SEM observations of Pre-breakdown Structures on OFHC Copper Surfaces

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MeVArc

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The Hebrew University of Jerusalem

Introduction

- One of the suggested models for breakdown (BD) is surface plastic activity leading up to BD.
- Such pre-BD plastic activity may create identifiable pre-BD surface features.
- Cu samples were exposed to DC fields up to BD and then analyzed using SEM to identify such features.

- The main aims:
  A. Identify pre-BD surface structure.
  B. Study surface evolution as a function of "drive" condition – applied field intensity and duration.
  C. Using laser ablation method to identify energy needed to form BD-like features.

- Three types of samples:
  - Heat treated
  - Heat treated and polished
  - Diamond machined only

- Samples are compared to a cut-out sample from a full RF structure (TD24)

A brief look at how the experiments are performed

Example: sample maps with identified spots

Sample 1

Sample 49

Sample 51

Diamond machined only sample

Spots that underwent BD
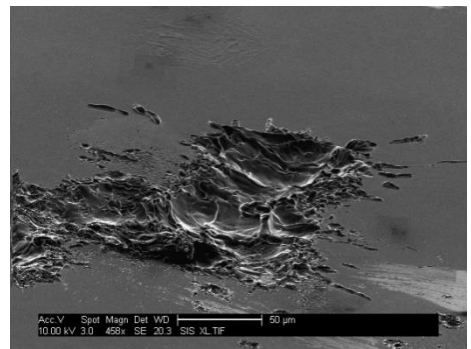
Spots that underwent FE tests

Spot 1
33-300MV/m

Spot 2 –90MV/m, 10sec
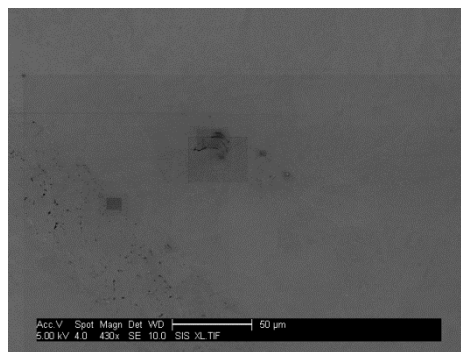
Spot 3 – 80MV/m, 10sec

Spot 4 - 80MV/m, 1sec

Spot 8
33-300MV/m

Spot 7 – 80MV/m, 10sec
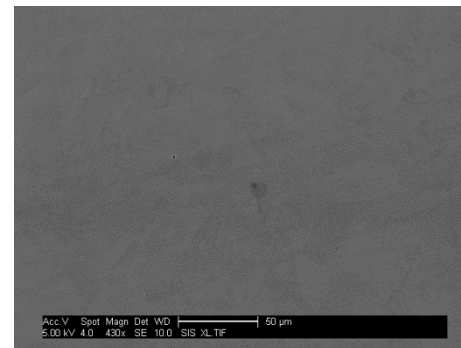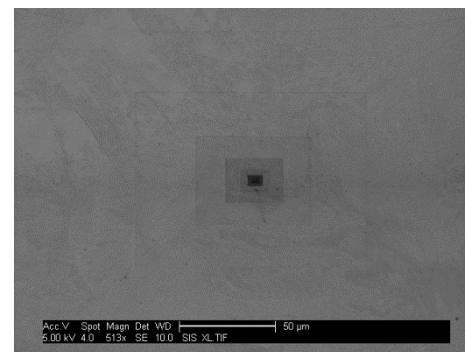
Spot 6 - 80MV/m, 1sec
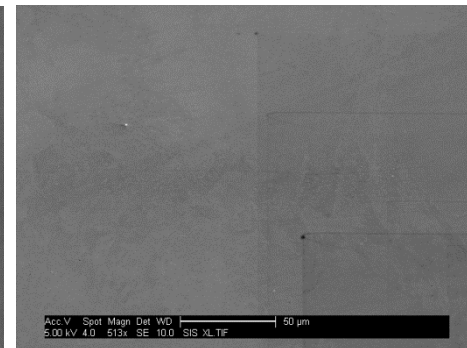
Heat treated samples

Most surfaces of heat treated samples contain various terraces (possibly due to small variations in the production process)
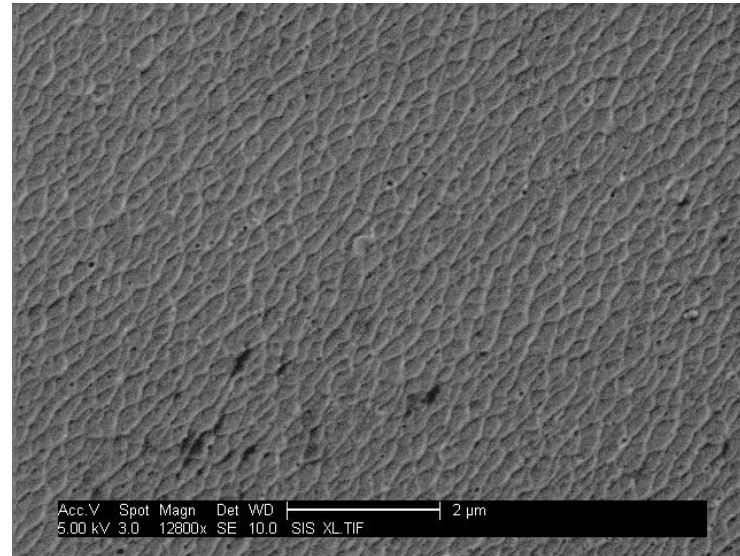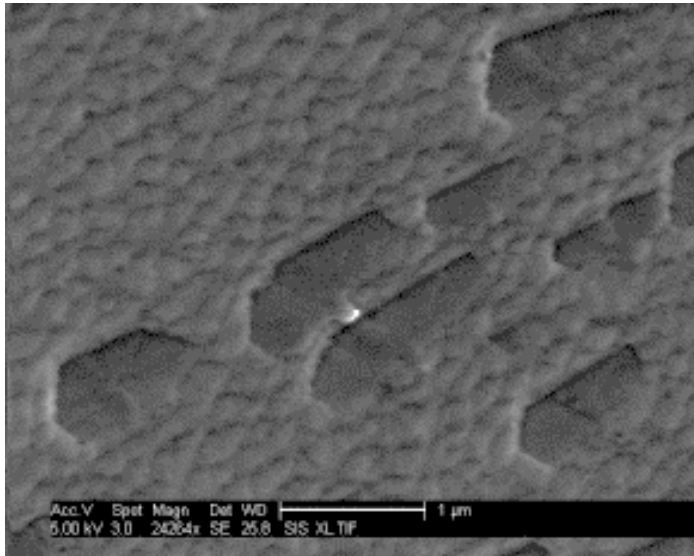
Embedded terraces are approximately 10nm in height
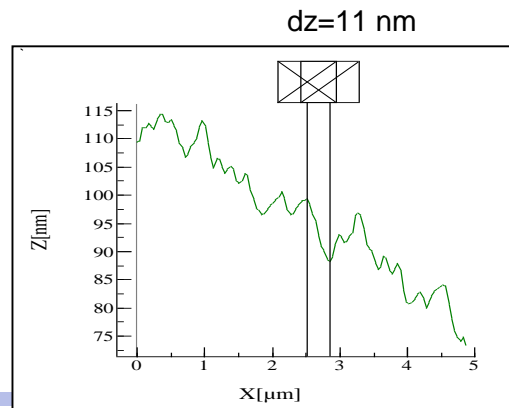
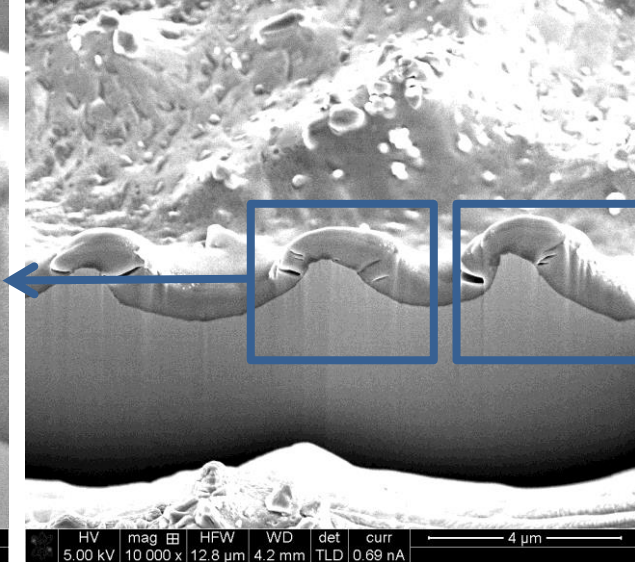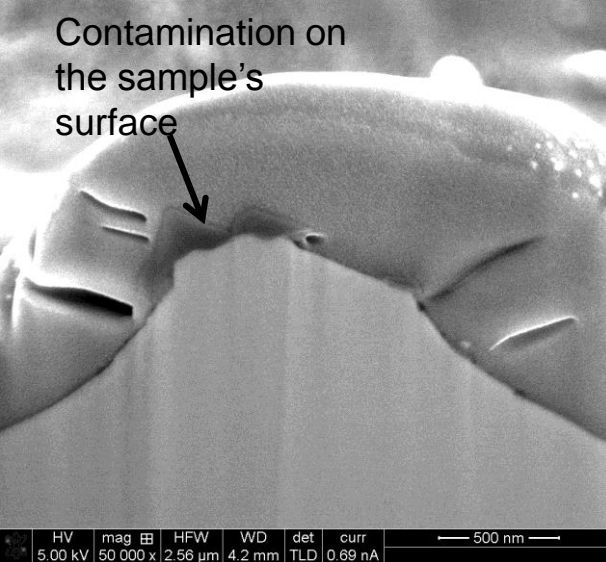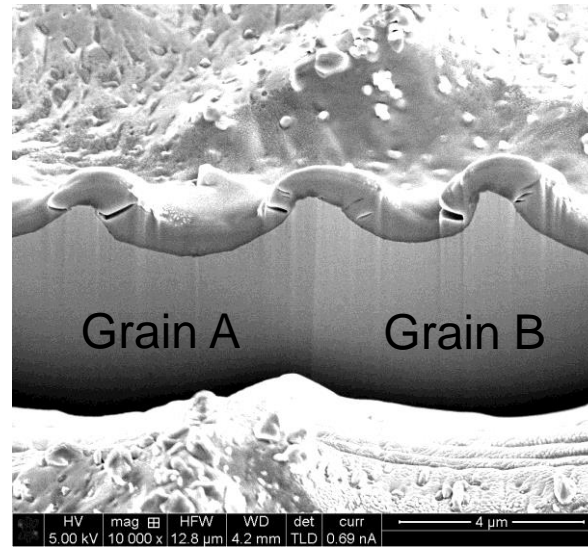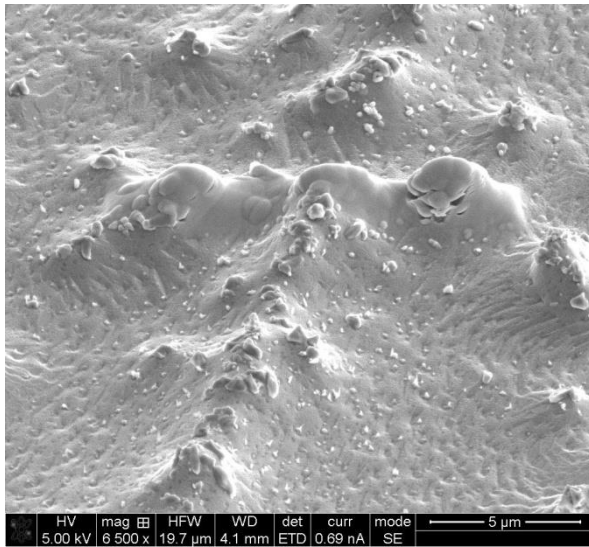# Heat treated samples - mounds

