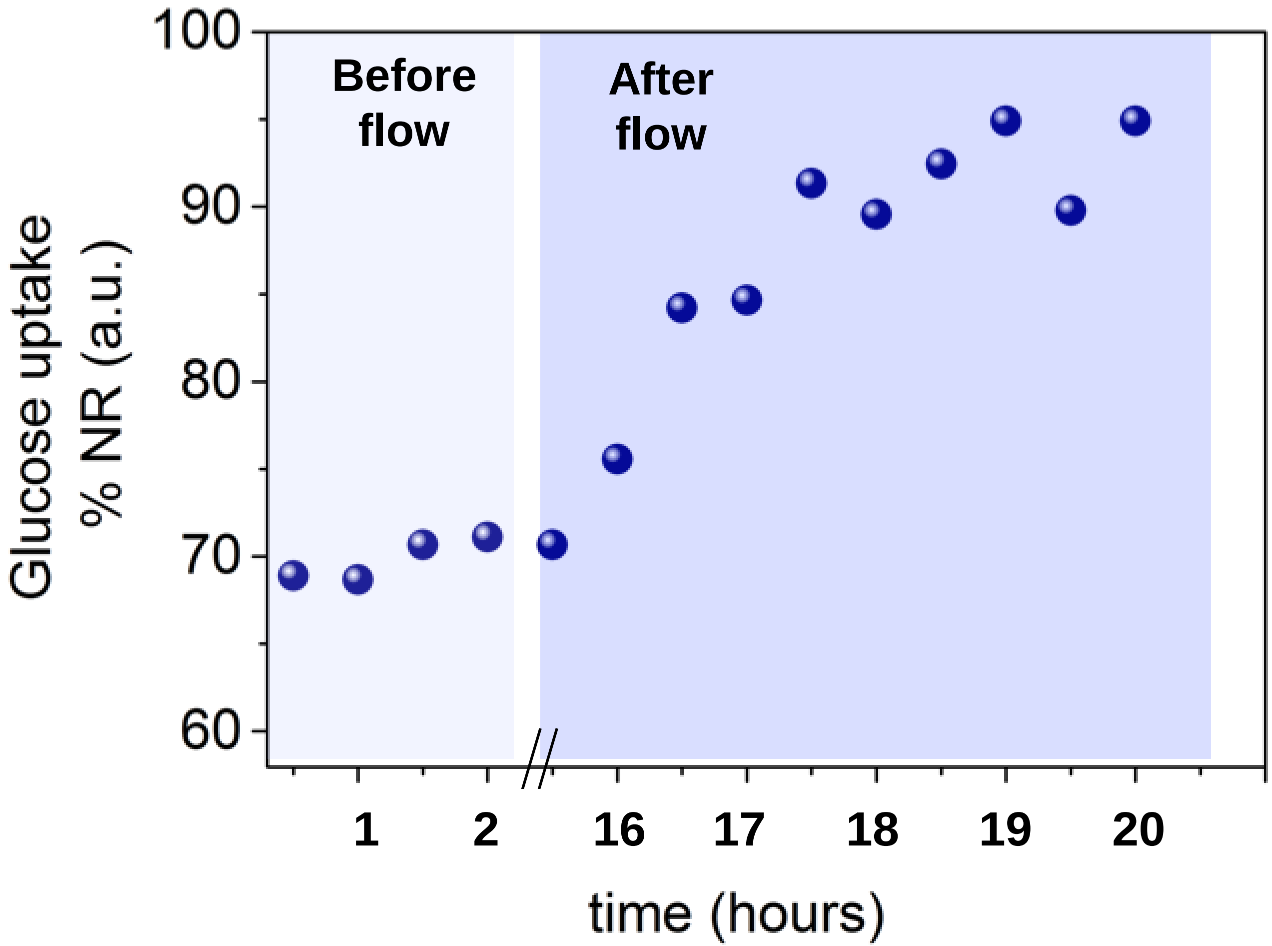




increase in Actin expression with flow

Curto.,V et al. In preparation

Changes in cell metabolism induced by flow



Anna Maria Pappa

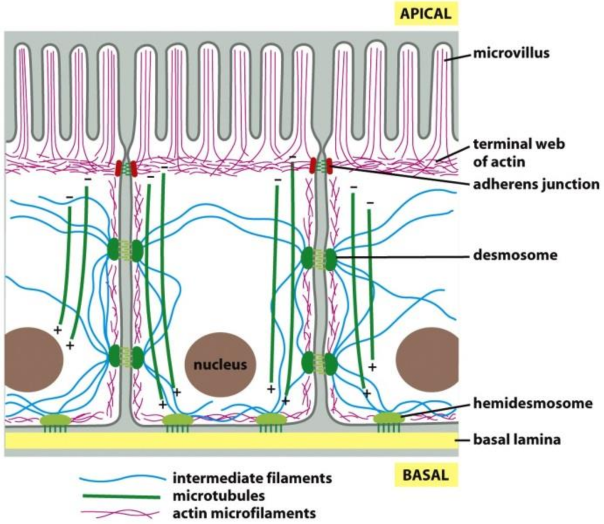
Efflux samples measured for glucose content using GOx functionalised OECT

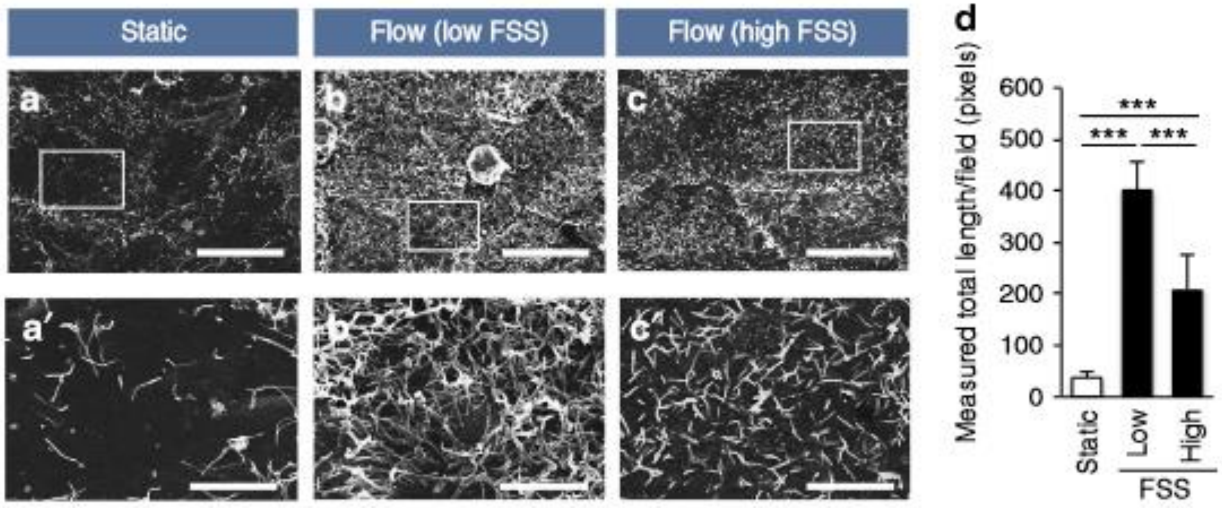
Curto.,V et al. In preparation

Flow induced microvilli formation

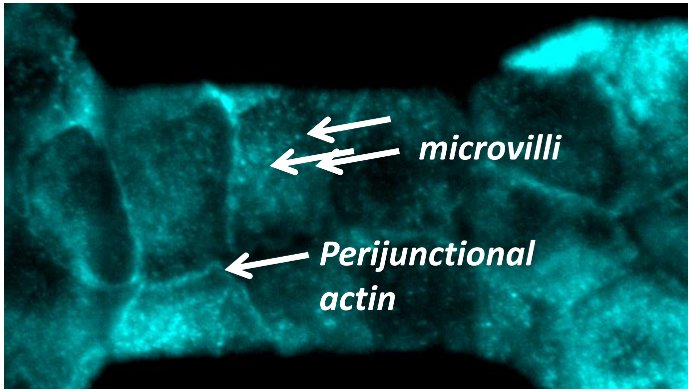
NATURE COMMUNICATIONS | DOI: 10.1038/ncomms9871

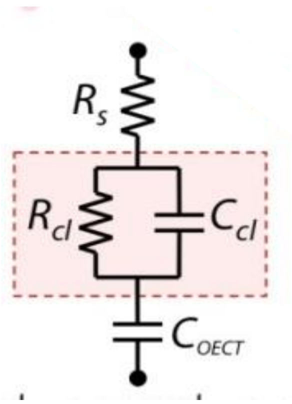
Fluid shear triggers microvilli formation via mechanosensitive activation of TRPV6. Shigenori Miura et al, 2015





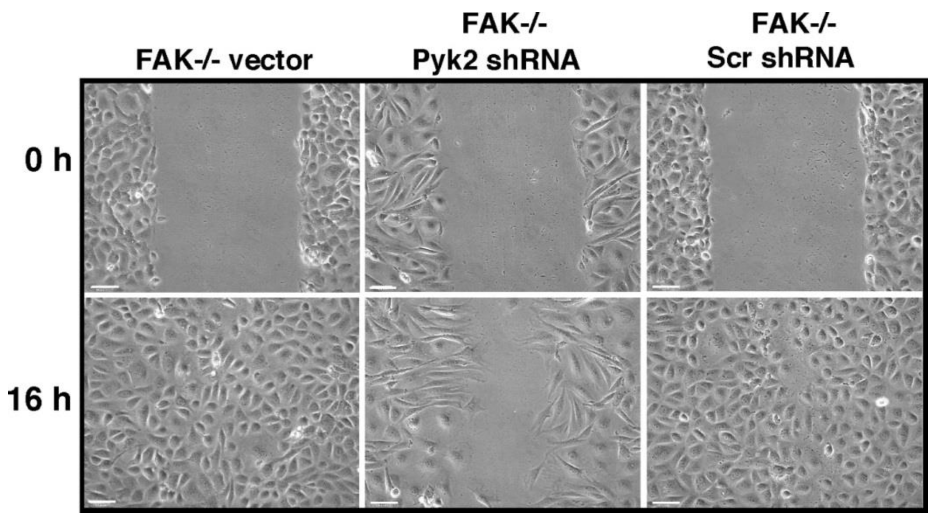
Changes in capacitance and protein expression associated with increased surface area of cell?



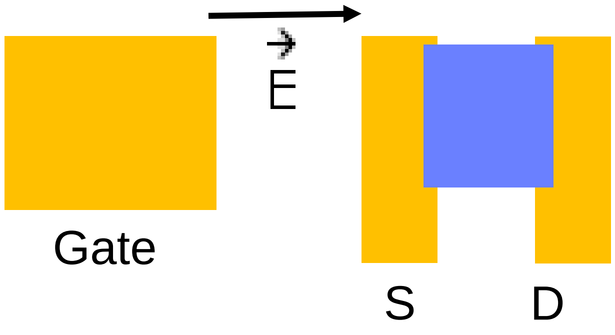


Electrical wound healing assay

- Wound-healing is used to characterize the ability of the cells to grow after being wounded
- Method uses chemicals or scratching, (tooth pick, razor blade)



$$\Delta\varphi = F\ g(\lambda) r\ E \cos(\theta)$$

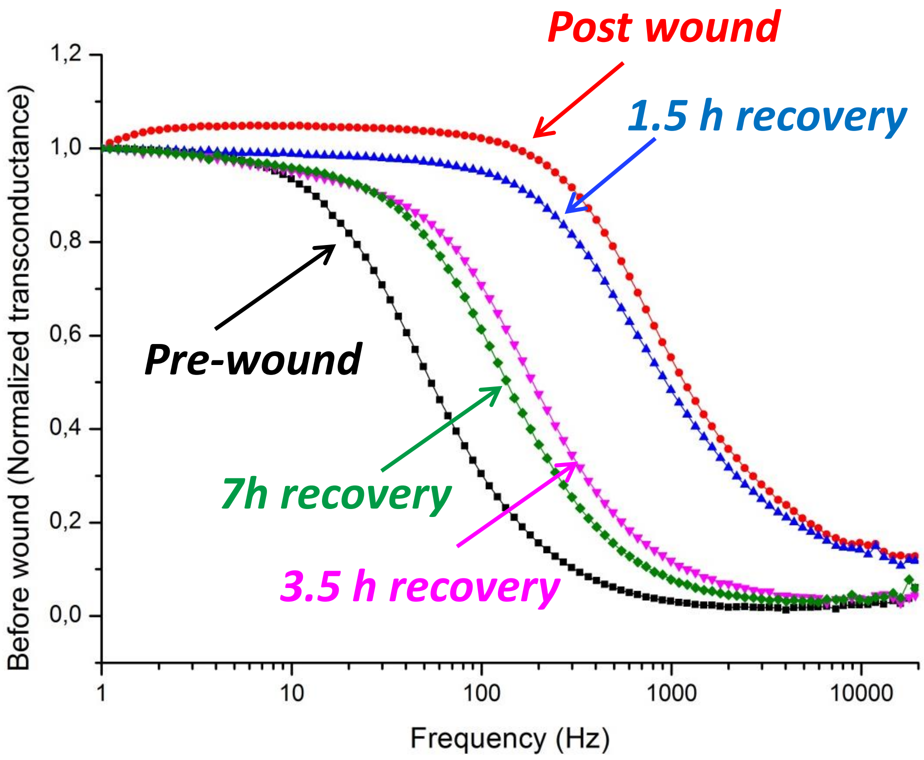


Planar OECT: $\theta = 0°$

F: shape factor
g(λ): function depending on the conductivity
R: radius of the cell
E: the applied electric field
ϑ: the angle between the electric field and the cell layer

Take advantage of optical transparency to image cells before and after wounding

Fully electronic wound healing assay using OECT



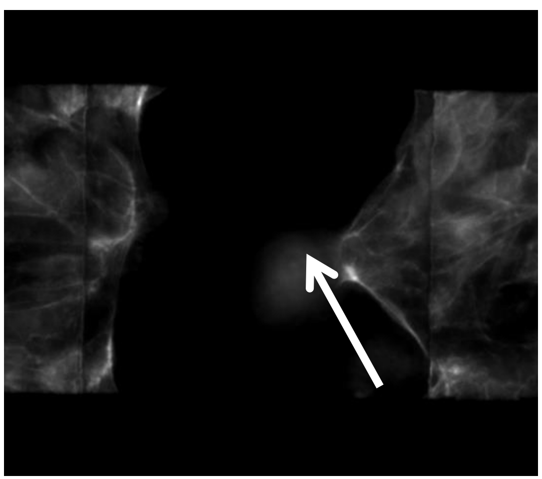
Wound: 2.7 V (0.3 DC) for 120s

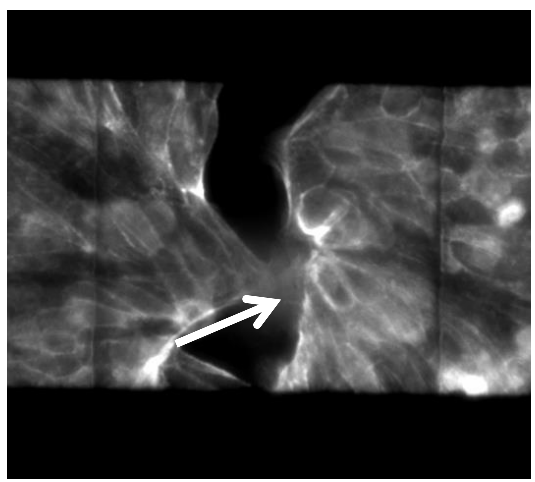
Automated wound healing assay improves precision and reproducibility: Better than a toothpick!

