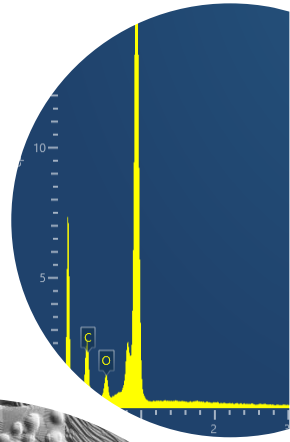
MeVArc 2024

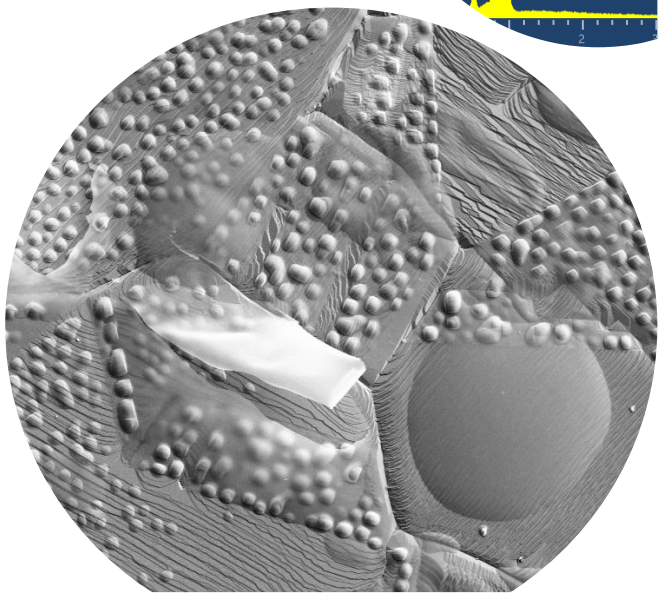
Tahoe City, USA

Catarina Serafim

Study of different materials in high voltage breakdown tests in the DC system, before and after H- low voltage irradiation



Supervisors:
Sergio Calatroni, CERN
Flyura Djurabekova, University of Helsinki

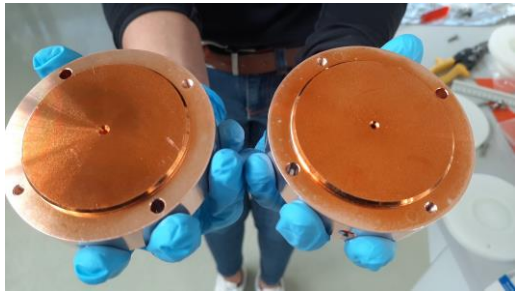


6th, March, 2024

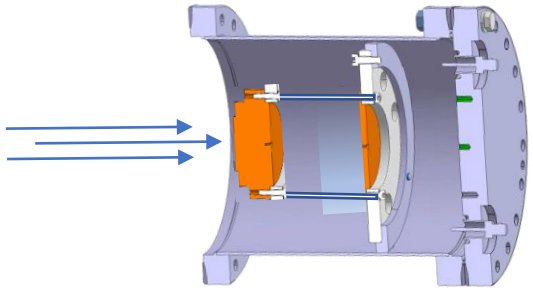
Procedure

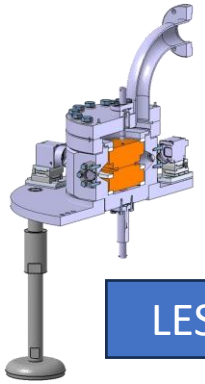
1st pair of electrodes

Treatment of electrodes



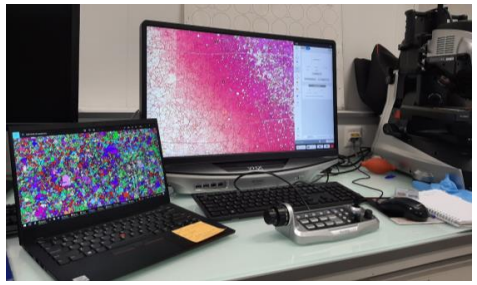
H- irradiation





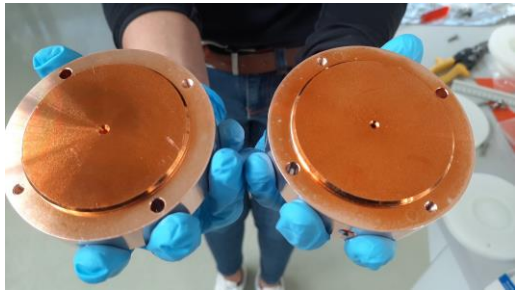
LES tests

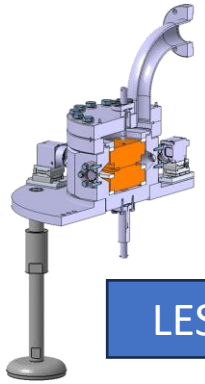
Analysis



2nd pair of electrodes

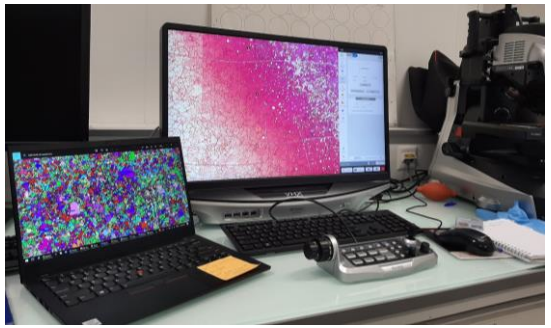
Treatment of electrodes



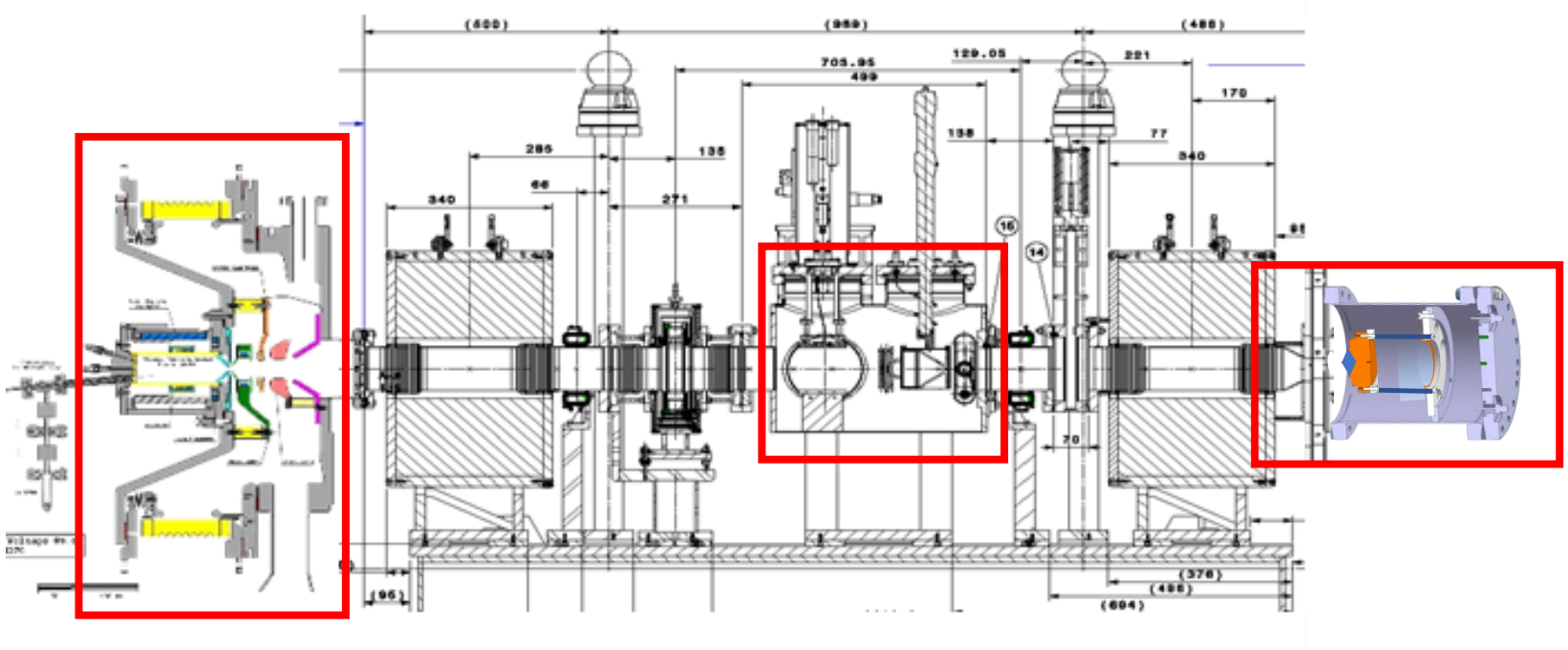


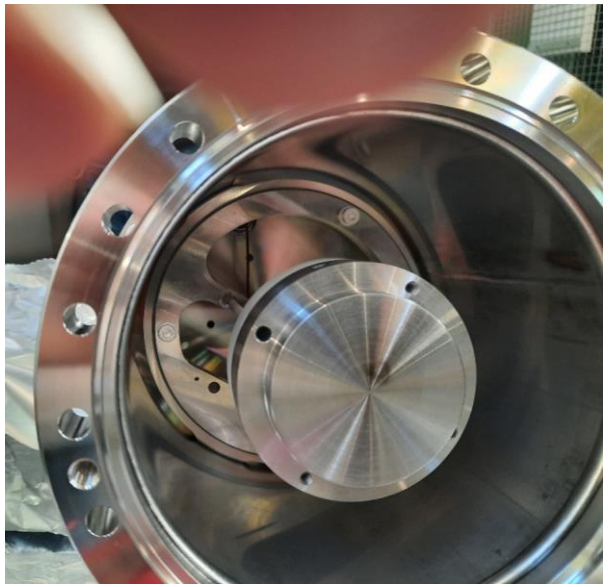
LES tests

Analysis

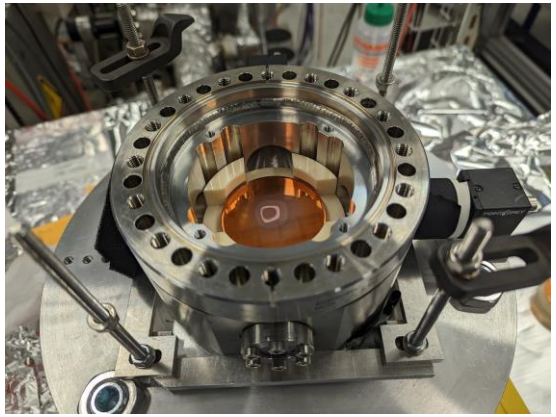


Irradiation setup – LINAC4 source test stand – Irradiation affects study





In this test stand, specific hardware was developed to use a cathode as the target for irradiation.



H^- Source 45 keV

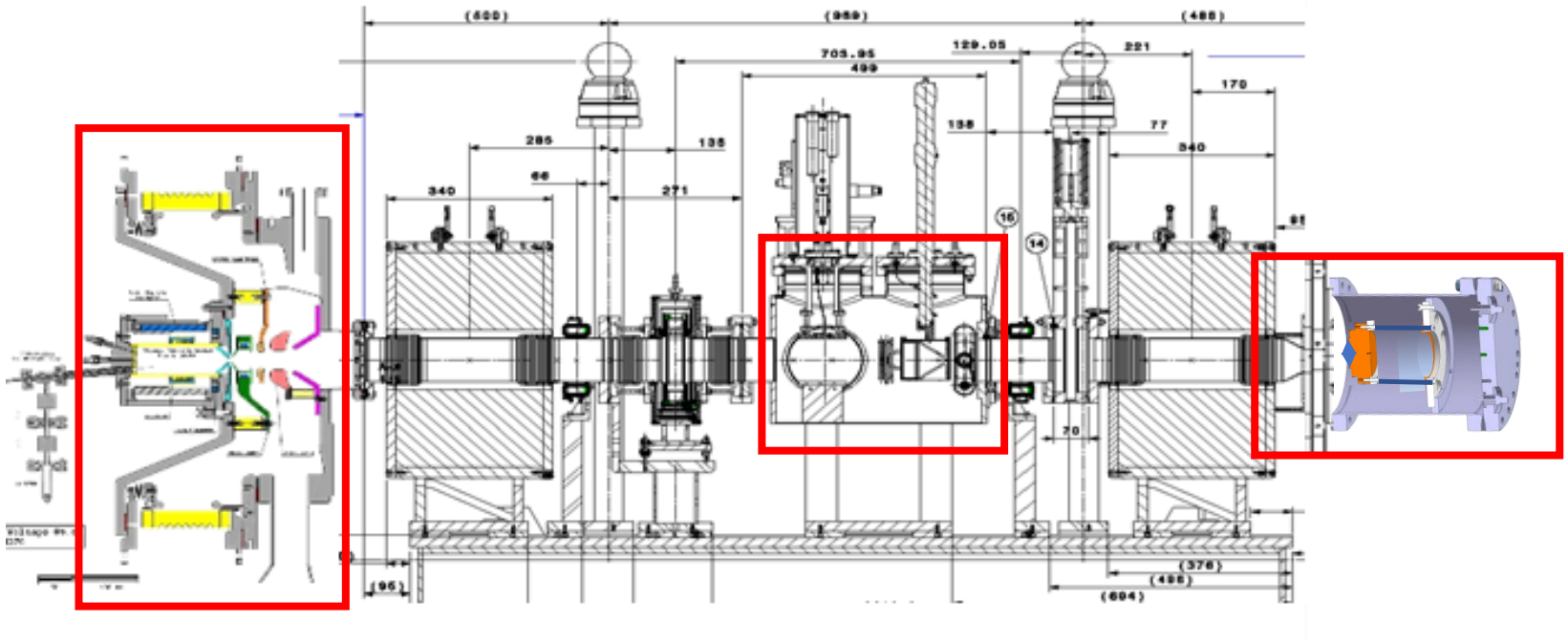
Low-energy beam transport

2 Steerers, 2 Solenoids

Sample holder

Schematic from Alessandra Lombardi

Irradiation setup – LINAC4 source test stand – Irradiation affects study



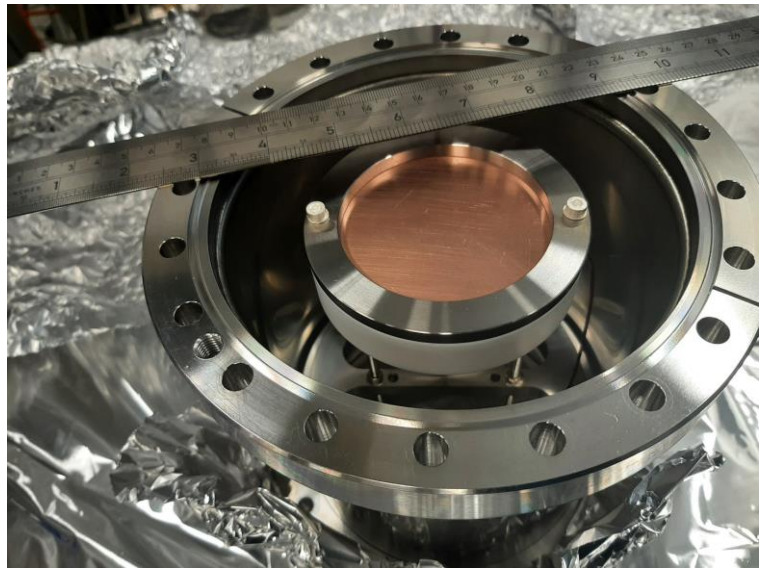
H⁻ Source 45 keV

Low-energy beam transport

2 Steerers, 2 Solenoids

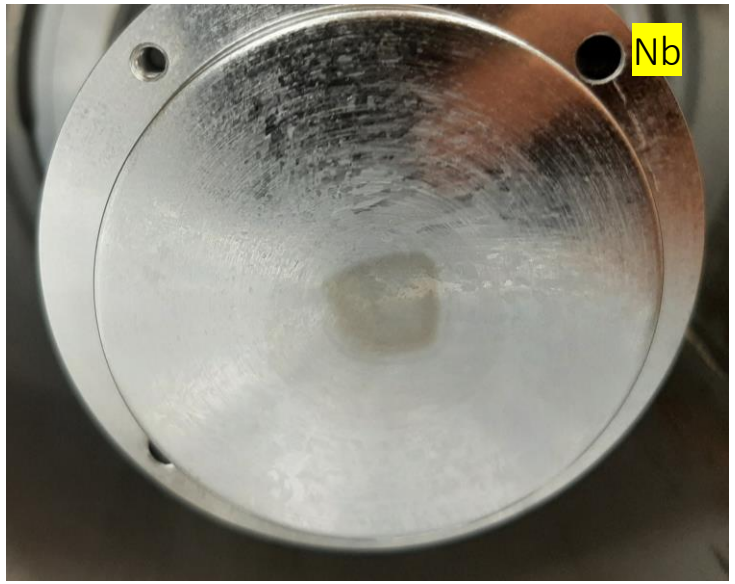
Sample holder

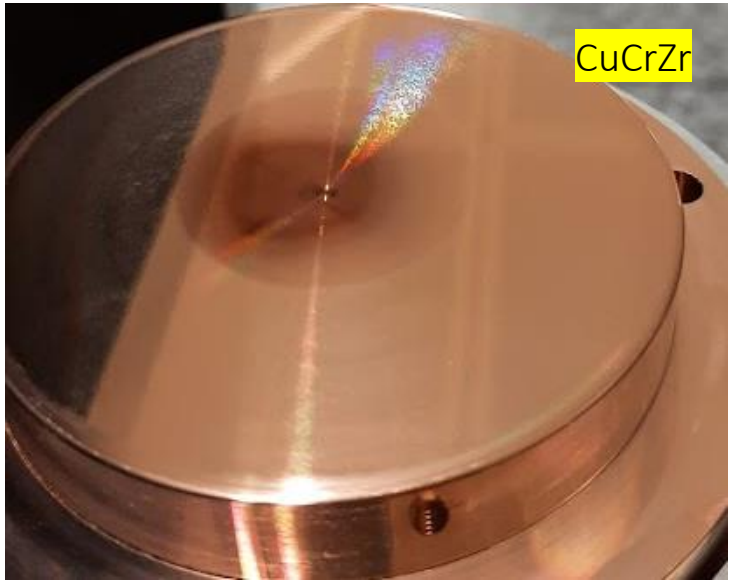
Schematic from Alessandra Lombardi

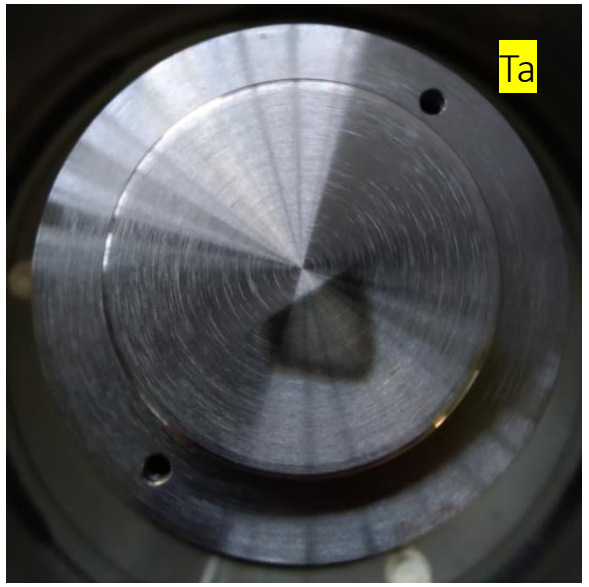


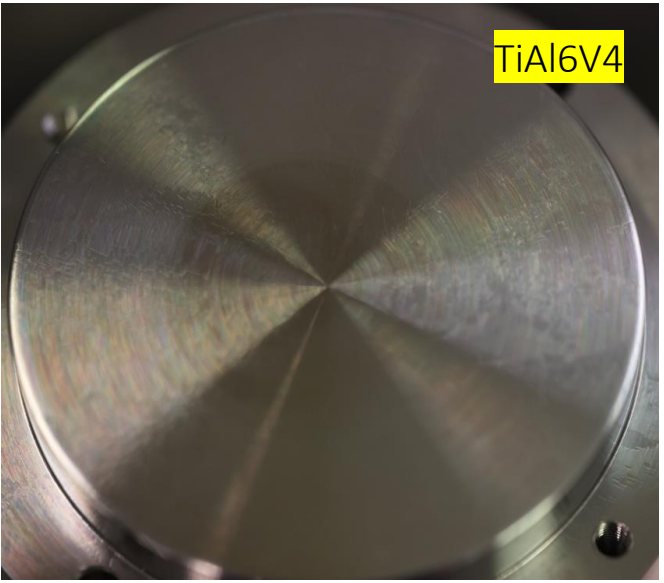
Low Energy H- beam	45 keV
Duration	40 hours
Pulse duration	600 µs
Repetition Rate	0.83 Hz
Peak current	20 mA
Deposition of particles on the target	1.2x $10^{\wedge 19}$ H^-p/cm^2

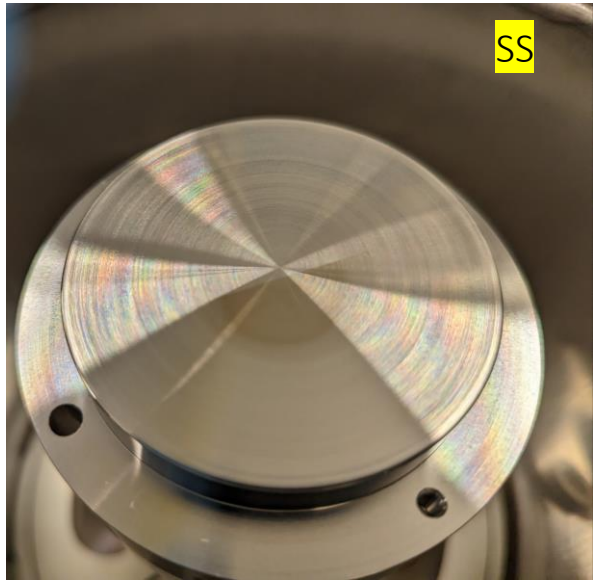
Pictures of each electrode from each material after irradiation testing.

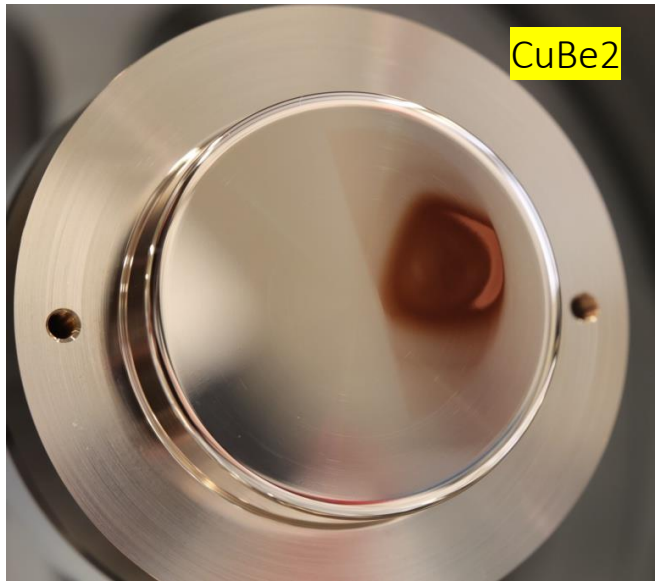


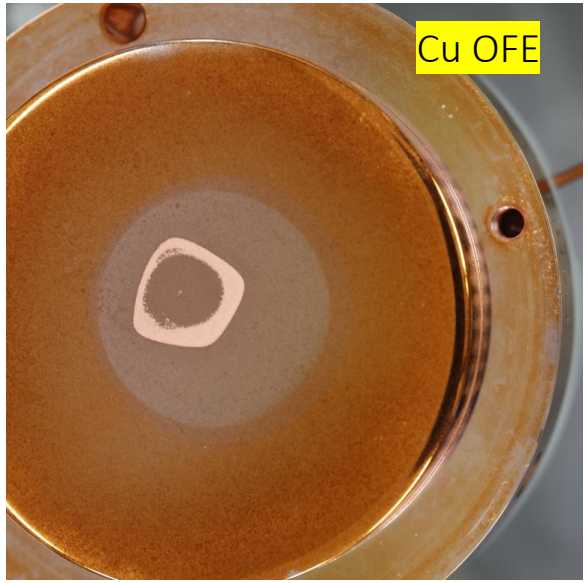


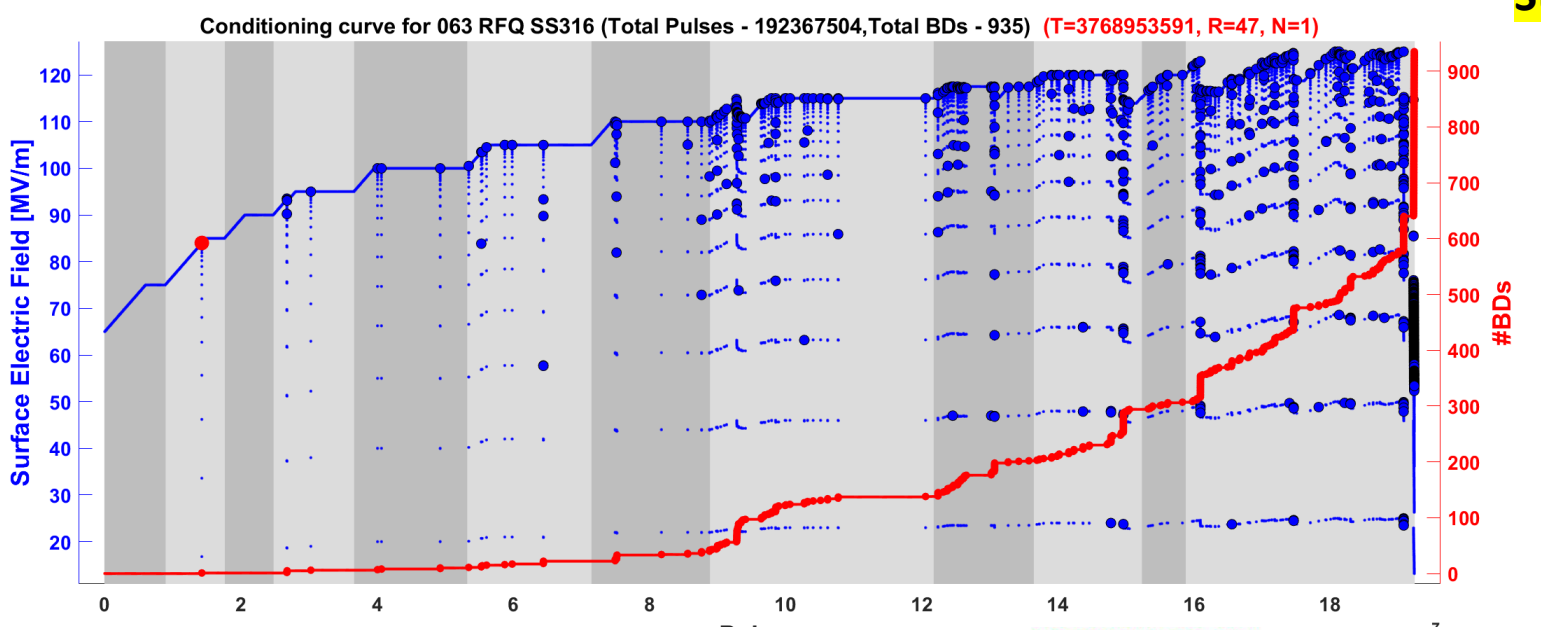


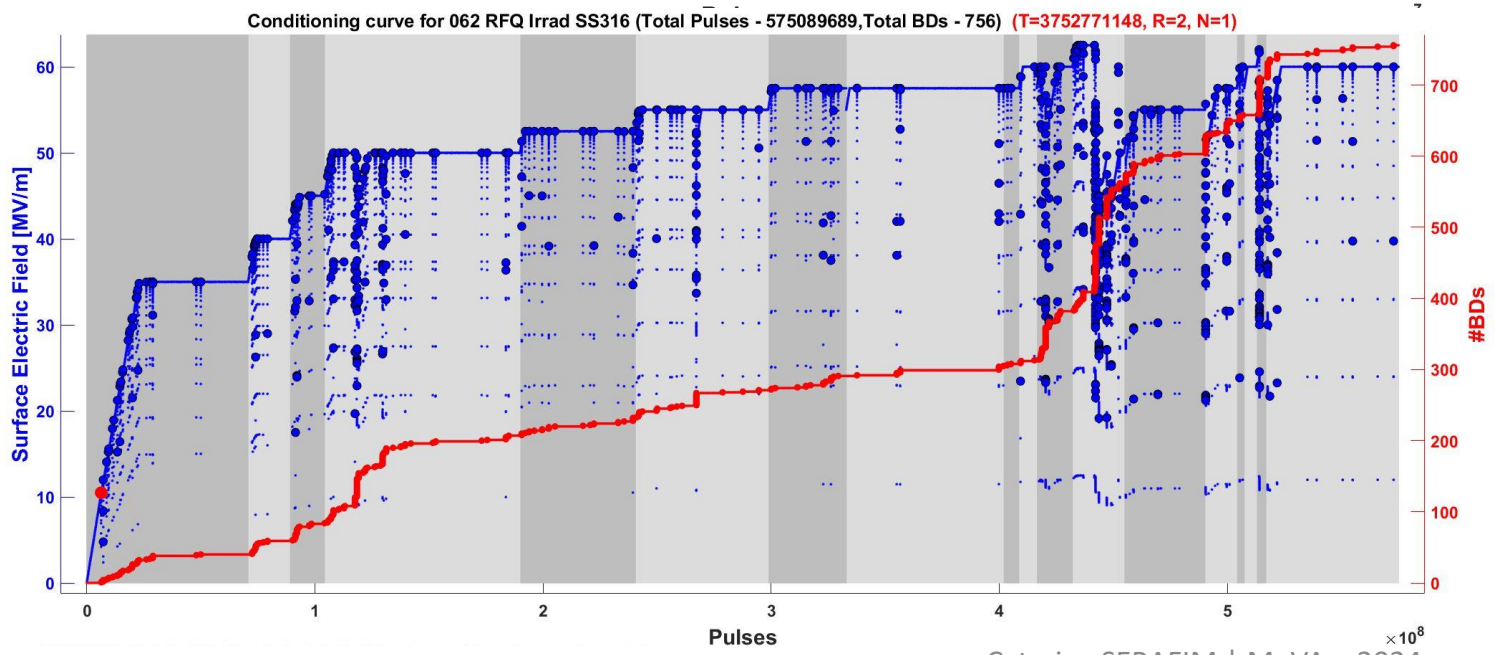




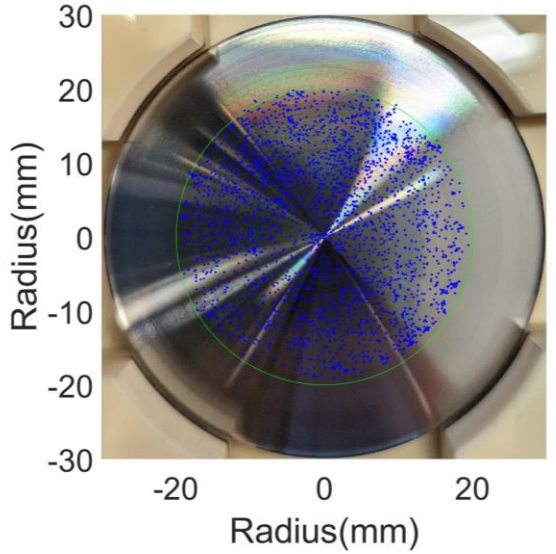


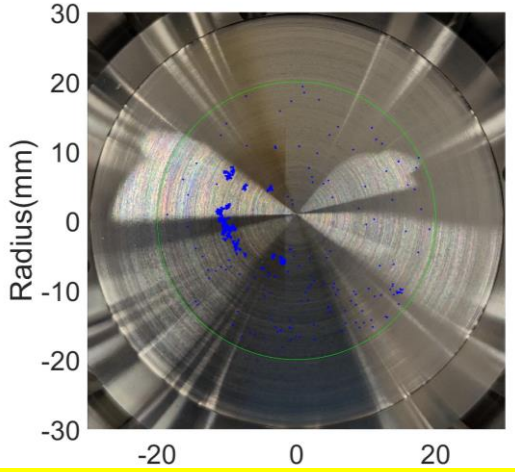






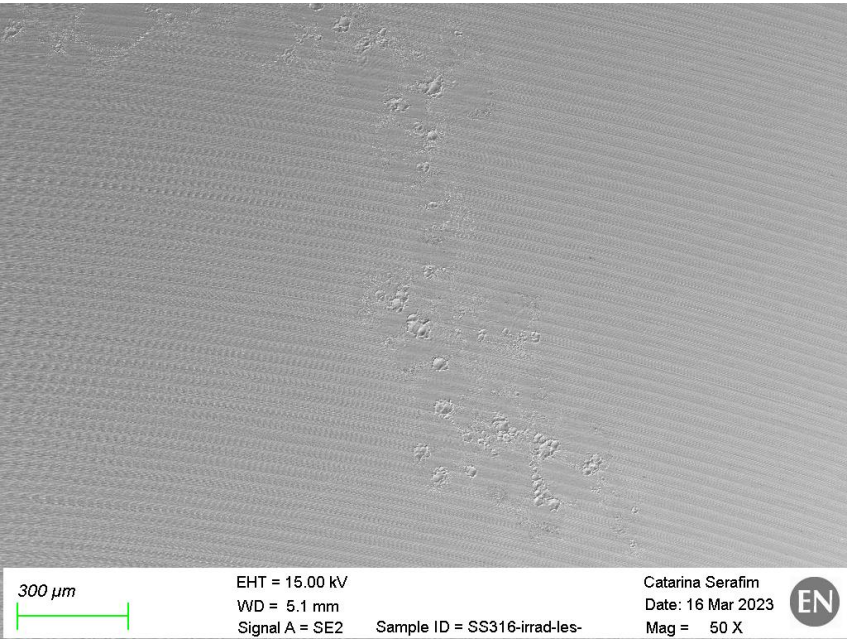
Stainless Steel electrodes non-irradiated (last 12 runs).
Maximum field 120 MV/m.