FE tested (out of FE test site)		Non FE tested
Sample ID3#7	Sample 38	Sample 50
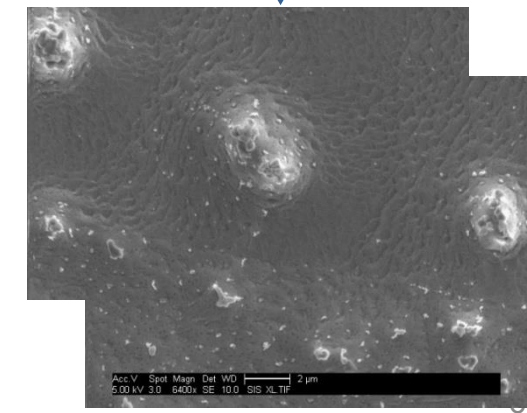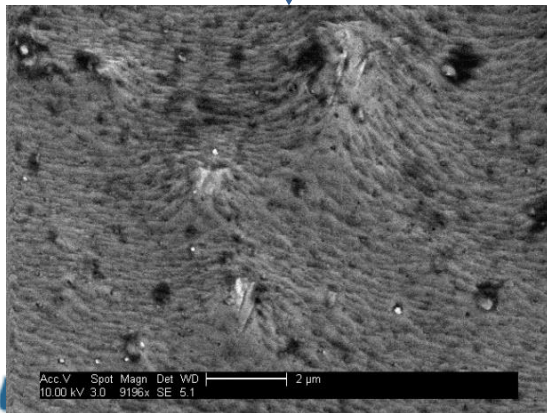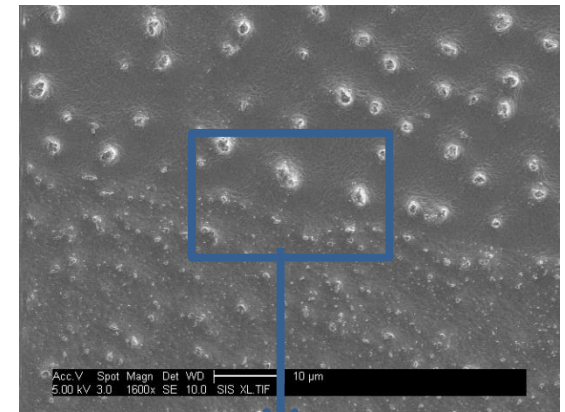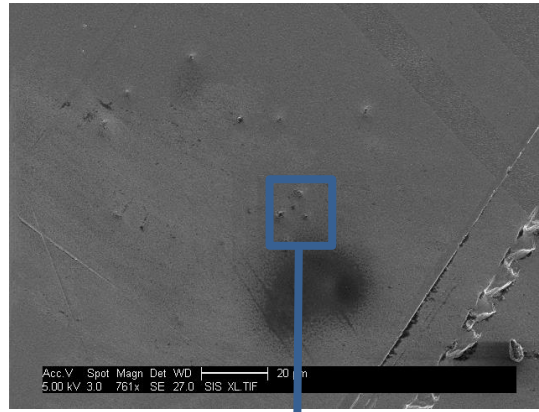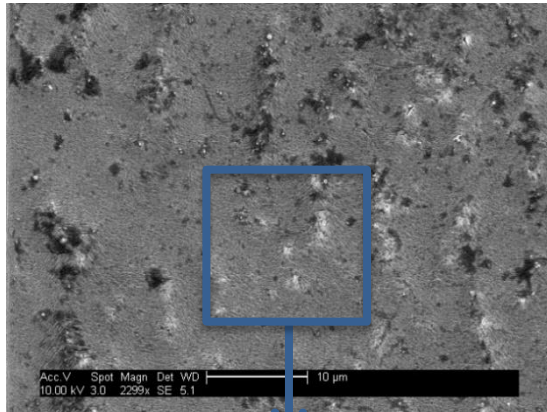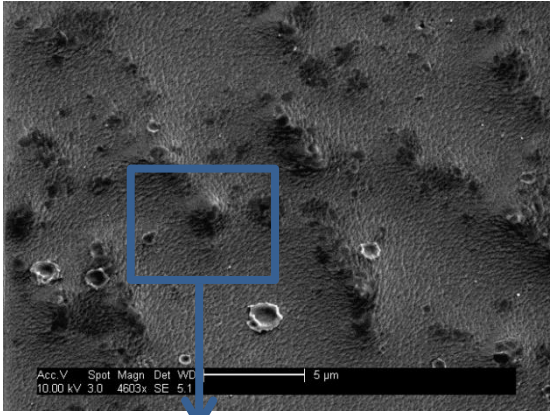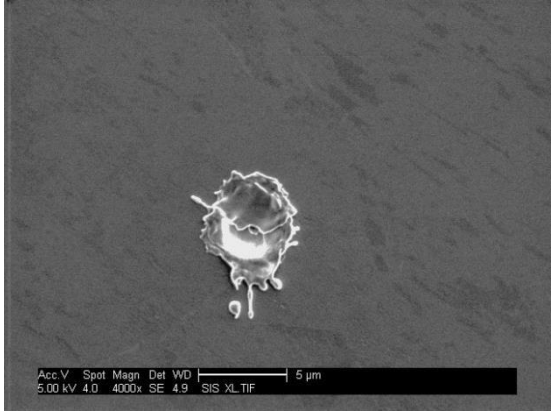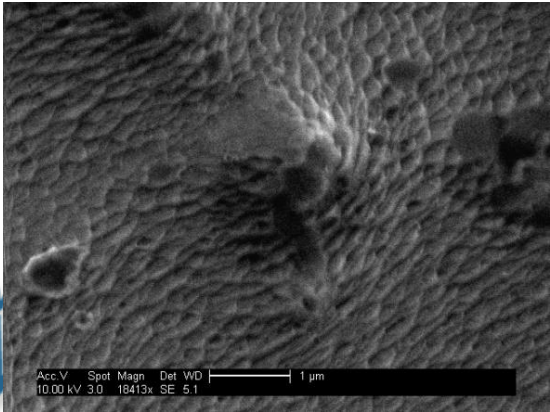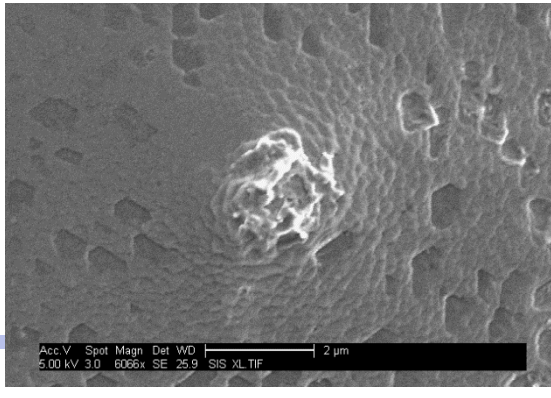
FIB examination of mounds on heat treated pre-field sample

