# Comparison of Pyrolytic Carbon Oxidation Techniques for Their Effect on the Electrochemical and Biological Properties of CF/PyC Composites Designed for Neural Cell Stimulation

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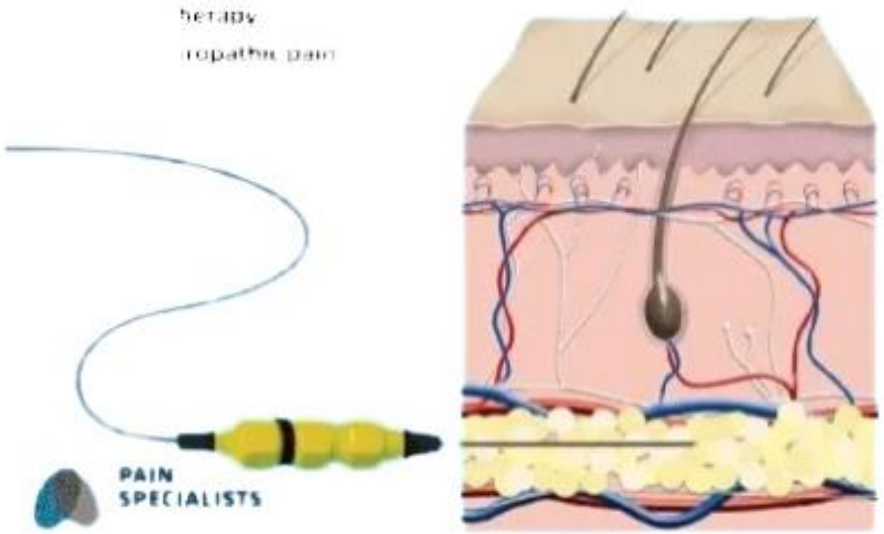
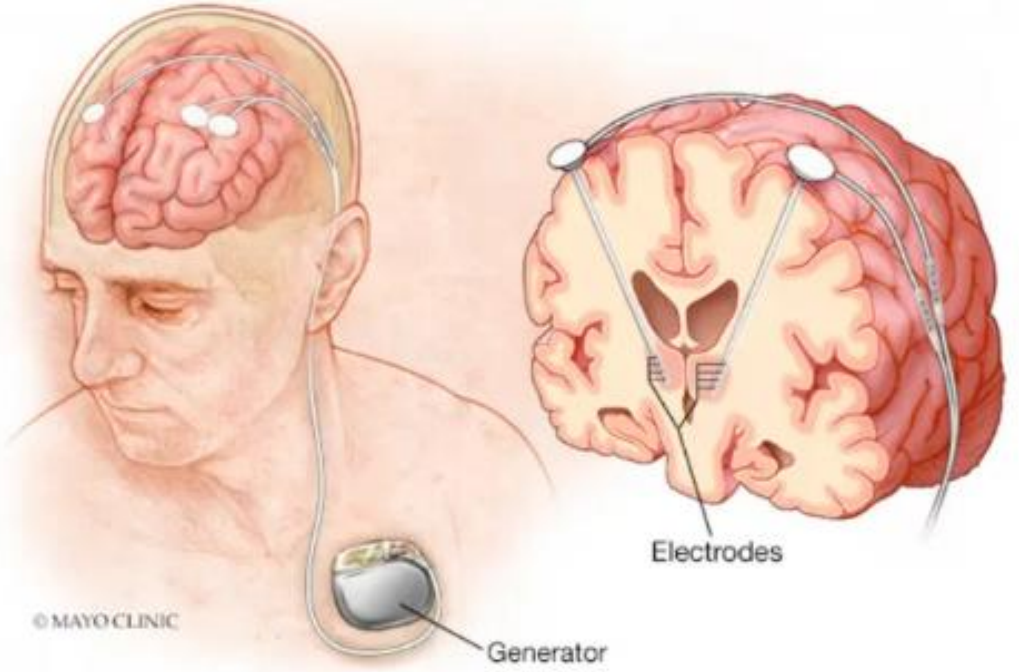
# Neurostimulation

- an alternative to pharmacological therapies




https://painspecialistsaustralia.com.au/blog/understanding-percutaneous-electrical-nerve-stimulation-pens-for-chronic-neuropathic-pain

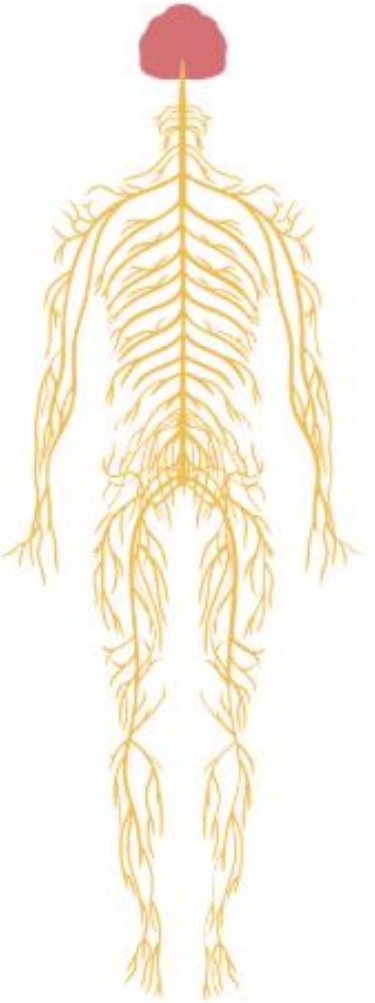



https://newsnetwork.mayoclinic.org/discussion/advances-in-deep-brain-stimulation-transform-lives/

# The importance of the electrode

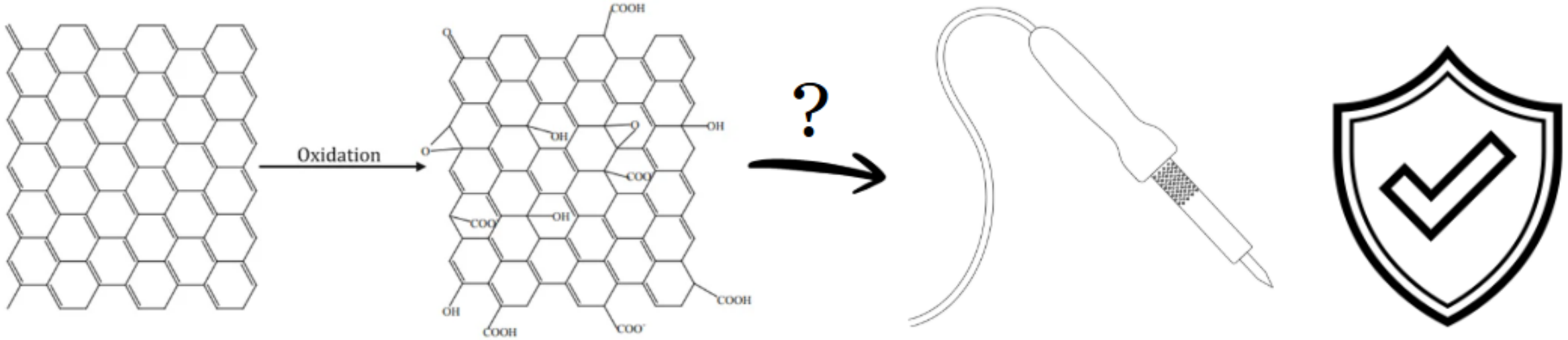
[1]

[2]



1) https://www.medtronic.com/en-us/healthcare-professionals/products/neurological/deep-brain-stimulation/electrical-stimulation-systems/percept-pc-neurostimulator.html
2) https://www.frontiersin.org/journals/neuroscience/articles/10.3389/fnins.2021.761525/full

# Purpose of the study




# Methods of modification

1) 

Chemical

2) 

Electrochemical

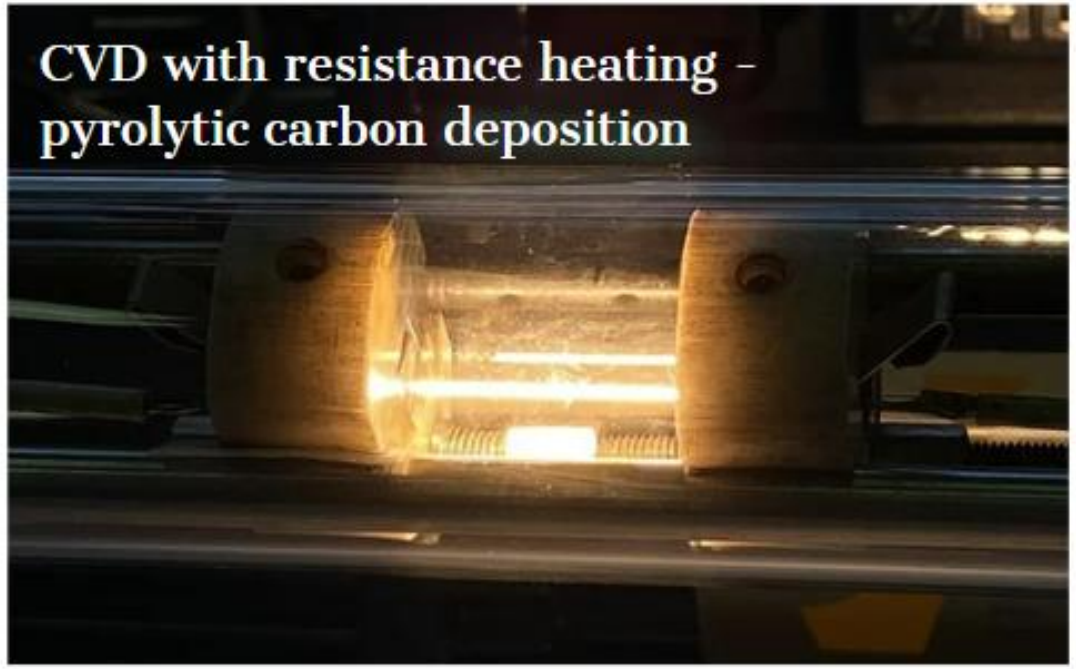
3) 


