Sensing devices that use electrical double-layers and impedance spectroscopy: Design strategies

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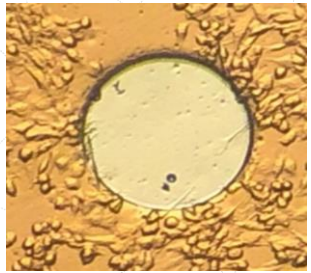
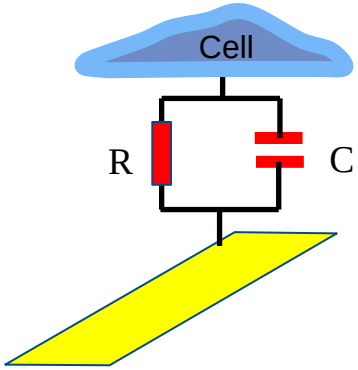
Devices physics and impedance spectroscopy

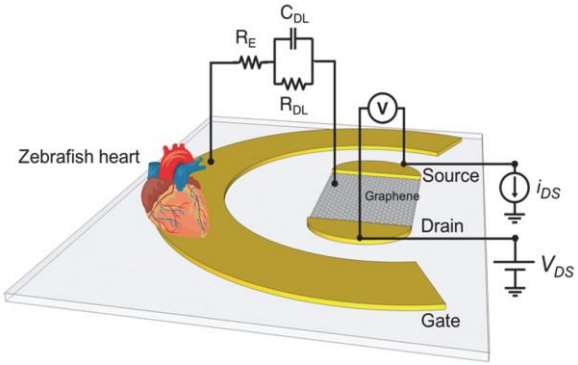
Emergent electronic devices operate in liquids or in contact with wet surfaces.

The electrical readout should be a small AC signal.



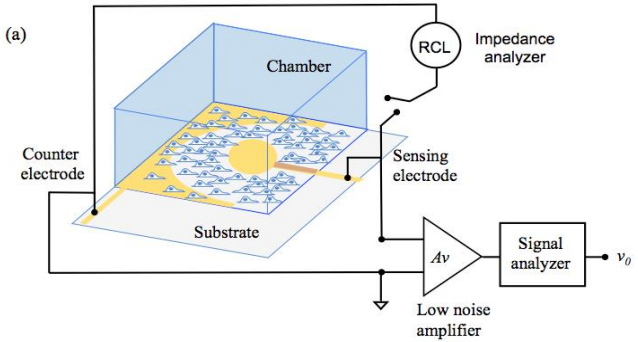


Devices to detect cells



Transistor structures

(biochemical sensing)



Multiparameter devices

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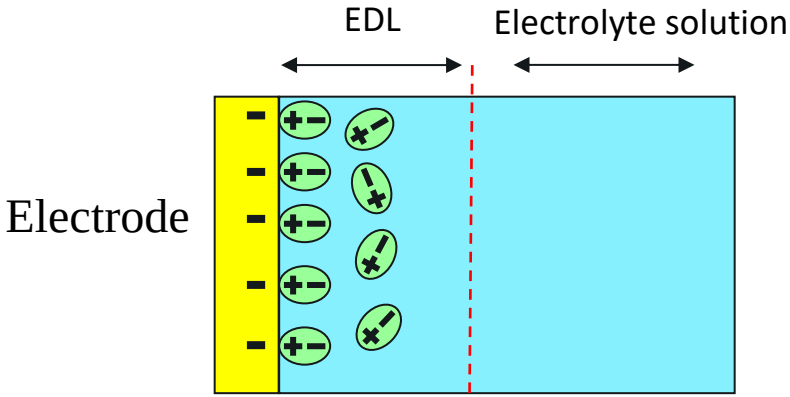
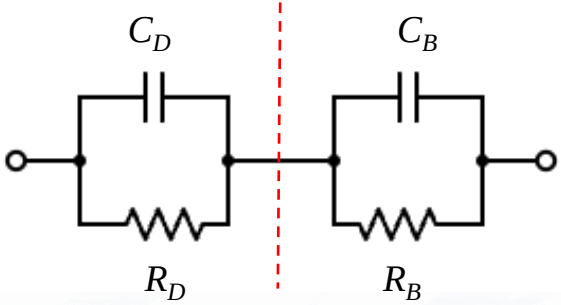
The electrical double layer (EDL)



The basic equivalent circuit



High impedance

Low impedance

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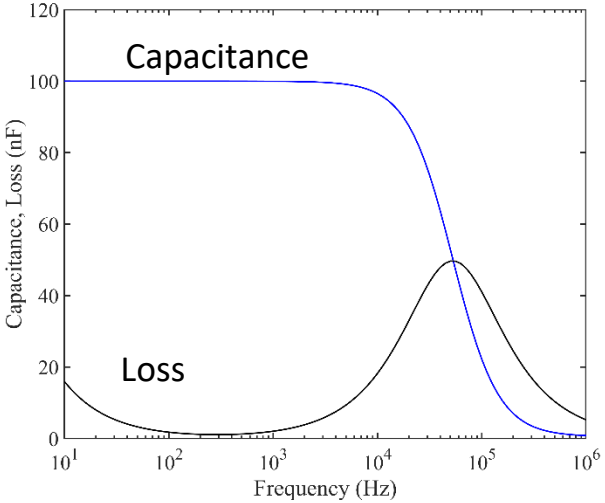
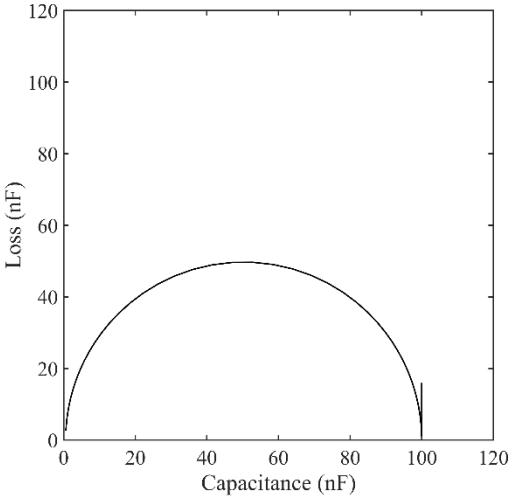
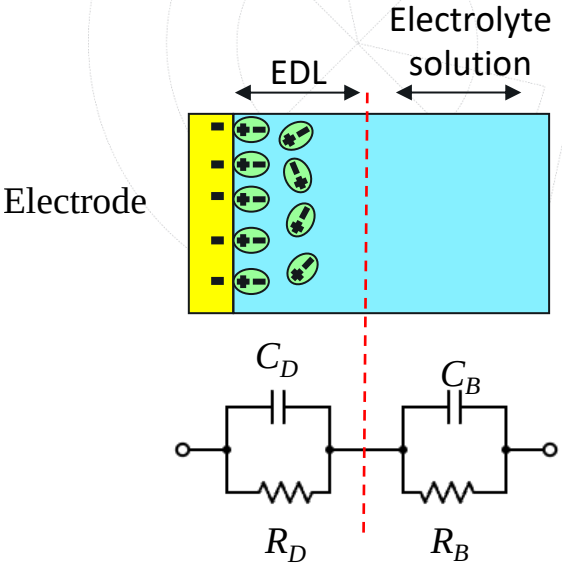
The EDL frequency response