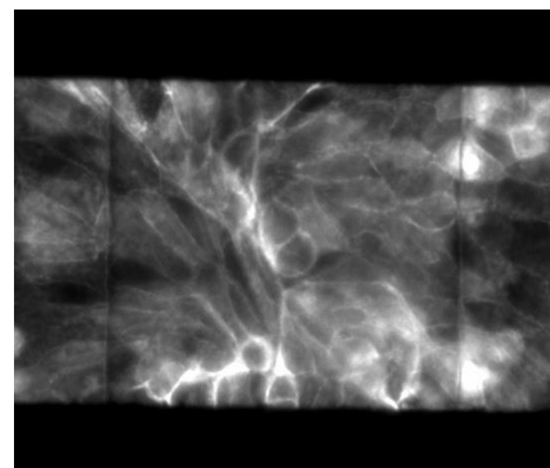
B. Marchiori

Direction and speed of cell recovery recorded

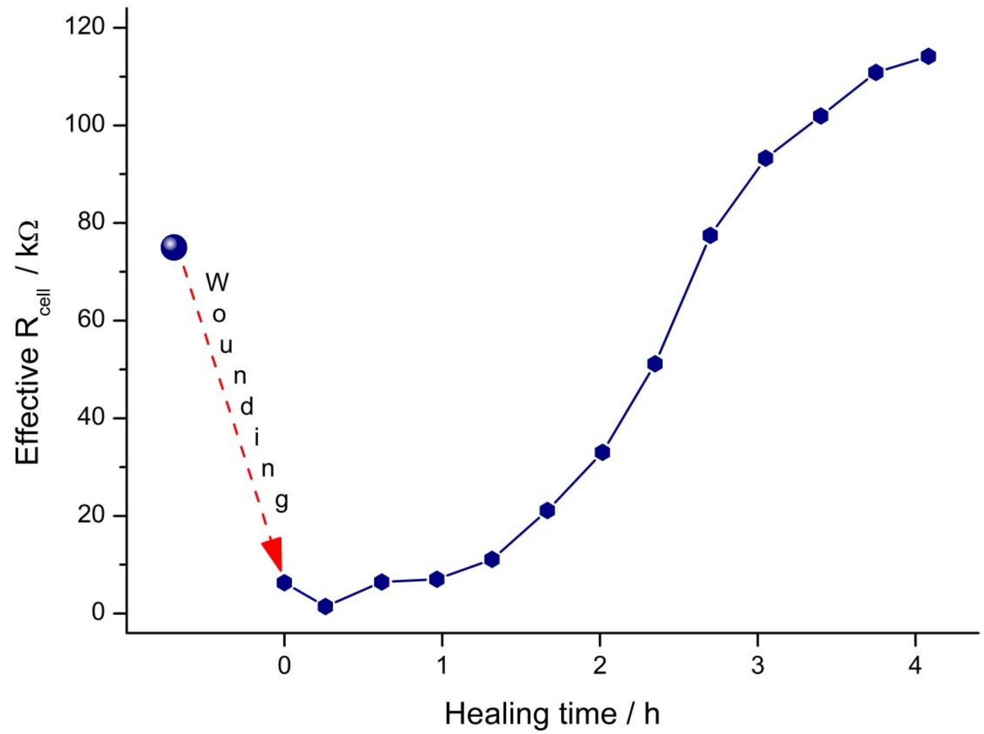
MDCK II cells transfected with Lifeact (Red fluorescent protein labeled actin)







Microfluidic OECT wound healing assay

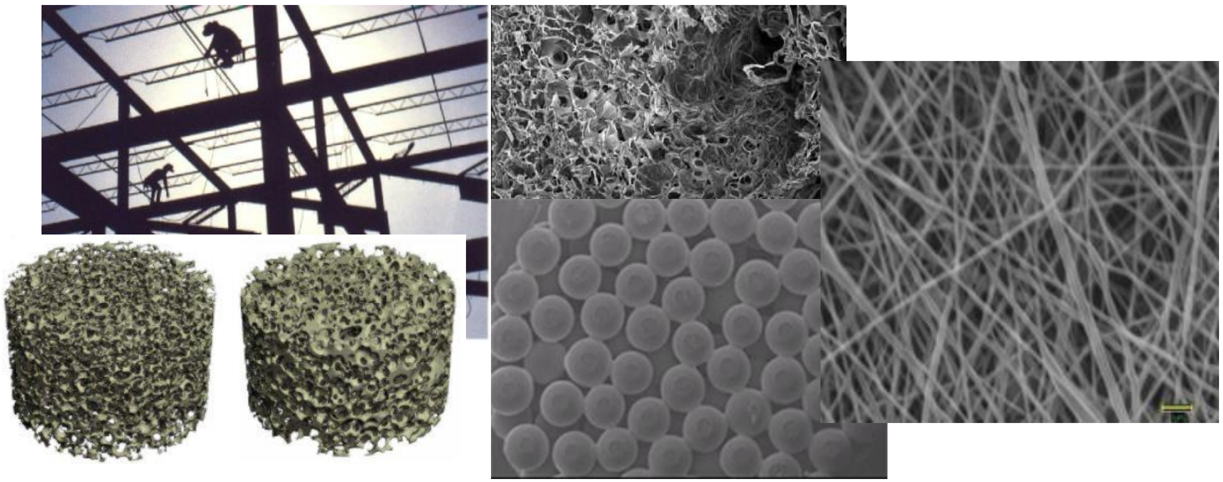


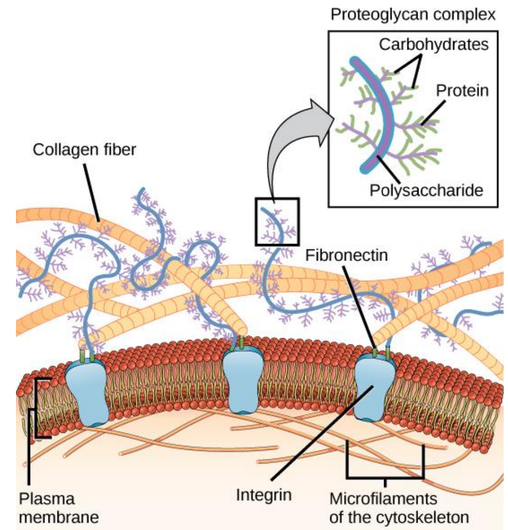
Totally automated wound healing assay without pipetting – more physiologically relevant

Engineering of tissues using scaffolds

Use of living cells to artificially grow tissue capable of function as *in vivo*

(drug discovery, organ generation or replacement)





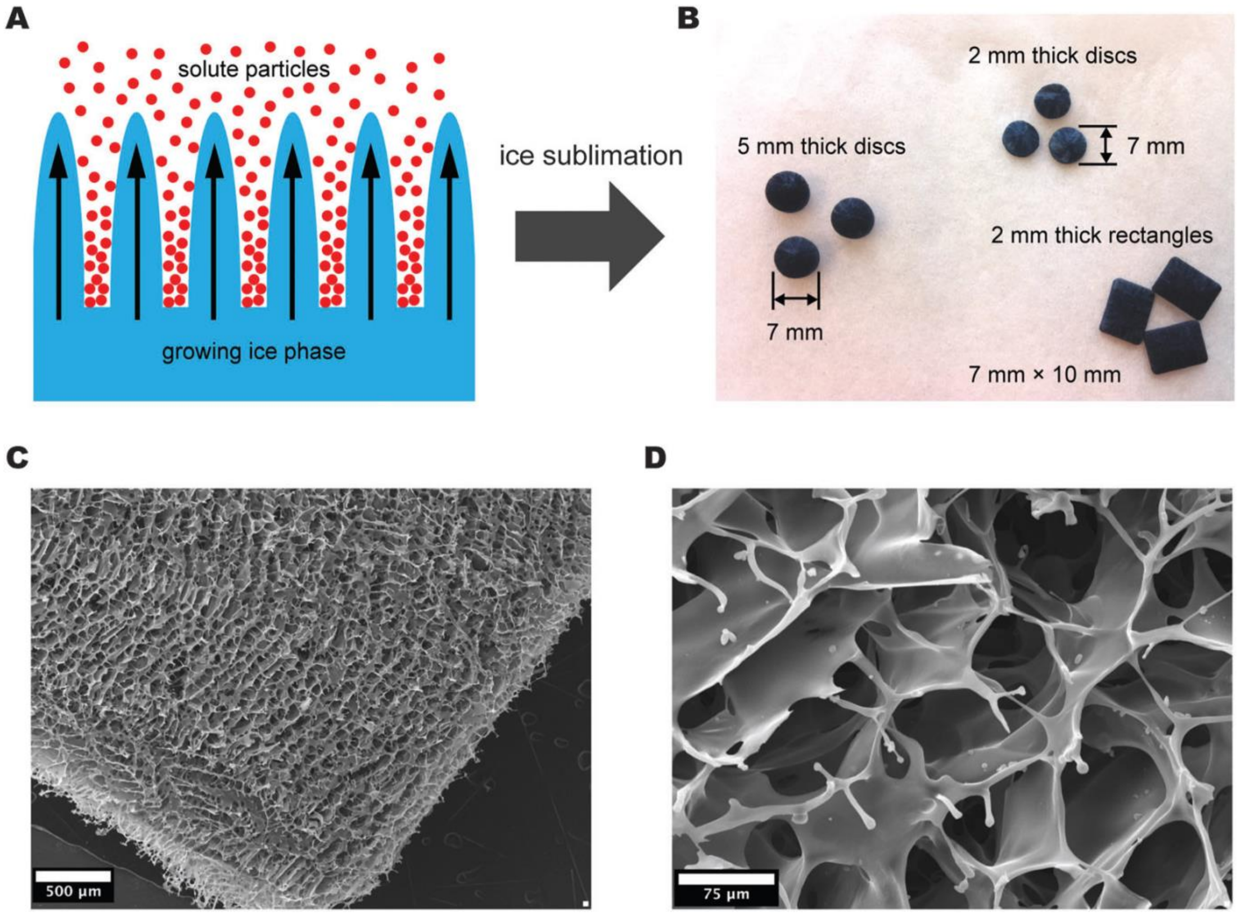
Tissue templates for cell attachment & proliferation: mimic the extracellular matrix

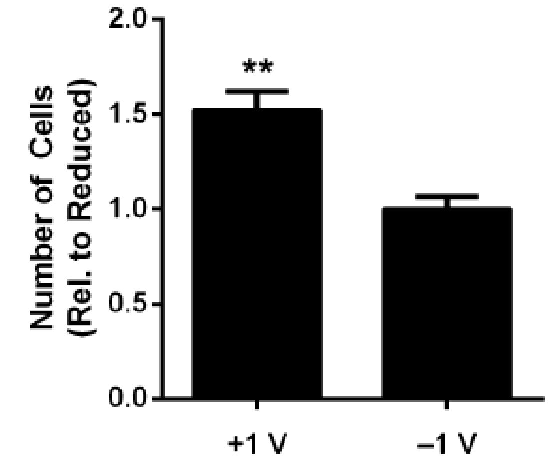
- **Existing: a porous 3D structure with optimized structural properties**
- **Missing: how do we monitor cells in the scaffold?**

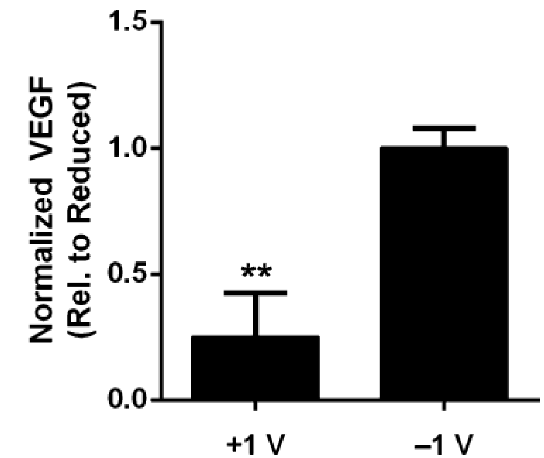
"Extracellular Matrix of Animal Cells." *Boundless Biology* https://www.boundless.com/biology/

3D PEDOT:PSS Scaffolds for controlling cell proliferation

Very promising scaffolds (excellent mechanical properties 4.5 +/-0.6 kPa) for tissue engineering



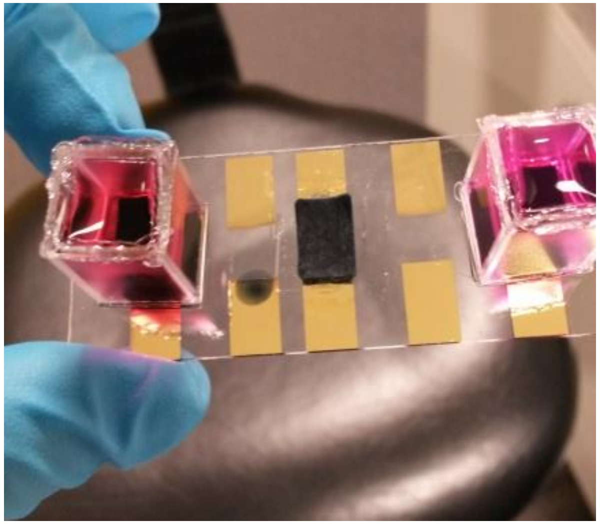




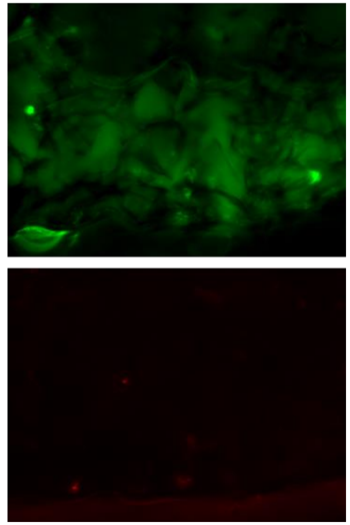
Redox properties of scaffold used to control cell growth

A. M. D. Wan and S. Inal et al. J. Mater. Chem. B, 3, 5040 (2015)

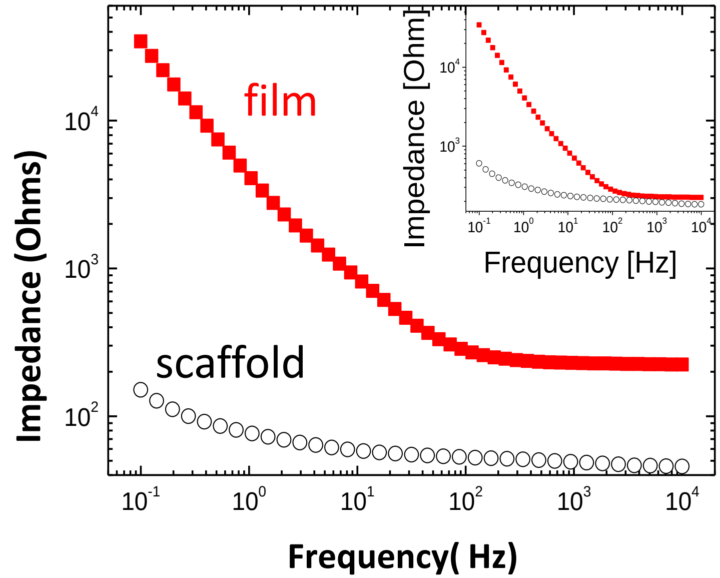
3D PEDOT:PSS scaffolds for impedance sensing