Ozonation

I. Nayak, M. Rahaman, and R. Giri, "Surface Modification/Functionalization of Carbon Materials by Different Techniques: An Overview," 2019, pp. 65–98. doi: 10.1007/978-981-13-2688-2_2.

# Materials and methods

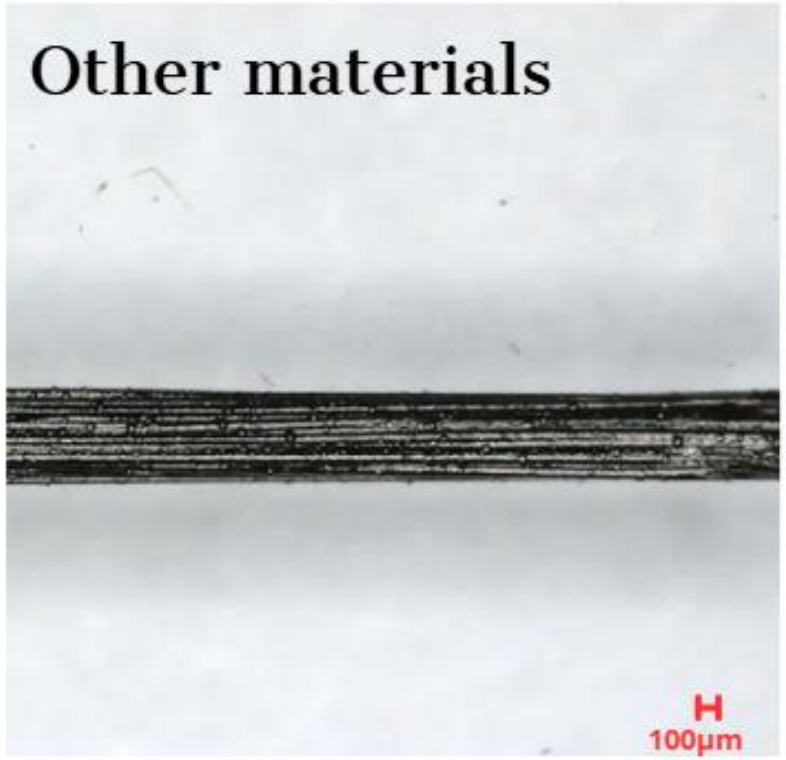
## Carbon - carbon composites

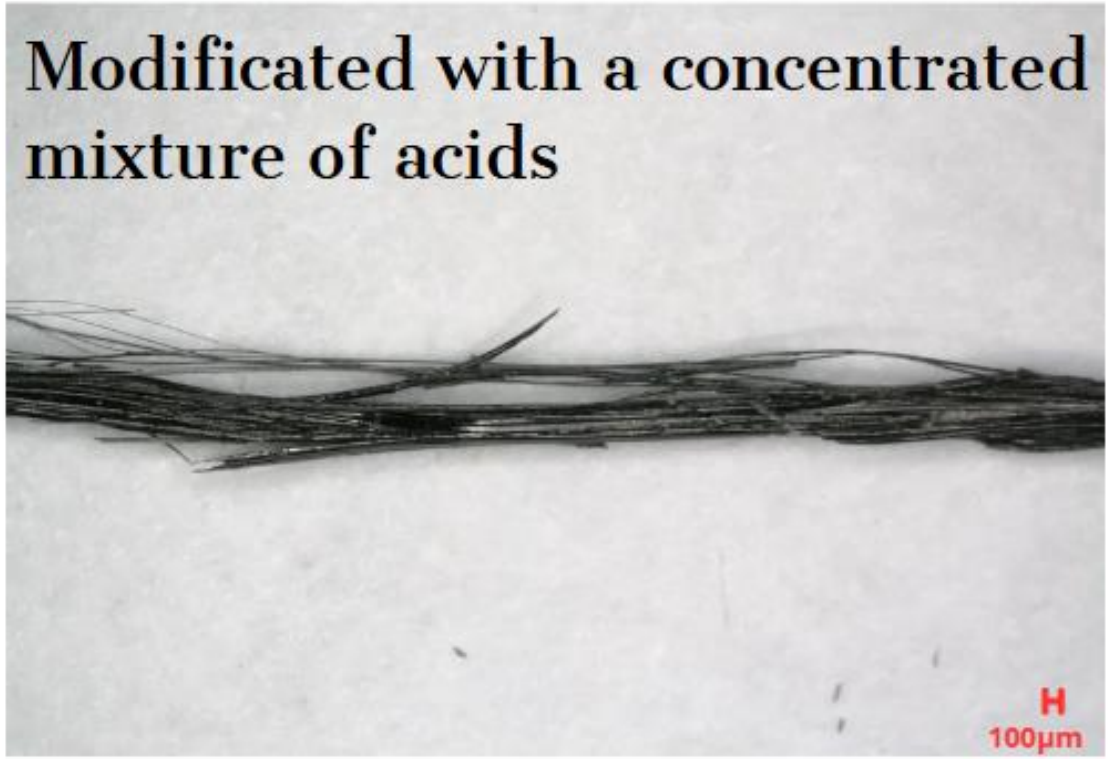



carbon-carbon composites consisting of carbon fibers in a pyrolytic carbon matrix

## Functionalization

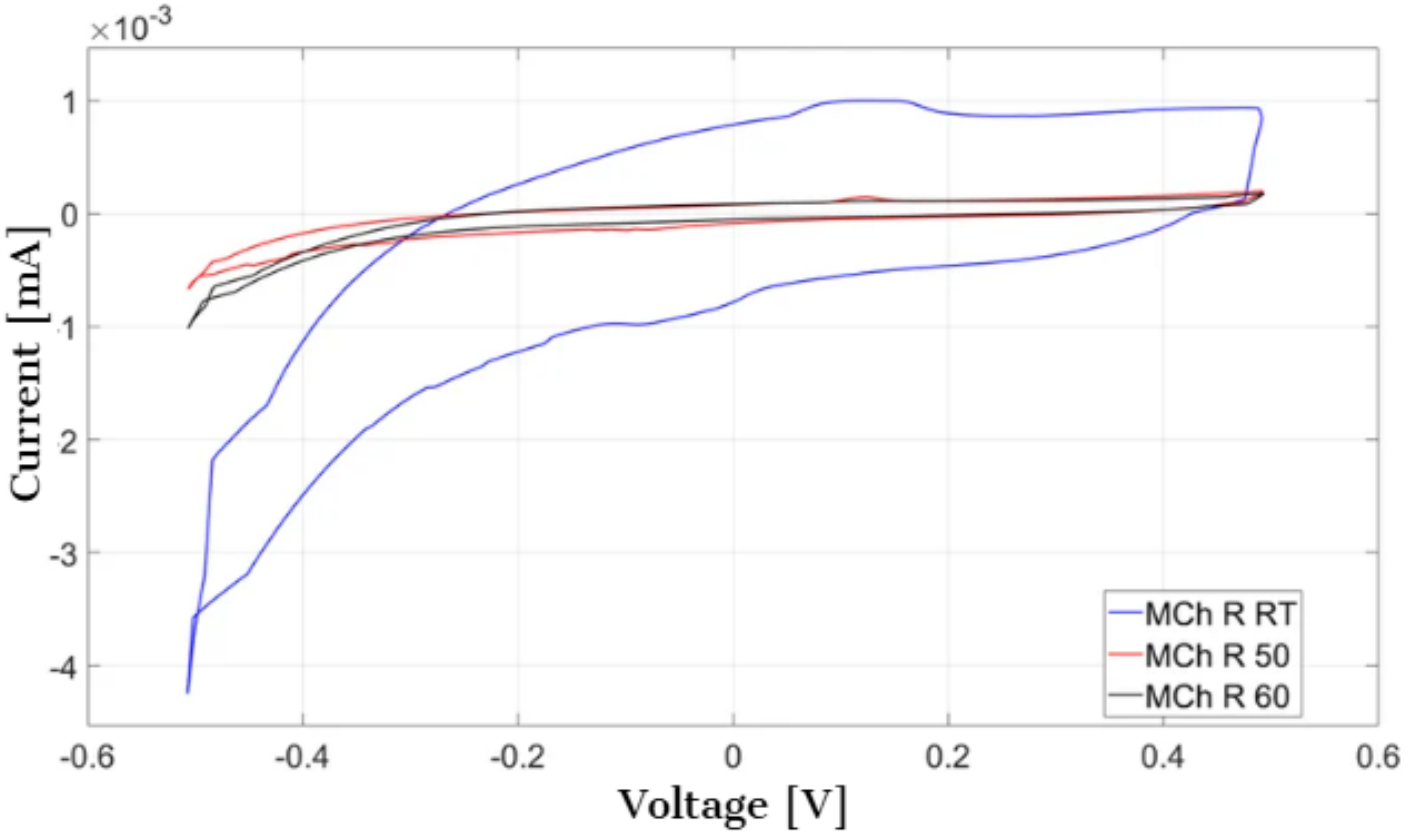
| | Parameter 1 | Parameter 2 |
|---|---|---|
| Chemical | Mixture type: concentrated/ diluted | Temperature: RT/ 50°C/ 60 °C |
| Electrochemical | Voltage range: from -2 to 2 V/ from -3 to 3 V | $H_2O_2$ concentration: 10 mM/ 100 mM |
| Ozonation | Time: 1h / 3h | |




