UMONS
Université de Mons

ALLSENSORS 2020

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

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POLYTECH MONS

EN MIEUX
www.enmieux.be

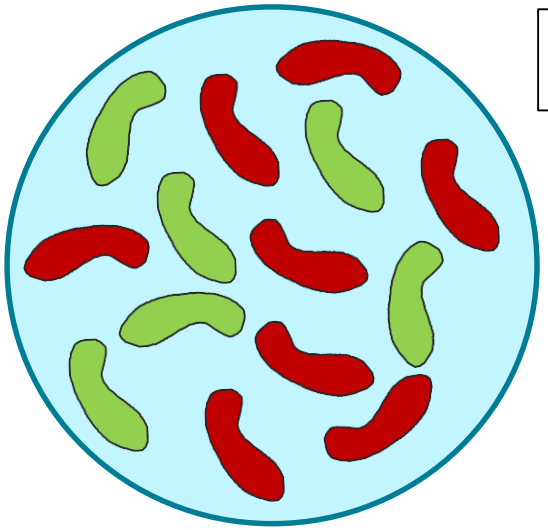
FEDER
UNION EUROPEENNE

Wallonie

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

Sensors for a Practical Implementation

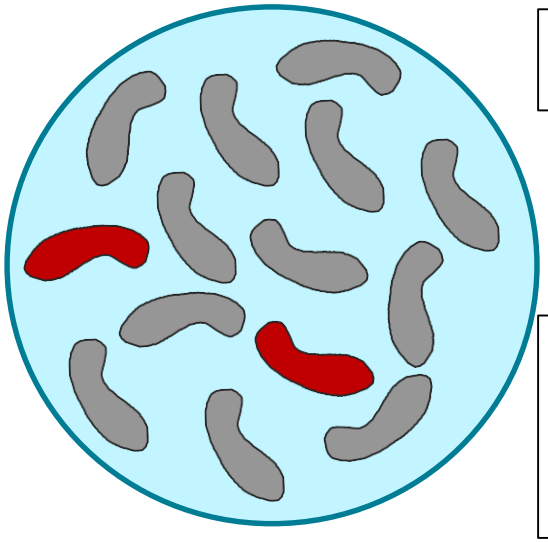
Antimicrobial resistance



Primary infection

Sensors for a Practical Implementation

Antimicrobial resistance



Primary infection

↓

Inadequate antibiotic treatment or bacterial resistance mutation

Sensors for a Practical Implementation

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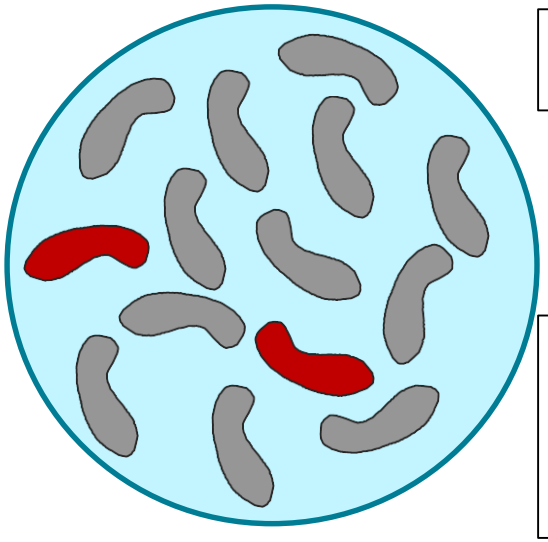

Primary infection

Inadequate antibiotic treatment or bacterial resistance mutation

Proliferation of resistant bacteria

Sensors for a Practical Implementation

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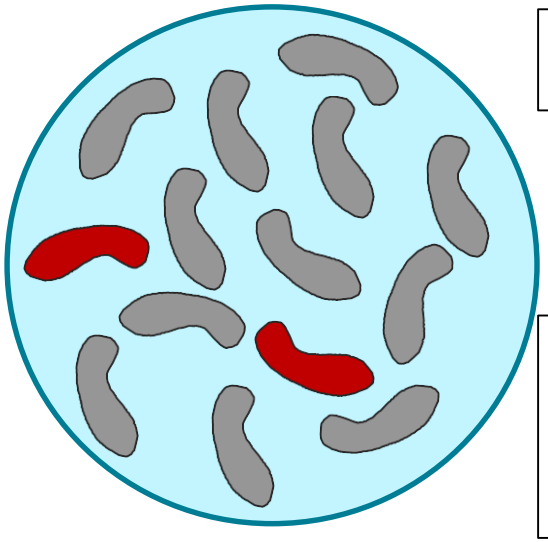

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Solution :
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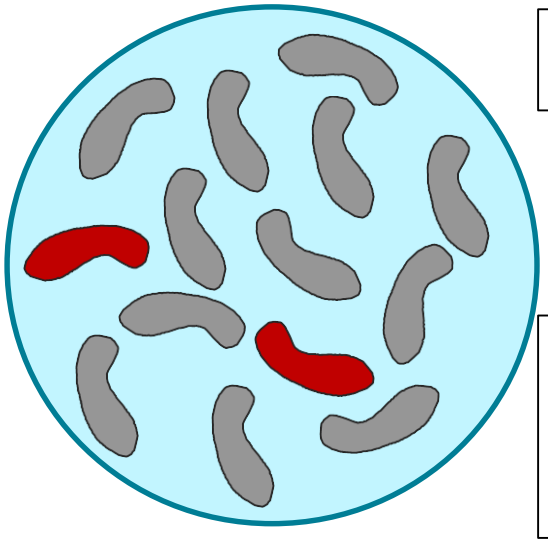

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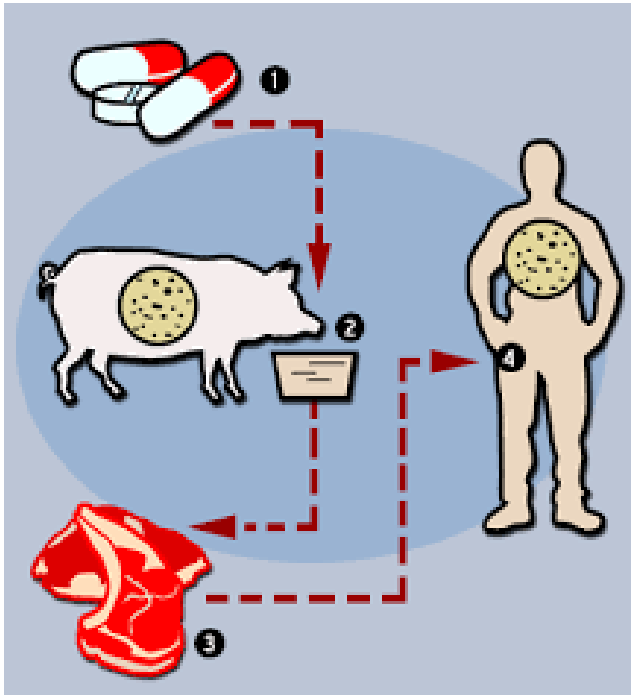
Widely used in the food industry



Must be controlled

Sensors for a Practical Implementation

Antimicrobial resistance

Primary infection

iotic
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tion

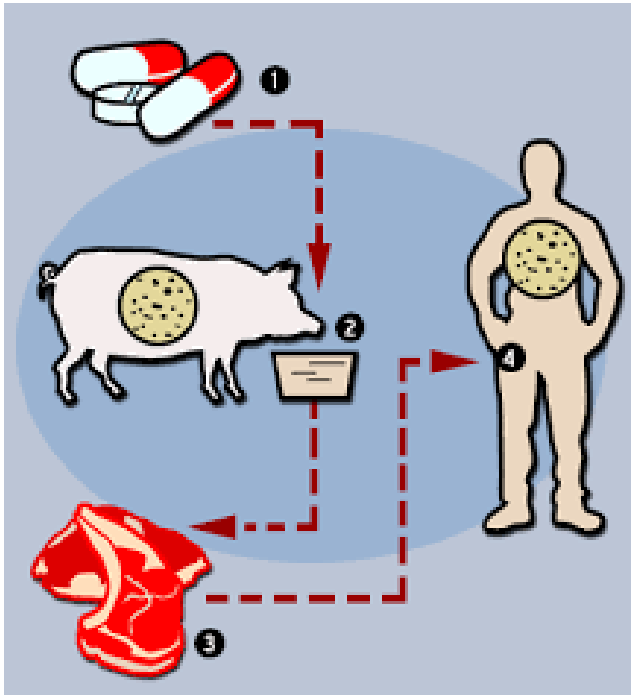
Proliferation of resistant bacteria

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

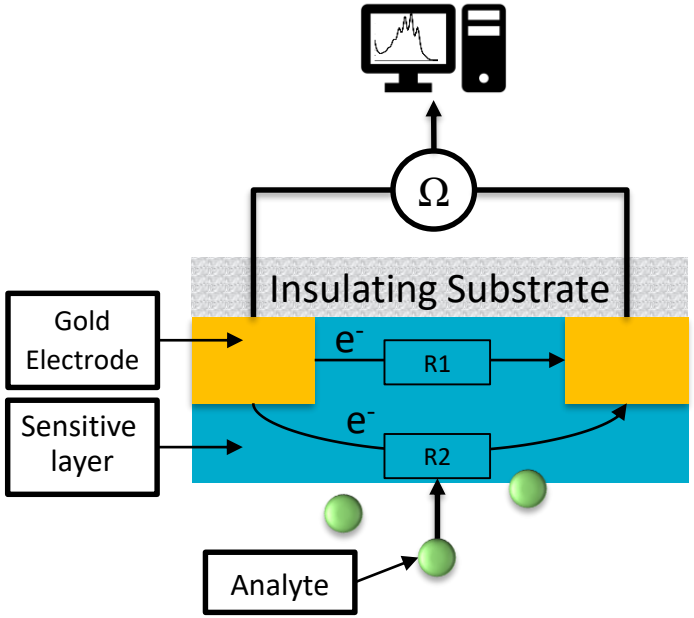


Must be controlled

Transduction Mechanisms

Suitable measurement techniques must consume as few energy as possible

Conductivity measurements

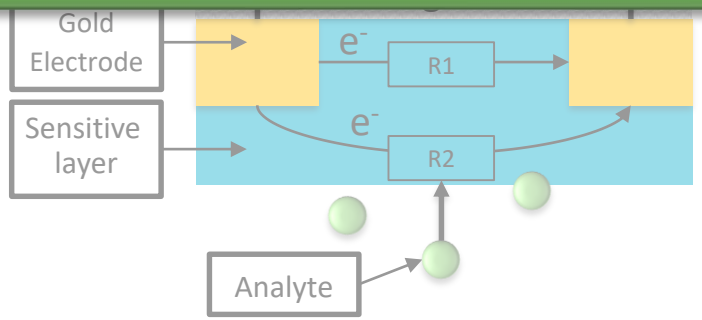


Transduction Mechanisms

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**



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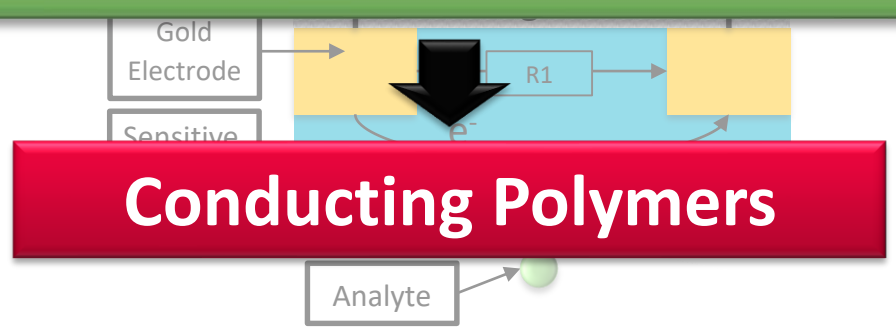
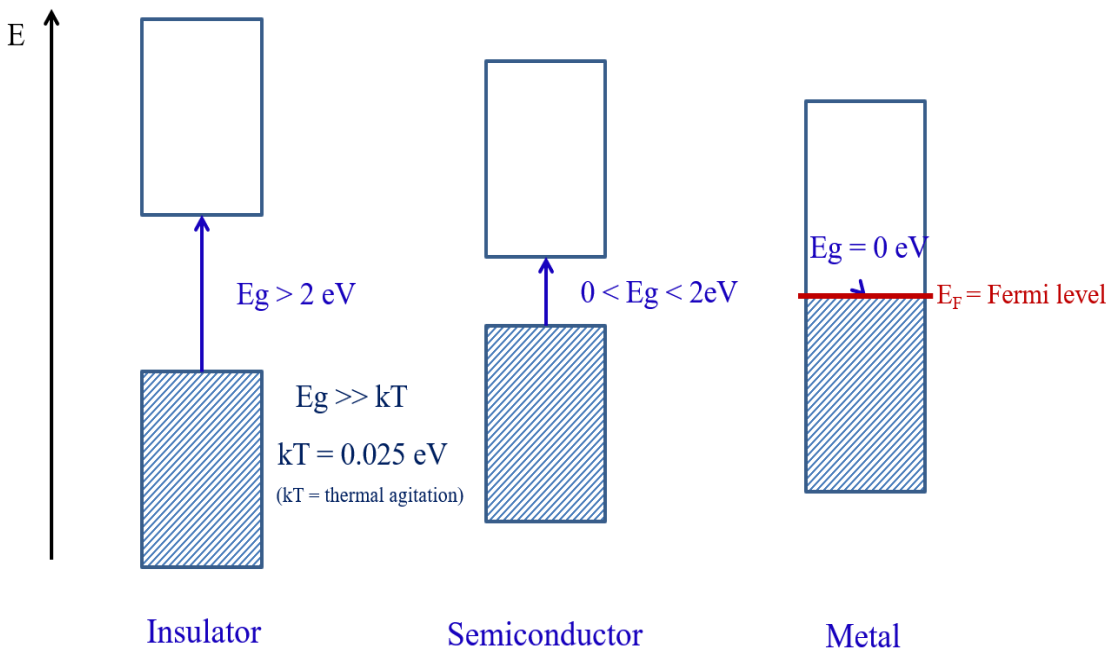


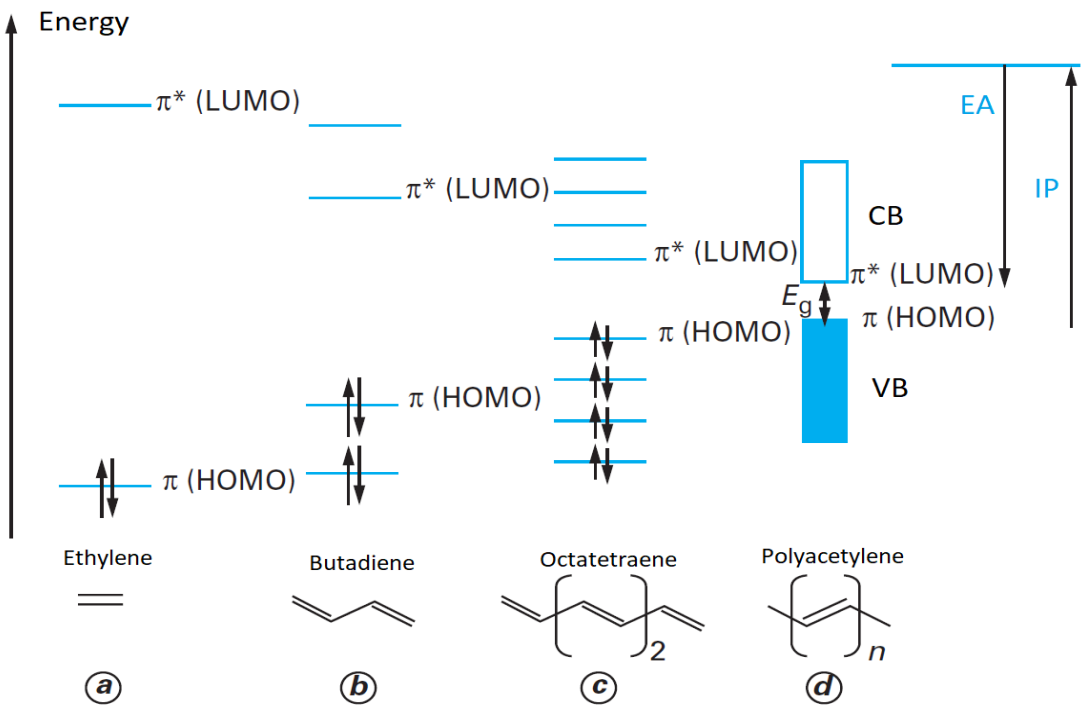
Conducting Polymers

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



Conducting Polymers

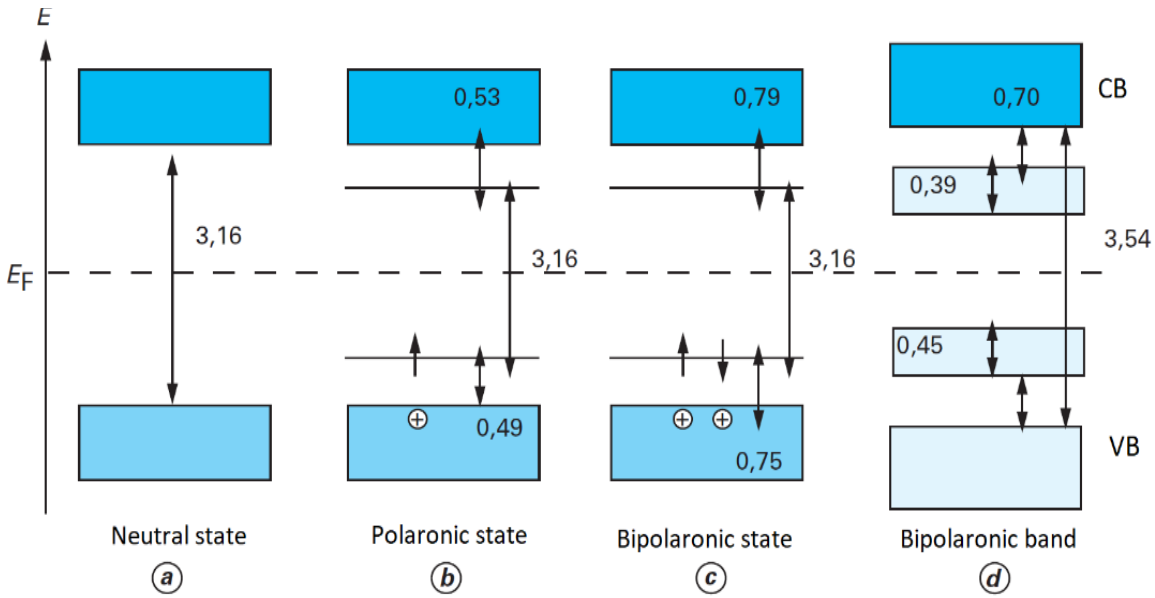
Polymers are usually considered as insulator