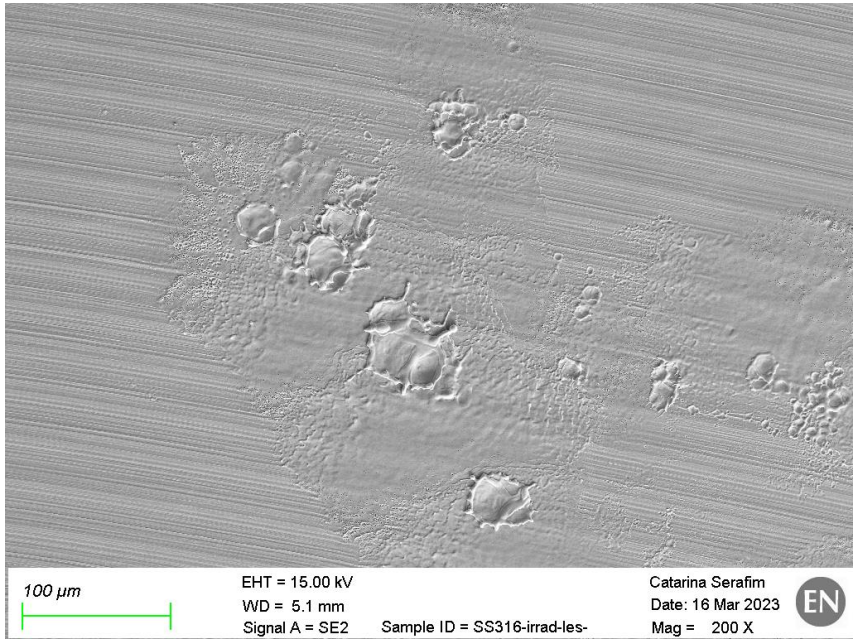


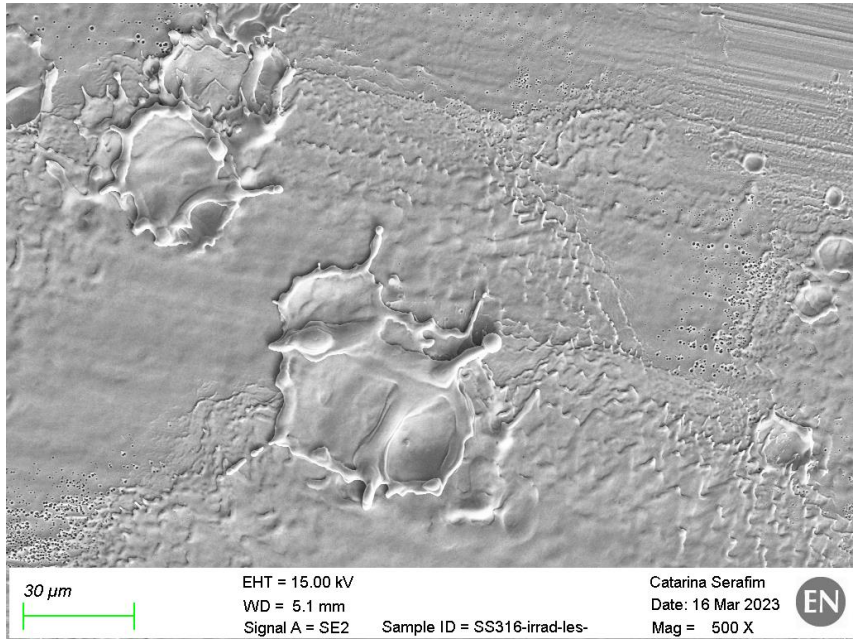


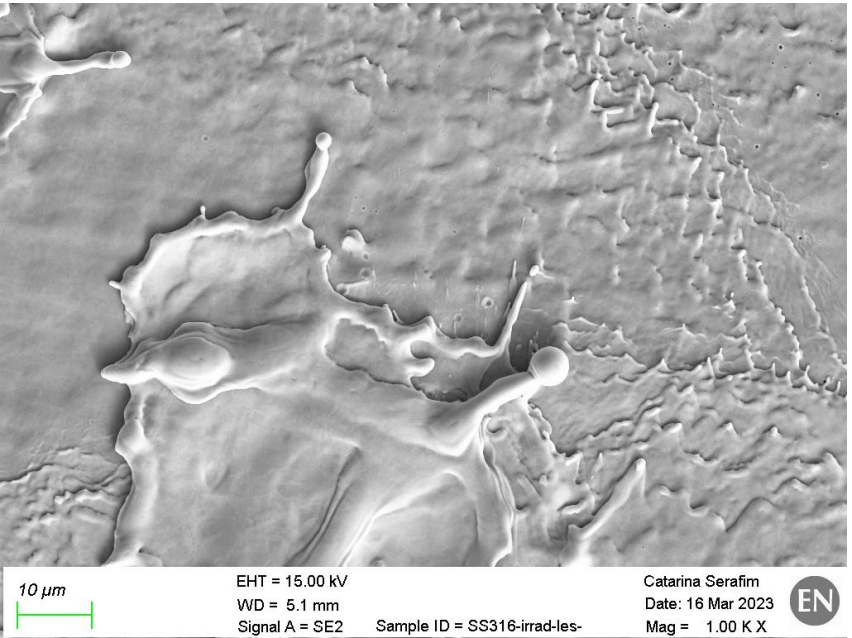
Stainless Steel electrodes irradiated
Maximum field 62 MV/m.

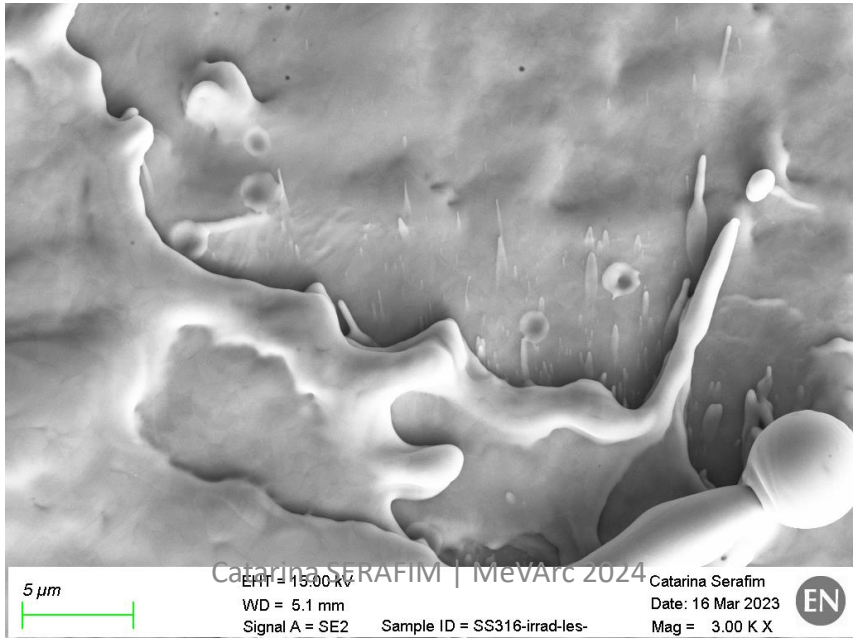
SS316 - Irradiated Electrodes - SEM

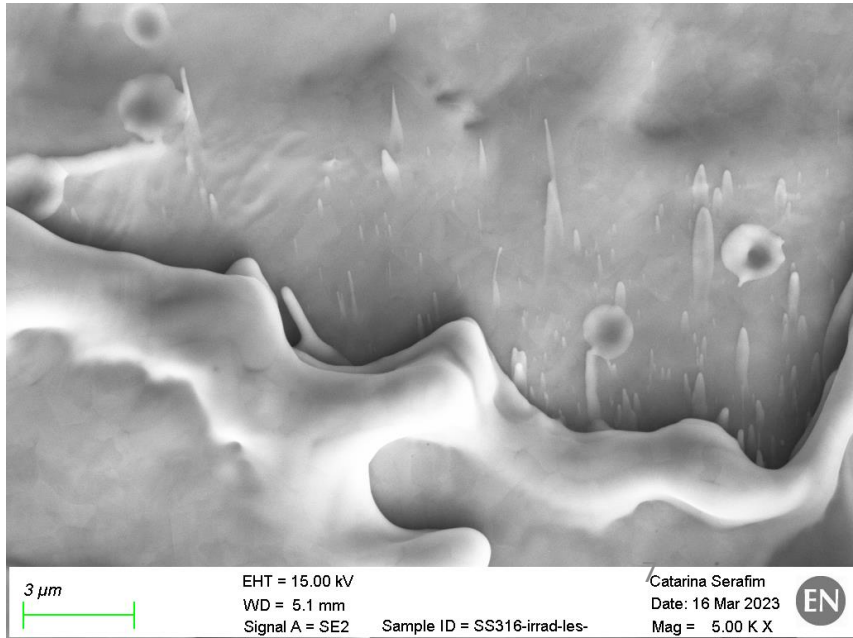


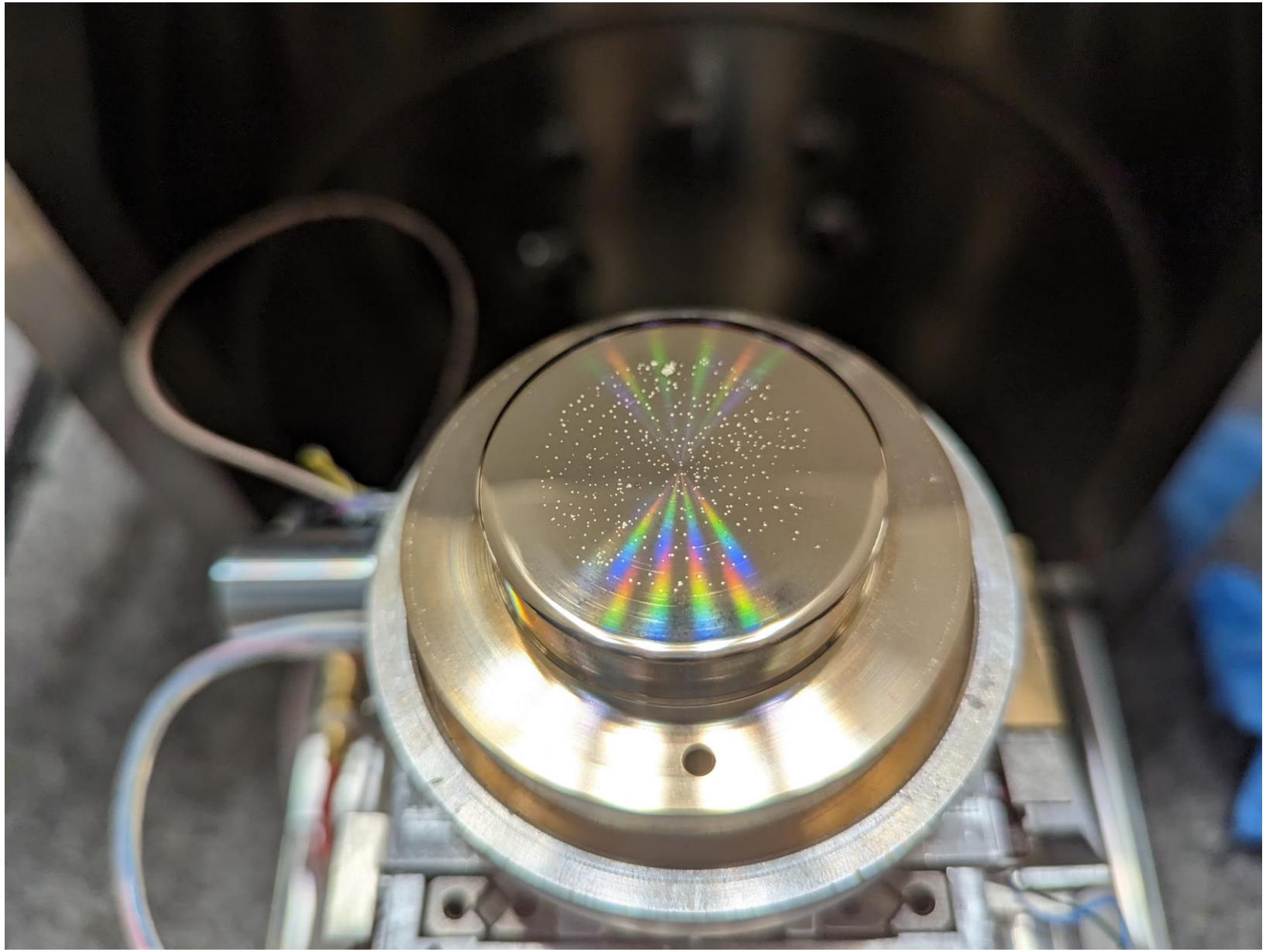




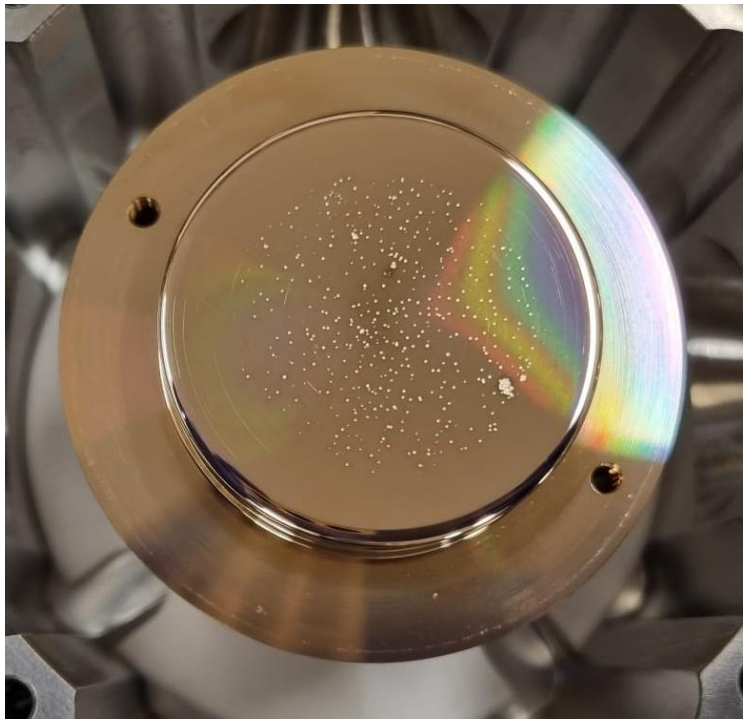




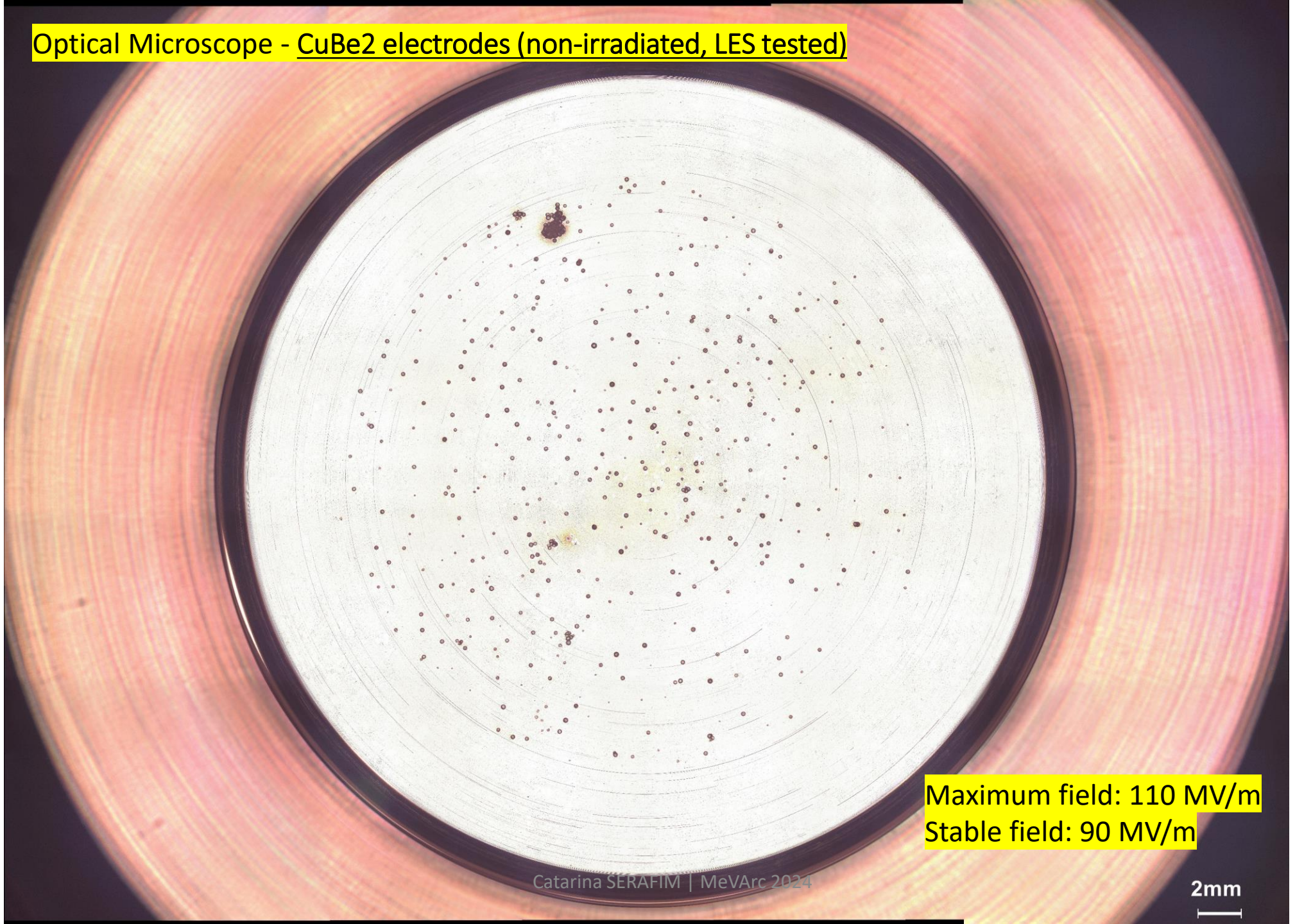




CuBe2 electrodes
(non-irradiated, LES tested)

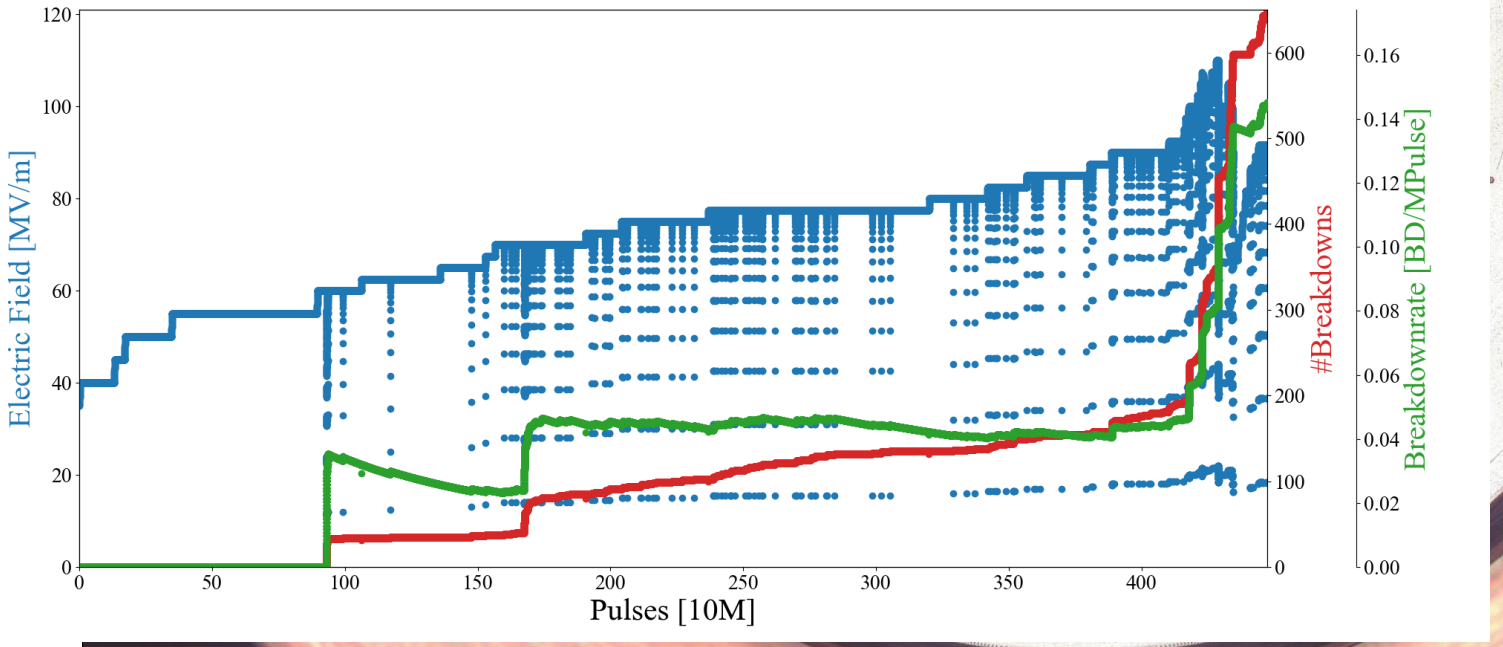


Optical Microscope - CuBe2 electrodes (non-irradiated, LES tested)



Maximum field: 110 MV/m
Stable field: 90 MV/m

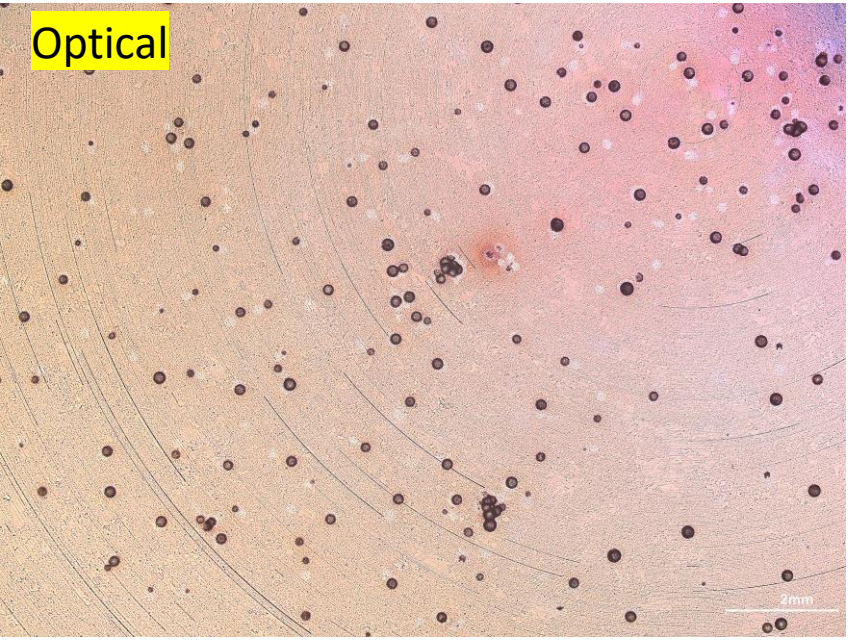
Optical Microscope - CuBe2 electrodes (non-irradiated, LES tested)

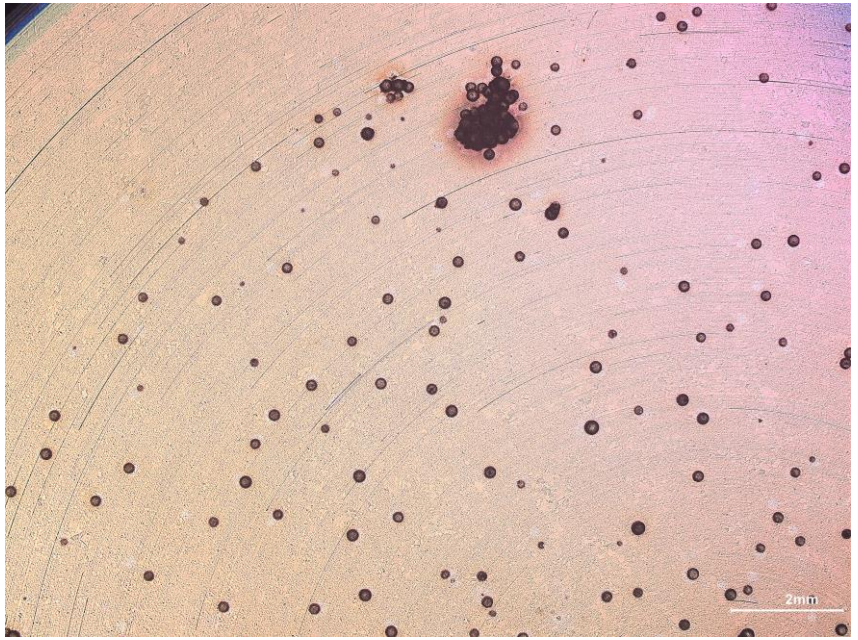


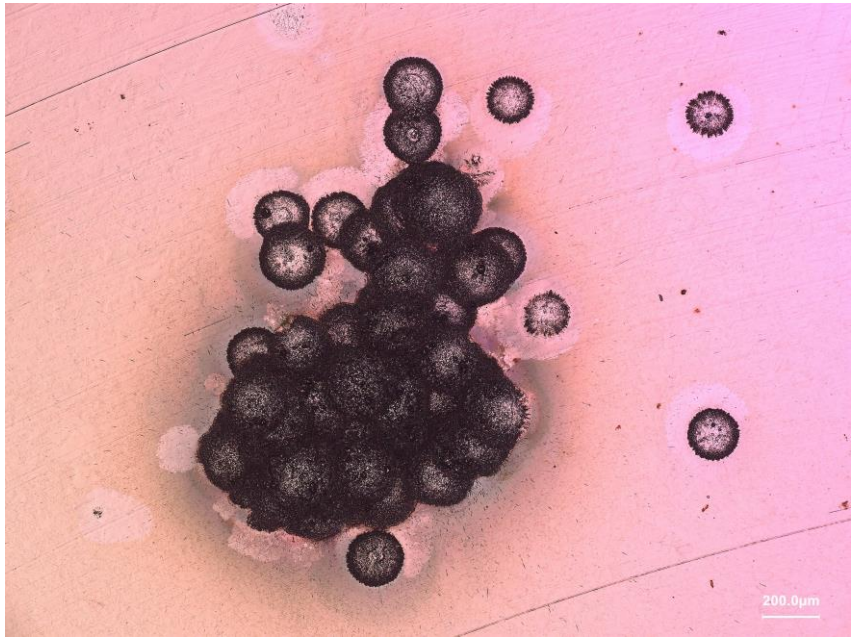
Maximum field: 110 MV/m
Stable field: 90 MV/m

