Faculté Polytechnique

ALLSENSORS 2020

Detection of Antibiotics with Molecularly Imprinted Polymers:
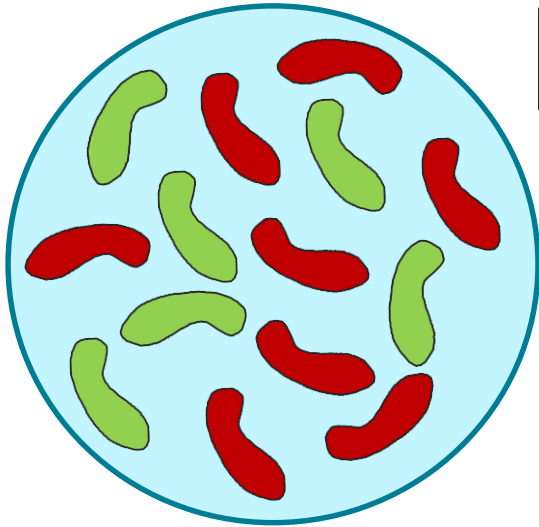**Theoretical Understanding of Detection Mechanisms using EIS and Molecular Dynamics**

Hugues Charlier

hugues.charlier@umons.ac.be

November 2020

www.enmieux.be

FEDER

UNION EUROPEENNE

Wallonie

LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL
ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

UMONS
Université de Mons

POLYTECH
MONS

Sensors for a Practical Implementation
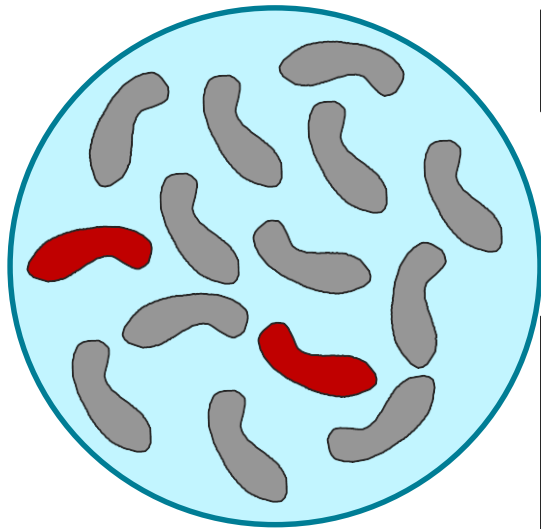
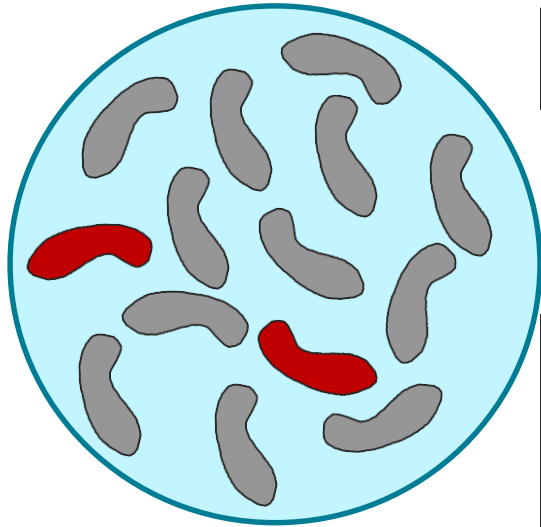**Antimicrobial resistance**

Primary infection

Sensors for a Practical Implementation

Antimicrobial resistance

Primary infection

Inadequate antibiotic treatment or bacterial resistance mutation

Sensors for a Practical Implementation

Antimicrobial resistance

Primary infection

↓

Inadequate antibiotic treatment or bacterial resistance mutation

Proliferation of resistant bacteria
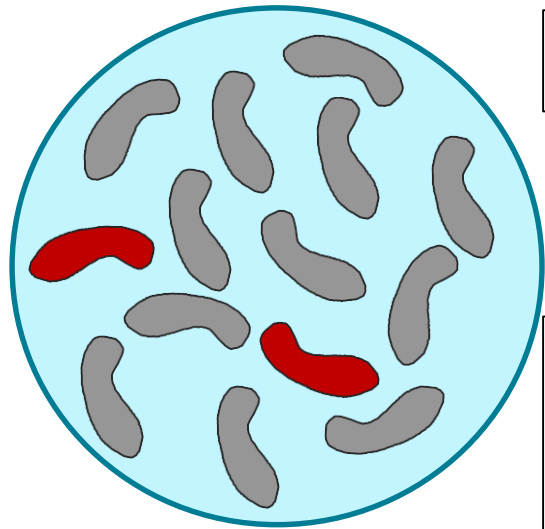
Sensors for a Practical Implementation

Antimicrobial resistance

Primary infection

Inadequate antibiotic treatment or bacterial resistance mutation
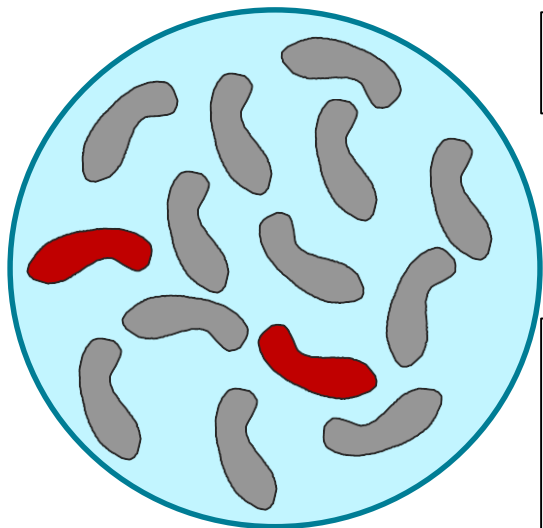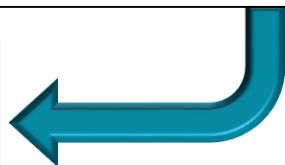
Proliferation of resistant bacteria

Solution :
limit the amount of antibiotic used

Sensors for a Practical Implementation

Antimicrobial resistance

Primary infection

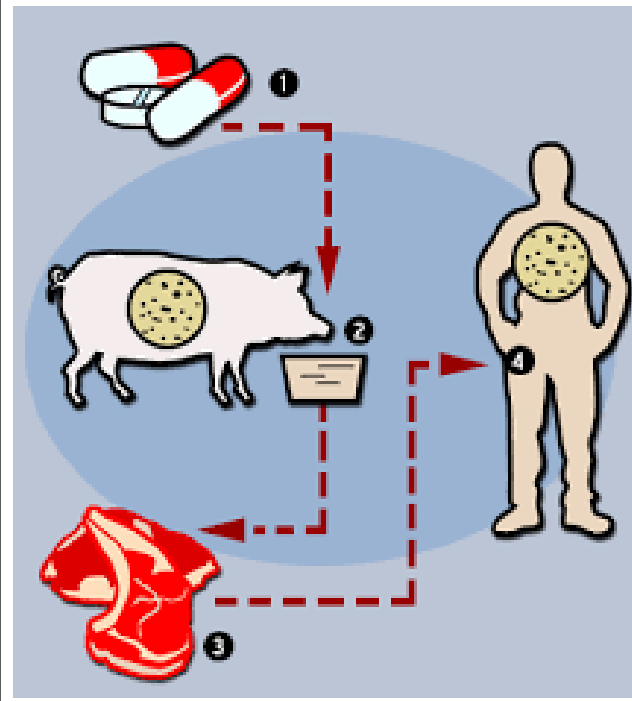Inadequate antibiotic treatment or bacterial resistance mutation

Proliferation of resistant bacteria

Solution :
limit the amount of antibiotic used

Widely used in the food industry

Must be controlled

Sensors for a Practical Implementation

Antimicrobial resistance

Primary infection

Proliferation of resistant bacteria

Case of PenG in milk :

MRL fixed by European Union at 4 ppb

Solution :
limit the amount of antibiotic used

Widely used in the food industry
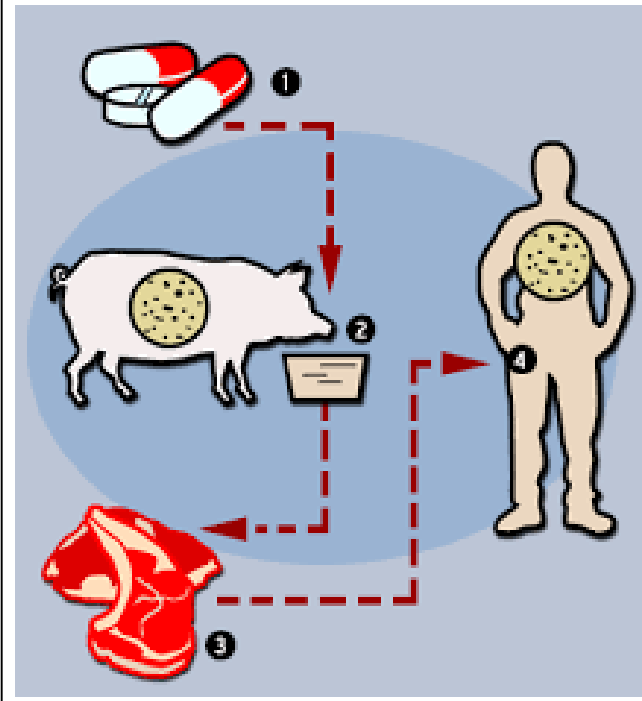
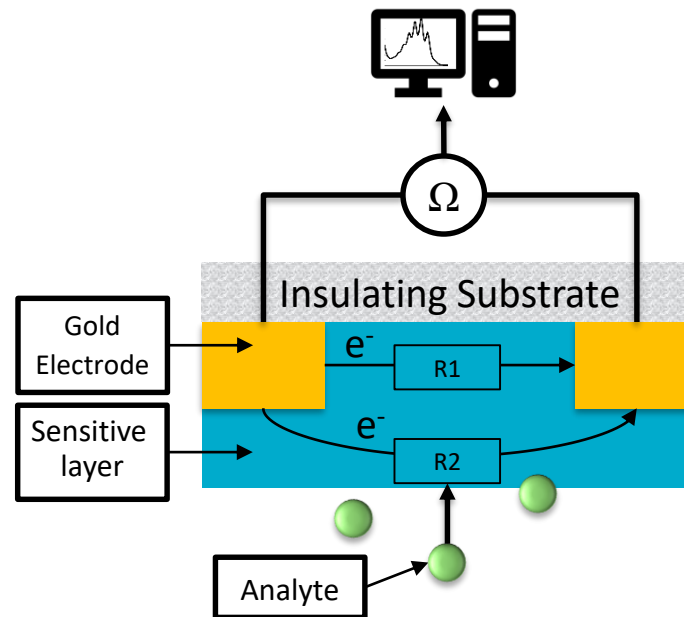### Must be controlled

Transduction Mechanisms

Suitable measurement techniques must consume as few energy as possible

Conductivity measurements
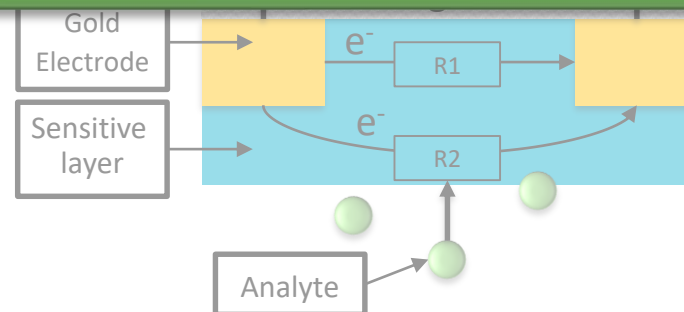
Transduction Mechanisms

Suitable measurement techniques must consume as few energy as possible

Sensitive Material should be :