(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

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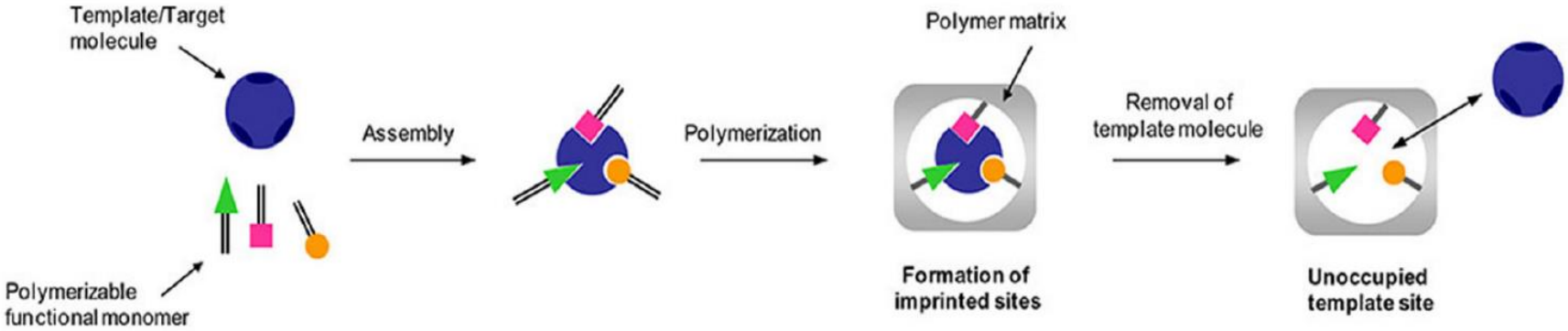
How to Solve Selectivity Issue ?

Molecularly **I**mprinted **P**olymer (MIP) :

Target molecule integrated in polymer matrix



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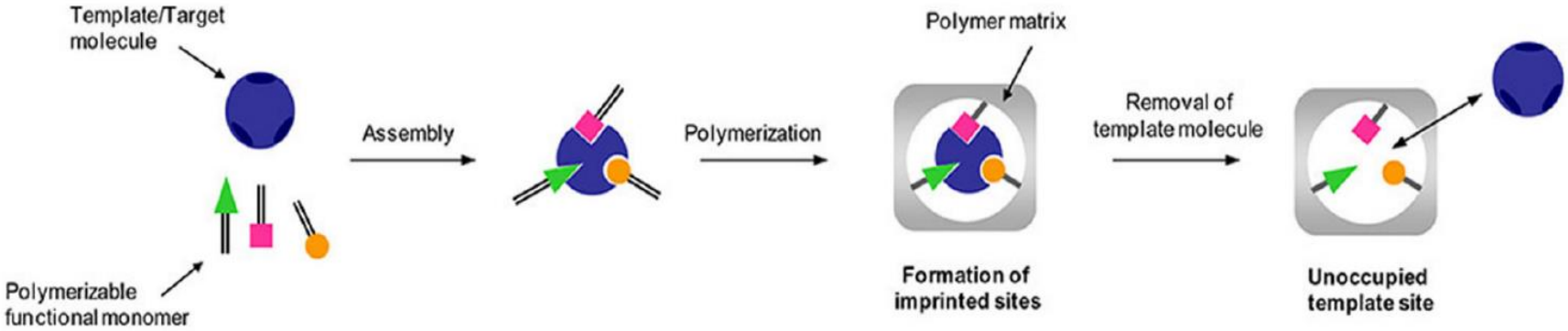


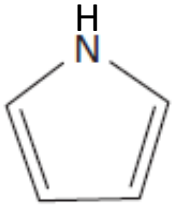
Significantly increase of selectivity

Highly adaptable, just need to change the template

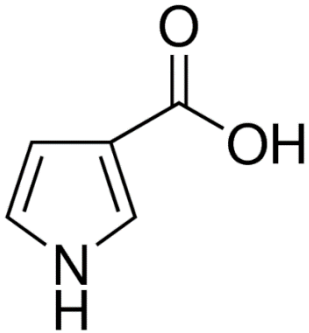
Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

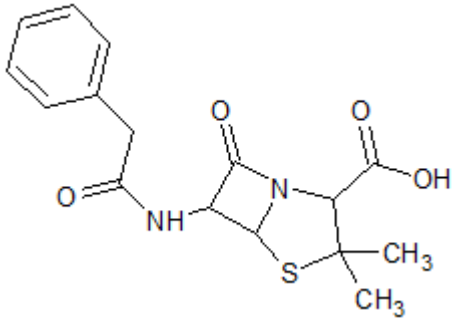
Crosslinker : Pyrrole



Functional monomer : Pyrrole carboxilic acid



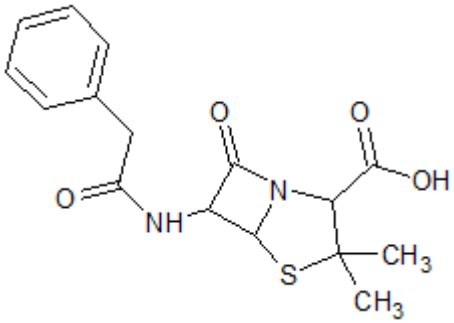
Target molecule / Template: Peniciline G



Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

Schematic Representation



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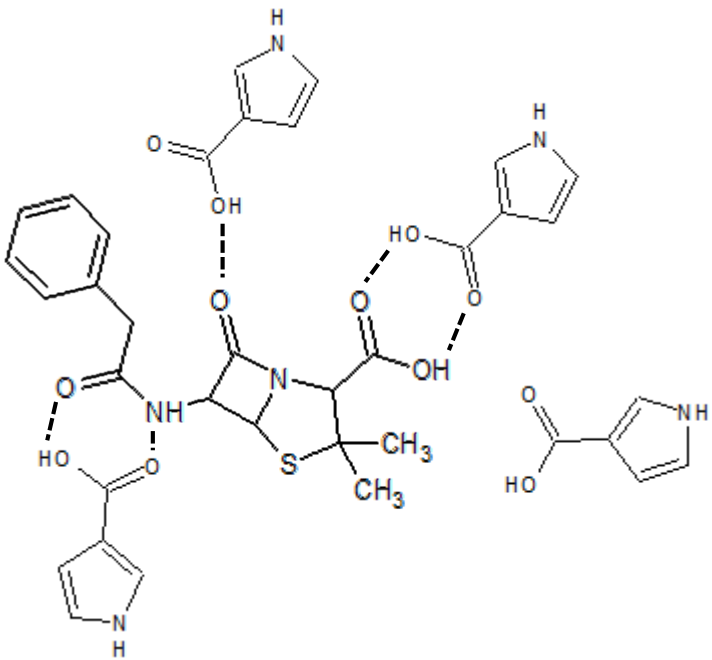
Schematic Representation

pH modification



Temperature adjustment

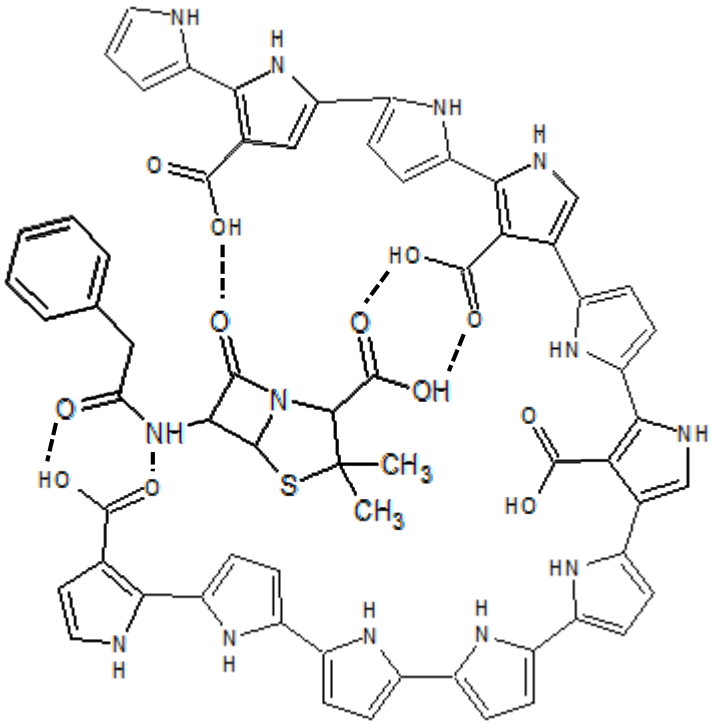
Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

Schematic Representation

pH modification

Oxidant addition



Temperature adjustment

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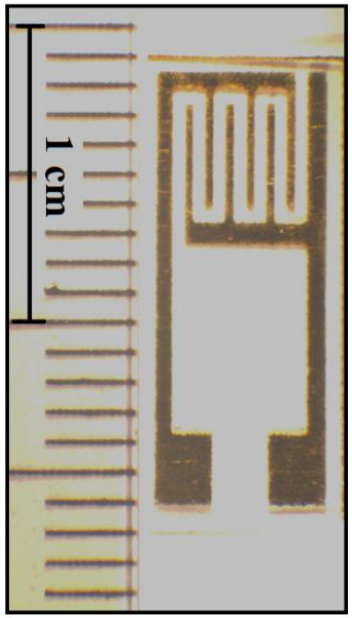
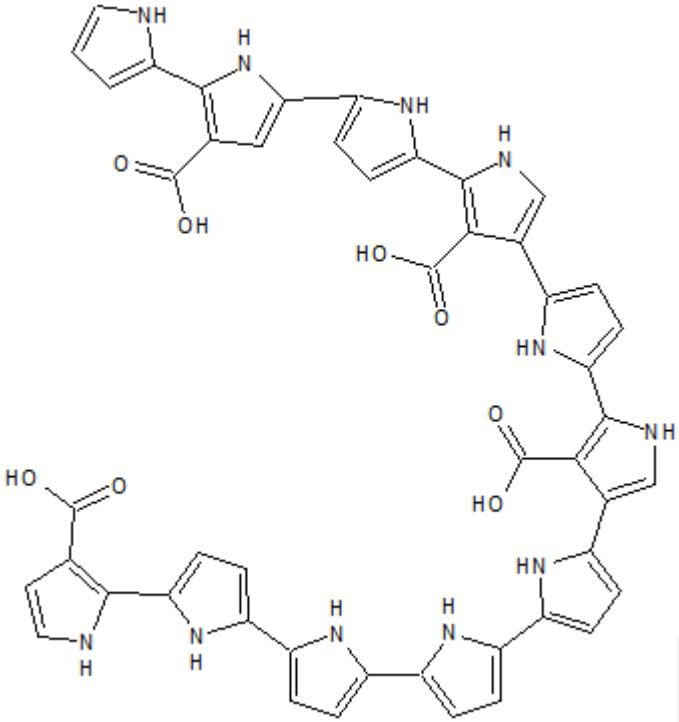
Schematic Representation

IDE on PET





Immersion in extraction solution

Sensitive Layer Synthesis

Penicillin G is chosen as template molecule

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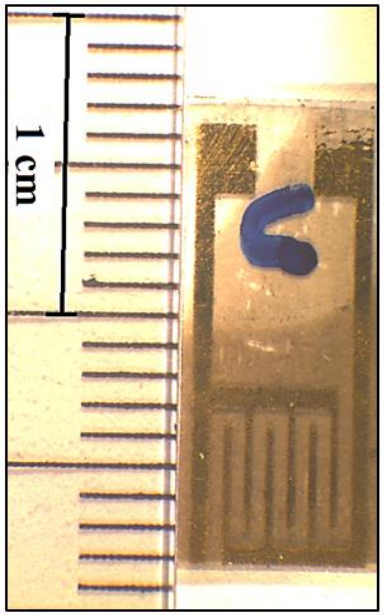
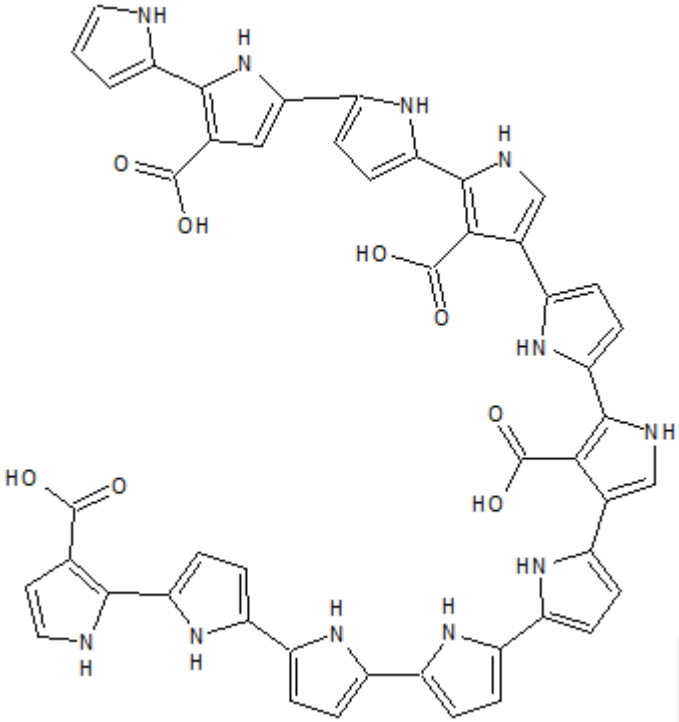