2mm

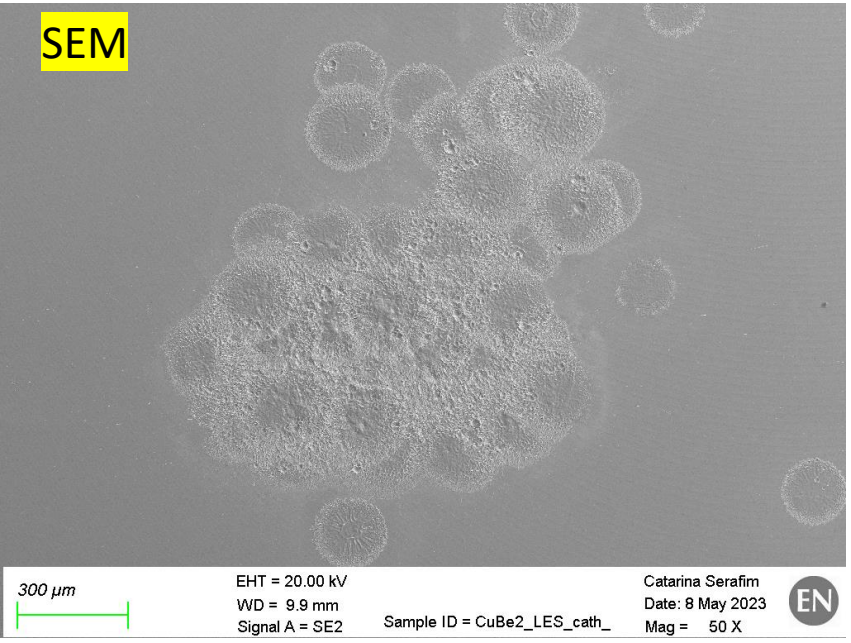
Optical

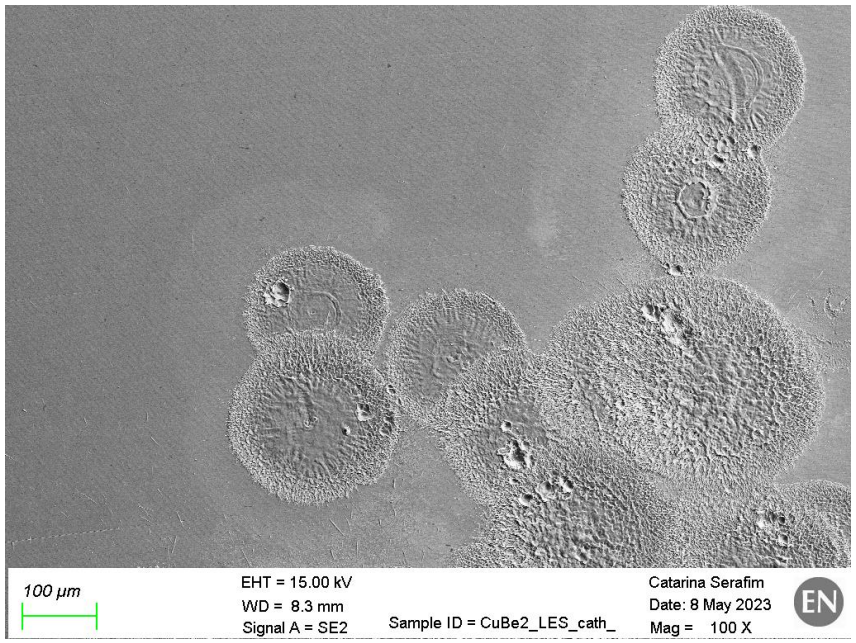

2mm

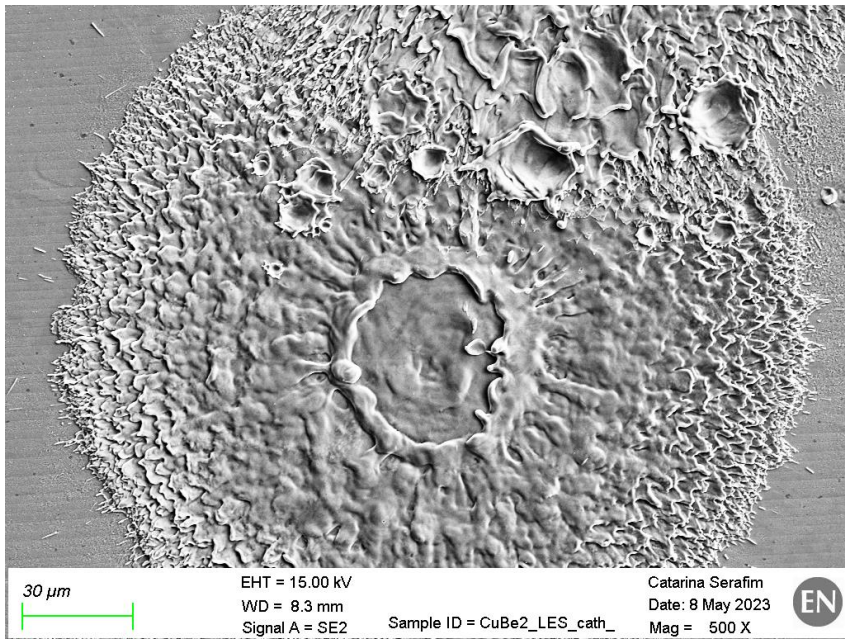

2mm


200.0µm

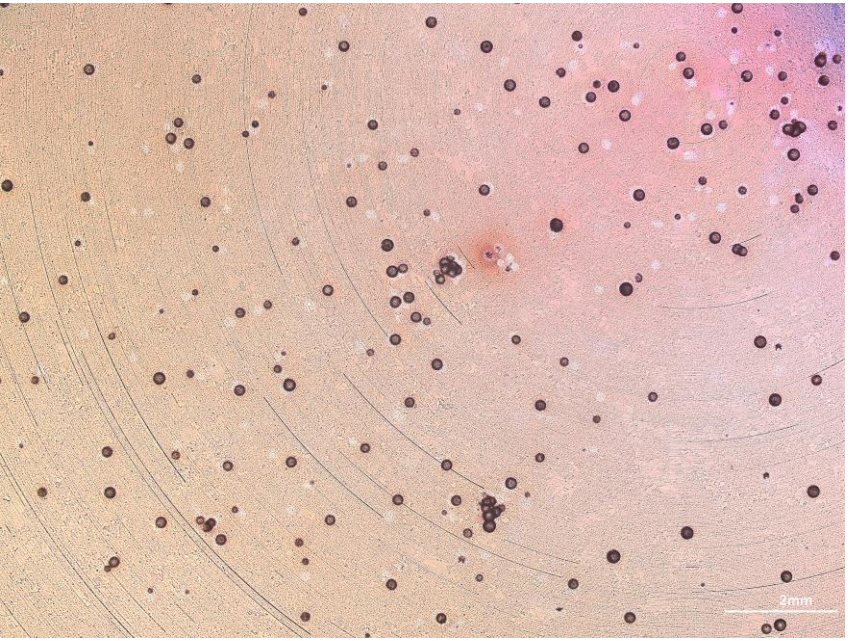
SEM

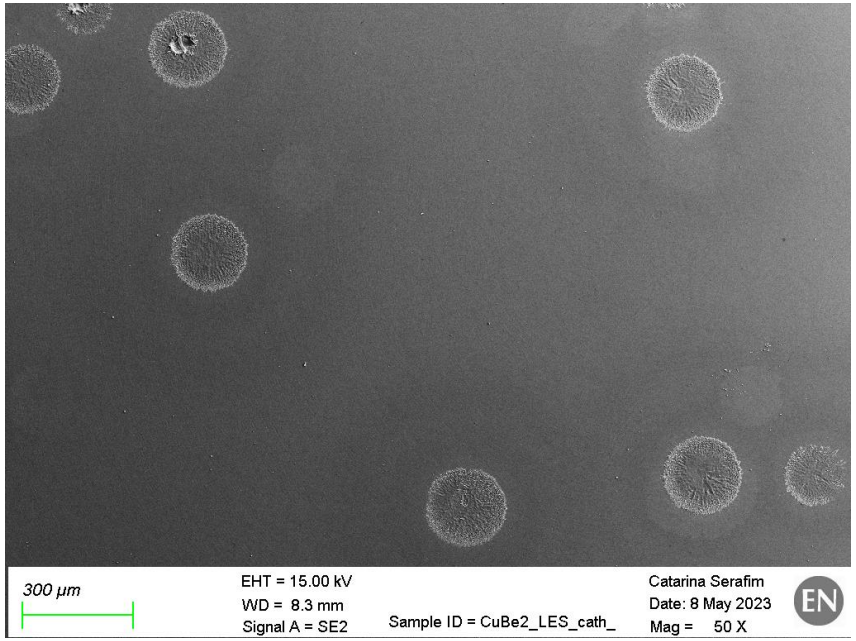

300 µm
EHT = 20.00 kV
WD = 9.9 mm
Signal A = SE2
Sample ID = CuBe2_LES_cath_
Catarina Serafim
Date: 8 May 2023
Mag = 50 X
EN

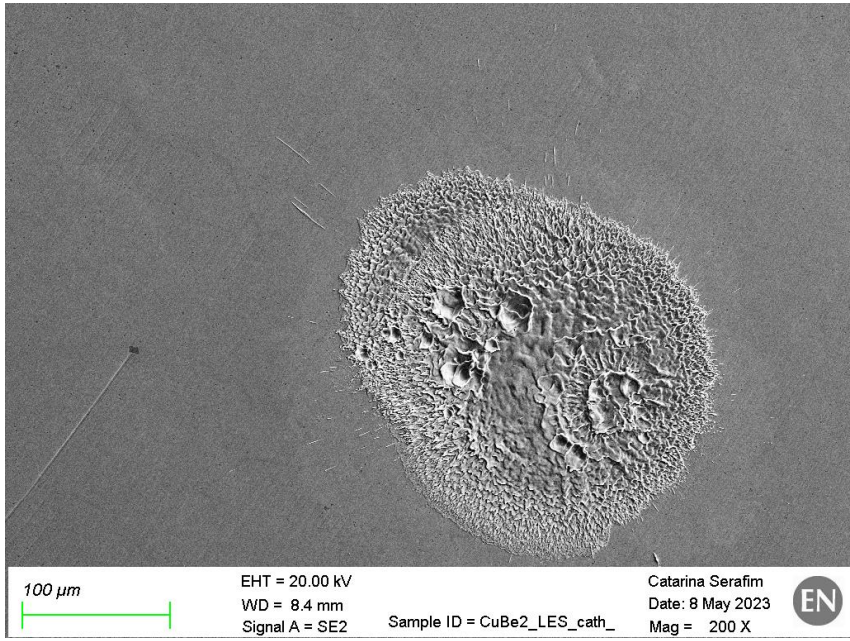

100 µm
EHT = 15.00 kV
WD = 8.3 mm
Signal A = SE2
Sample ID = CuBe2_LES_cath_
Catarina Serafim
Date: 8 May 2023
Mag = 100 X
EN

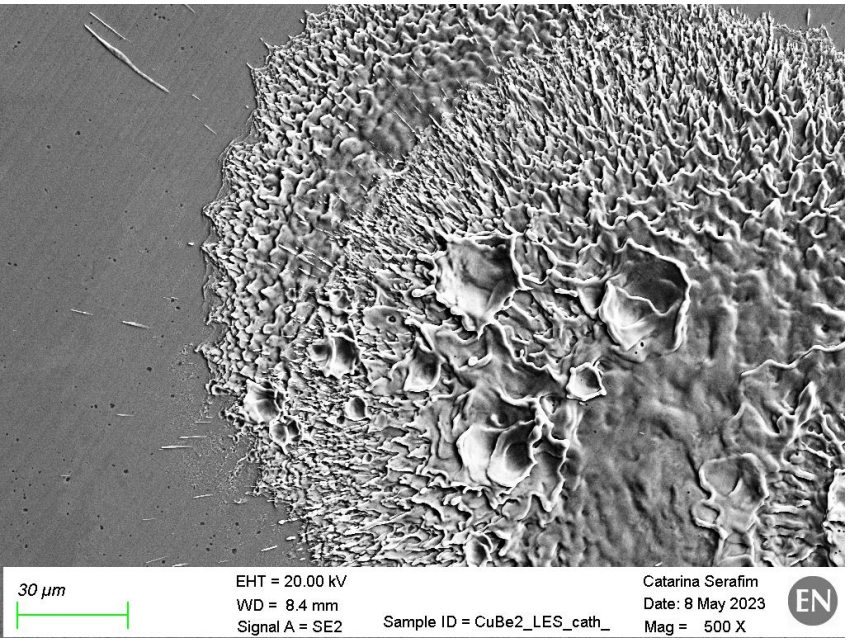

30 µm
EHT = 15.00 kV
WD = 8.3 mm
Signal A = SE2
Sample ID = CuBe2_LES_cath_
Catarina Serafim
Date: 8 May 2023
Mag = 500 X
EN

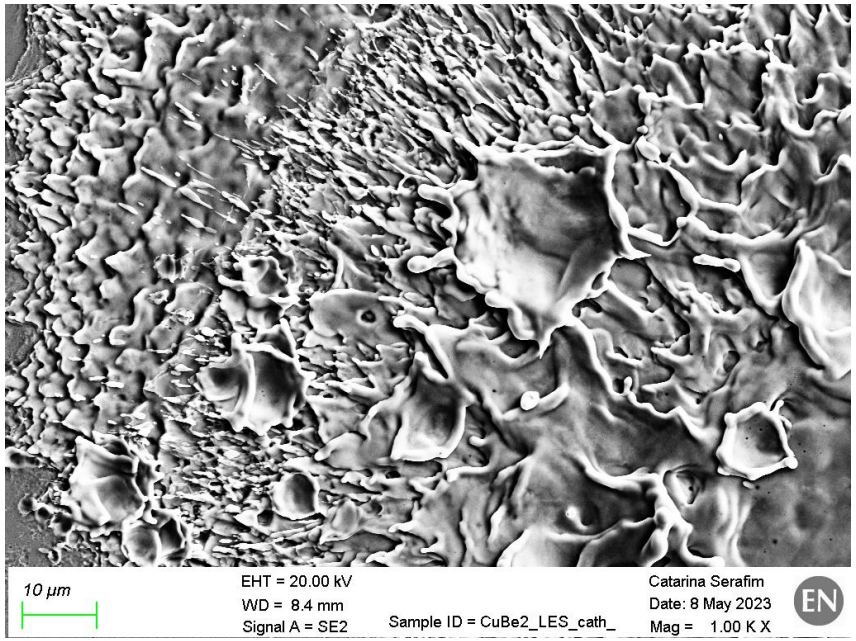
SEM CuBe2 electrodes (non-irradiated and LES tested)

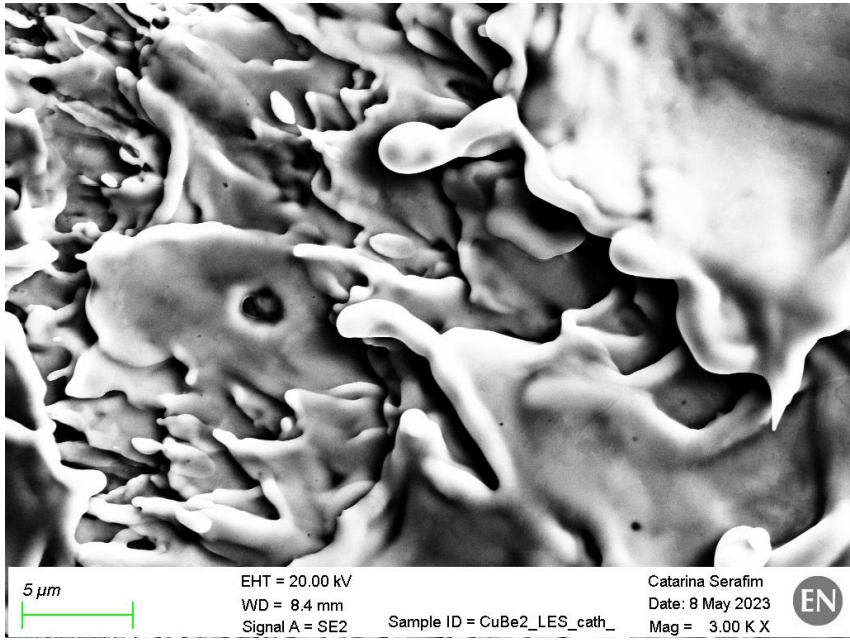




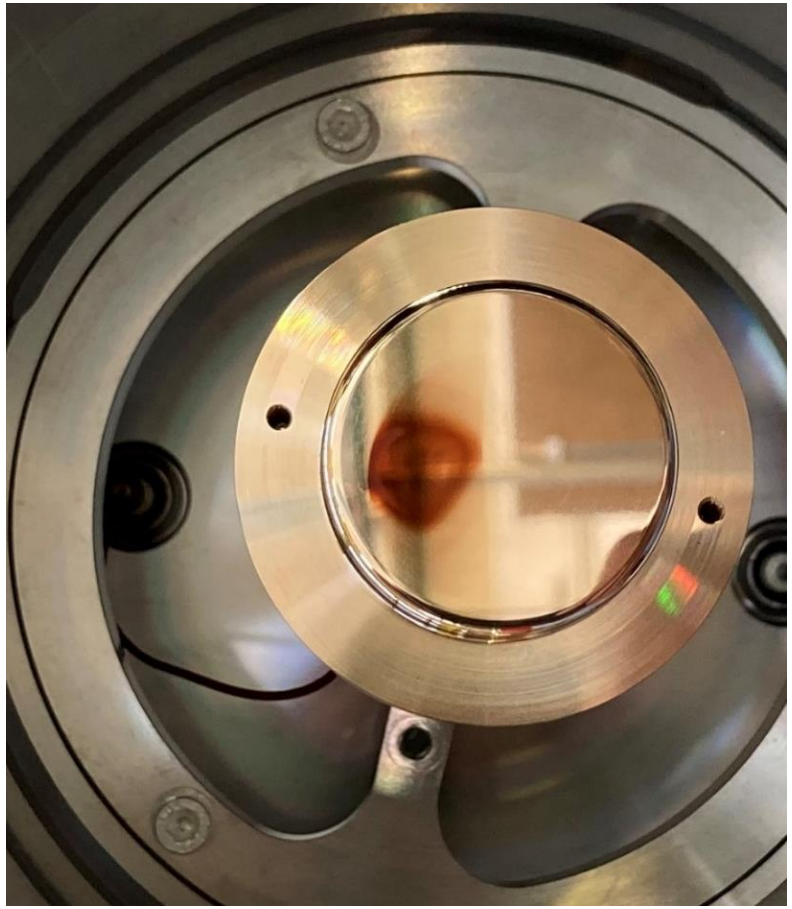




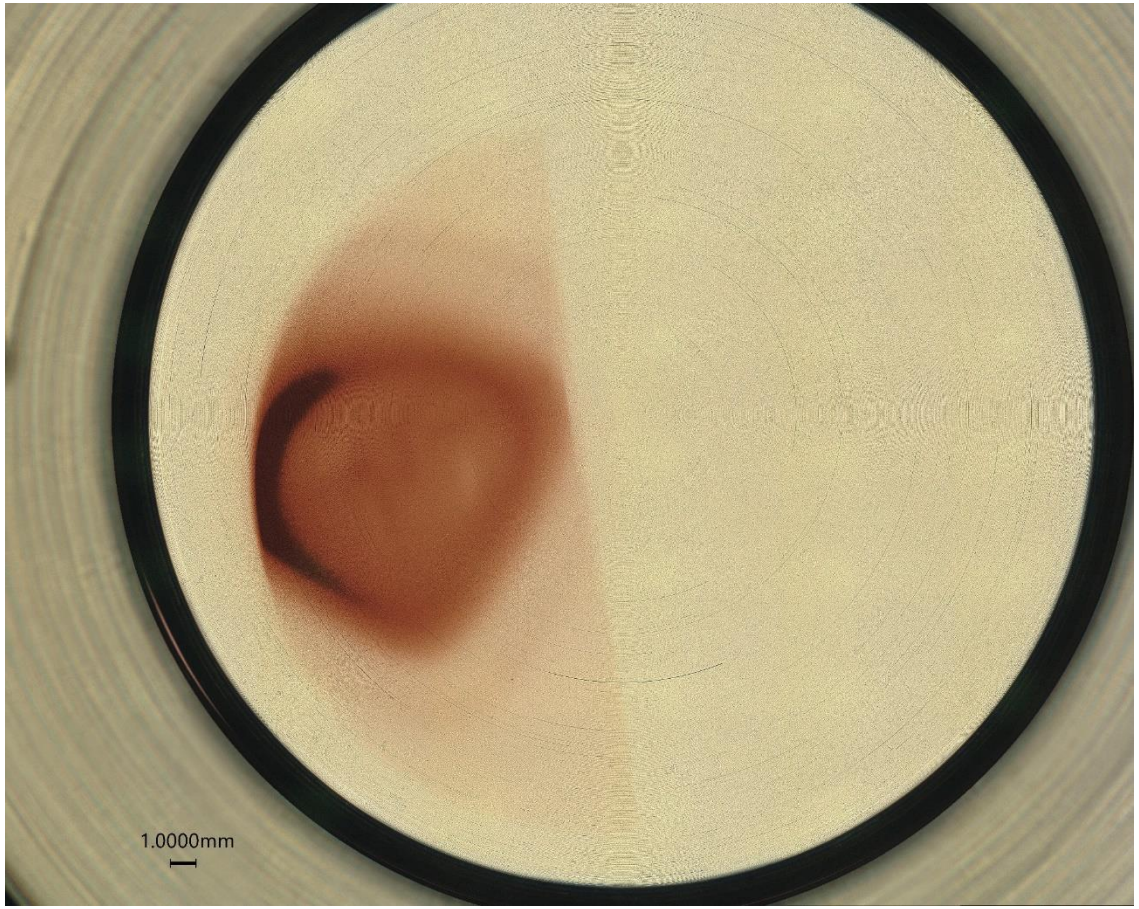




CuBe2 cathode – irradiated



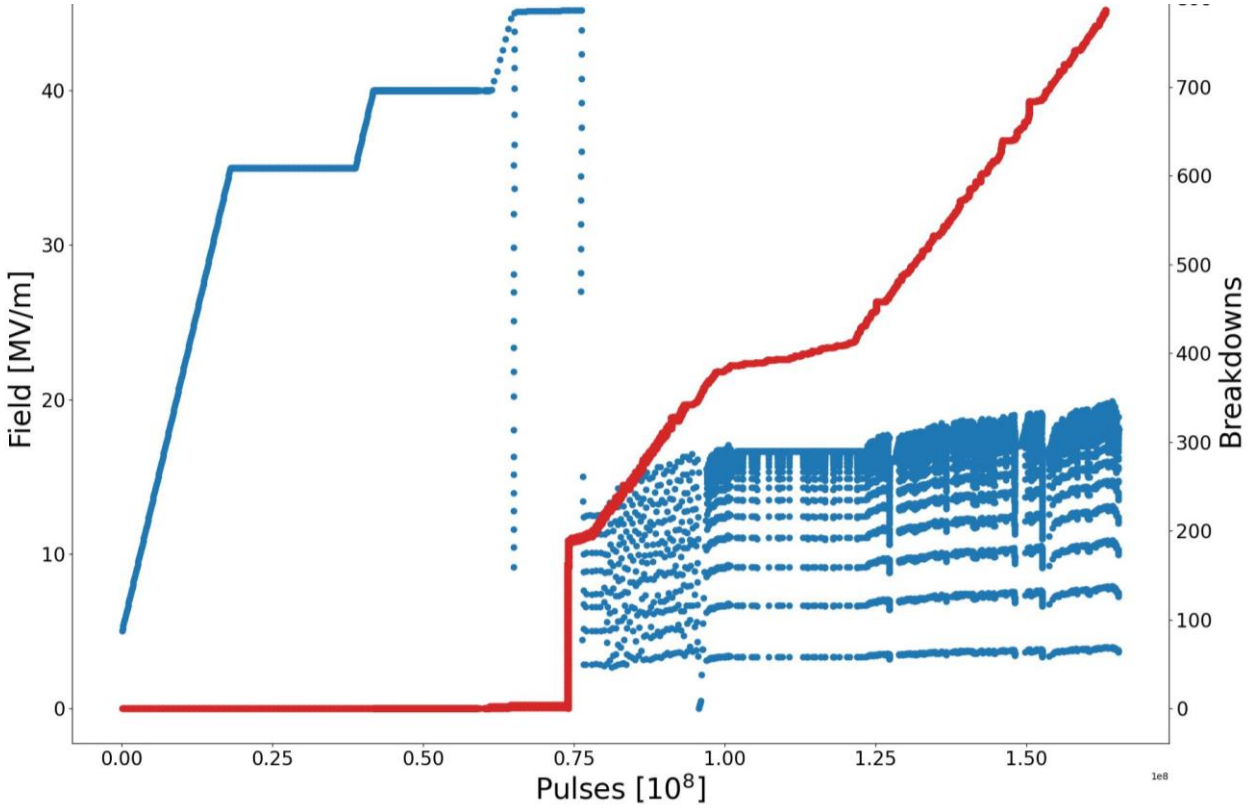
Dismounting of CuBe cathode after irradiation



Optical imaging of the surface using lens 80x.


CuBe2 cathode – after irradiation


CuBe2 cathode irradiated after LES testing
This electrodes have reached a maximum field of 45 MV/m.


Field [MV/m]
Breakdowns
Pulses [10^8]
0
10
20
30
40
0
100
200
300
400
500
600
700
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1e8

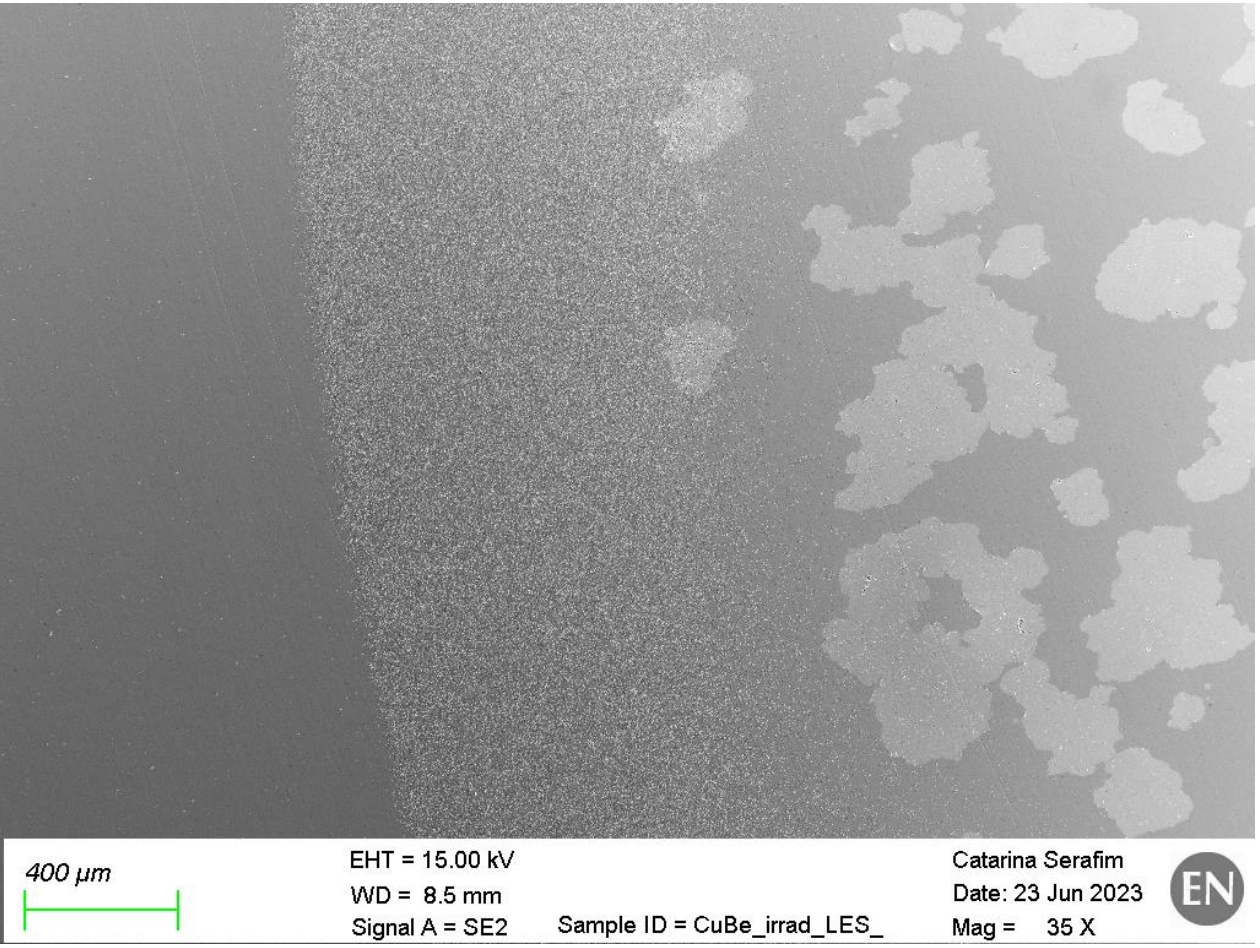

CuBe2 cathode irradiated after LES testing
This electrodes have reached a maximum field of 45 MV/m.

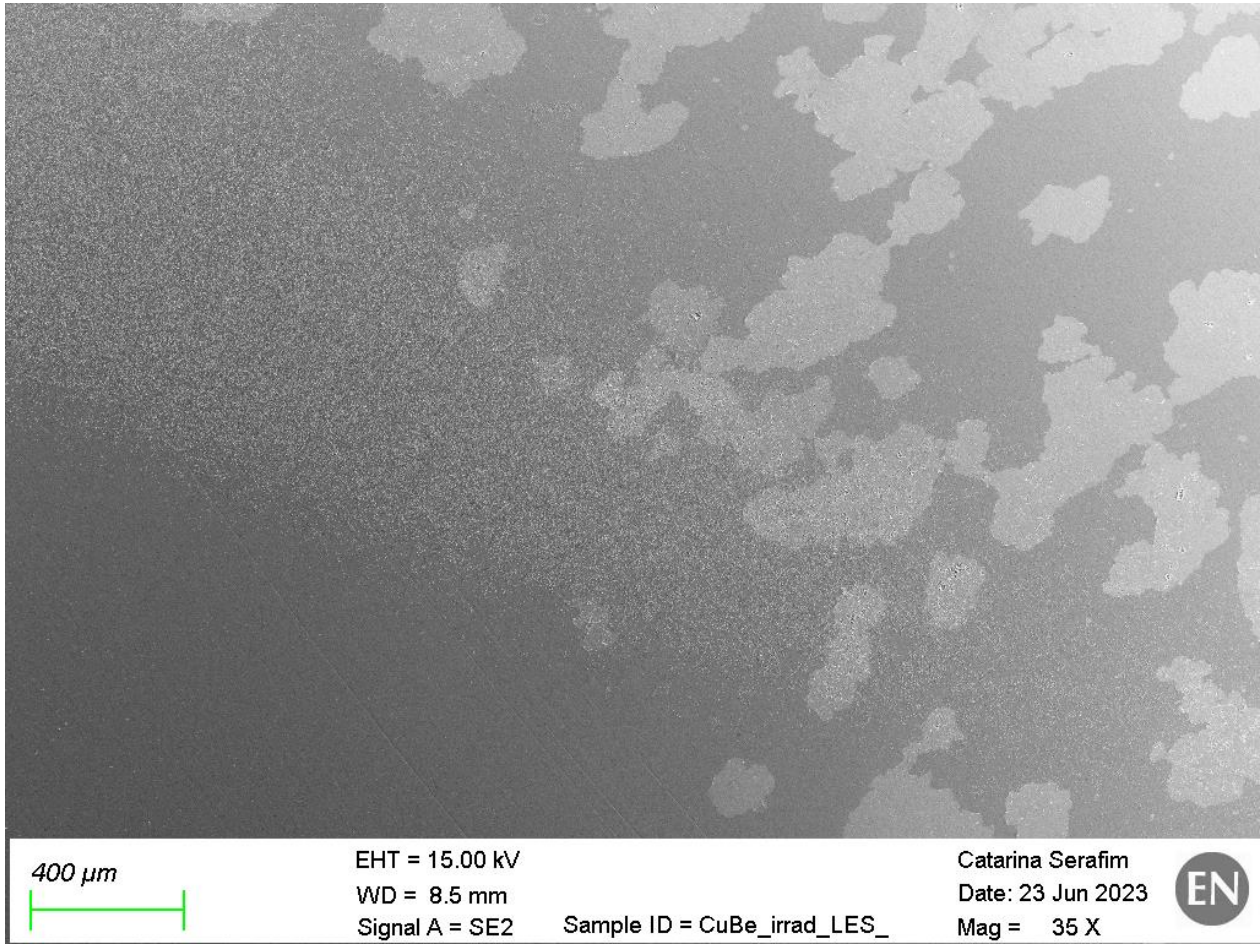
Conclusion of LES Tests for all Materials

	Non-irradiated		Irradiated	
	Max Field (MV/m)	Stable Field (MV/m)	Max Field (MV/m)	Stable Field (MV/m)
SS316LN	120	120	62.5	60
CuBe2	110	100	40	16.7
TiAl6V4	110	100	95	90
CuCr1Zr	87.5	82.5	29	25
Cu-OFE	80	80	80	80
Nb (BCP)	94	80	42	21.7
Ta	60	60	38.1	24

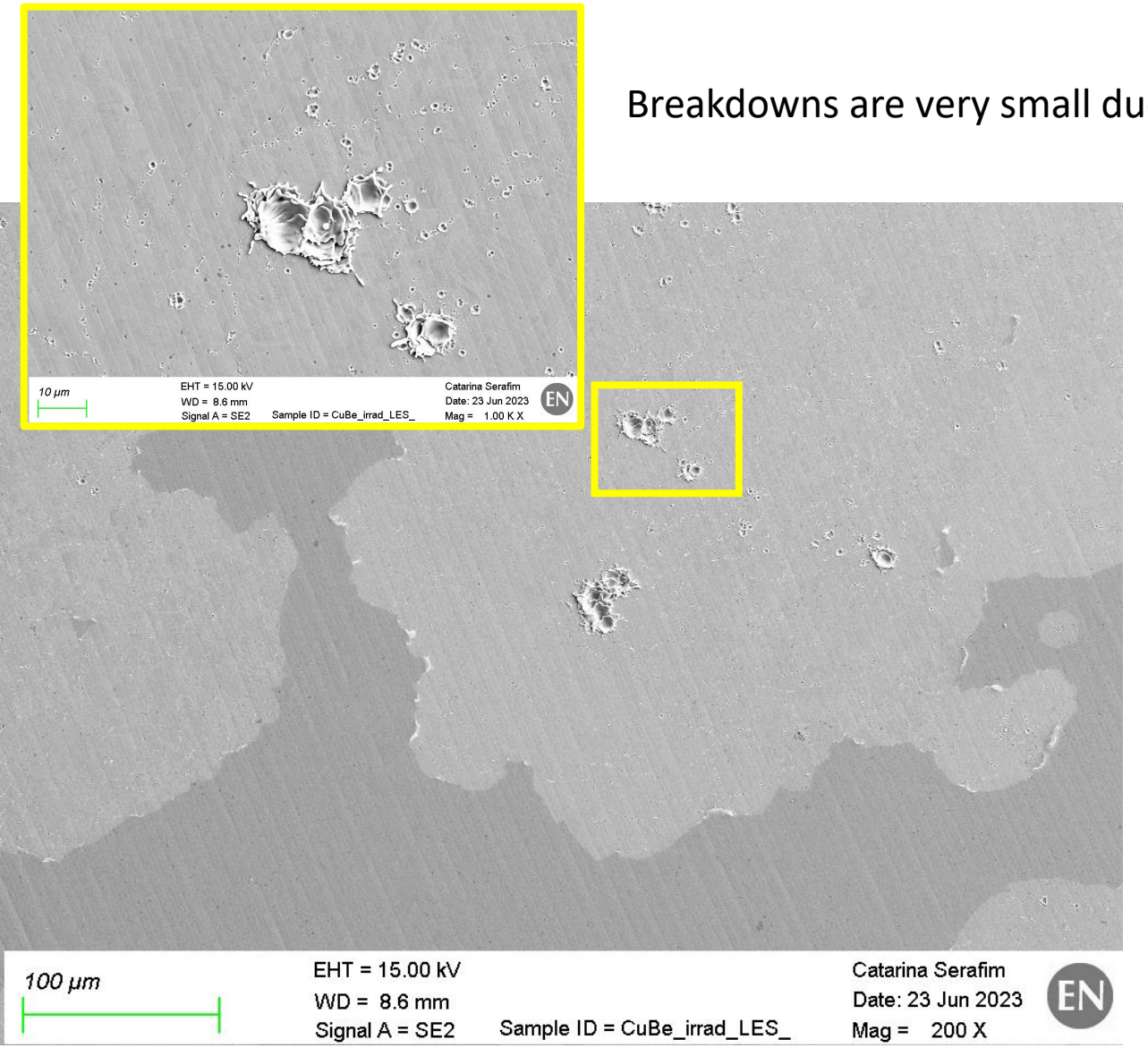
- ✓ Cu-OFE, TiAl6V4, CuBe2 and SS316 seem to be the best materials in reaching a stable field.
- ✓ We see very big differences in the fields reached between irradiated pairs and non irradiated pairs.
- ✓ Carbon deposition from irradiation seems to be directly correlated with breakdowns appearance.
- ✓ The blistering effect from irradiation doesn't seem to provoke a decrease of performance on the electrodes.