exclusion of modification with a concentrated mixture of acids

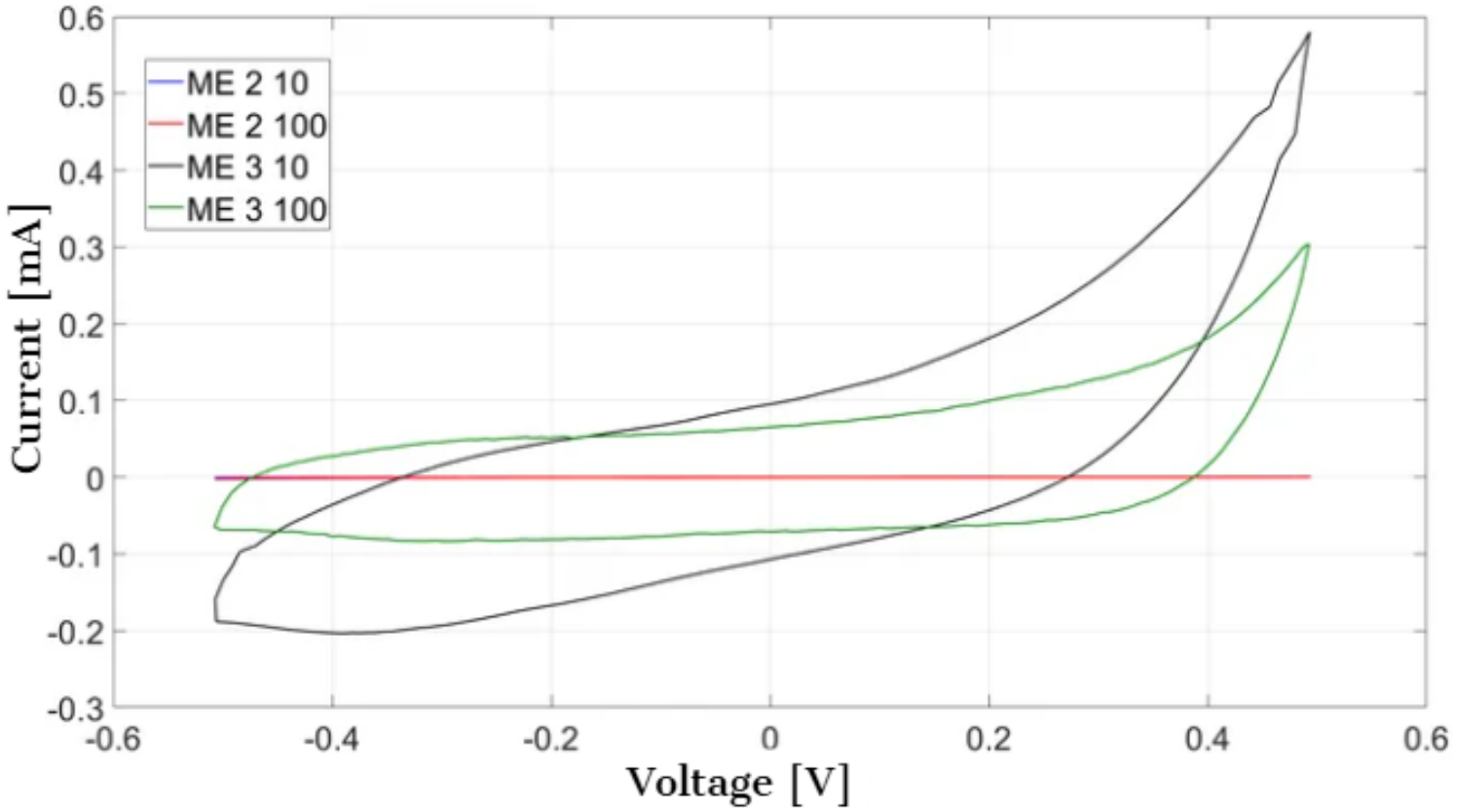
# Chemical functionalization - MCh




**Best results for modification at room temperature**

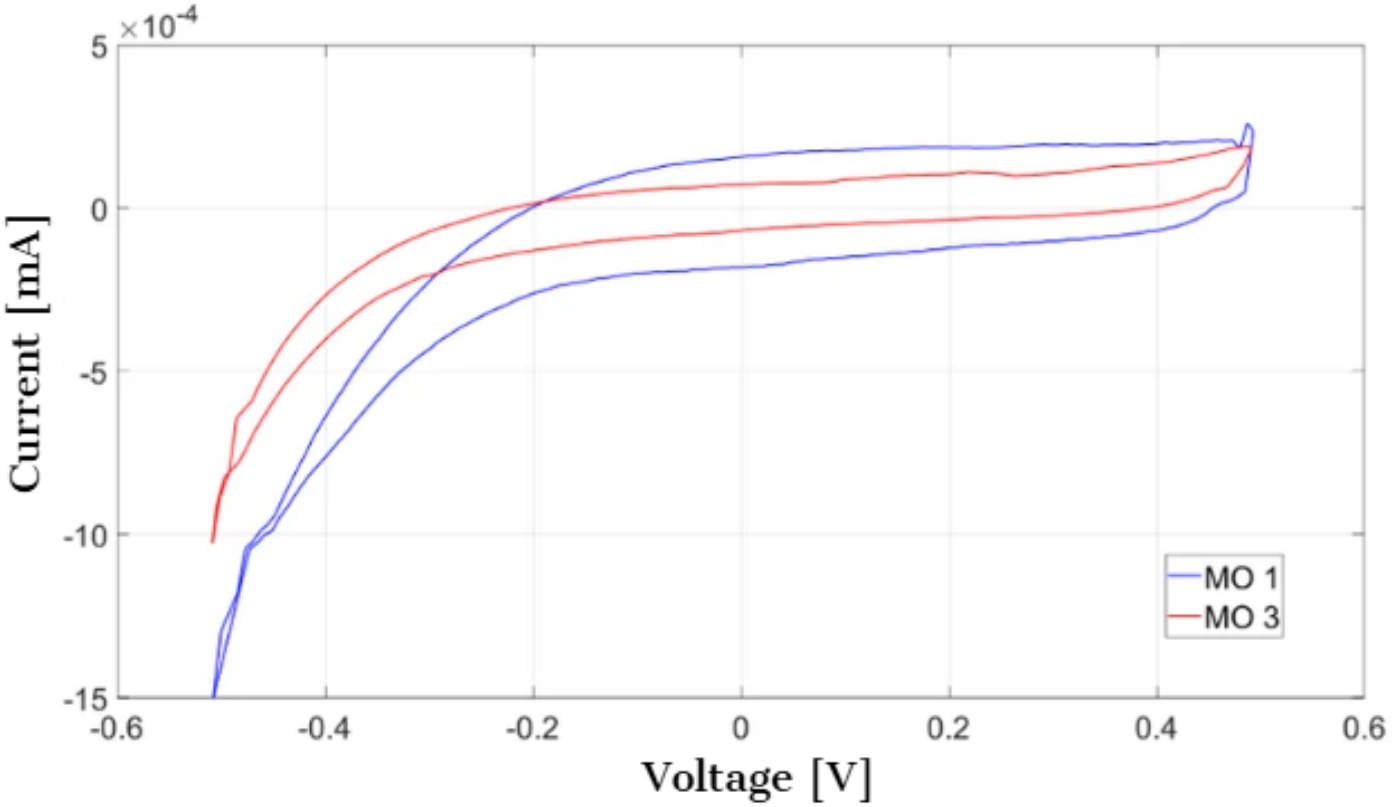
CSC - Charge Storage Capacity
ACSF - Artificial Cerebrospinal Fluid