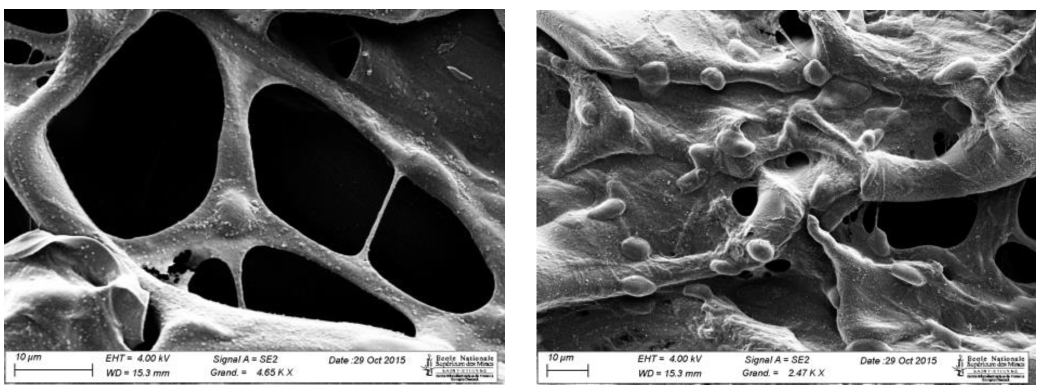


Scaffolds for impedance monitoring

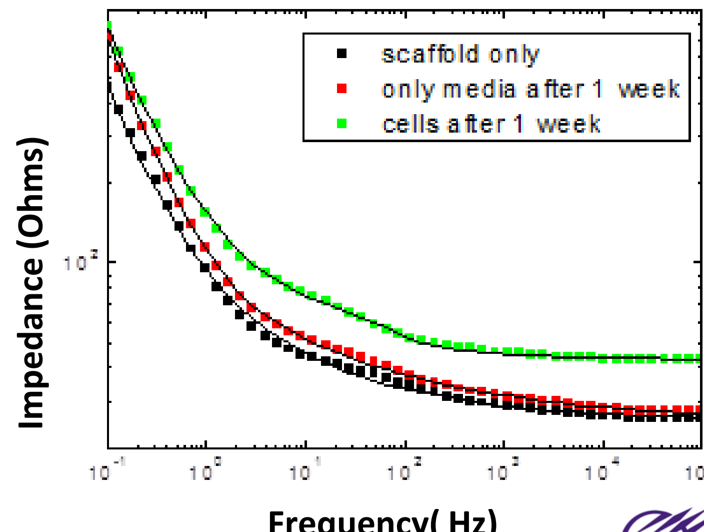


Viability test (Live/ Dead) after 6 days

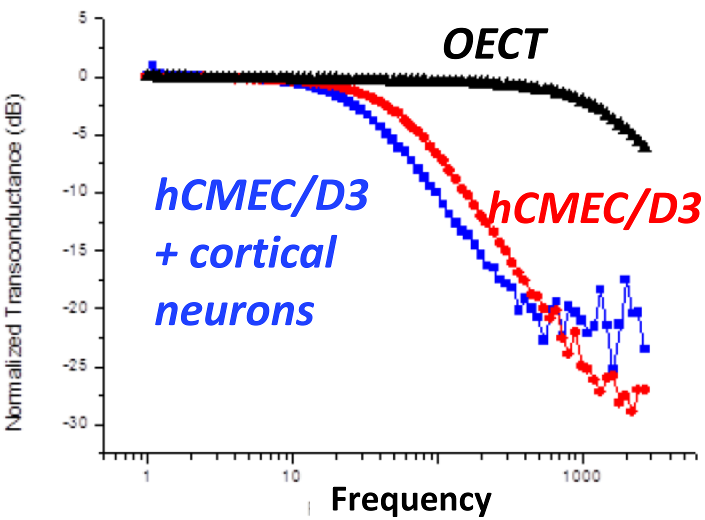


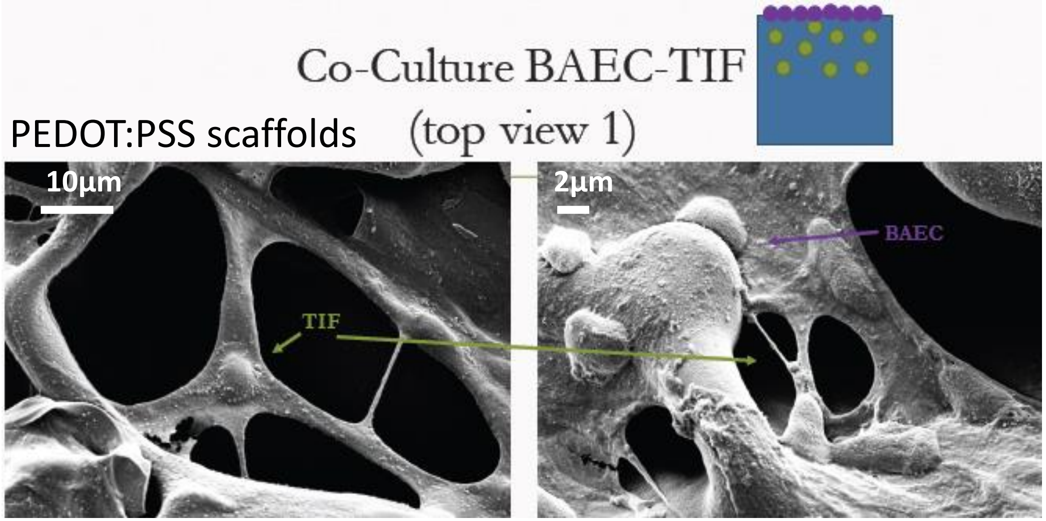


SEM images of scaffolds with TIF cells after 6 days

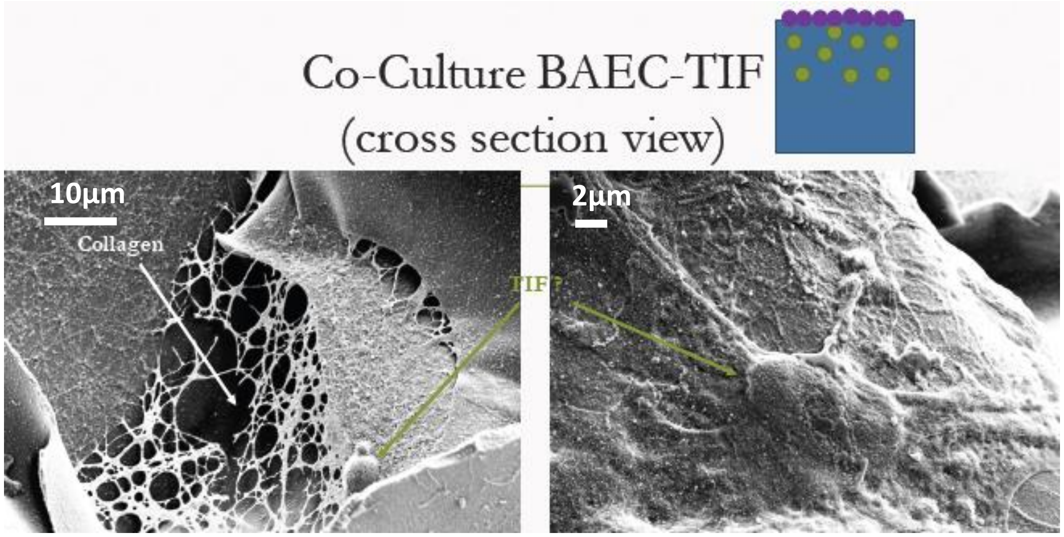


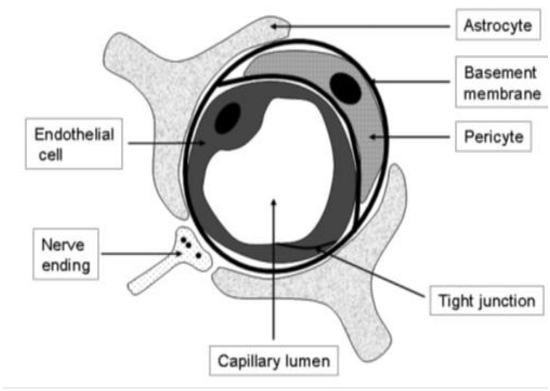
Towards 3D model of BBB in PEDOT:PSS scaffolds





Development of a 3D model of the blood brain barrier in vitro





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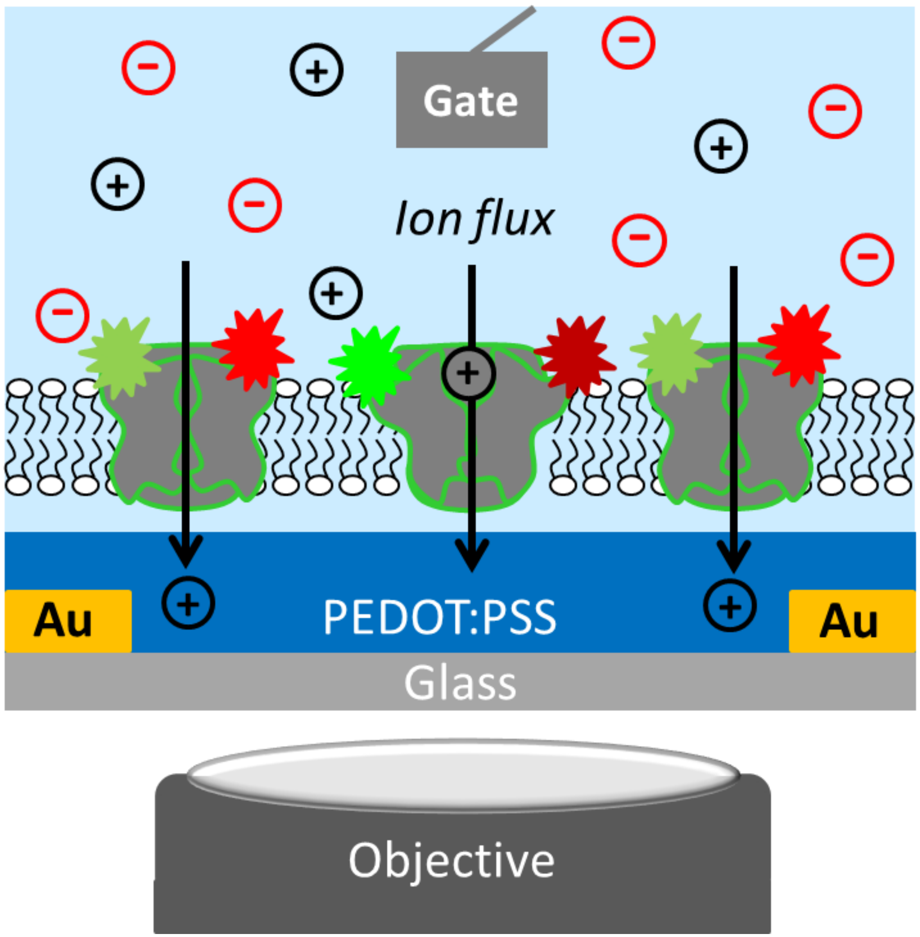
OECT application 2: Interfacing with lipid bilayers



- *Can the benefits of the OECT extend to the molecular scale?*
- *Will the softness of PEDOT:PSS allow functional protein integration?*
- *Can we integrate imaging into the platform for functional readout?*

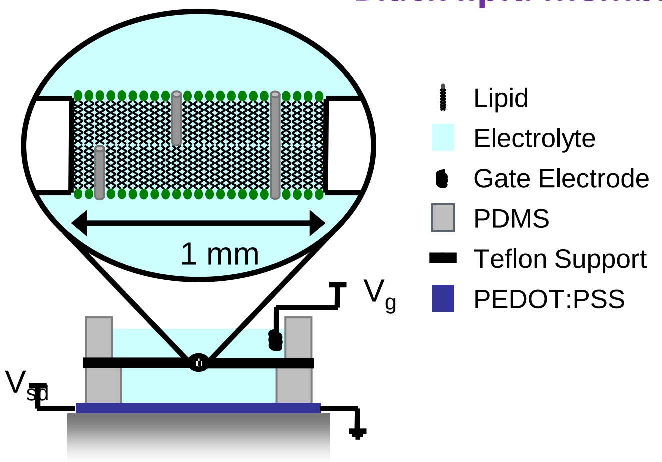
Pros

- *Lipids are labile (don't die!)*
- *No contamination issues*
- *Access to single molecule data*

Cornell University

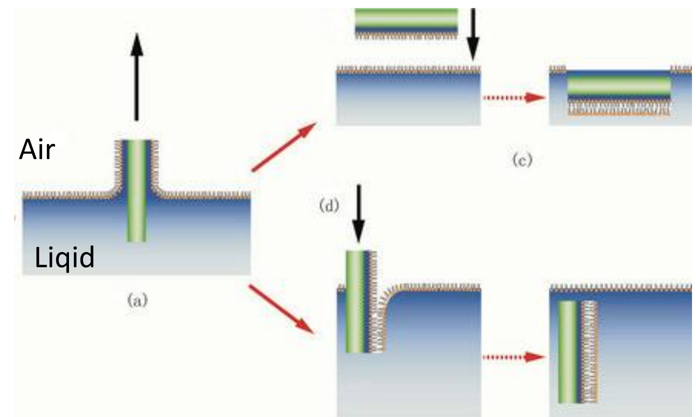
Planar lipid bilayers assembly techniques

Black lipid membrane



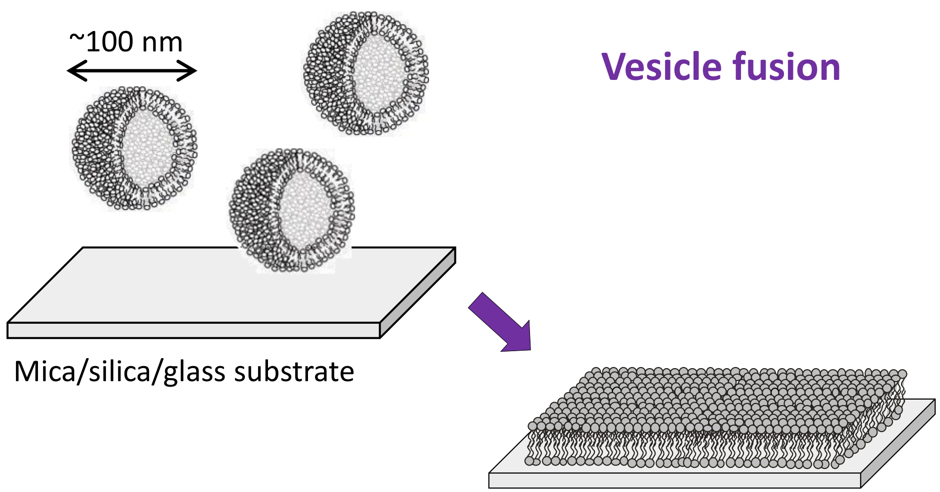
D. A. Bernards *et al.*, *Applied Physics Letters* ***89, 053505 (2006).***

Langmuir–Blodgett /Langmuir–Schaefer



I. P. McCabe, M. B. Forstner, *Open Journal of Biophysics* ***11 (2013).***

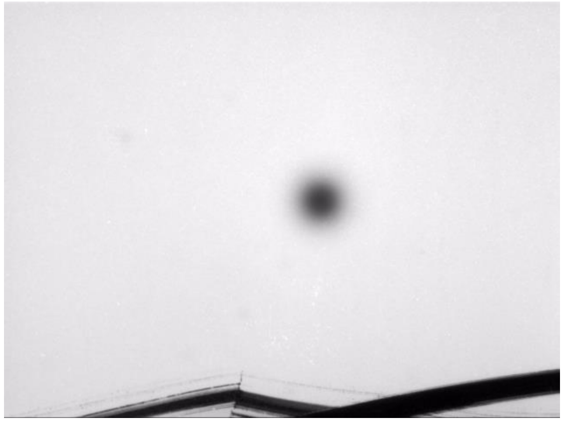
Vesicle fusion



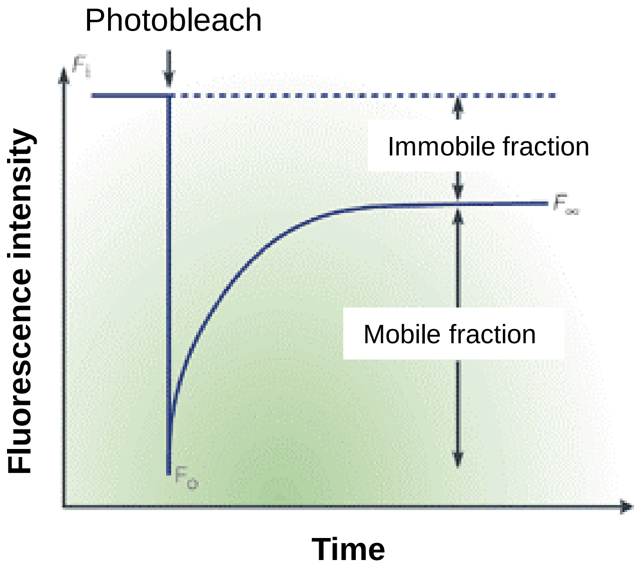
Dr. Yi Zhang

Characterization techniques

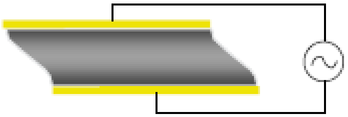
Fluorescence recovery after photobleaching (FRAP)



10 x magnification, 15s/frame



Quartz crystal microbalance with dissipation monitoring (QCM-D)

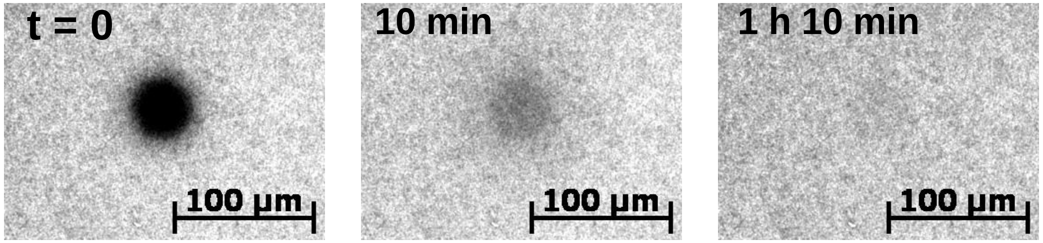


- Adsorbed mass → Change in frequency
- Viscoelastic properties → Change in dissipation