The following imagens are from the irradiated cathode, submitted to high pulsing test.
Similar to previous irradiations, we have observed a carbon content inside the irradiated zone, around 10%.
In the irradiated zone, exfoliation of this carbon layer was observed (white spots).





Breakdowns are very small due to the low field achieved.



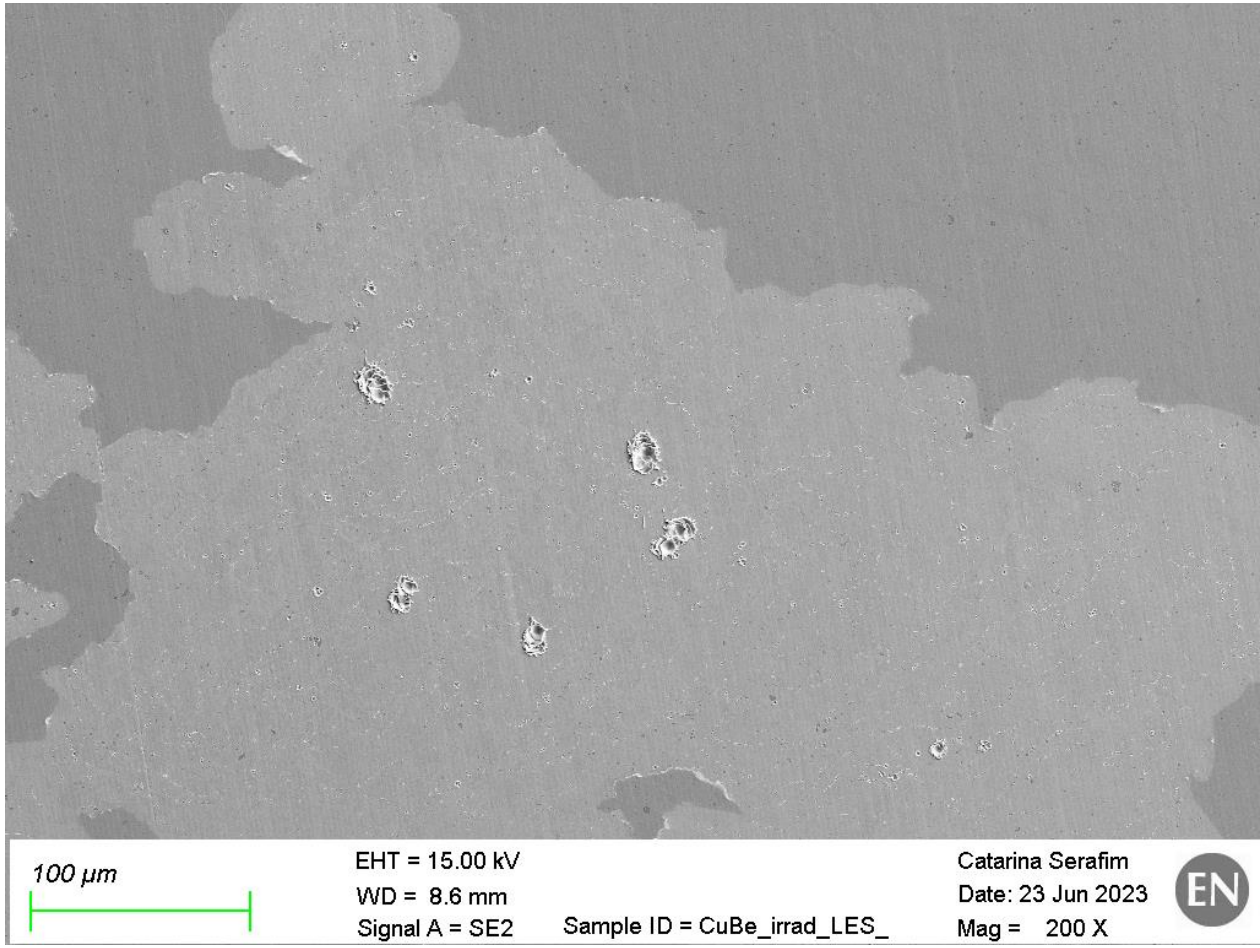
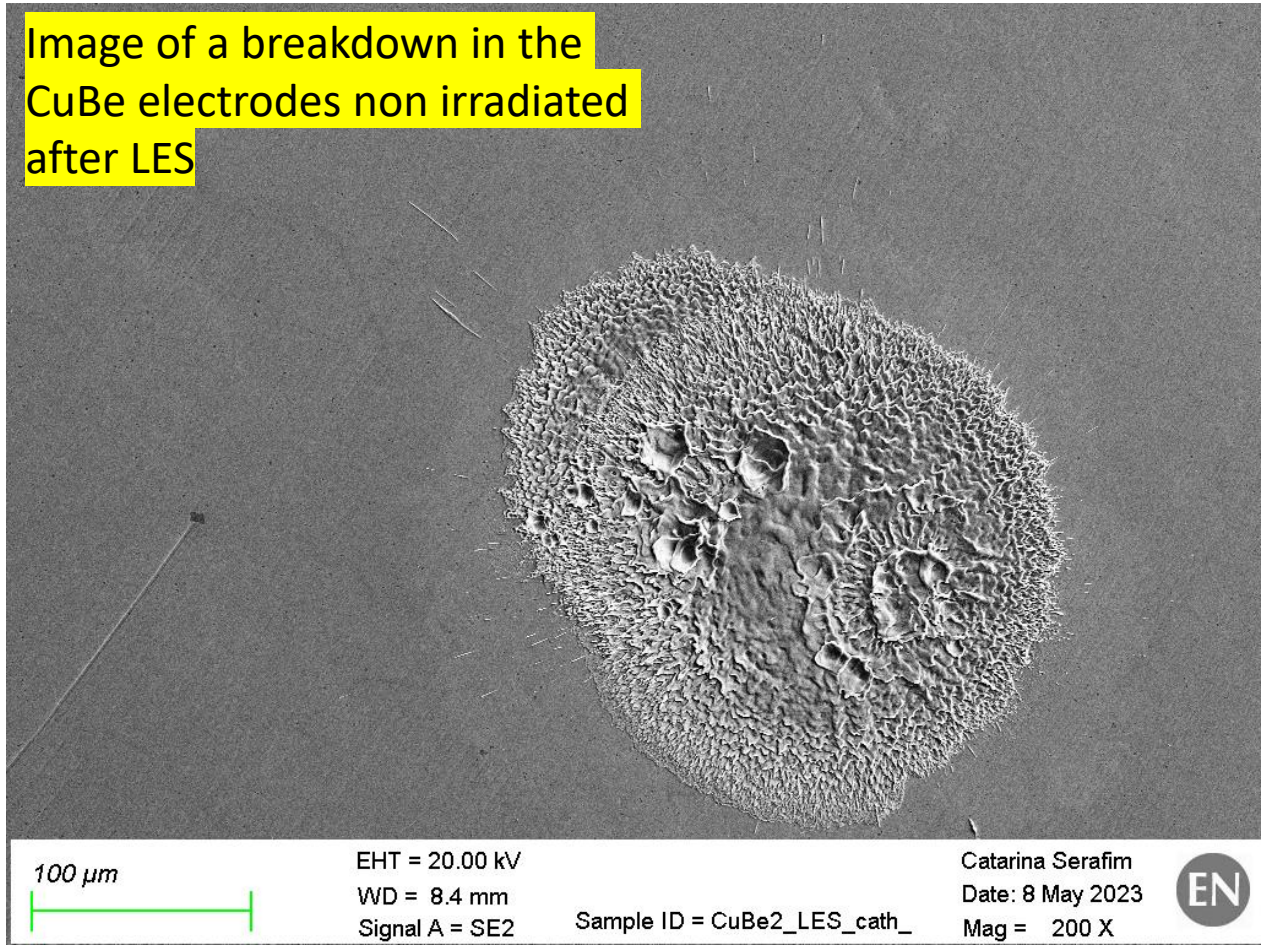
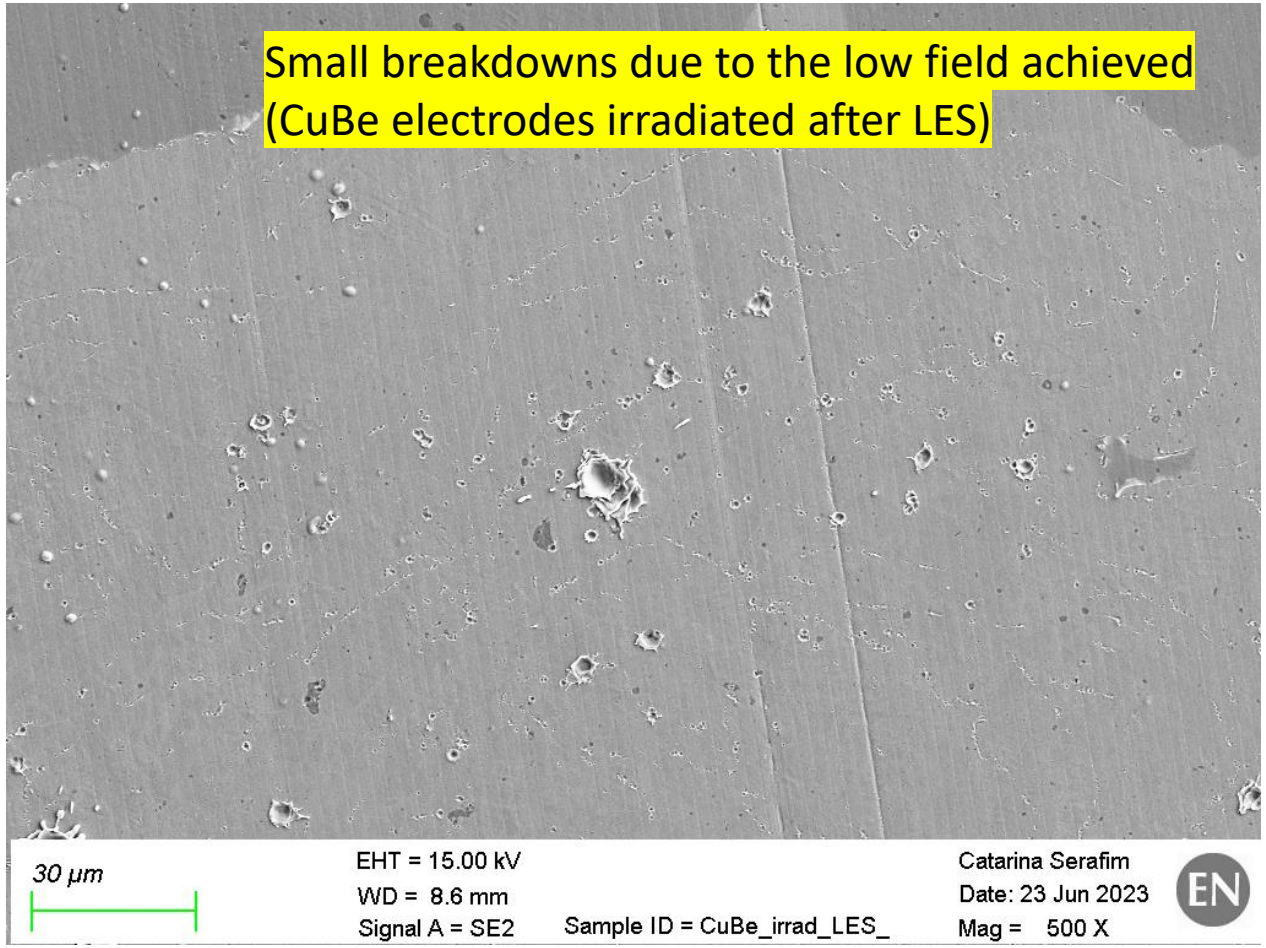


Image of a breakdown in the CuBe electrodes non irradiated after LES

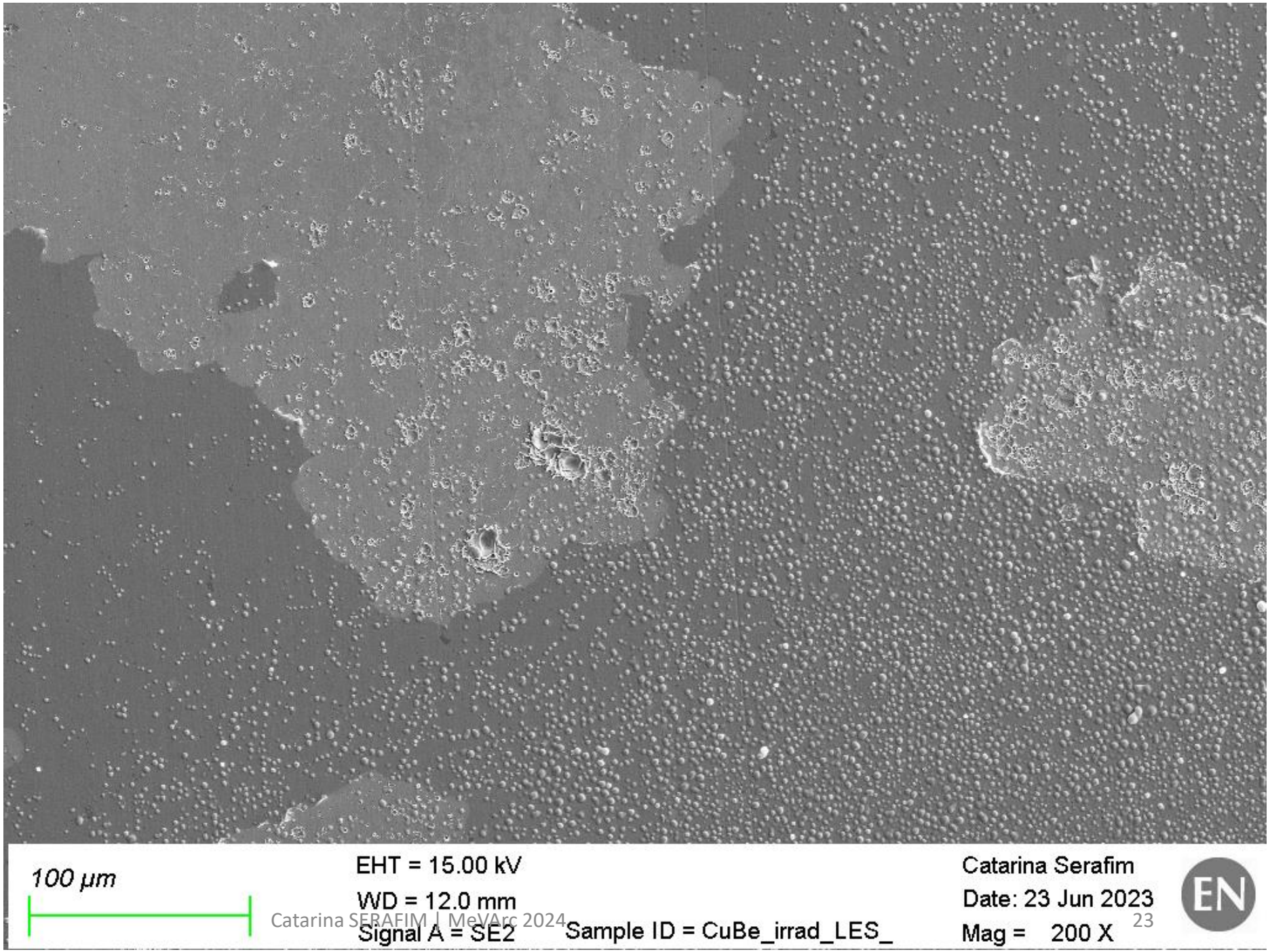


Small breakdowns due to the low field achieved (CuBe electrodes irradiated after LES)

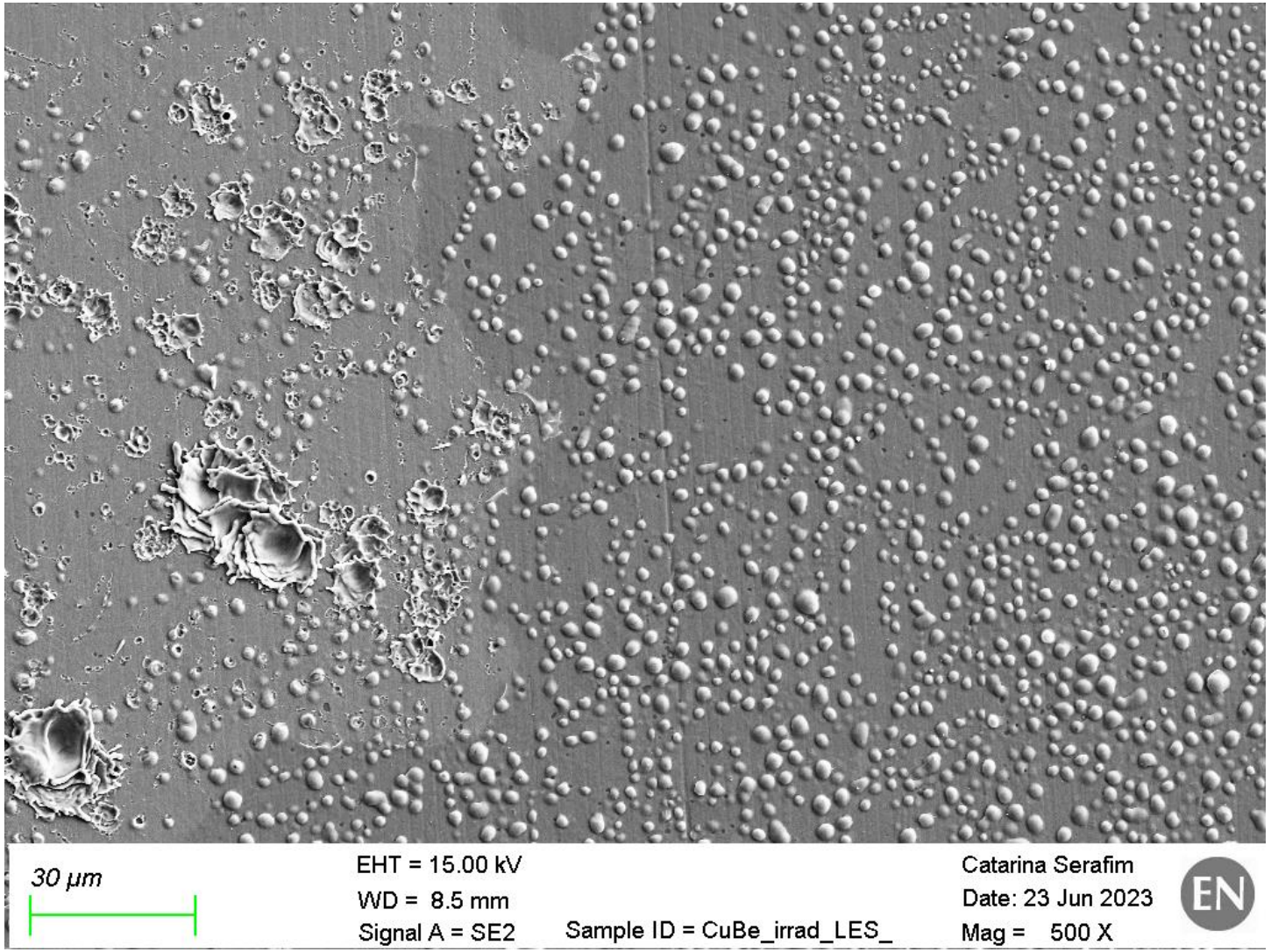


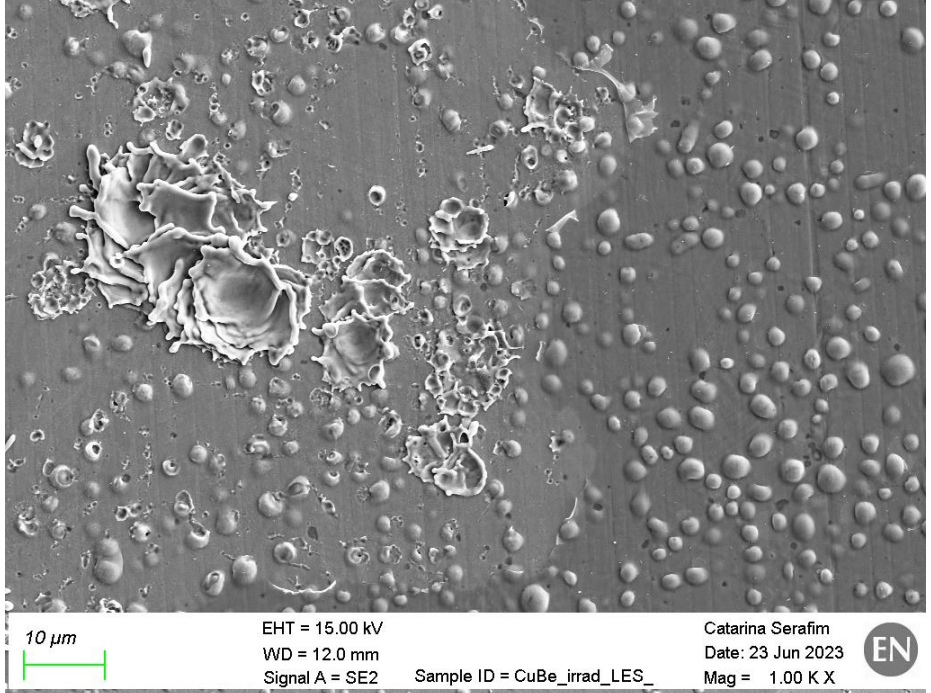
We have observed that the breakdowns are only concentrated inside the exfoliated zones.

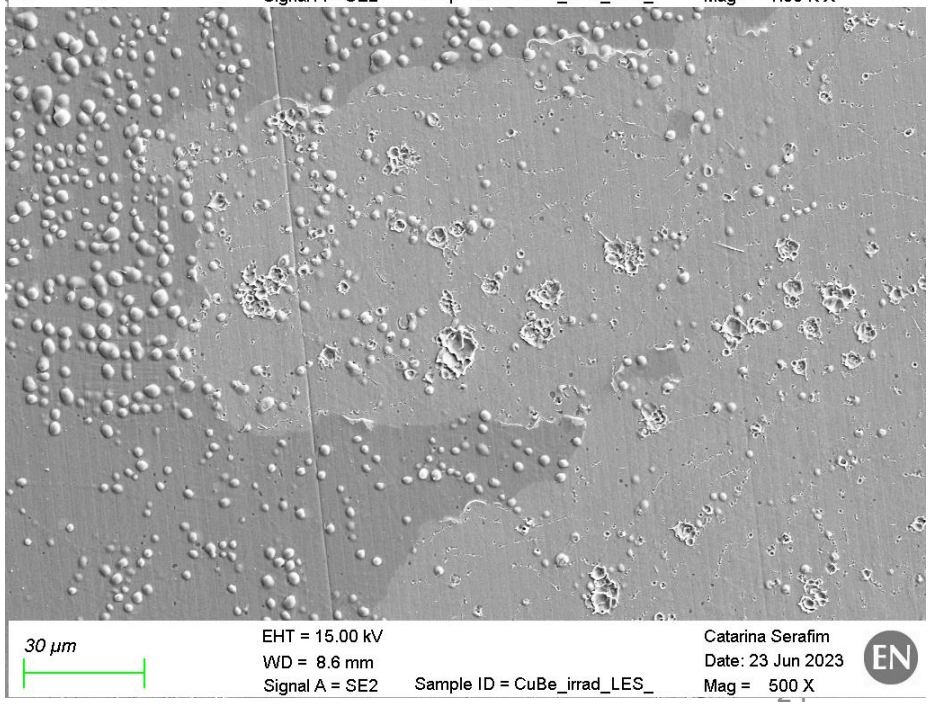
The zones without those exfoliations, i.e. with a protective carbon layer, are free from breakdowns, even in the zones with high density of blisters.

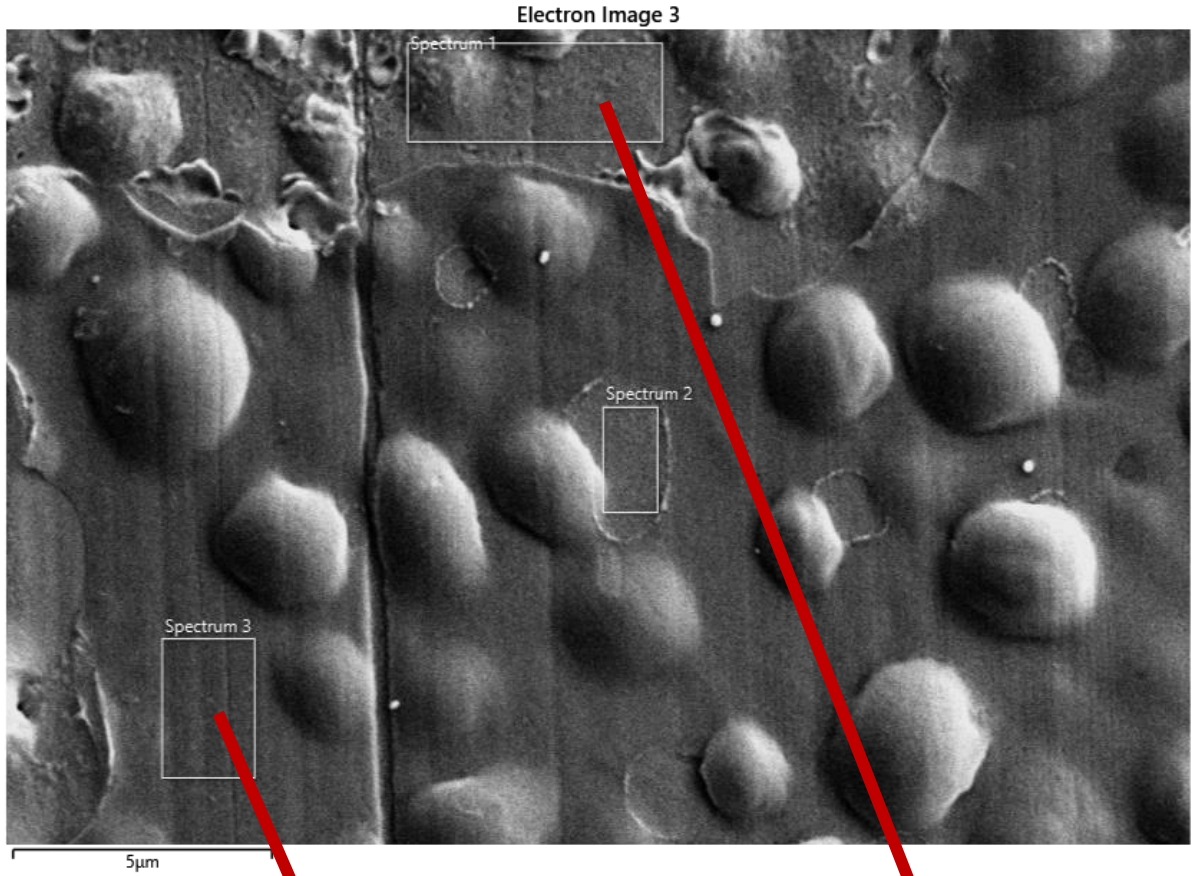


Zone with a higher density of blisters.
The blisters have no influence on the triggering of breakdowns.