# Electrochemical functionalization - ME



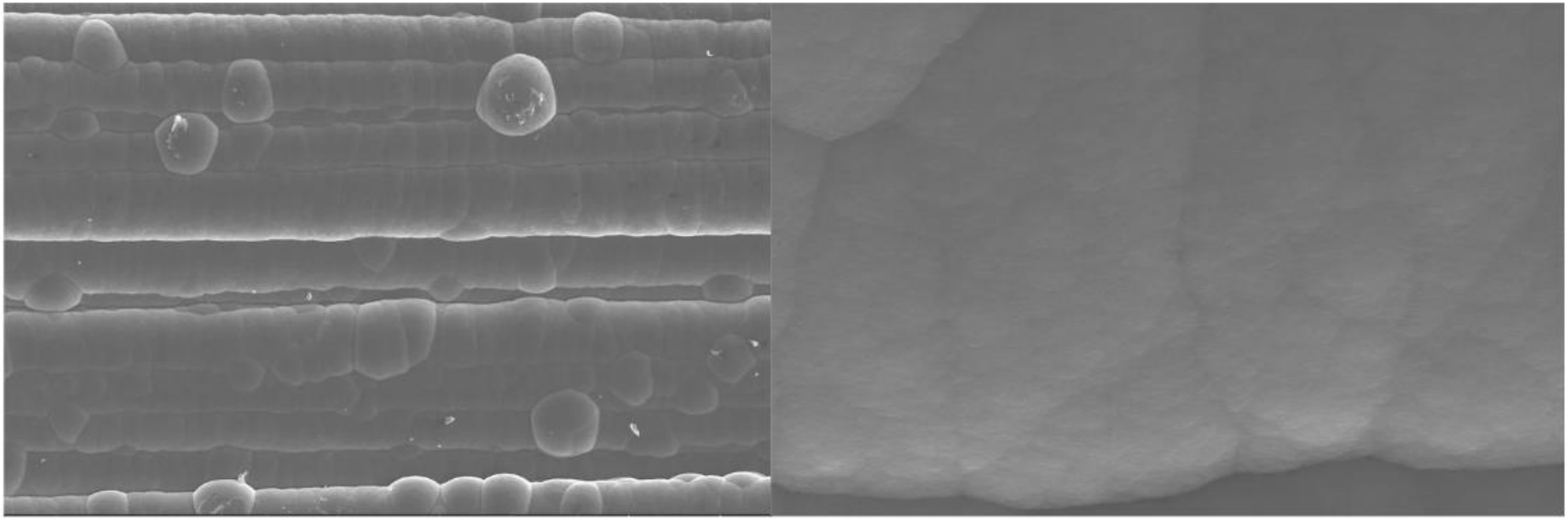

Best results for modification in the voltage range from -3 to 3 V and a concentration of $H_2O_2$ 10 mM