- **Semi-conductor**

- **Sensitive to the target molecule**

- **Easily processible**

- **Allowing low energy measurement**

Transduction Mechanisms

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Gold Electrode

R1

Sensitive
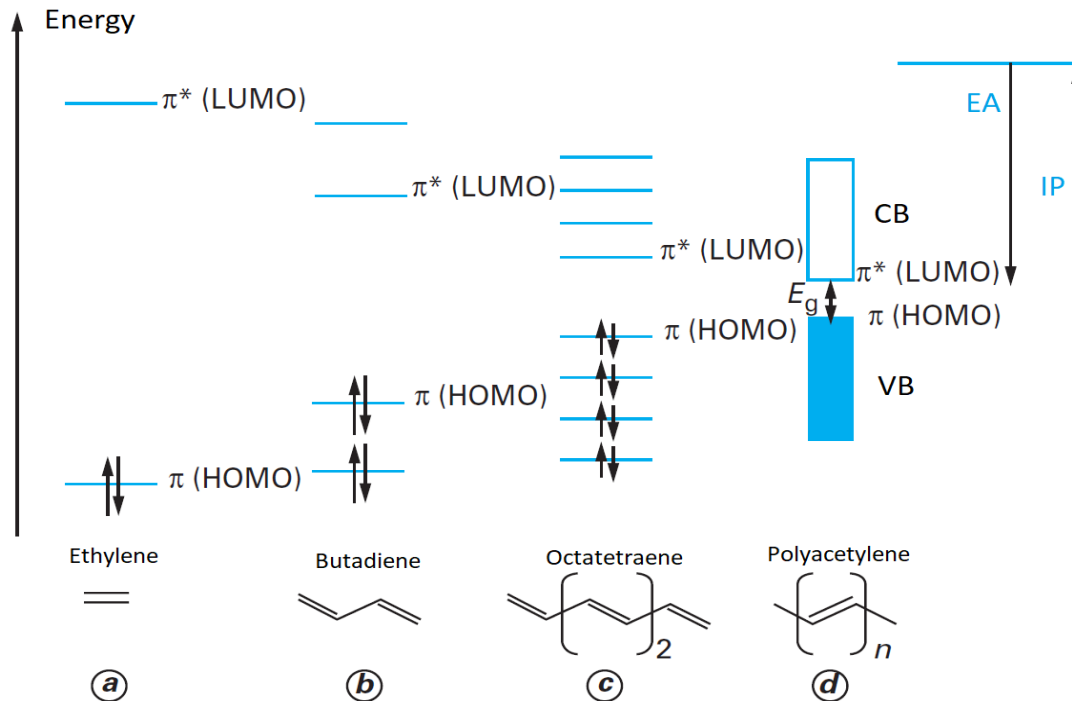
e⁻

Conducting Polymers

Analyte

Conducting Polymers

Usually materials are separated in three main groups according to their conducting properties
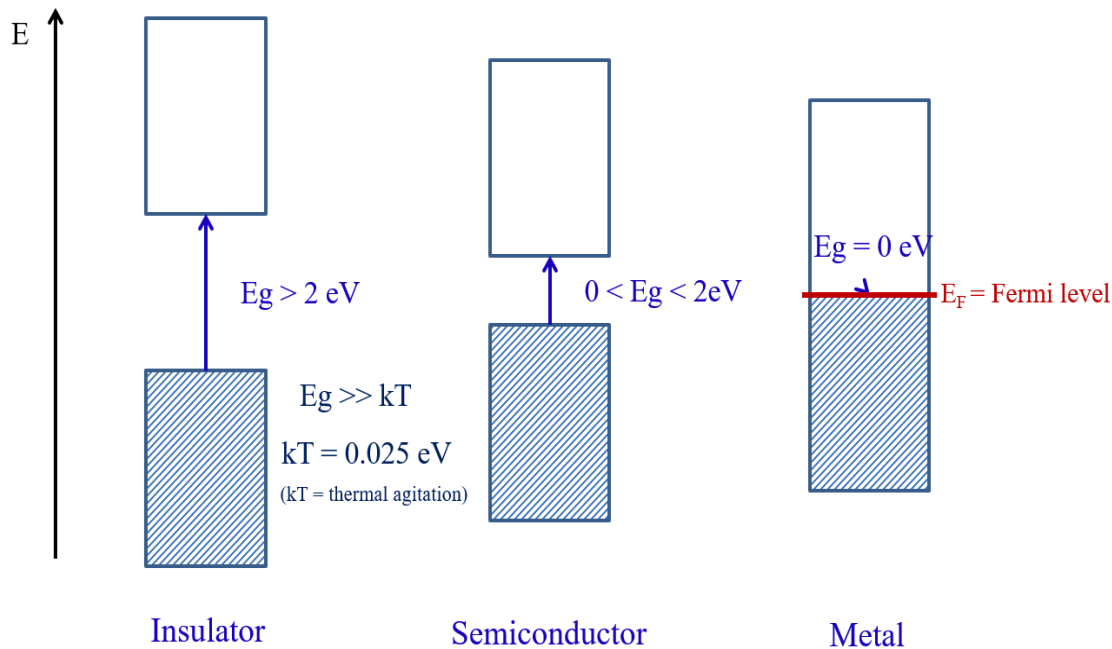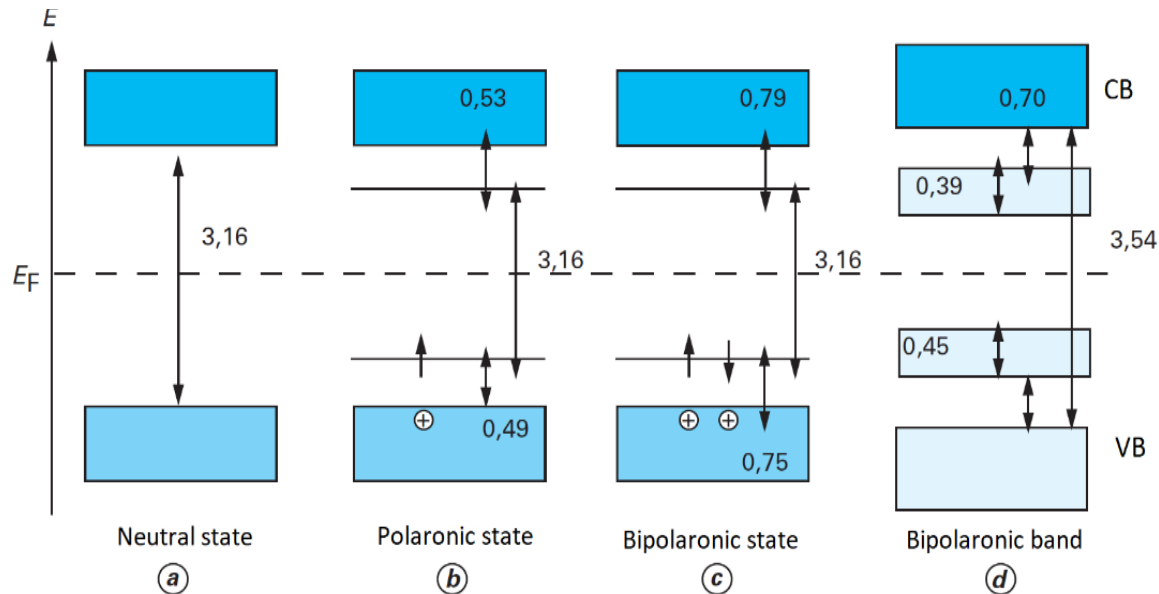
Conducting Polymers

Polymers are usually considered as insulator

(Semi)Conducting properties only for conjugated polymers
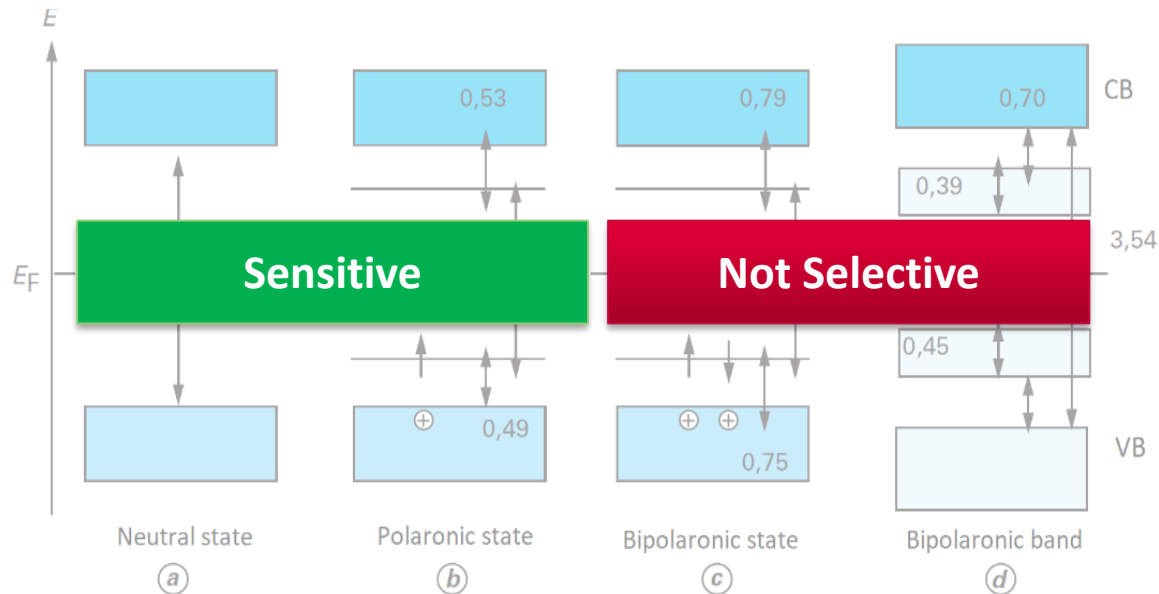
# Doping for Conducting Polymers

By **doping**, it is possible to significantly **increase** the polymer **conductivity**

(De)doping possibilities allow to modify physical properties of the sensitive material

Doping for Conducting Polymers

By **doping**, it is possible to significantly **increase** the polymer **conductivity**

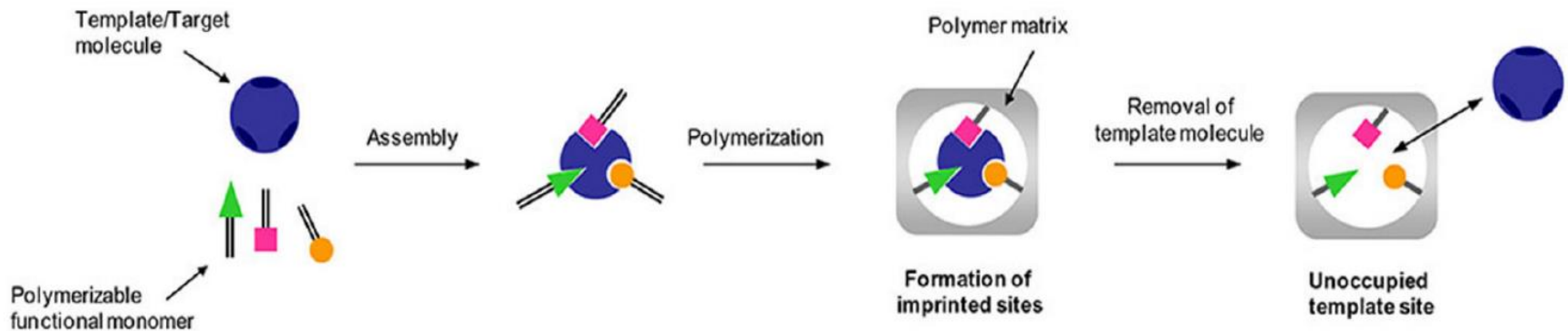**(De)doping possibilities allow to modify physical properties of the sensitive material**

How to Solve Selectivity Issue ?

Molecularly **I**mprinted **P**olymer (MIP) :
Target molecule integrated in polymer matrix
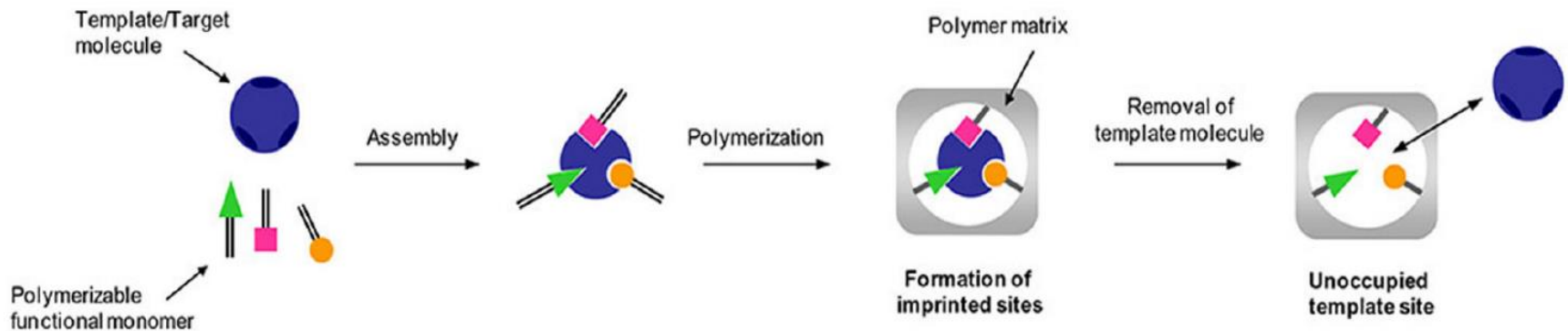
How to Solve Selectivity Issue ?

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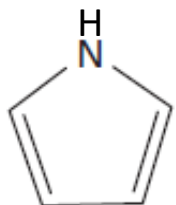

Significantly increase of selectivity

Highly adaptable, just need to change the template
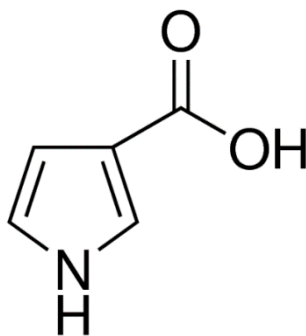
Sensitive Layer Synthesis
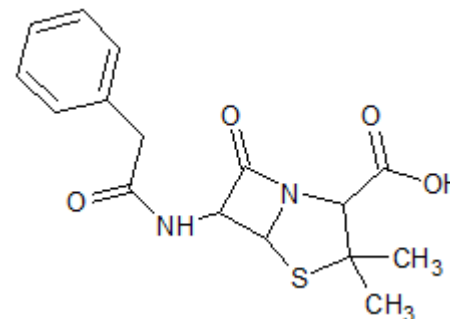
Penicillin G is chosen as template molecule

Crosslinker : Pyrrole
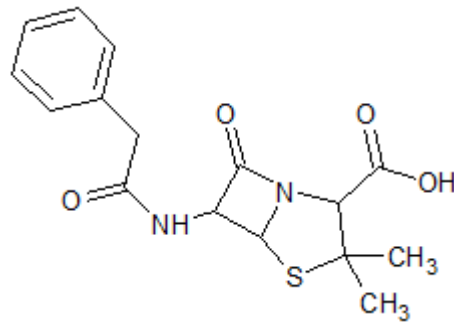
Functional monomer : Pyrrole carboxilic acid

Target molecule / Template: Peniciline G

Université de Mons

Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

Schematic Representation

Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

Schematic Representation
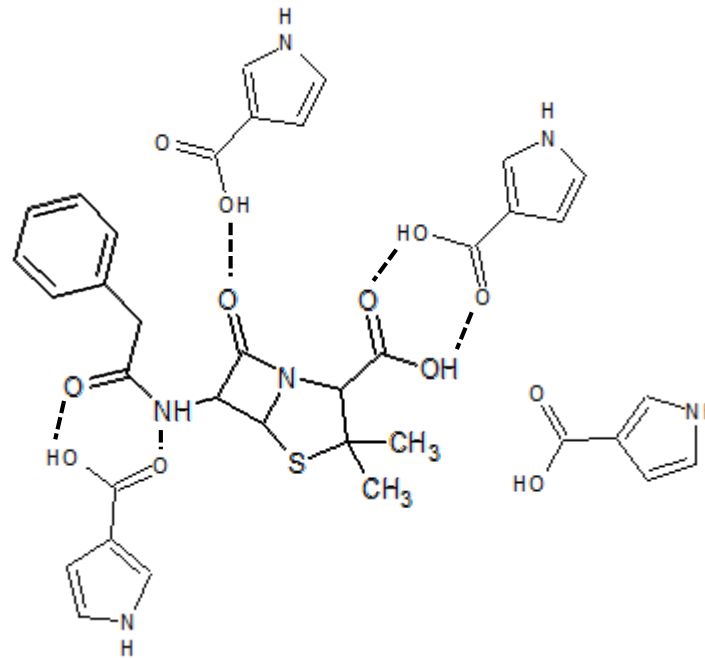

pH modification

Temperature adjustment

Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

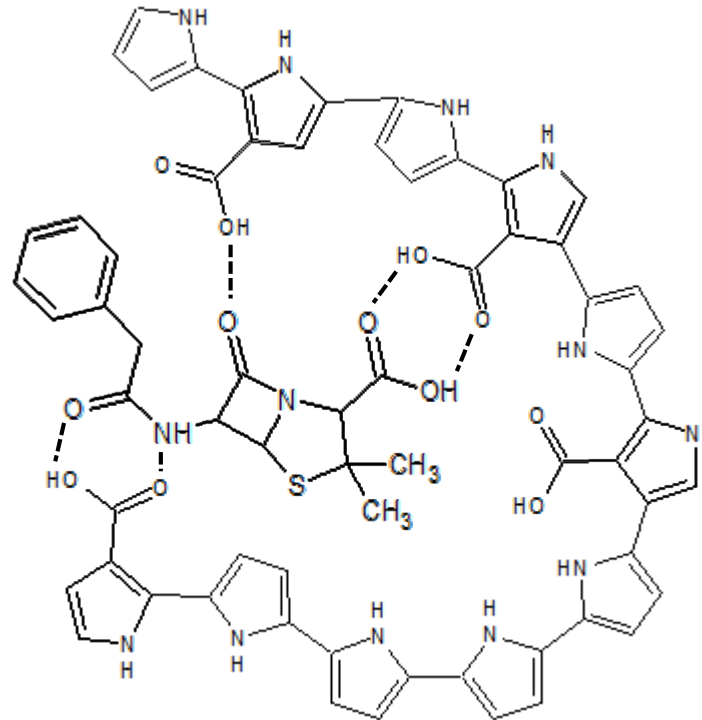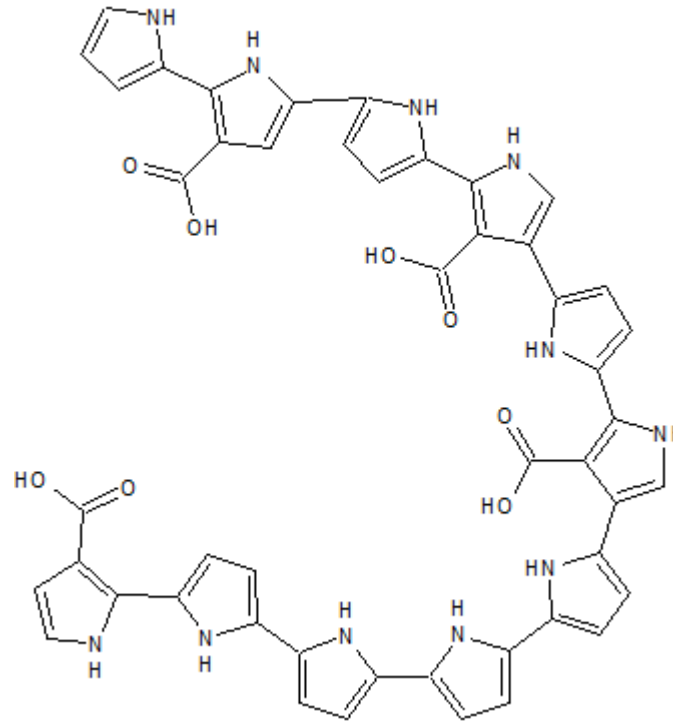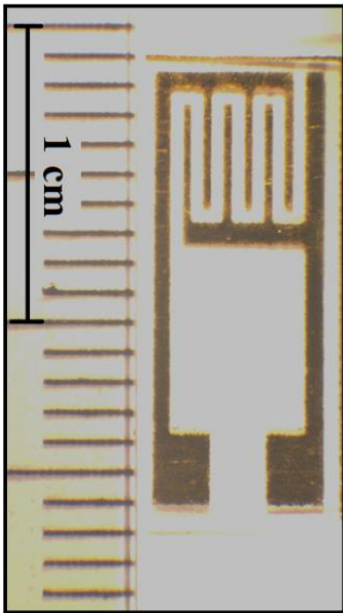### Schematic Representation