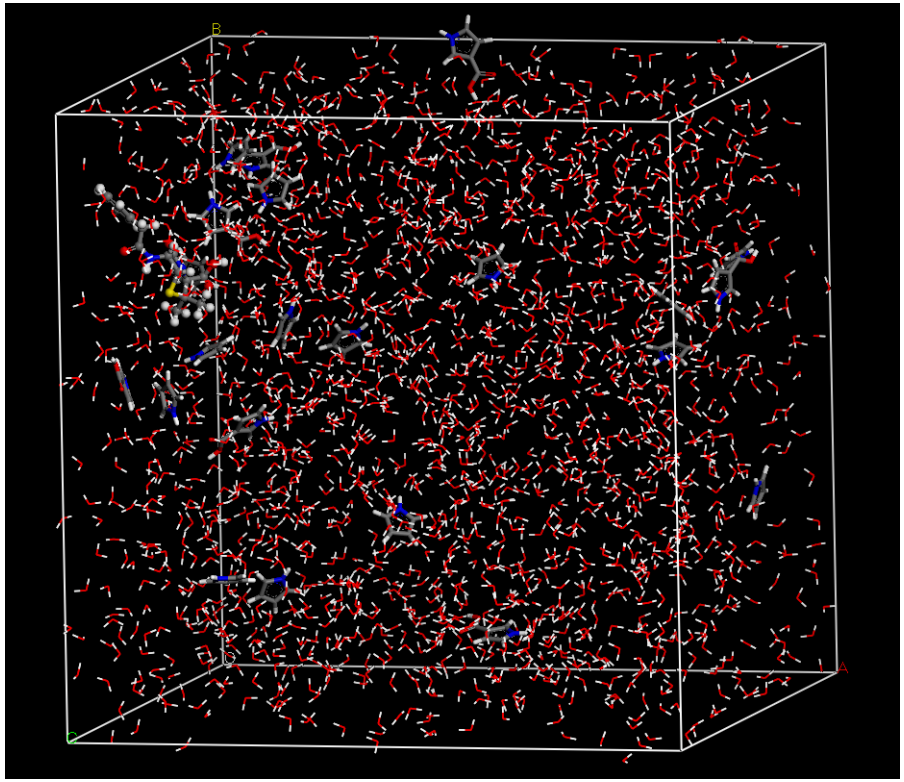


Immersion in extraction solution

Molecular Dynamics Simulations

Polymerization solution optimization

Conception of boxes



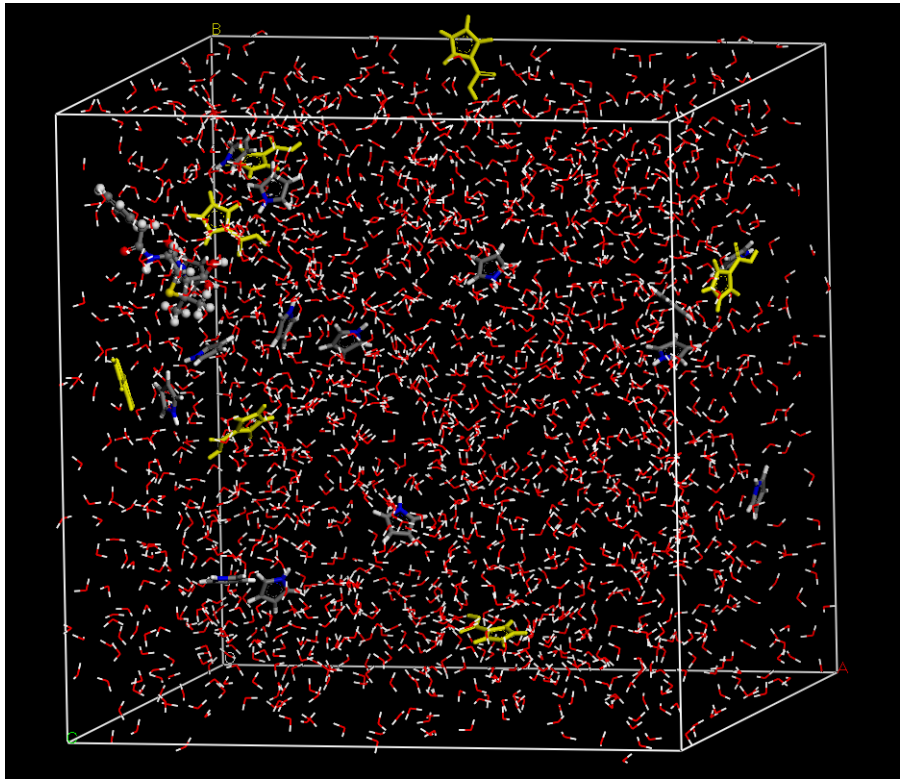
15 molecules of Pyrrole

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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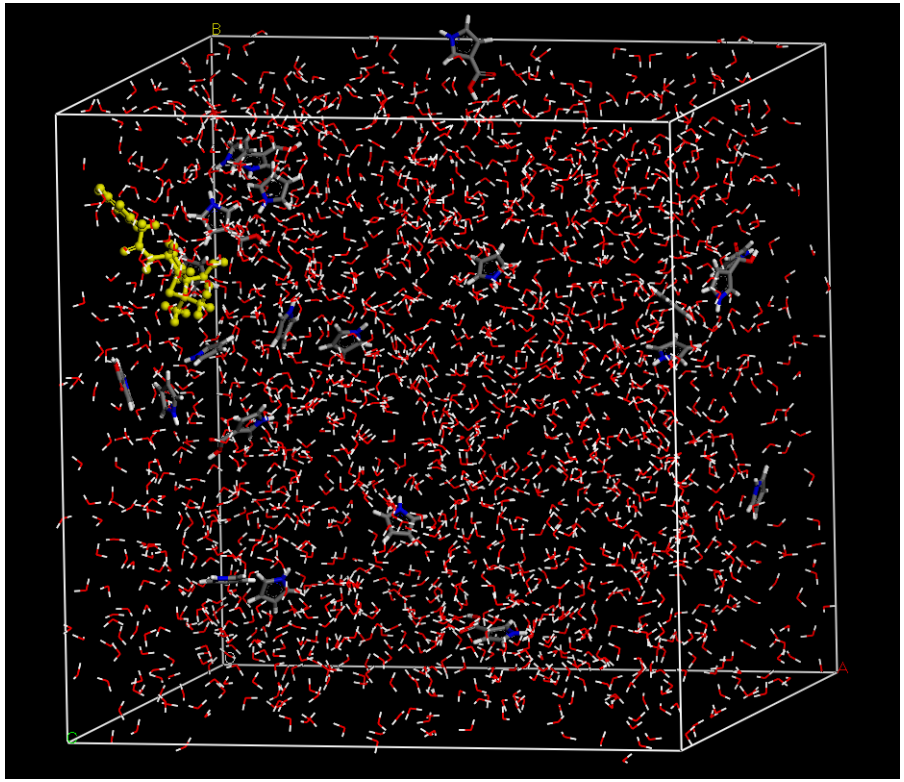
1 molecule of PenG

15 molecules of Pyrrole



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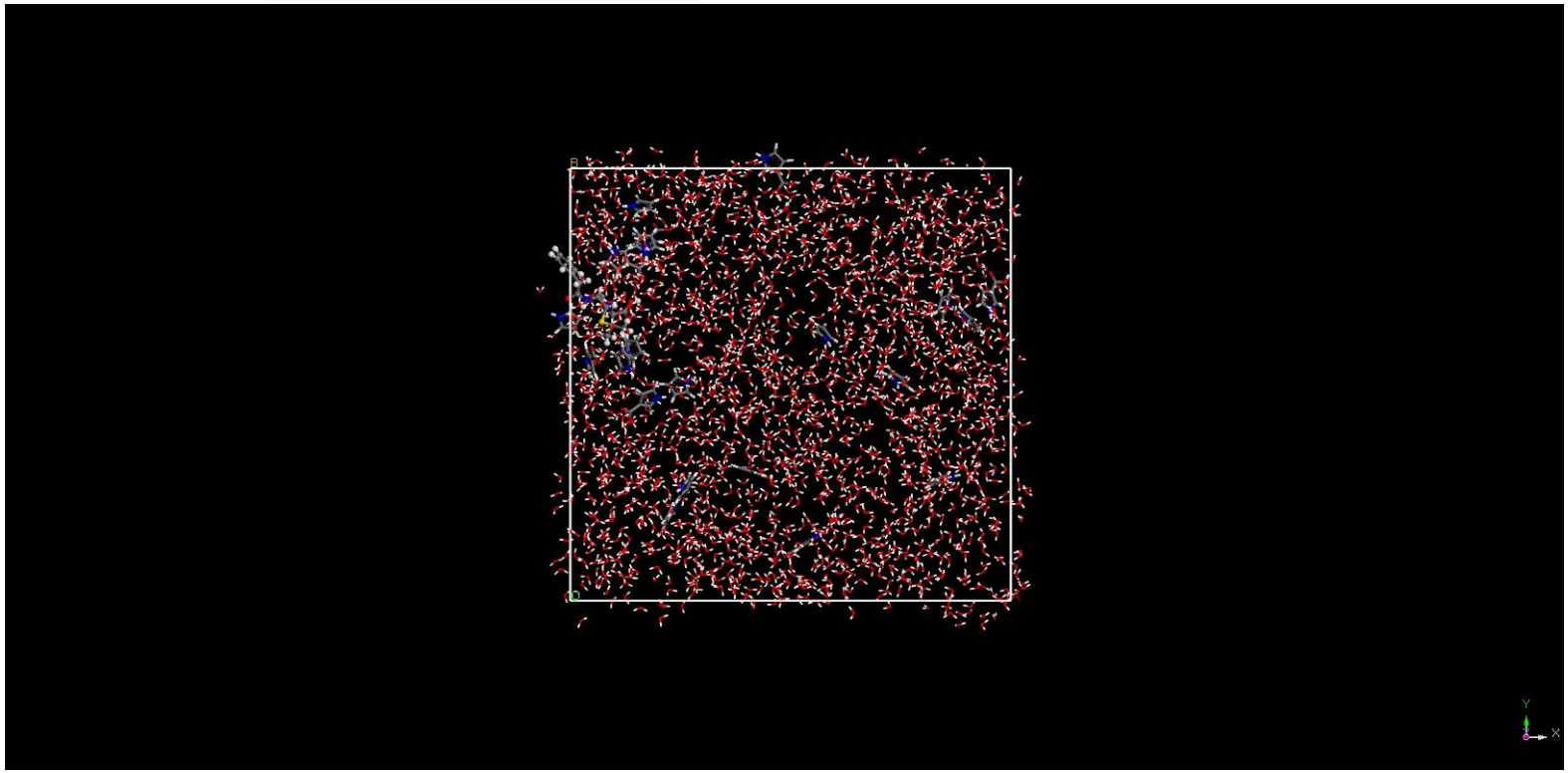
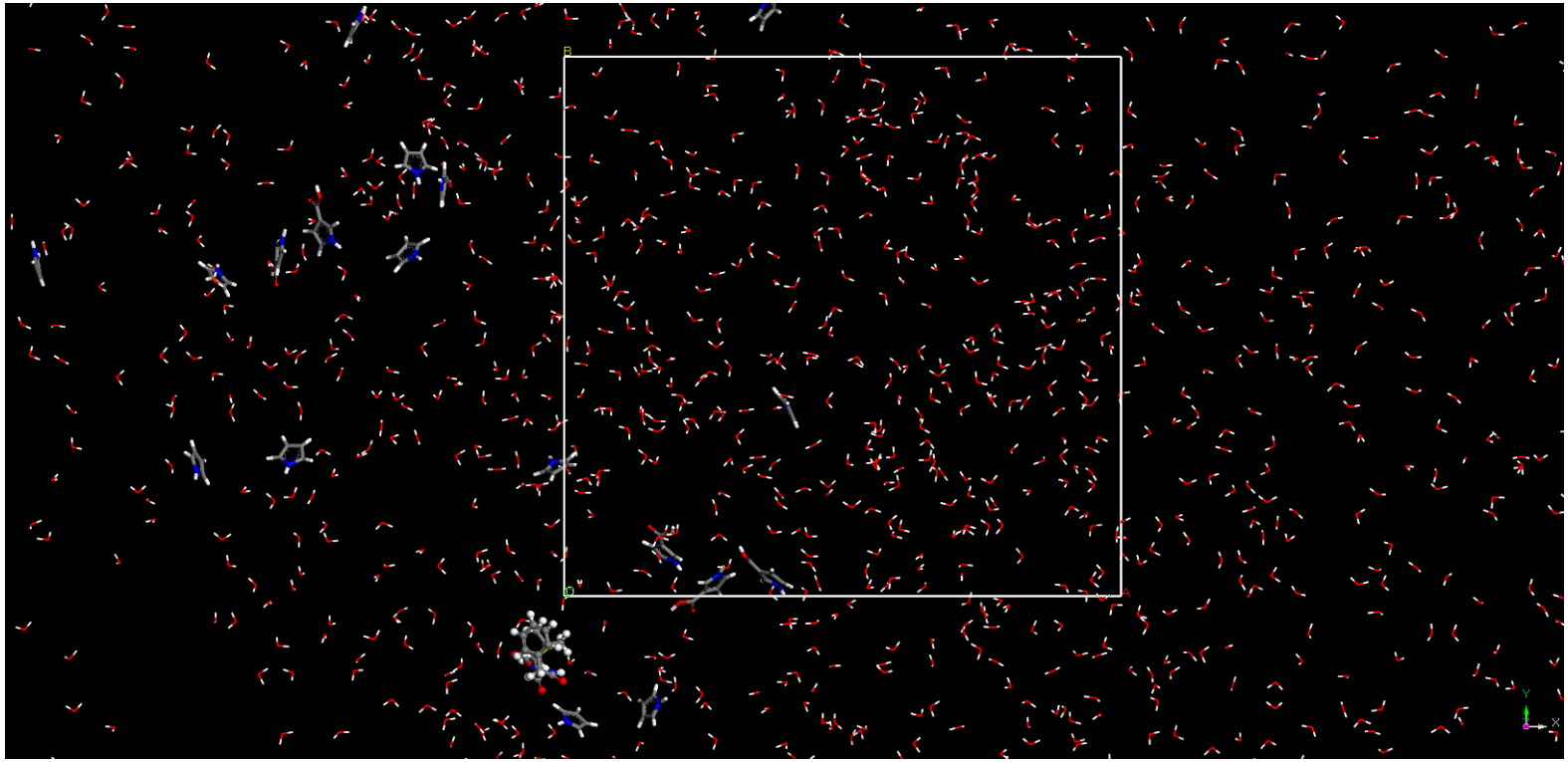
Homogenization



Molecular Dynamics Simulations

Polymerization solution optimization

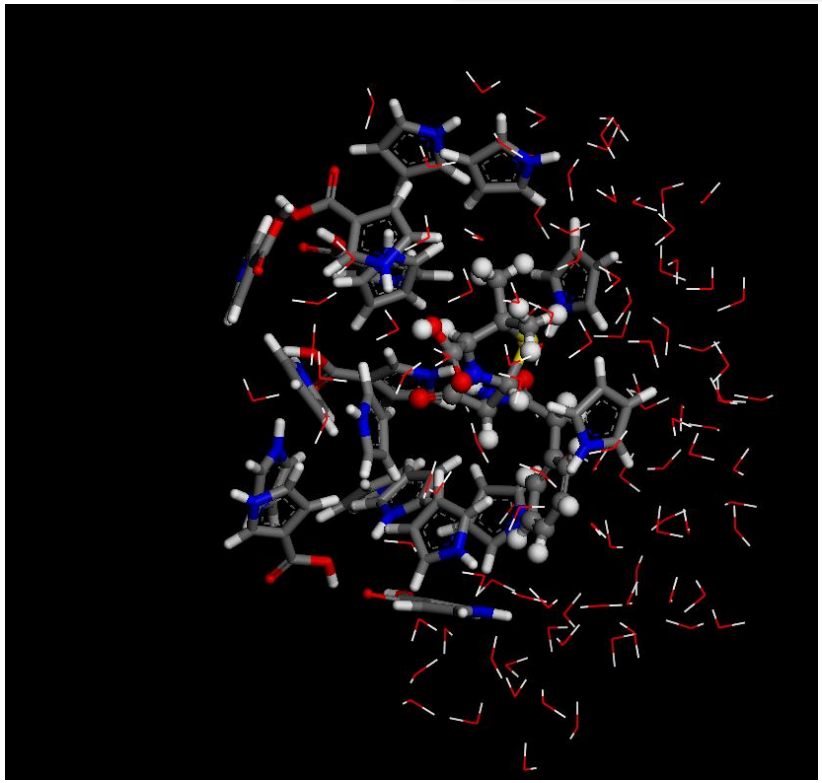
Back to ambient conditions



Molecular Dynamics Simulations

Polymerization solution optimization

System analysis



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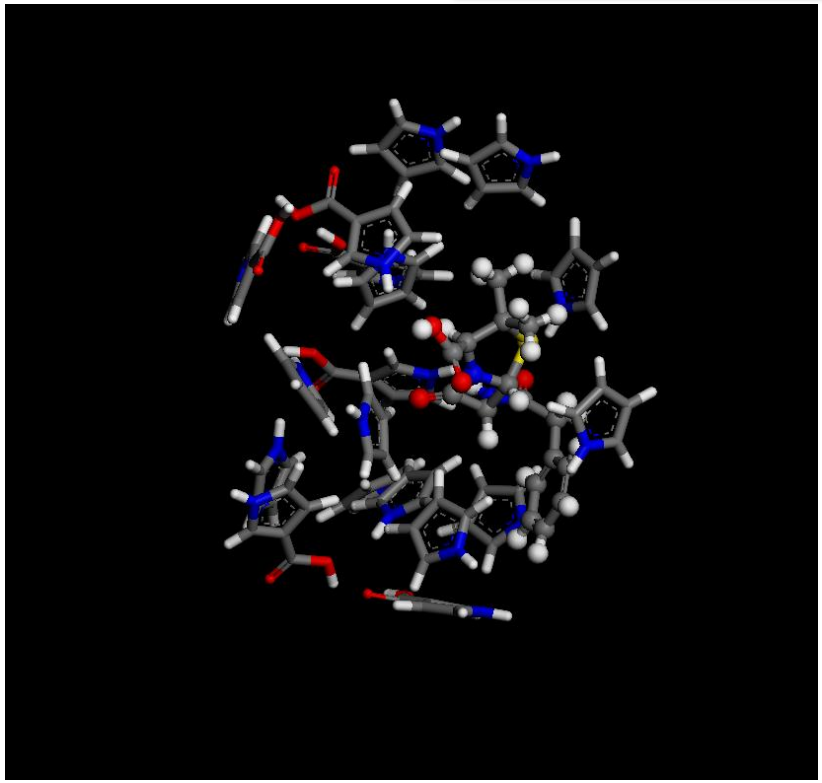