# Ozonation - MO

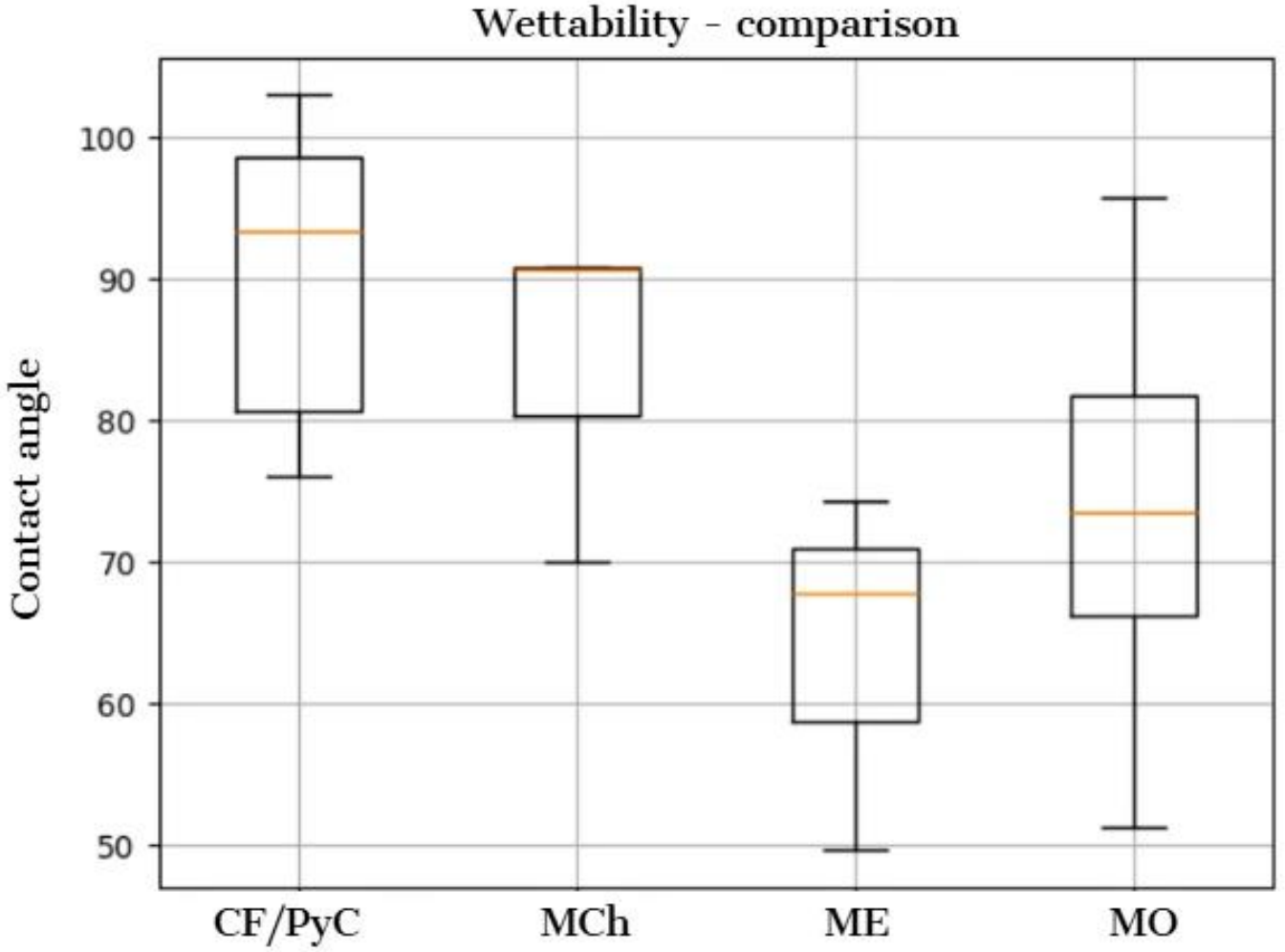



Best results for modification within 1 hour

# SEM

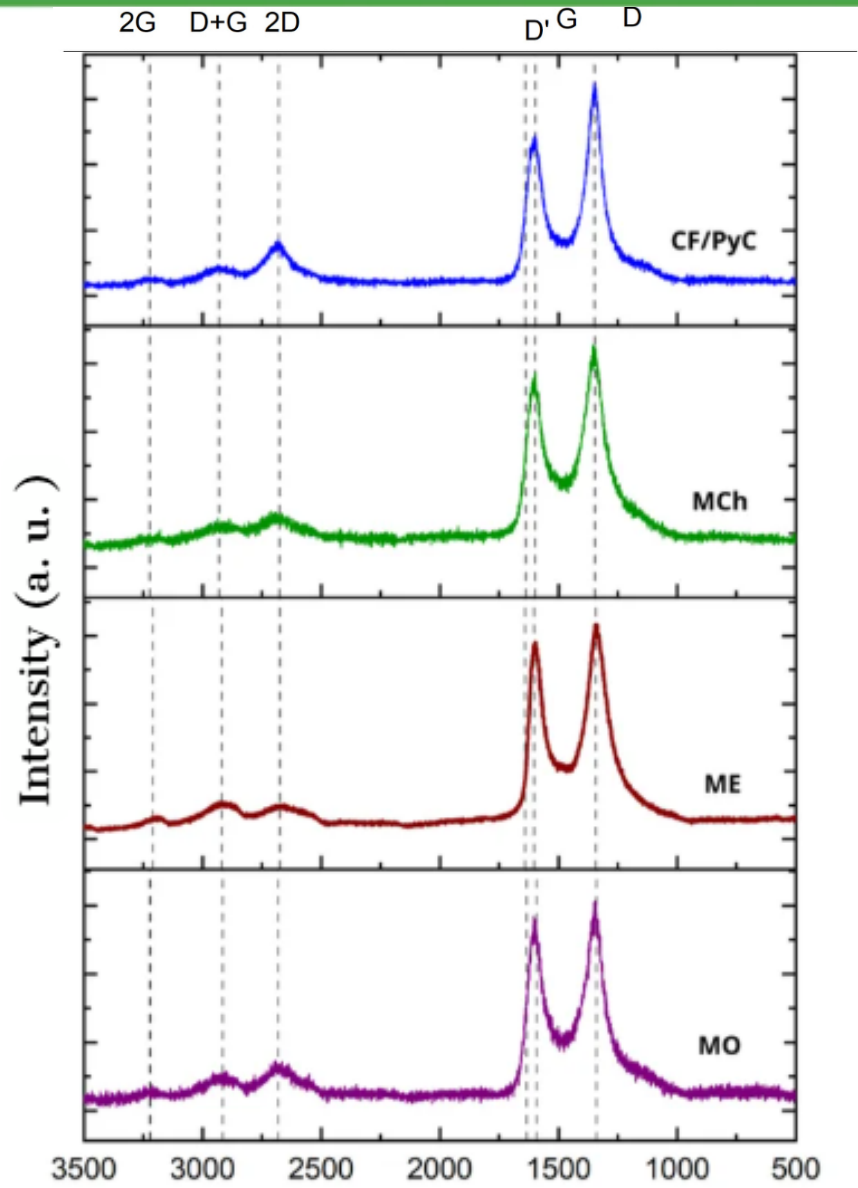


# Wettability

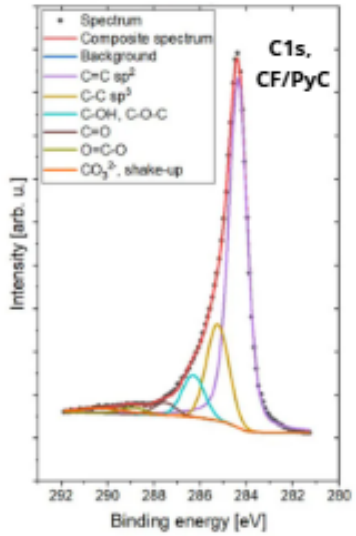


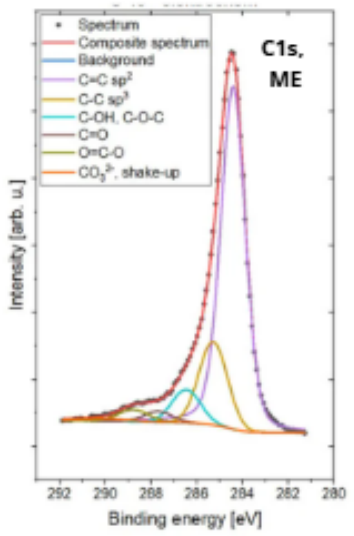
# Raman Spectroscopy

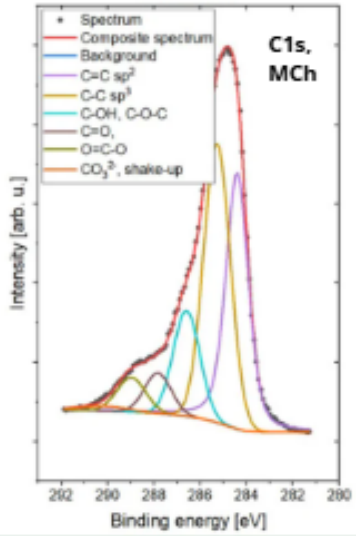
| | AD/AG | AD/AD’ |
|---|---|---|
| CF/PyC | 2.02 ± 0.14 | 7.01 ± 0.78 |
| MCh | 2.37 ± 0.21 | 11.07 ± 2.23 |
| ME | 2.50 ± 0.16 | 25.66 ± 2.30 |
| MO | 1.57 ± 0.08 | 10.47 ± 0.56 |