pH modification

Temperature adjustment

Oxidant addition

Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

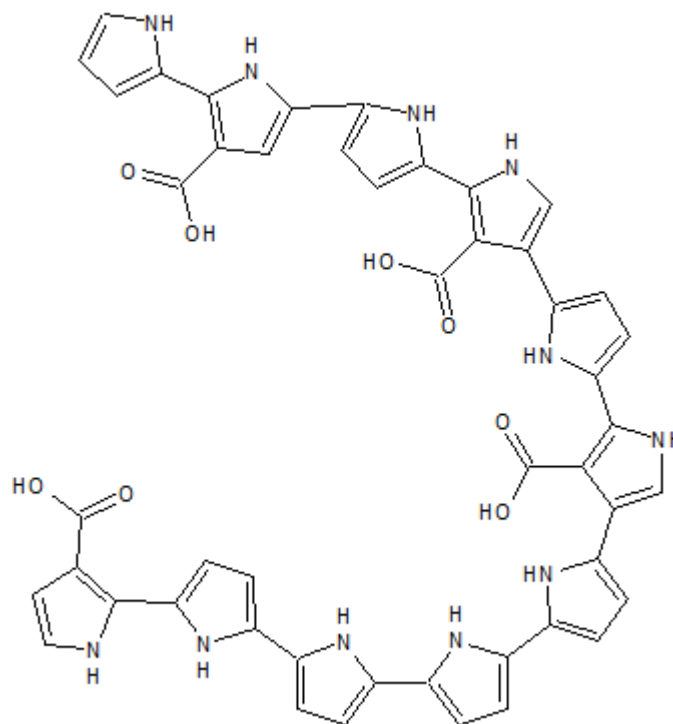### Schematic Representation
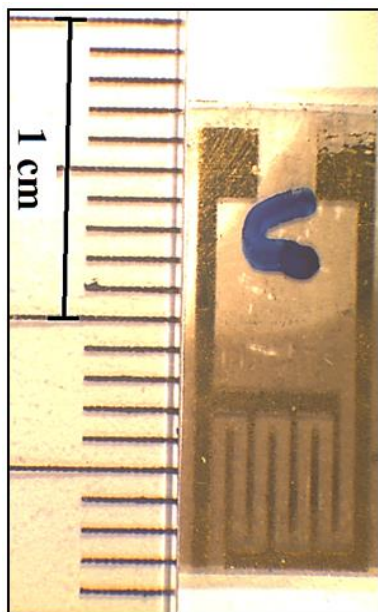
IDE on PET

Immersion in extraction solution

Sensitive Layer Synthesis

Penicillin G is chosen as template molecule
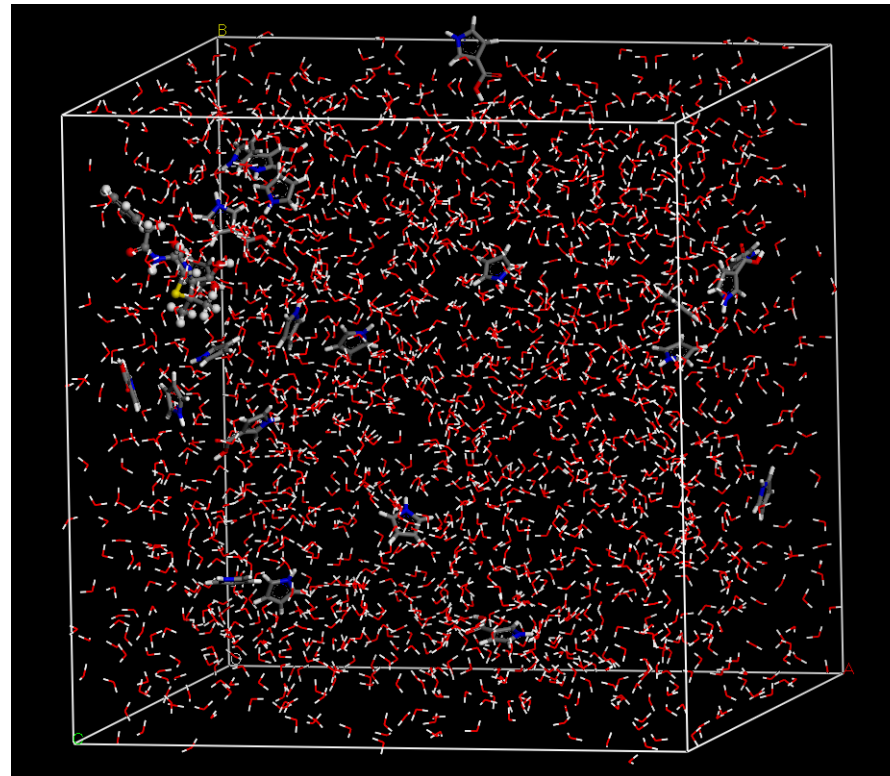
Schematic Representation

IDE on PET

Immersion in extraction solution

Molecular Dynamics Simulations

Polymerization solution optimization
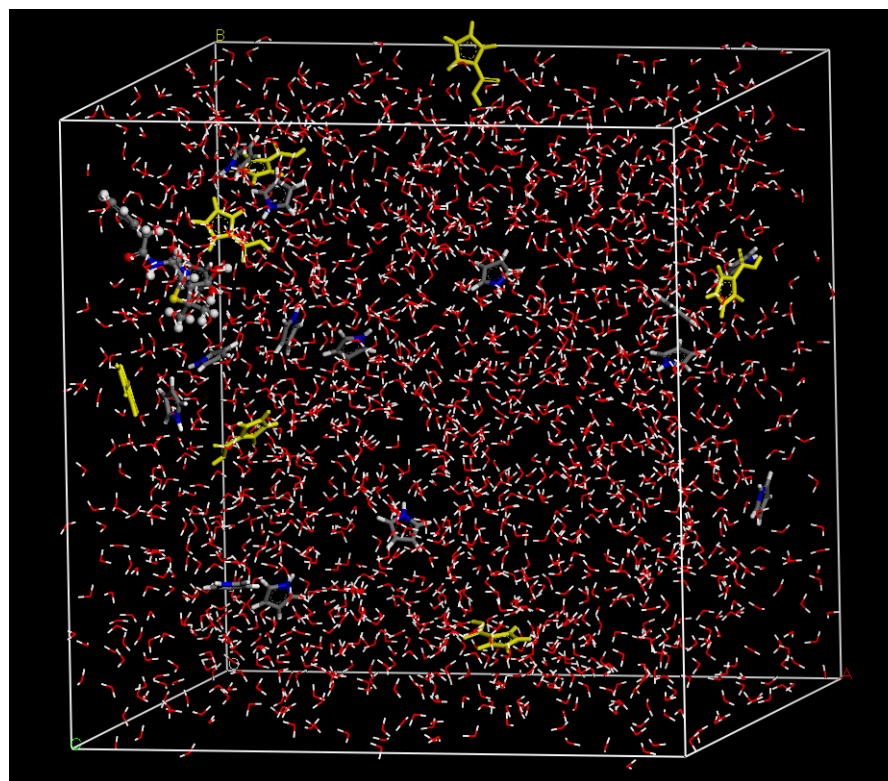
Conception of boxes

15 molecules of Pyrrole

2000 molecules of Water

Molecular Dynamics Simulations

Polymerization solution optimization

Conception of boxes

7 molecules of Pyrrole-3-carboxylic acid
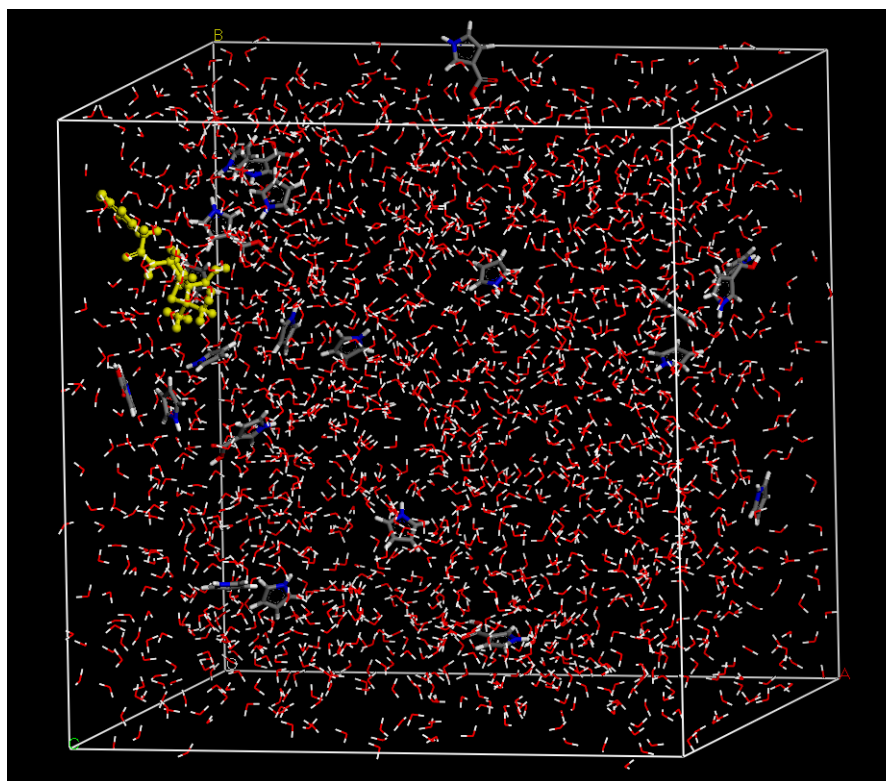
15 molecules of Pyrrole

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Molecular Dynamics Simulations

Polymerization solution optimization

Conception of boxes

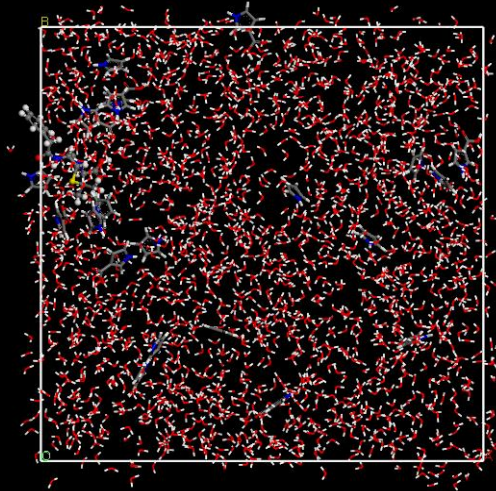**1 molecule of PenG**

15 molecules of Pyrrole

7 molecules of Pyrrole-3-carboxylic acid

2000 molecules of Water

Molecular Dynamics Simulations
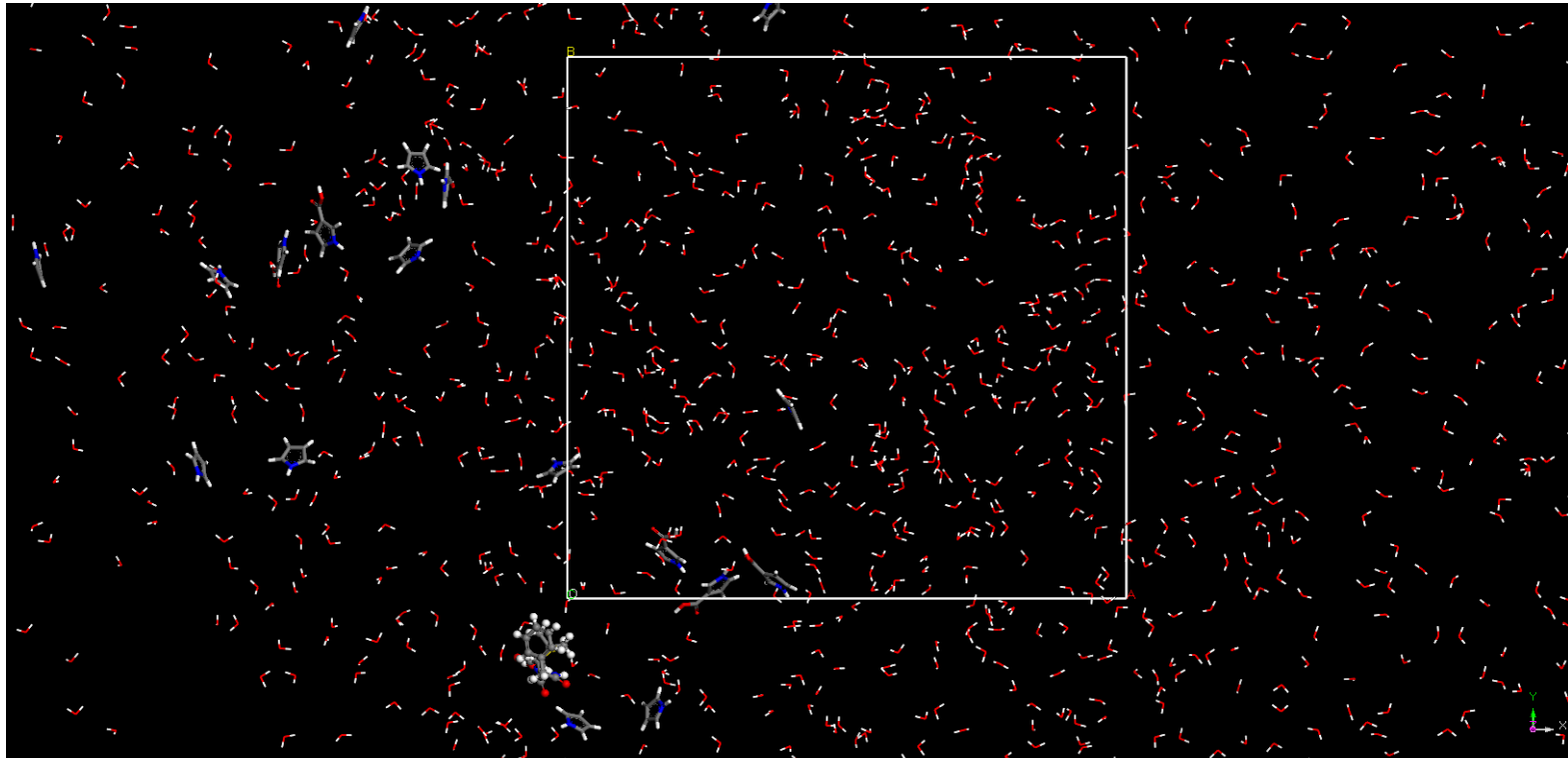
Polymerization solution optimization