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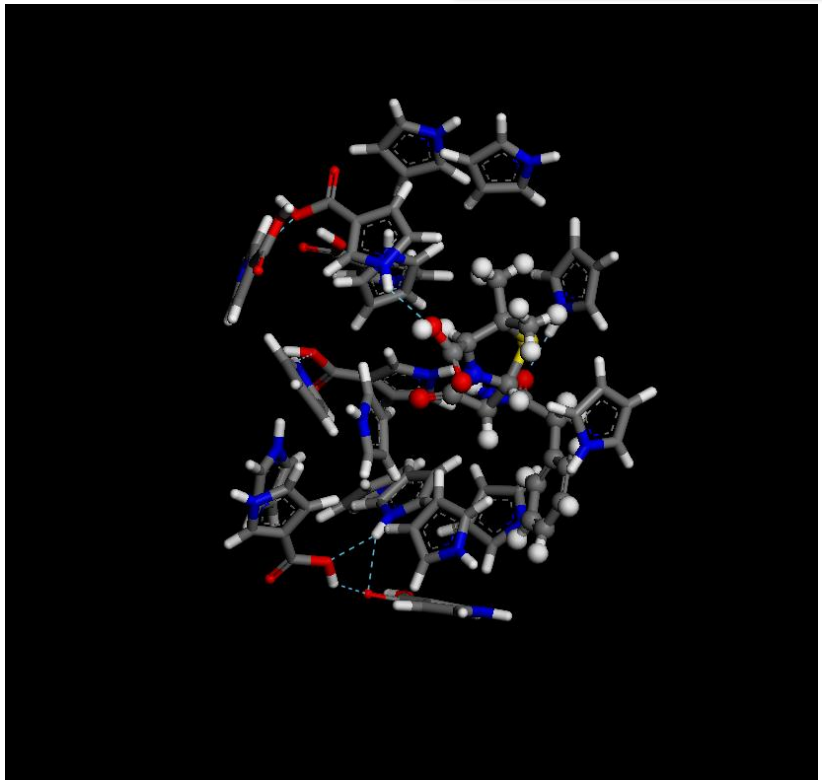

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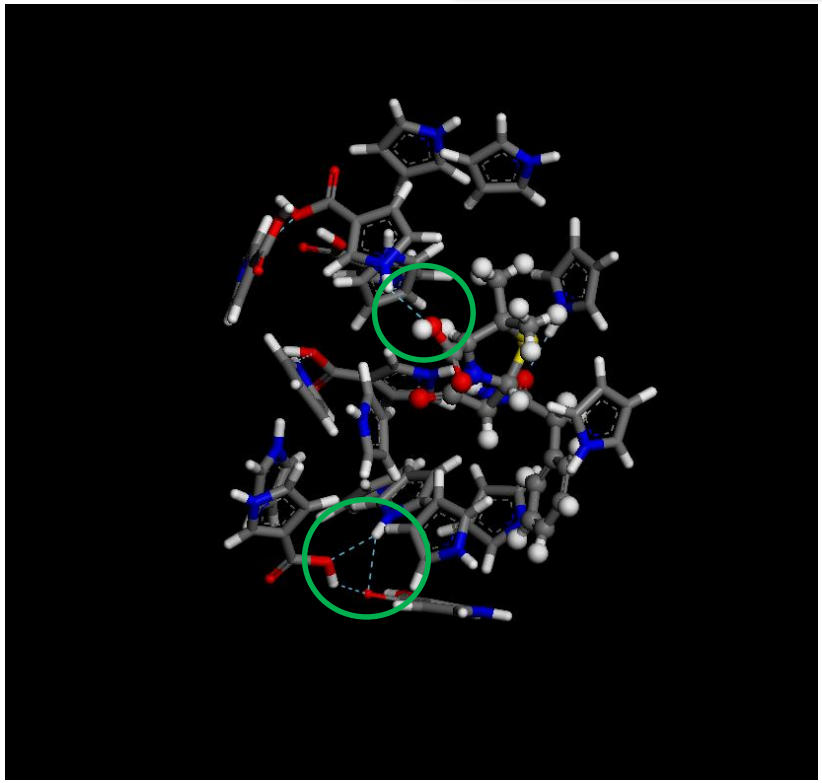

Molecular Dynamics Simulations

Polymerization solution optimization

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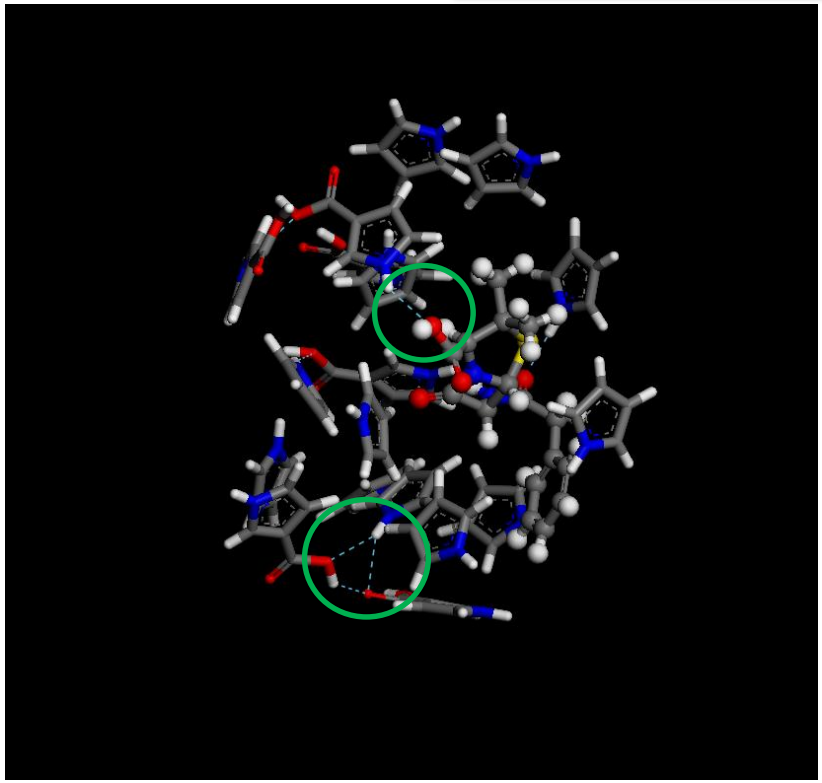
For 1 PenG molecule :

11 < Py < 15

4 < PyCOOH < 10



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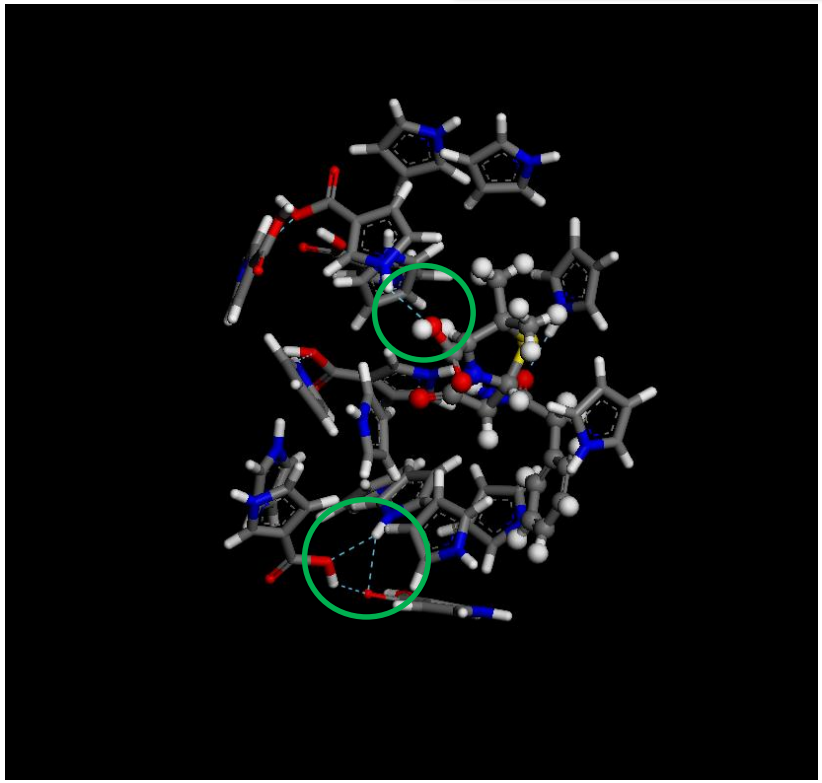

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Experimentally

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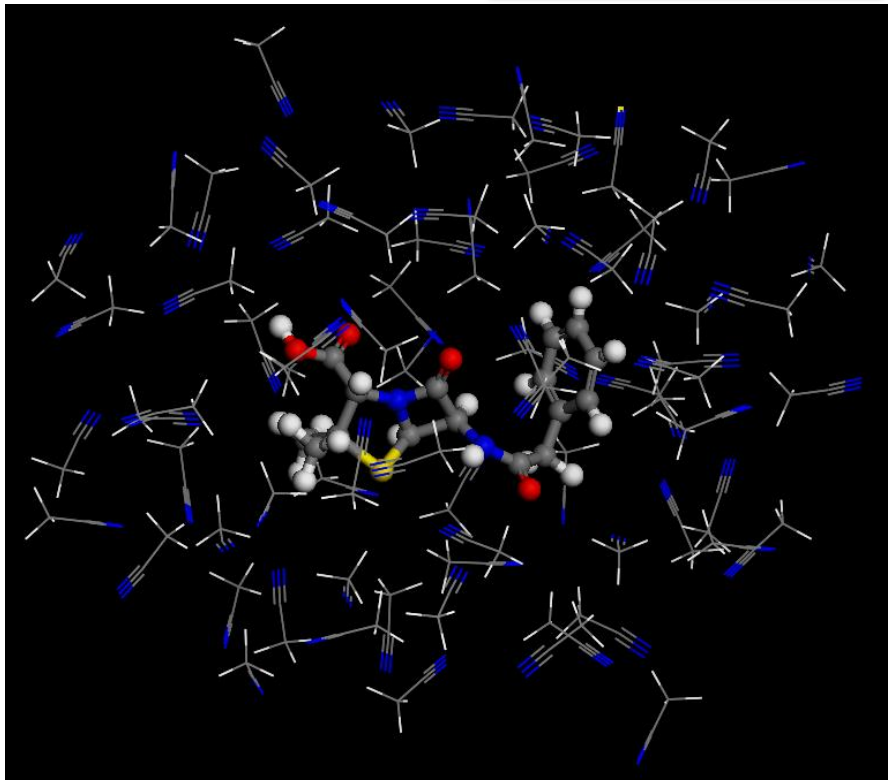

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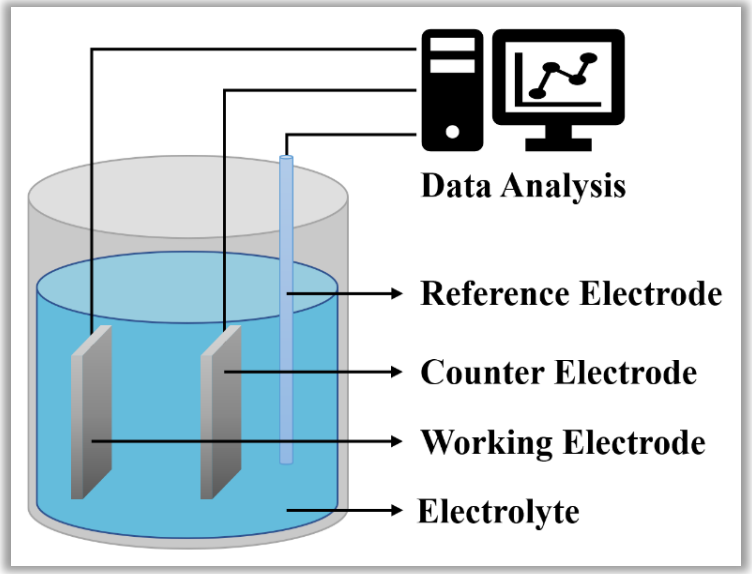
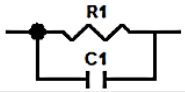
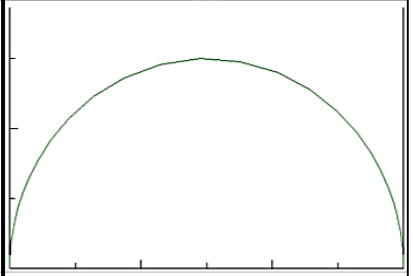
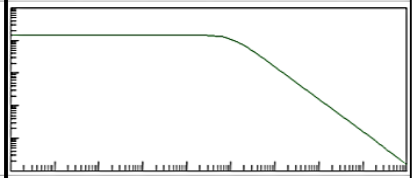
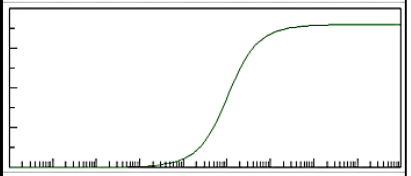
Experimentally

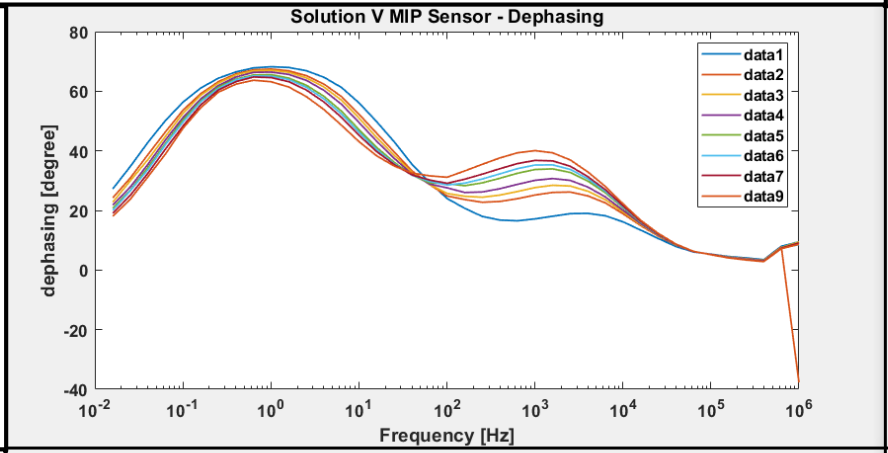
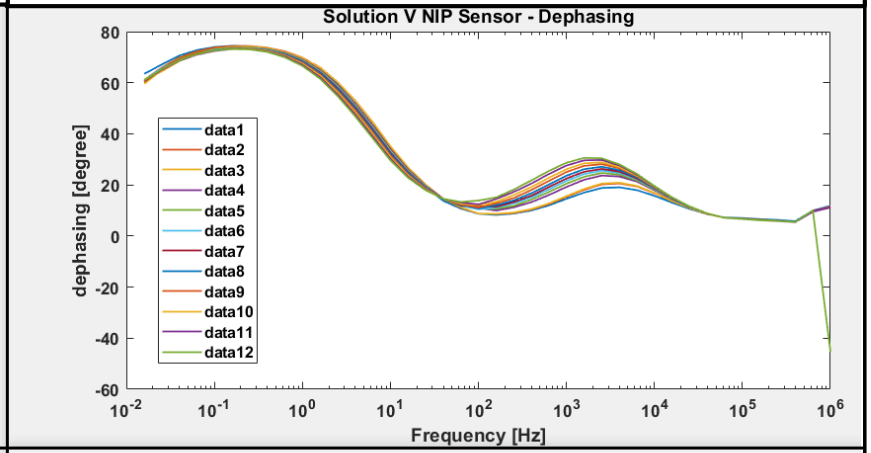
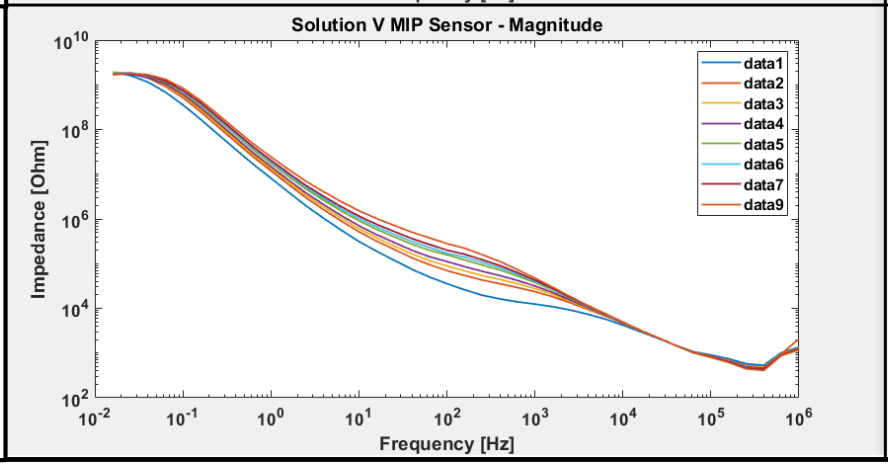
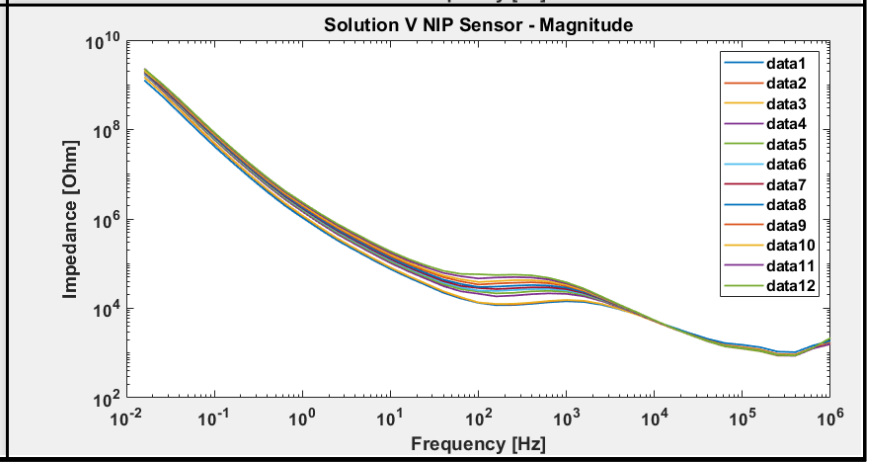
Electrochemical Impedance Spectroscopy