Grain A   Grain B

Contamination on the sample's surface
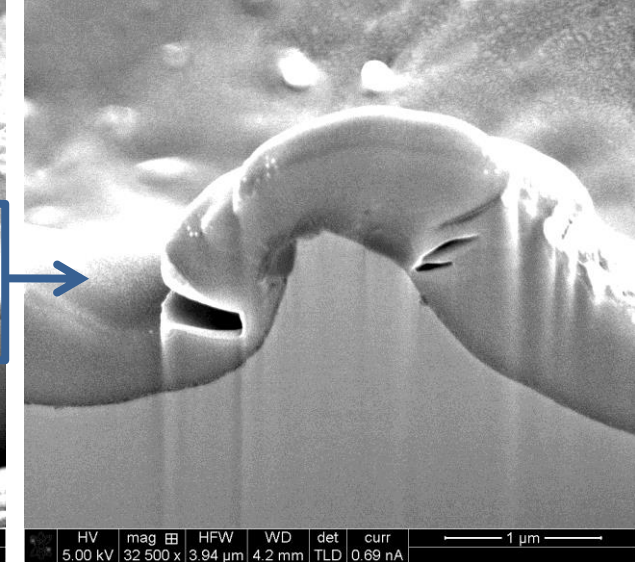
Mounds are not related to applied fields

Field exposure effect

Heat treated		Diamond machined only (no mounds)
Sample ID3#7 (304um from a BD site)	Sample 38	Sample 51

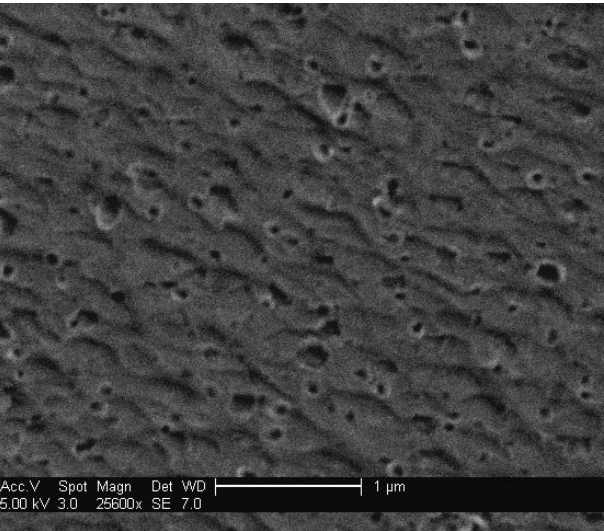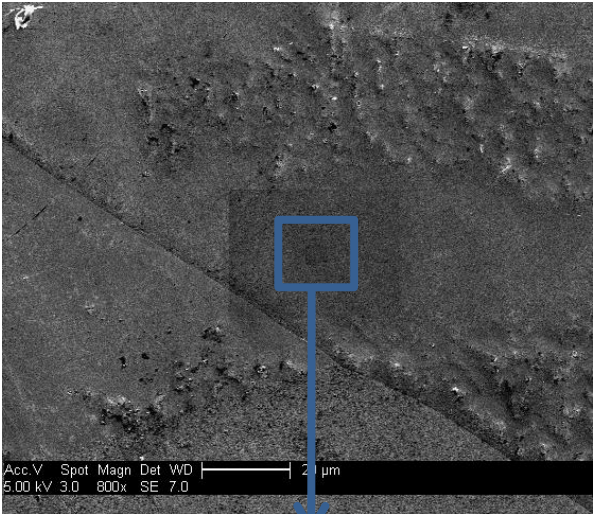# Effects of applied fields on surface structure (Pre-post BD)

Localized modification of surface terraces in heat treated samples, post field exposure