Homogenization

Molecular Dynamics Simulations

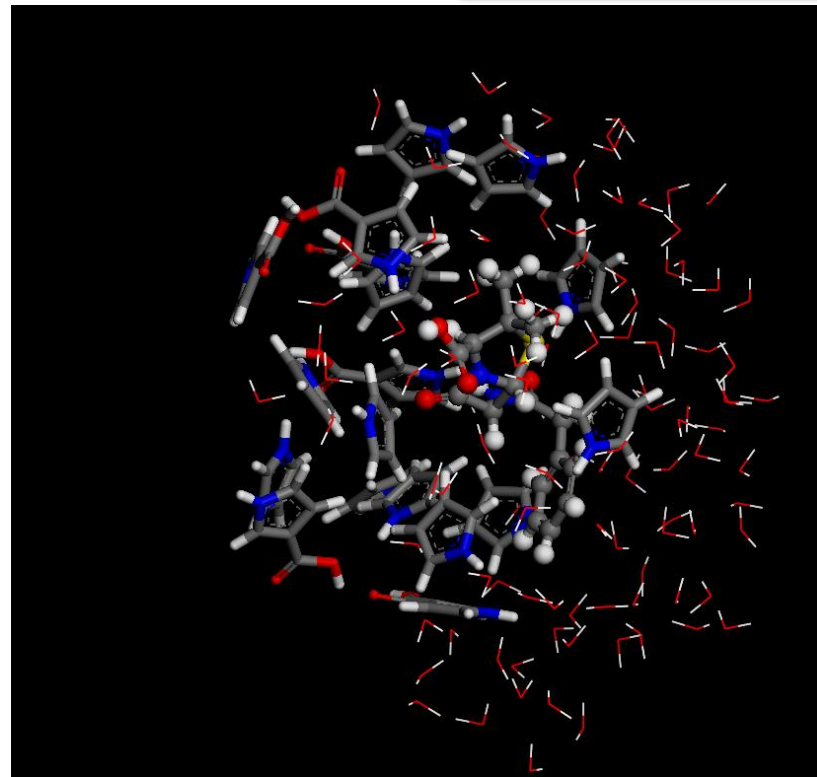## Polymerization solution optimization

Back to ambient conditions
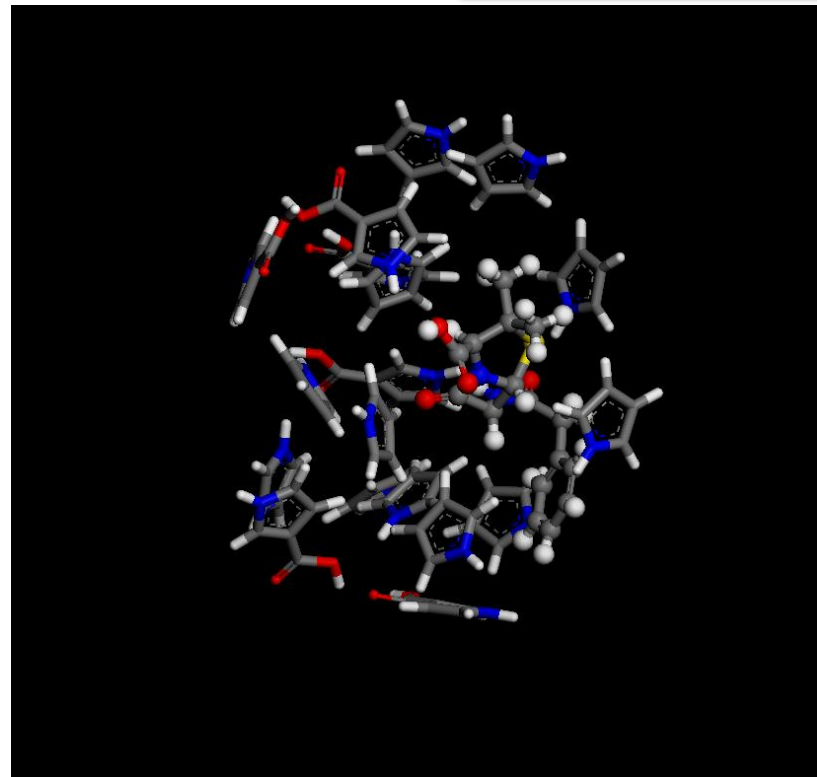
Molecular Dynamics Simulations

Polymerization solution optimization
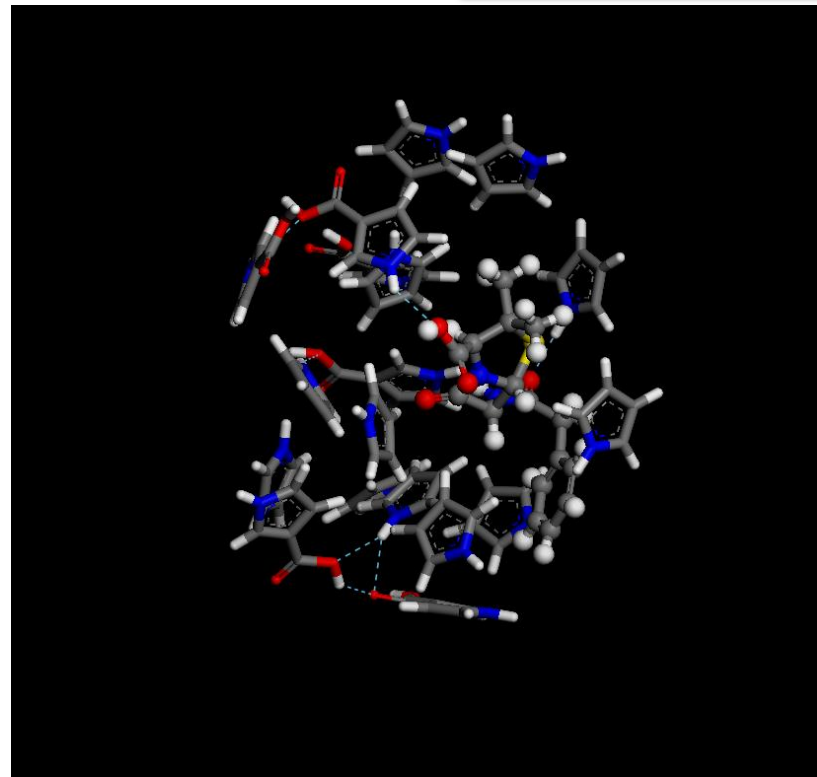
System analysis

Molecular Dynamics Simulations

Polymerization solution optimization

System analysis

Molecular Dynamics Simulations

Polymerization solution optimization
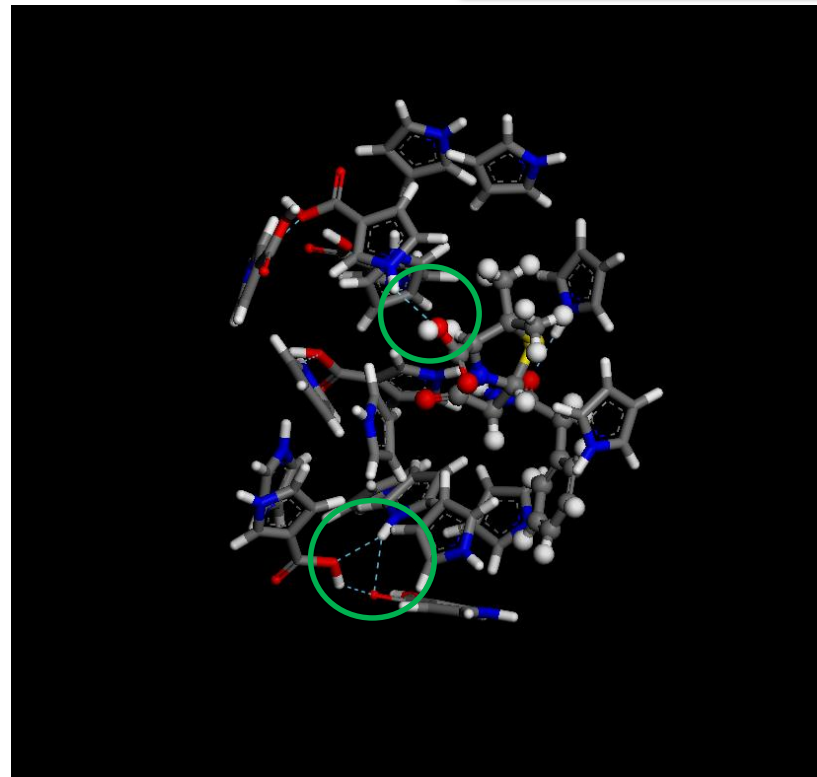
System analysis

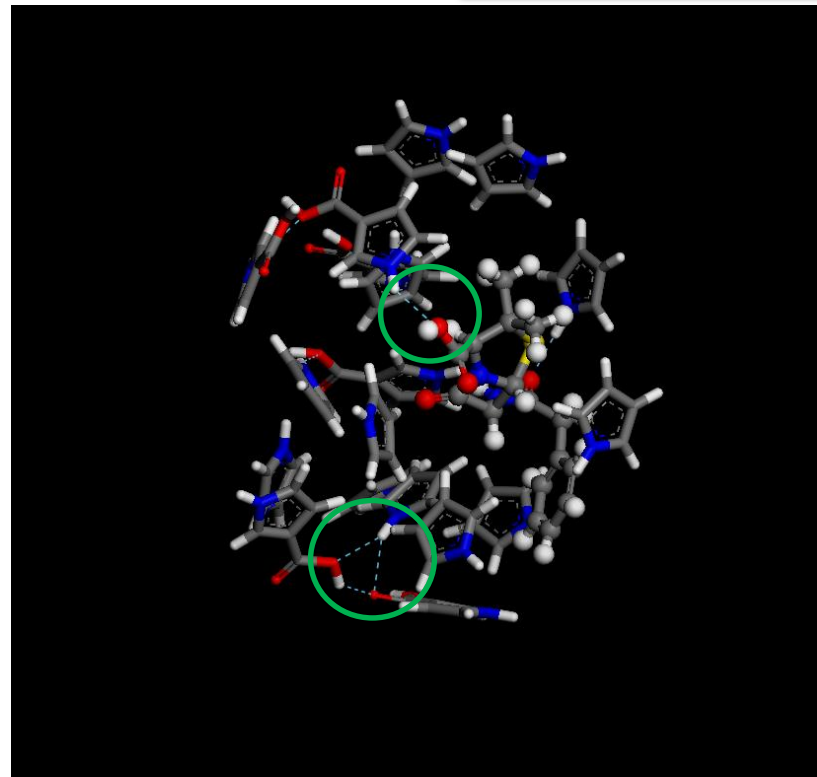# Molecular Dynamics Simulations

Polymerization solution optimization

System analysis

Molecular Dynamics Simulations

Polymerization solution optimization

System analysis

For 1 PenG molecule :

11 < Py < 15

4 < PyCOOH < 10

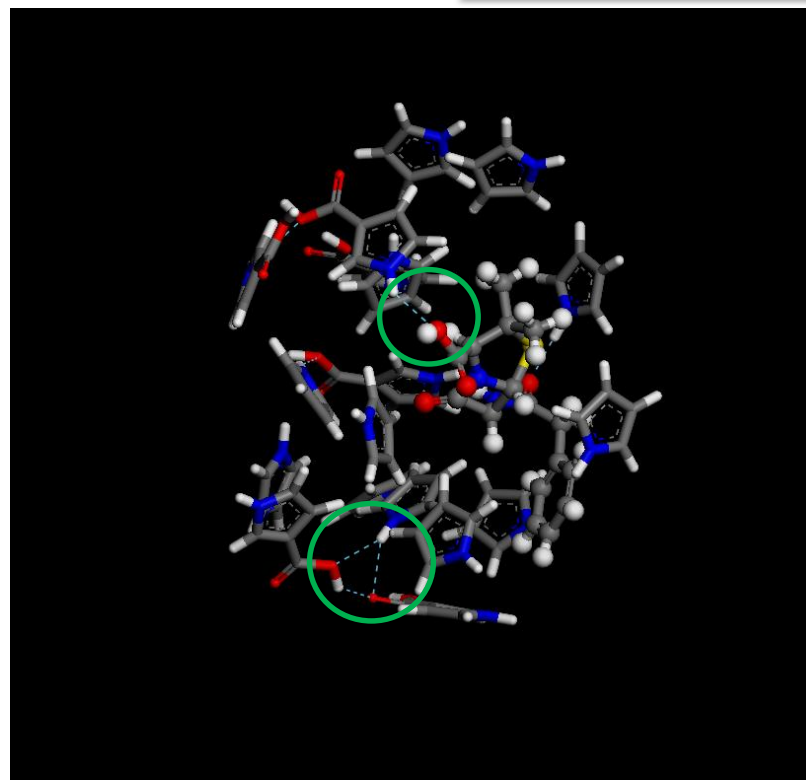# Molecular Dynamics Simulations

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Experimentally

Molecular Dynamics Simulations

Polymerization solution optimization

System analysis

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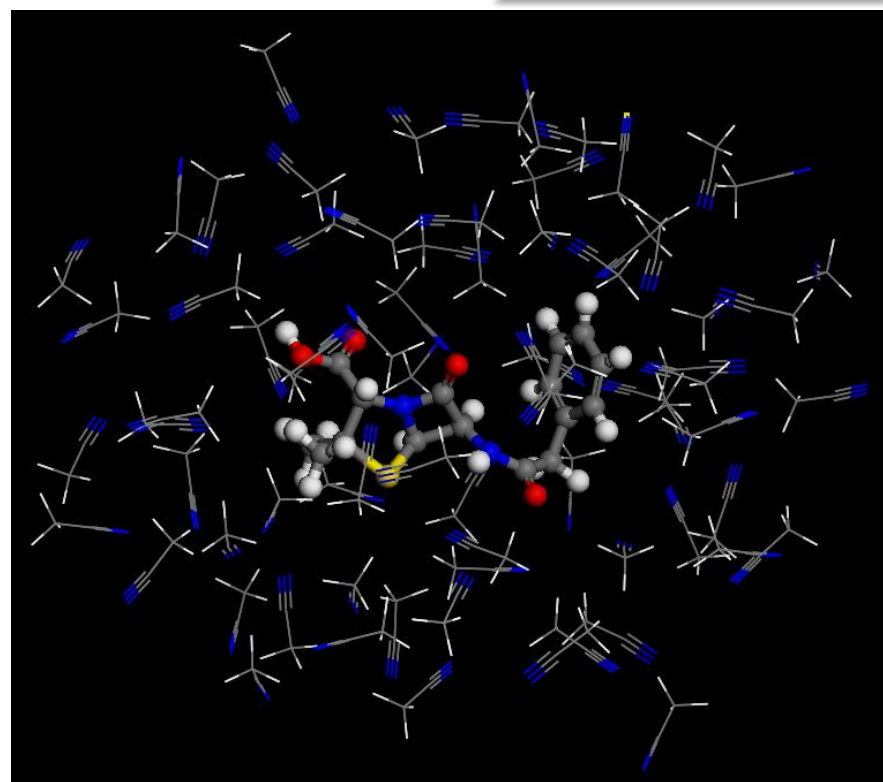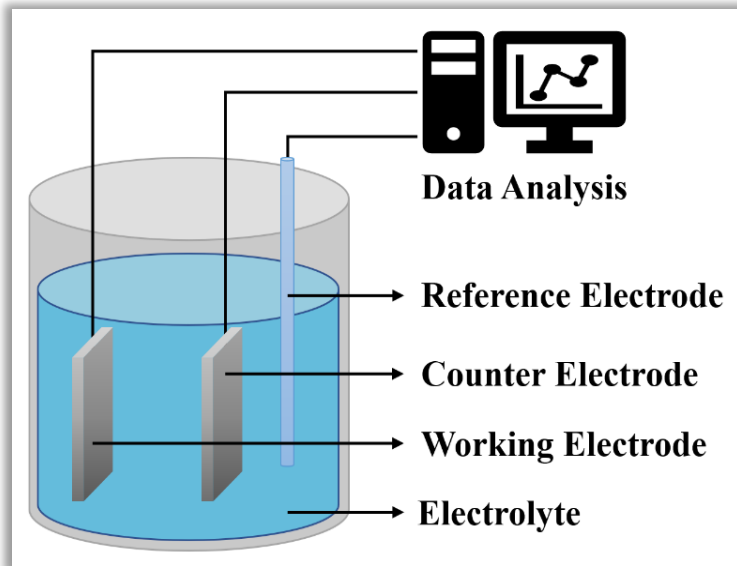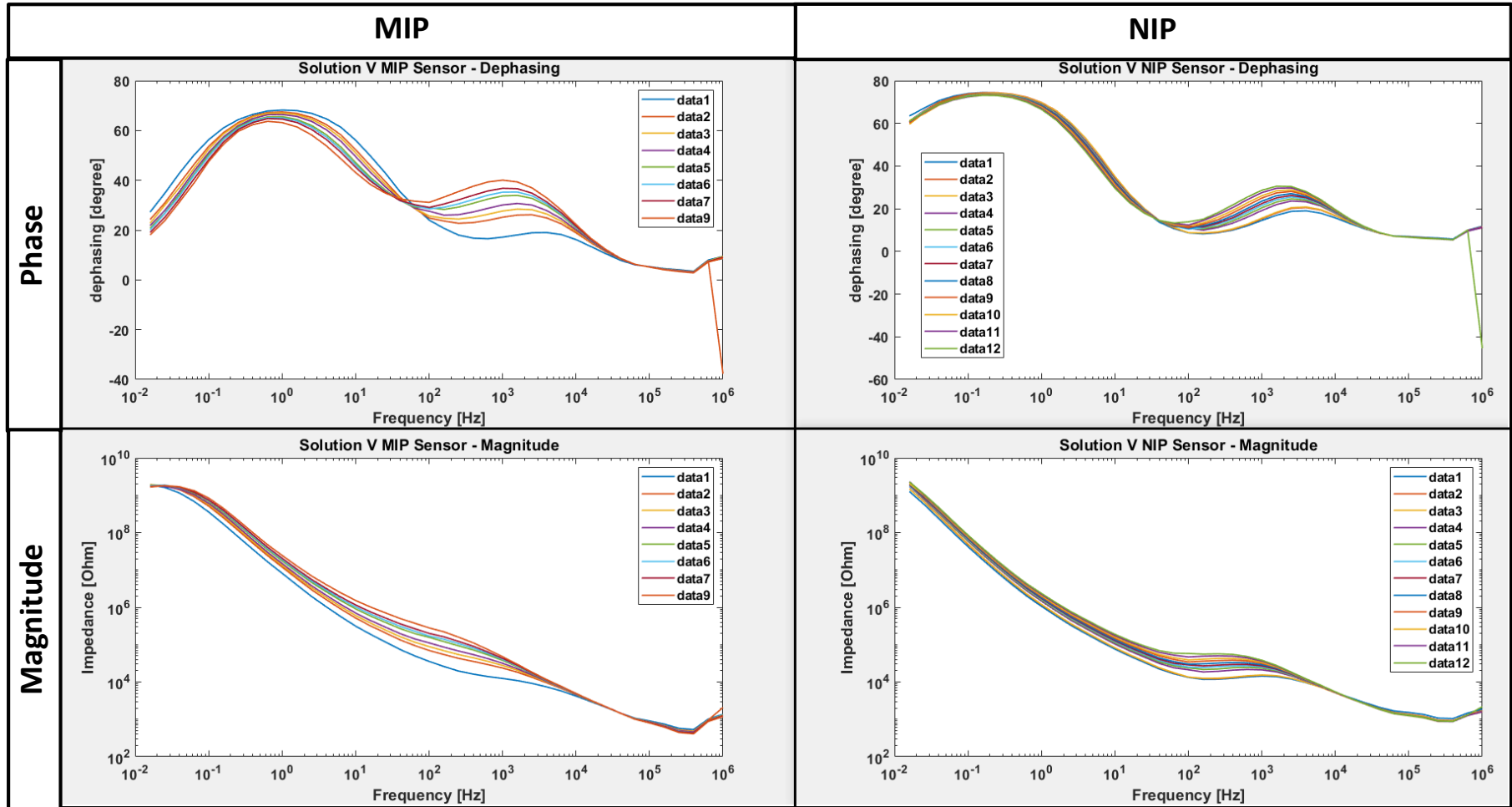**4 < PyCOOH < 10**