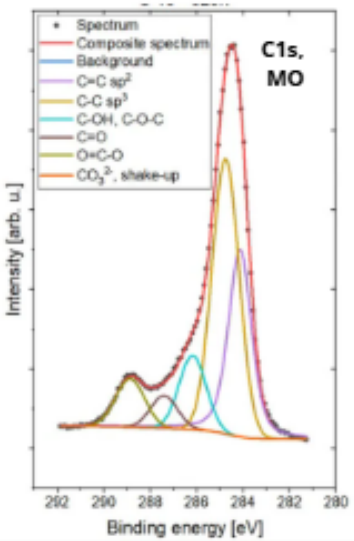


# XPS



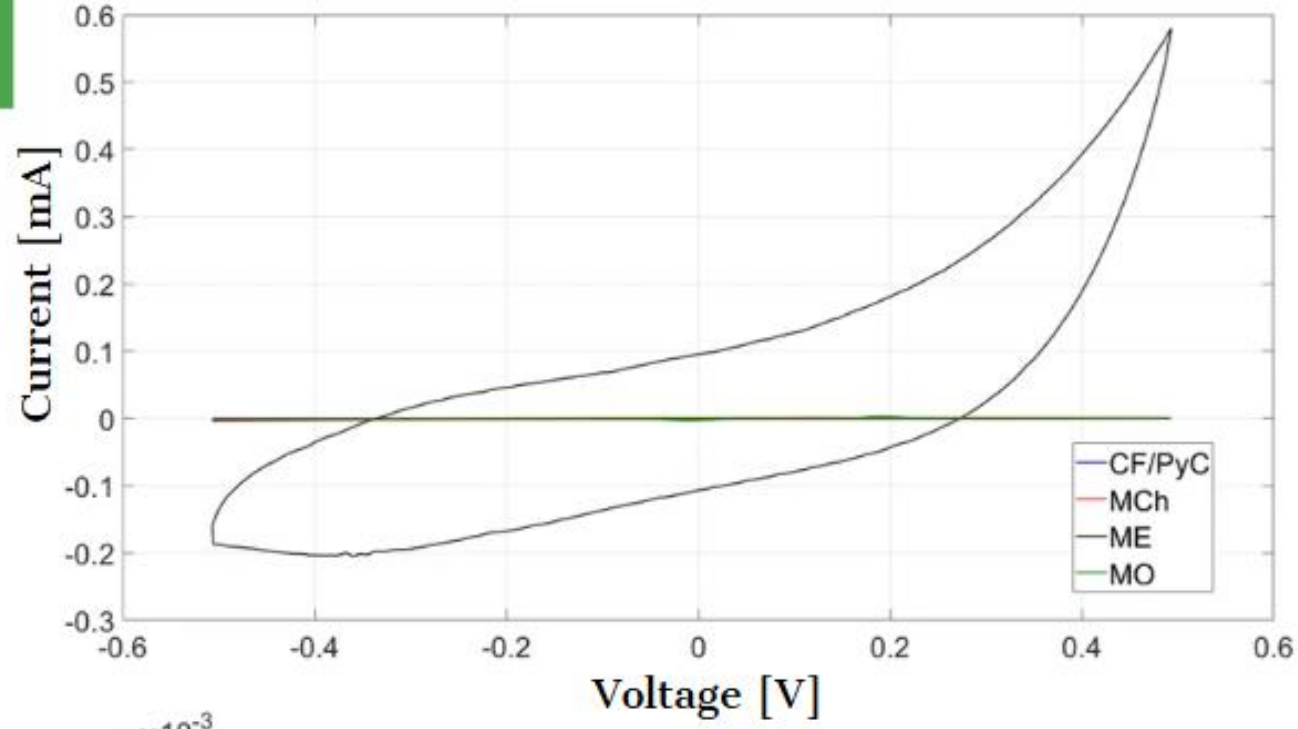



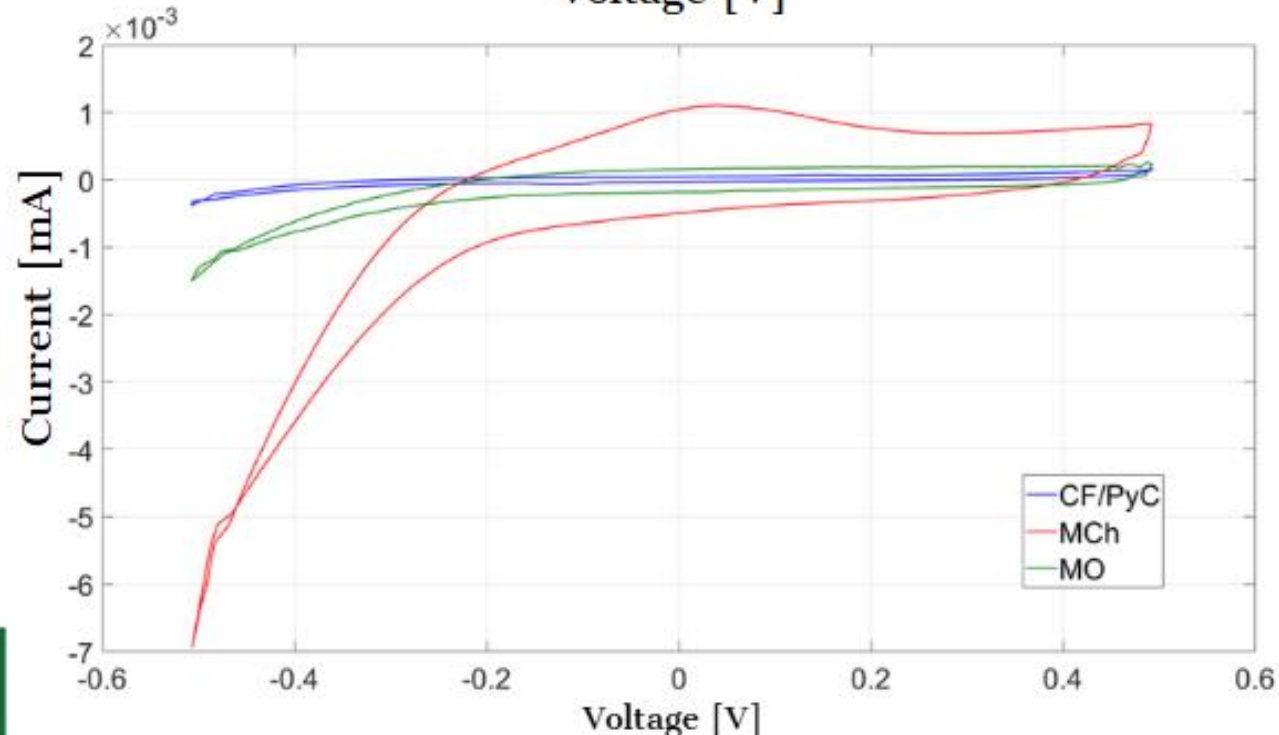




| | C1s | | | | | | O1s | |
|---|---|---|---|---|---|---|---|---|
| | C = C sp2 | C – C sp3 | C-OH, C- OC | C = O, N- C=O, | O=C-O | CO32-, shake - up | O=C, CO32- | O-C, -OH, H2O |
| CF/PyC | 62.5 | 18.3 | 7.2 | 2.4 | 1.4 | 1.7 | 3.5 | 2.9 |
| MCh | 28.8 | 31.3 | 11.9 | 4.6 | 4.1 | 0.9 | 9.2 | 9.1 |
| ME | 53.6 | 13.5 | 5.4 | 2.0 | 1.8 | 0.7 | 17.3 | 5.6 |
| MO | 23.7 | 33.5 | 9.0 | 4.0 | 6.7 | 0 | 14.3 | 9.1 |

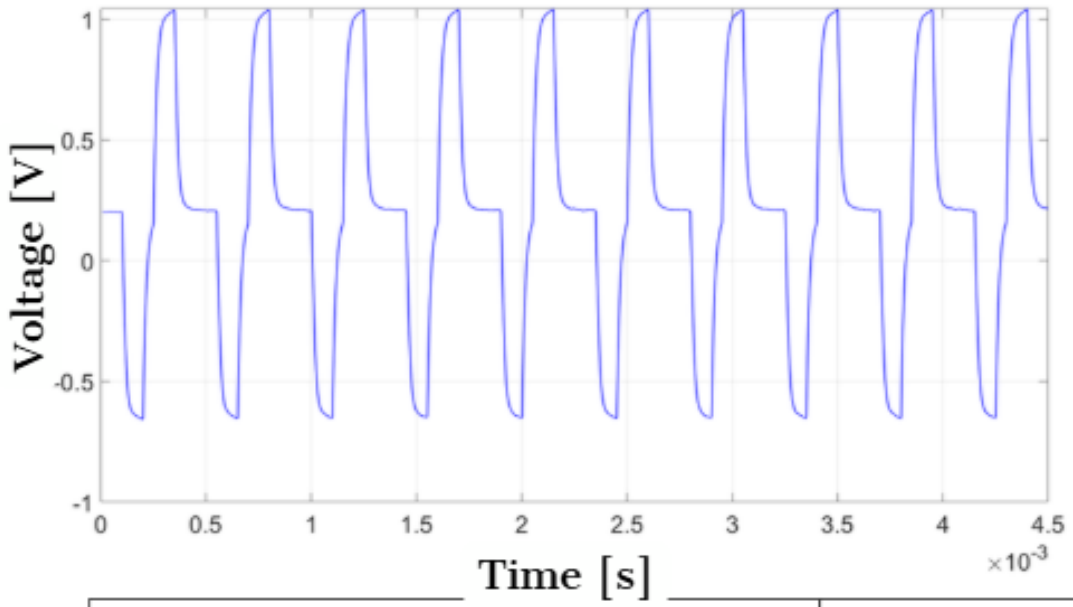
| Type of modification | CSC (voltage range from -0.5 to 0.5 V) [mC/cm2] | Water window [V] | CSC (water window) [mC/cm2] |
|---|---|---|---|
| CF/PyC | 0.015 ± 0.009 | -1.5 - 1.5 | 0.79 ± 0.16 |
| MCh | 0.136 ± 0.009 | -1.75 - 1.4 | 2.63 ± 0.42 |
| ME | 38.925 ± 2.798 | -1.75 - 1.5 | 734.77 ± 3.16 |
| MO | 0.064 ± 0.007 | -1.5 - 1.5 | 0.85 ± 0.06 |