Semilogarithm plot



Cole-Cole Plot



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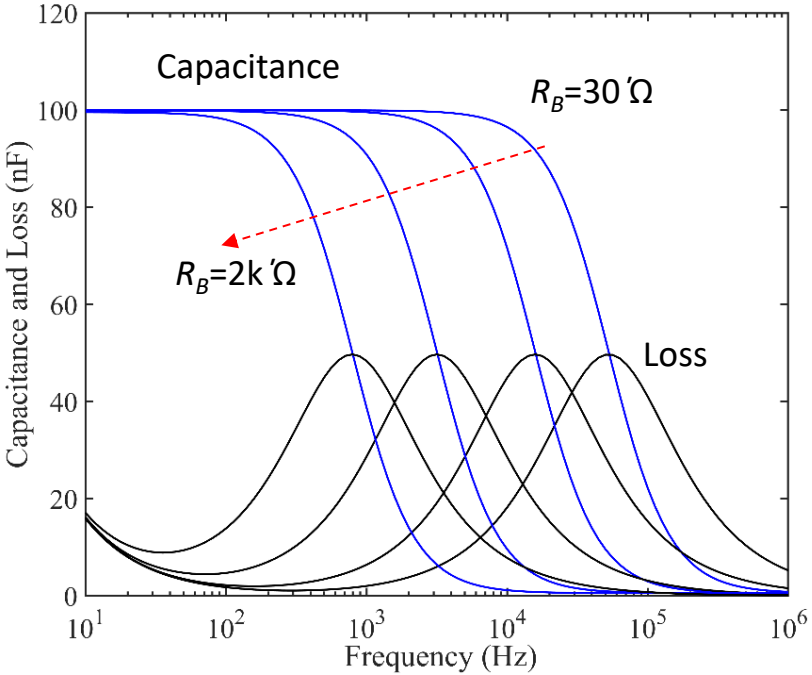
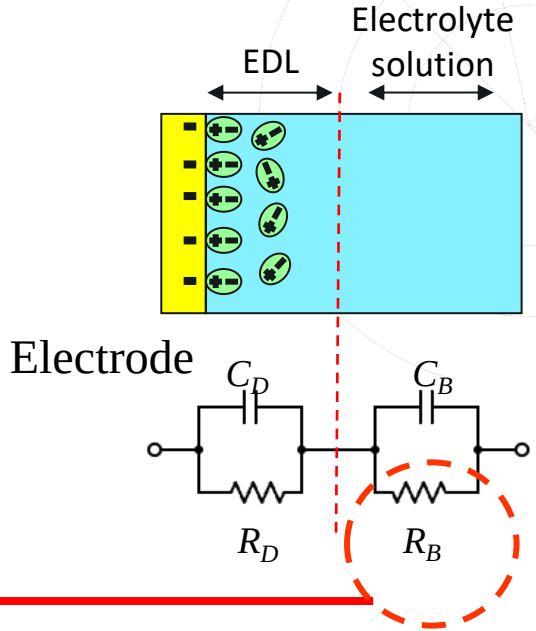
The EDL frequency response





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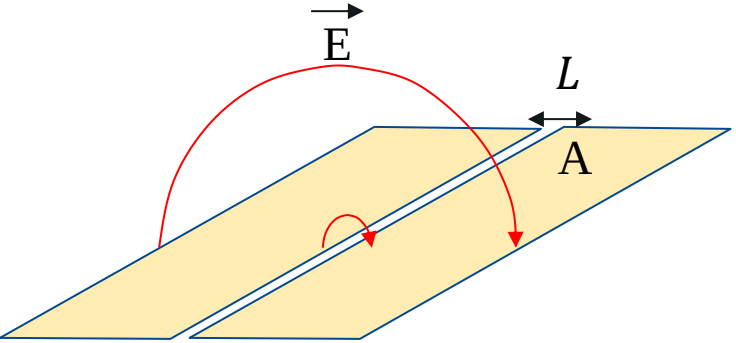
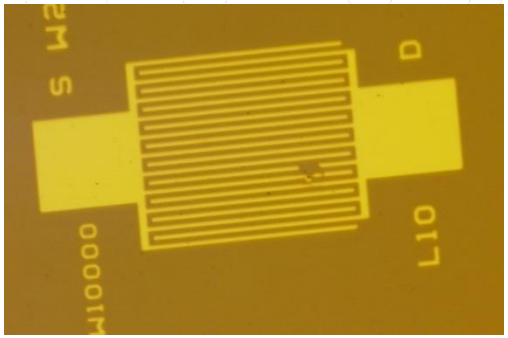
Device design

What is the best electrode geometry to increase the Maxwell-Wagner relaxation frequency ?



$$R_B = \rho \frac{L}{A}$$



It is not a good strategy.
This is because the effective distance L is not constant.

Increase the area while keep the gap between electrodes constant.
It is a good strategy

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Examples of devices

- Food control and certification;
- Biosensors (detection of potassium and dopamine);
- Immune system response;
- Cell migration;

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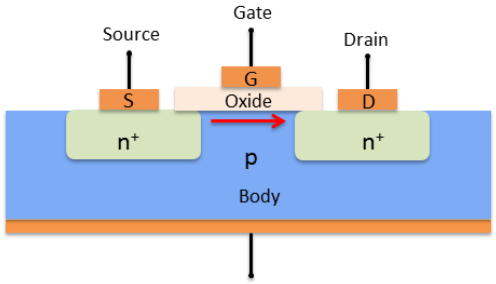
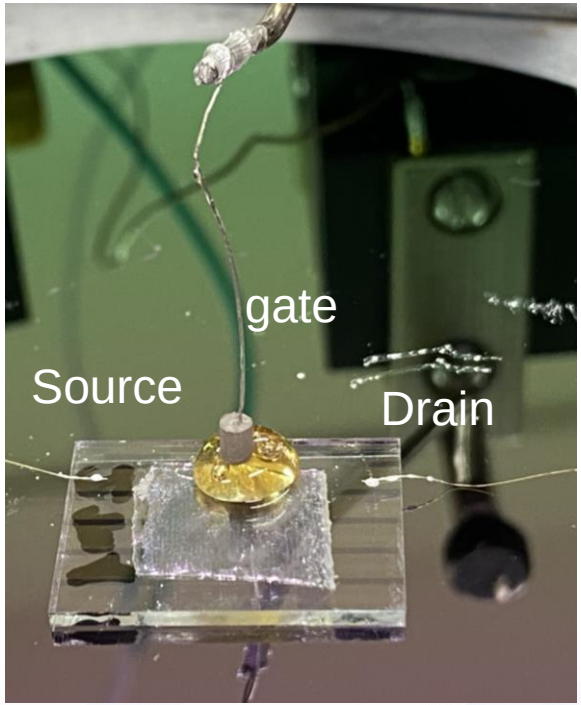
Dielectric spectroscopy and devices: Transistors



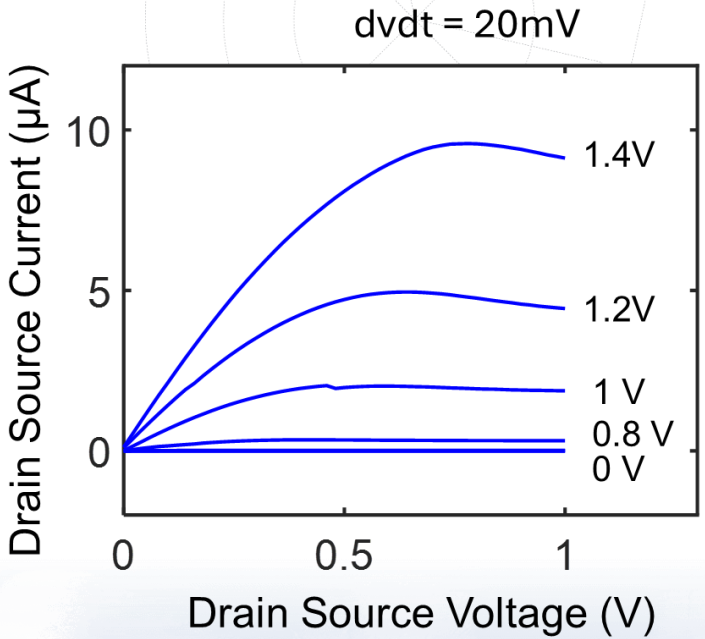
MOSFET device

On average each of
100 billion transistors

A15 Bionic chip
(iPhone 13)
15 billion transistors



Youssef Elamine



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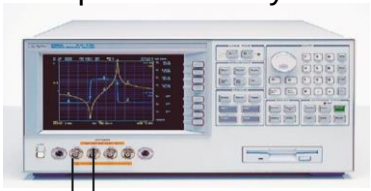
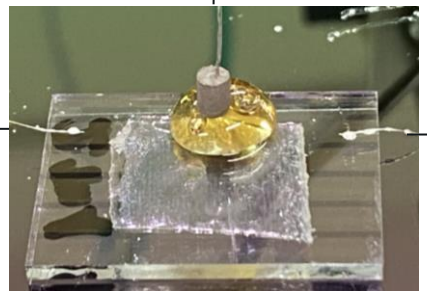
Dielectric spectroscopy and devices

Potassium
(k)

Impedance analyzer





Flowers ⟷ Honey dielectric properties

Why is this important for society?