Experimentally

Electrochemical Impedance Spectroscopy

Application of alternative current, in a 3-electrode system, at variable frequency allowing to point out different kind of interfacial reaction.
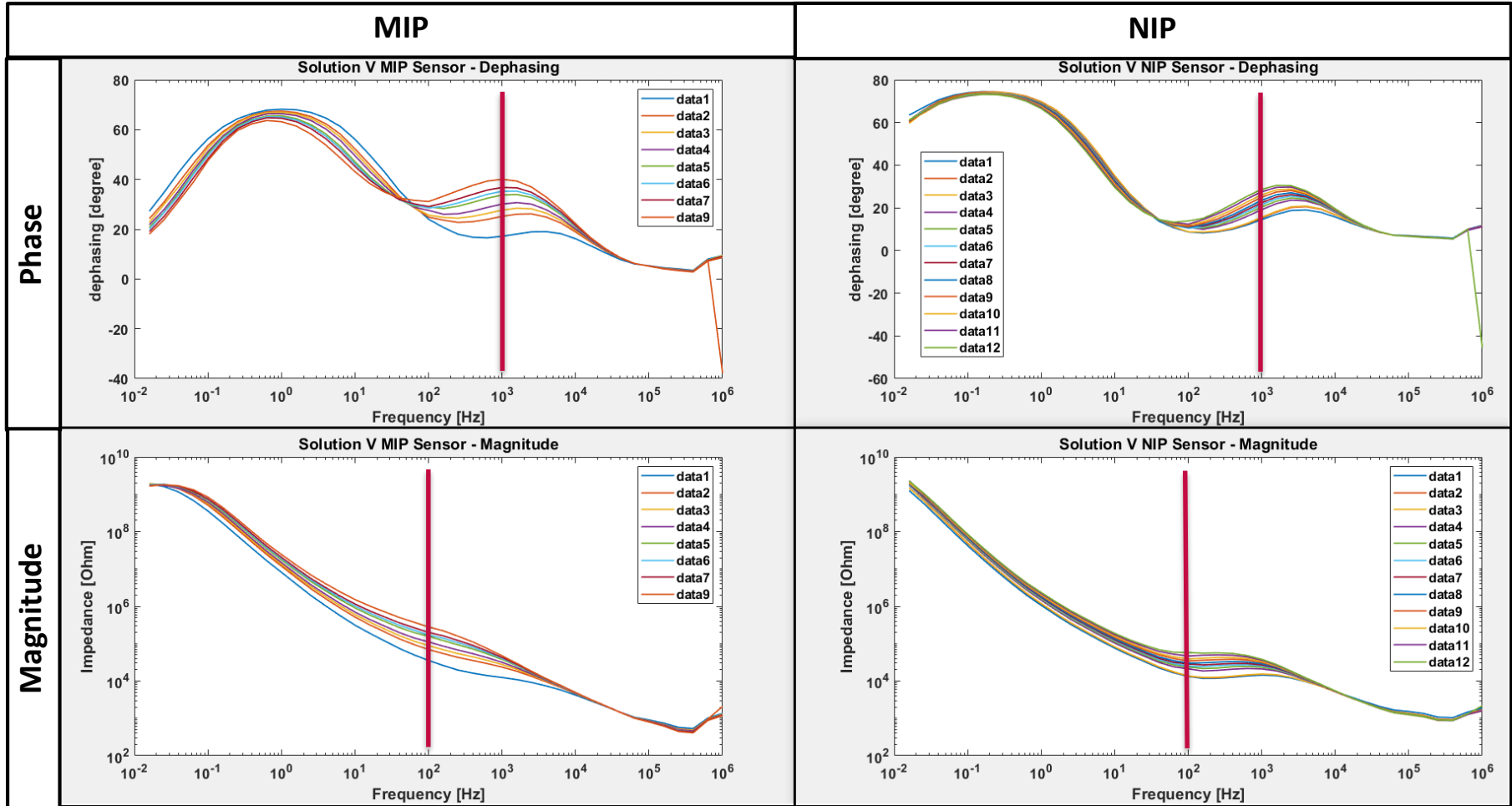

Data Analysis

→ Reference Electrode

→ Counter Electrode

→ Working Electrode

→ Electrolyte

	Time Constant
Electrical Circuit representation	
Niquyst Diagram (Imaginary Part [Ω] vs Real Part [Ω])	
Bode Diagram : Magnitude (Magnitude [Ω] vs Frequency [Hz])	
Bode Diagram : Phase (Phase [degree] vs Frequency [Hz])	
Physical Meaning	**Pure Charge Transfer**
Impedance value	$\dfrac{R}{1 + R\,j\omega C}$

Electrochemical Impedance Spectroscopy

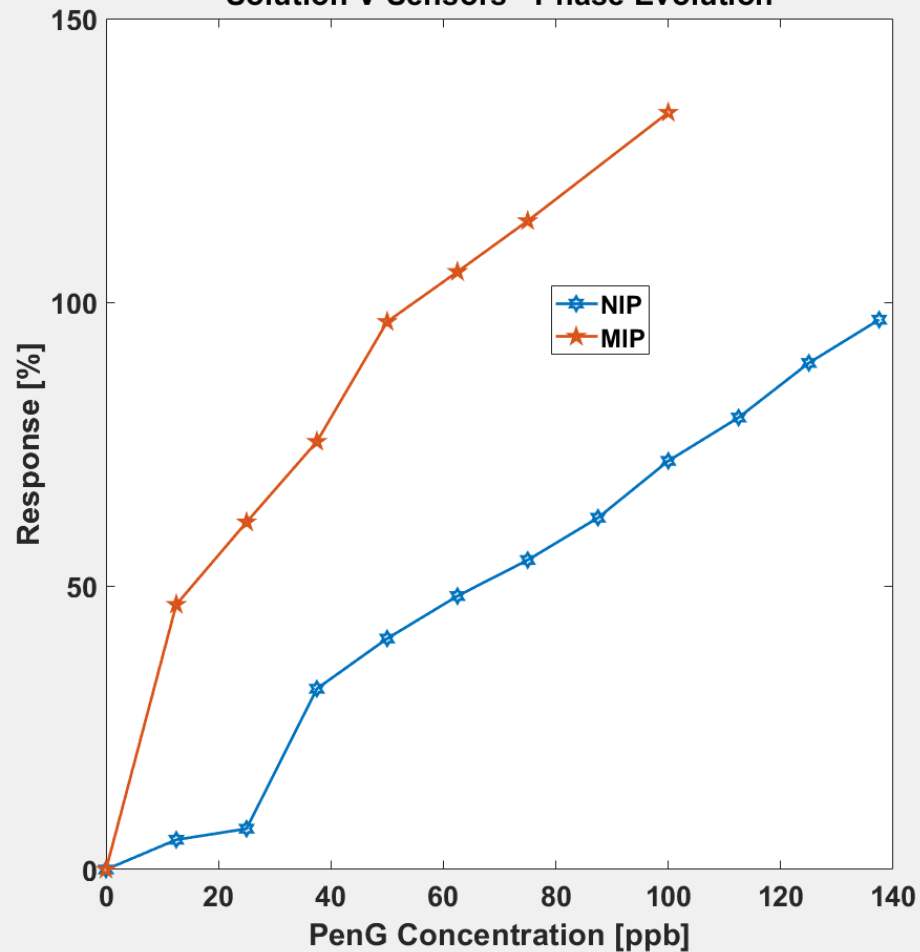# Electrochemical Impedance Spectroscopy

Electrochemical Impedance Spectroscopy

Impedance Spectroscopy Models

Idea :

Develop an electric equivalent circuit whose elements parameters are equivalent to physical properties of the real system.

Impedance Spectroscopy Models

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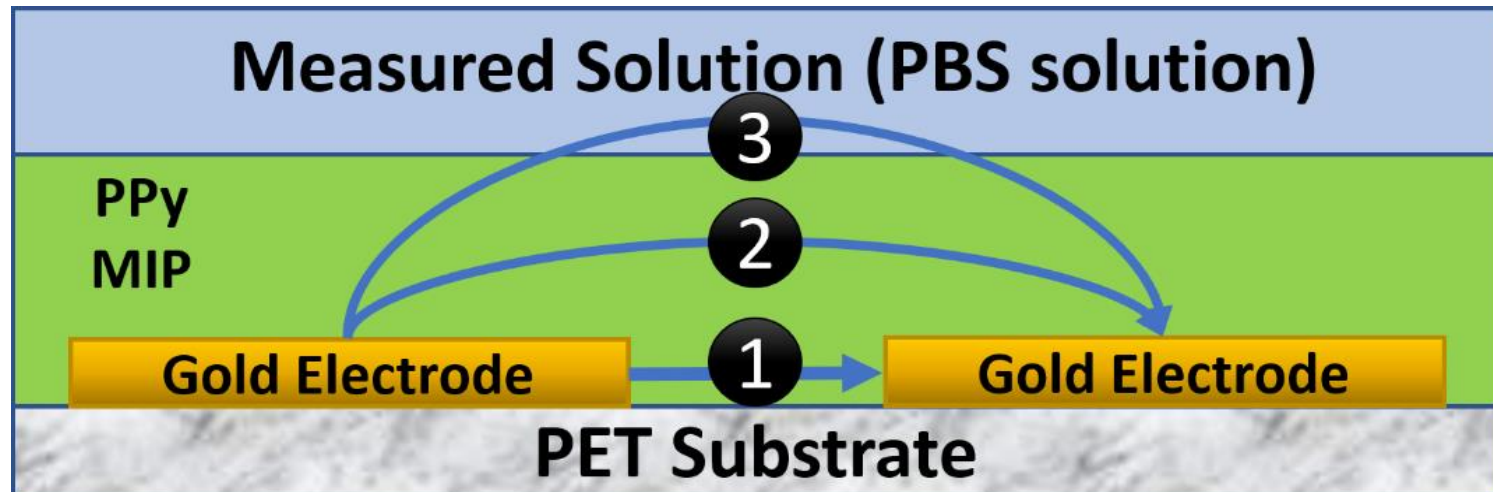
Impedance Spectroscopy Models

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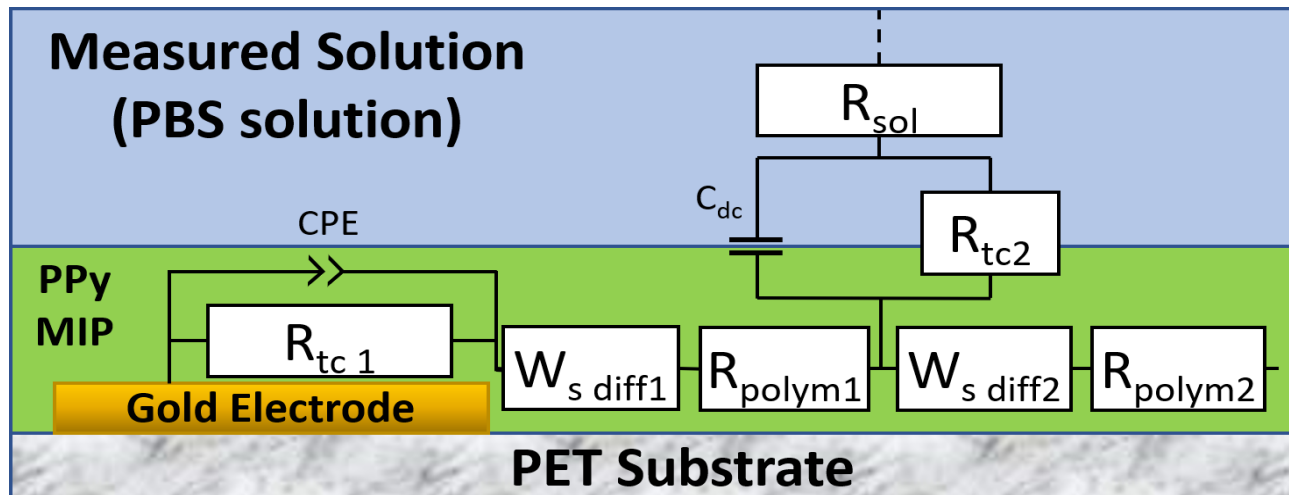
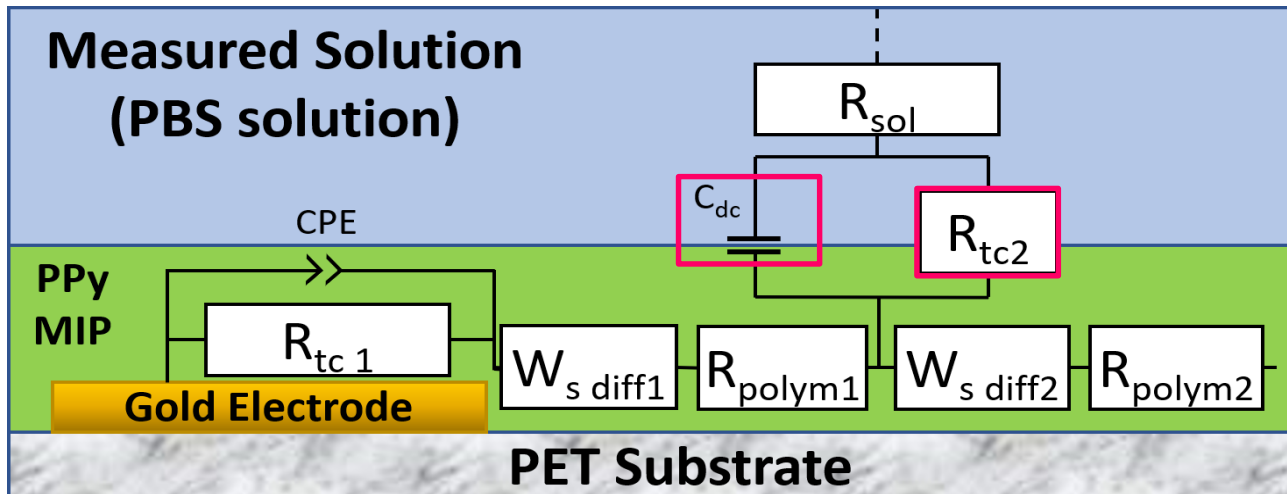# Impedance Spectroscopy Models