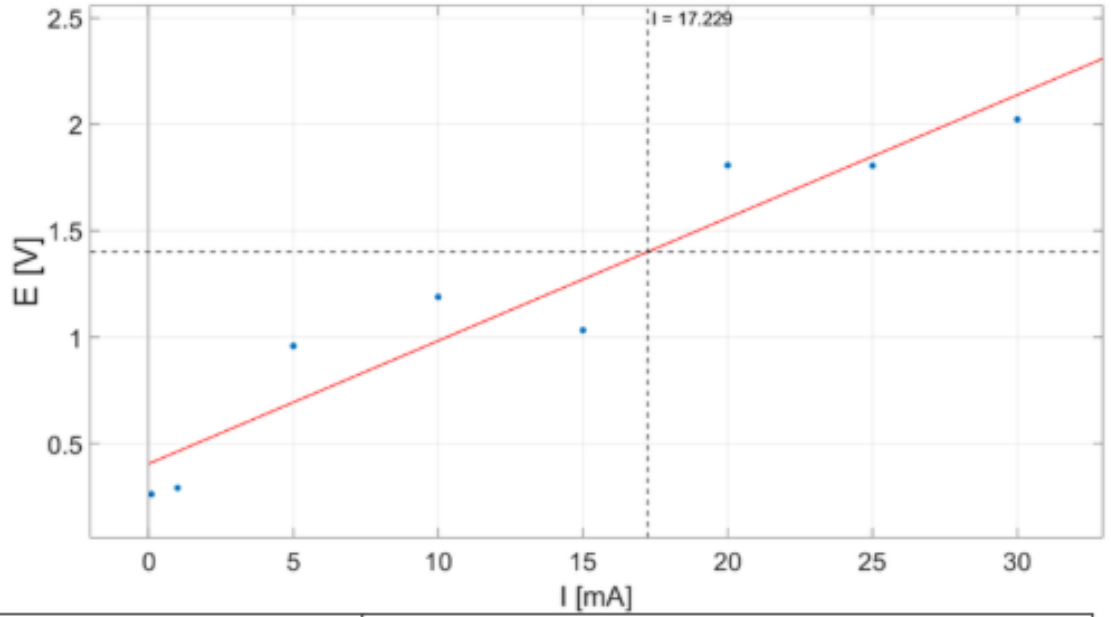


# Pulse stimulation tests

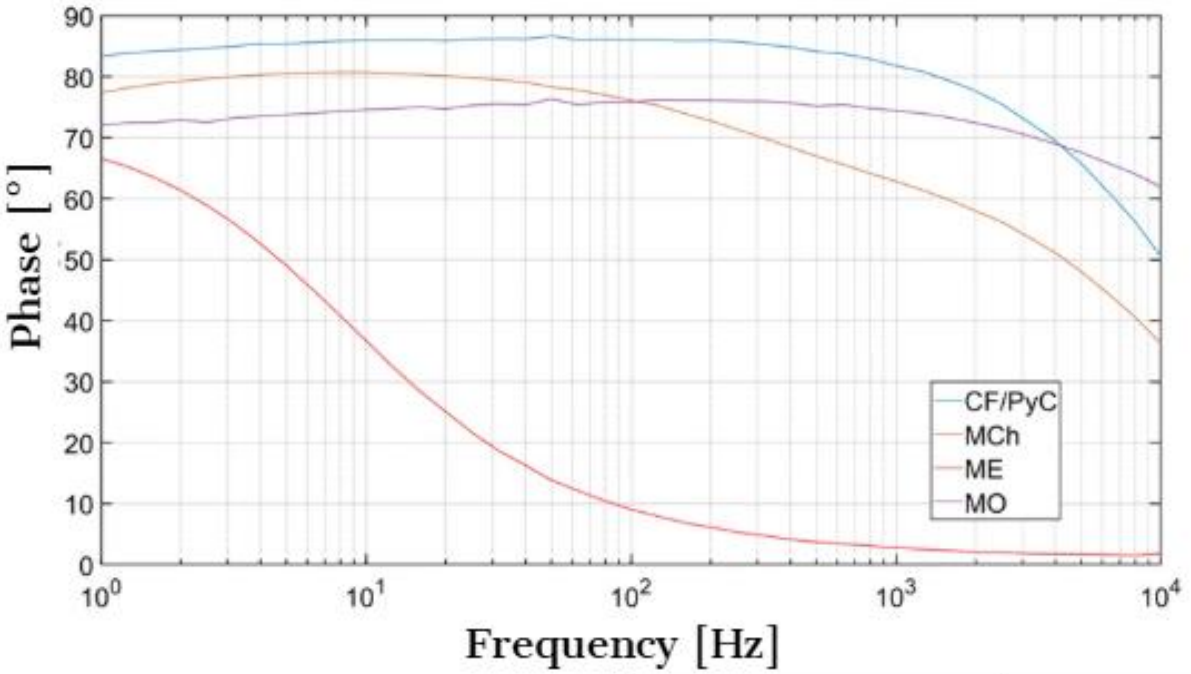
CIC - Charge Injection Capacity

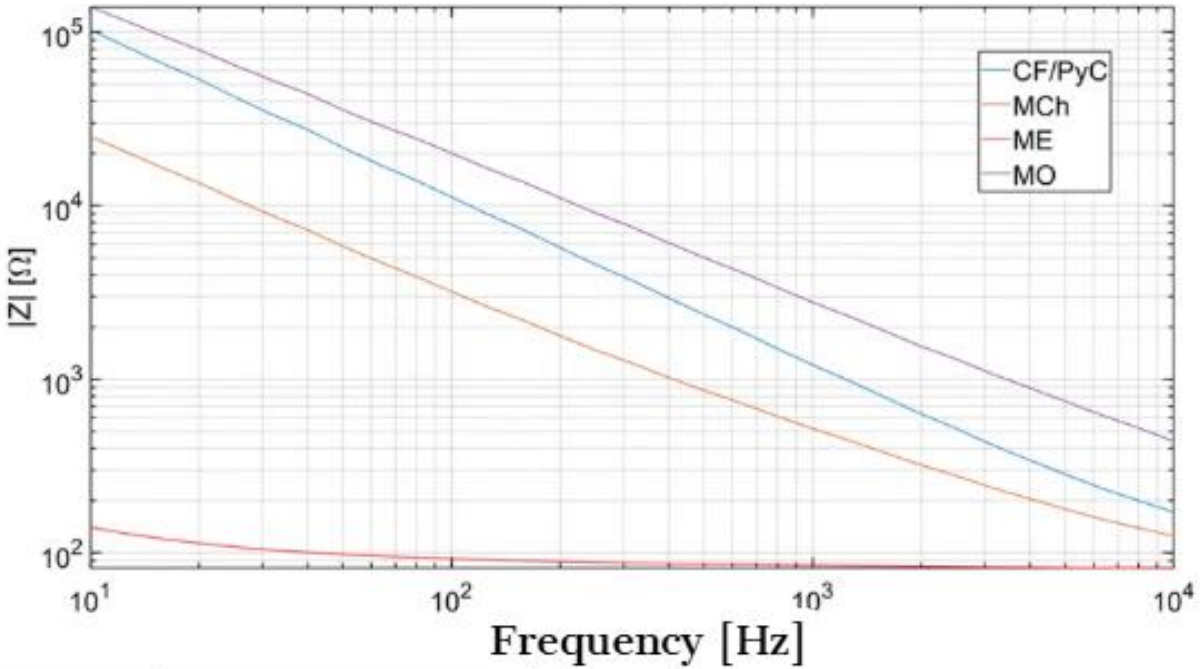



| Method of modification | Cathodic CIC [mC/cm2] | anodic CIC [mC/cm2] |
|---|---|---|
| CF/PyC | 55.38 ± 35.09 | 50.77 ± 2.22 |
| MCh | 57.89 ± 7.17 | 39.31 ± 13.32 |
| ME | 190.36 ± 29.04 | 177.01 ± 25.92 |
| MO | 53.93 ± 20.04 | 45.11 ± 5.01 |

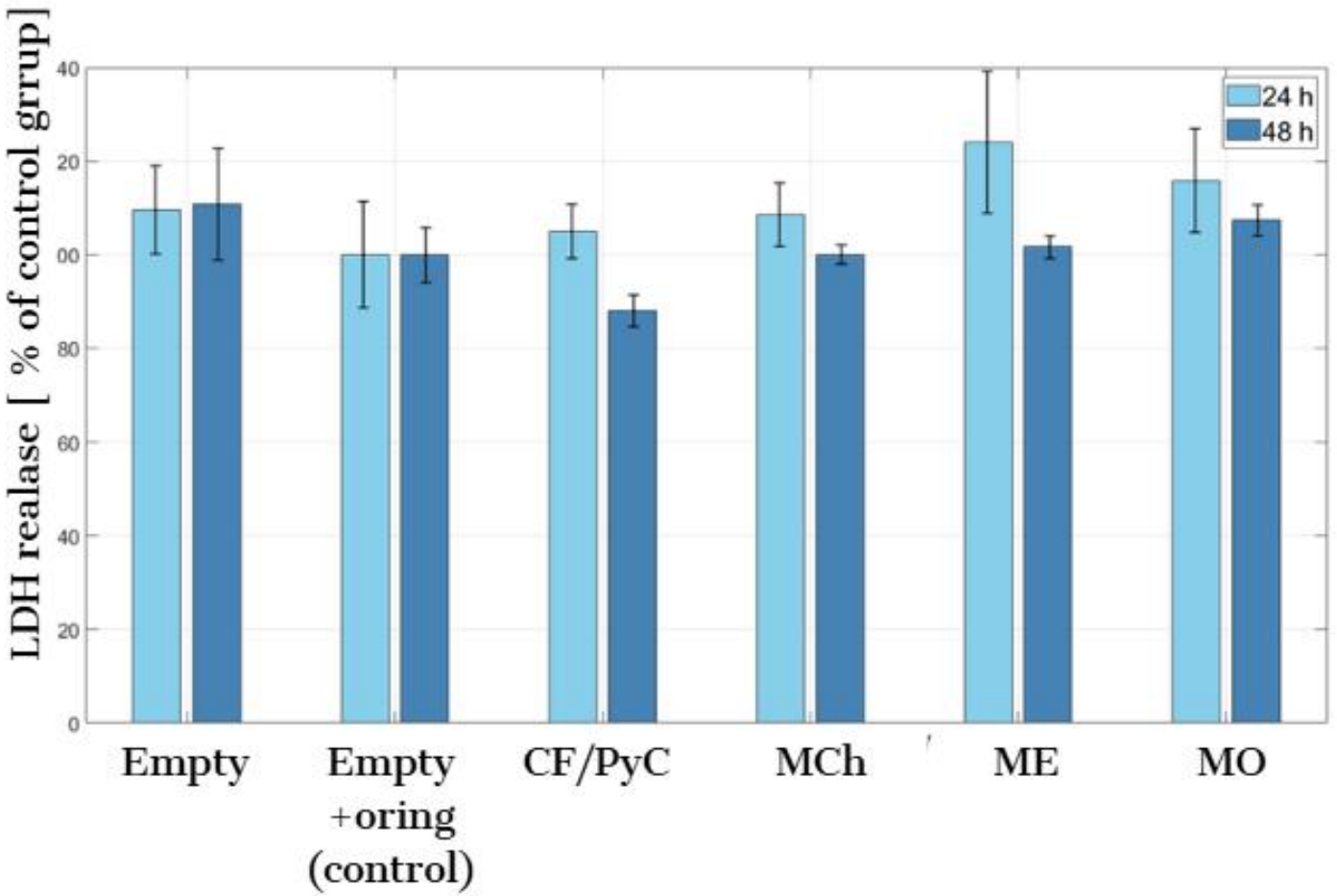
# Electrochemical Impedance Spectroscopy