USD 9.01 billion

The global honey market size in 2022

46 %

of the honey samples analysed were fraudulent

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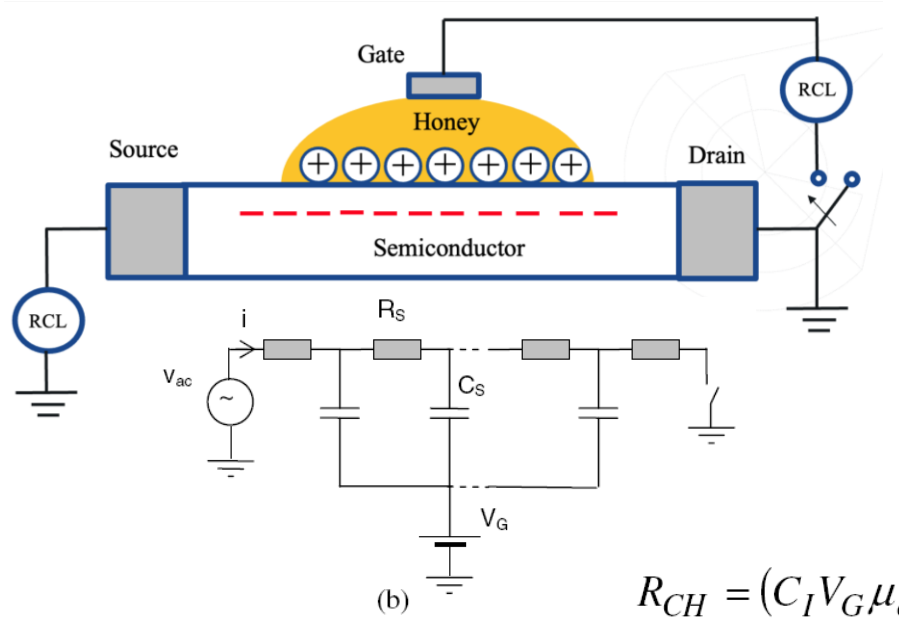
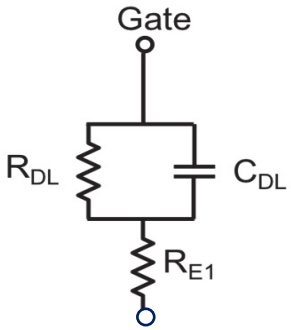
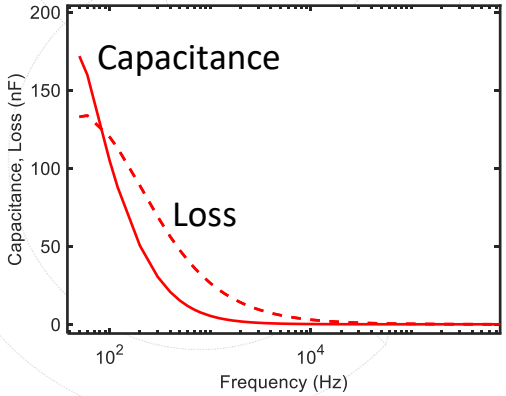
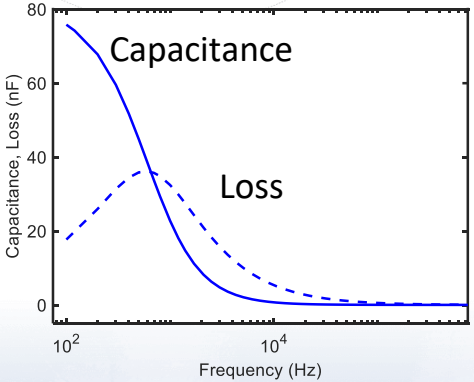
Strategy for transistor optimization





$$R_{CH} = (C_I V_G \mu_{ch})^{-1}$$





K.-D. Jung, C. A. Lee, D.-W. Park, B.-G. Park, H. Shin and J.D. Lee, *IEEE Electron. Device Lett.*, ***28, 204, (2007).***

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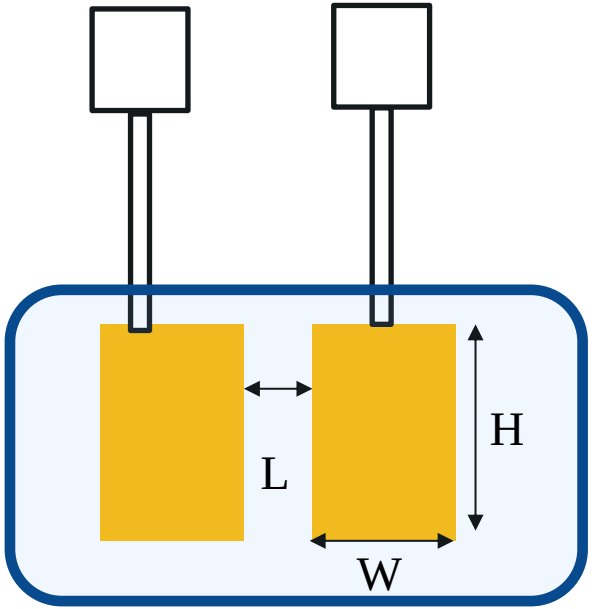
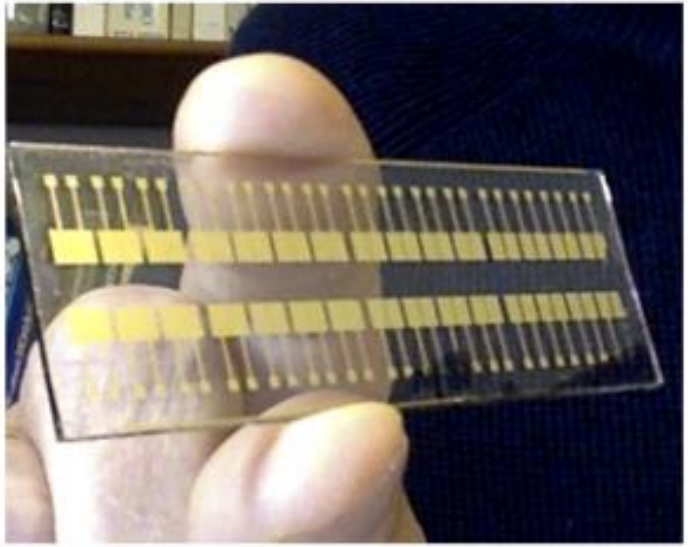
An electrode design to measure K^+ concentration





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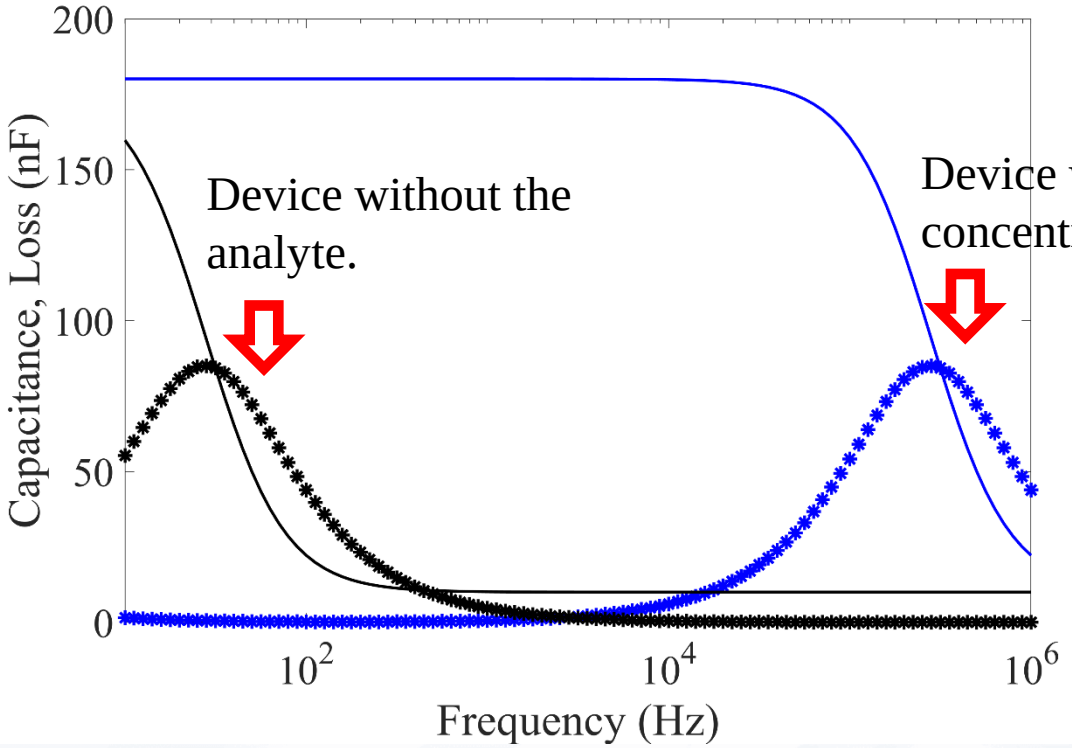
Device design to improve detection limit