After FE test at 32.5MV/m: modified surface features, deposition? / melting? / diffusion?
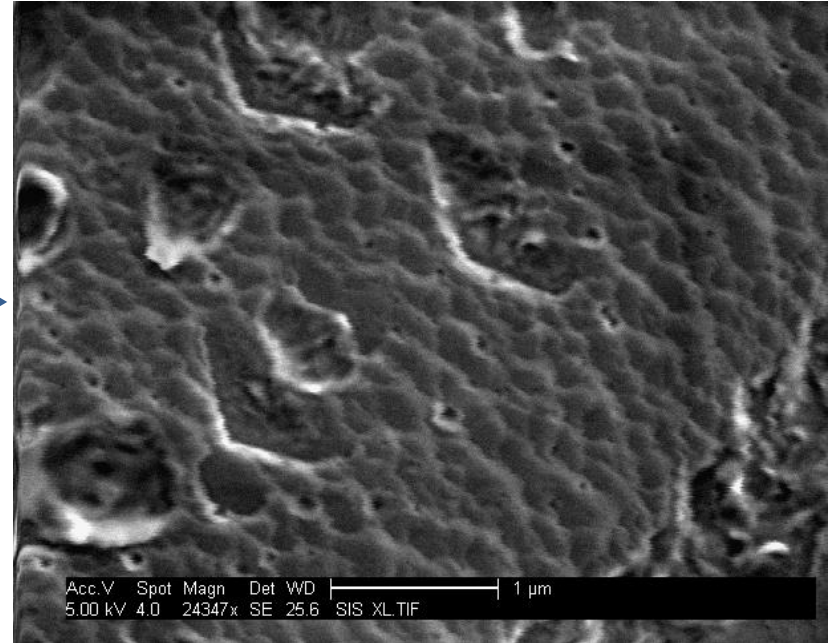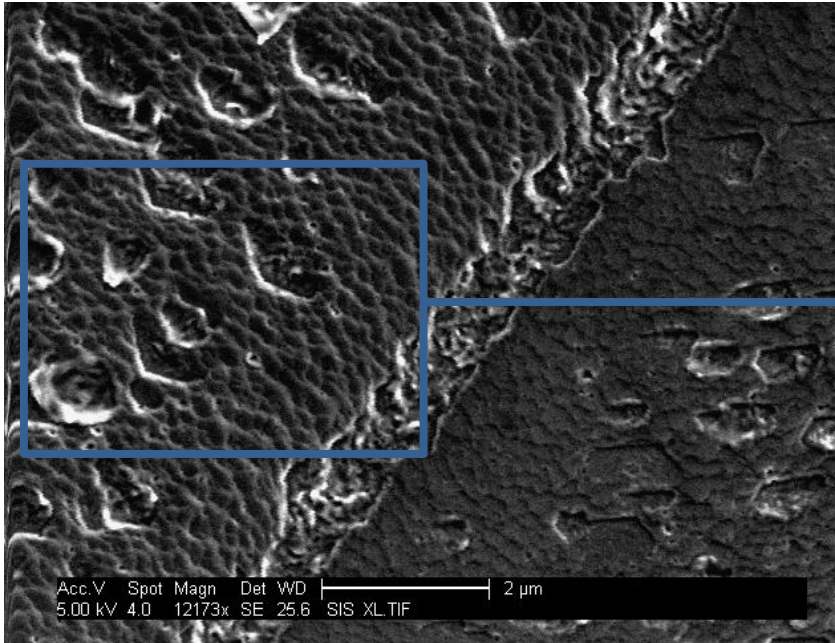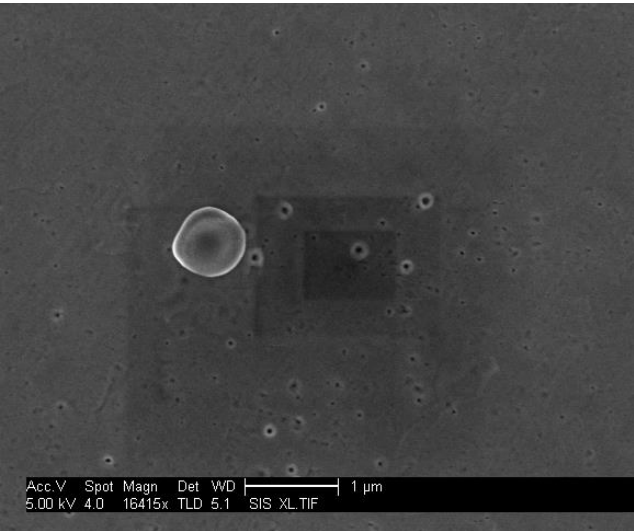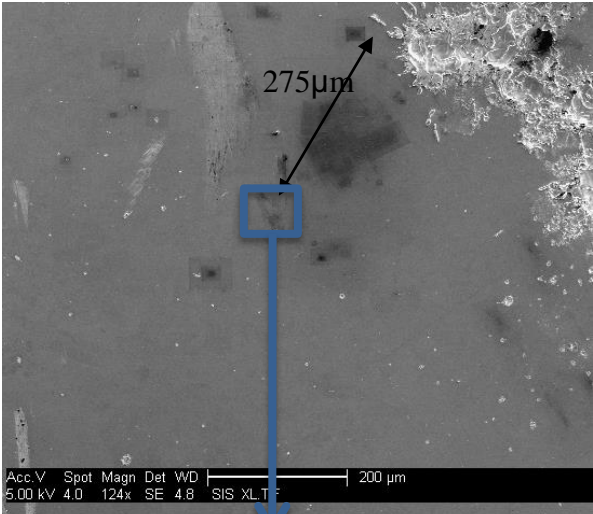
Unique features of field exposed sample: localized imprints (unknown source)
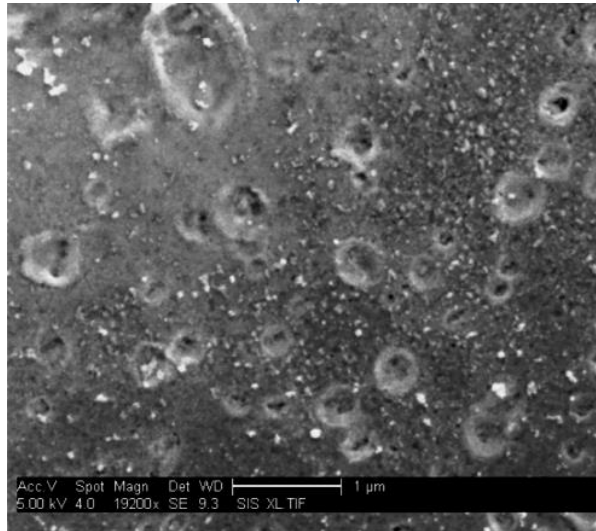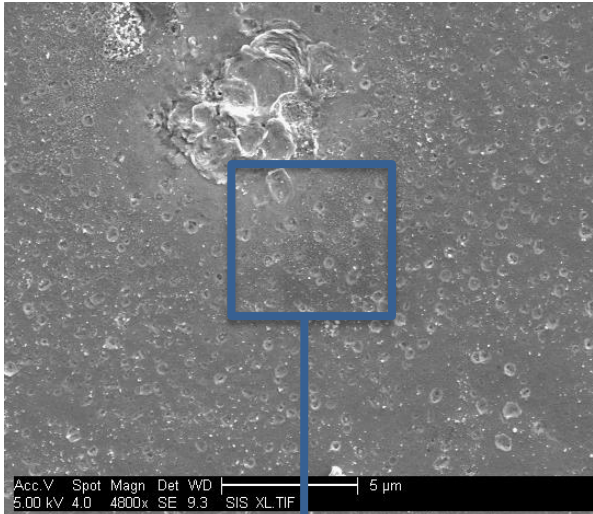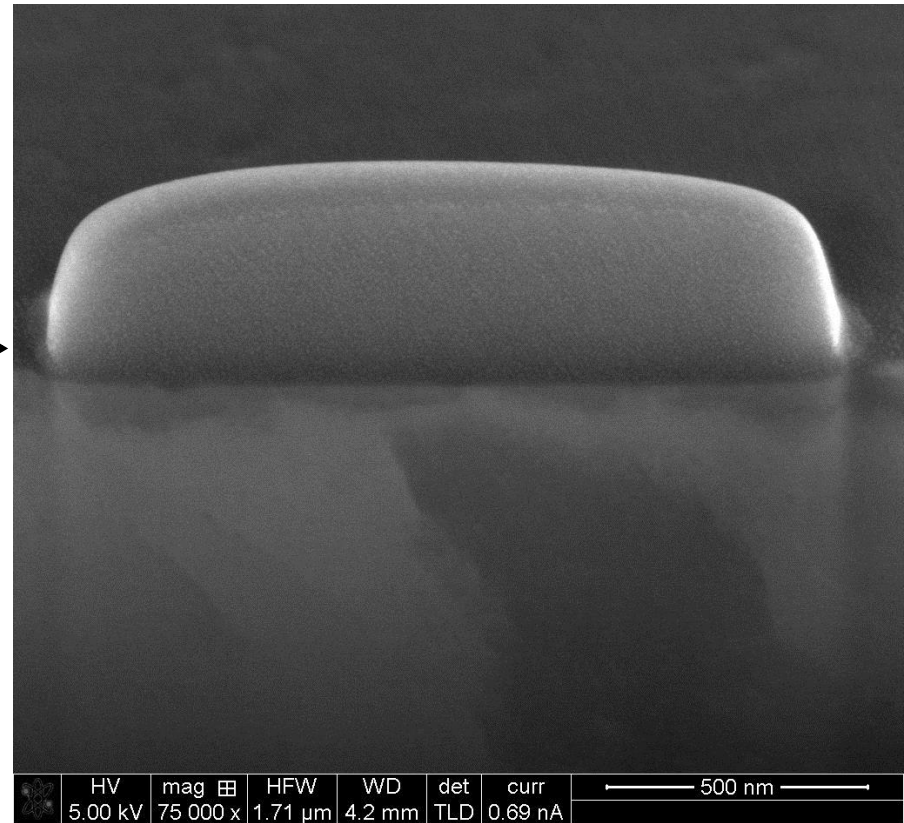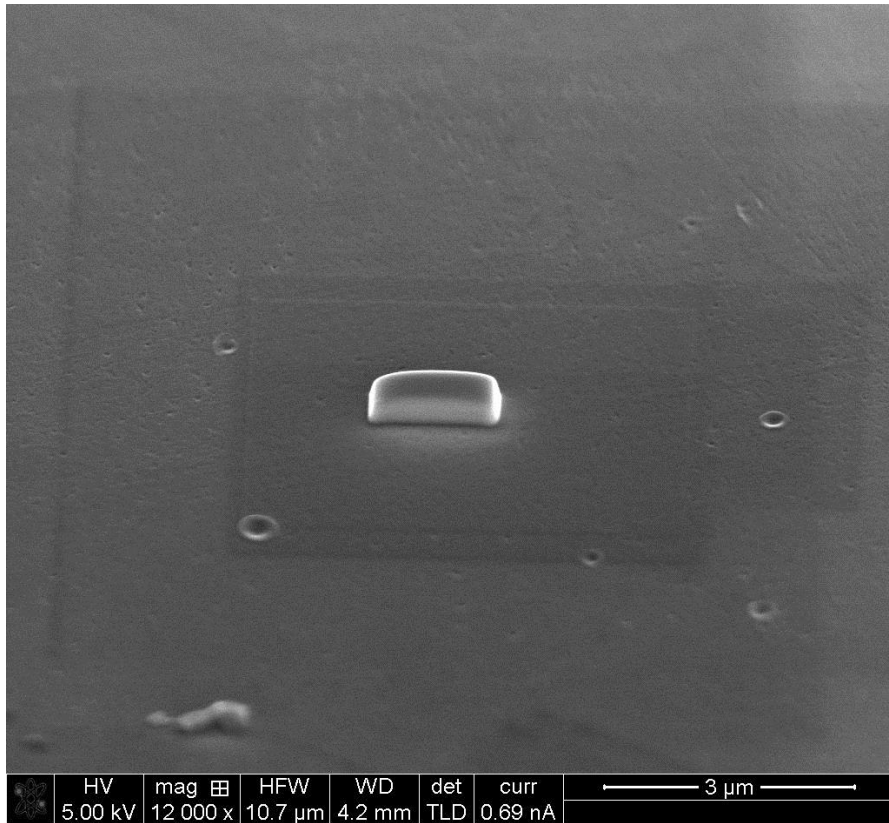
Heat treated