J. Lippincott-Schwartz, E. Snapp, A. Kenworthy, *Nat Rev Mol Cell Biol* ***2, 444 (2001).***

Vesicle fusion on glass/SiO_2

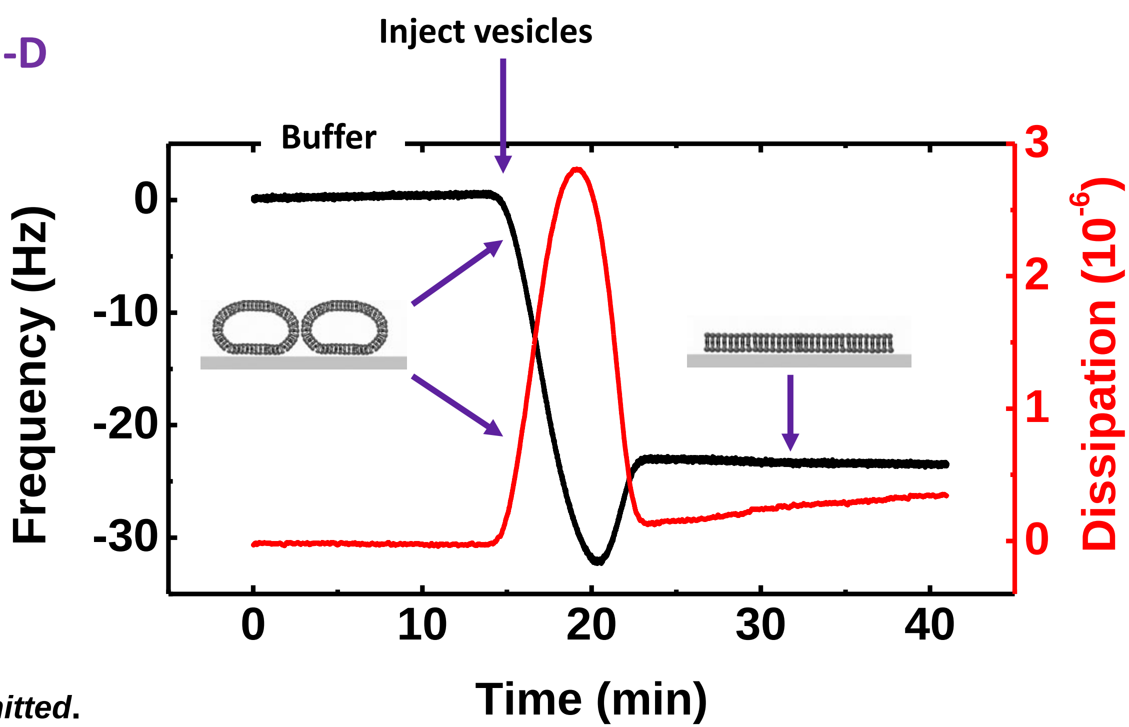
FRAP



Diffusion coefficient (D) = 0.26 µm²/s
Mobile fraction (MF) = 0.95

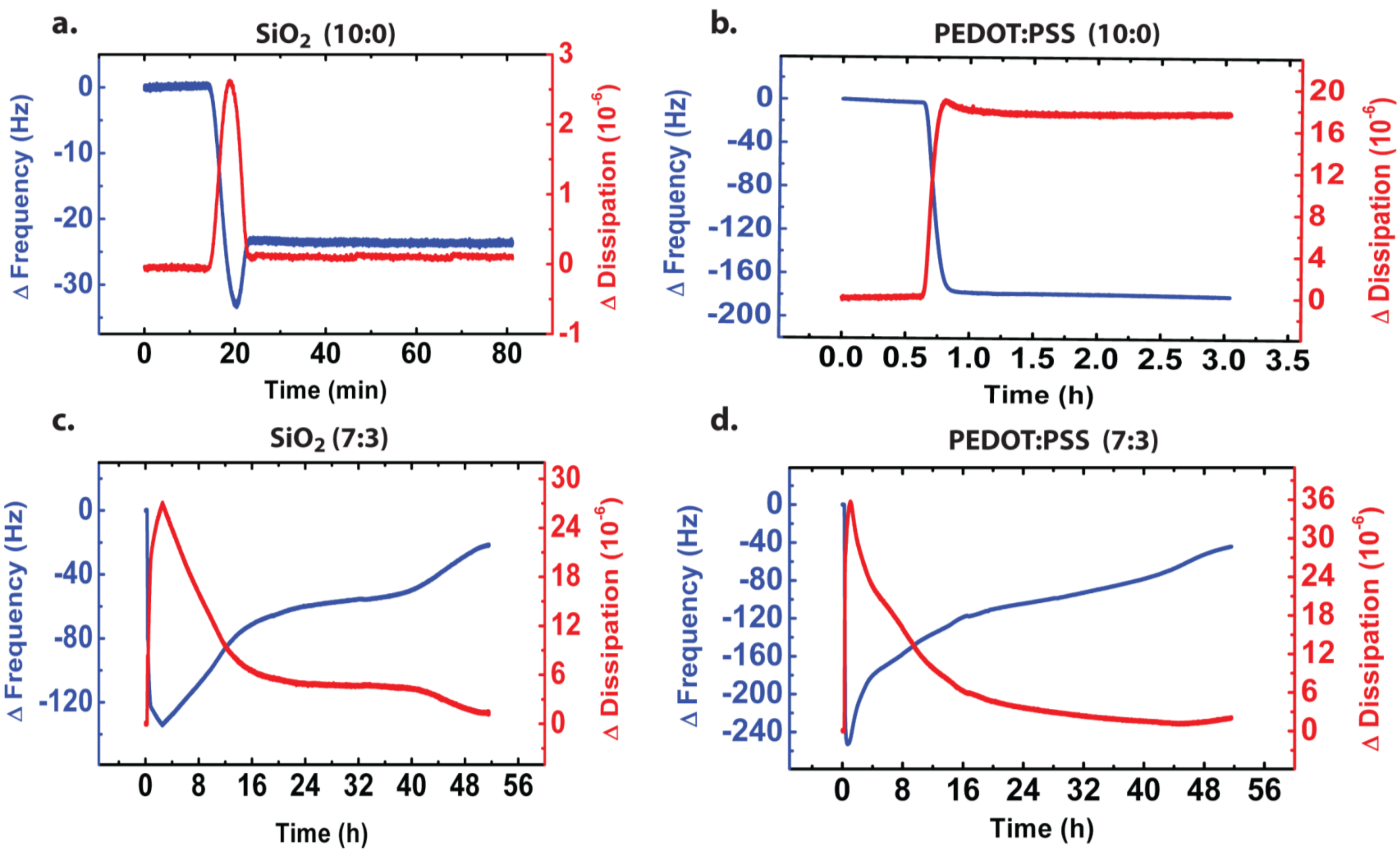
1,2-diphytanoyl-sn-glycero-3-phosphocholine (DPhPC)

QCM-D



Y. Zhang *et al.*, *submitted*.

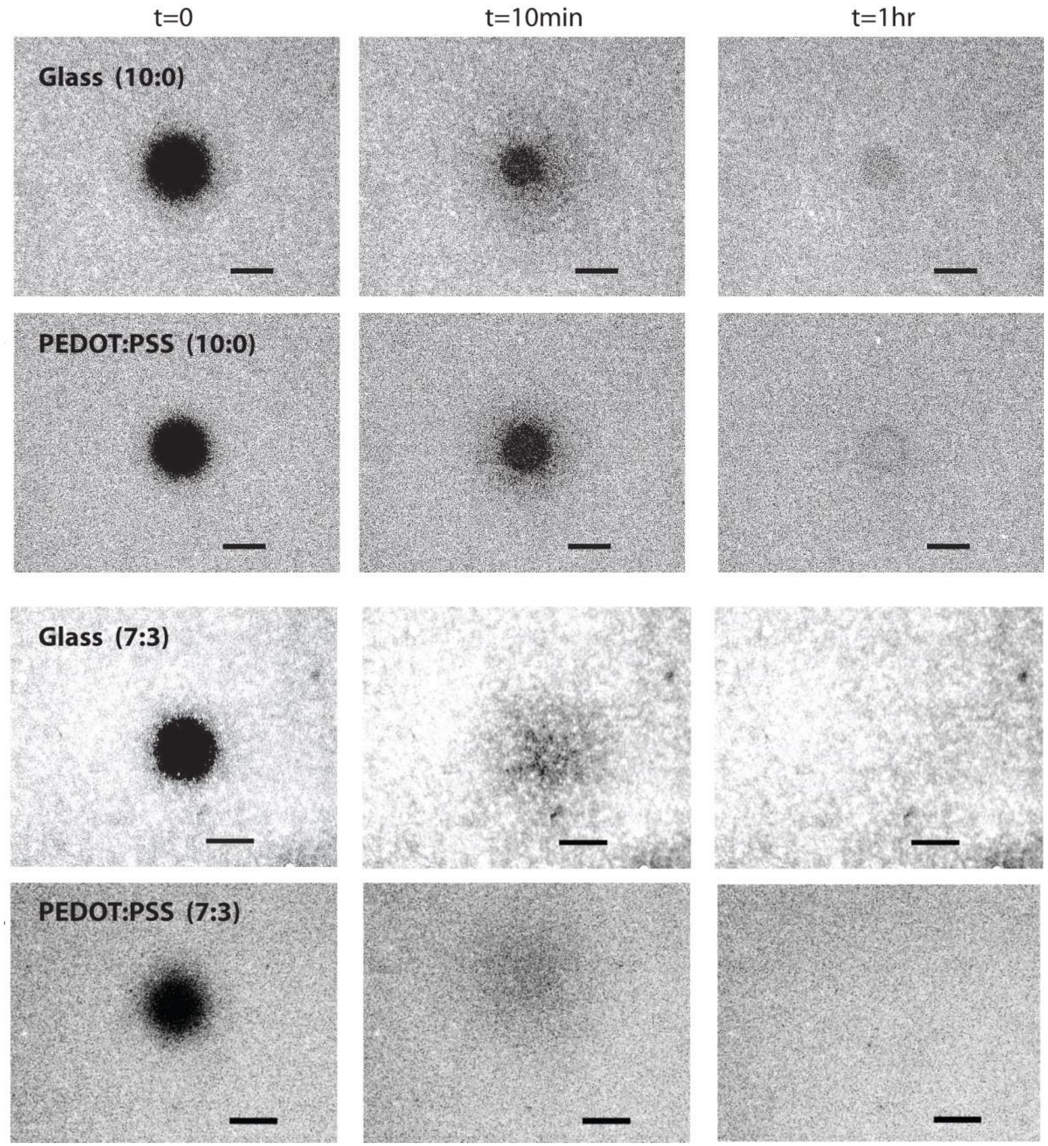
Vesicle fusion on PEDOT:PSS



Challenge: **assembling bilayer on conducting polymer**

Y. Zhang ***et al.***, ***submitted*****.**

Lipids on PEDOT:PSS are mobile and diffuse



D = 0.54 ± 0.01 um^2/s
MF = 0.94 ± 0.01

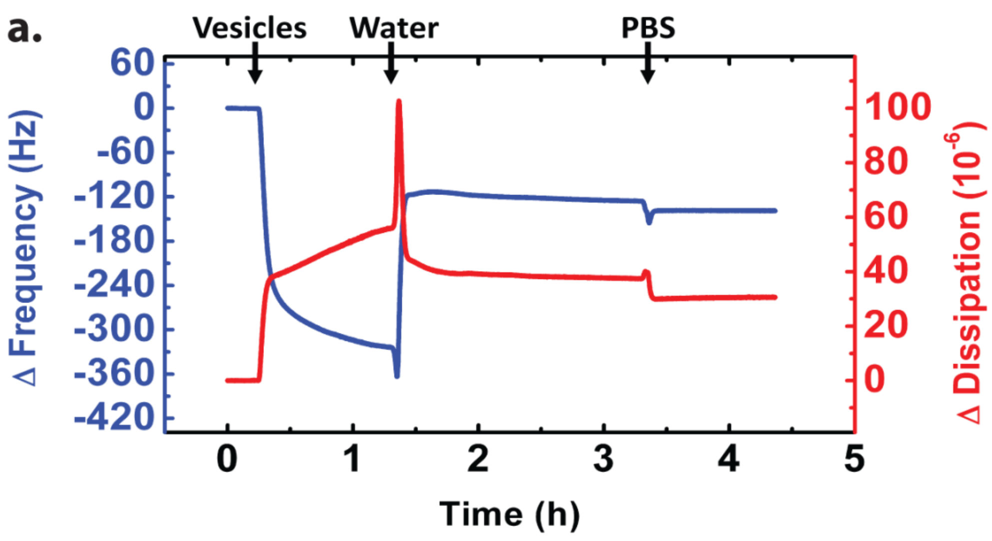
D = 0.35 ± 0.08 um^2/s
MF = 0.85 ± 0.07

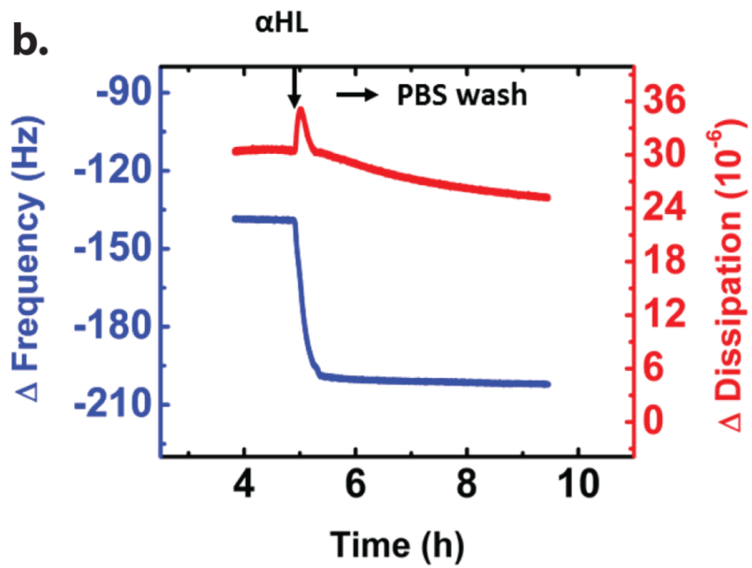
D = 0.5 ± 0.15 um^2/s
MF = 0.95 ± 0.06

D = 0.5 ± 0.06 um^2/s
MF = 0.97 ± 0.02

Y. Zhang *et al.*, *submitted*.

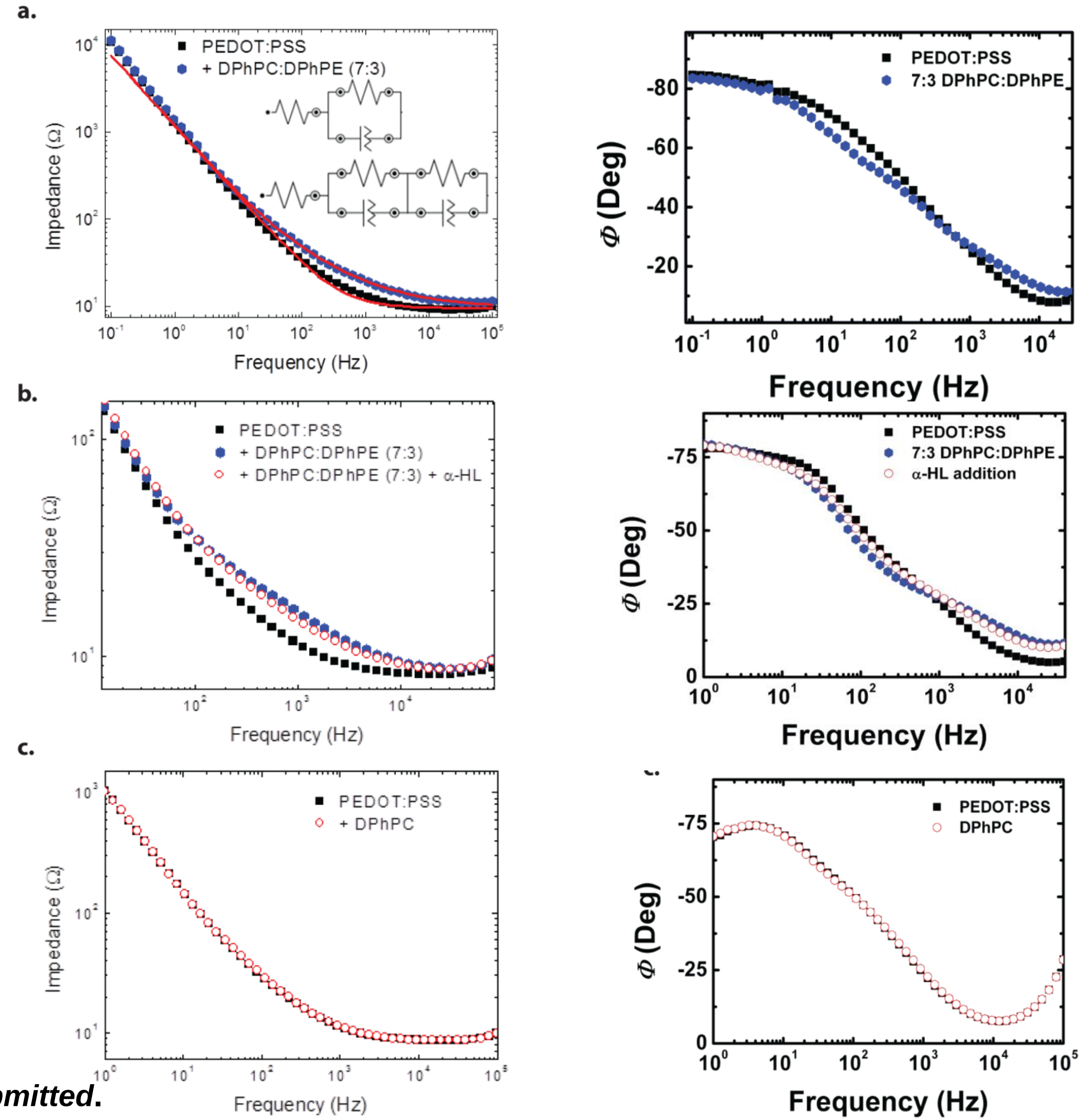
Osmotic shock accelerates rupture (200 x)





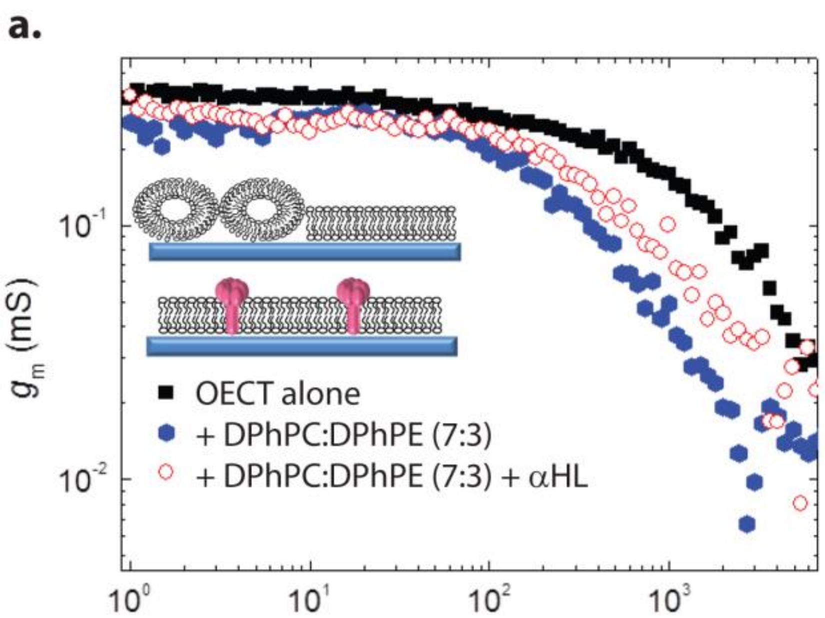
Y. Zhang *et al.*, *submitted*.