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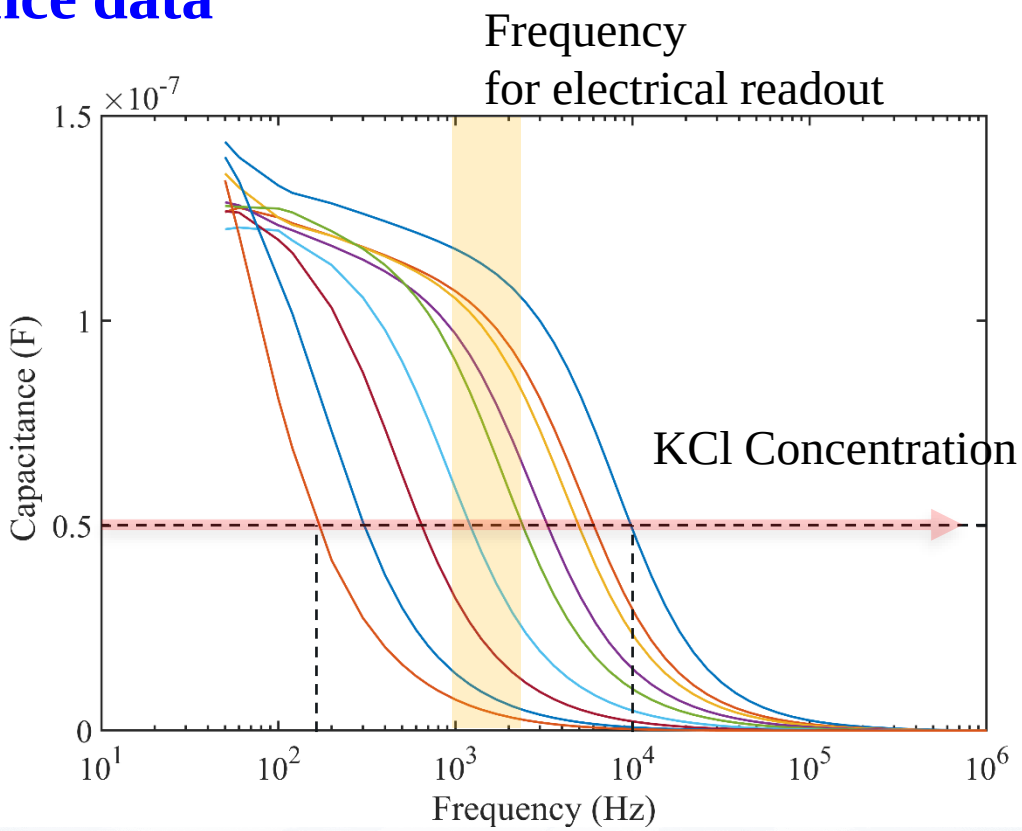
Real impedance data



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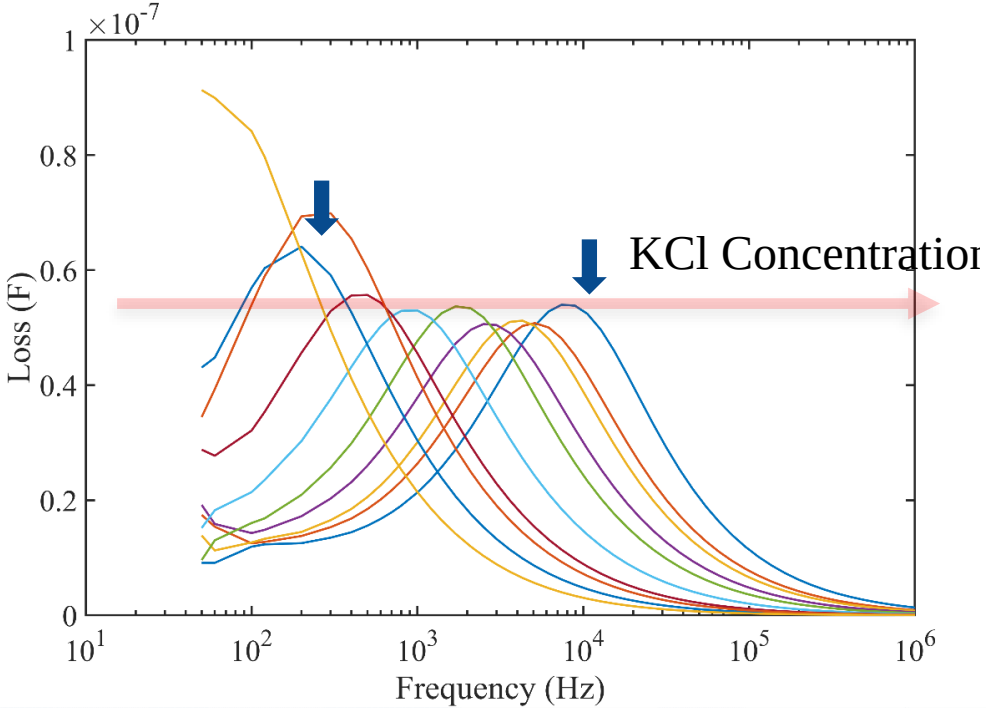
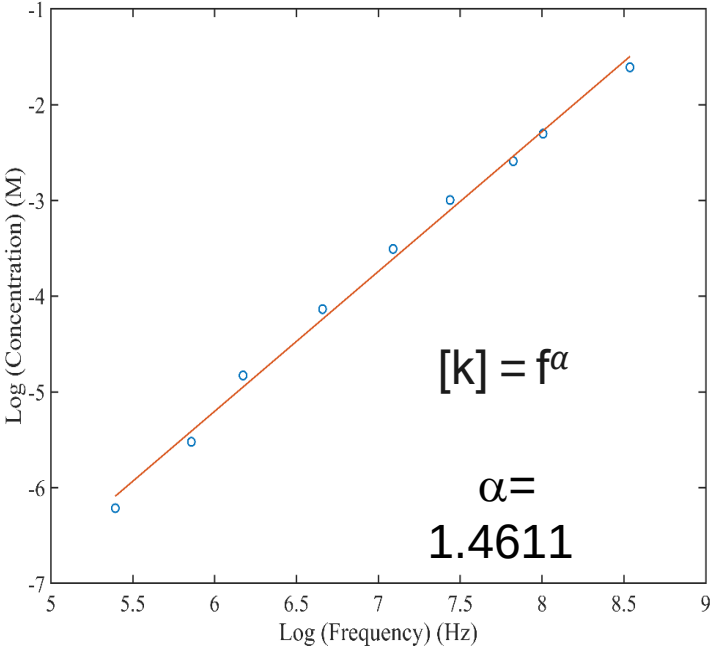
Real impedance data