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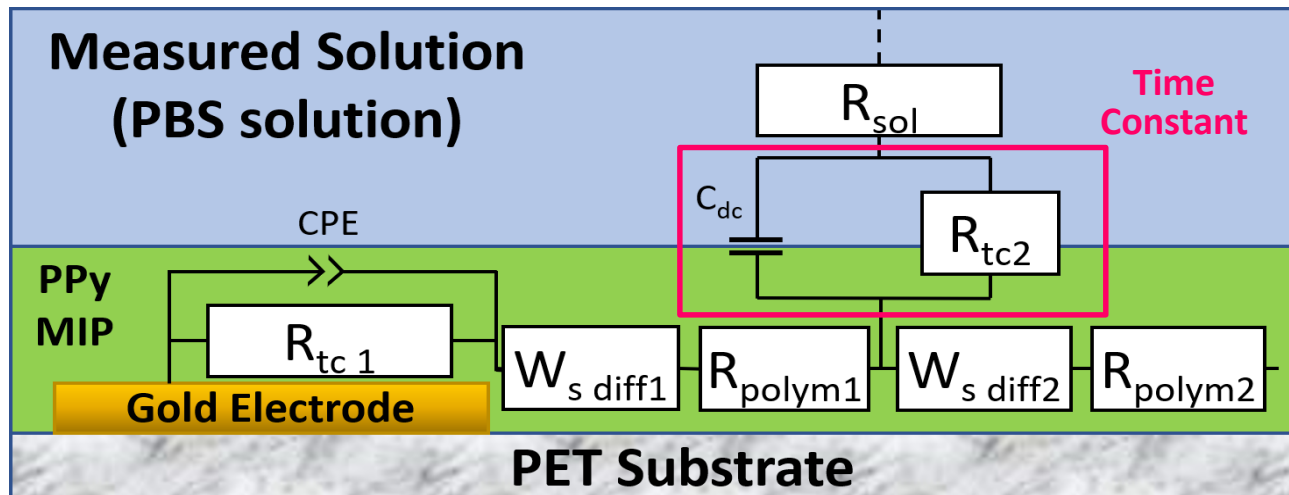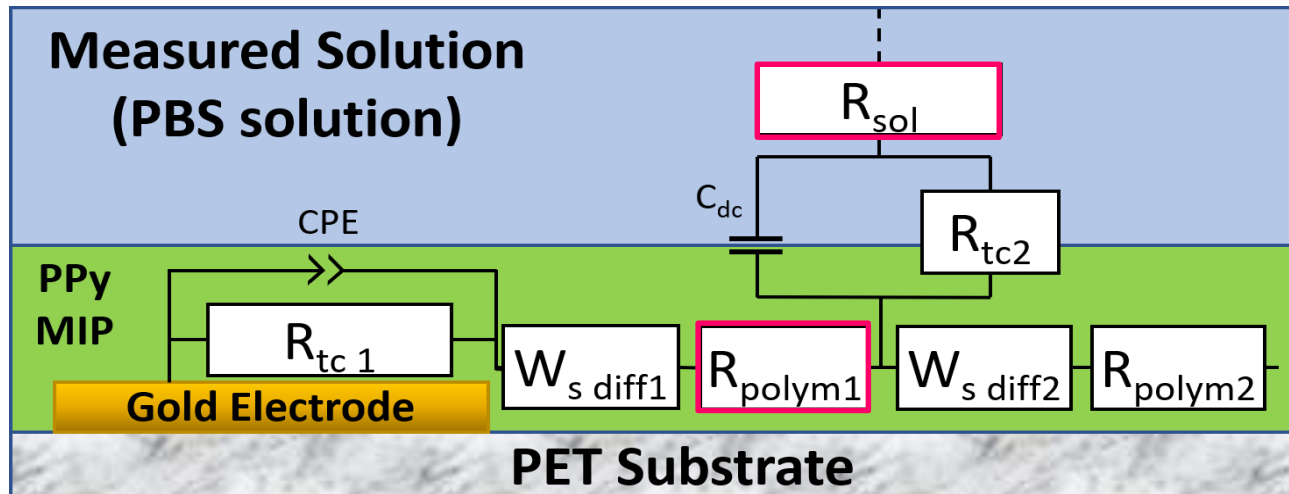# Impedance Spectroscopy Models

Idea :
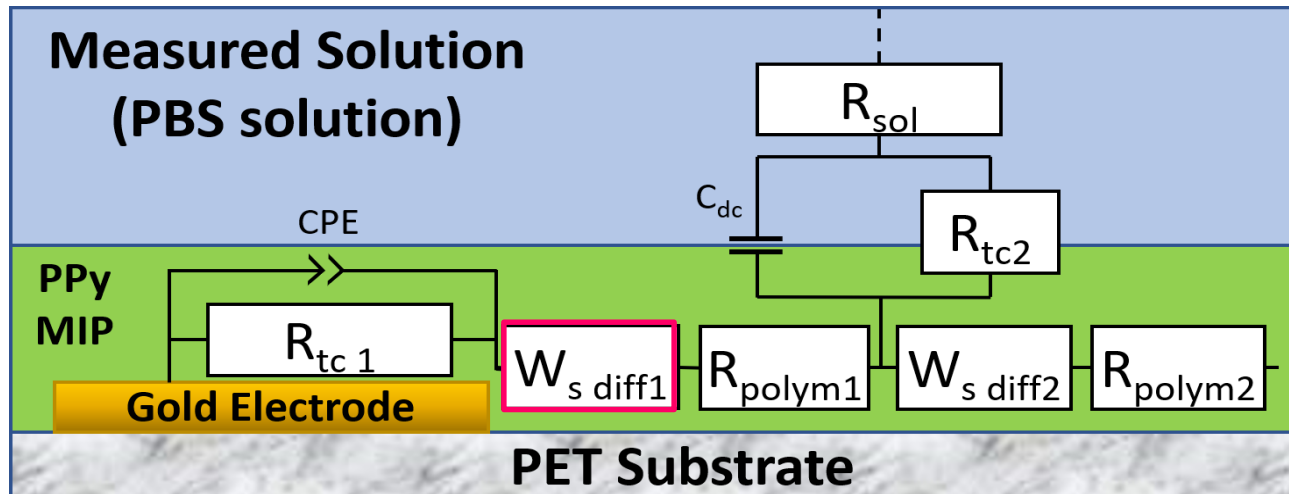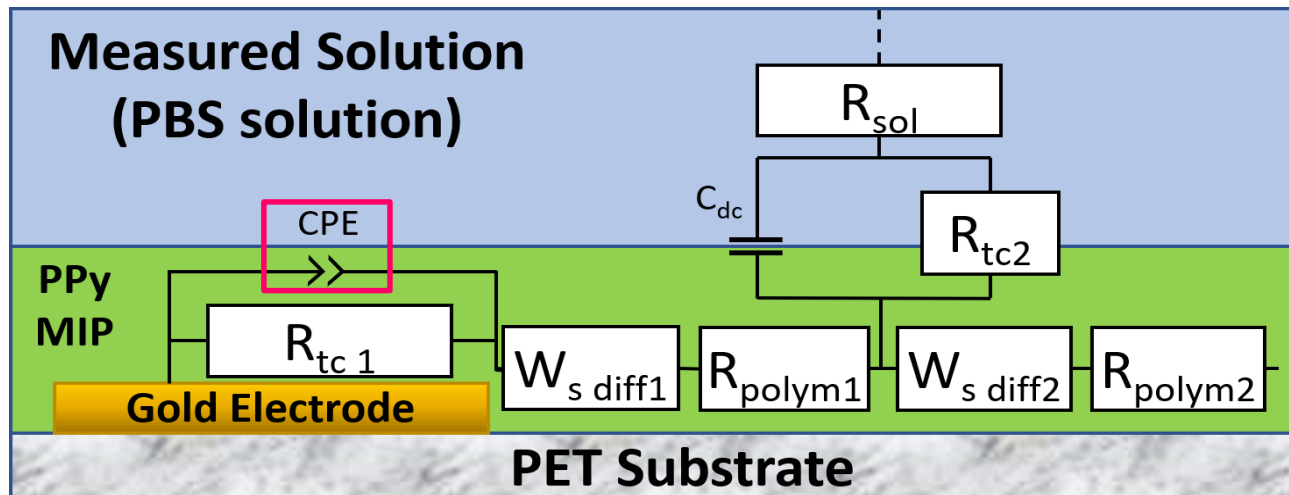
Develop an electric equivalent circuit whose elements parameters are equivalent to physical properties of the real system.

Impedance Spectroscopy Models

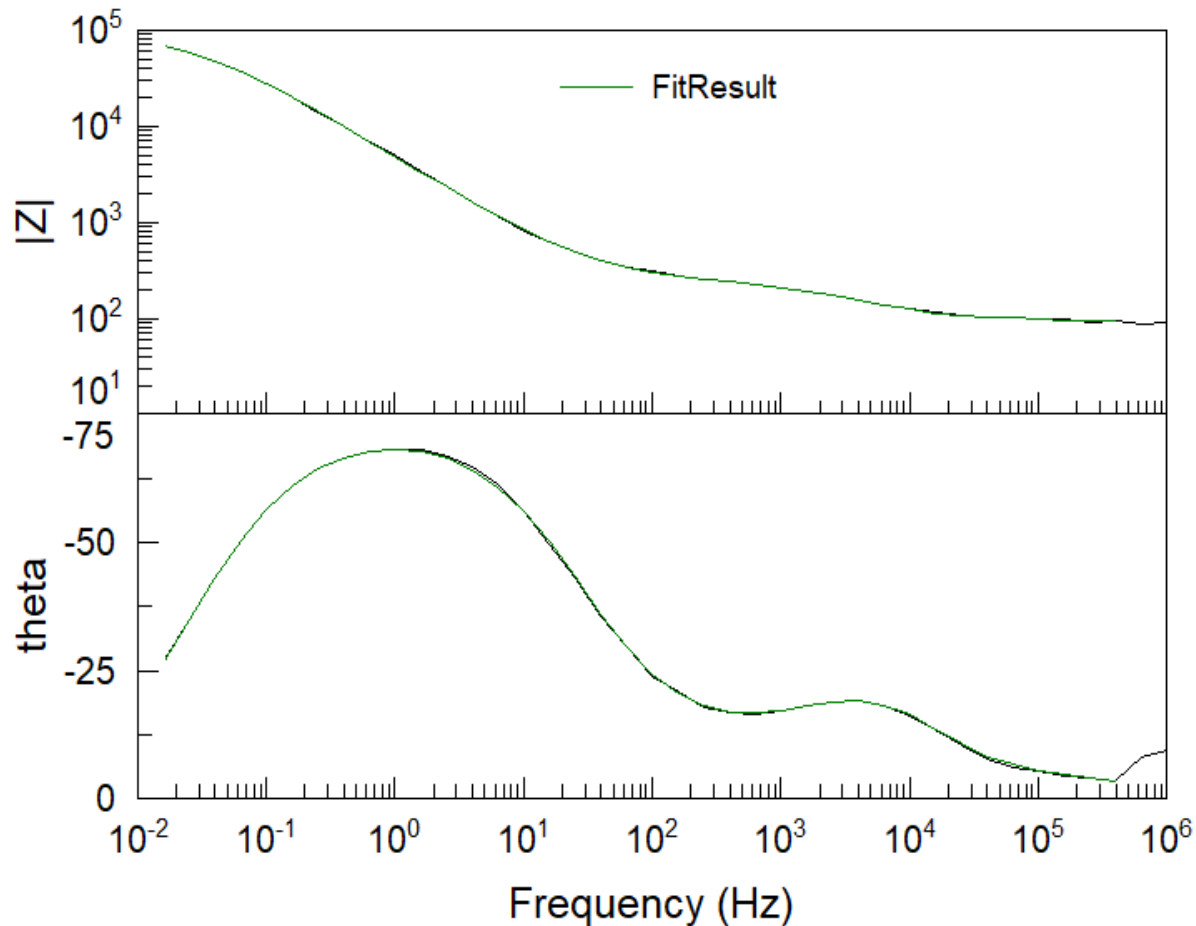**Idea :**

Develop an electric equivalent circuit whose elements parameters are equivalent to physical properties of the real system.