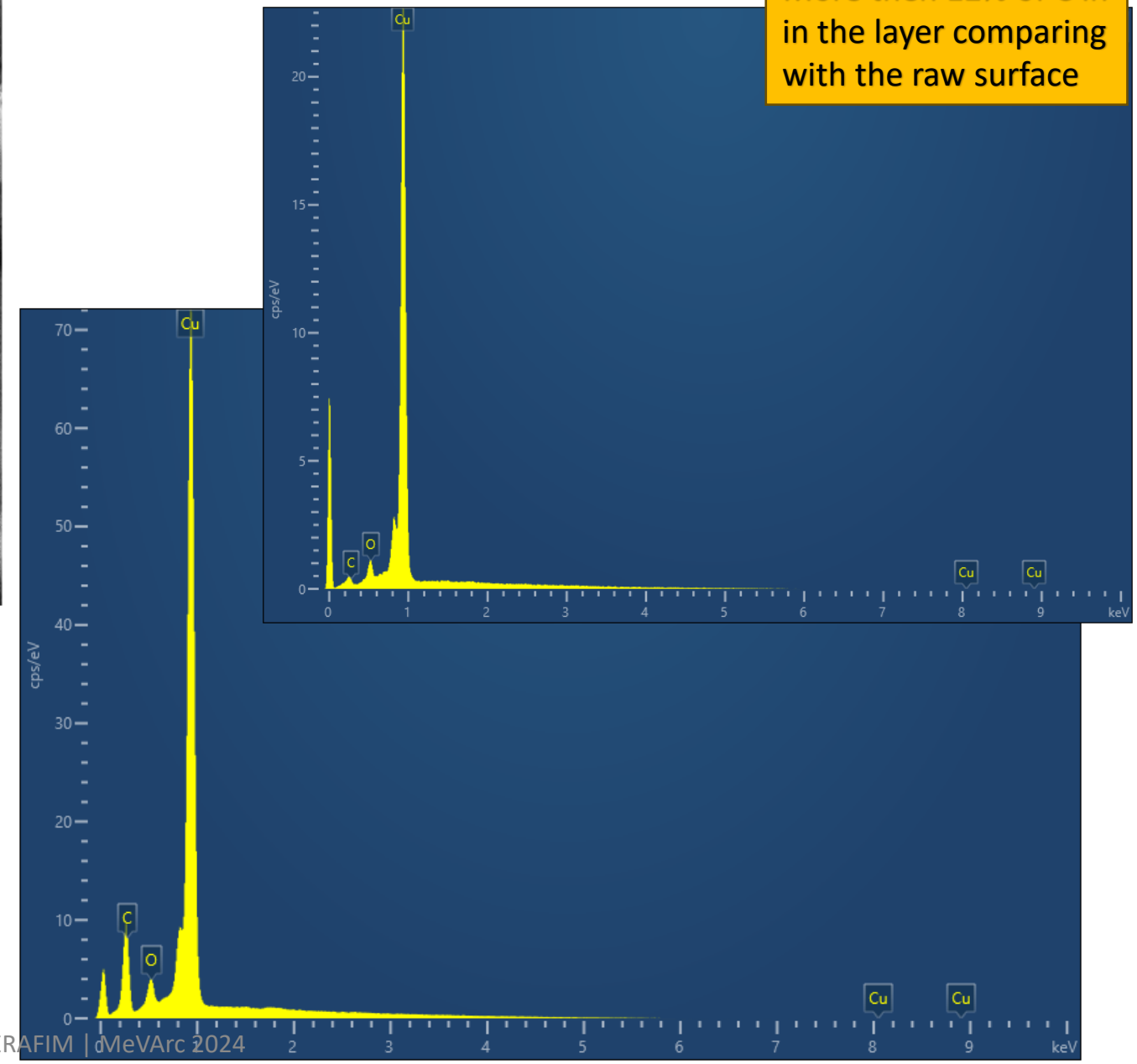




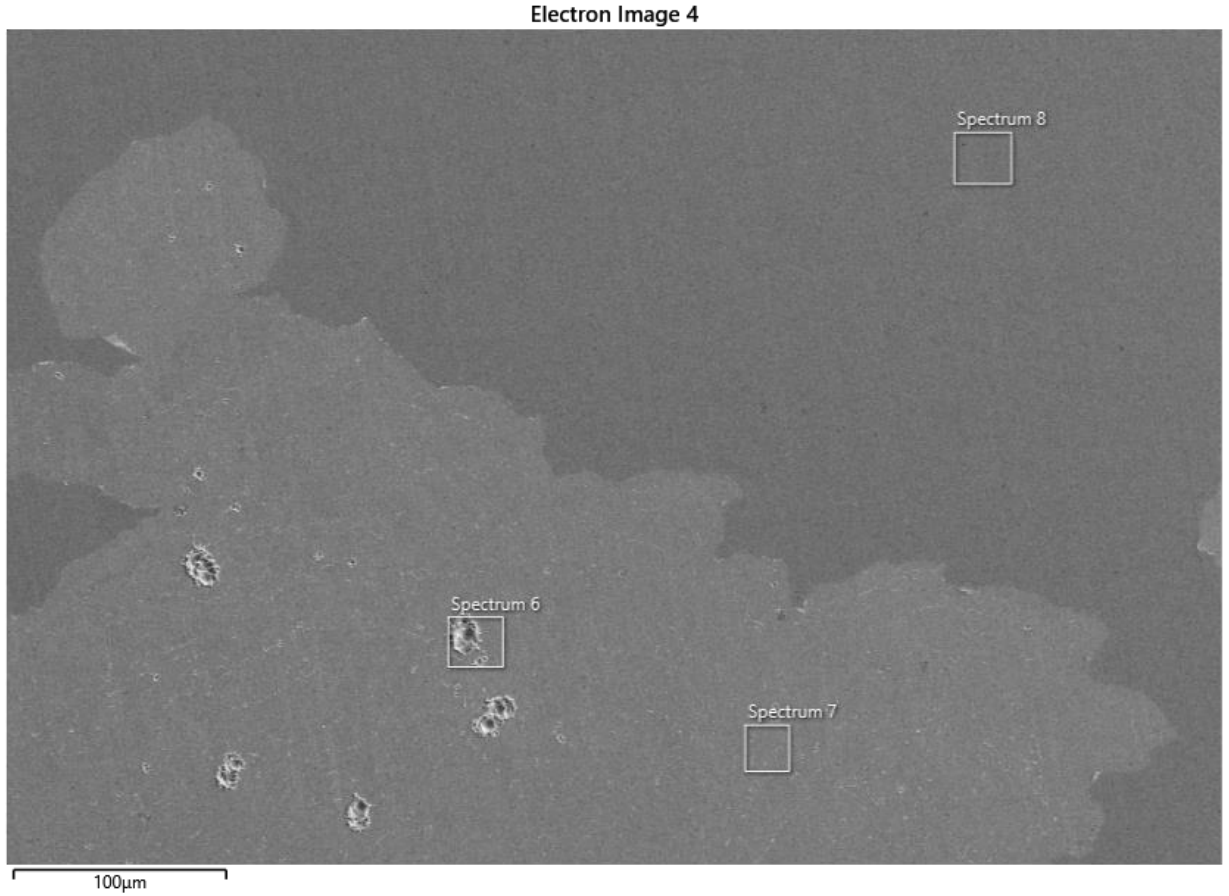
Element	Wt%
C	12.23
O	1.1
Cu	86.68

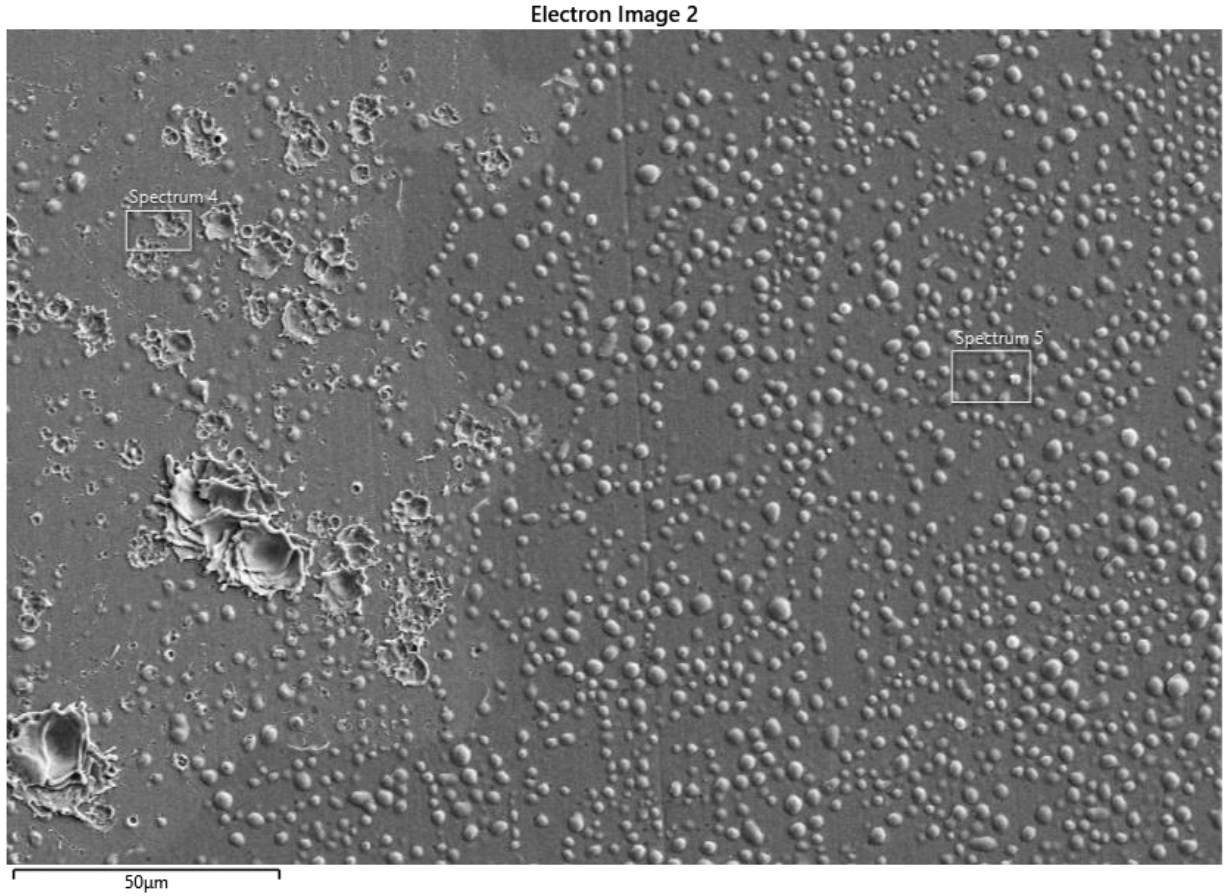
Element	Wt%
C	0.49
O	0.53
Cu	98.99

Chemical analysis
More then 12% of C in in the layer comparing with the raw surface



Chemical analysis





Spectrum 6

Element	Line Type	Wt%
C	K series	1.25
Cu	L series	98.75

Spectrum 7

Element	Line Type	Wt%
C	K series	1.15
Cu	L series	98.85

Spectrum 8

Element	Line Type	Wt%
C	K series	8.86
Cu	L series	91.14

Spectrum 4

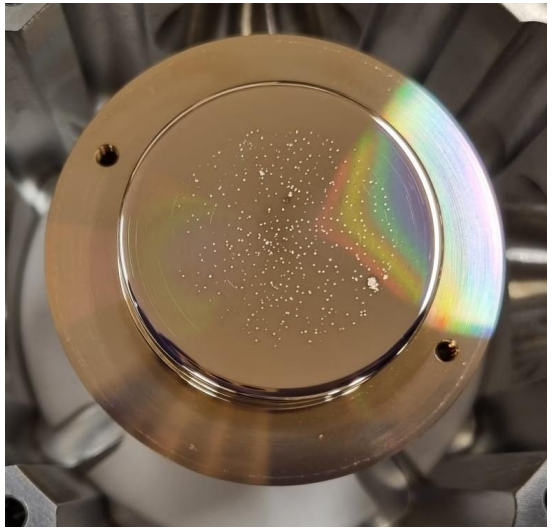
Element	Line Type	Wt%
C	K series	1.38
Cu	L series	98.62

Spectrum 5

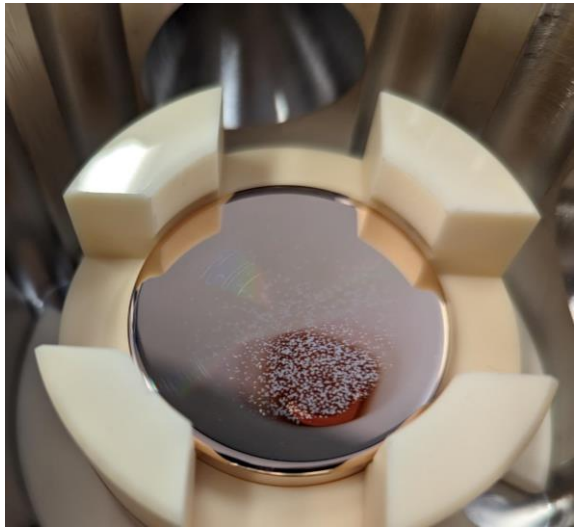
Element	Line Type	Wt%
C	K series	11.04
Cu	L series	88.96

The CuBe2 electrodes

CuBe2 non-irradiated
achieved 90 MeV/m

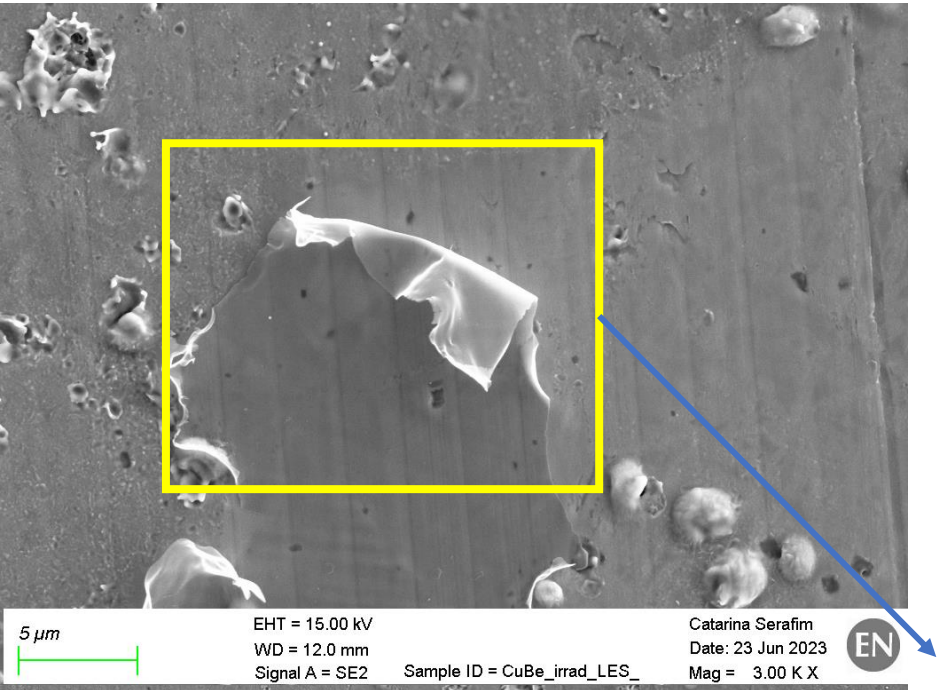


CuBe2 irradiated (without plasma cleaning)
achieved 45 MeV/m

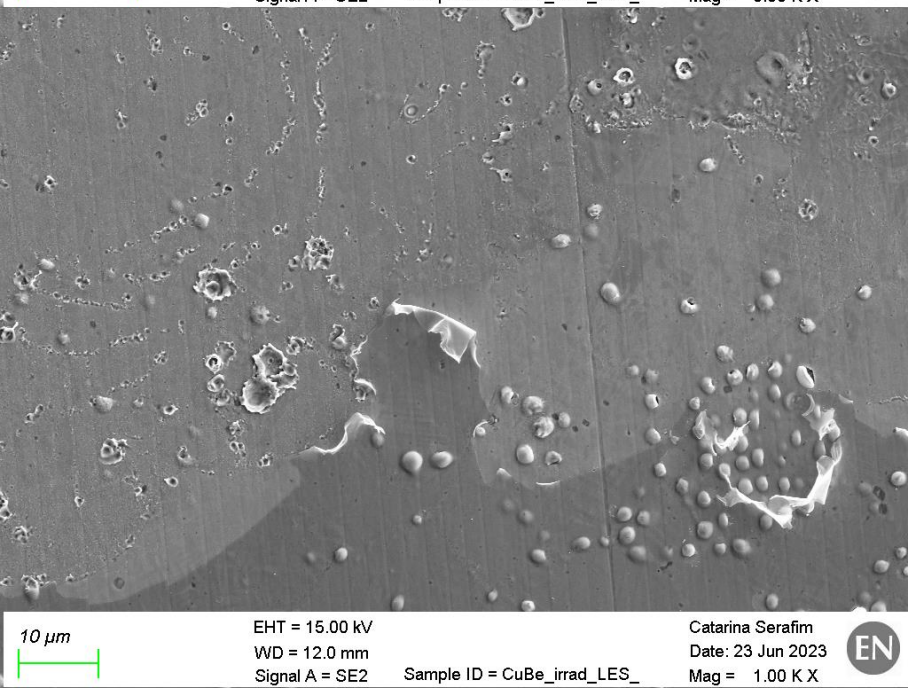


CuBe2 irradiated
(with plasma cleaning)

Repeat LES testing after Plasma Treatment

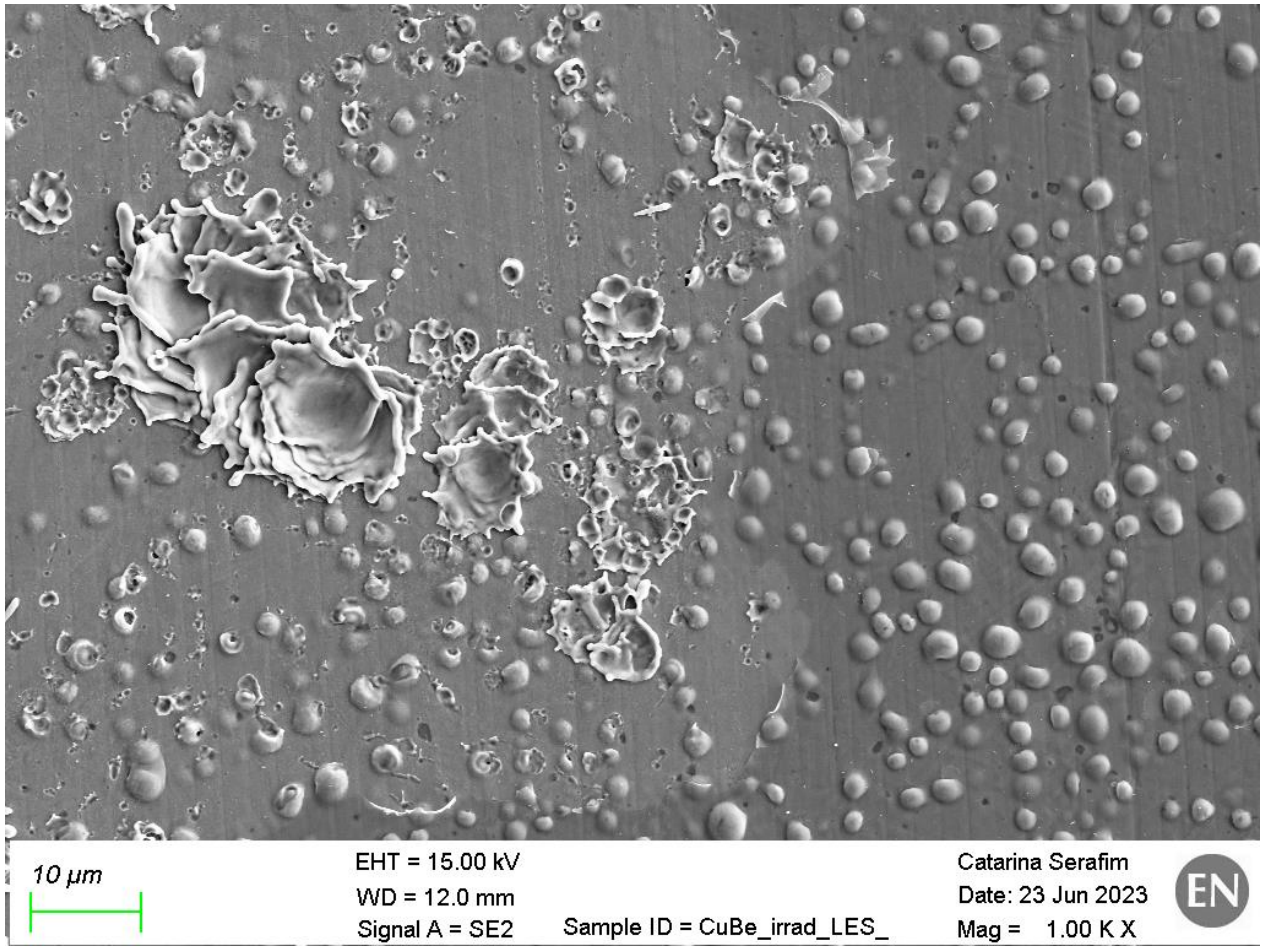


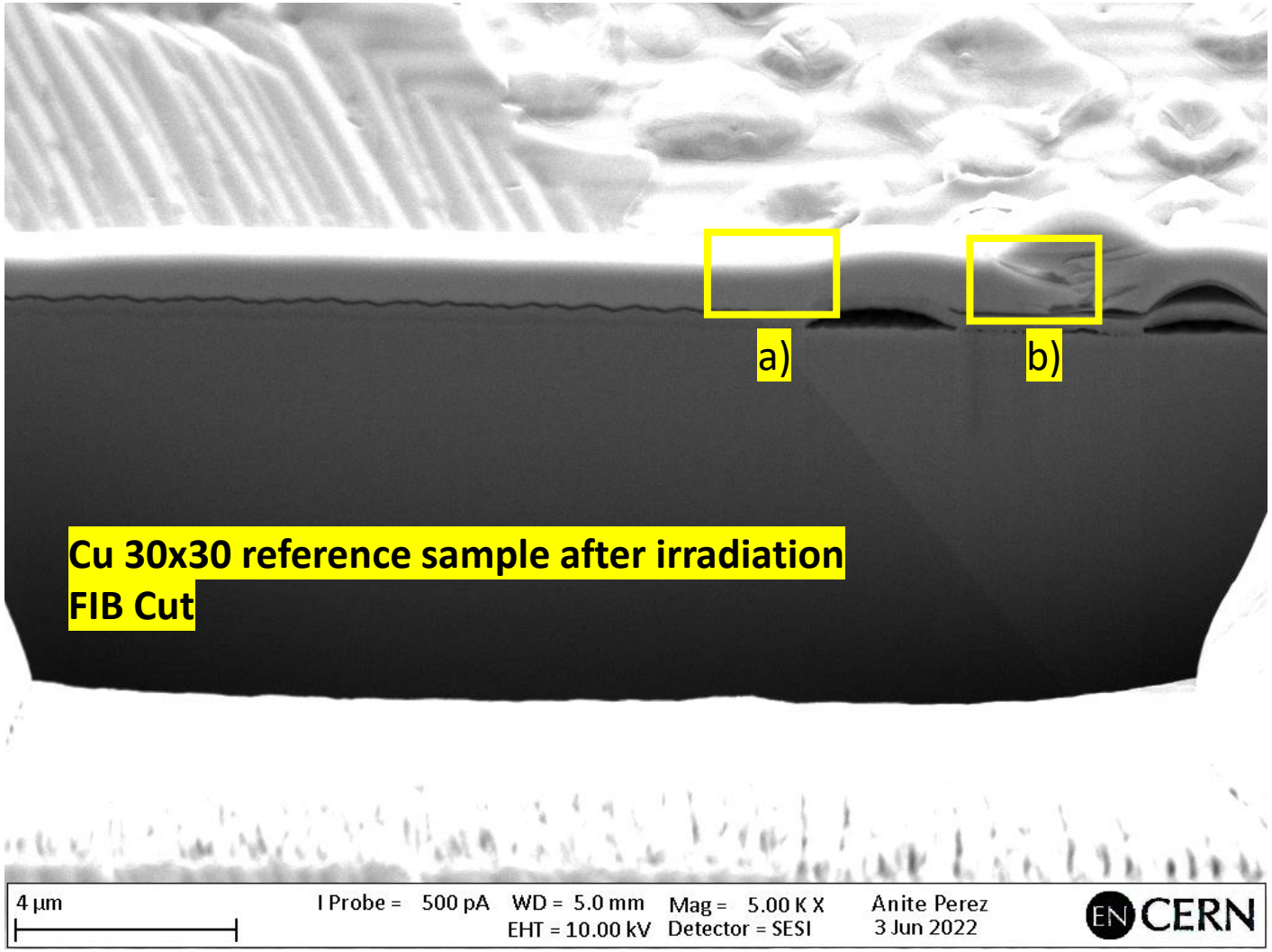
Carbon layer

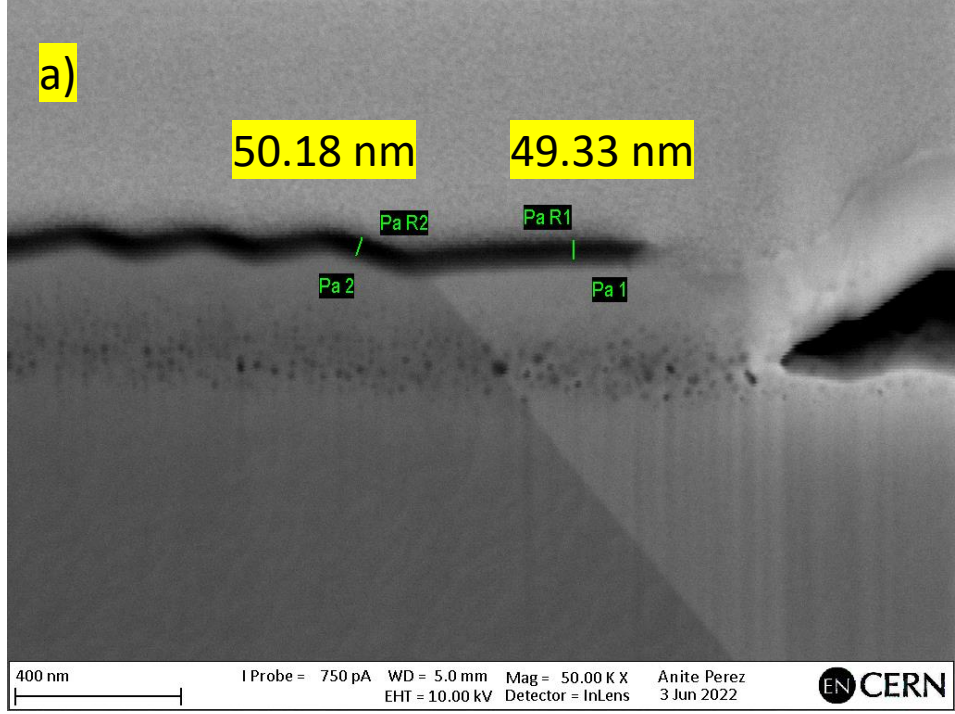


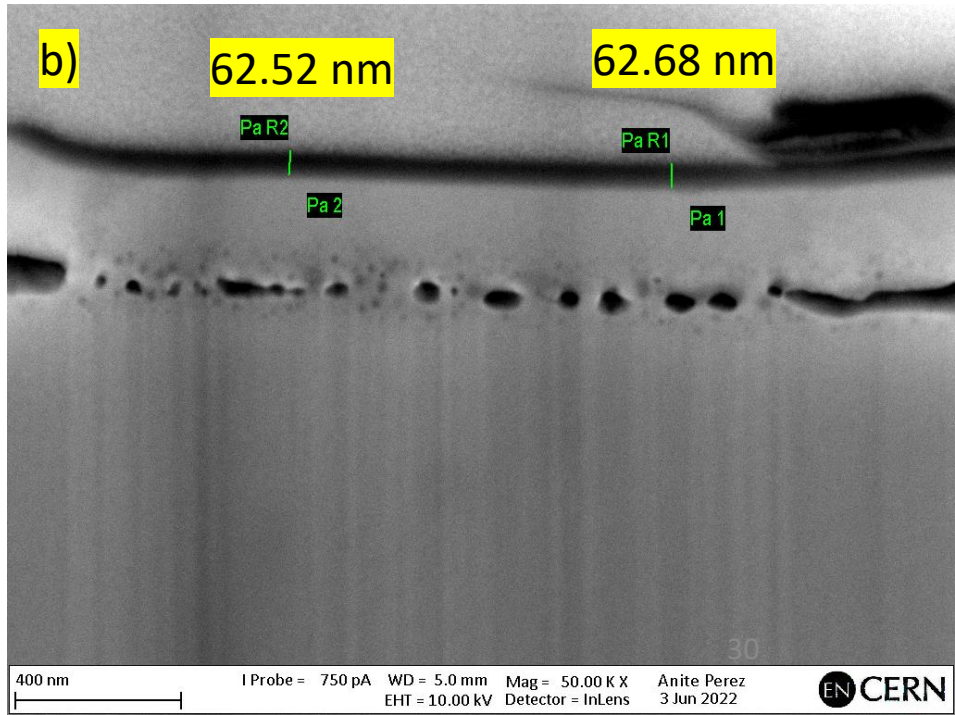
Is the carbon preventing the electrodes from reaching a high field?

Plan for Plasma cleaning treatment
+ Repeat LES testing









Data from a Cu sample previously analyzed after being exposed to irradiation (same parameters as the electrodes)

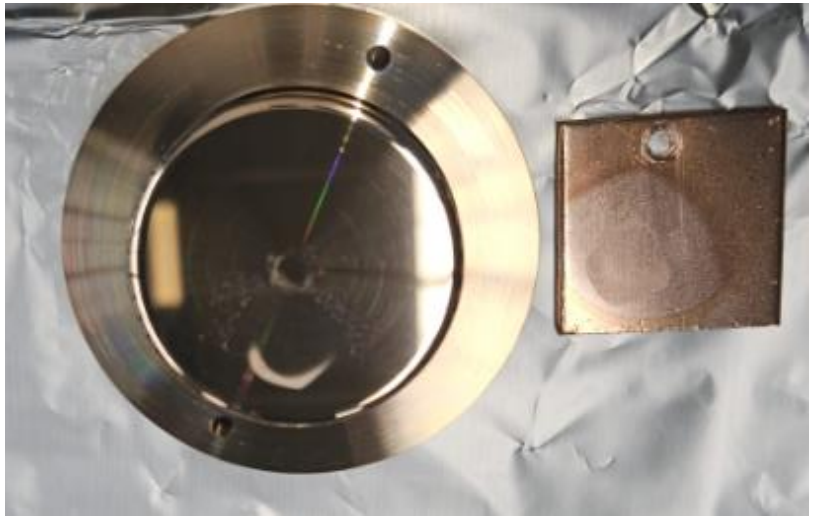
As we approach de irradiation zone we see an increase of the thickness of the C with a factor of aprox.2

Cu layer aprox. 56 nm

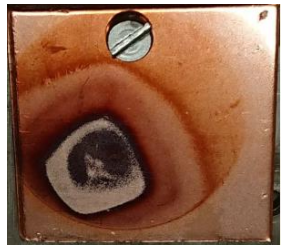
Plasma cleaning of H- irradiated CuBe cathode and reference Cu sample irradiated

viewport

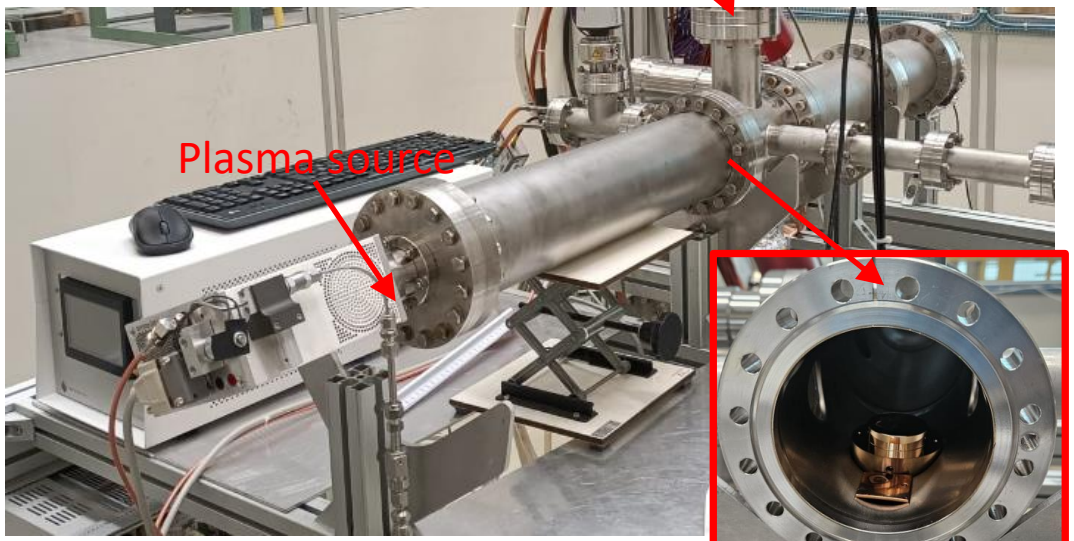
After O_2 plasma cleaning



Before O_2 plasma cleaning



System in 181

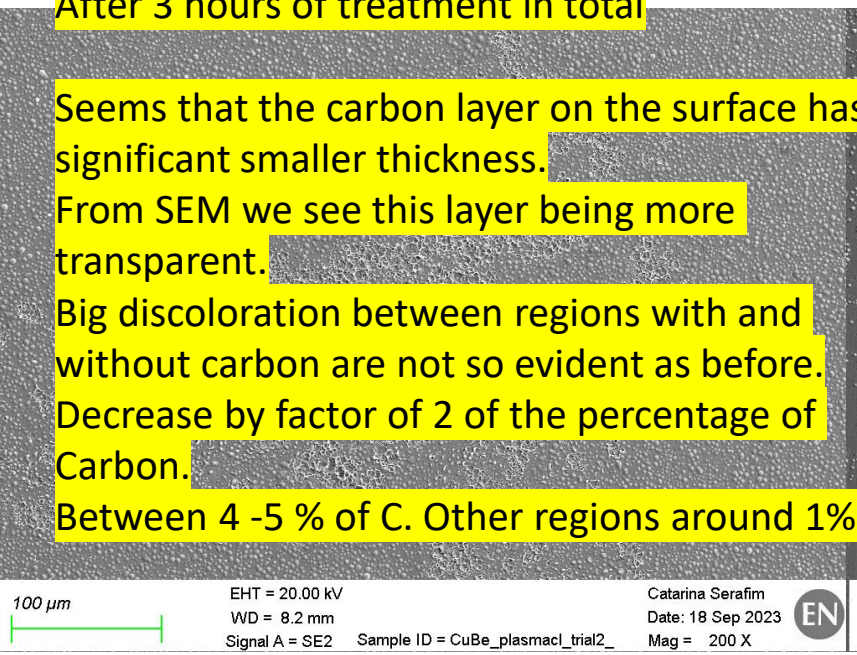


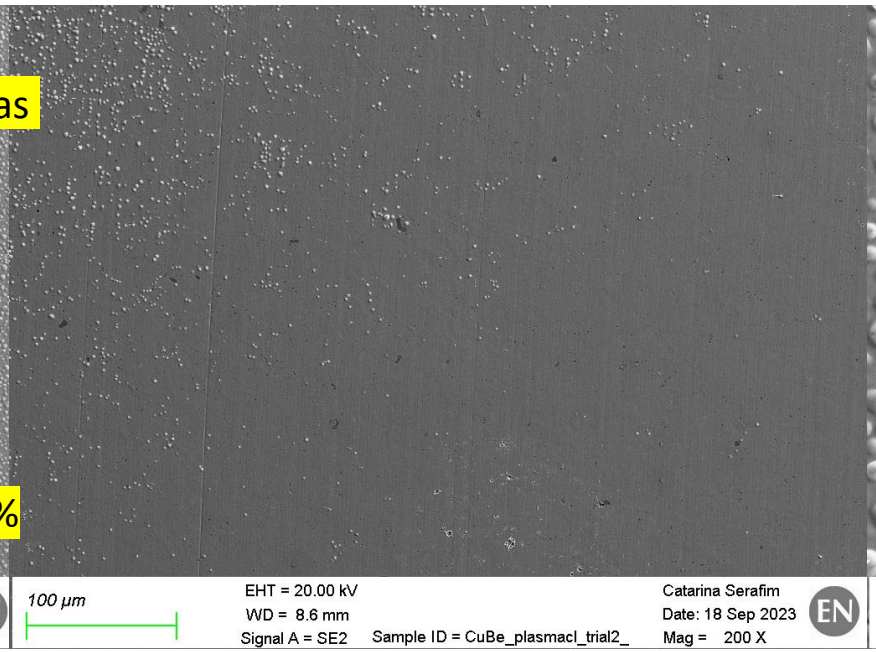
Plasma treatment parameters

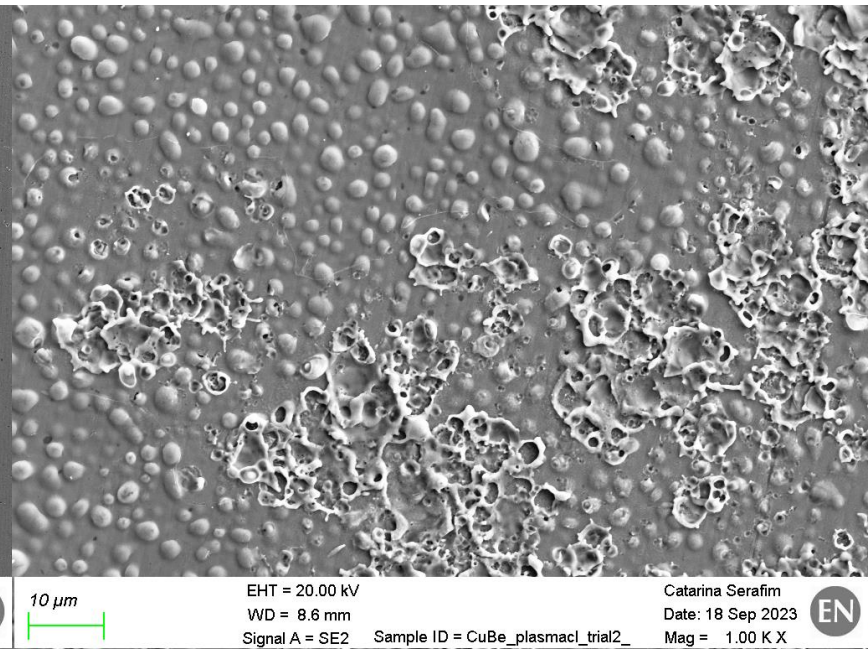
Plasma source: ibss alumina tube 300W prototype, φ = 0.147 in
p = 4E-3 mbar, pure oxygen (pressure)
P_{rf} = 50 W (pl.source rf power)
L = 610 mm ± 10 mm (distance samples - plasma source); D_{ch} = 100 mm
a-C dth/dt in these conditions = 0.015 nm/s (removal rate)
Plasma ion energy in these conditions : 35 eV (measured by RFEA)
Treatment duration = 1h 15 min (nominally 68 nm of a-C)