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

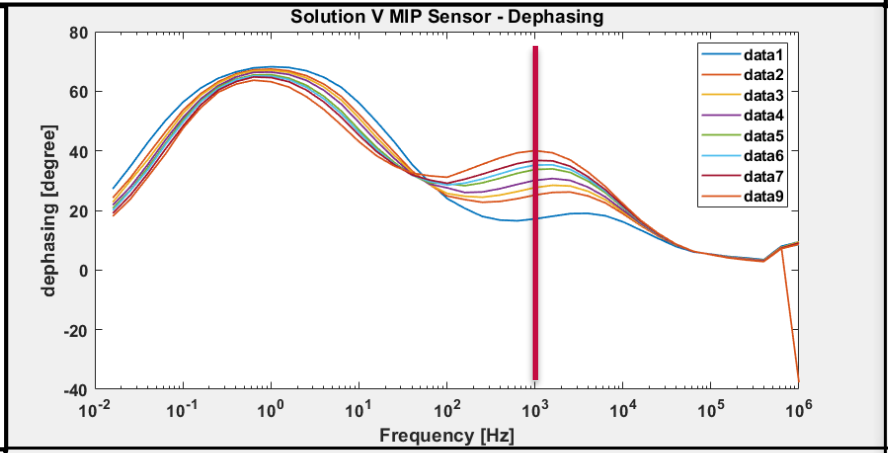
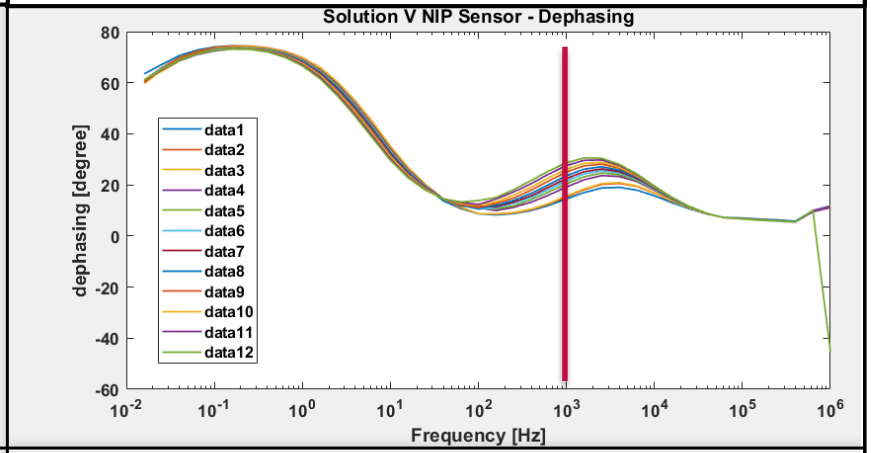
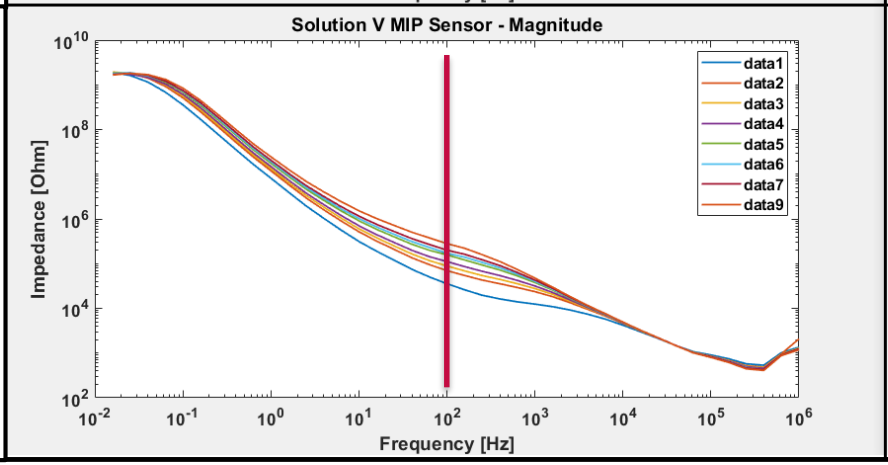
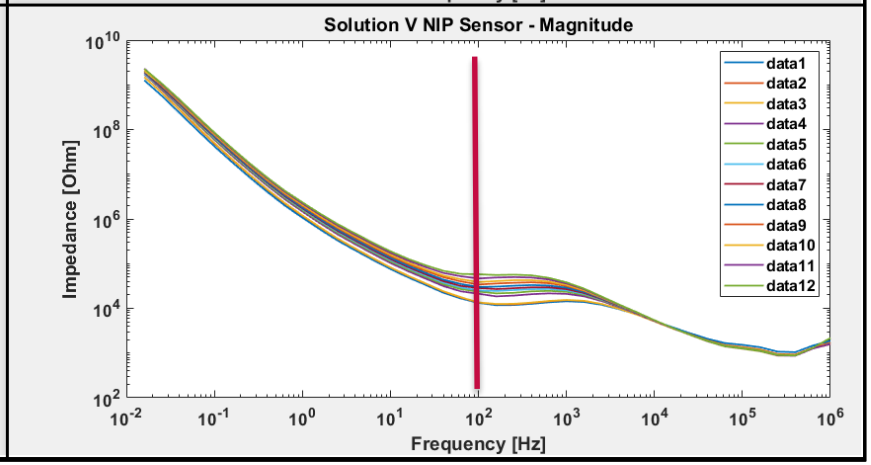


	Time Constant
Electrical Circuit representation	
Niquyst Diagram (Imaginary Part [Ω] vs Real Part [Ω])	
Bode Diagram : Magnitude (Magnitude [Ω] vs Frequency [Hz])	
Bode Diagram : Phase (Phase [degree] vs Frequency [Hz])	
Physical Meaning	Pure Charge Transfer
Impedance value	$\frac{R}{1 + R\, j\omega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

Electrochemical Impedance Spectroscopy

	MIP	NIP
Phase		
Magnitude		

Electrochemical Impedance Spectroscopy

	MIP	NIP
Phase		
Magnitude		

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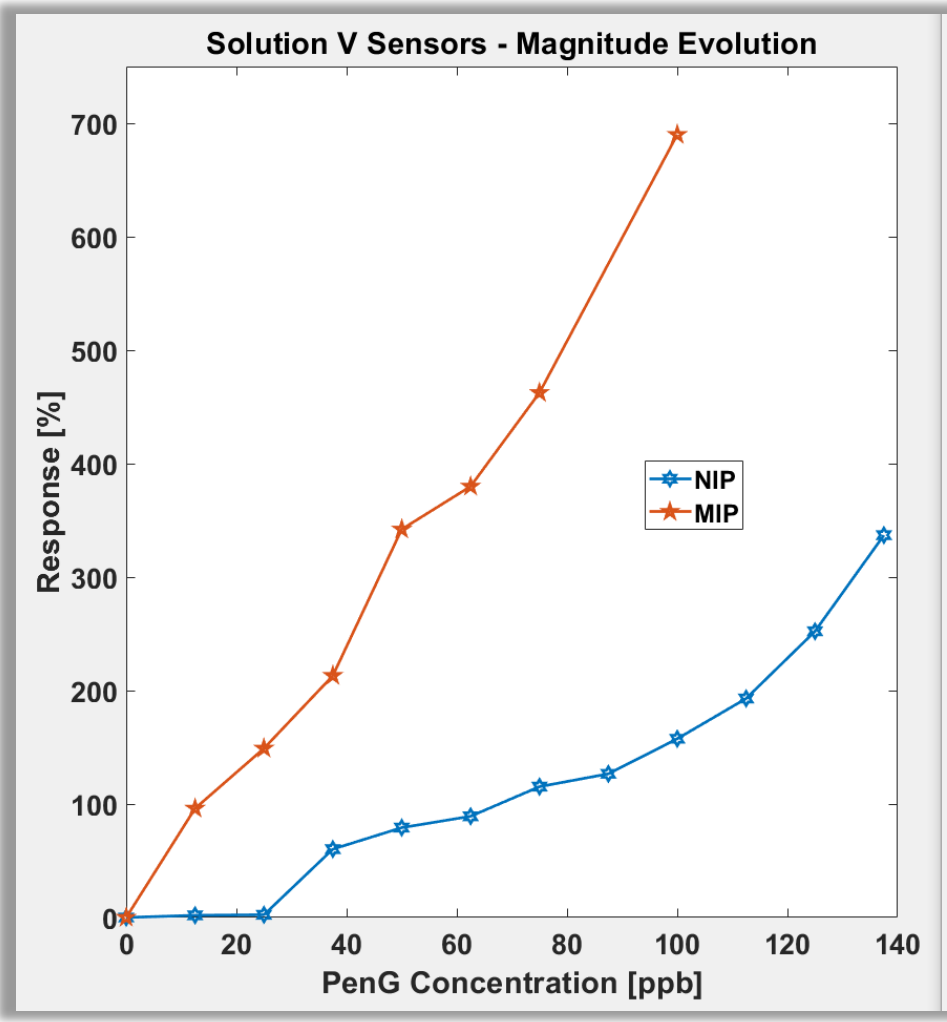

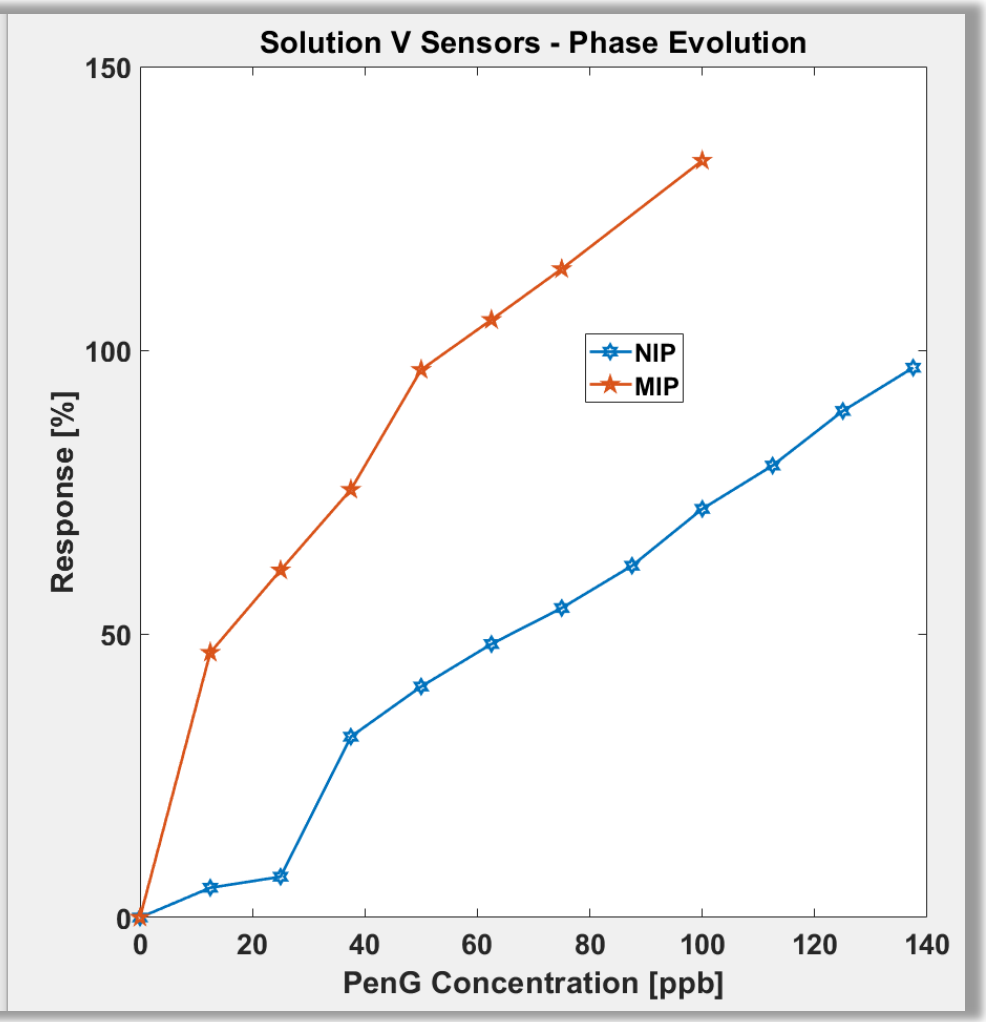

Impedance Spectroscopy Models

Idea :

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

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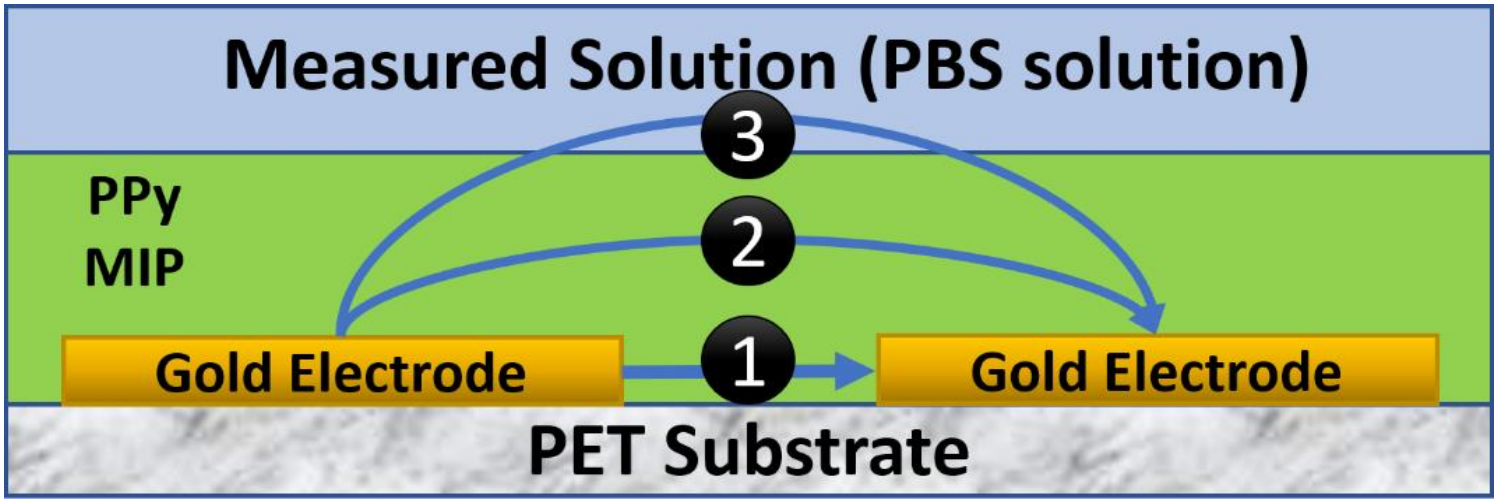

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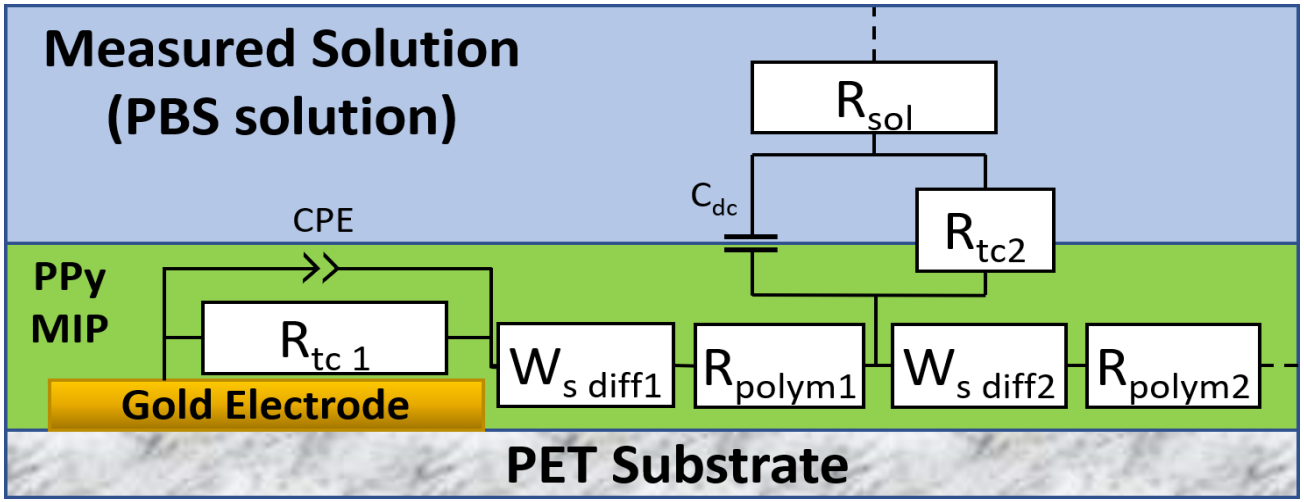