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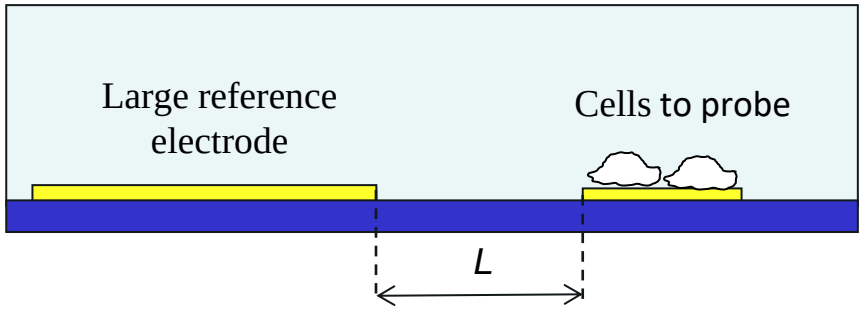
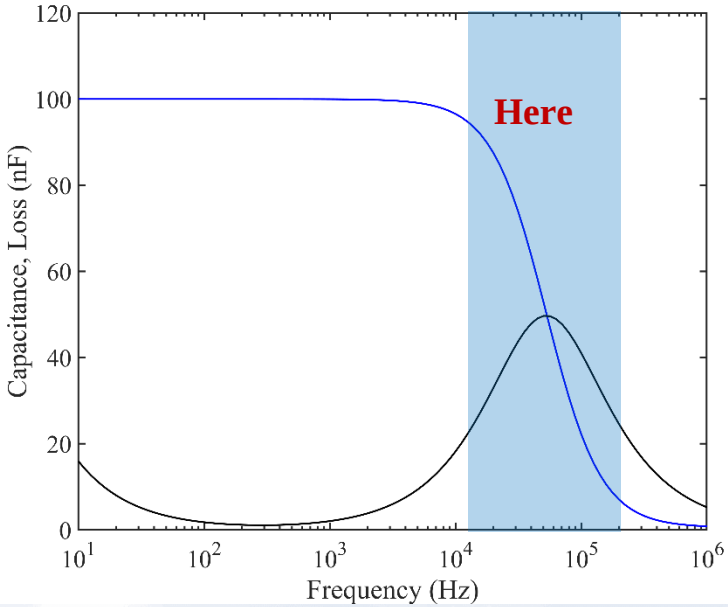
Example II: Design a device for probe living cells on top of electrodes

Where in the impedance spectrum will the effects of cell activity be observed?





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Example II

(Measuring the interaction between the immune system of an oyster and a parasite)

A Parasite (*Perkinsus atlanticus*) interfere with respiration reproduction (fertility/fecundity).

Extensive mortalities in breeding areas located on the south coast of Portugal.

Strong impact on fishery productivity

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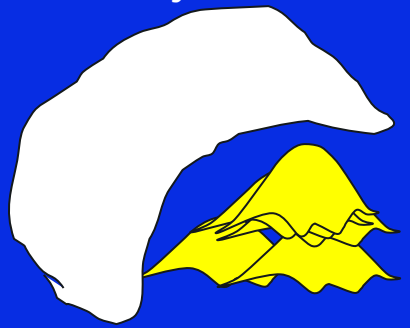
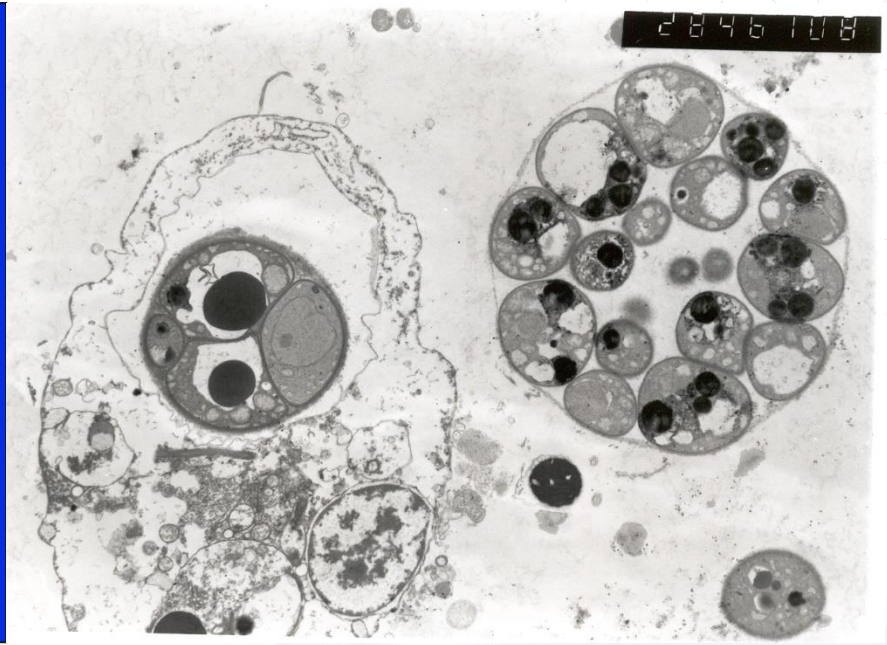
Hemocytes



Parasites aggregate as a defence mechanism.



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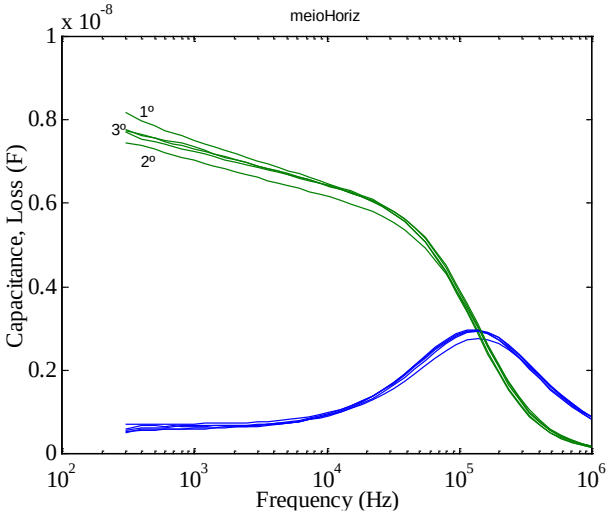
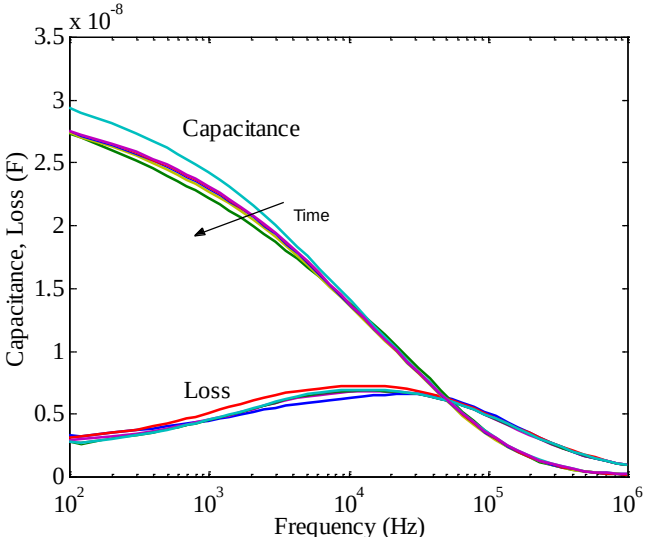
The frequency response of the medium





The medium does not cause a frequency shift

Measurements carried out using lateral electrodes

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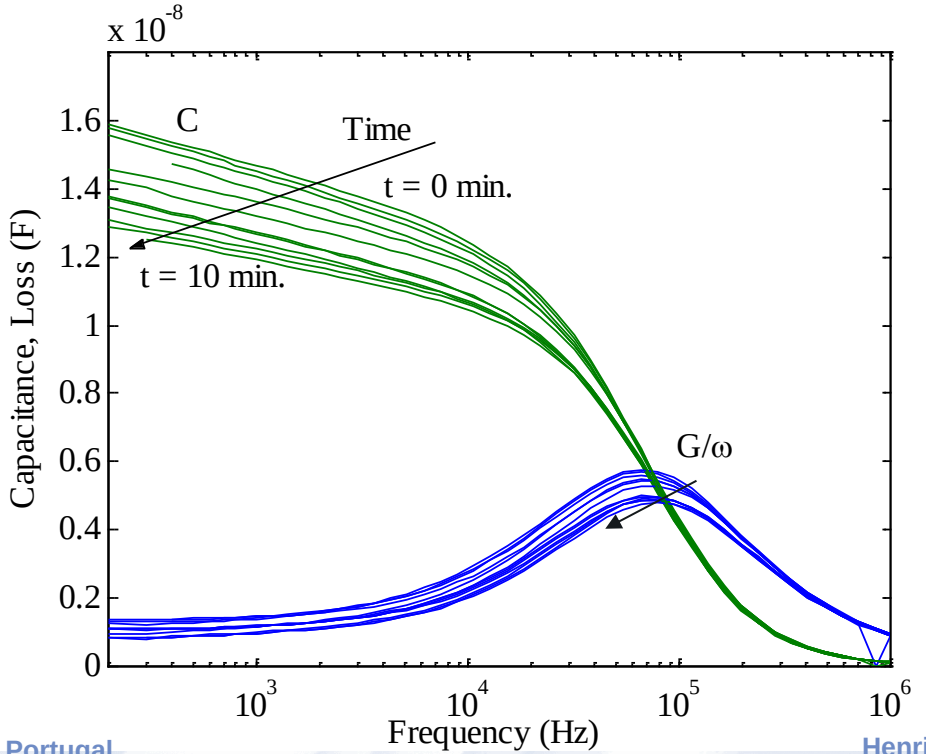
The frequency response of hemocytes + medium