Fitting Results on Different Sensors
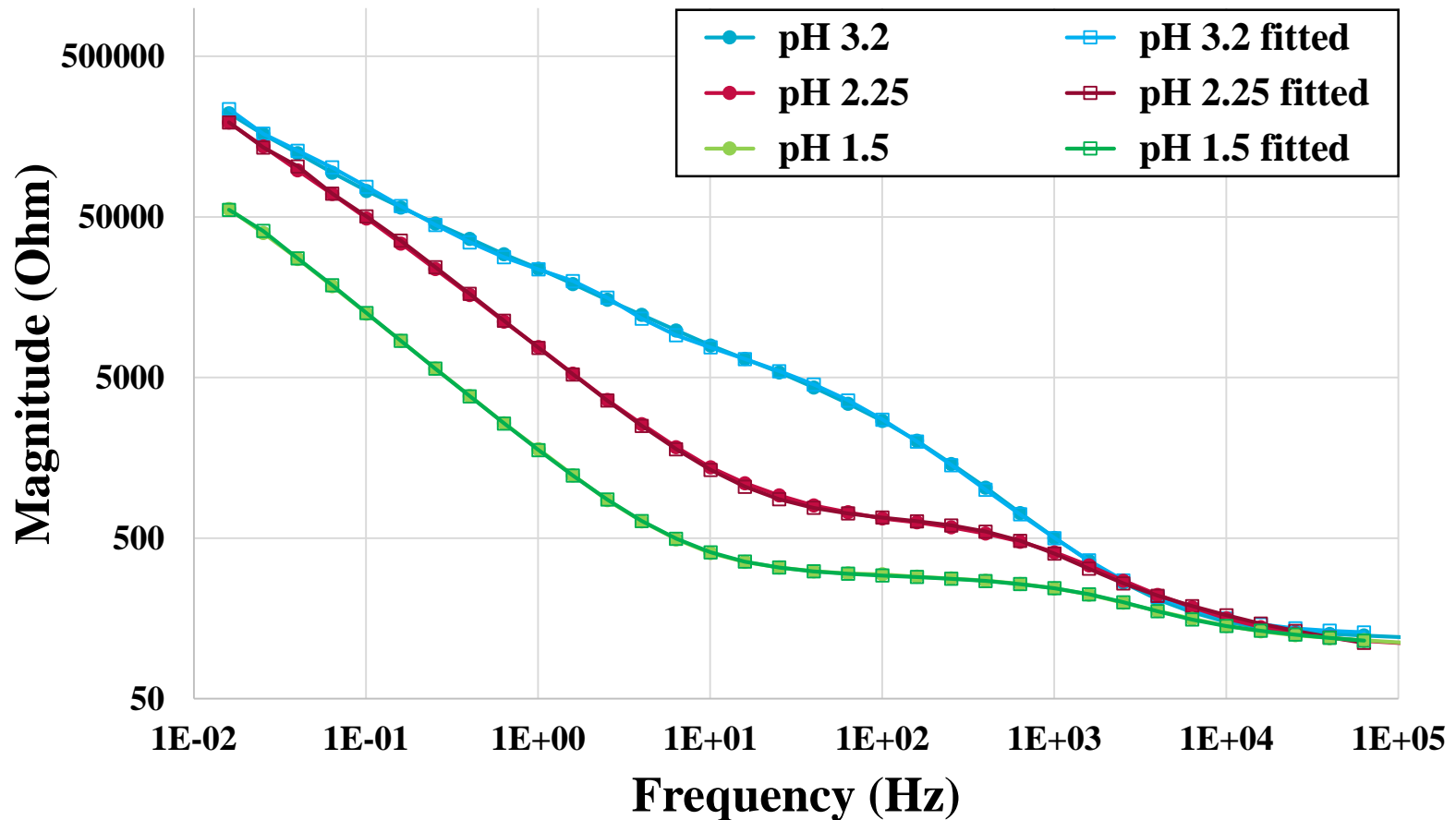
Obtained fitting results at 0 ppb :

Fitting Results on Different Sensors

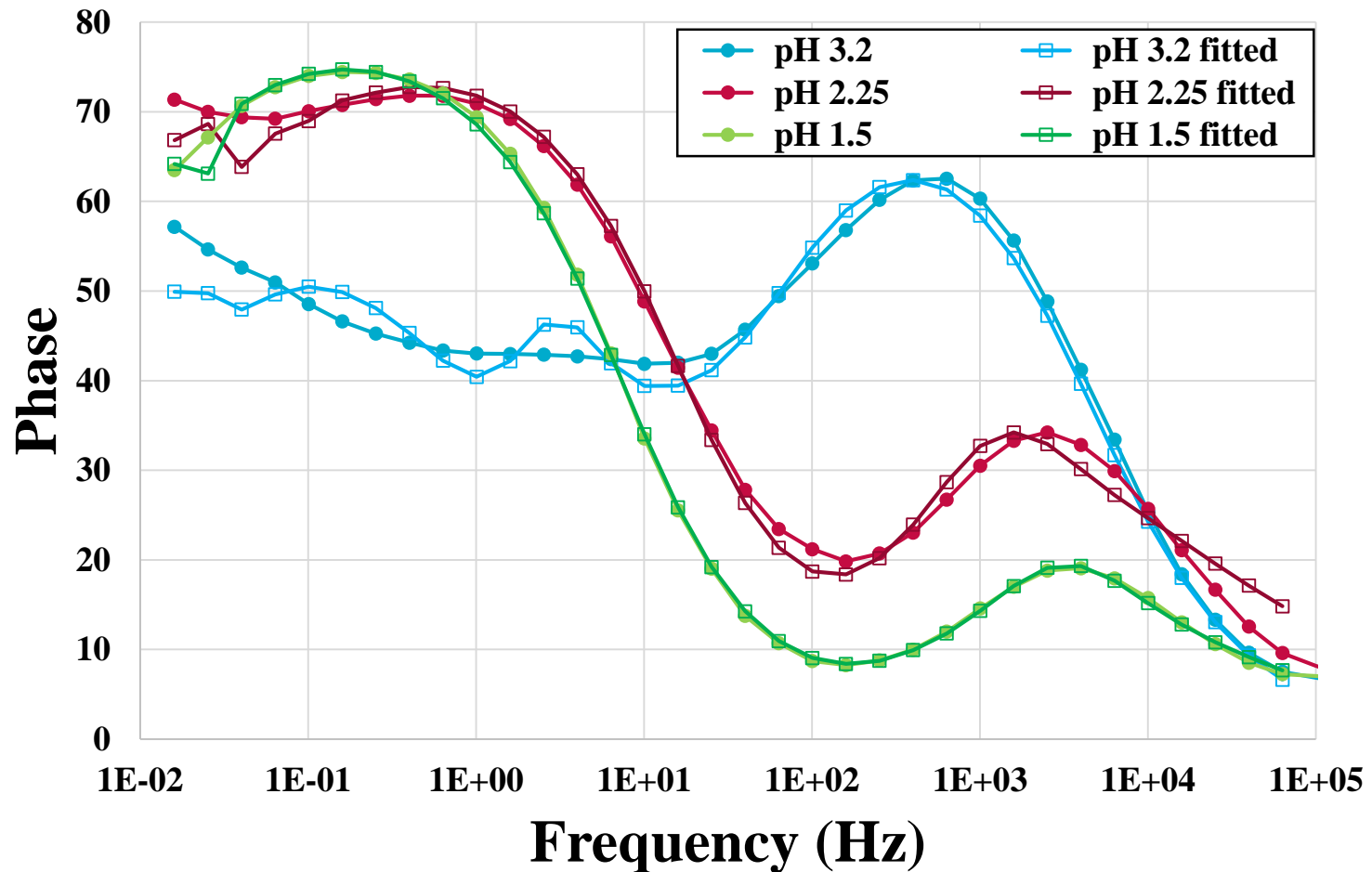## Obtained fitting results at 0 ppb :

Fitting Results on Different Sensors

Obtained fitting results at 0 ppb :

Fitting Results at Different PenG Concentrations

Obtained fitting results for a single sensor :

Hugues Charlier (hugues.charlier@umons.ac.be) – ALLSENSORS 2020

Fitting Parameters Variation

Main variations of the fitting parameters with an increase of PenG concentration :

Fitting Parameters Variation

Main variations of the fitting parameters with an increase of PenG concentration :

Fitting Parameters Variation

Main variations of the fitting parameters with an increase of PenG concentration :

W_s - Finite Length Warburg

$$Z = R \cdot \frac{\tanh[(j \cdot T \cdot \omega)^P]}{(j \cdot T \cdot \omega)^P}$$
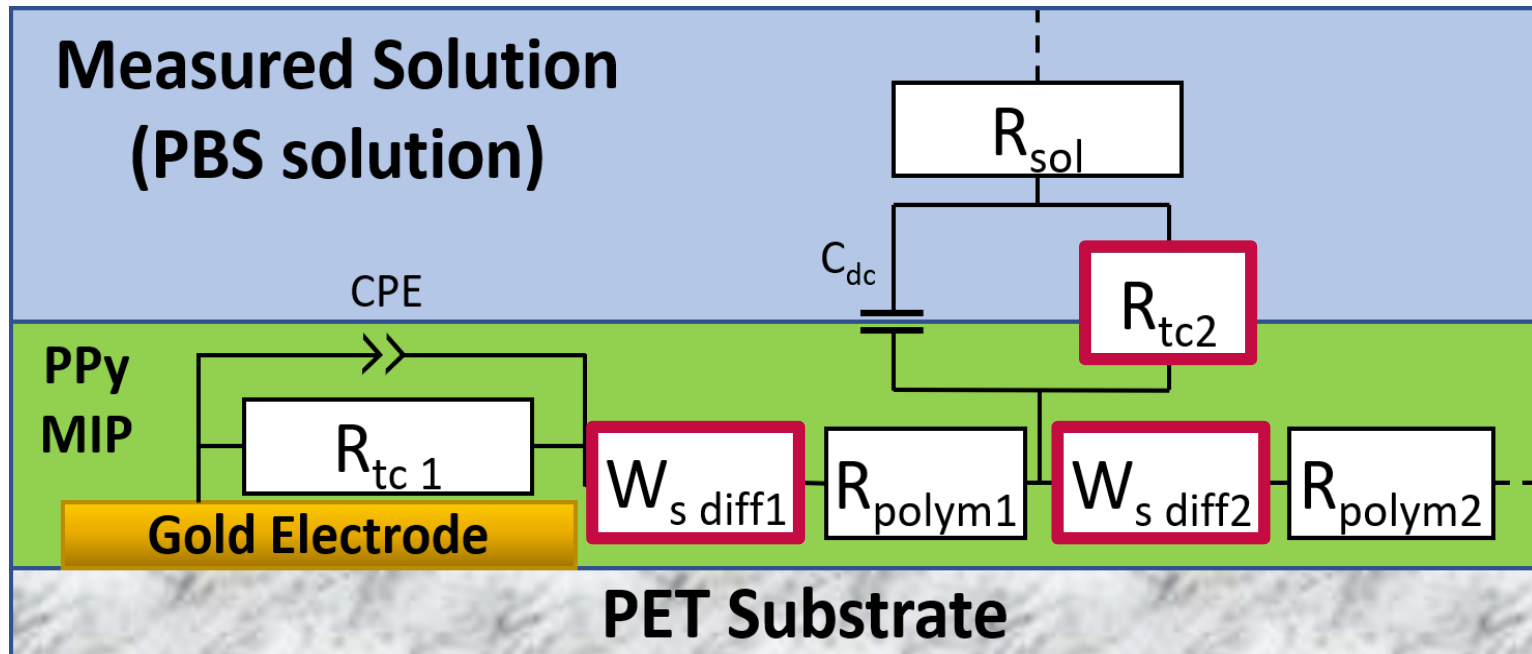
Fitting Parameters Variation

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W_s - Finite Length Warburg

$$Z = R \cdot \frac{\tanh[(j \cdot T \cdot \omega)^P]}{(j \cdot T \cdot \omega)^P}$$

Diffusion parameter (0<P<1)

Resistive Parameter

$$T = \frac{L^2}{D}$$

**with L, the diffusion Thickness
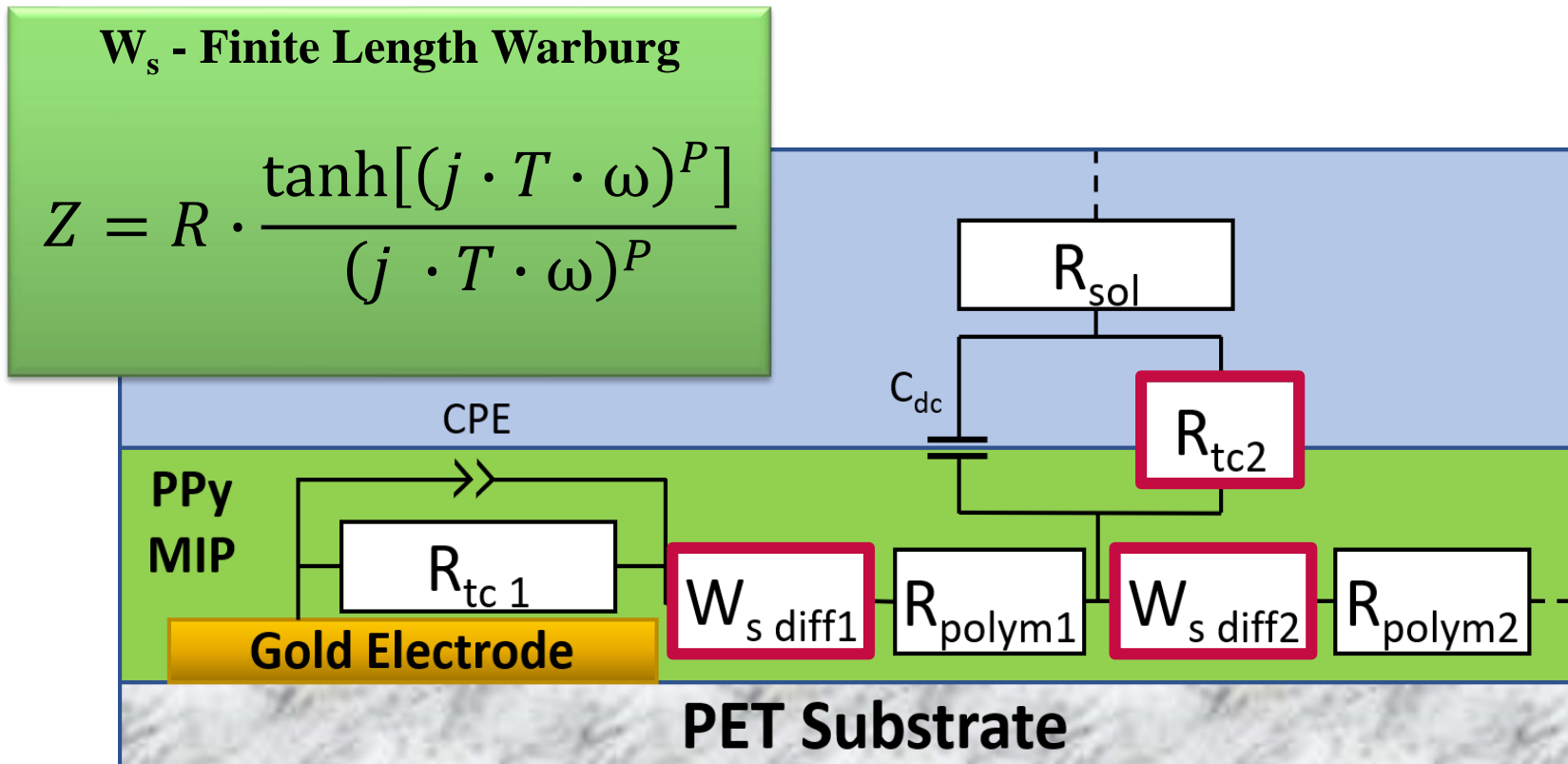and D, the effective diffusion coefficient**

Fitting Parameters Variation

Main variations of the fitting parameters with an increase of PenG concentration :