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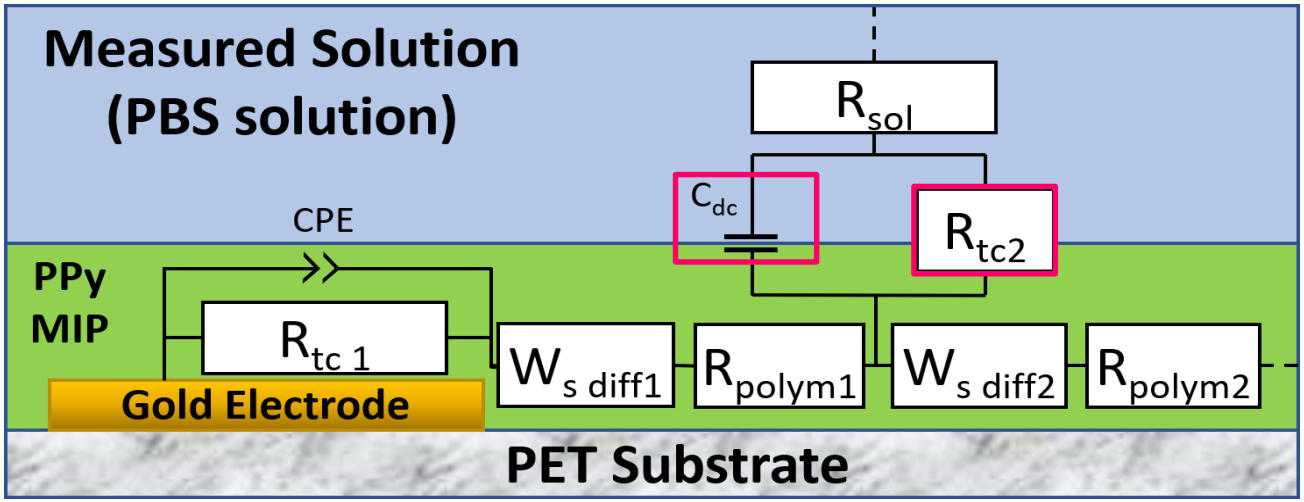

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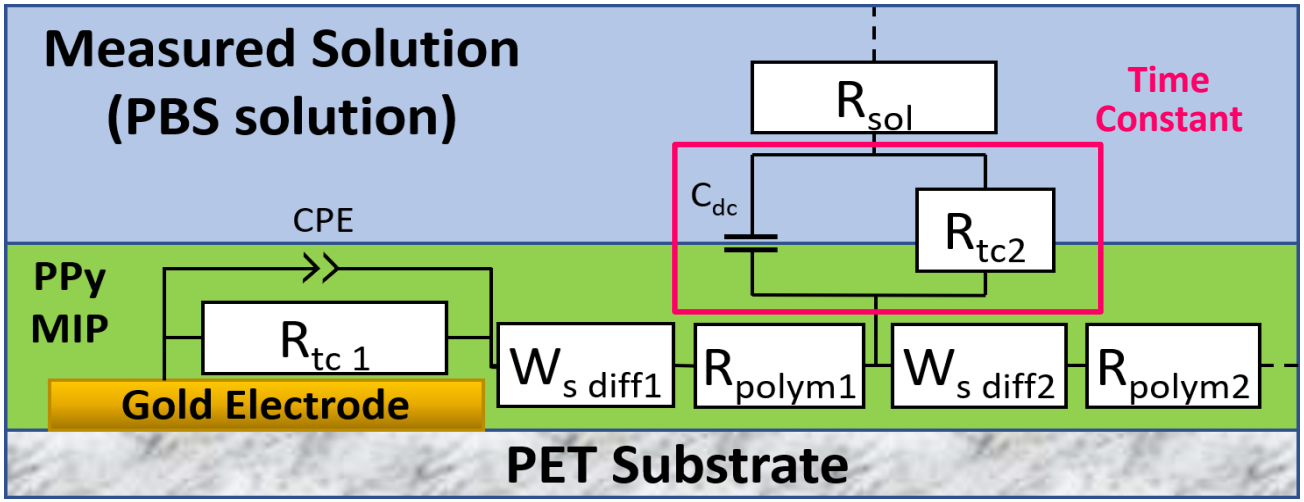

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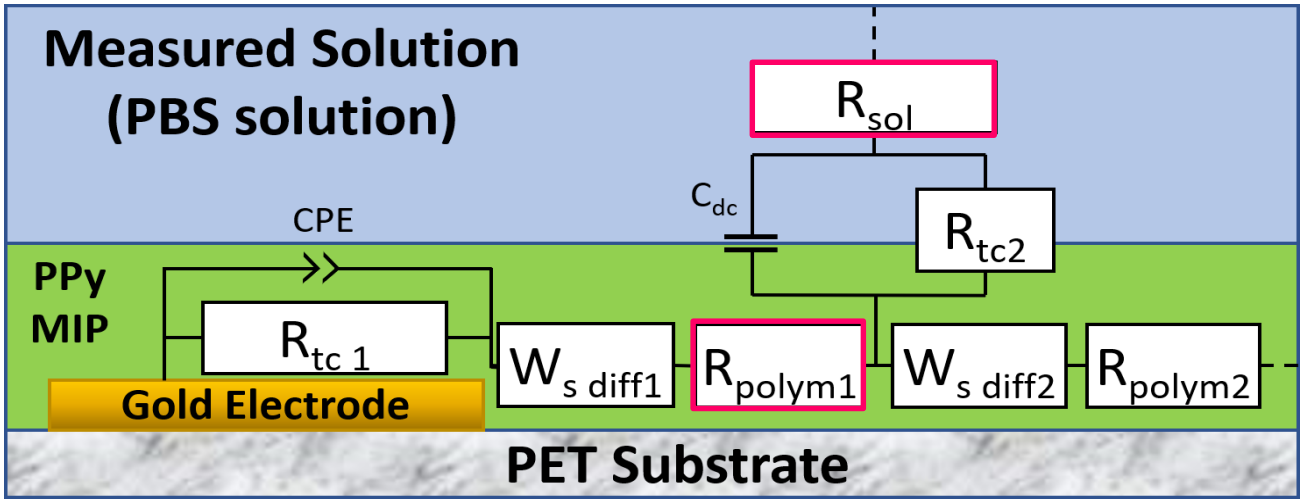

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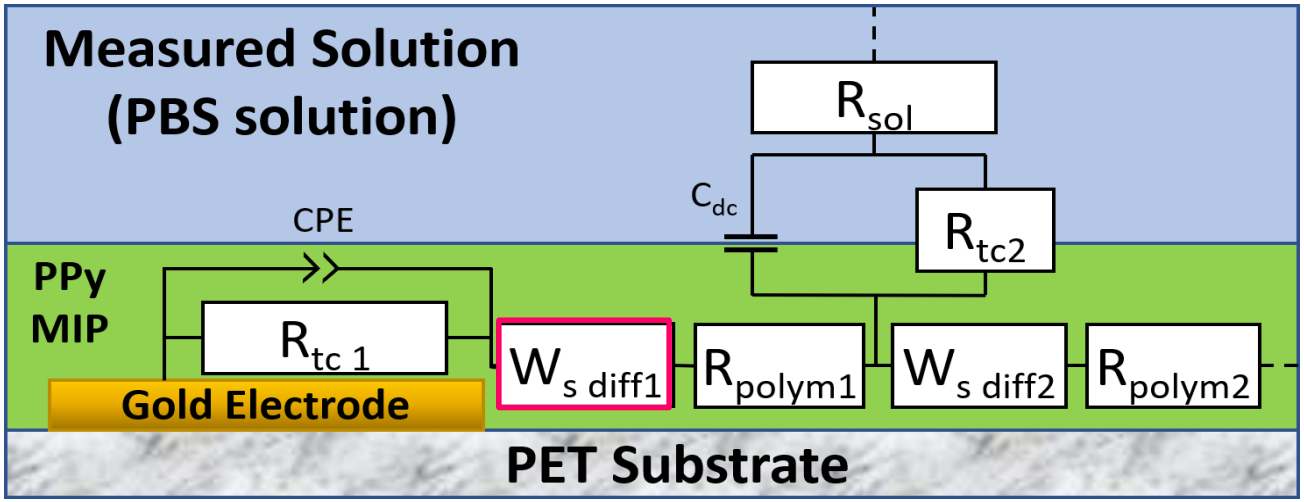

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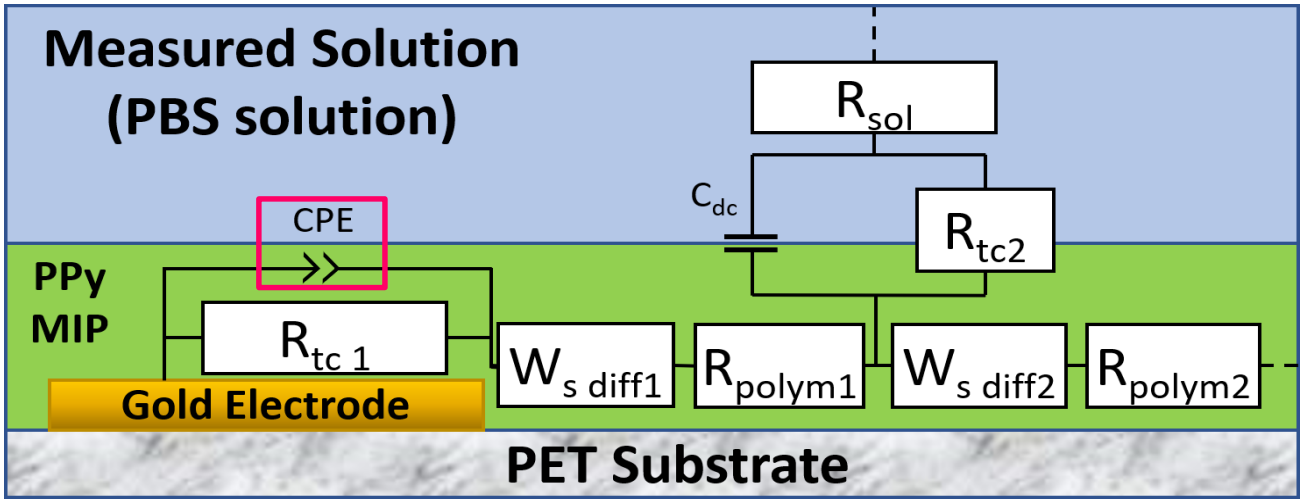
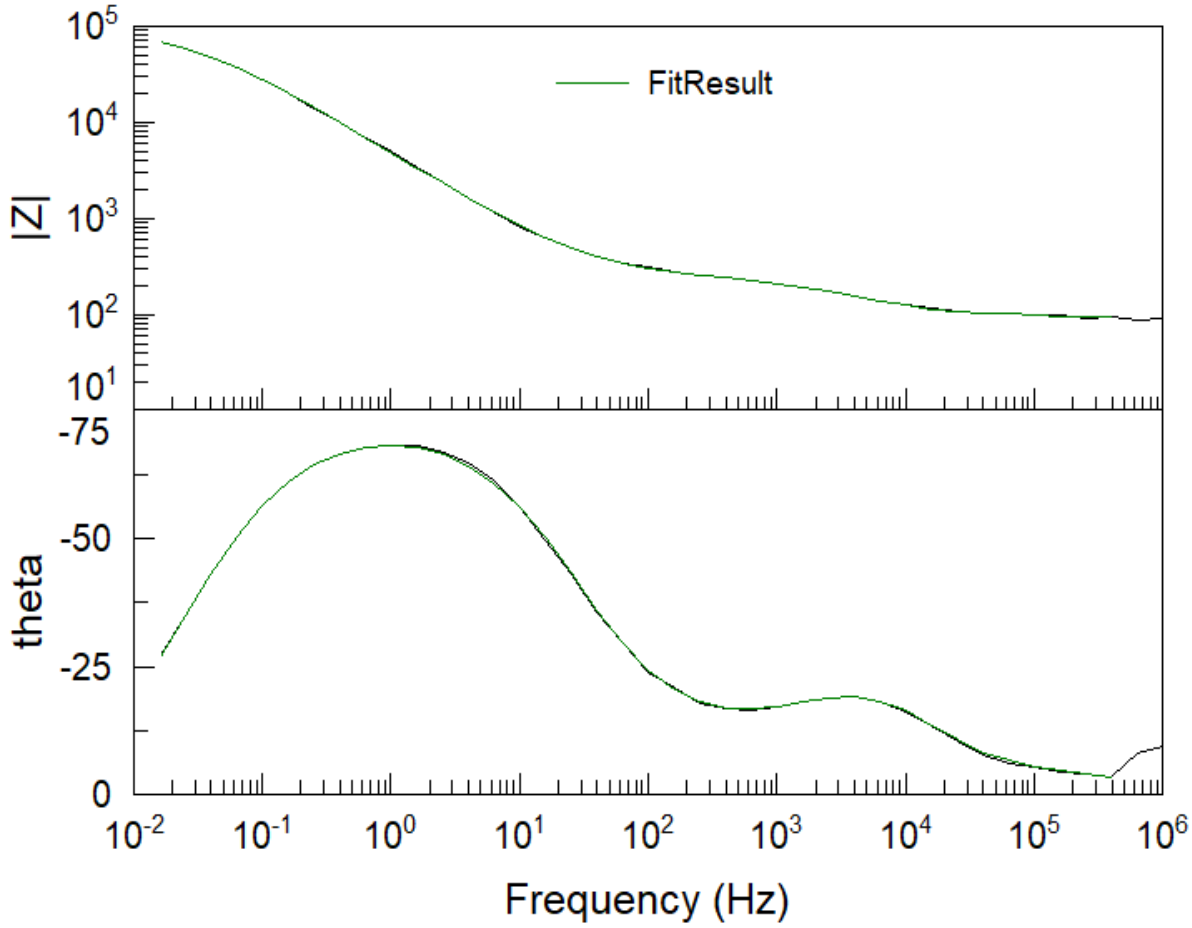


Fitting Results on Different Sensors

Obtained fitting results at 0 ppb :



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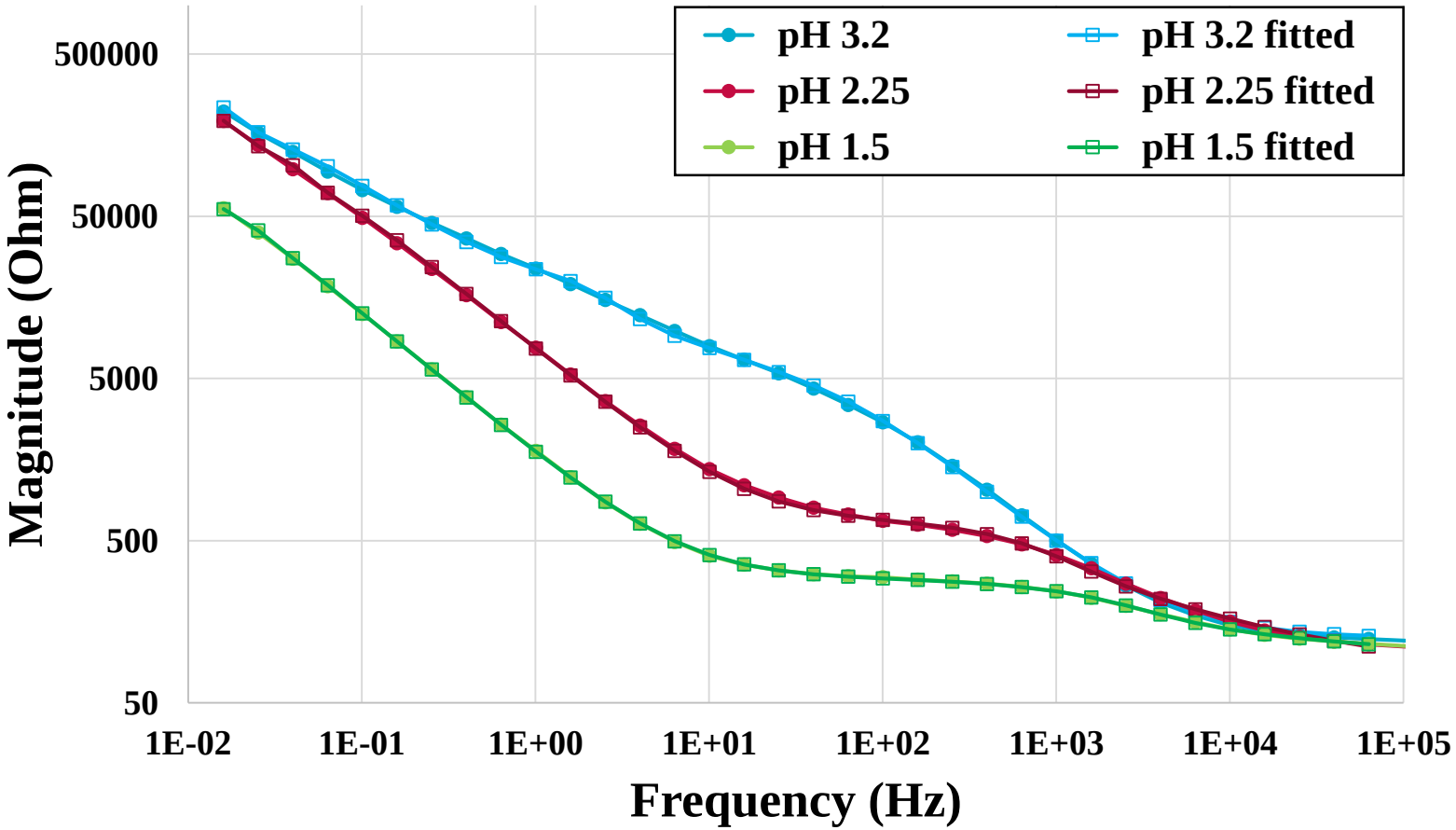