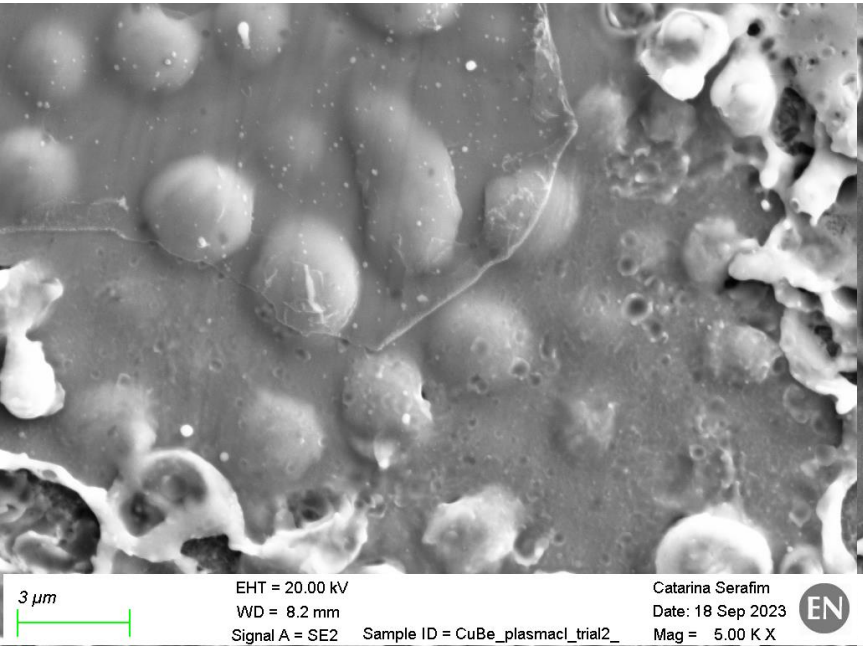
After 3 hours of treatment in total

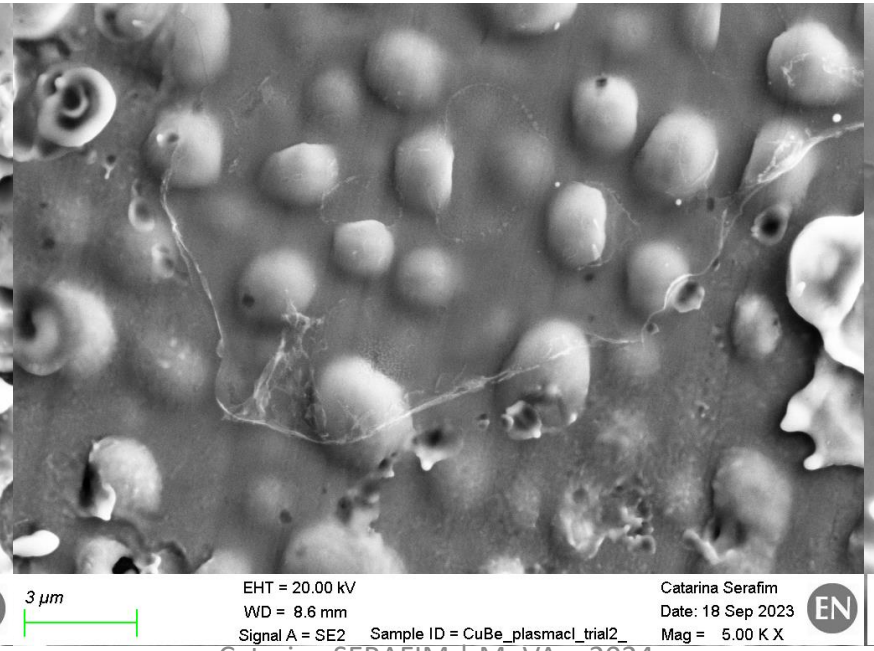
Seems that the carbon layer on the surface has significant smaller thickness.
From SEM we see this layer being more transparent.
Big discoloration between regions with and without carbon are not so evident as before.
Decrease by factor of 2 of the percentage of Carbon.
Between 4 -5 % of C. Other regions around 1%

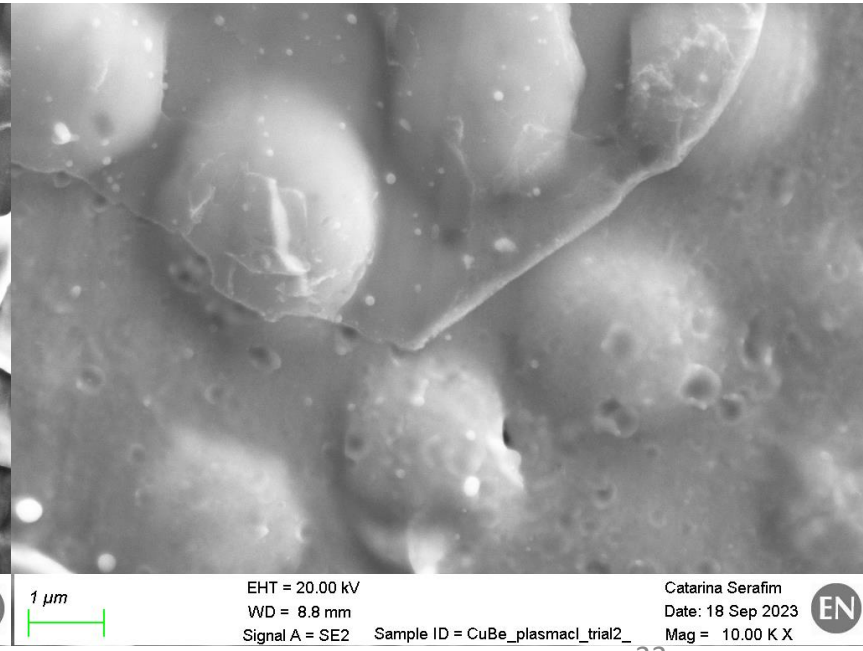


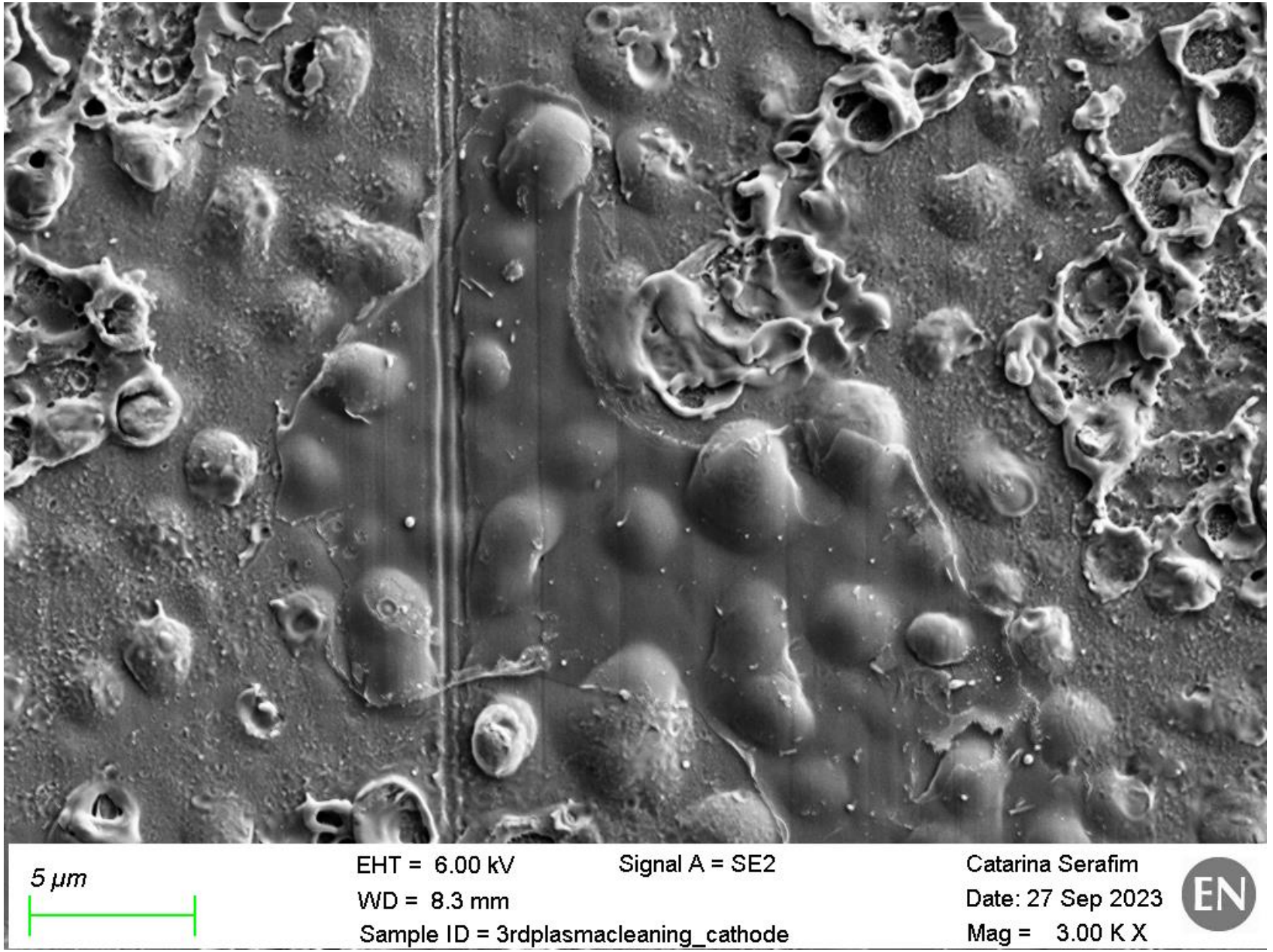












In total 6h hours of treatment was preformed.
The quantity of C in the surface is now significantly lower.
We have concluded that because of the roughness of the surface (due to breakdowns from the LES test), C seems to be very difficult to be removed in these regions (see next images).
For the other hand, the regions without breakdowns seem to be cleaned (1-2% of C).

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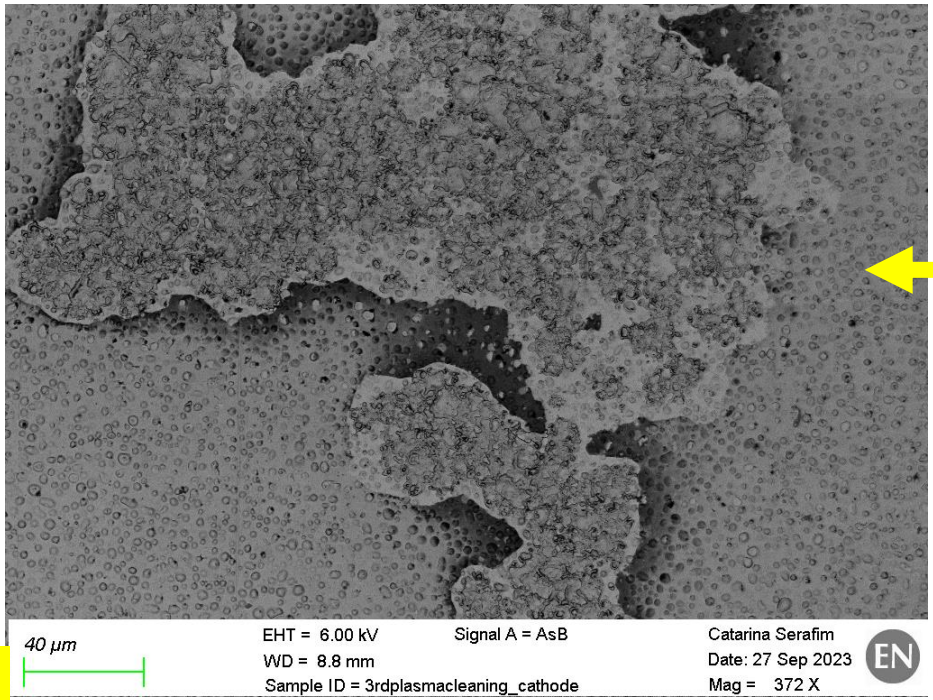
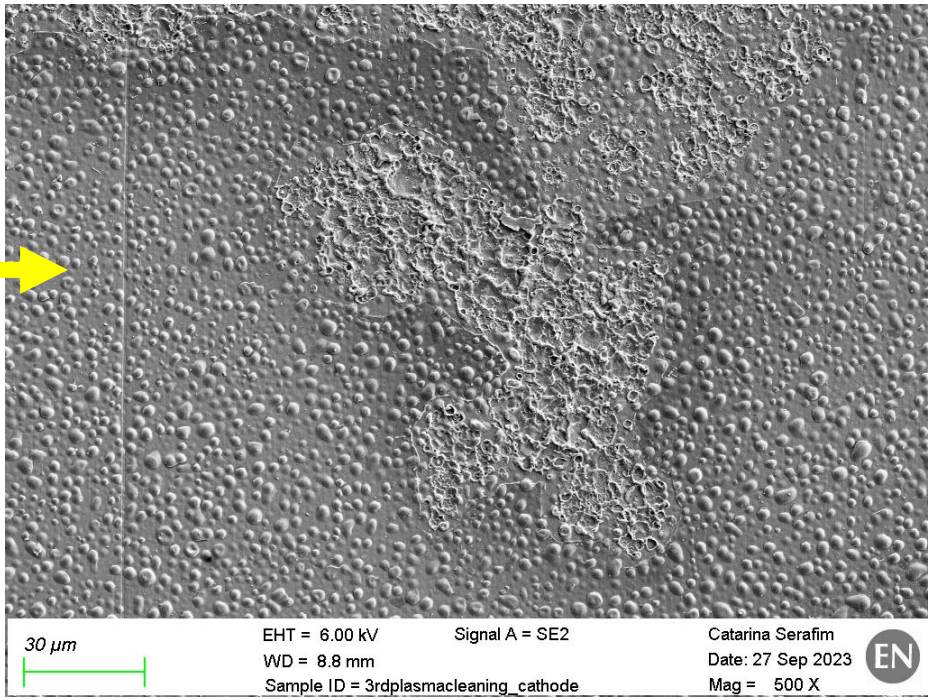
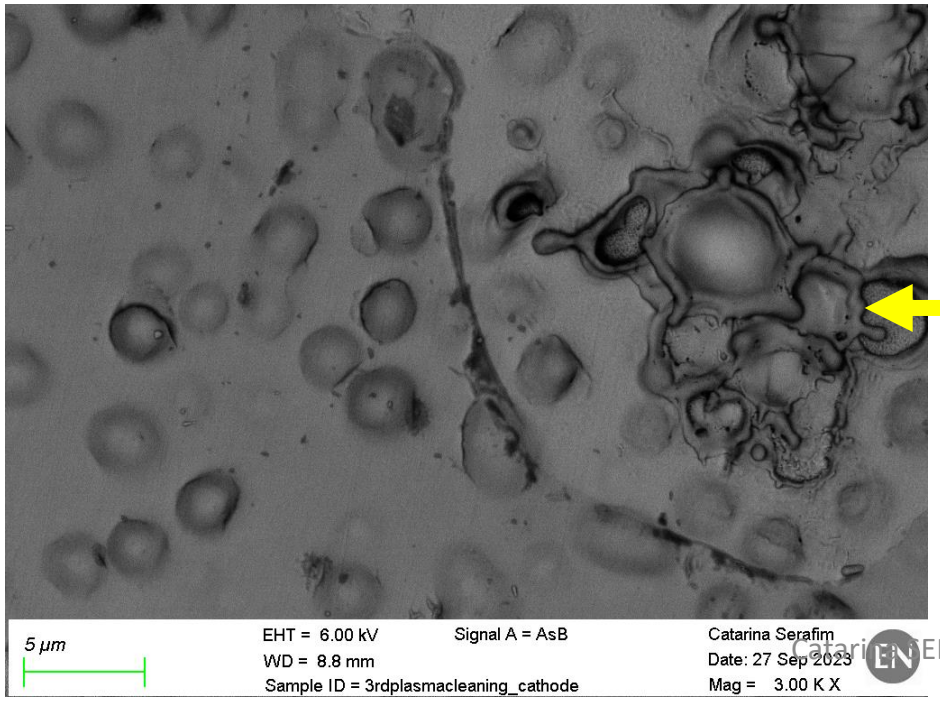
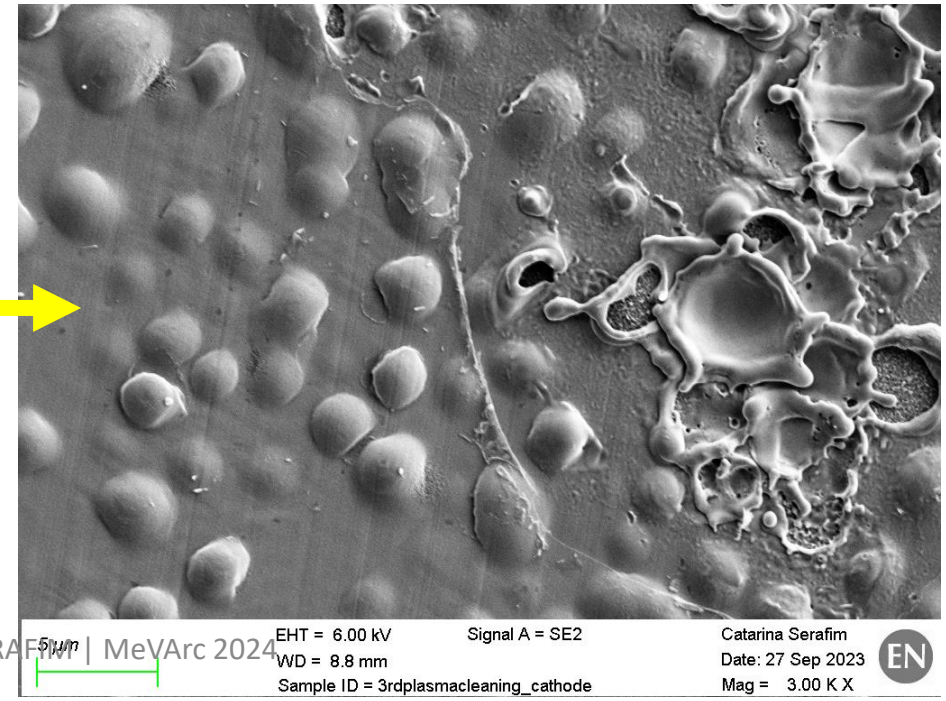
Backscatterd detector

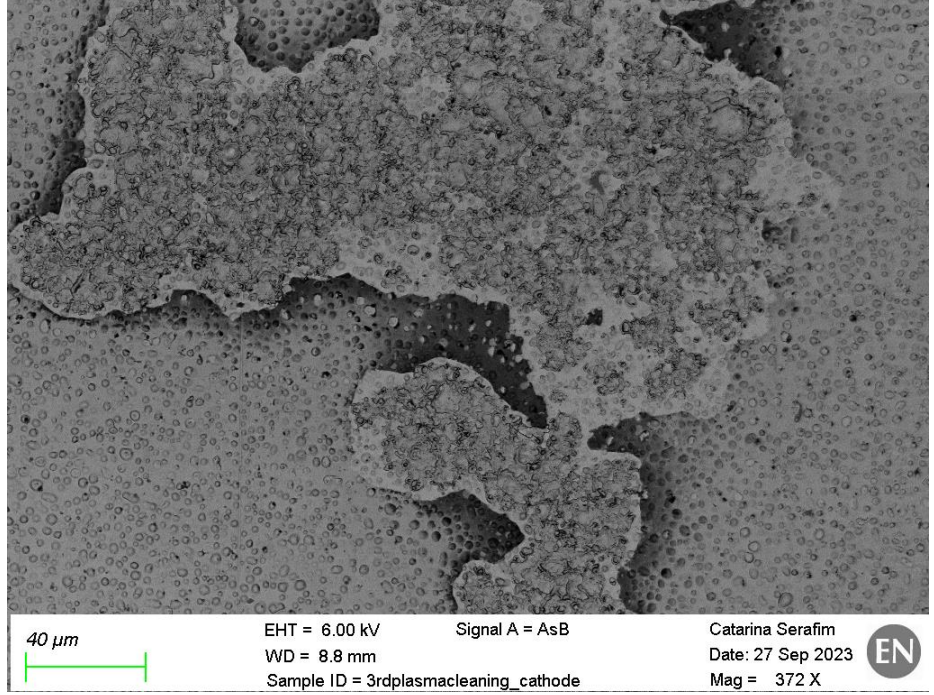




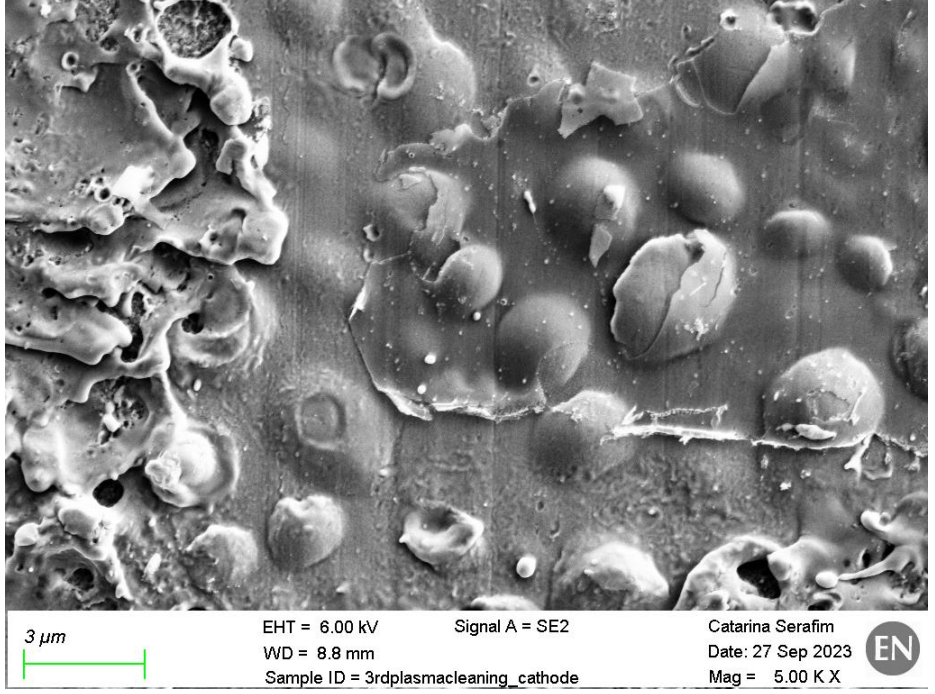
Secondary electron detector

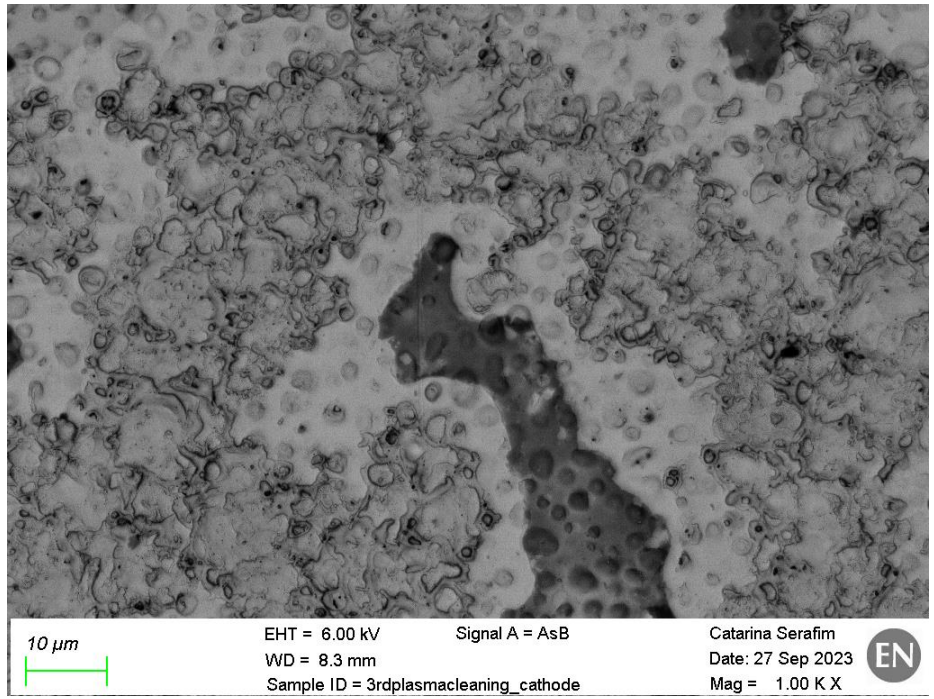


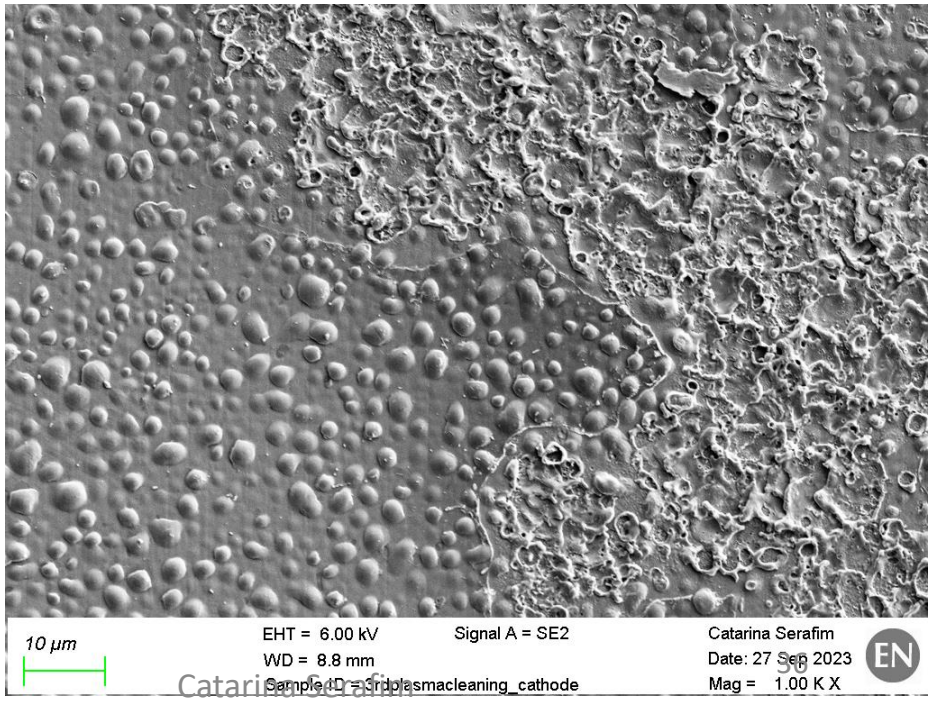




Imaging using Backscattered detector. Darker color means the detection of lighter elements (in our case C).