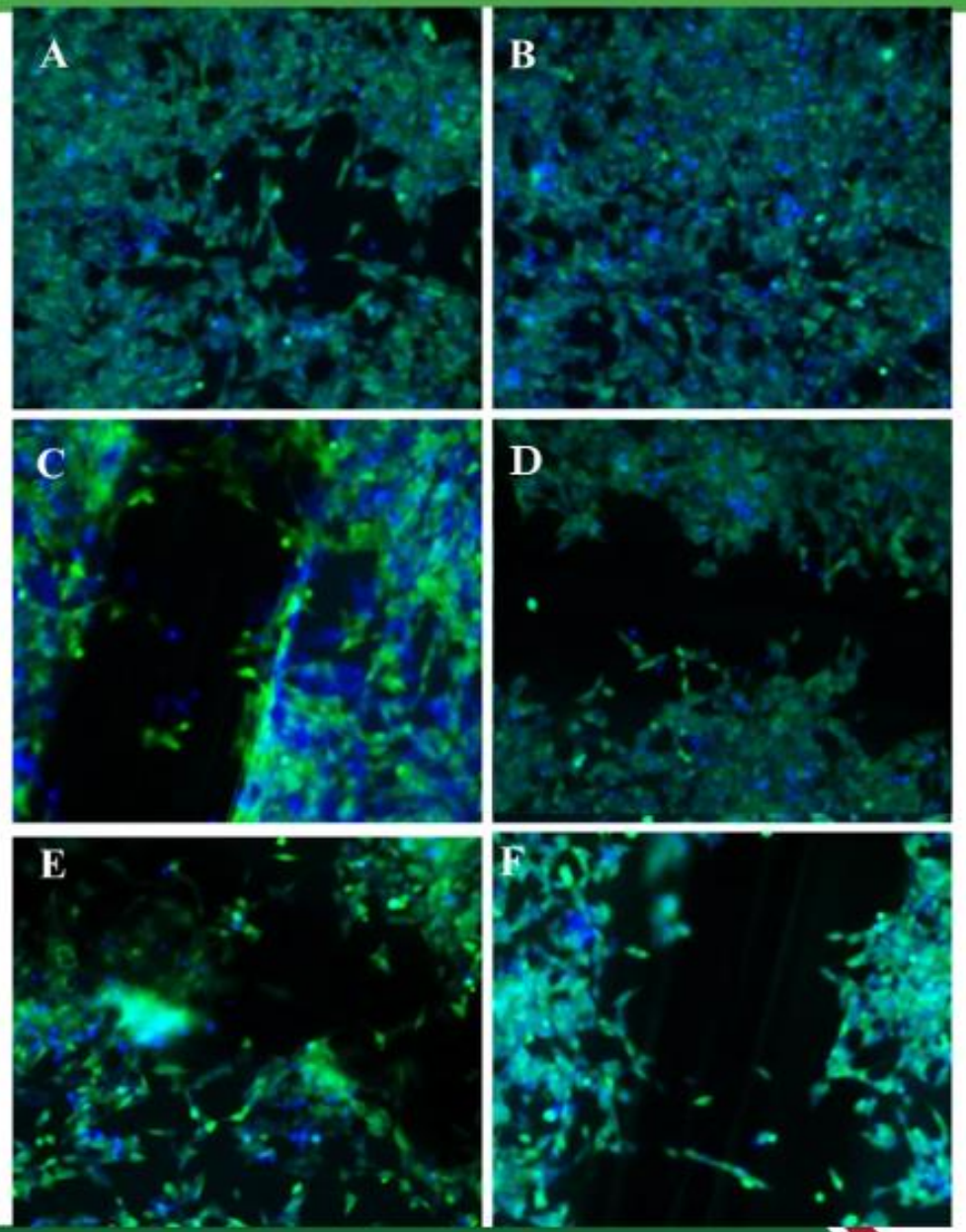



| Type of modification | Impedance modulus \|Z1kHz\| [Ω] | Cutoff frequency[kHz] |
|---|---|---|
| CF/PyC | 1250.50 | 19.79 |
| MCh | 582.04 | 5.42 |
| ME | 90.81 | 0.004 |
| MO | 48507.20 | 59.72 |

# Biological tests

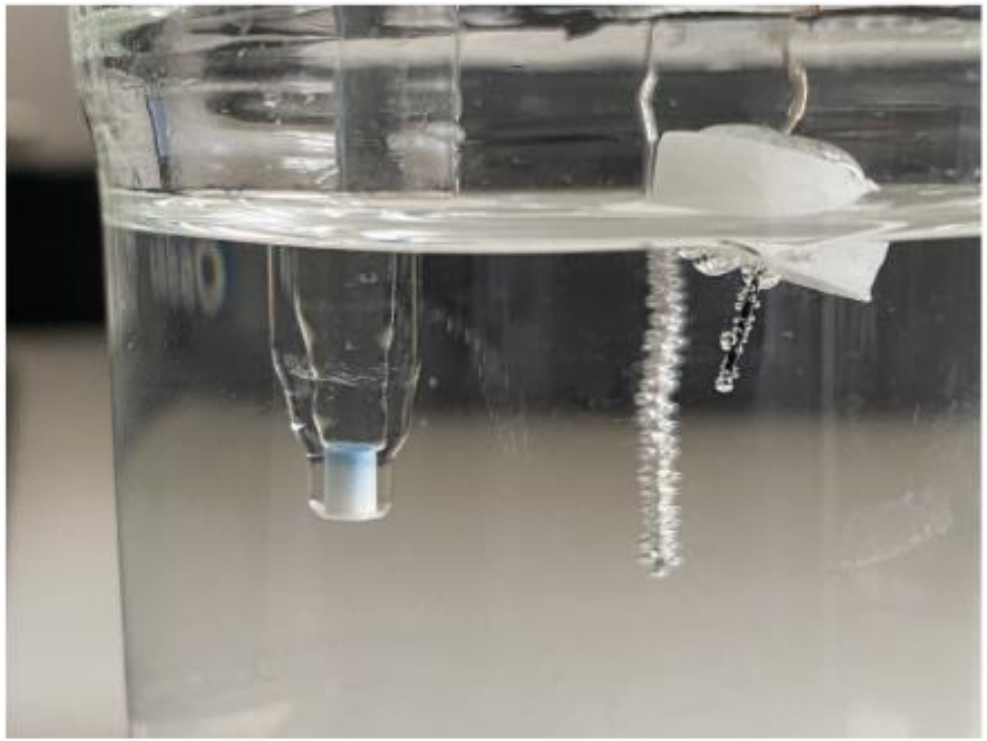


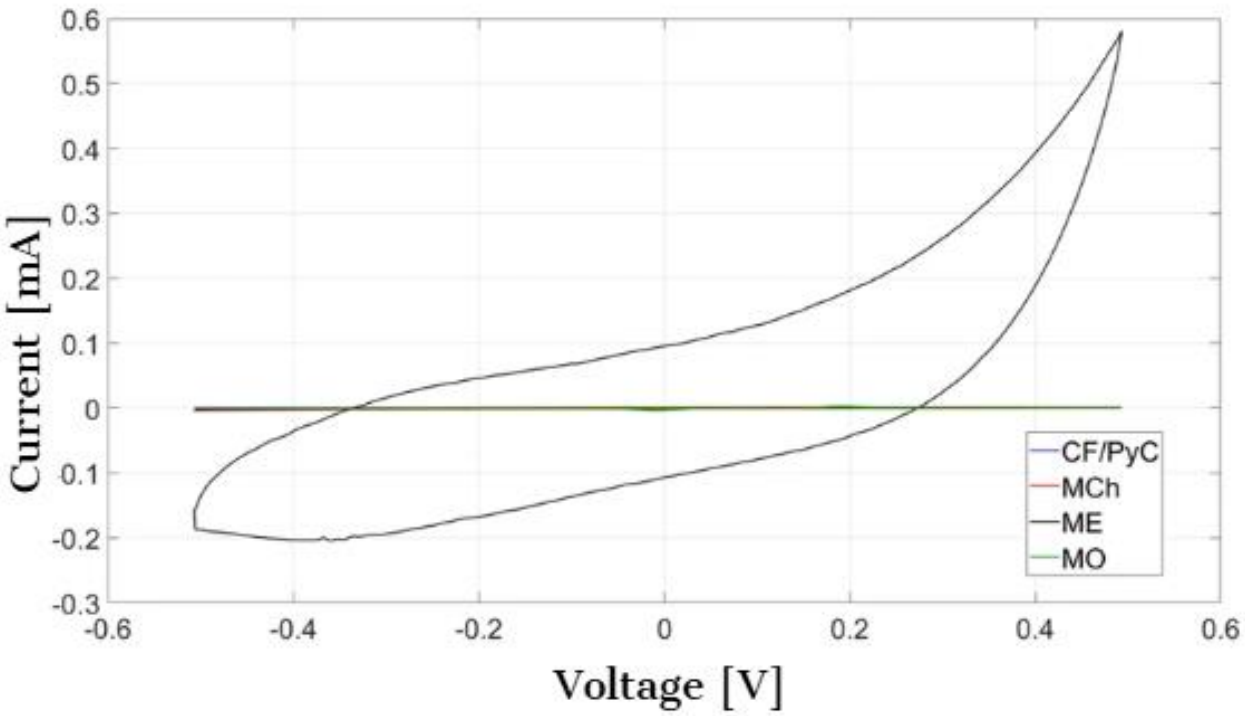



# Results

| Method of modification | Wettability | Charge Storage Capacity | Charge Injection Capacity | Impedance and cut-off frequency |
|---|---|---|---|---|
| Chemical | + | + + | – | + |
| Electrochemical | + + | + + + | + + + | + + |
| Ozonation | + + + | + | – | – |

# Summary and conclusions






great potential of electrochemical functionalization in terms of increasing the efficiency and safety of electrodes used in neurostimulation.

# Thank you for your attention

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