Diamond machined only

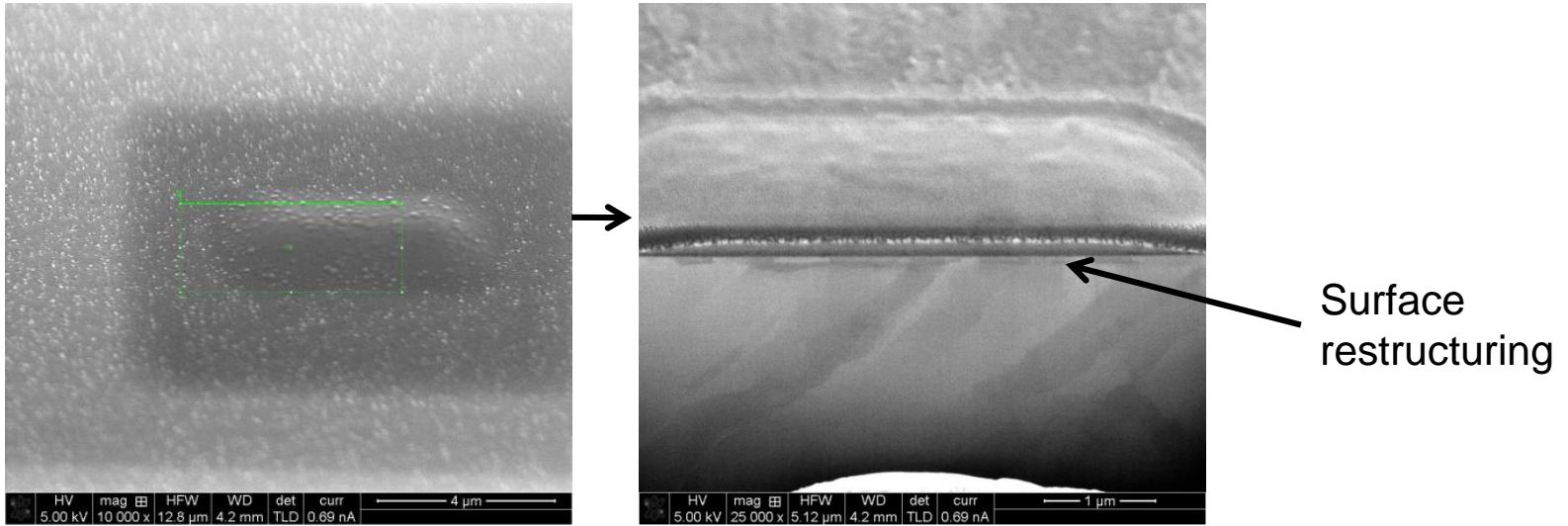## RF sample

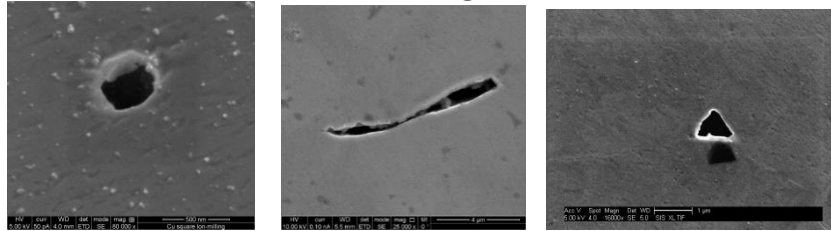Focus Ion Beam (FIB) at the imprints region
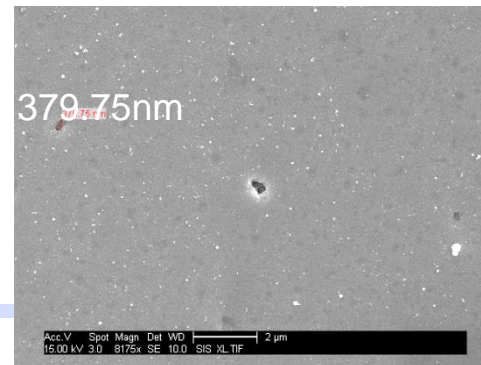

Localized surface phenomena

Diamond machined only
FIB at a reference region - far from a field emission region
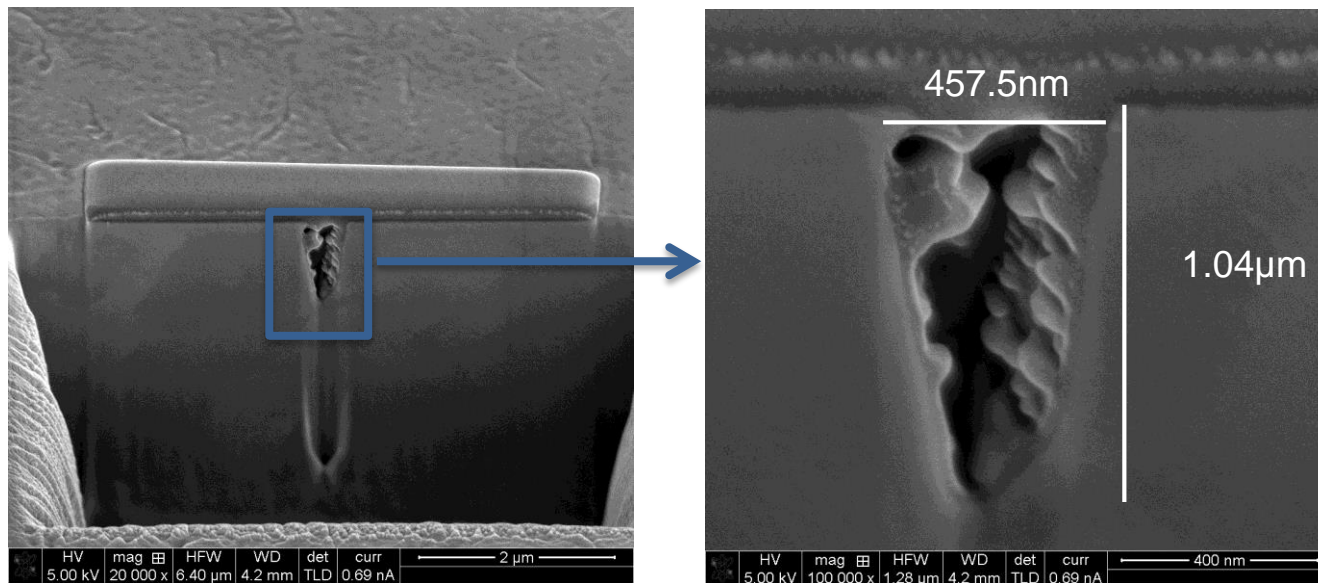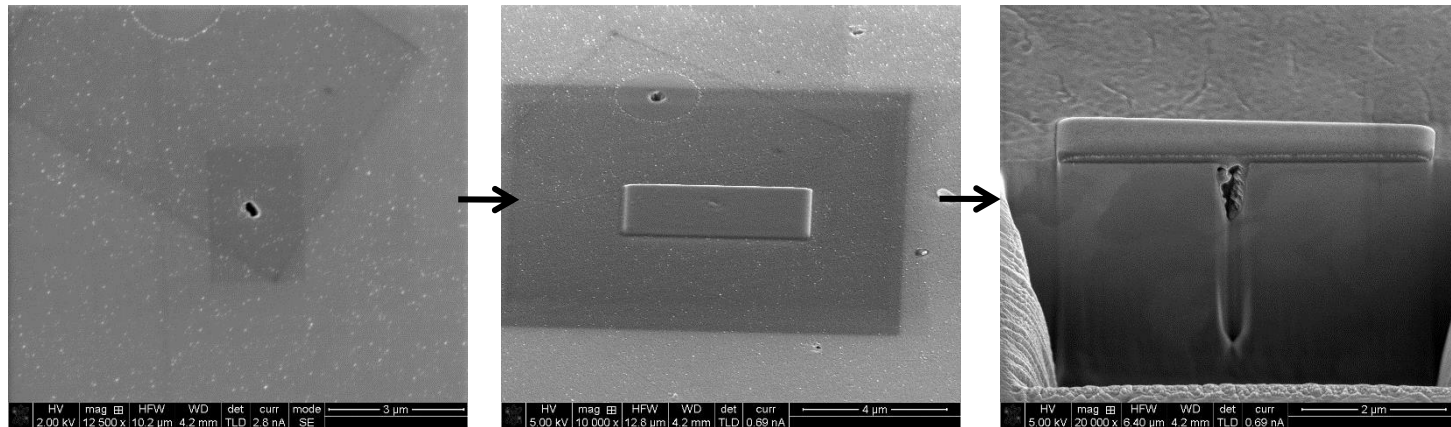