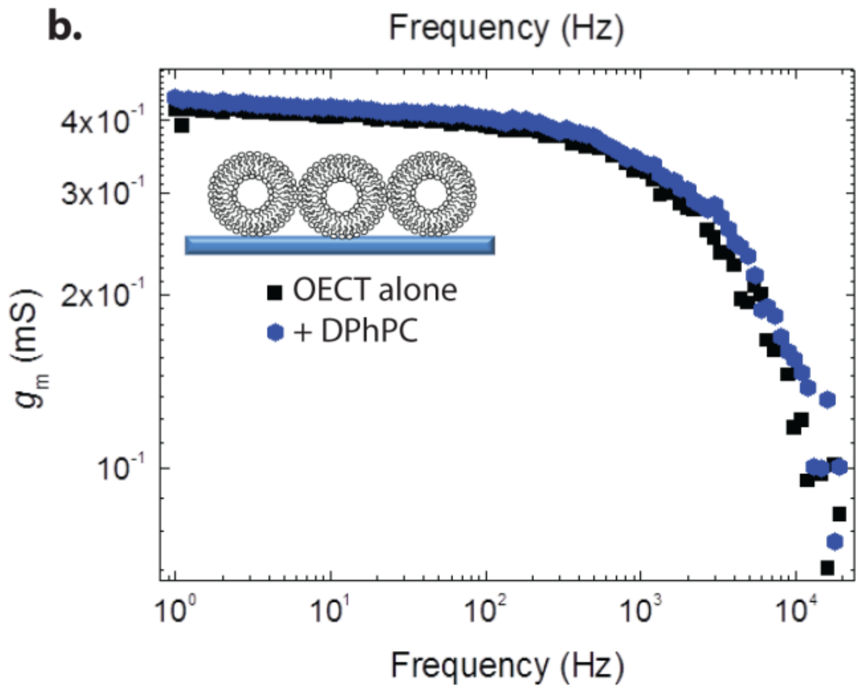
(E)QCM-D measurements of PEDOT:PSS + lipids



Y. Zhang *et al.*, *submitted*.

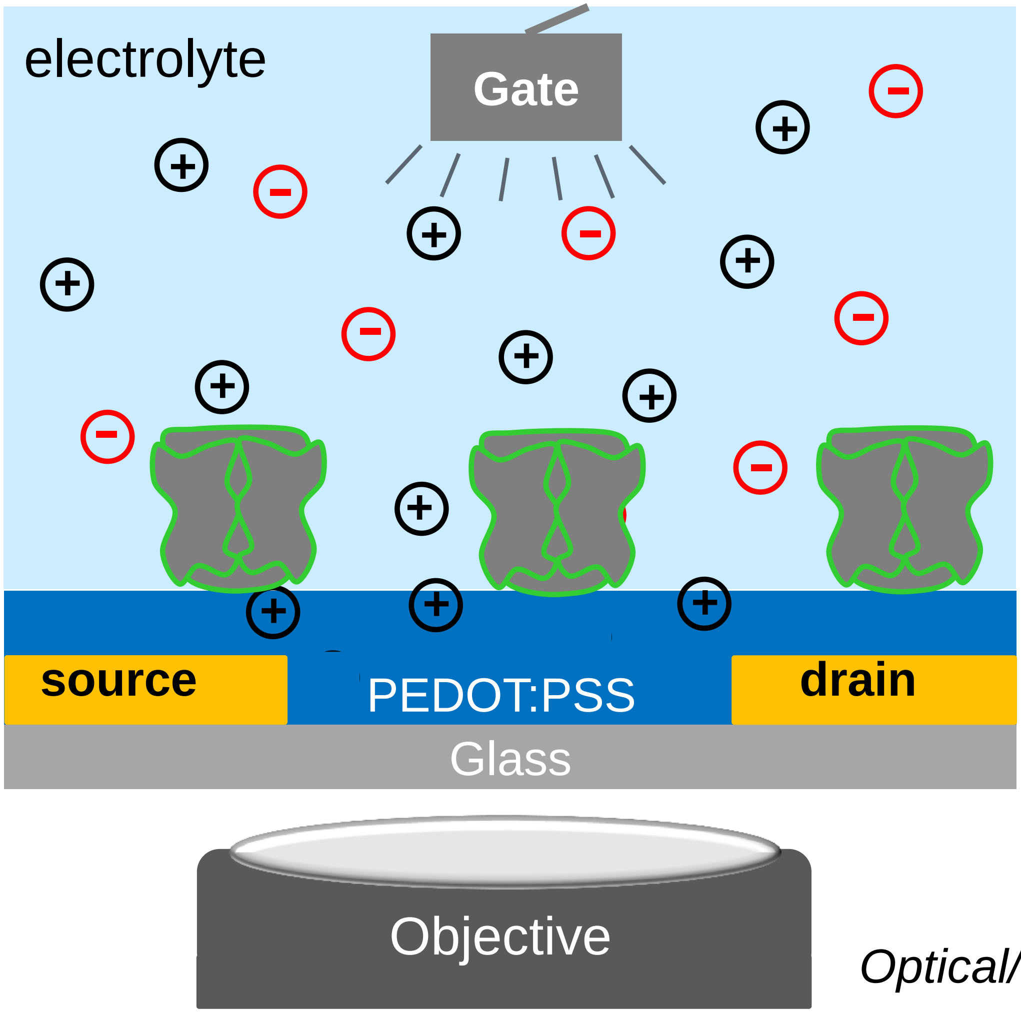
OECT detection of lipid bilayer and protein insertion





Y. Zhang *et al.*, *submitted*.

OECT application 1: Interfacing with proteins

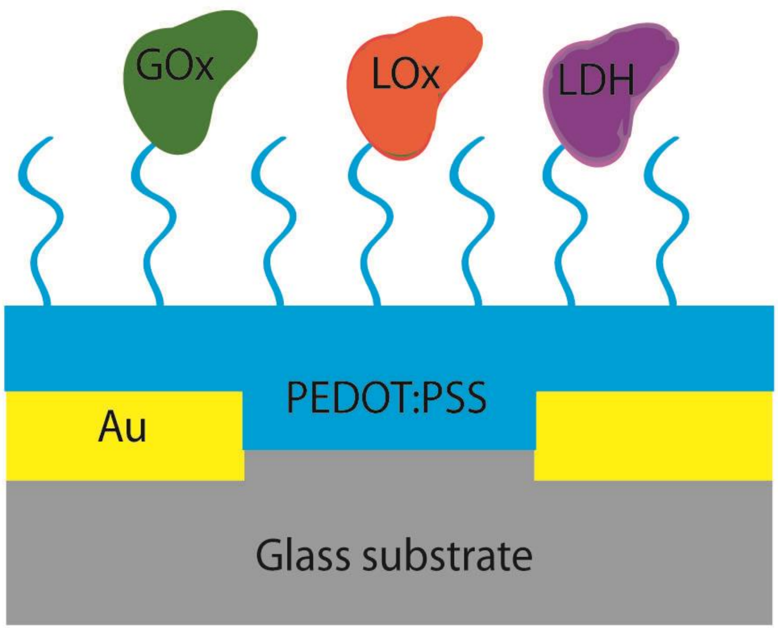


- *Integrated, robust device platform*
- *Fast response times*
- *Dynamic information captured*
- *Transparent for real time optical monitoring*

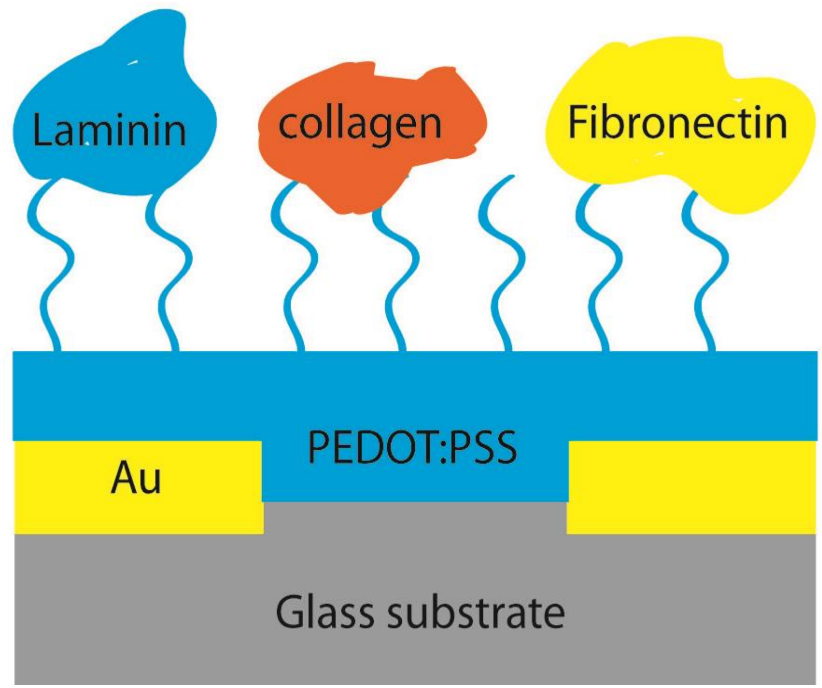
Optical/fluoroscence imaging

L.H. Jimison, et al., Adv. Mater. (2012)

Reasons for functionalising OECTs

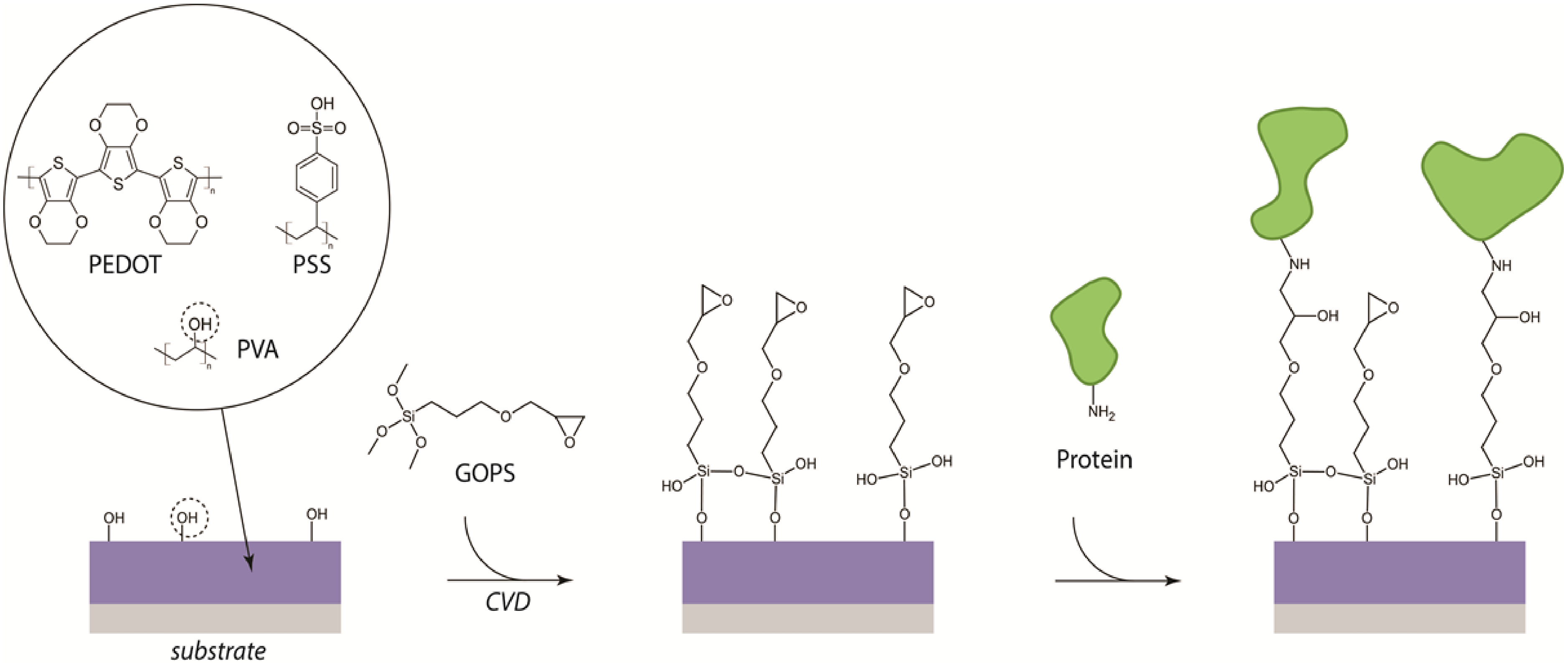


For metabolite detection
(using redox enzymes)



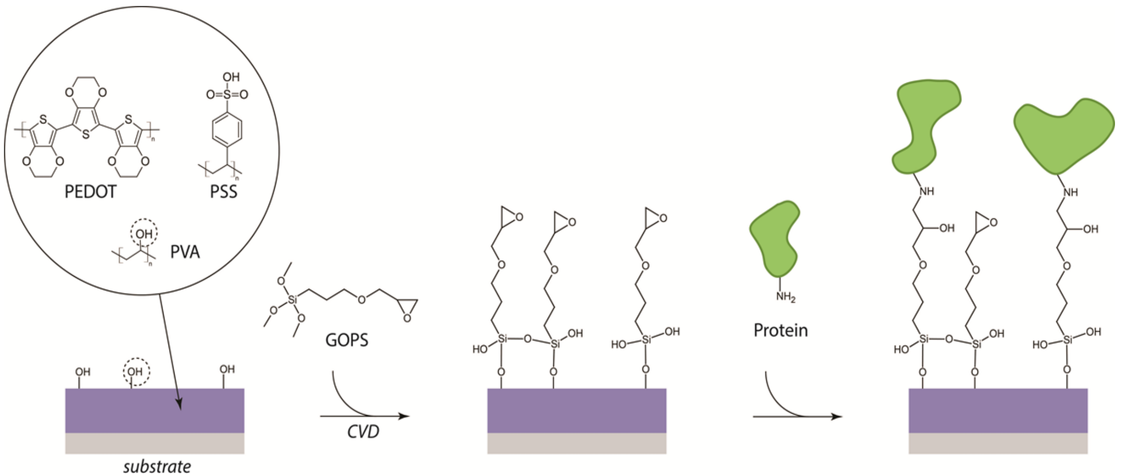
Mimic in vivo environment
(improve tissue functionality)

Functionalization of PEDOT:PSS via silanization



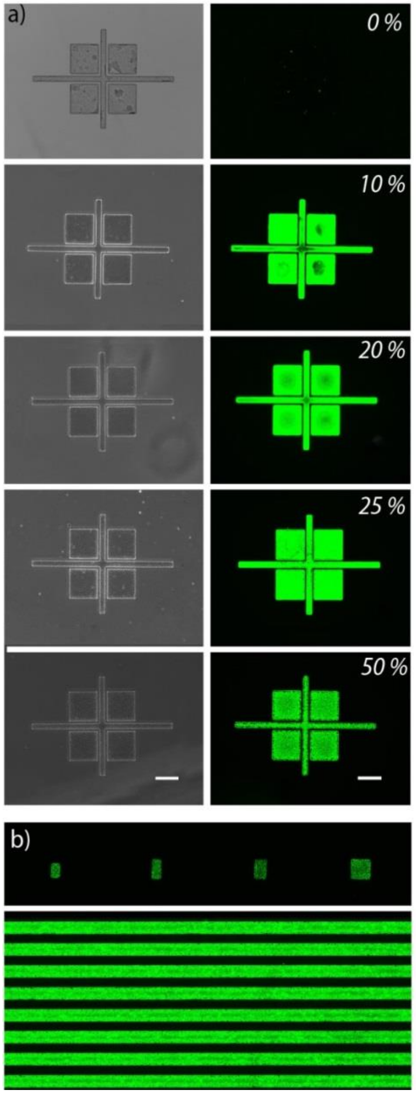
X. Strakosas *et al.*, *J. Mater. Chem. B* (2013).