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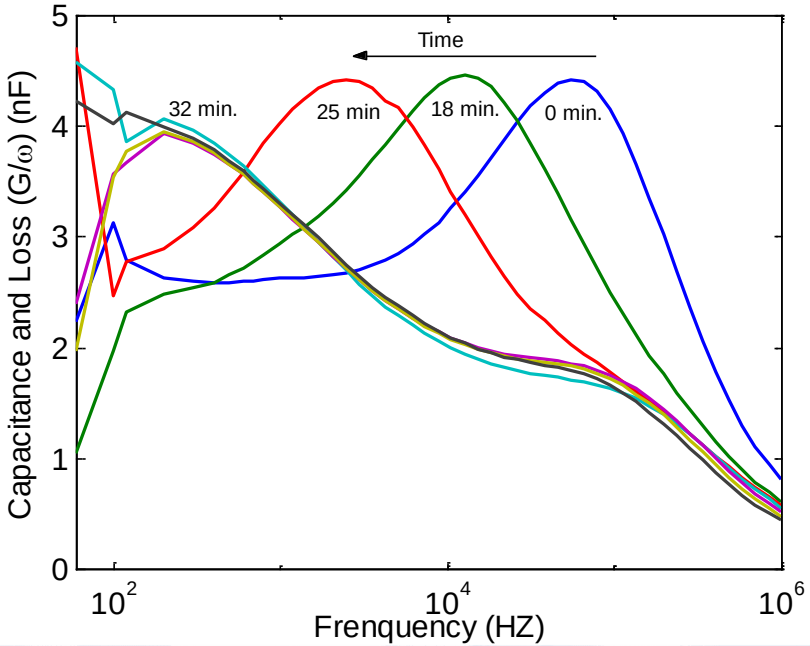
The frequency response of the parasites + hemocytes



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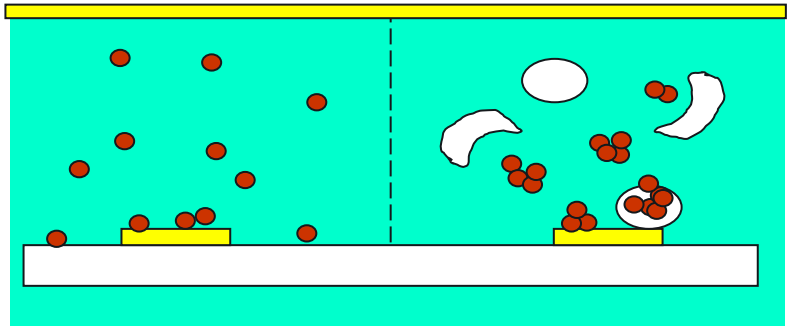
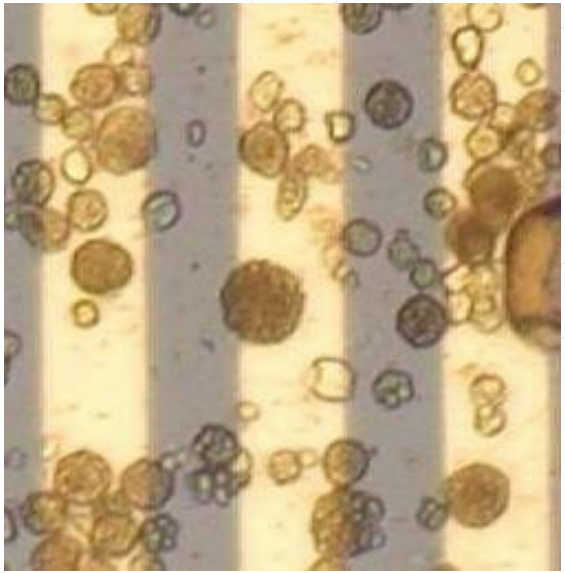
Hemocytes and the deposition rate



The interaction between parasites and hemocytes induces a faster sedimentation ratio.



Photograph of clusters of parasites on top of the microelectrodes.

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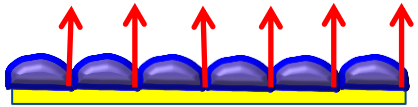
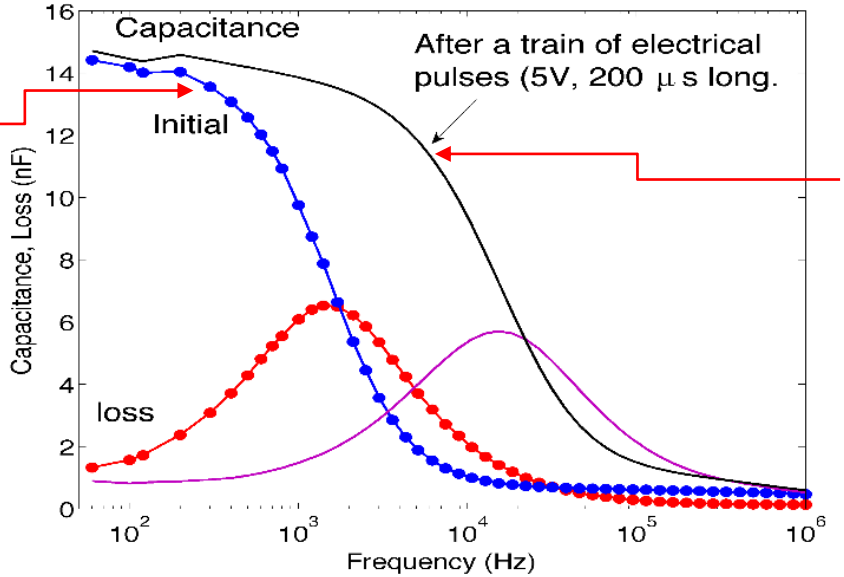
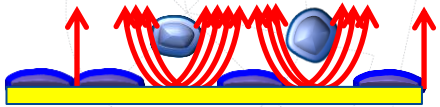
Example III:
Design a device for probing cancer cell migration



Confluent cell monolayer





Disrupted cell monolayer

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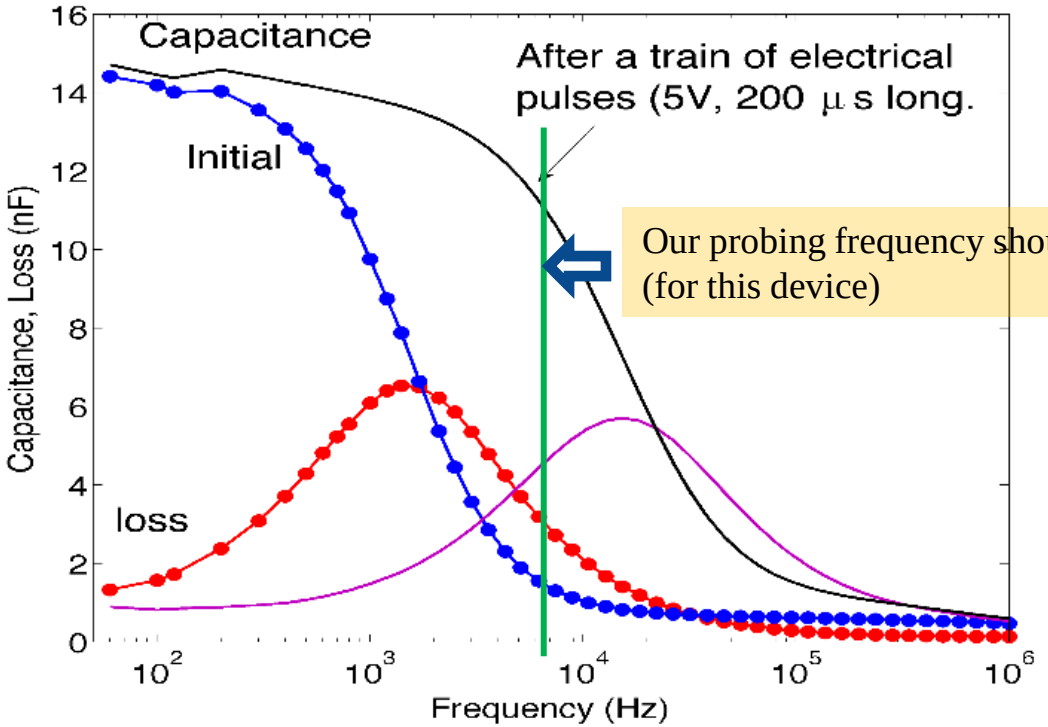
Problem II: Design a device for probe living cells on top of electrodes