Surface restructuring

The samples contain a population of large holes with different shapes and forms
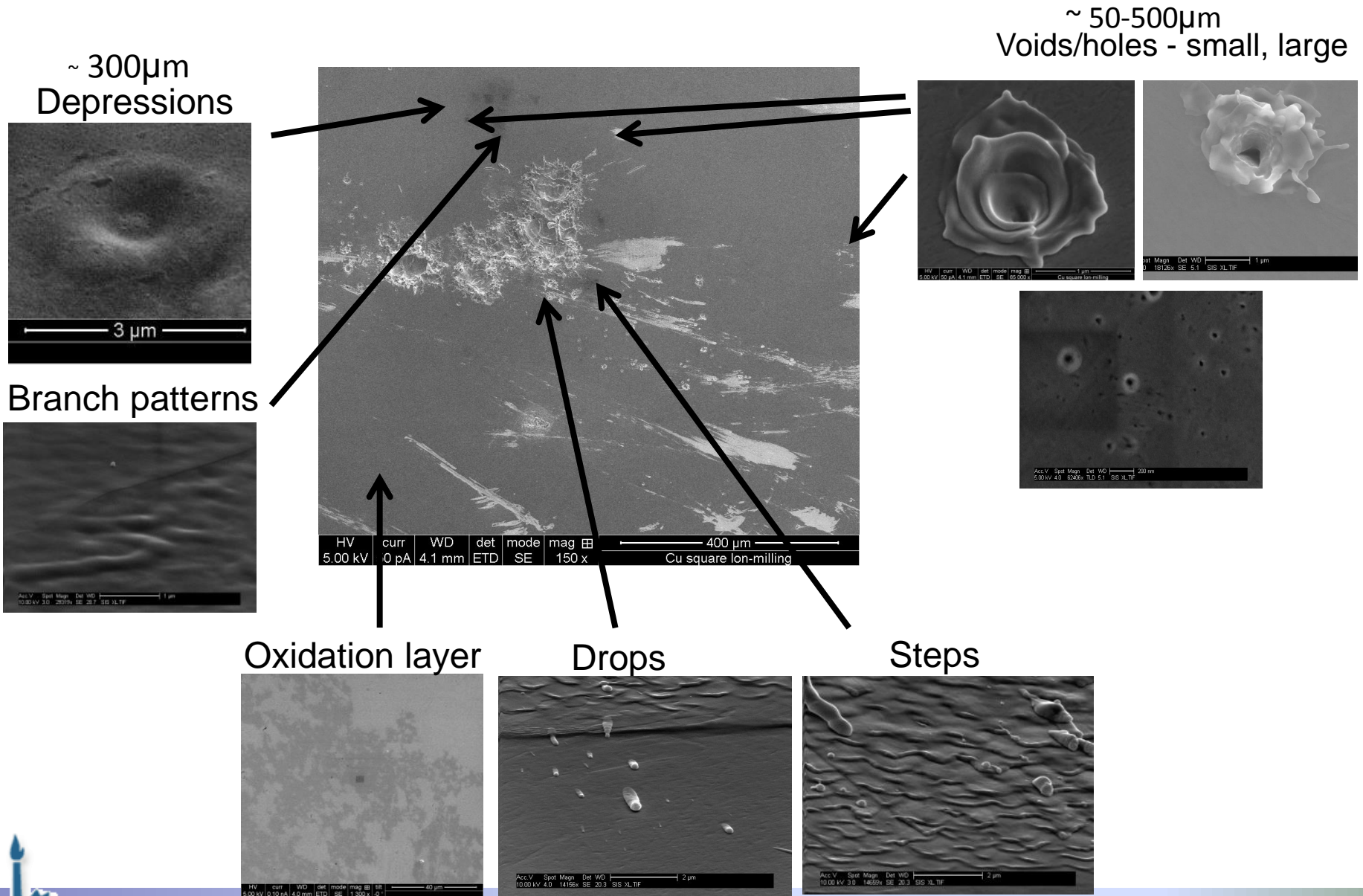

Holes can also be found in the RF sample:

379.75nm

FIB at a hole site in a DC sample (far from a breakdown site)

457.5nm

1.04μm

Features unique to non heat treated samples

Diamond machined only – effects of applying fields

~ 300µm
Depressions

~ 50-500µm
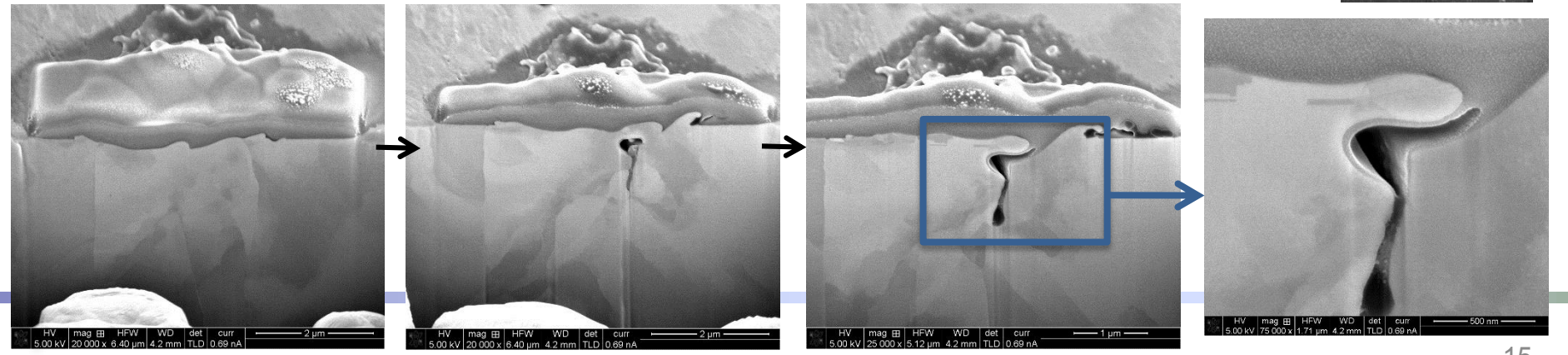Voids/holes - small, large

Branch patterns

Oxidation layer

Drops

Steps

14

Two types of splash - holes near the breakdown

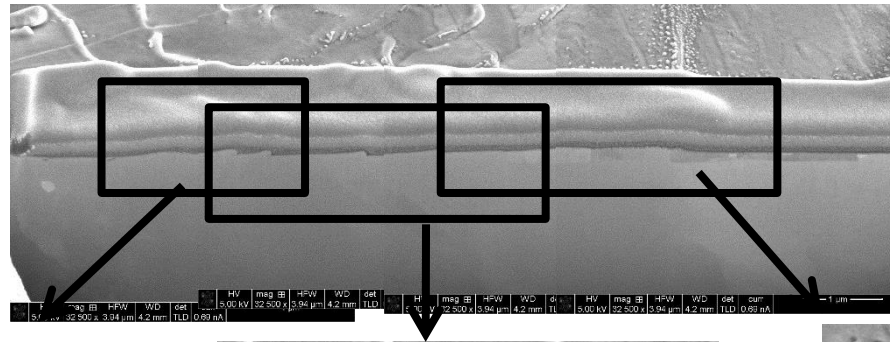## Splash when the hole is visible

1.11μm

1.68μm

580nm

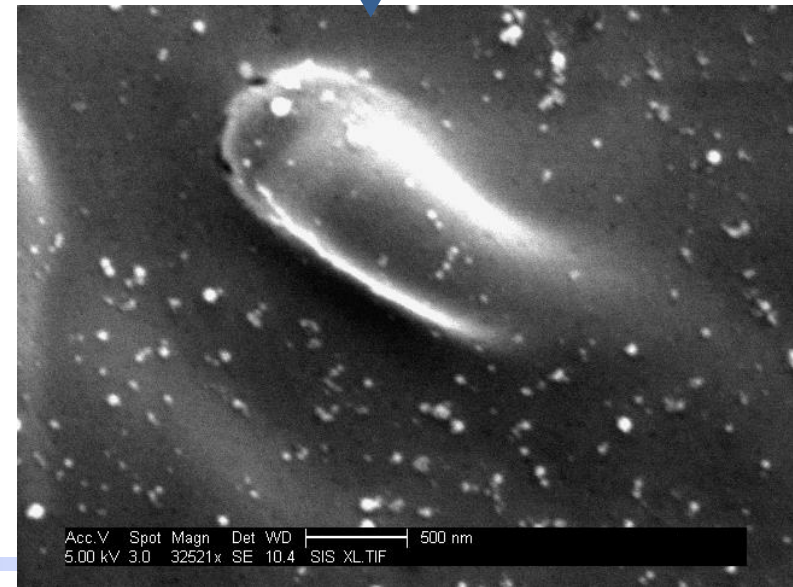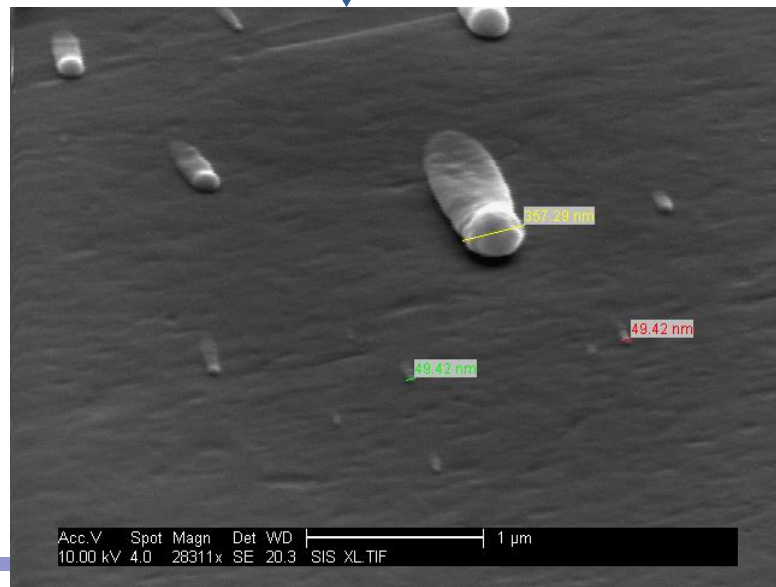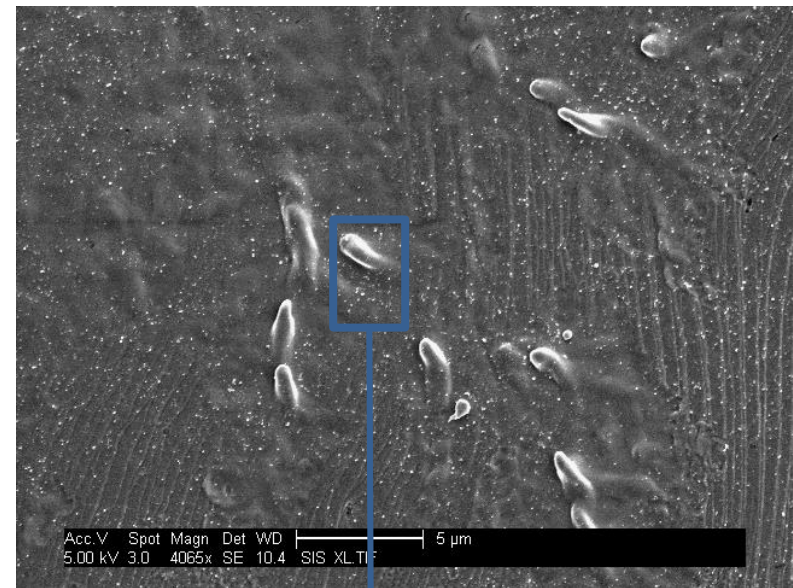## Hole with a splash cover