Biofunctionalization of OECTs



X. Strakosas et al., J. Mater. Chem. B (2013).

Versatile repertoire of functionalization methods generated

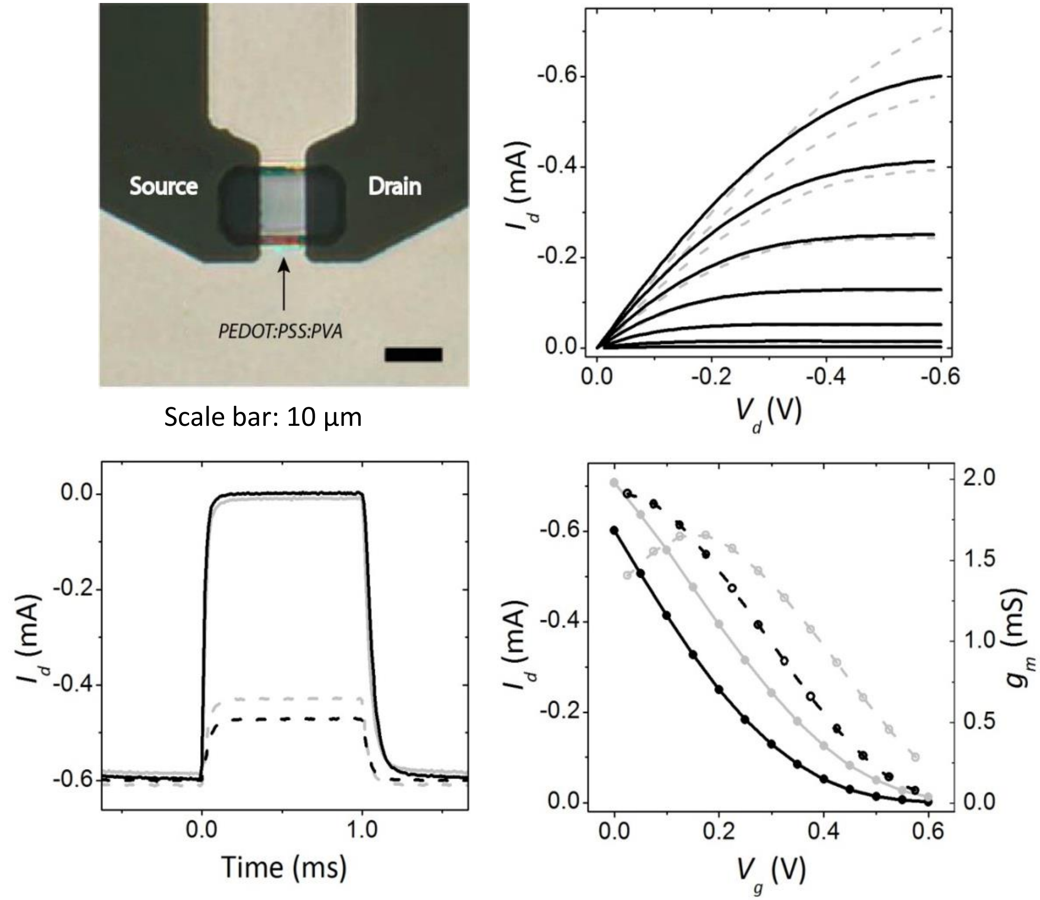


PEDOT:PSS:PVA OECTs maintain performance

- ***Transconductance:***

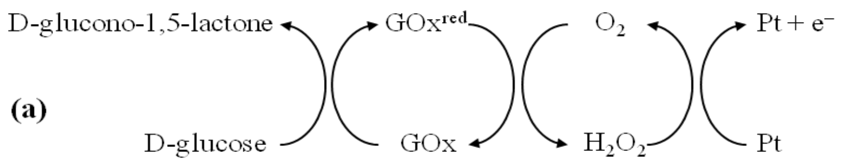
$$g_m = \frac{\Delta I_d}{\Delta V_g} = 1.86 \text{ mS}$$

- ***Time constant τ = 20.6 µs***

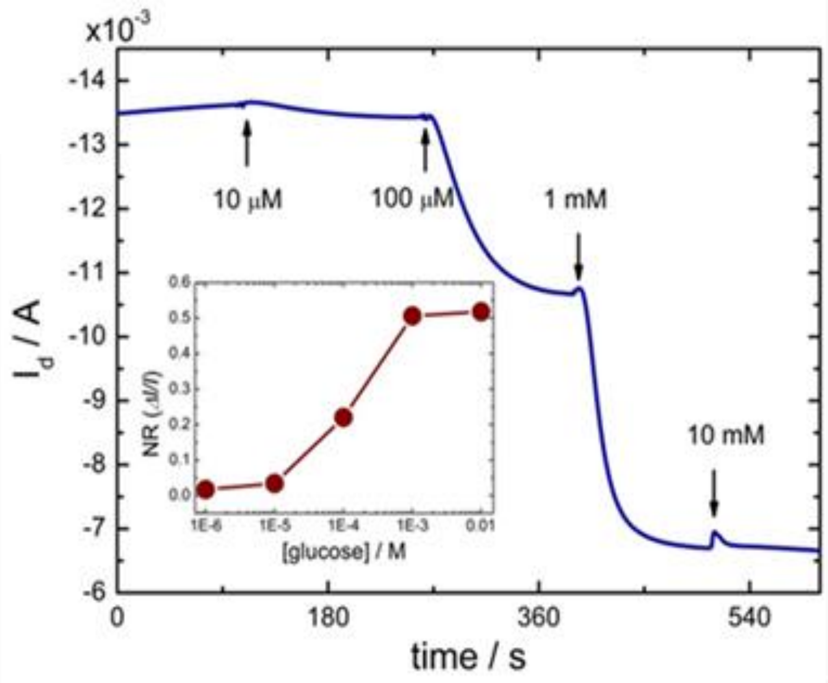


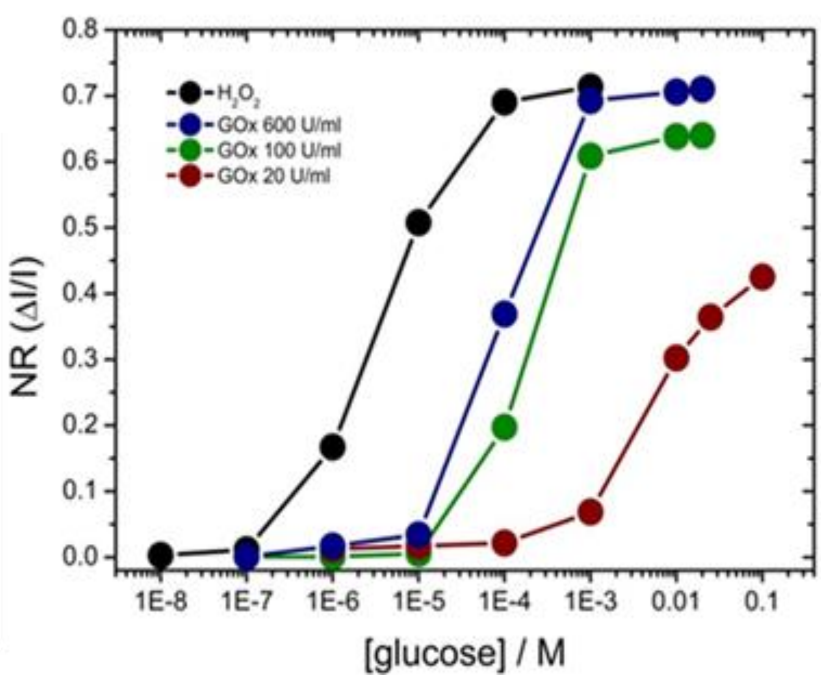
X. Strakosas ***et al., J. Mater. Chem. B*** **(2013).**

The OECT for monitoring metabolites: mechanism



transfer of e- to the gate: the drain current will change in response to the potential change
Need to avoid redox reactions from interfering species





Drain current change is ∝ to [glucose]

GOx can be tuned for sensitivity

Motivation: Emerging POC technologies

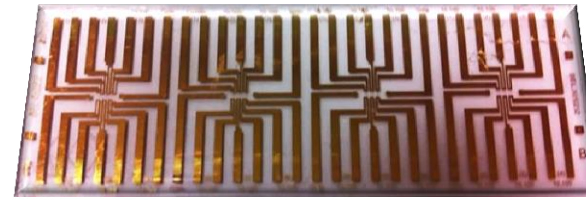
Routine Blood Testing

Portable single-analyte sensor

Lactate Sensor

Glucose Sensor

Miniaturized portable multi-analyte sensor



1cm

Glucose, Lactate, Cholesterol … Sensor

GOAL — **IDEA** — **CHALLENGES**

GOAL

- ✓ **Rapid**
- ✓ **Sensitive**
- ✓ **Accurate**
- ✓ **Multiplexed**
- ✓ **Low-cost**
- ✓ **Portable**

IDEA

Miniaturized multiplatform for

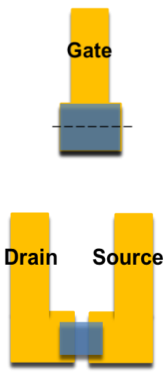
- ✓ **Real time**
- ✓ **Electrochemical** detection of
- ✓ **Multiple** biomarkers **simultaneously**
- ✓ **From a SINGLE sample**

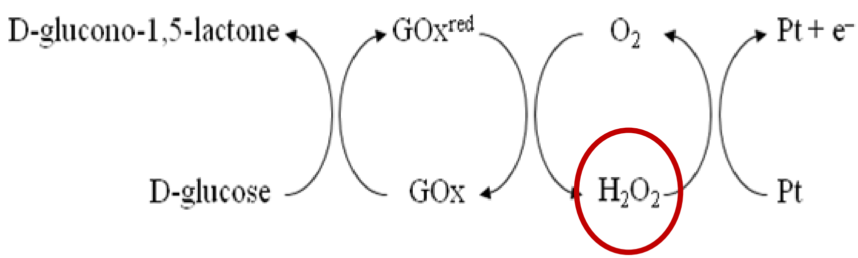
CHALLENGES

- ✓ **Sensitivity**
- ✓ **Specificity**
- ✓ **Electrochemical interference**
- ✓ **Electrical cross talk**

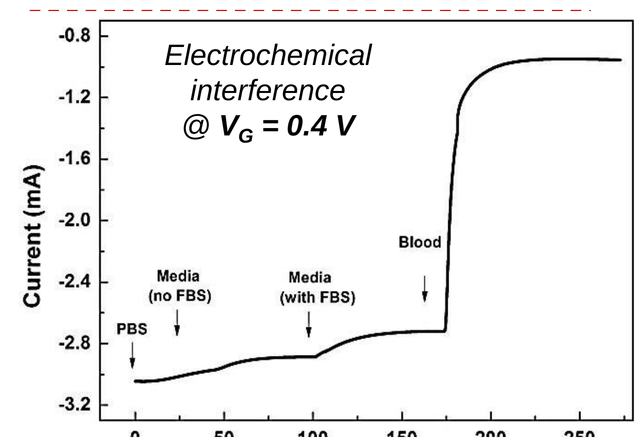
OECTs for metabolite sensing: How it works

- 1st generation of enzymatic biosensors: H_2O_2 detection

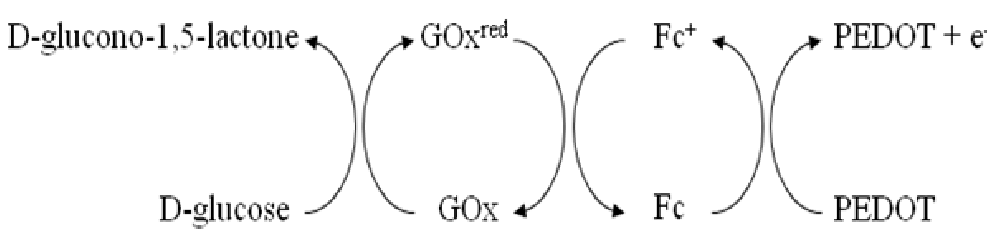




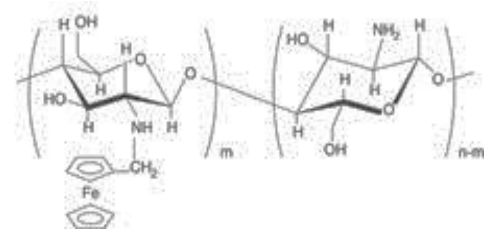
$$PEDOT^{+}:PSS^{-} + M^{+} + e^{-} \longrightarrow PEDOT + M^{+}:PSS^{-}$$



- Electron shuttling using ferrocene to transfer an electron directly to the PEDOT channel…



Chitosan-Ferrocene (CS-Fc) complex



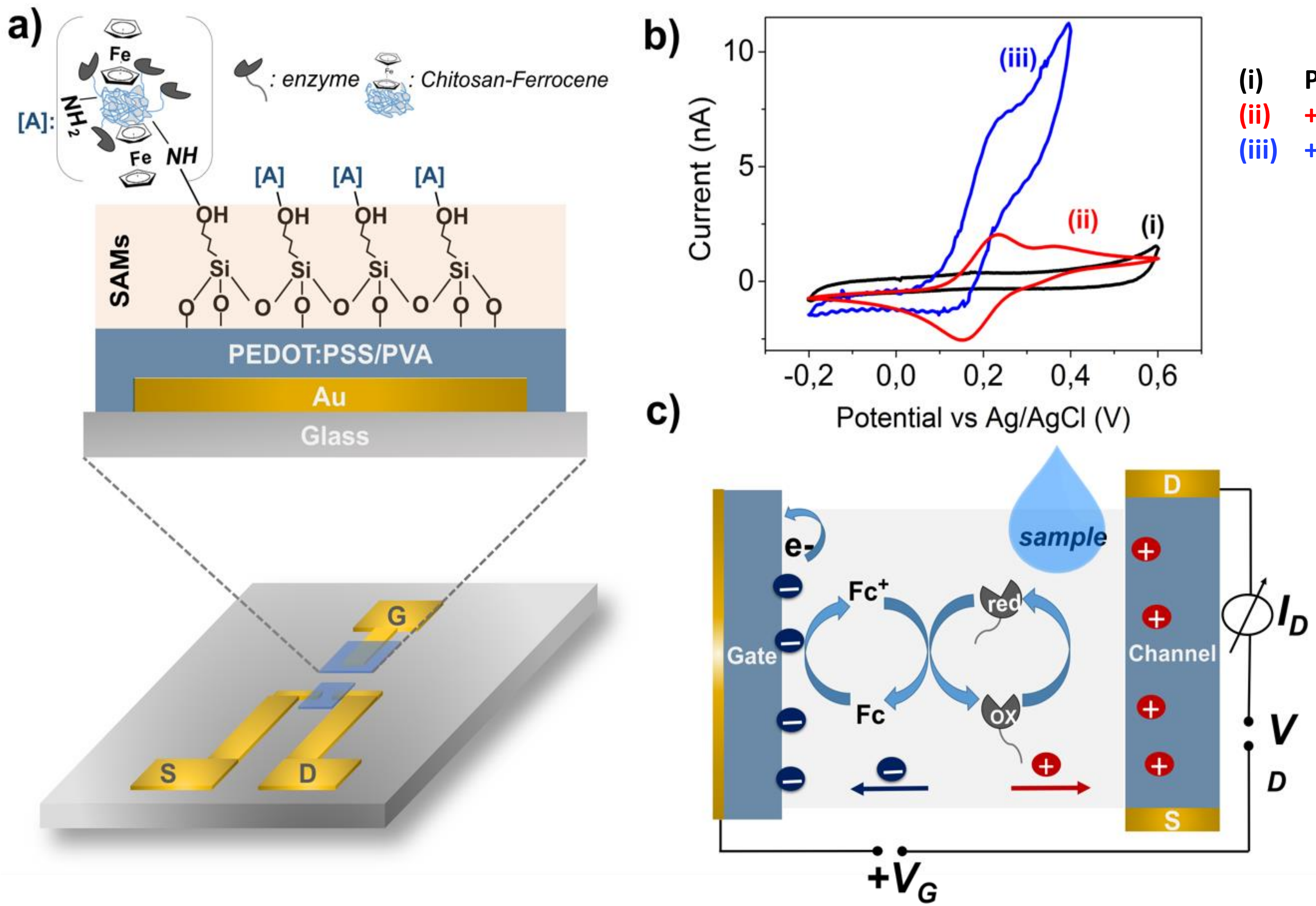
- *Electrochemical reversibility*
- *Stability at low potential*