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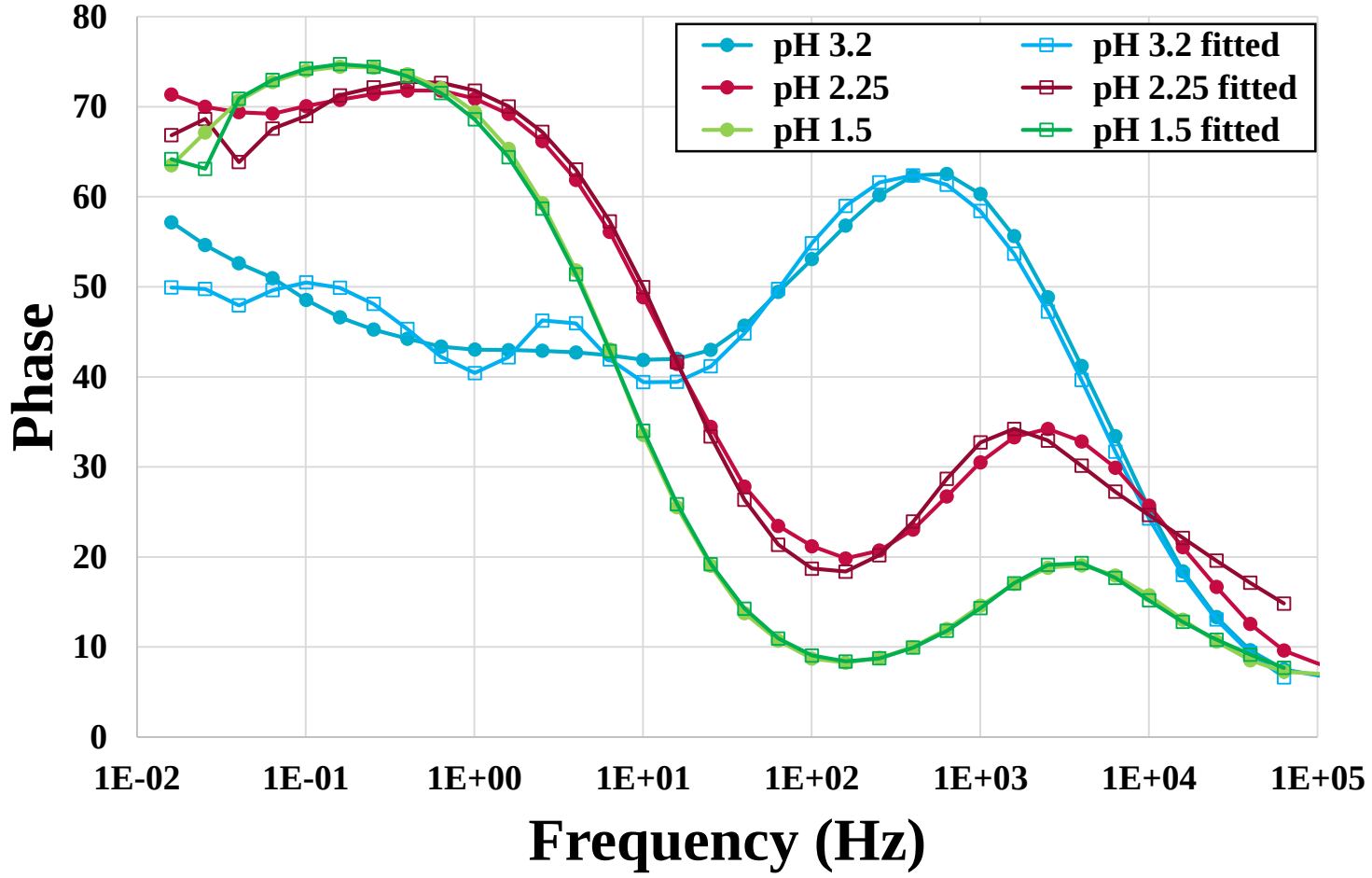
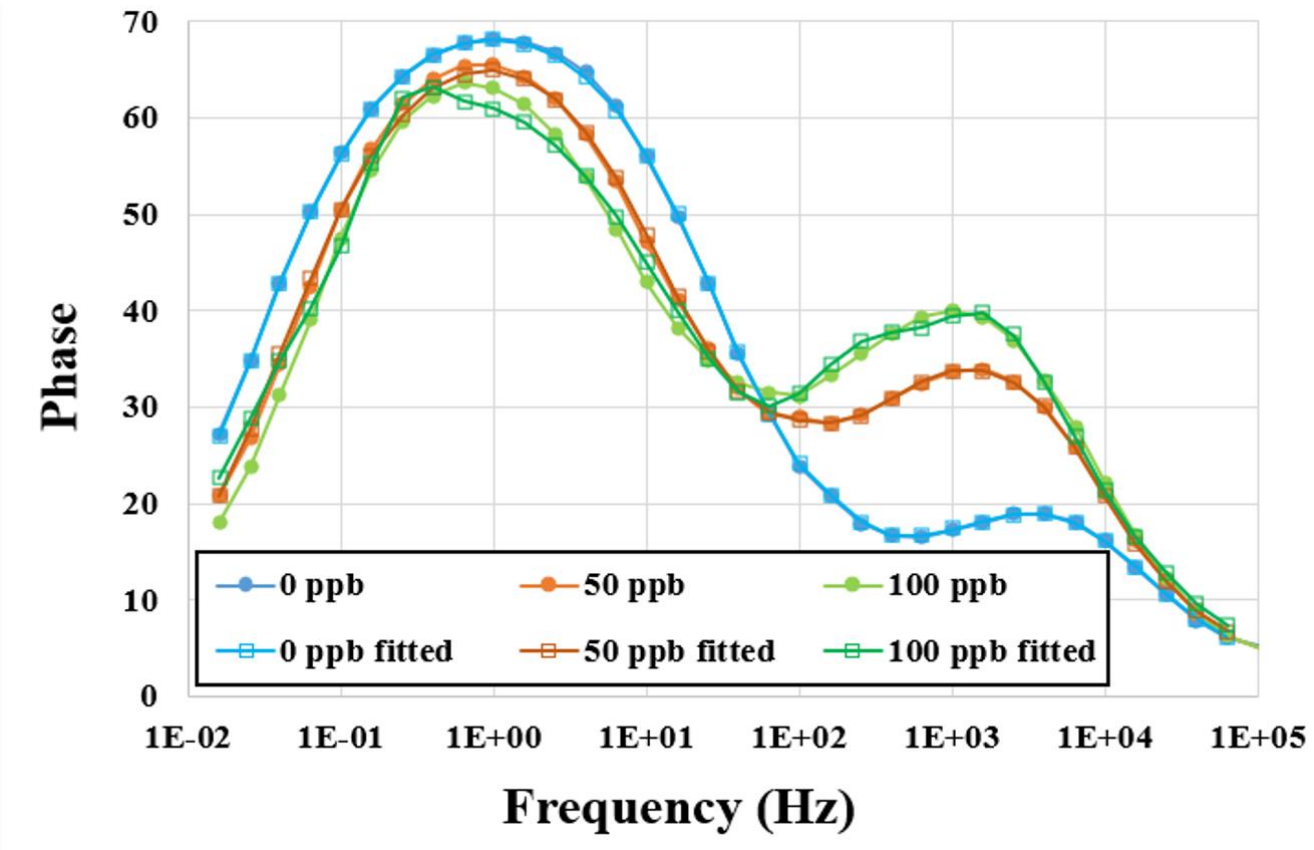


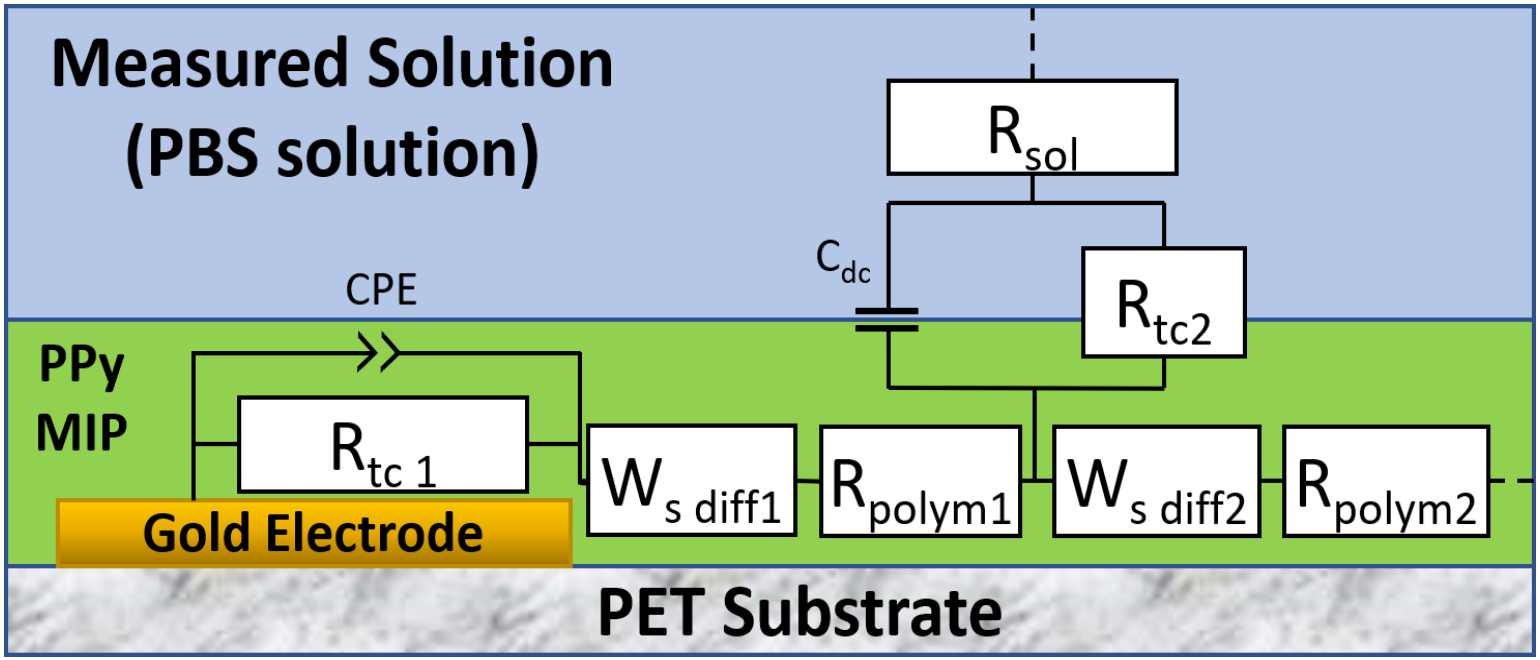
Fitting Results at Different PenG Concentrations

Obtained fitting results for a single sensor :



Fitting Parameters Variation

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



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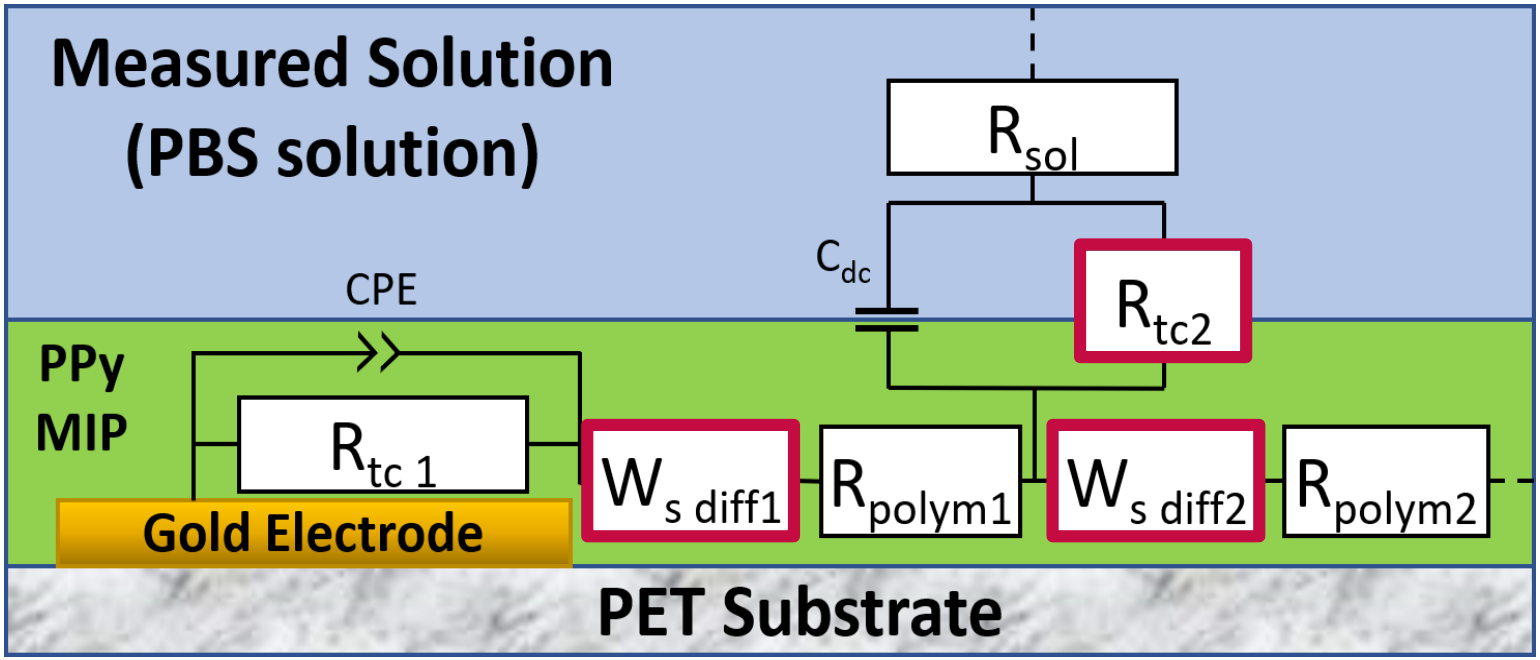

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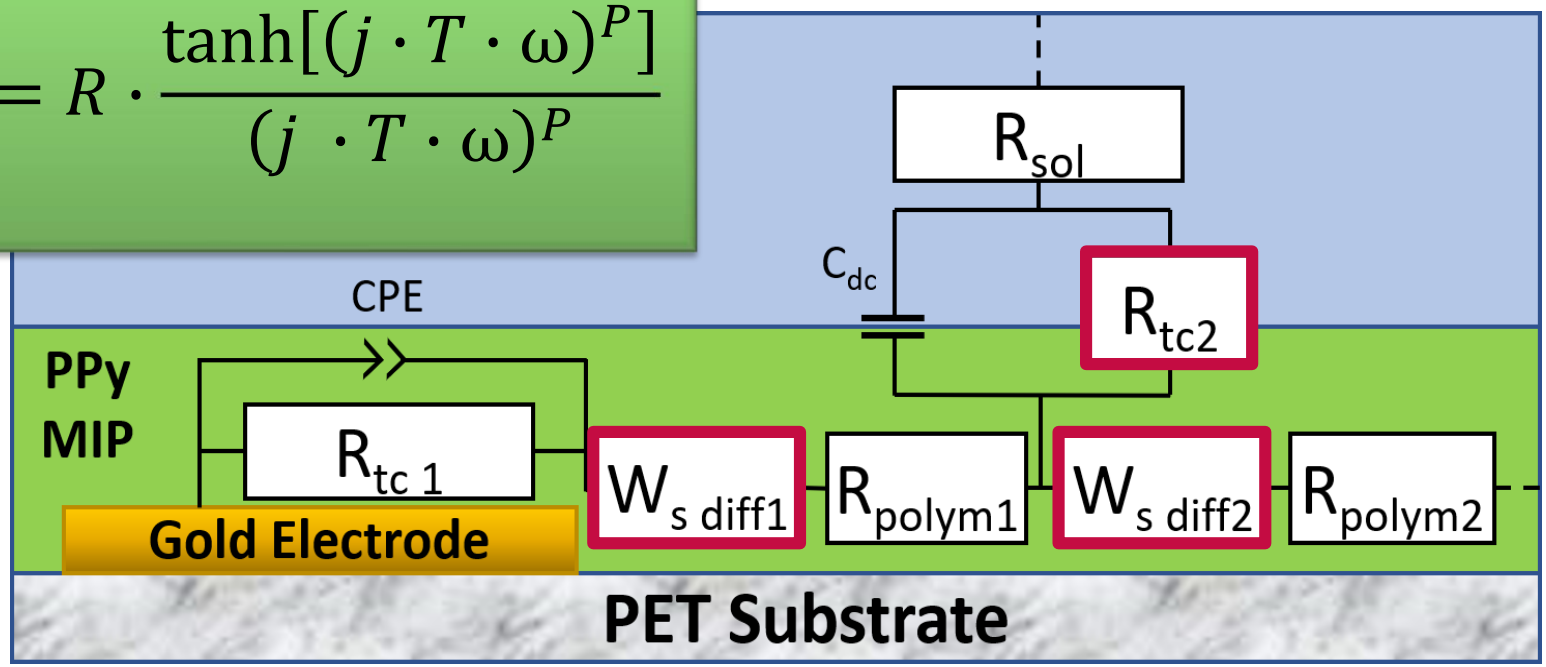
W_s - Finite Length Warburg