Wave-like

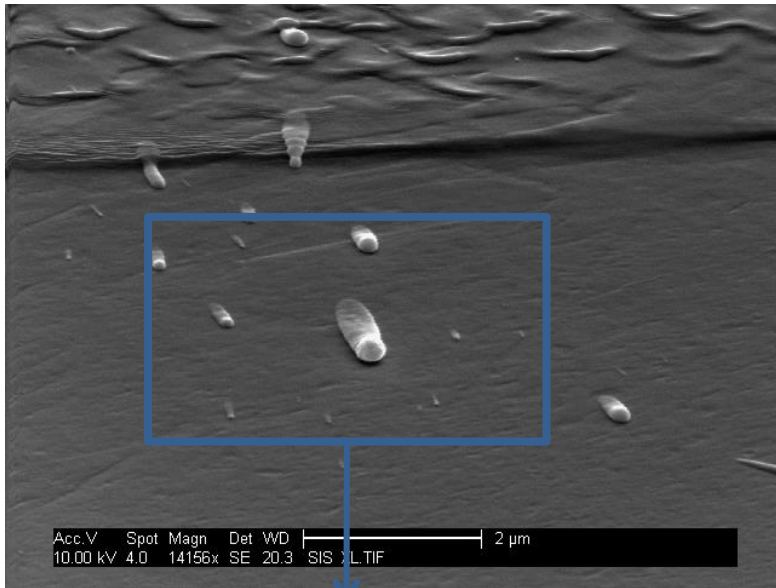Sharper edges

Surface recrystallization
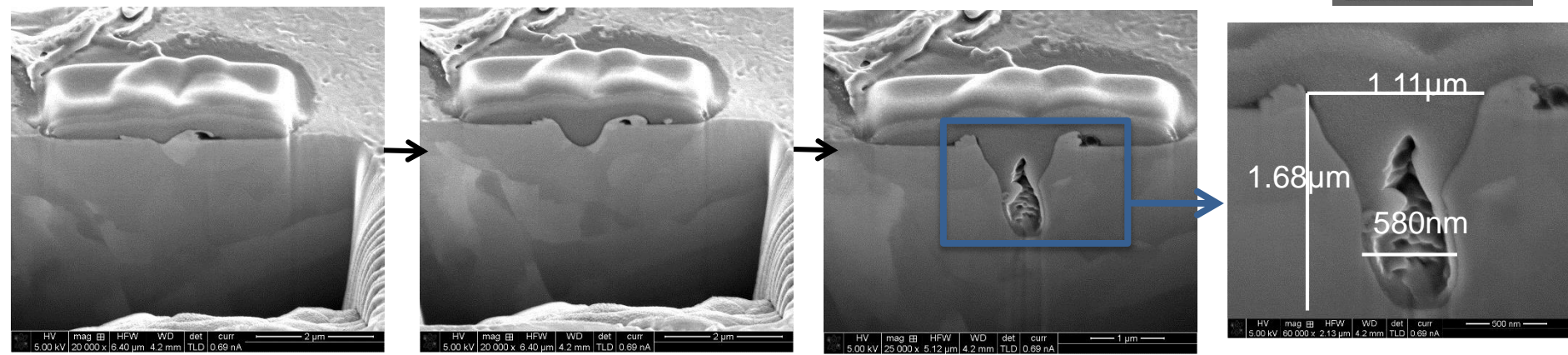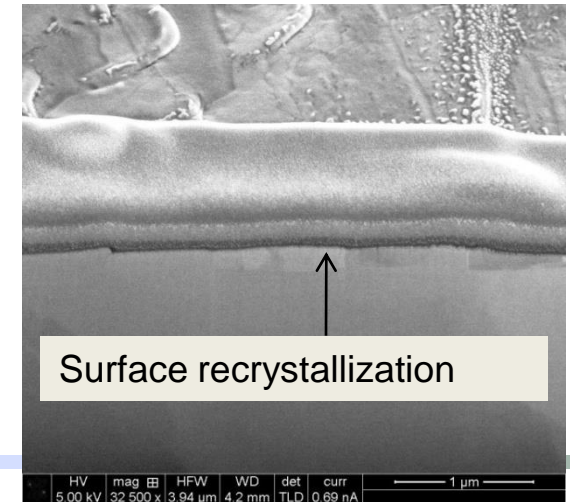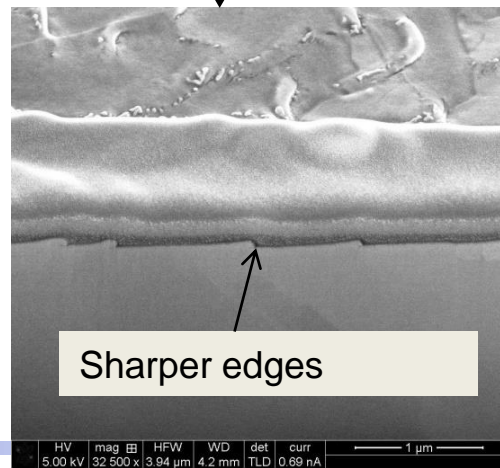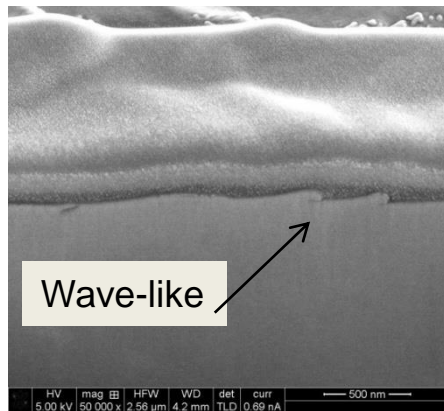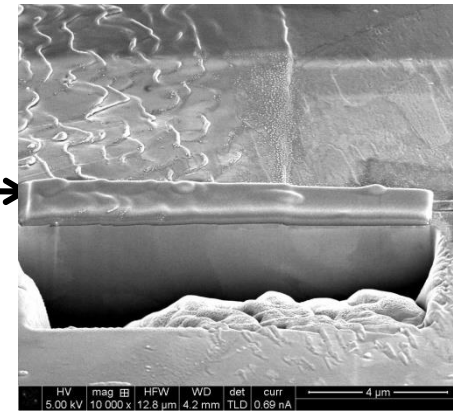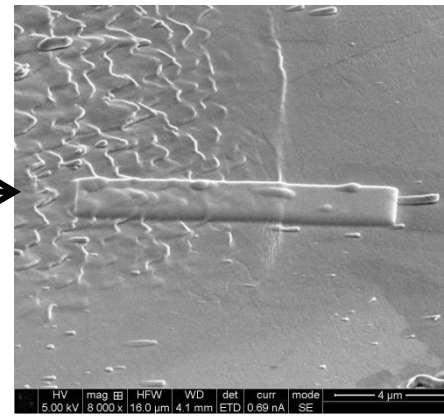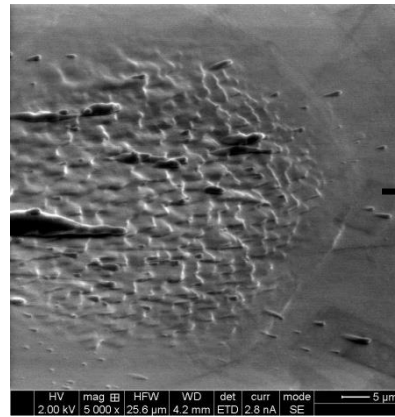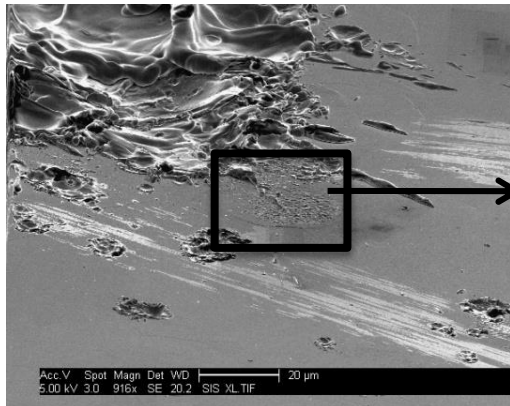
Comparison with a RF sample: drops on the surface