<u>**Previous work**</u>: All in solution (electrolyte)

Shim, N.Y., et al. *Sensors* (2009)

MINES Saint-Étienne

Biofunctionalisation of OECT with chitosan-Fc



(i) PEDOT:PSS
(ii) +Cs-Fc/Gox
(iii) +glucose

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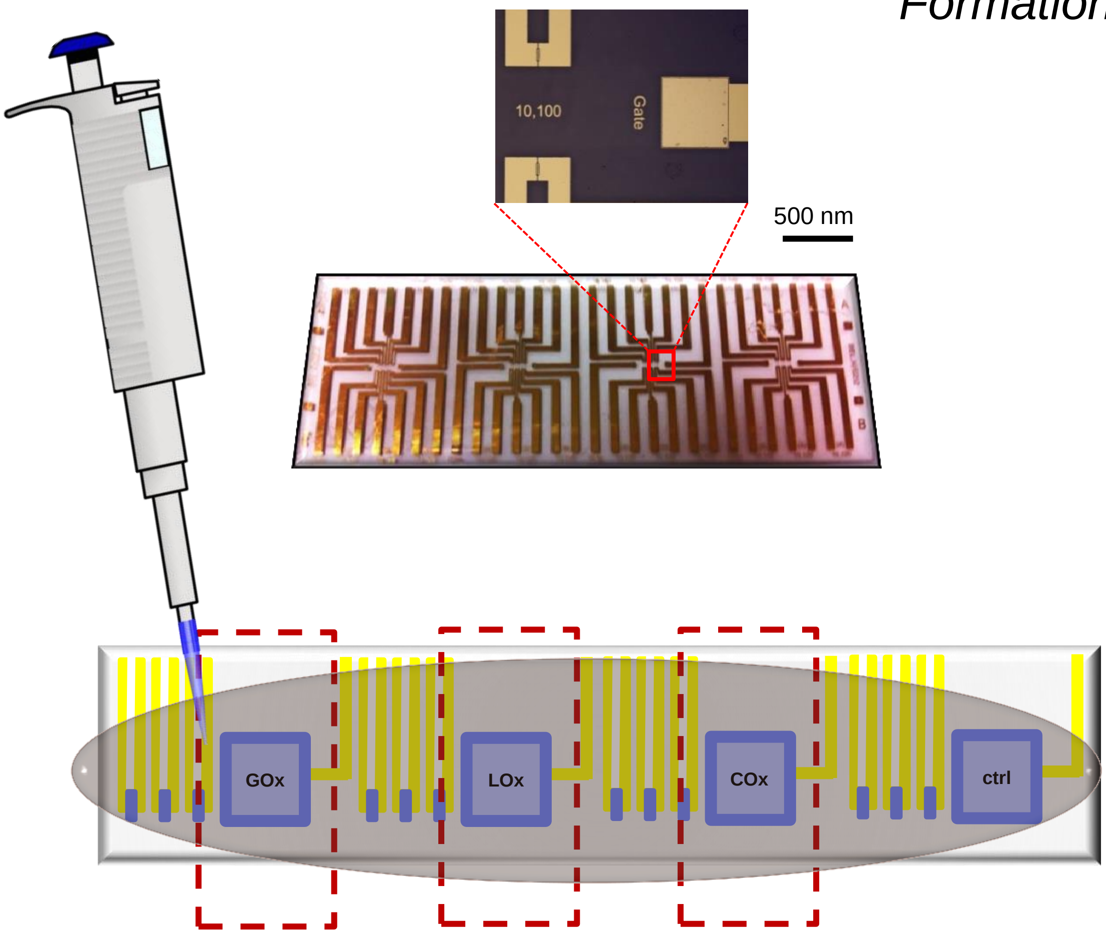
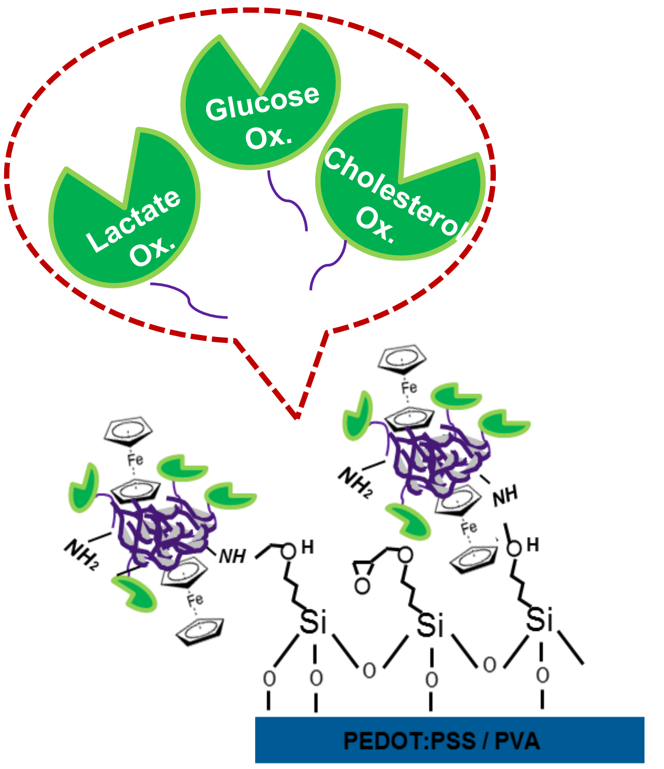
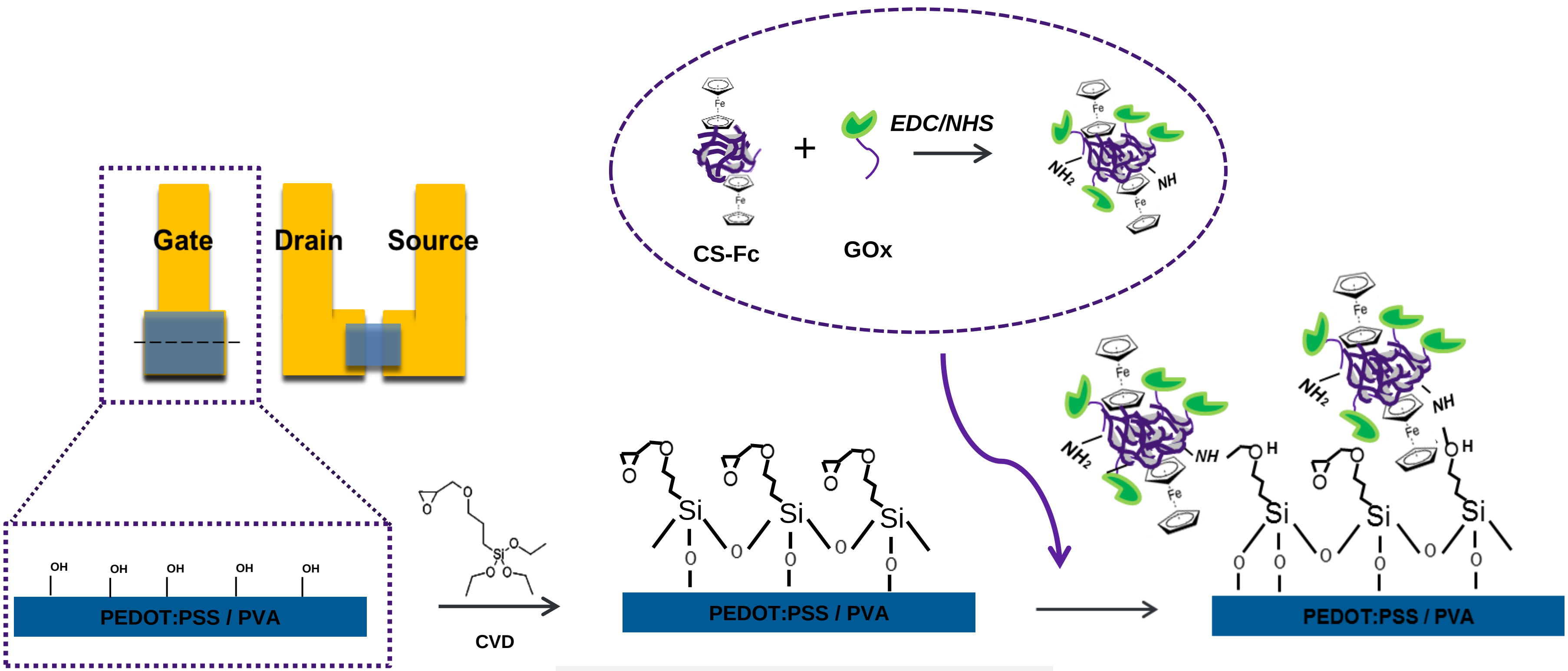
Concept design of our biosensing multiplatform



*Formation of different **analyte-responsive** functional surfaces*



Enzyme immobilization onto the gate

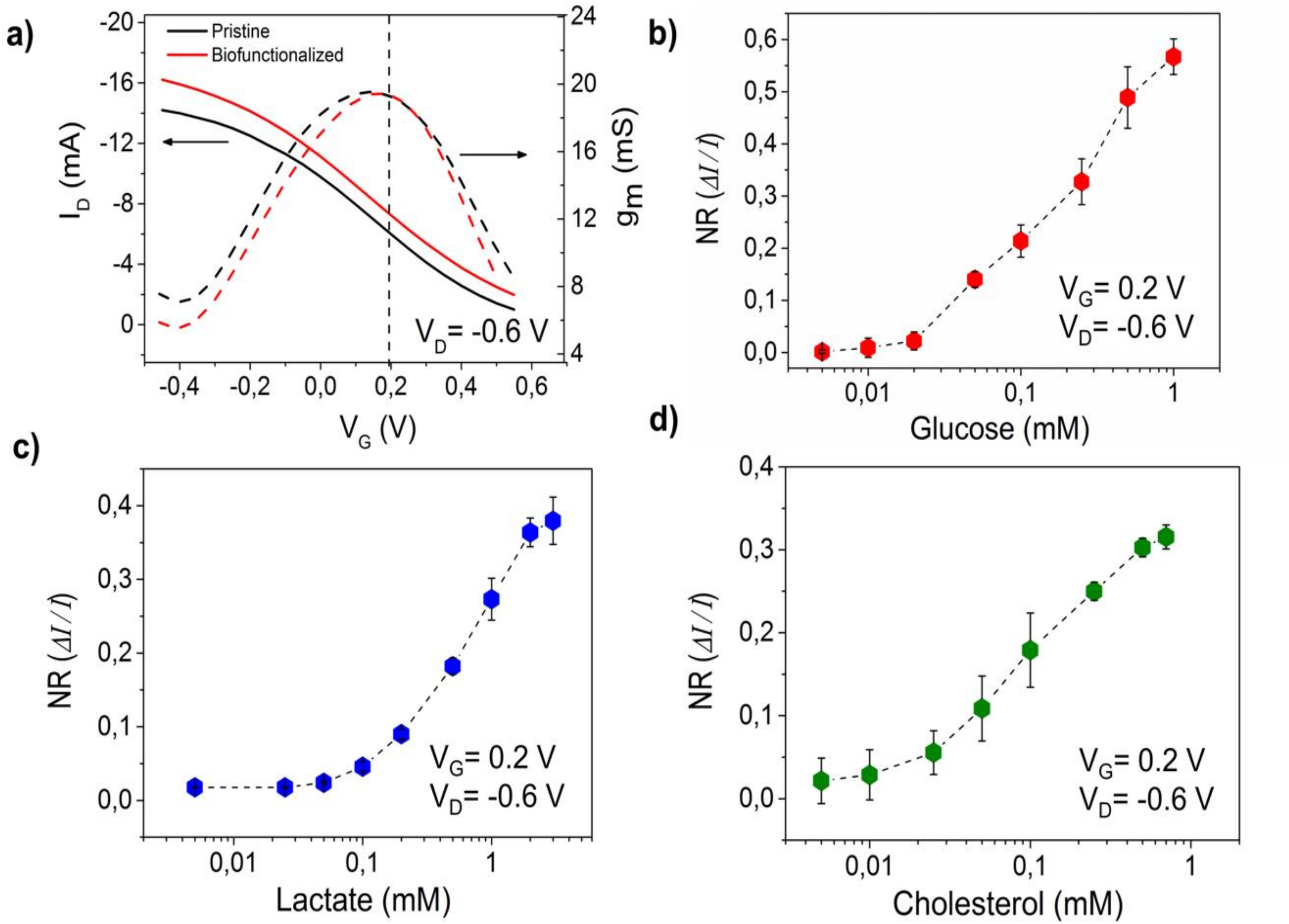


2 critical steps include…

- ✓ Formation of the **Cs-Fc /enzyme complex**
- ✓ Formation of **analyte-responsive surfaces**

Based on: ***X. Strakosas et al., 2014***

Calibration curves of the individual analytes

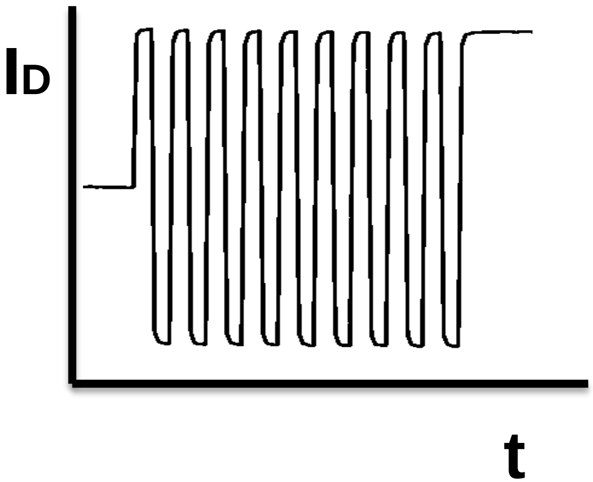


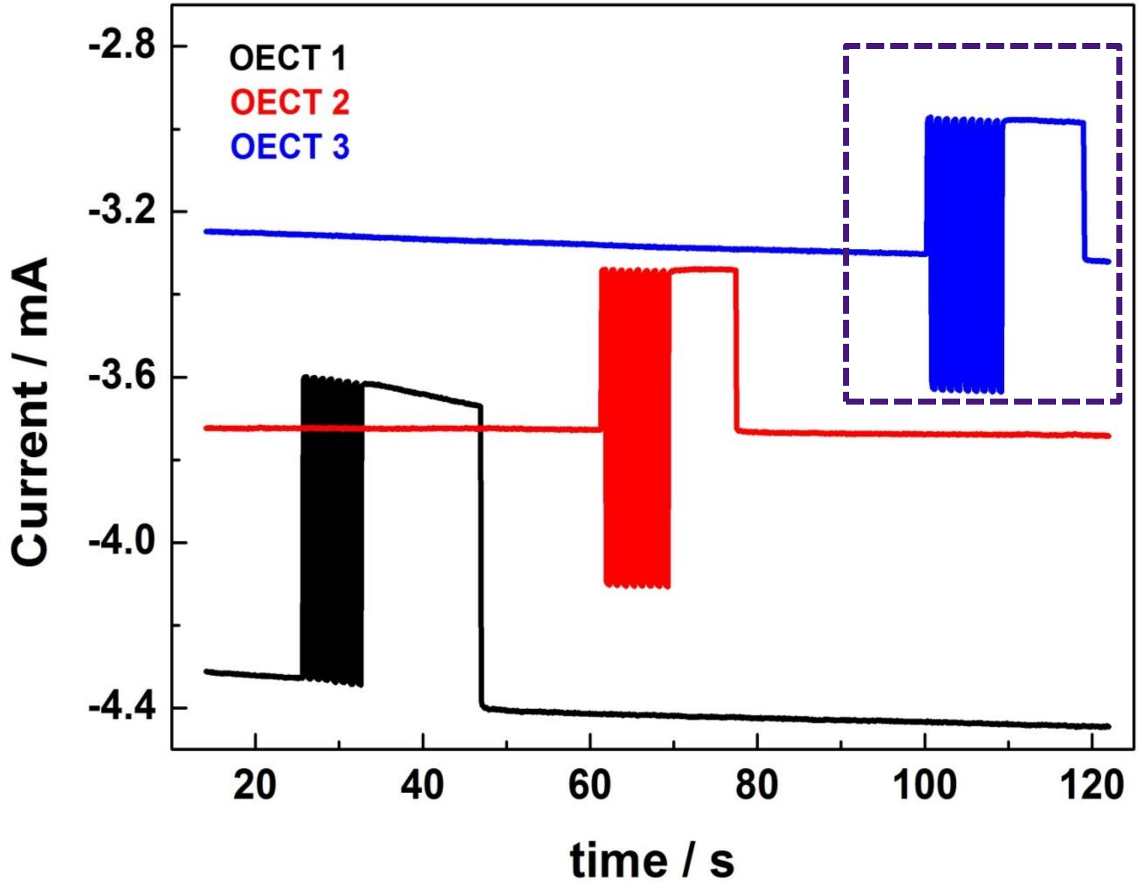
MINES Saint-Étienne

Elimination of electrical interference

- **Sequential pulsing of each gate showed no electrical cross-talk among the different transistors (physical separation of source)**