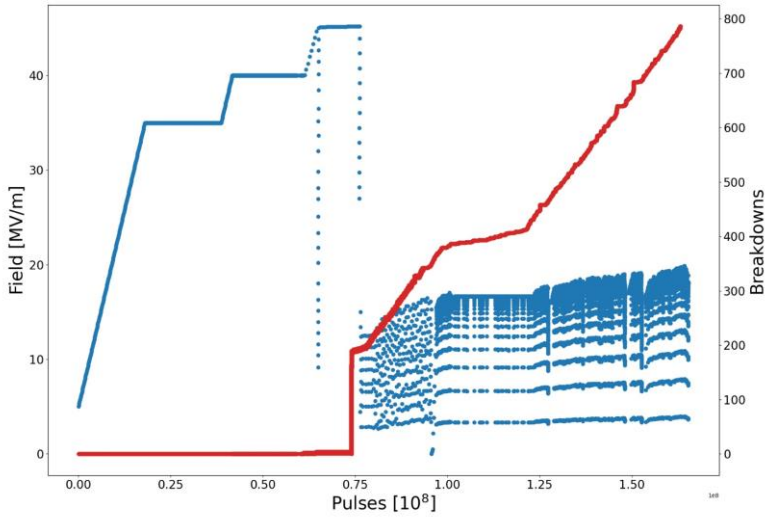


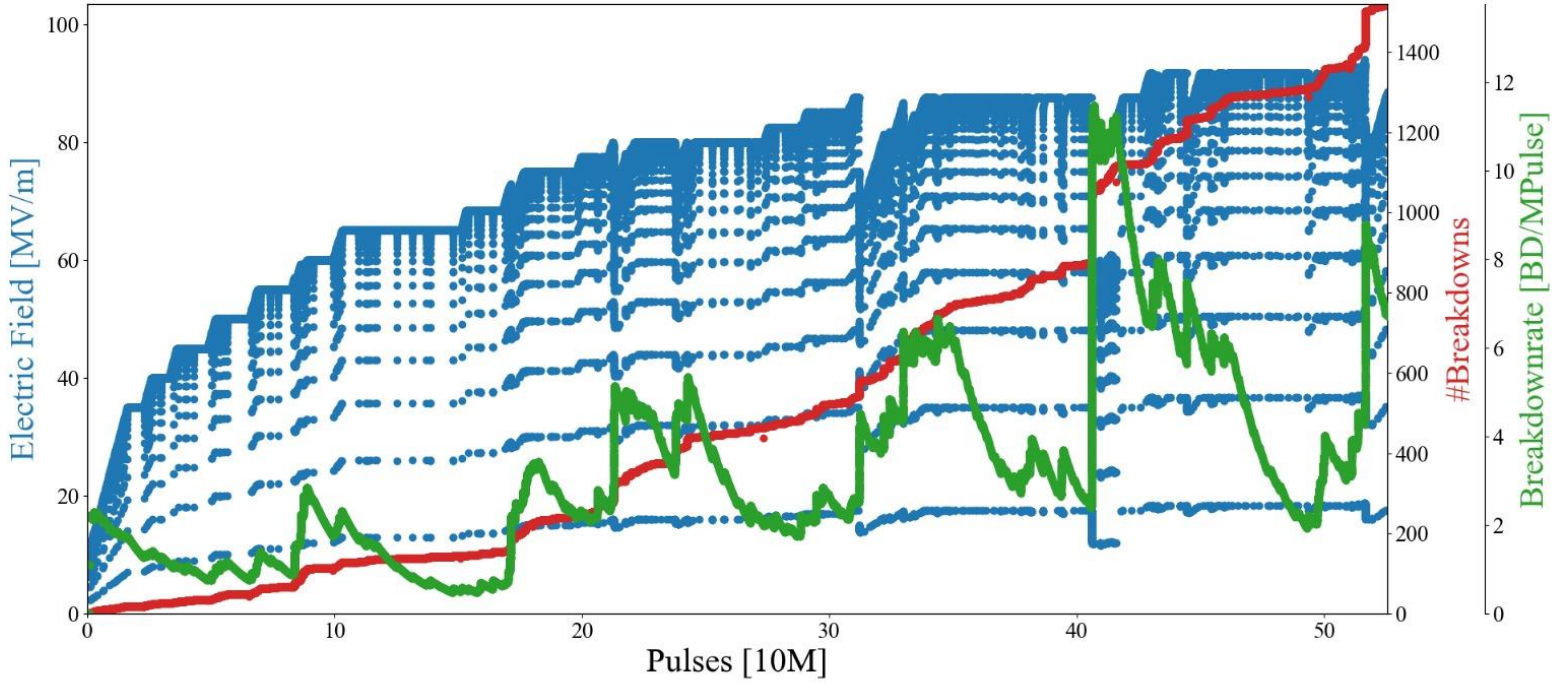


CuBe2 breakdown test

The followings plots are from the same set of electrodes:

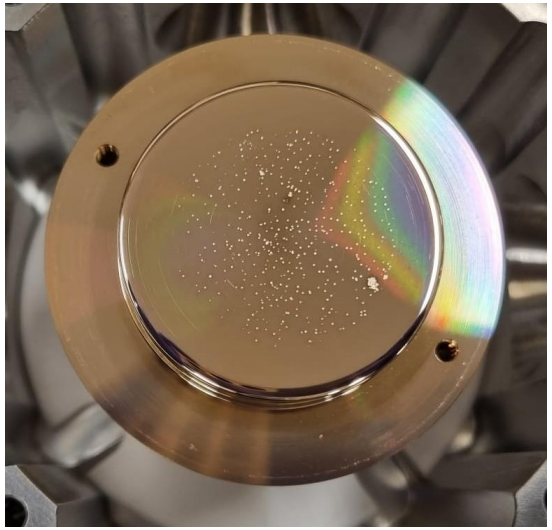
- On the **left before plasma treatment**
- On the **right after plasma treatment**



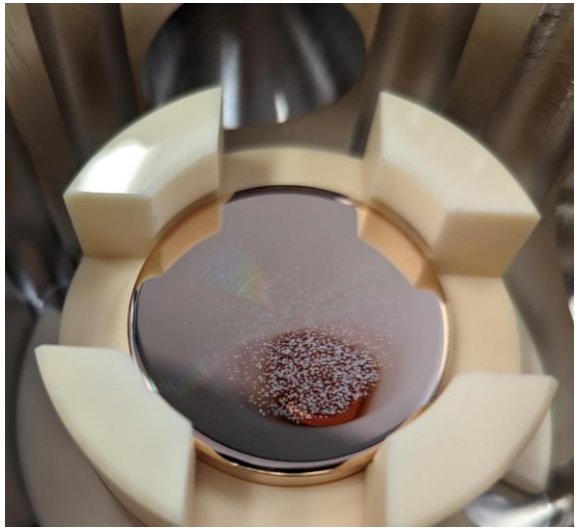


After the plasma cleaning, we decided to re-test the electrodes in the LES system

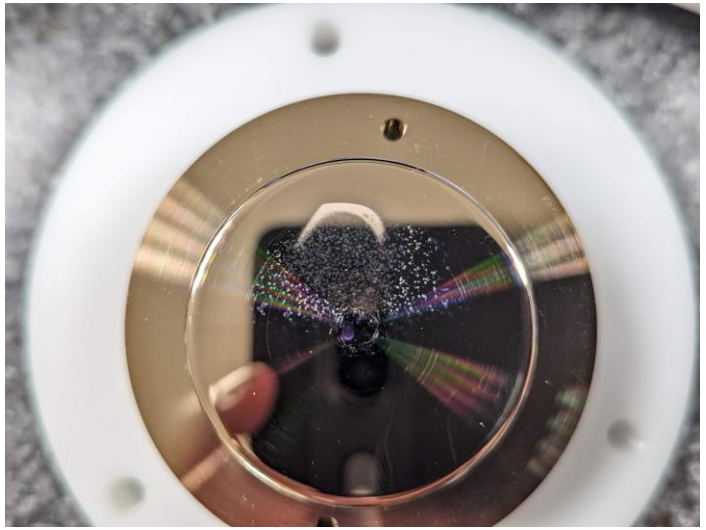
CuBe2 non-irradiated
achieved 90 MeV/m



CuBe2 irradiated (without plasma cleaning)
achieved 45 MeV/m



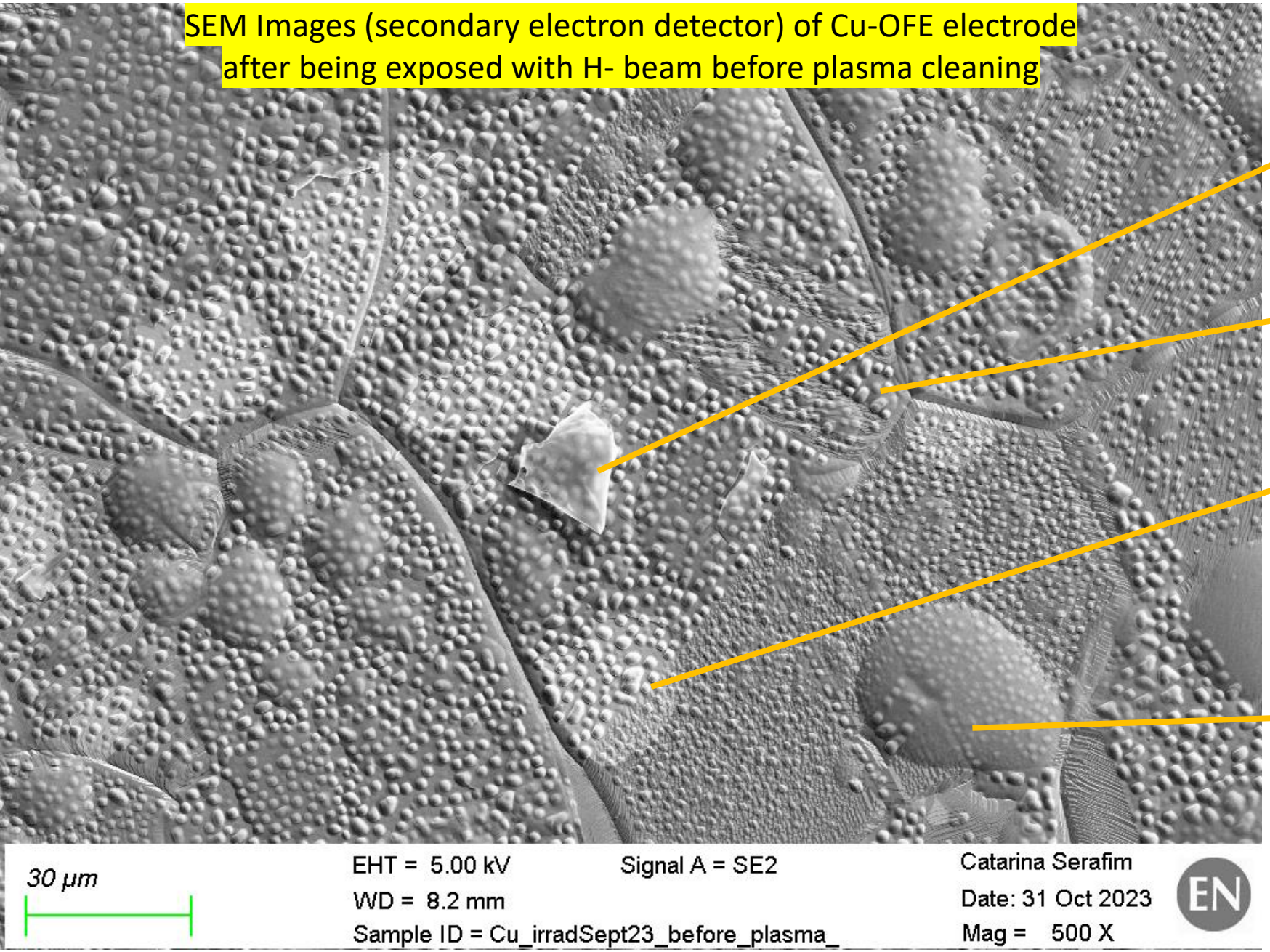
CuBe2 irradiated
achieved 82 MeV/m (with plasma cleaning)



- We have concluded that the plasma treatment was a success for Carbon removal from the surface.
  The electrode for the trial was CuBe2. This electrode has been exposed to irradiation and also has been tested with high pulsing voltage in a dedicated system (LES), which has triggered the breakdowns on the surface.

- The next step was to preform the treatment also in two different electrodes (Cu-OFE and Stainless Steal) right after the irradiation (without high voltage testes). We hope to eliminate completely the C residuals that we still see on CuBe after 6h hours of treatment.

SEM Images (secondary electron detector) of Cu-OFE electrode after being exposed with H- beam before plasma cleaning



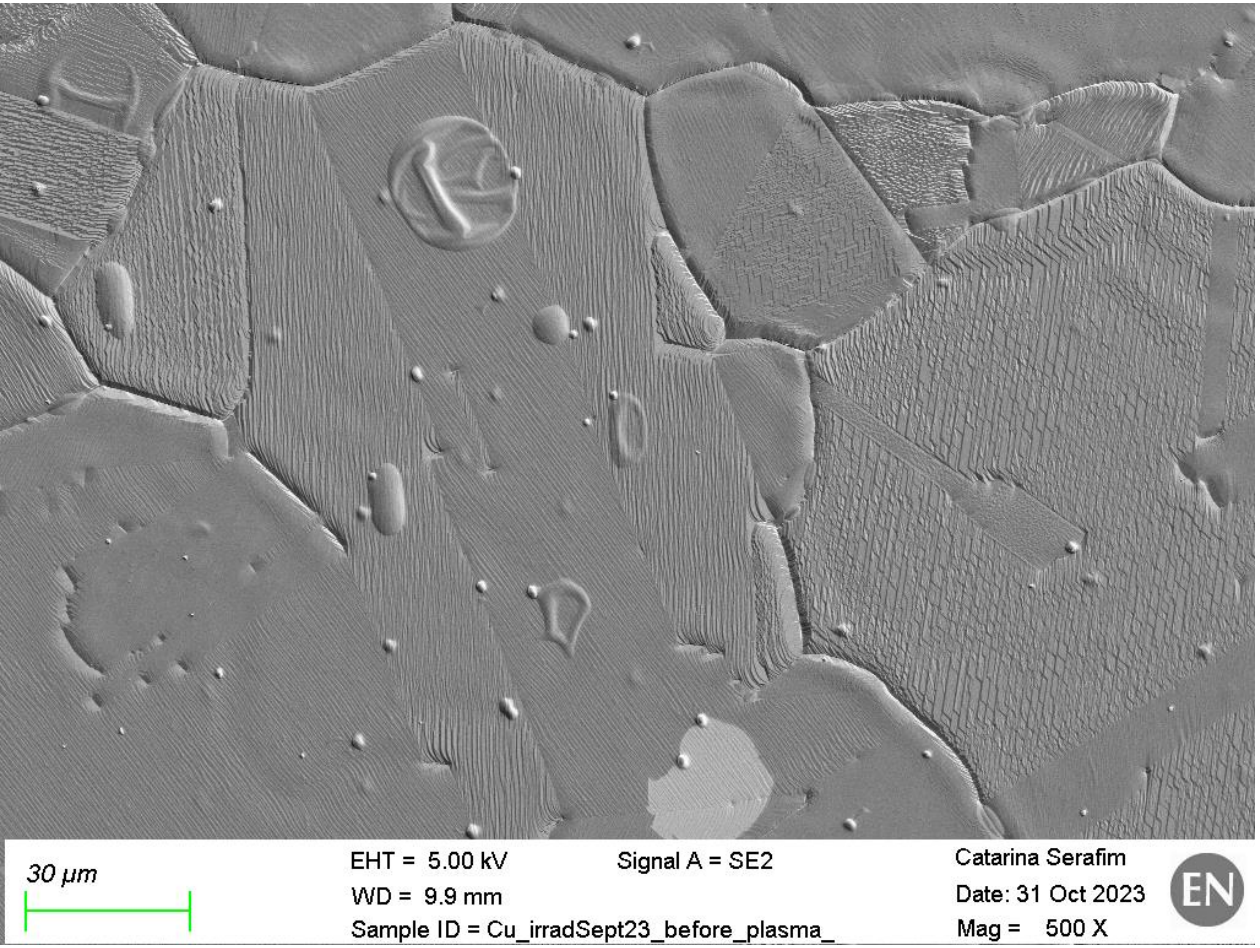
Carbon layer that was partially exfoliated from the surface

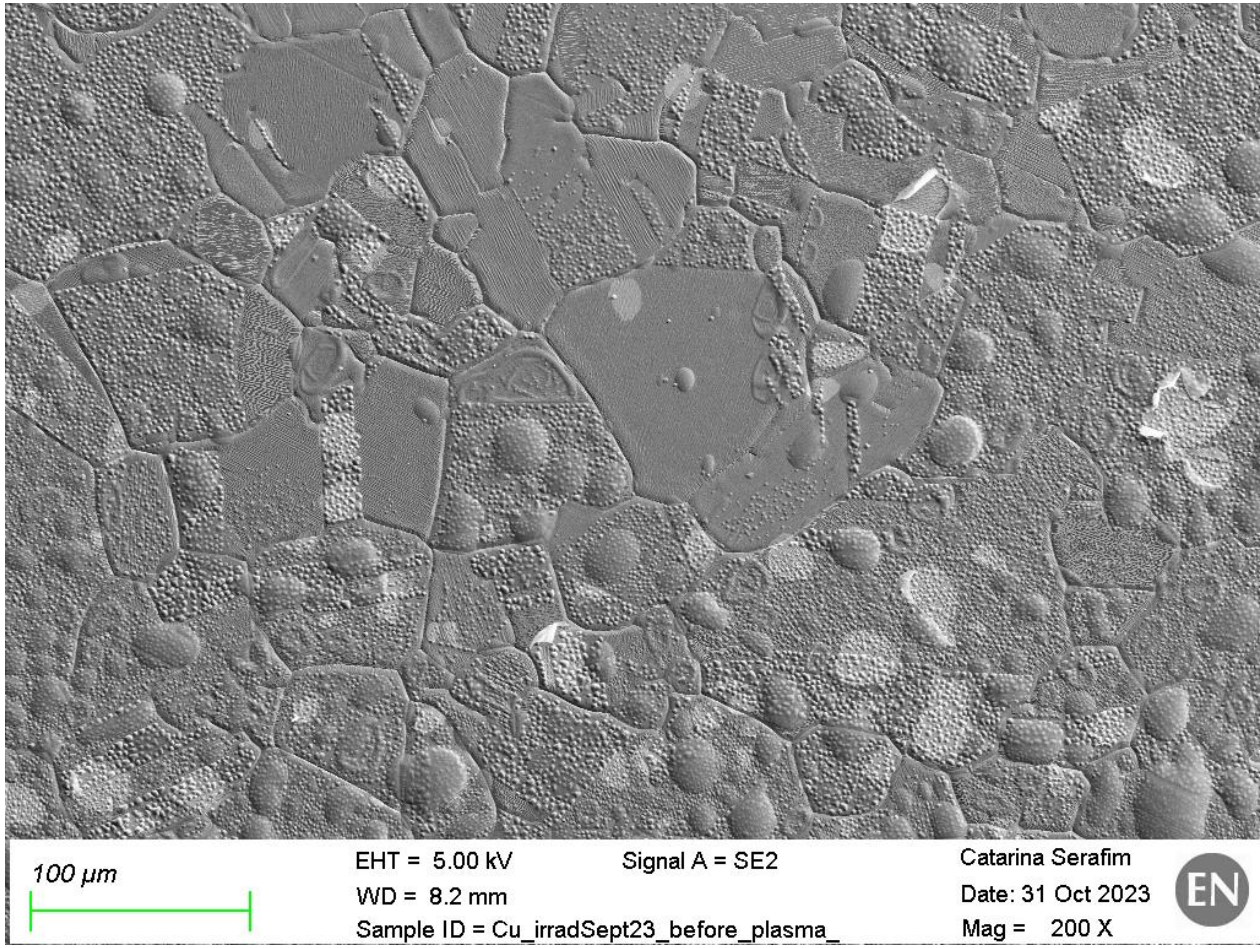
Blisters caused by the irradiation with H- beam

Regions without carbon (white regions). C has been completely exfoliated

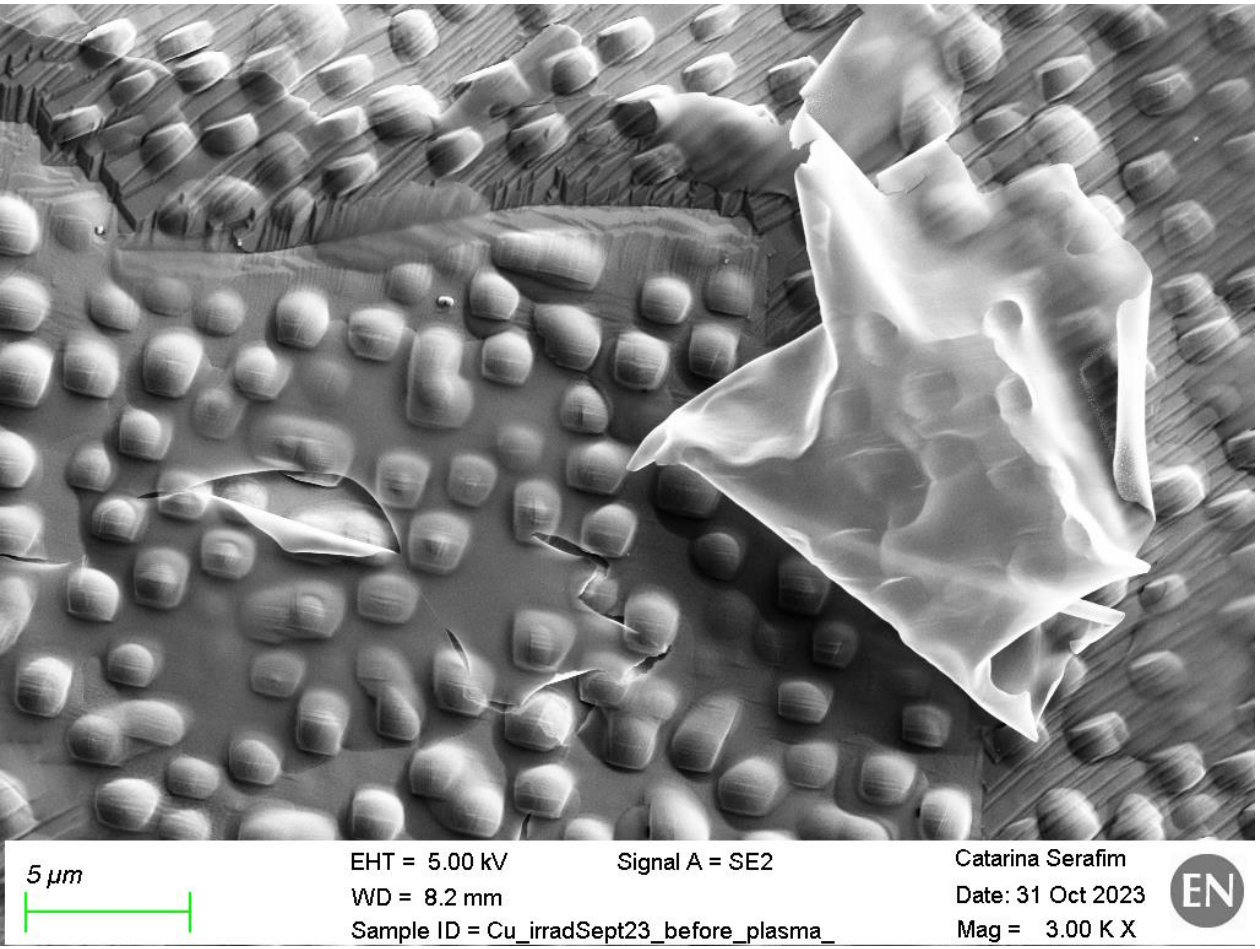
'Bubbles' of C – implementation of H between C layer and Cu surface

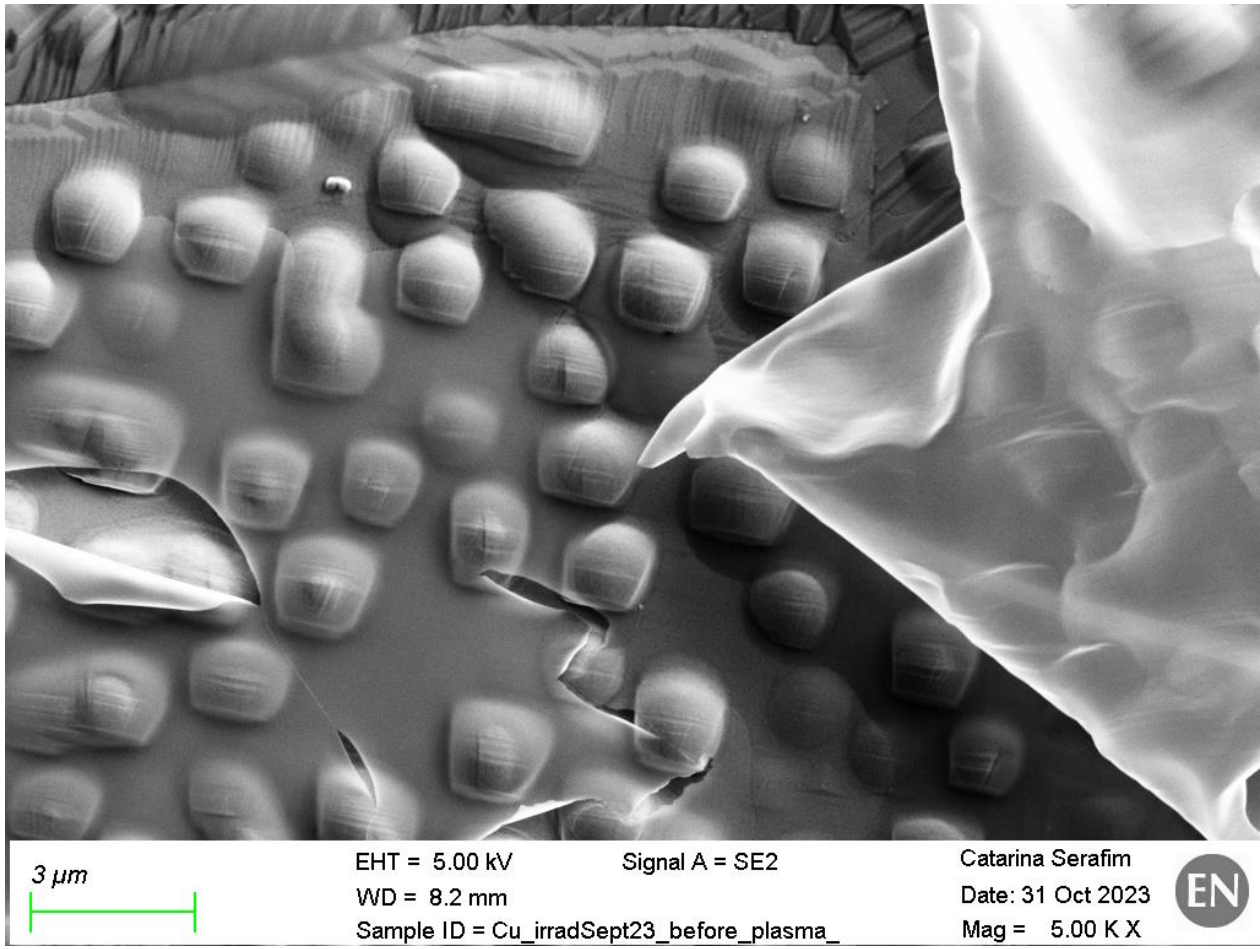
SEM Images (secondary electron detector) of Cu-OFE electrode
after being exposed with H- beam before plasma cleaning





SEM Images (secondary electron detector) of Cu-OFE electrode
after being exposed with H- beam before plasma cleaning





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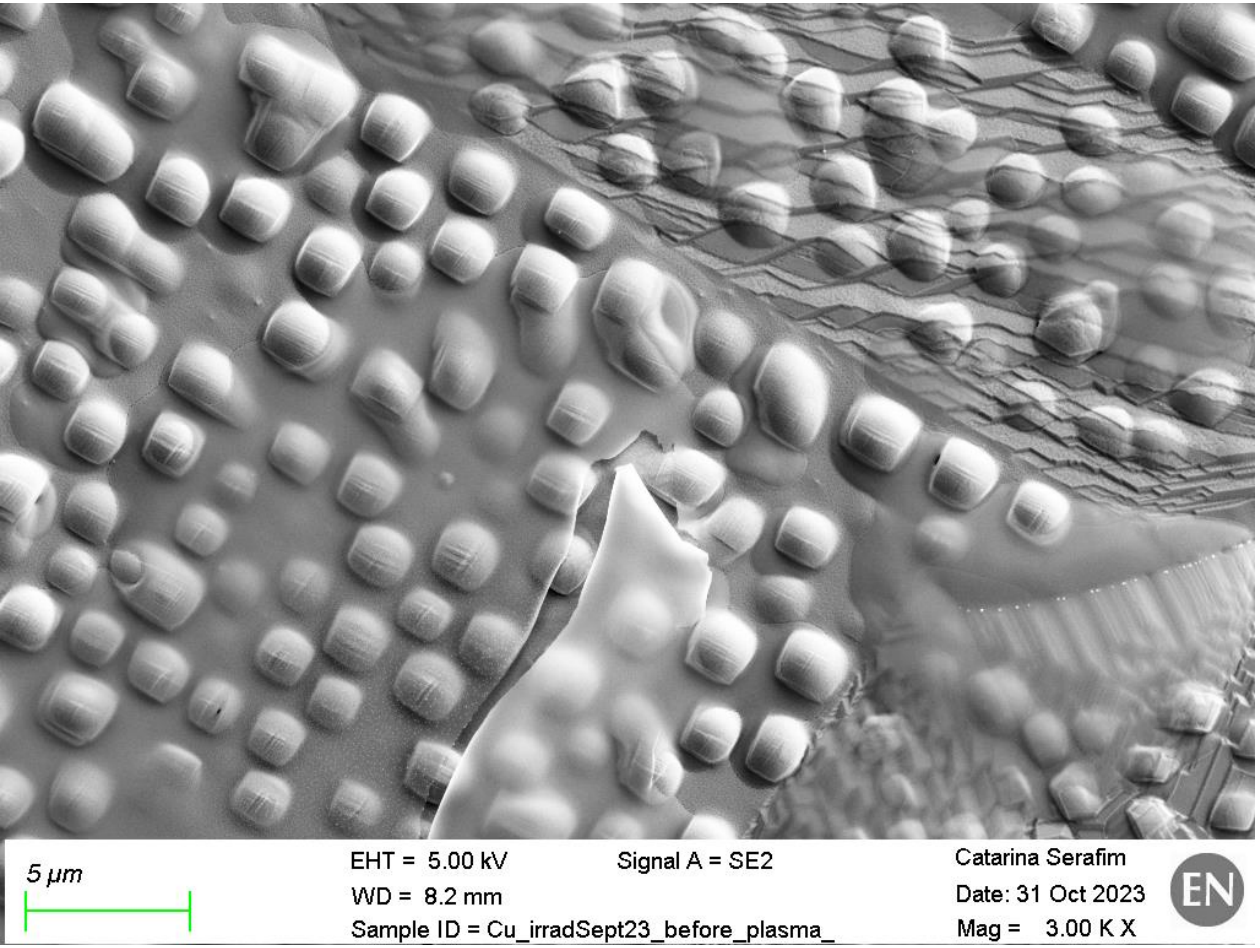
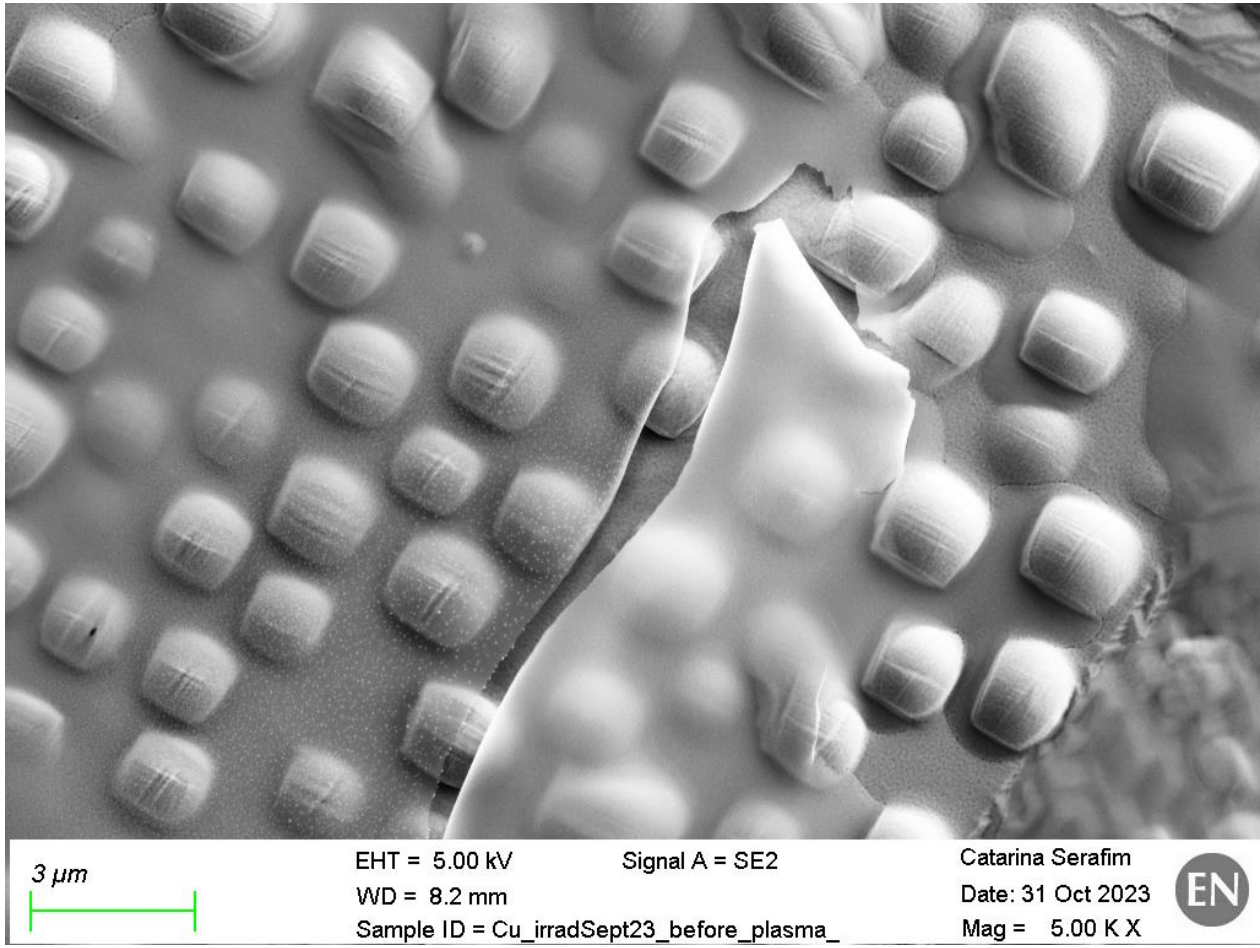
SEM Images (secondary electron detector) of Cu-OFE electrode
after being exposed with H- beam before plasma cleaning