Our probing frequency should be here @ 6 kHz (for this device)

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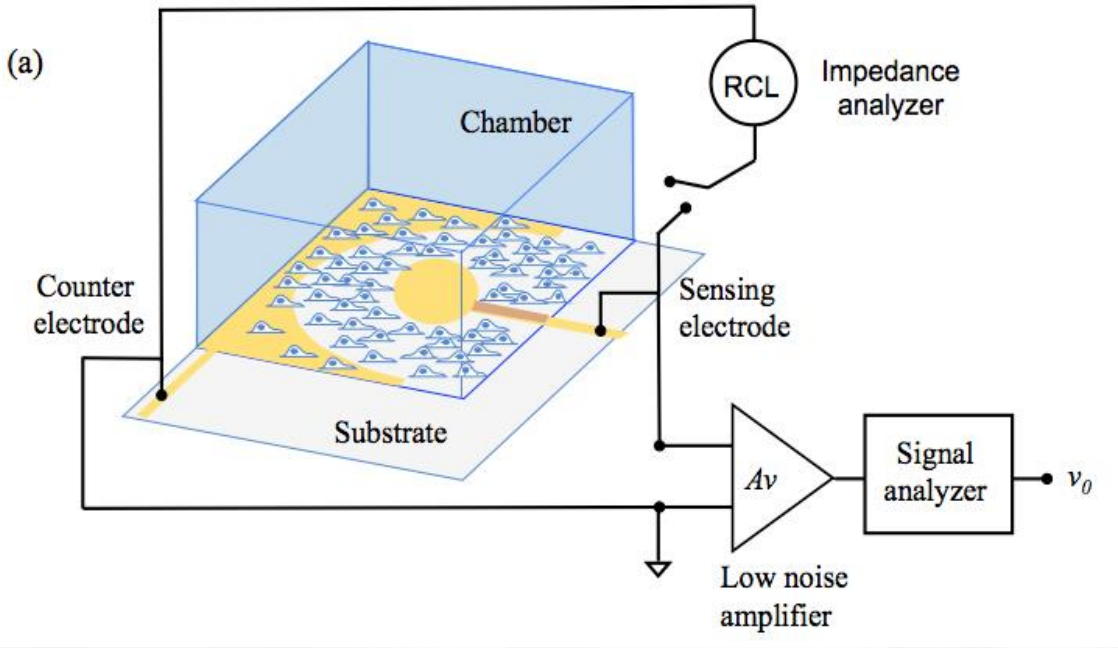
Applications:
Cancer cell migration



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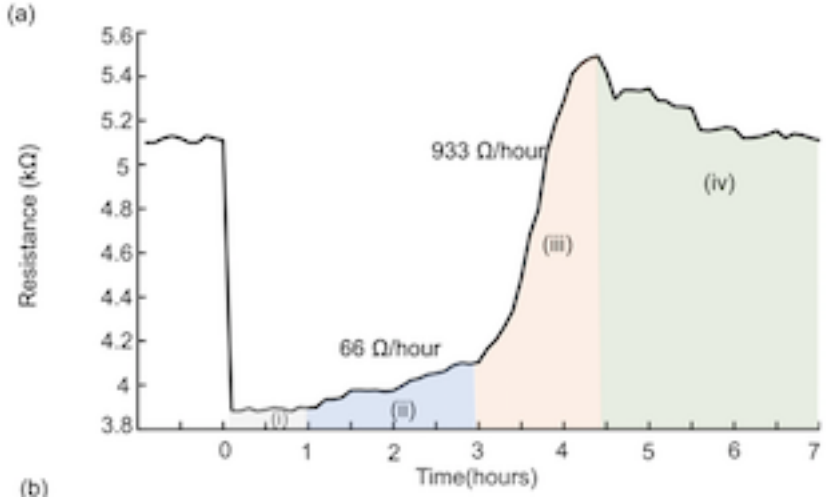
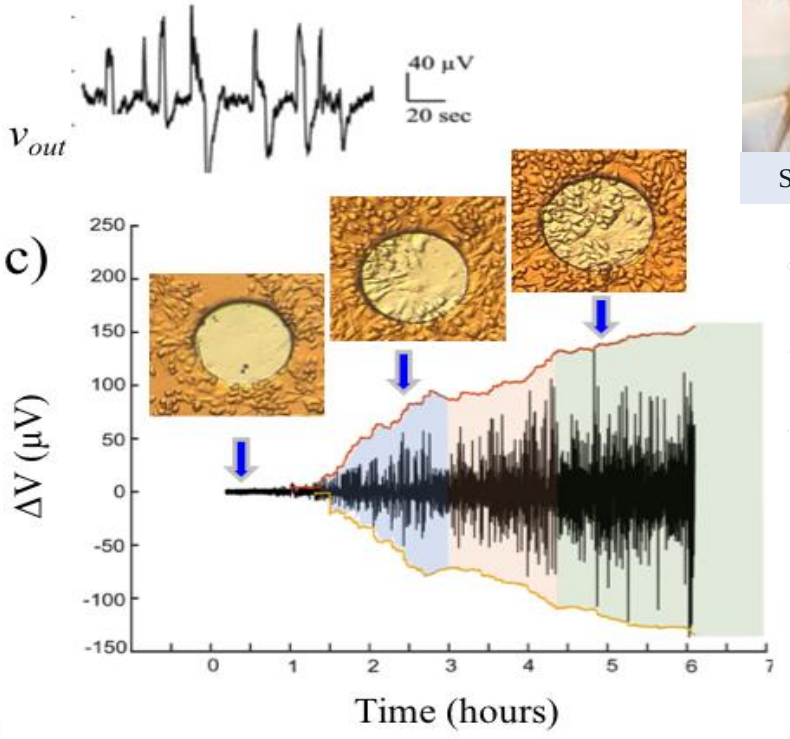
Measuring how cell-cell connections are established.