Fitting Parameters Variation

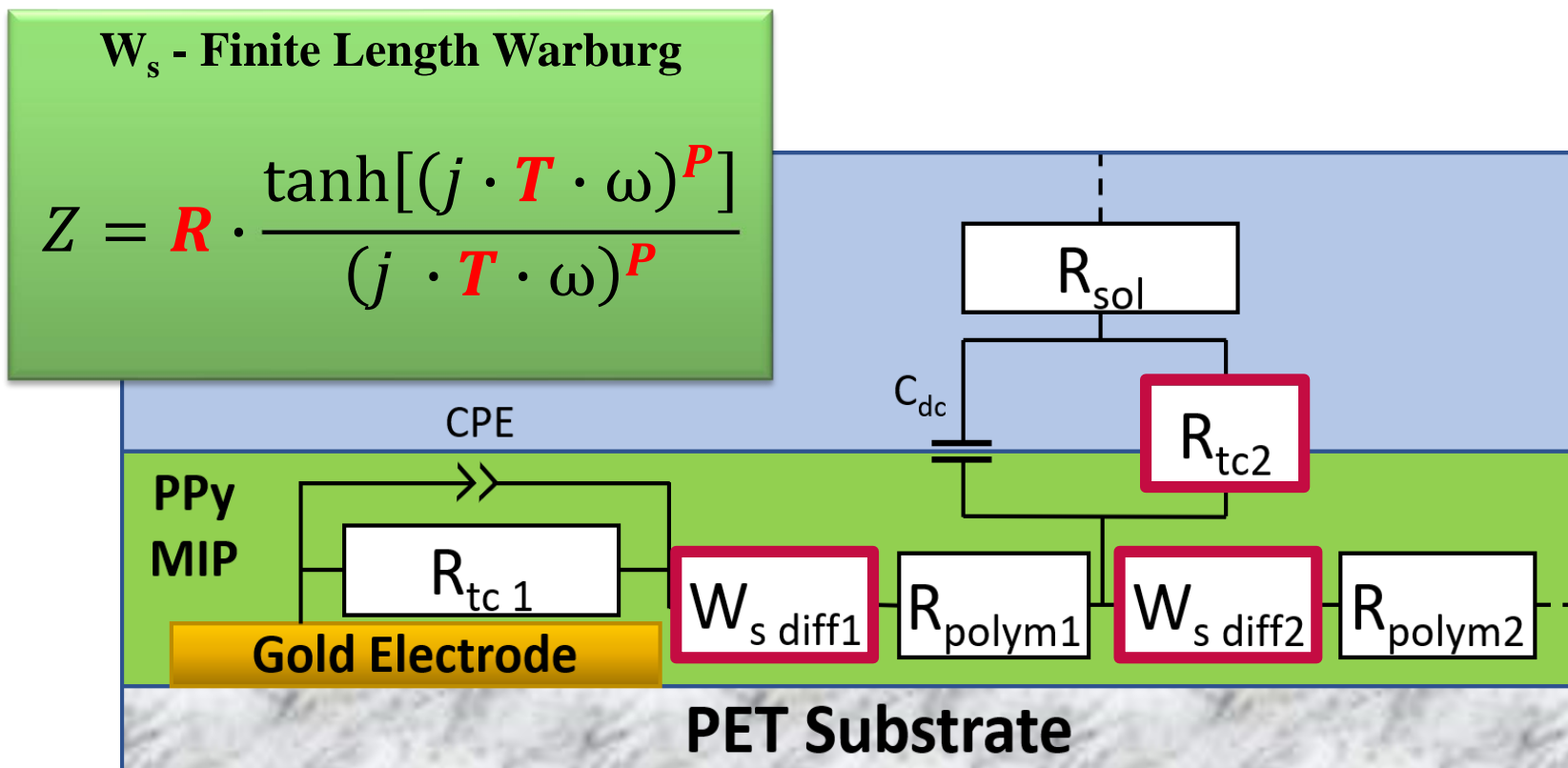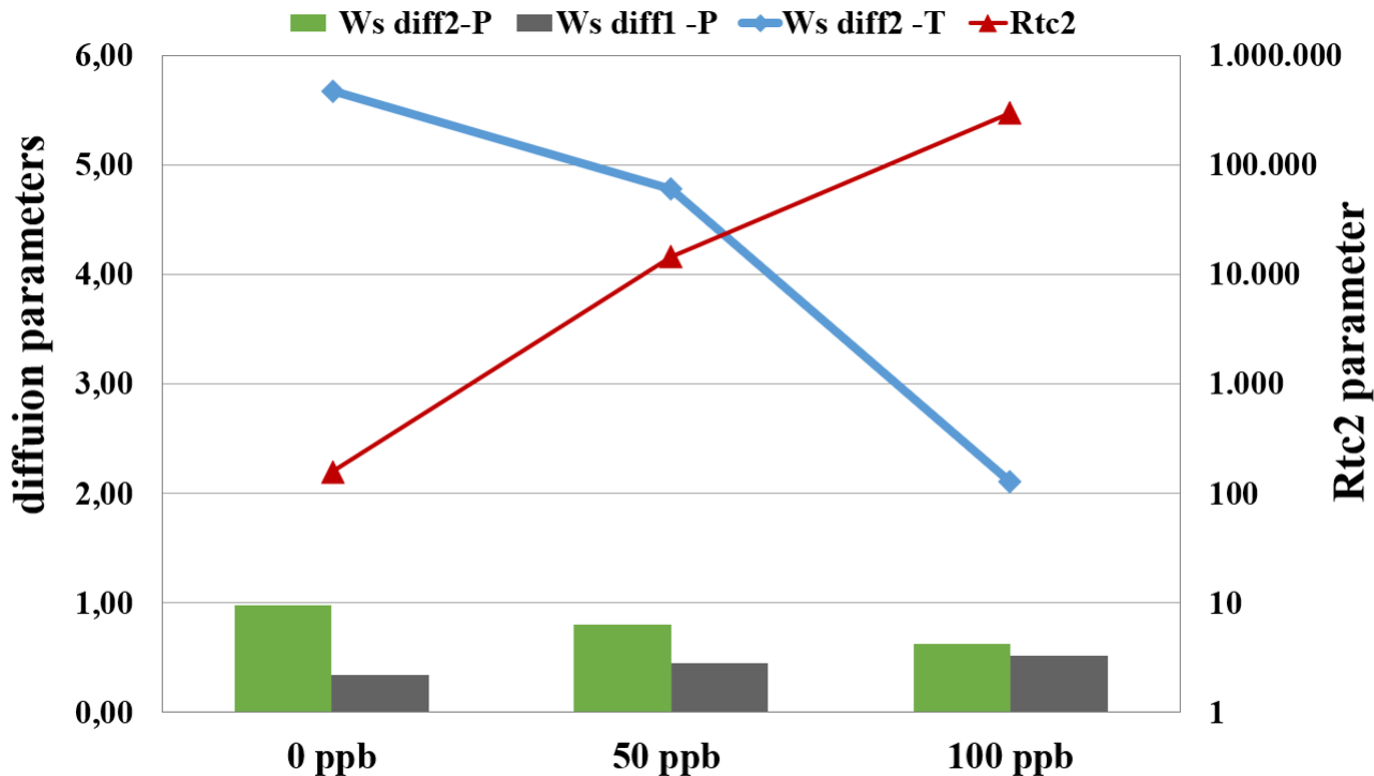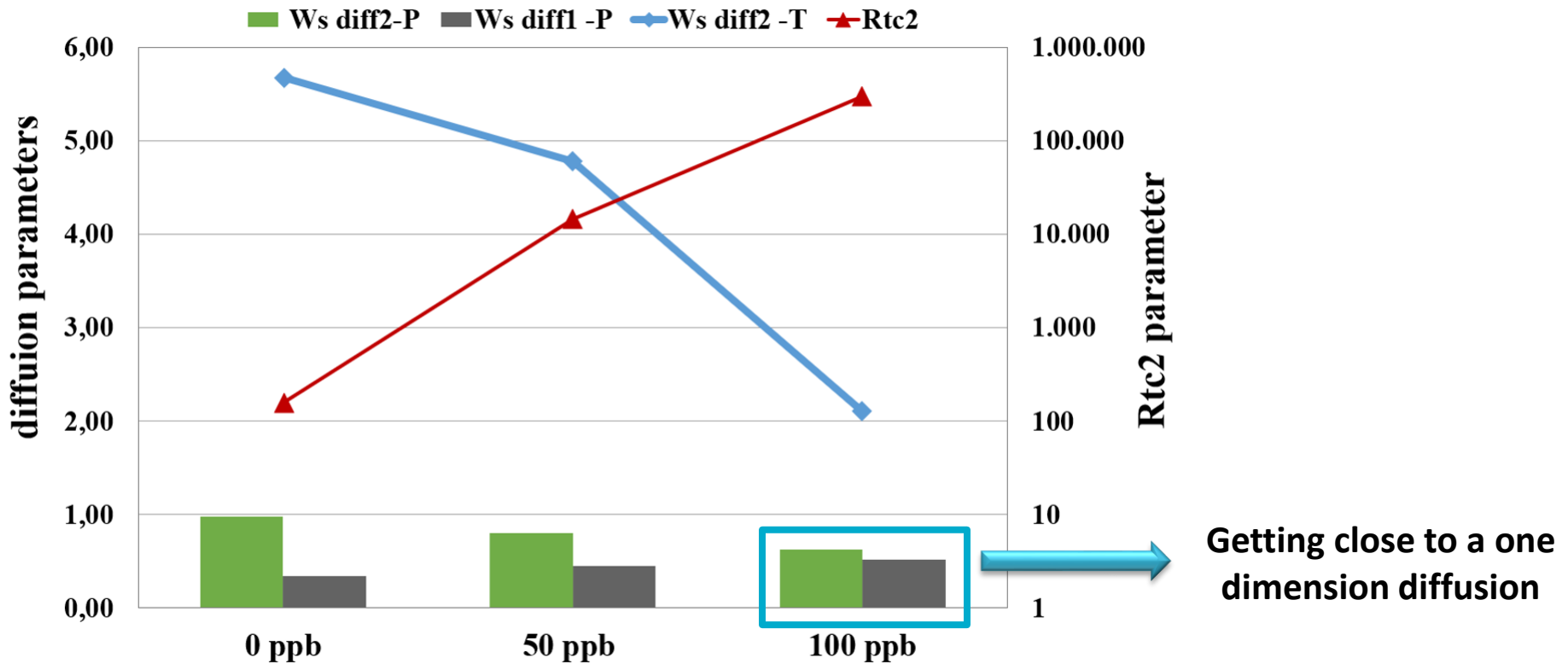## Main variations of the fitting parameters with an increase of PenG concentration :

Getting close to a one dimension diffusion

Fitting Parameters Variation

Main variations of the fitting parameters with an increase of PenG concentration :

Diffusion thickness ↘

Getting close to a one dimension diffusion

Fitting Parameters Variation

Main variations of the fitting parameters with an increase of PenG concentration :

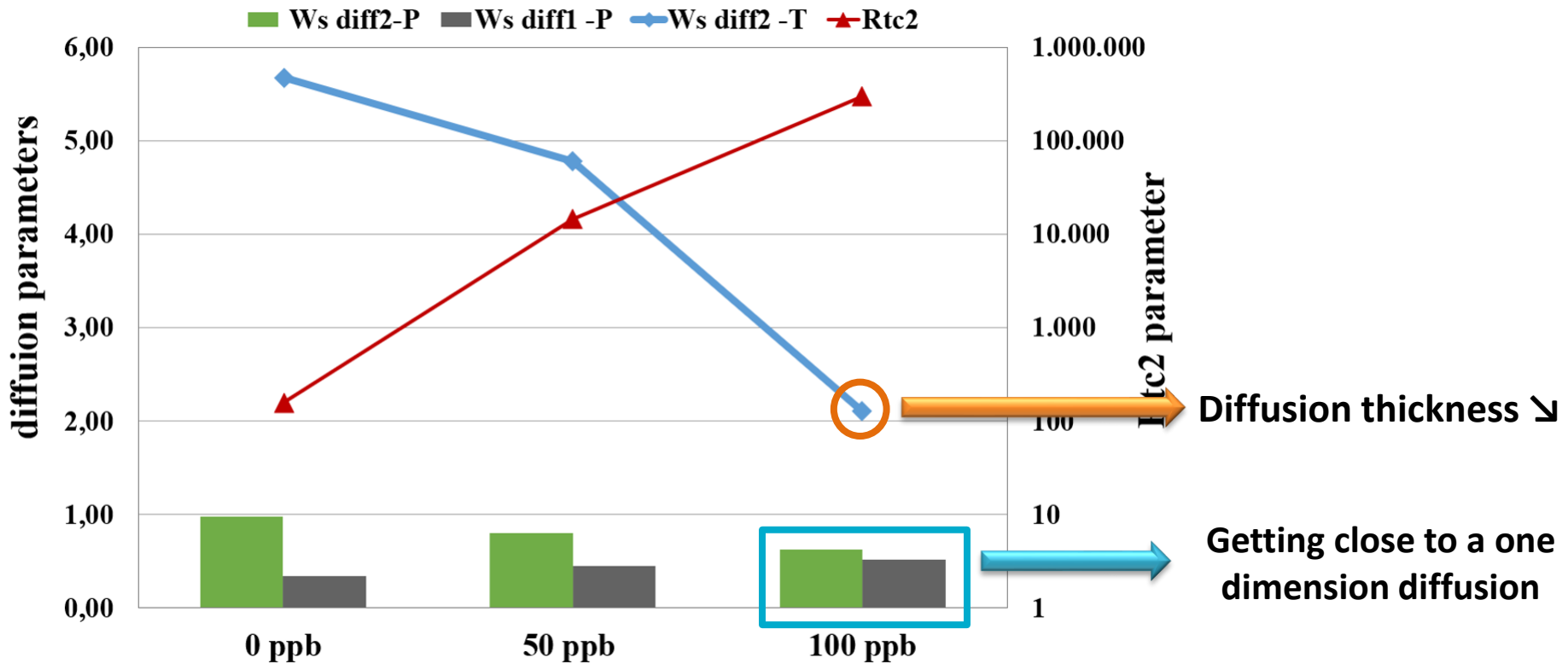Ppy/PBS charge transfer resistance ↗
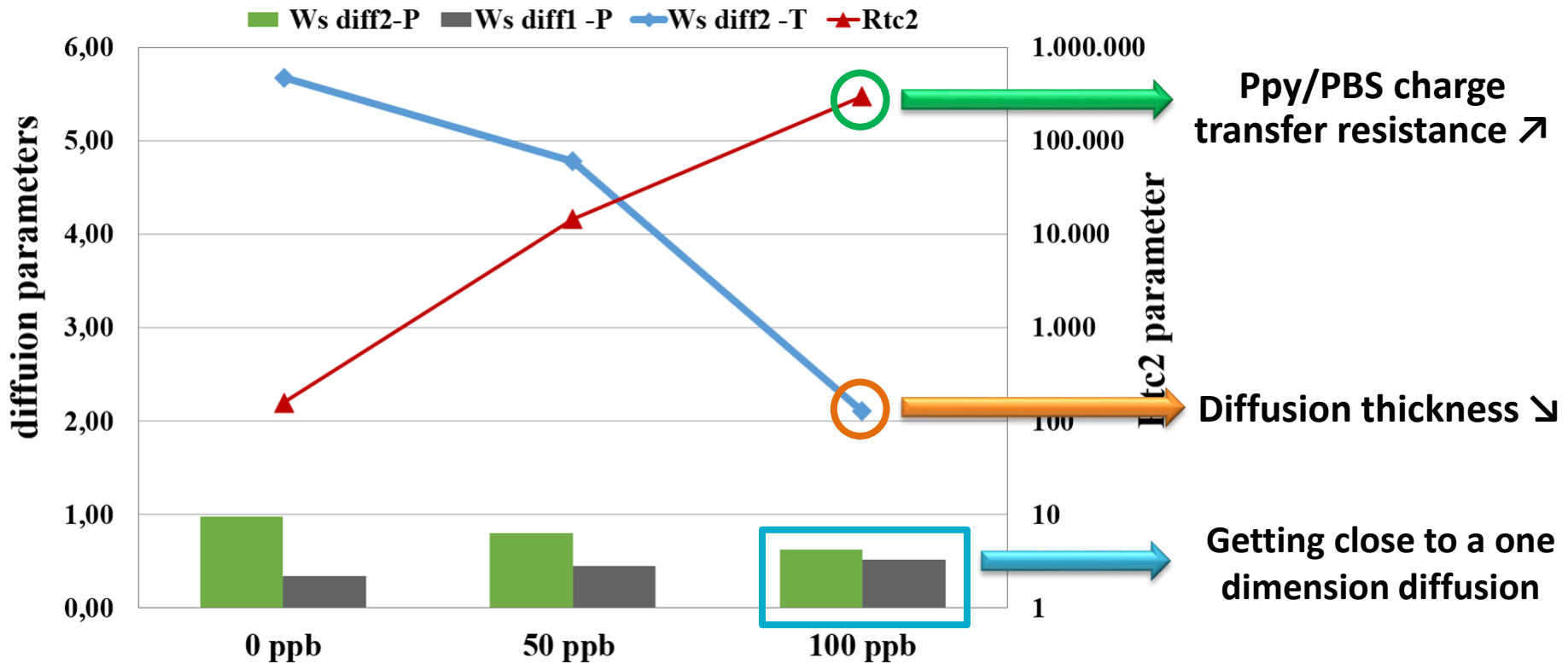
Diffusion thickness ↘

Getting close to a one dimension diffusion

Conclusions

- ☑ Theoretical optimization of the composition of the polymerization solution

- ☑ Determination of the variation of physical parameters of the sensitive layer during the detection

Prospects

❑ Further investigations on the polymerization solution composition

❑ Model the extraction phenomenon

❑ Model the detection phenomenon

❑ Perform DFT analysis (in order to verify optical measurement results)

Thanks for your attention