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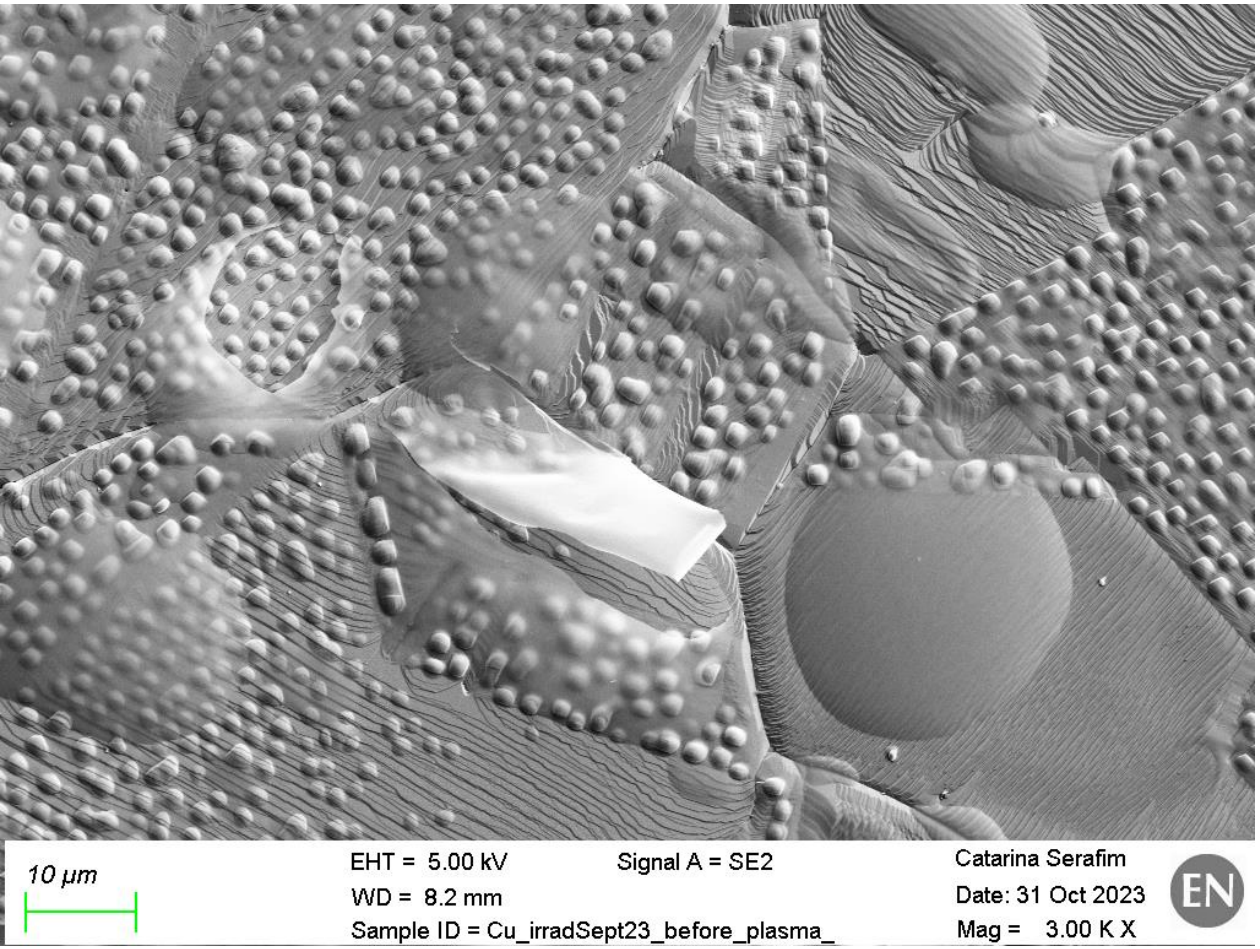
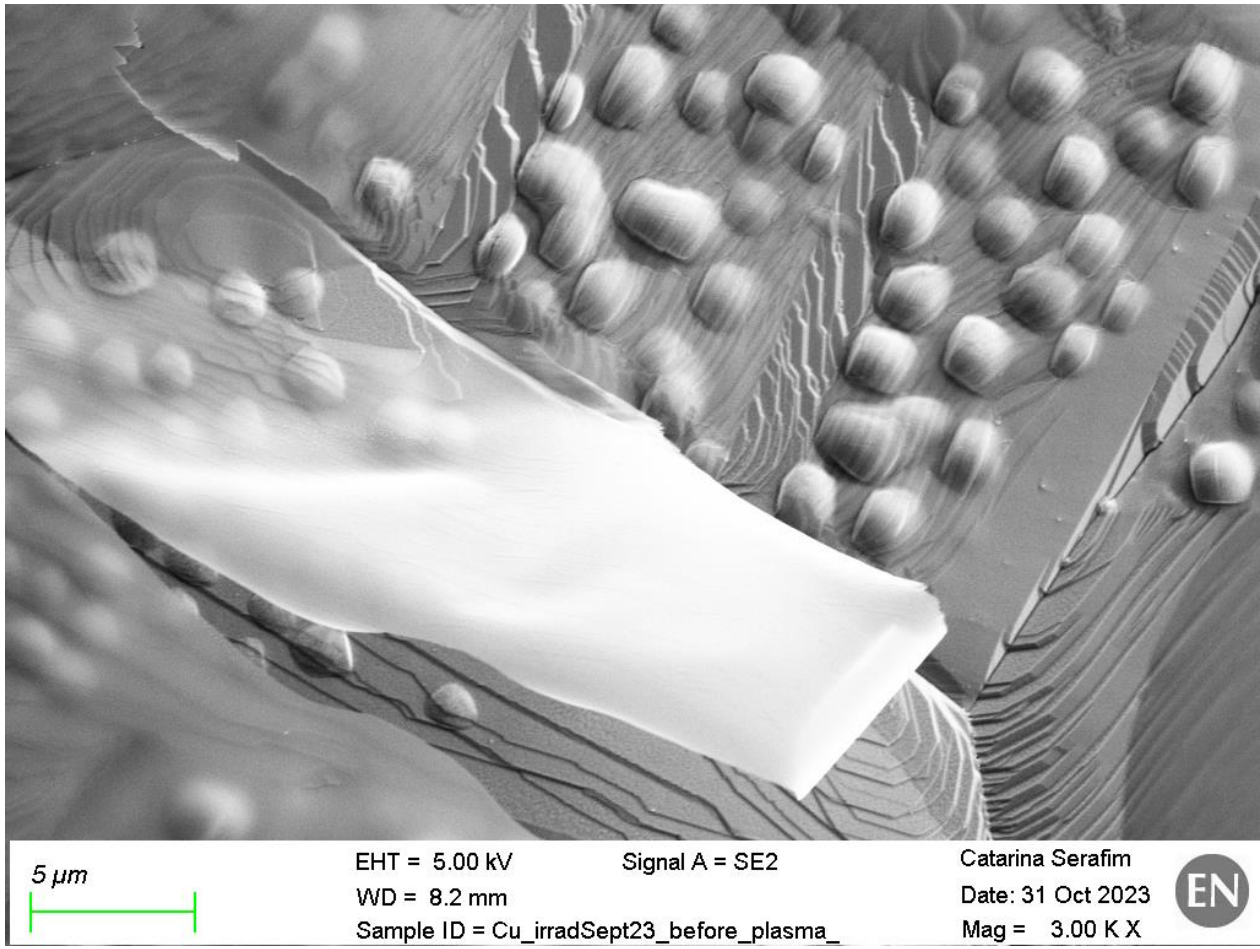
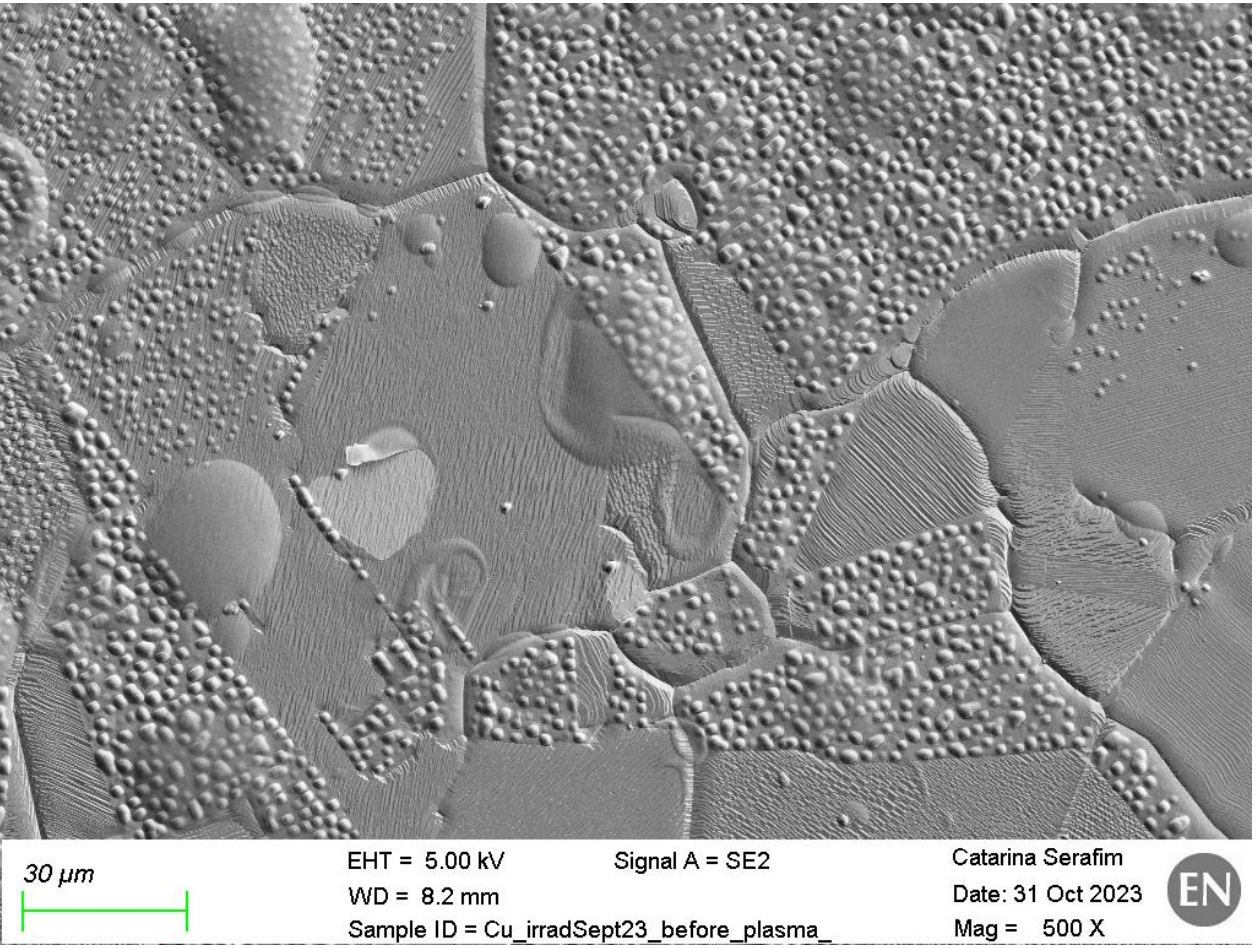
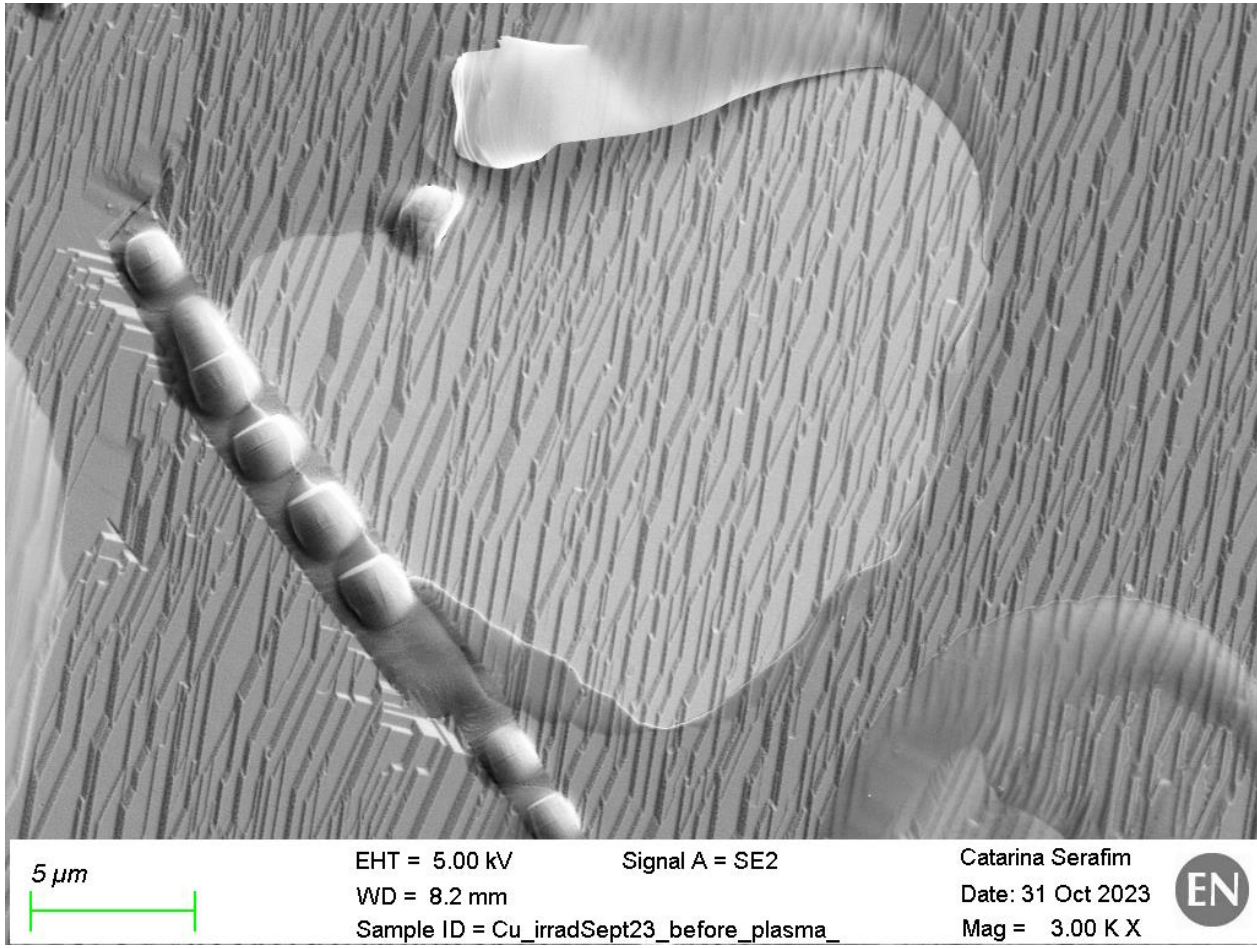
SEM Images (secondary electron detector) of Cu-OFE electrode
after being exposed with H- beam before plasma cleaning



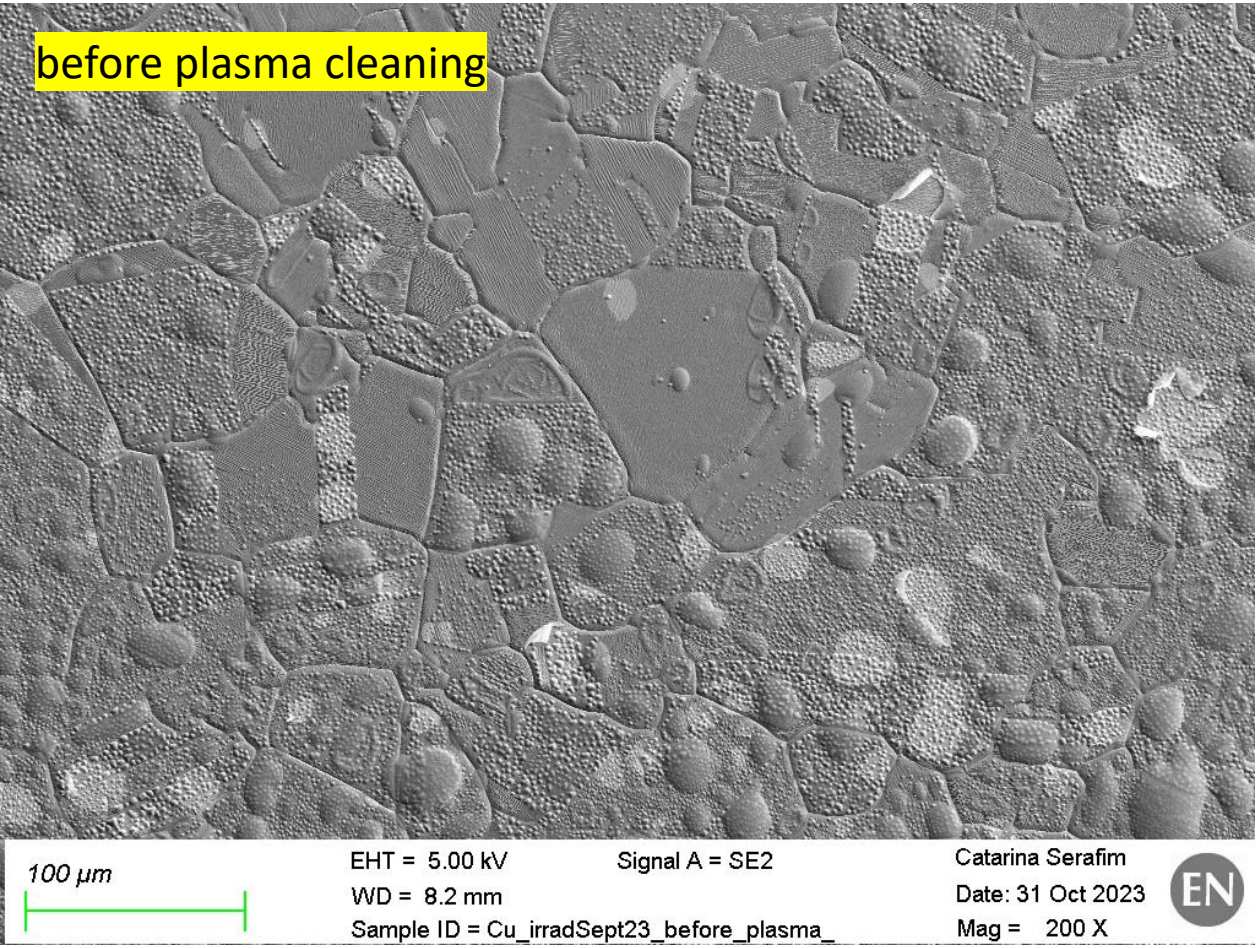


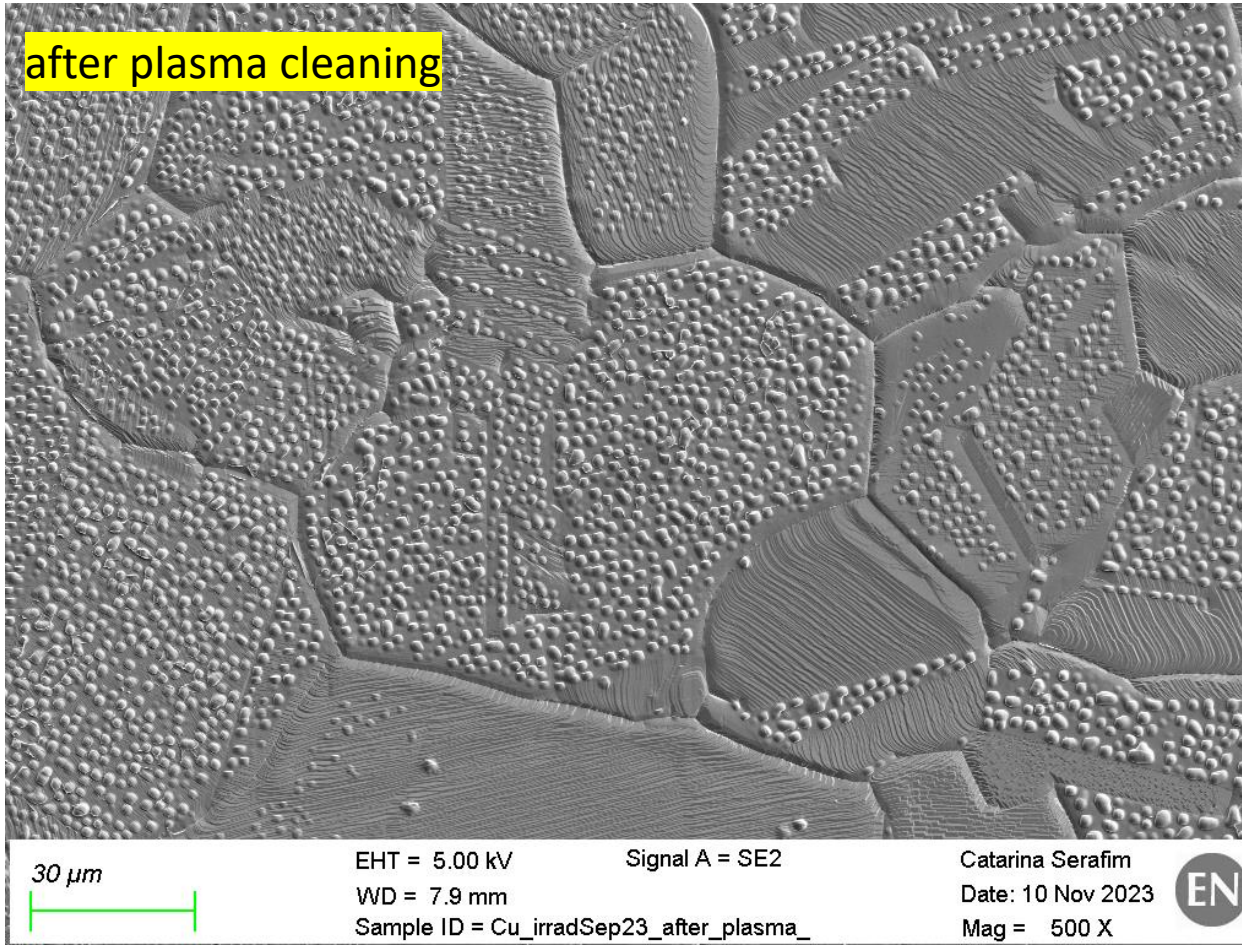
SEM Images (secondary electron detector) of Cu-OFE electrode
after being exposed with H- beam before plasma cleaning



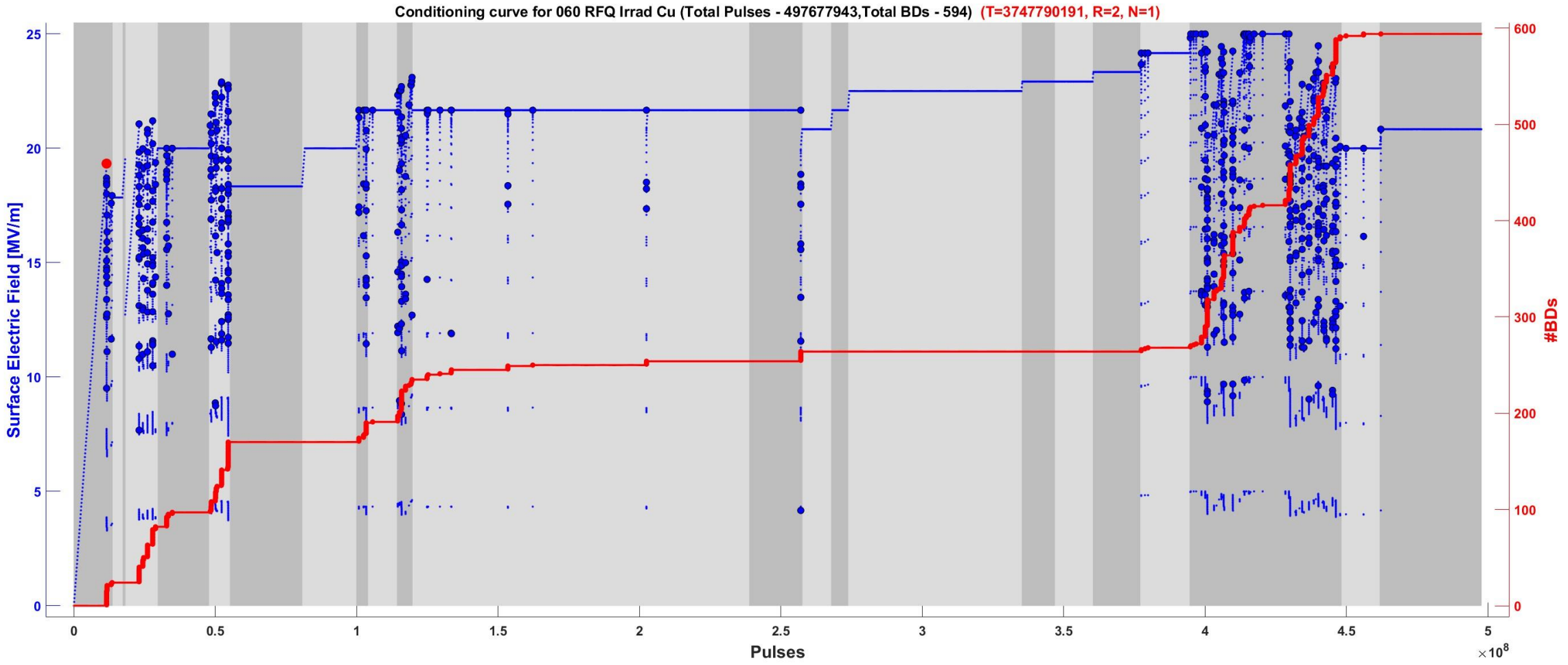


SEM Images (secondary electron detector) of Cu-OFE electrode
after being exposed with H- beam

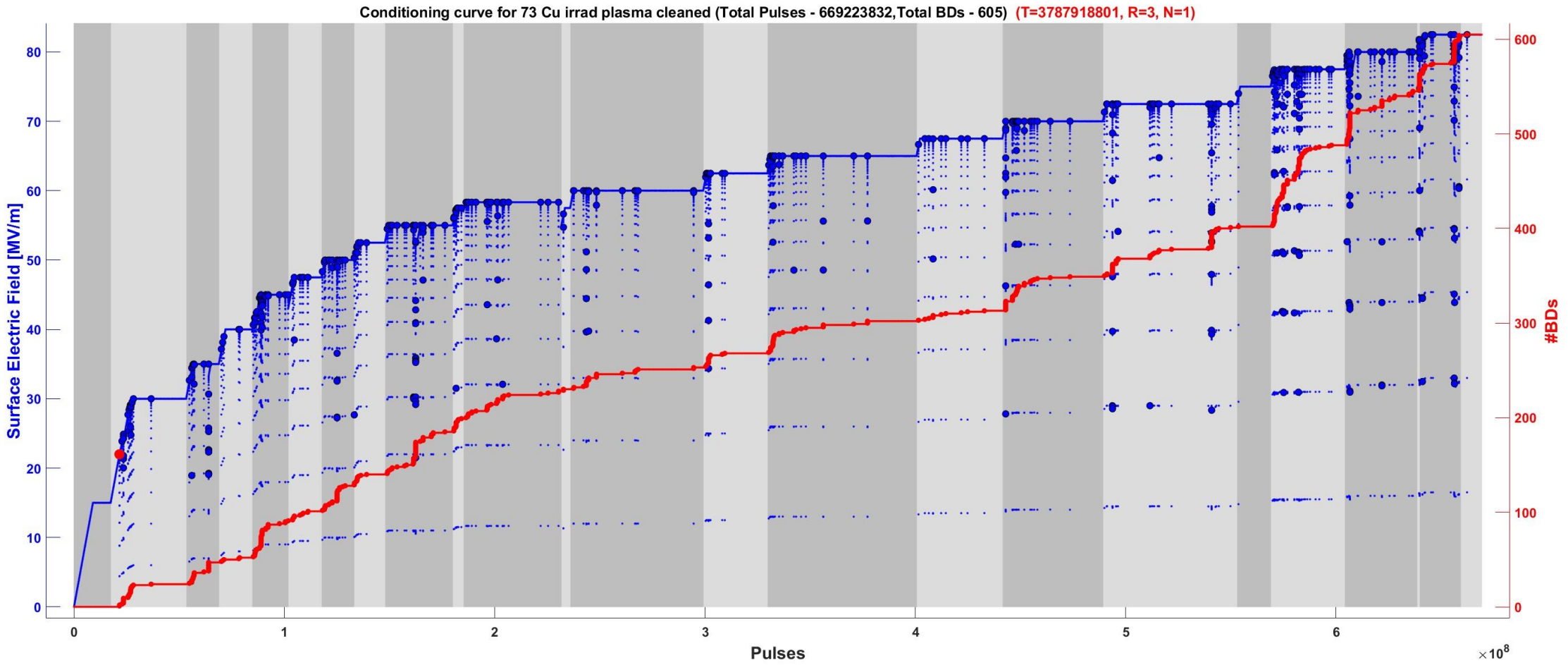




Cu-OFE electrodes after irradiation (not plasma treated)



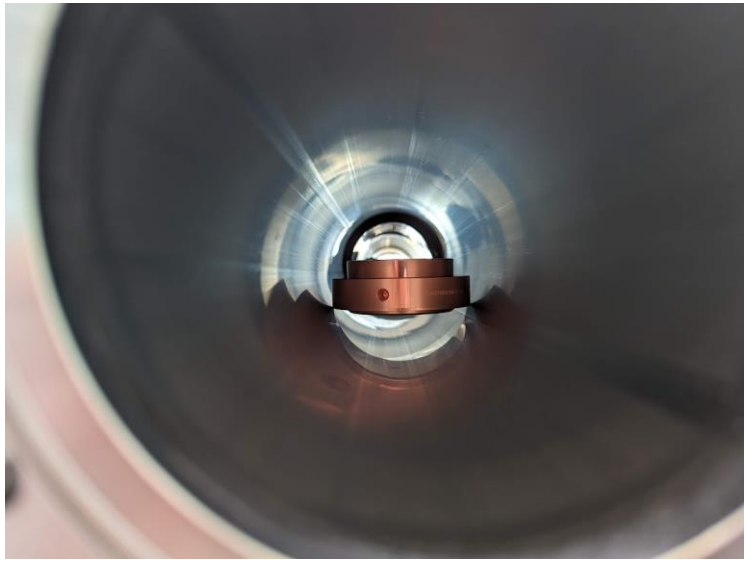
Cu-OFE electrodes after irradiation and plasma cleaning



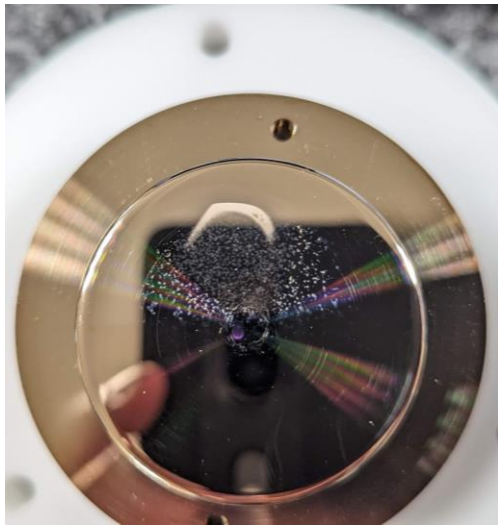
In general, some fragments of the C layer are still visible in the surface.
Chemical analysis was preformed in different areas before and after plasma cleaning.

- Before plasma treatment we had 9-12% of C
- After plasma cleaning we have 1-3% of C

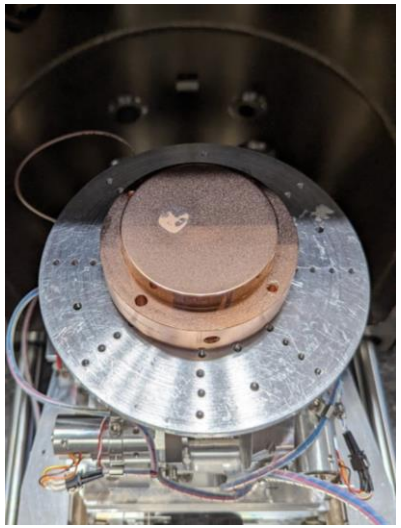
Cu-OFE and CuBe2 have shown good conditioning results after the treatment.
Next Step will be to test SS316, which achieved 120 MV/m (non-irradiated).



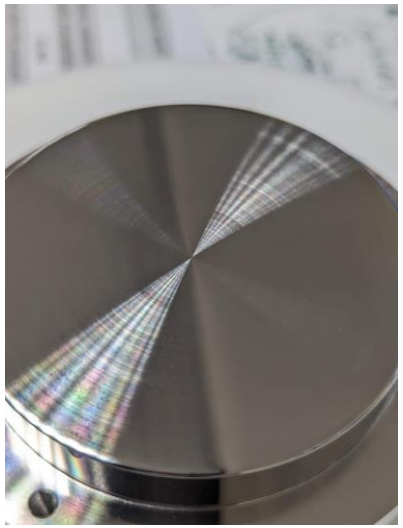
Plasma treated electrodes 2023/2024



CuBe2



Cu-OFE



SS316

Thank you