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



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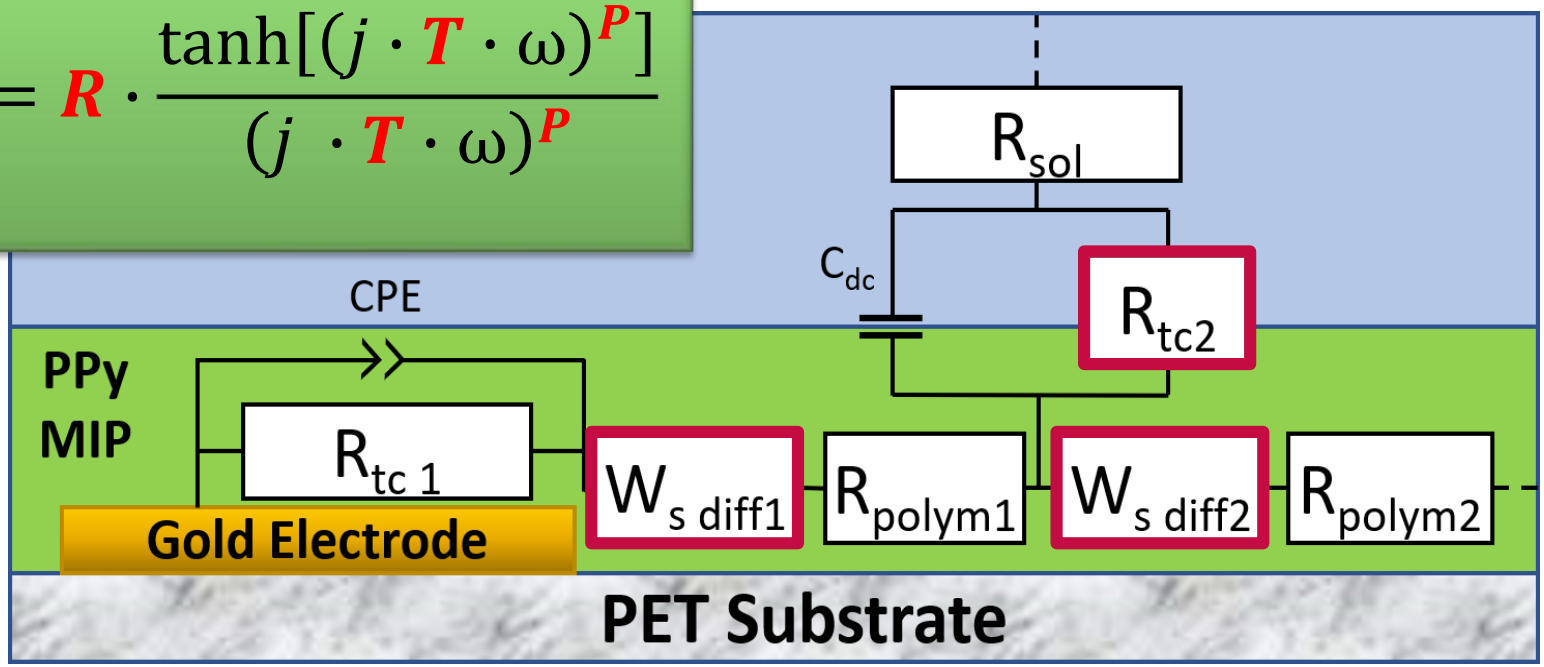

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Diffusion parameter (0<P<1)

Resistive Parameter

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

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

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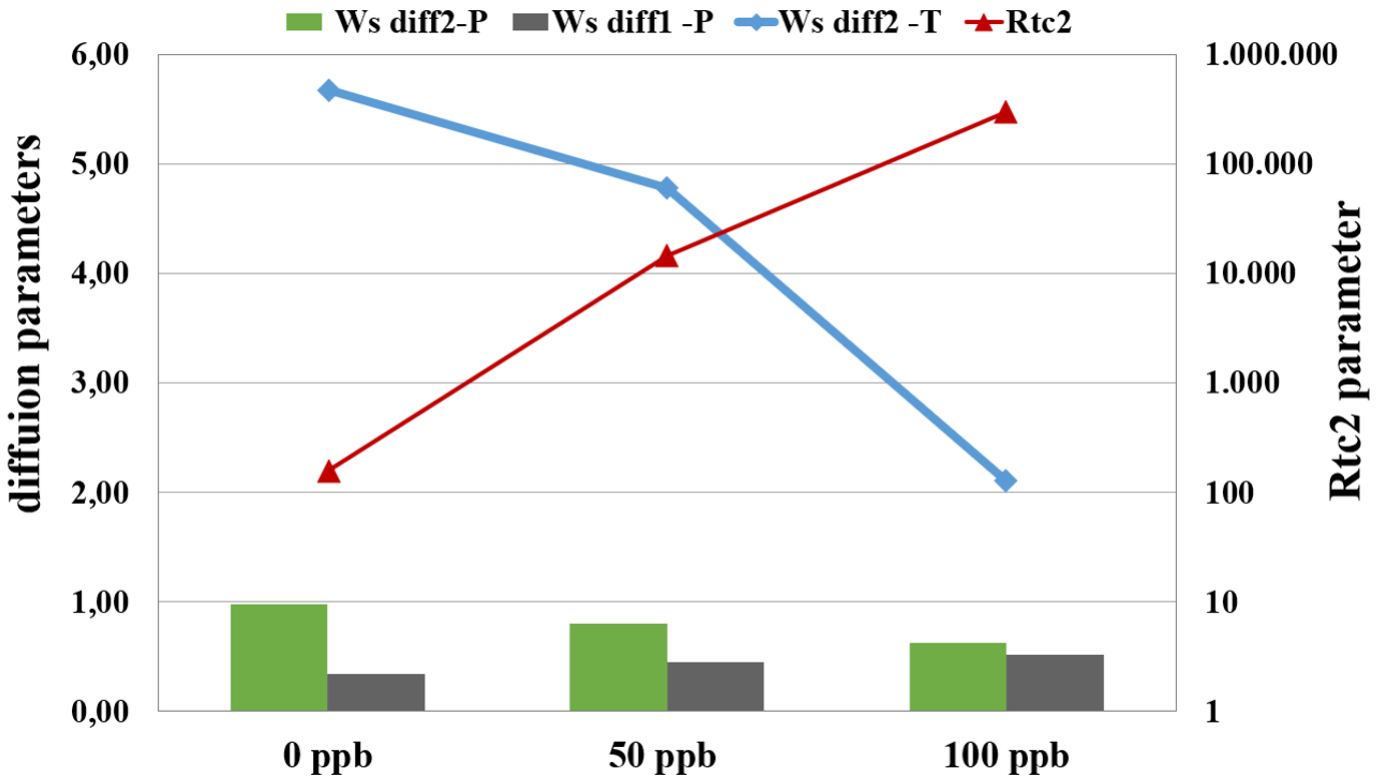

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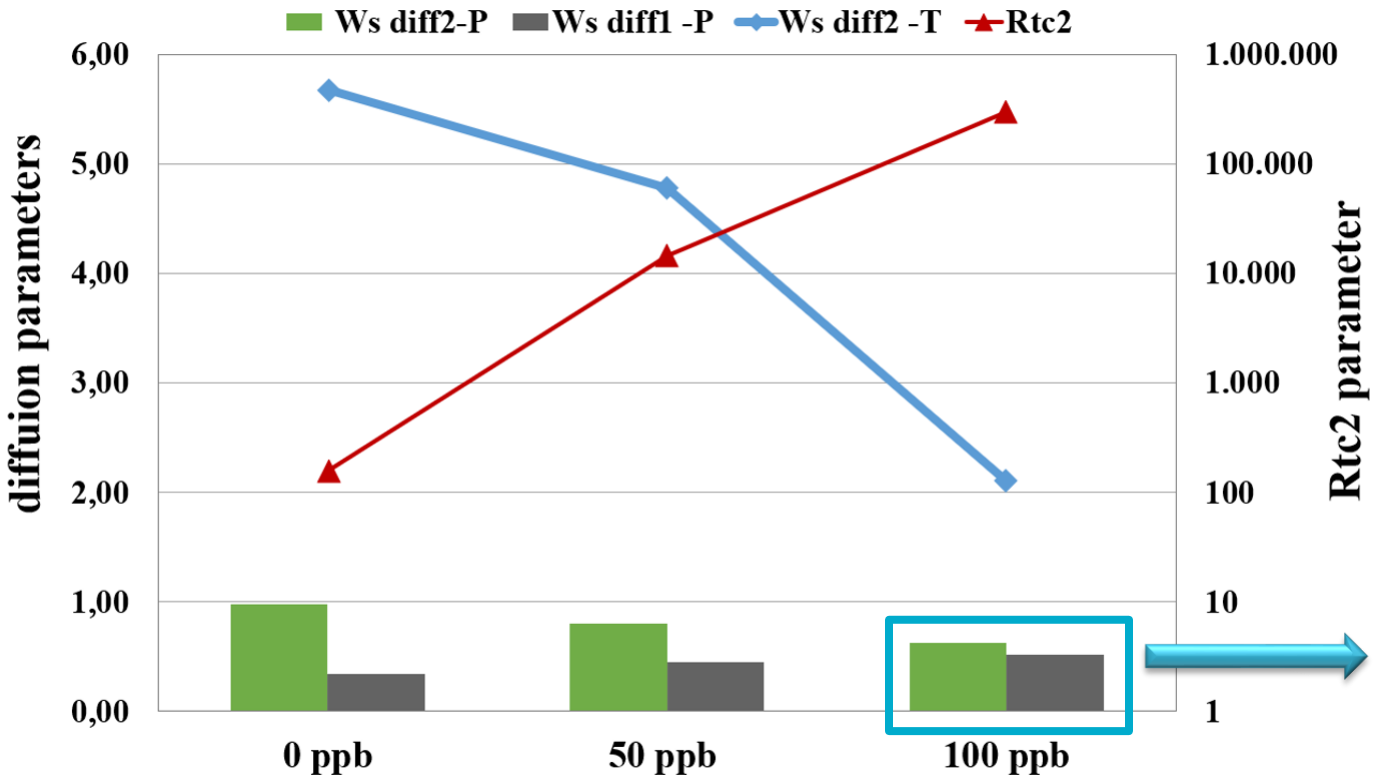

Getting close to a one dimension diffusion

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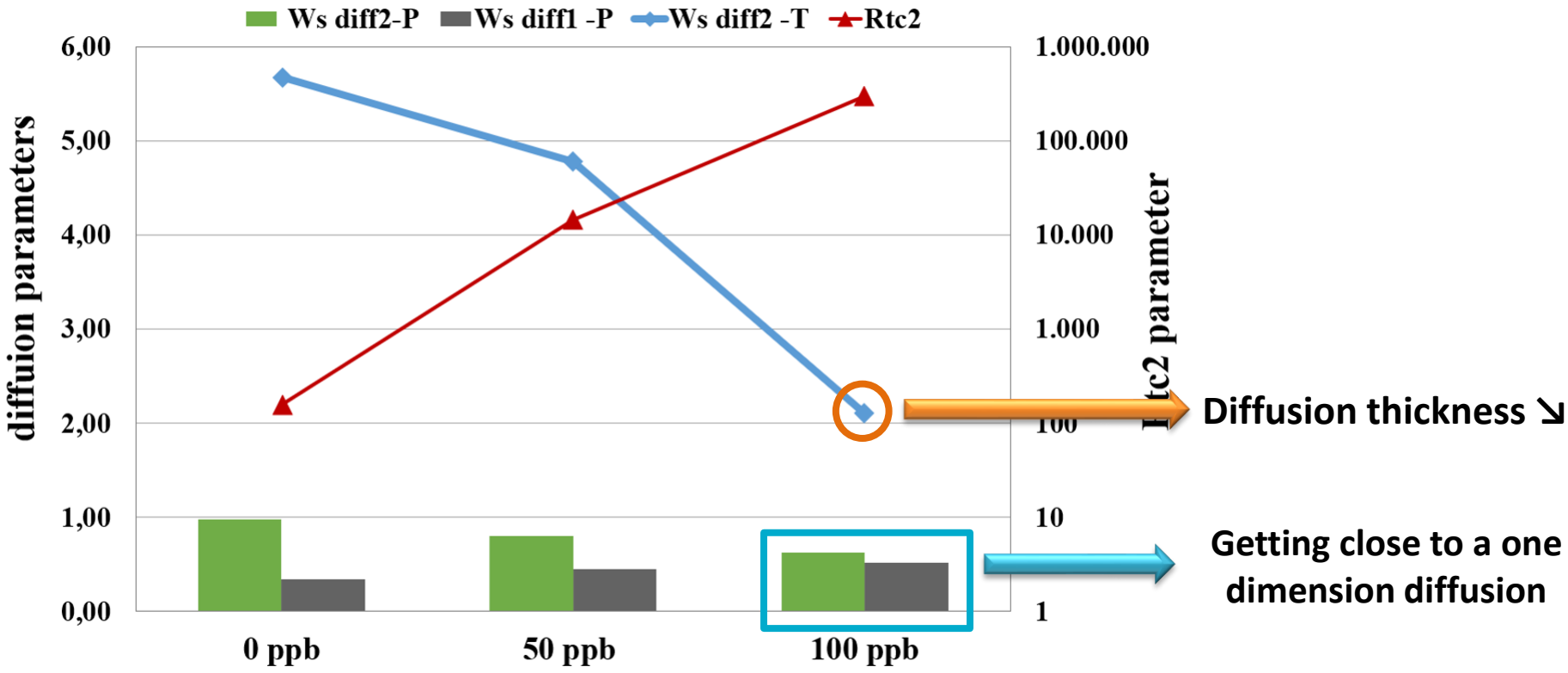

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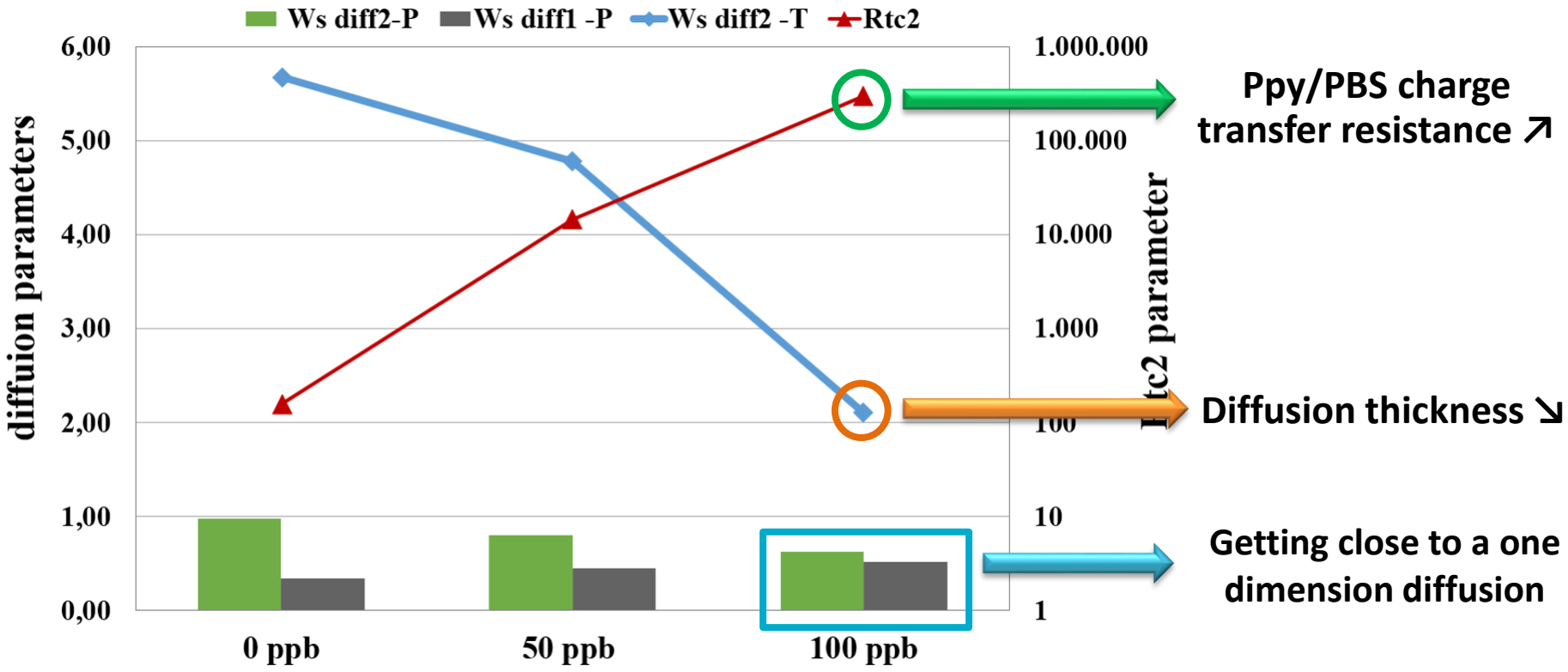

Conclusions

- ☑ 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