$V_D = -0.6V$
$V_{G\ rest} = 0.1\ V$
Gate pulse: 0.1-0.2V
Pulse frequency: 10Hz

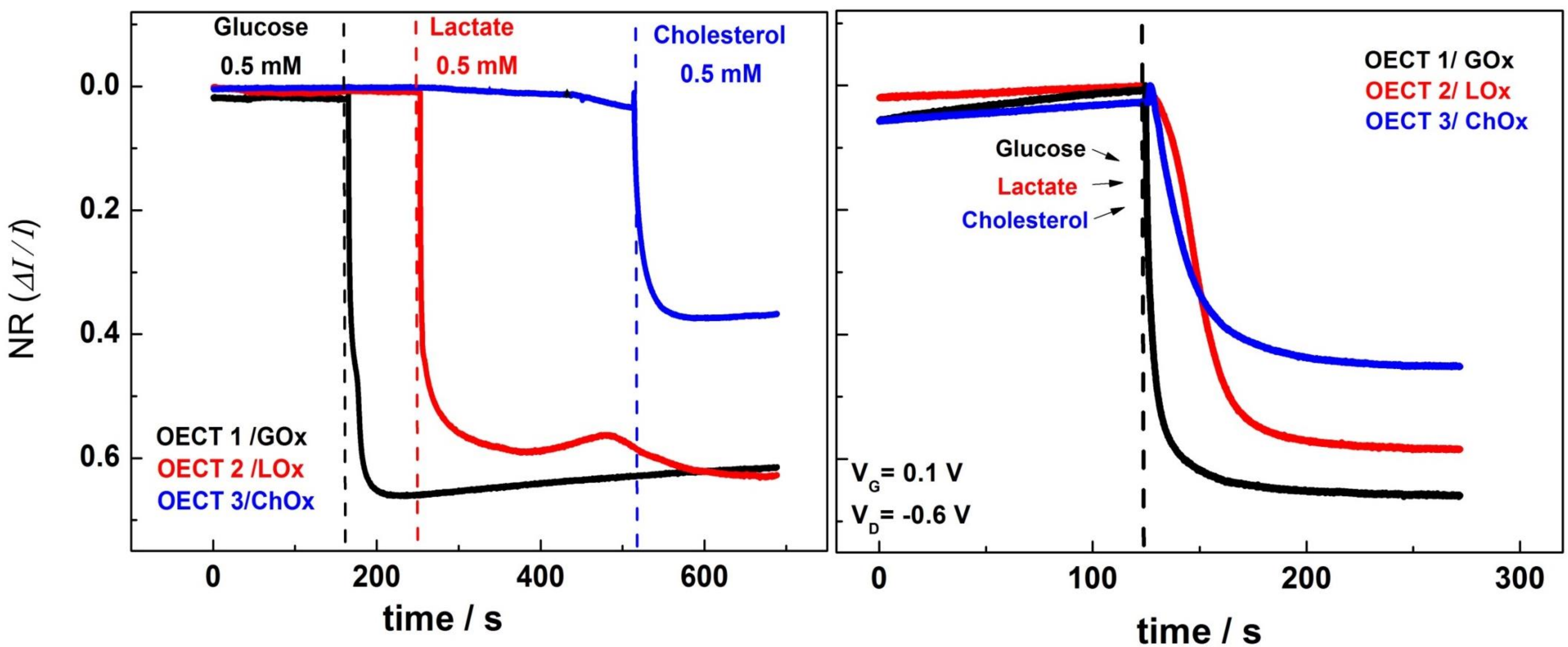




Real-time multianalyte monitoring

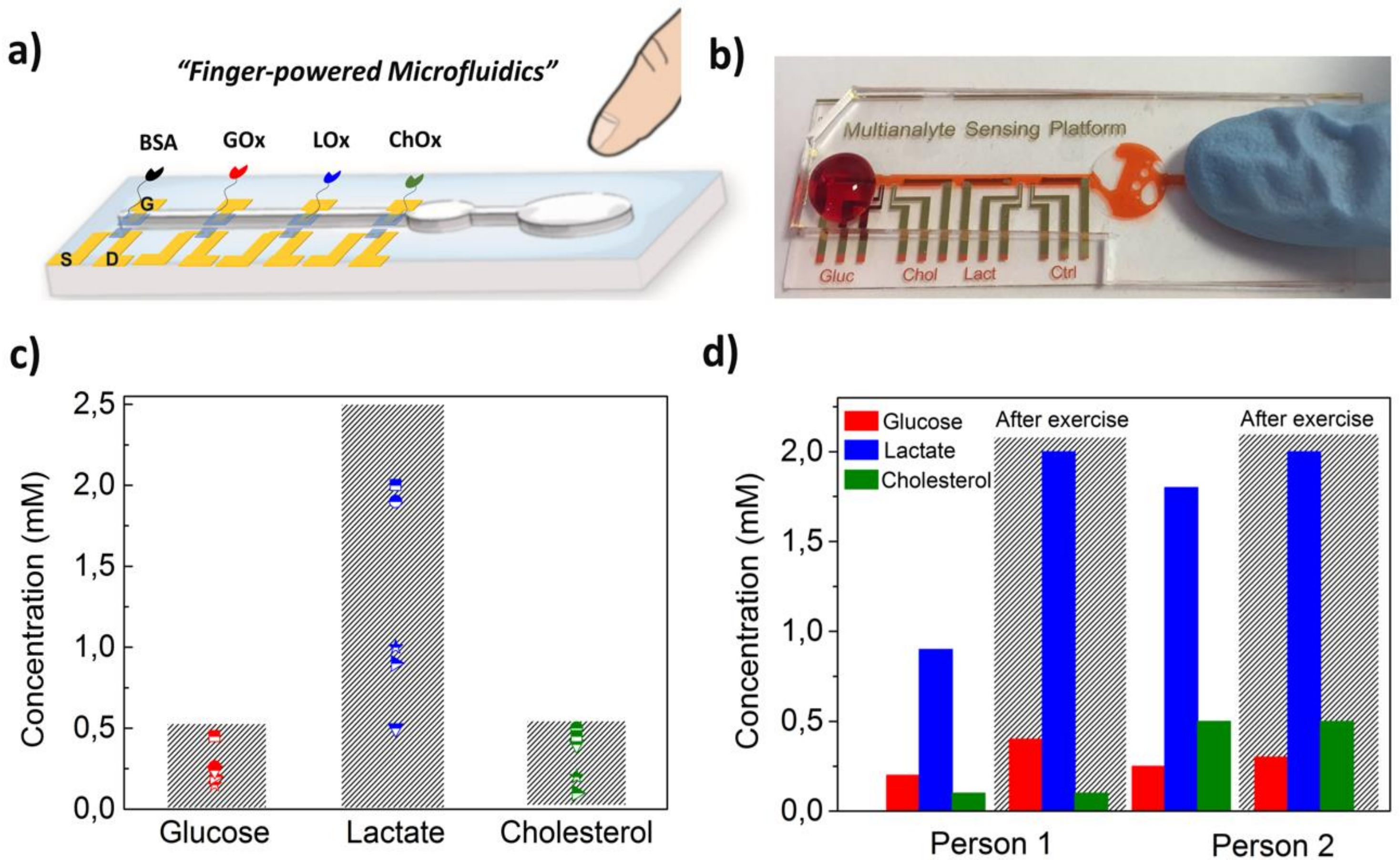
- **Successive additions the different analytes showed no biological interference among the differently functionalized transistors**

in PBS…



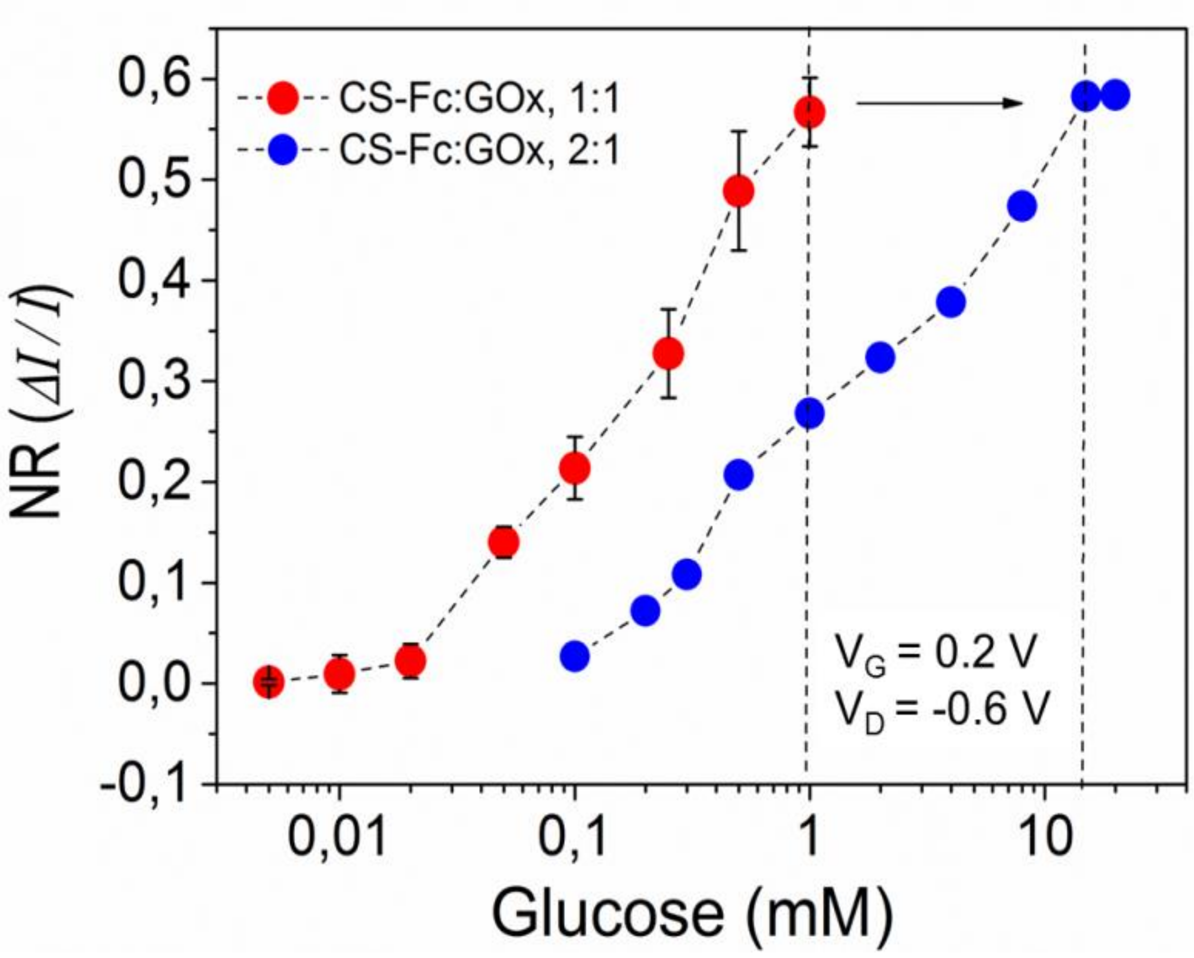
Real-time multianalyte detection using POC device

- **Saliva samples from healthy volunteers**

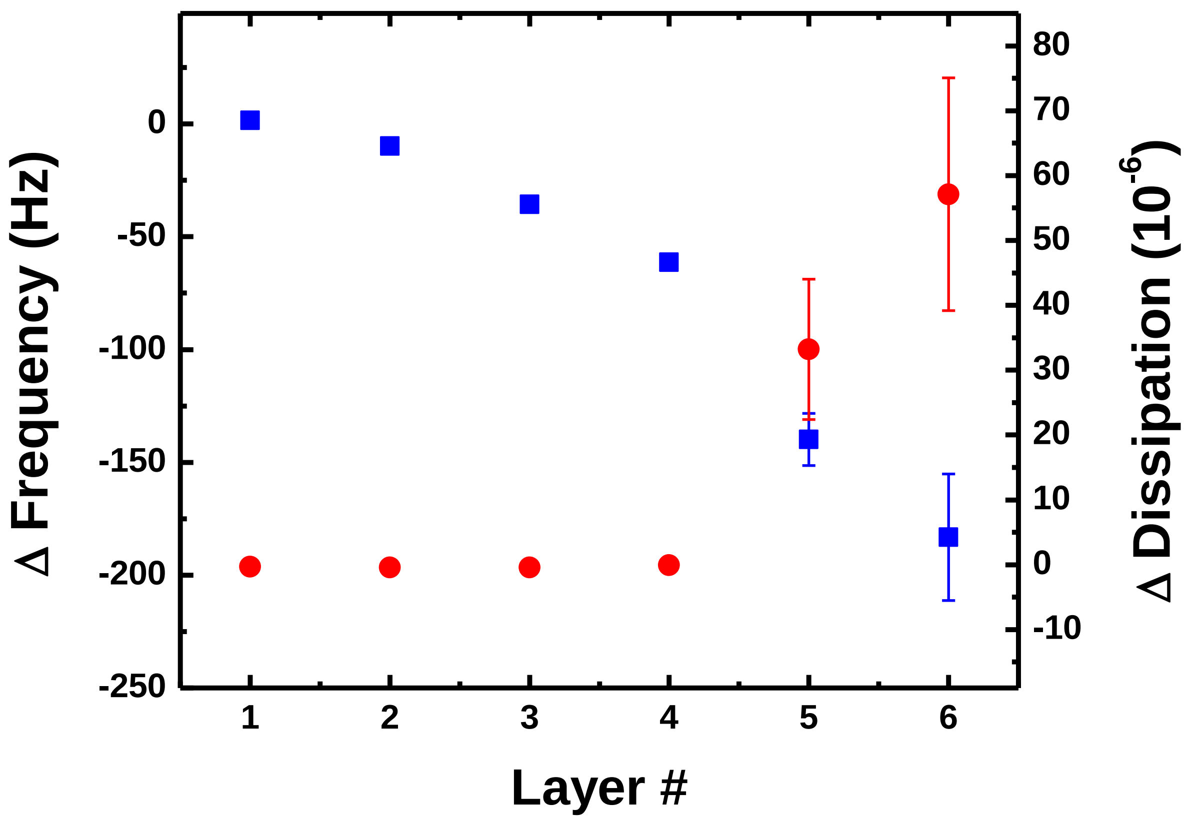


Changing sensitivities of devices

- **Tuning of linear range**



LBL deposition of PLL and PSS on PEDOT:PSS



-- Sample: PEDOT:PSS/PVA/GOPS

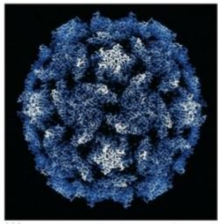
-- Solvent: PBS

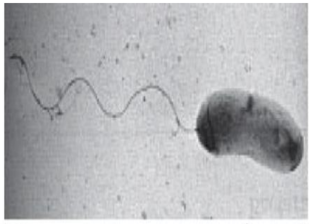
-- Layer 1 is PLL @ pH 8.5 …; deposited $(PLL/PSS)_3$ layers

-- Take the average of 3^{rd}, 5^{th} and 7^{th} overtones for plotting

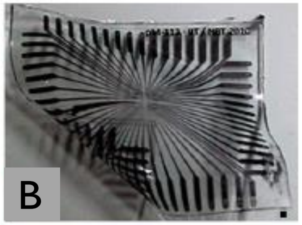
The future of organic bioelectronics

- **Identifying new areas for interfacing with biology**
  - Devices to stimulate/record electrically active cells
    - not just neurons, cardiac cells, muscle cells
    - not just CNS, also PNS, neuromuscular junction
  - Processes involving ion transfer/flow
    - Ion channels, signal transduction, oxidative phosphorylation
    - Electron transfer chain, redox reactions
    - Bio fuel cells
  - Plants/bacteria/viruses– biotechnology





- **Materials development**
  - Biodegradable/bioerodible/biofunctional – but still highly conducting
  - Materials designed for specific applications
  - Conformable, disposable substrates



Acknowledgements

<u>EMSE: Dept of Bioelectronics</u>

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<u>Alumni</u>

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