Sanaz Asgarifar





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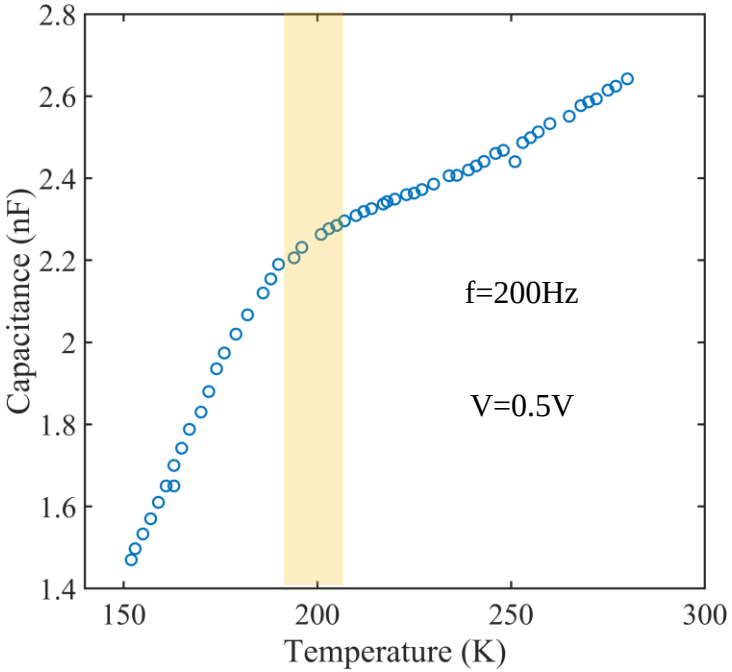
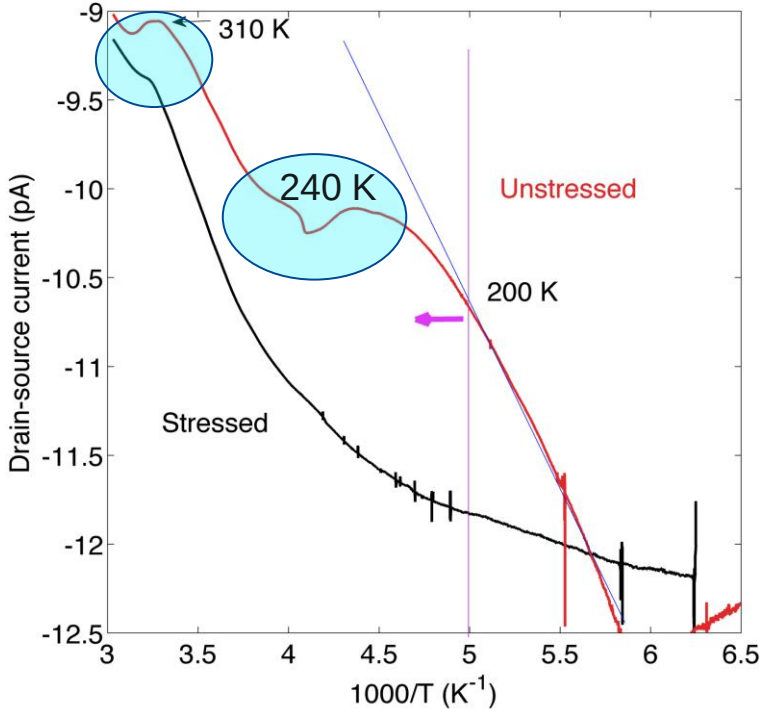
Confined water in electronic devices



Capacitance of bulk heterojunction solar cell.



Temperature dependence of the current in an organic-based transistor.

Conclusions

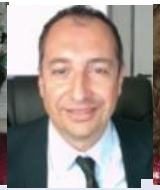
- There is an emergent class of electronic devices operating in wet environments that rely heavily on ELDs .

- We offer expertise in designing device architectures using low-impedance techniques.

Acknowledgements


Maria Medeiros


Leonor Cancela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Deborah Power


Ana Mestre


Pedro Inácio


Youssef Elamine


Sanaz Asgarifar


Rute Félix


Catarina Bispo

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FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

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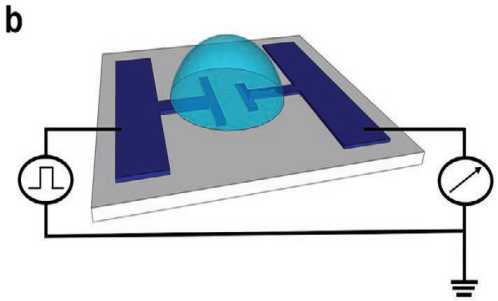
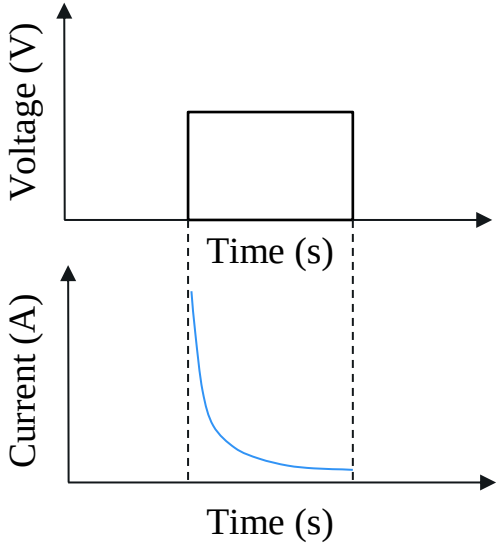
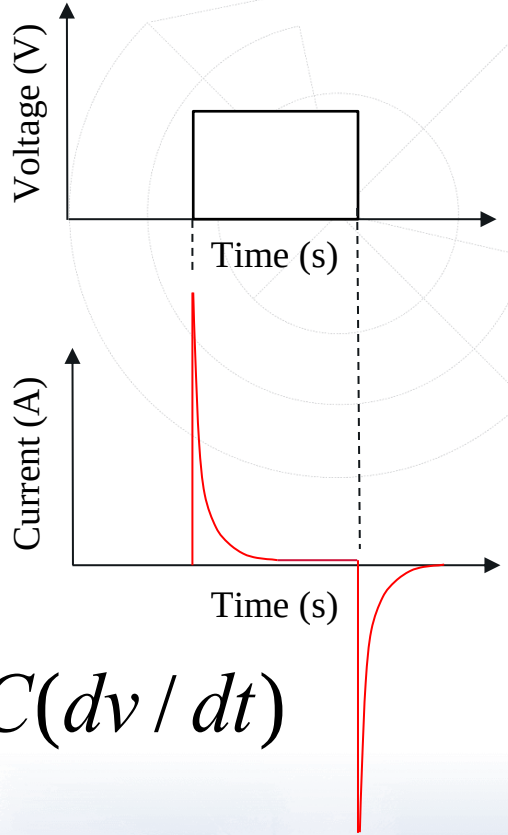
Detection of dopamine

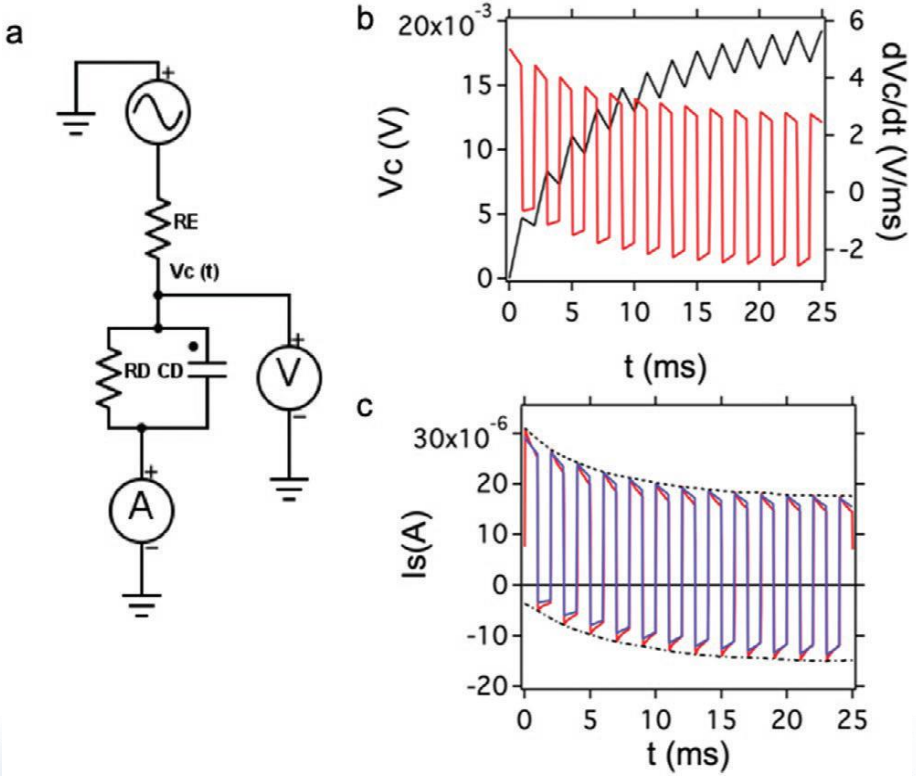






$$I = C(dv/dt)$$

Using impedance from a device physics point of view



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Neuromorphic Organic Devices that Specifically Discriminate Dopamine from Its Metabolites by Nonspecific Interactions

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