DC sample 49

RF sample 23

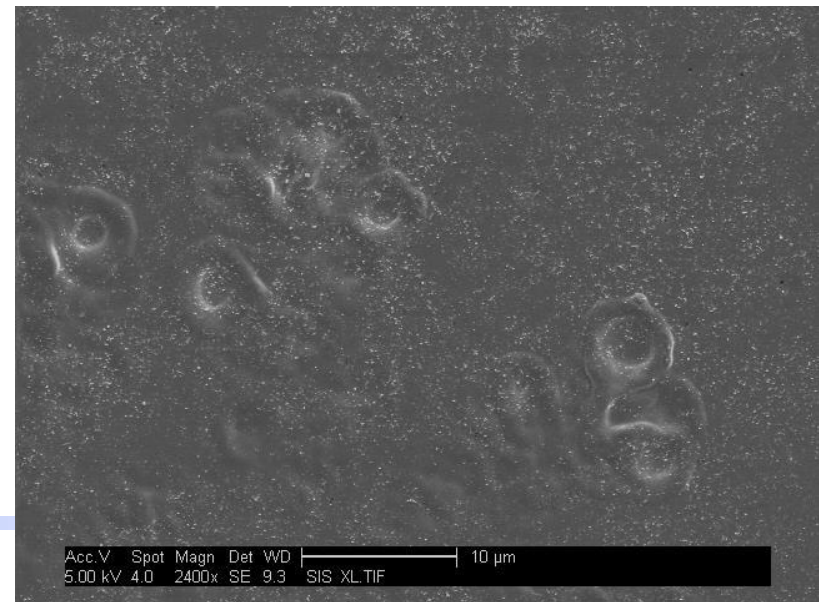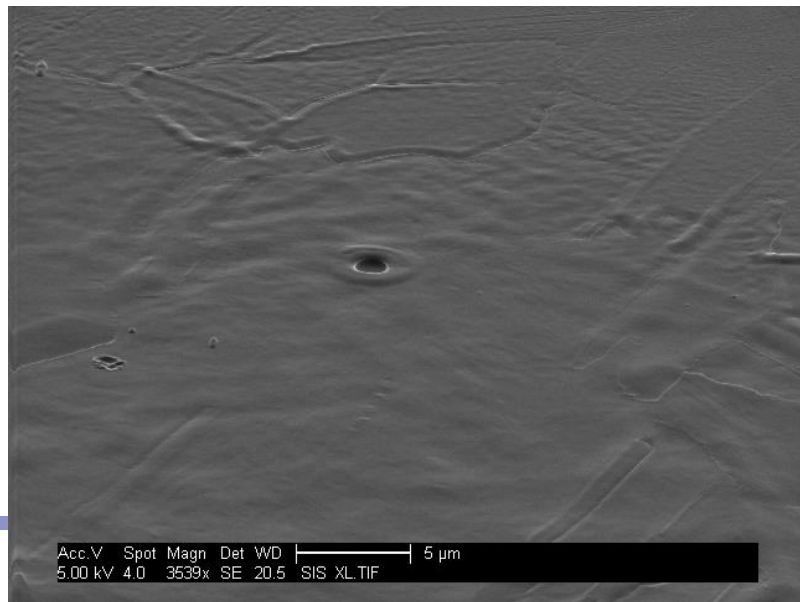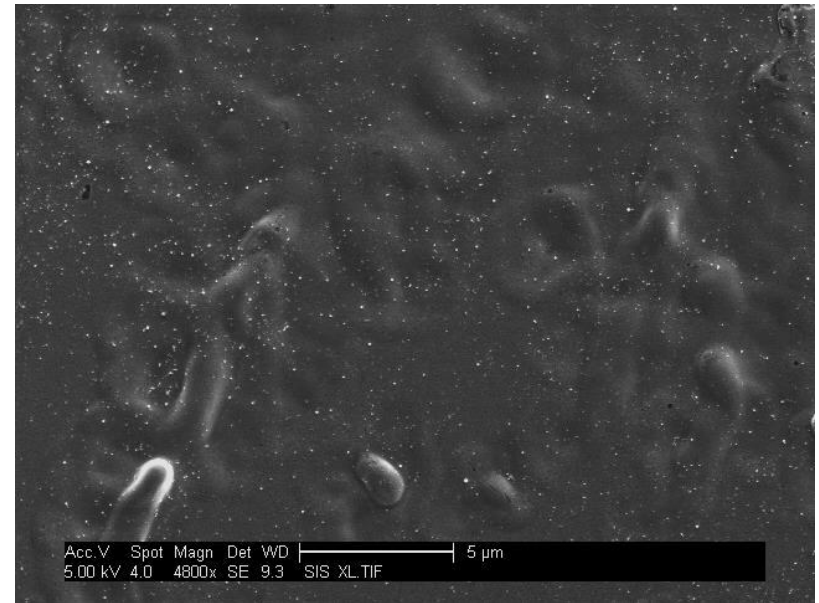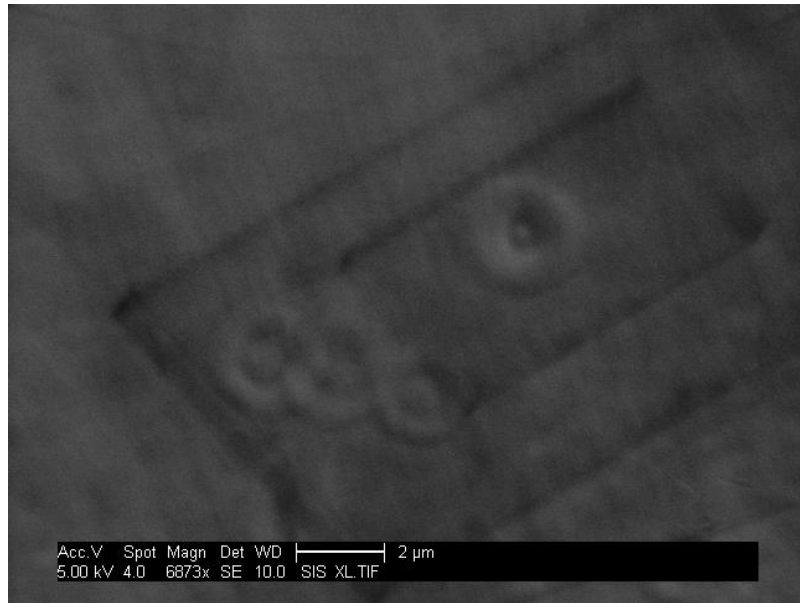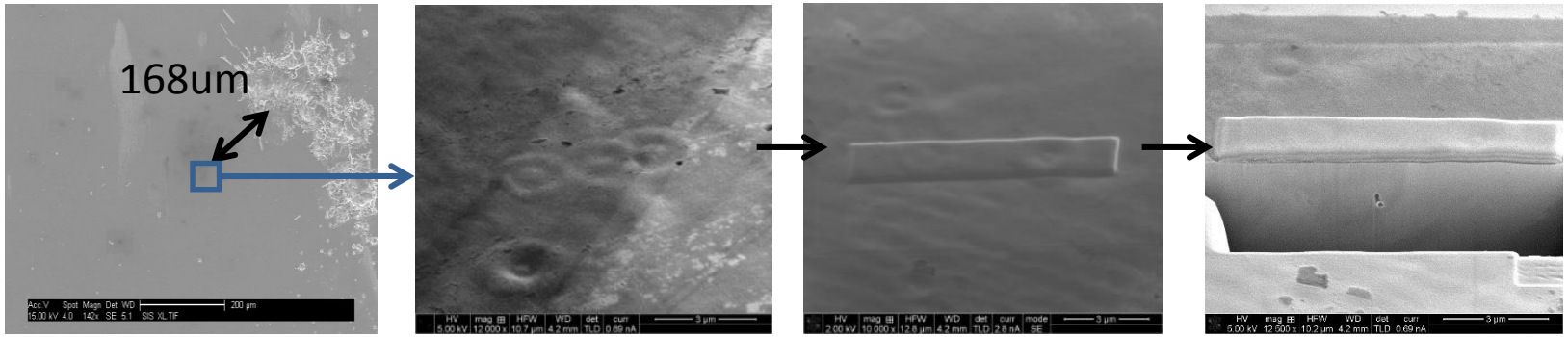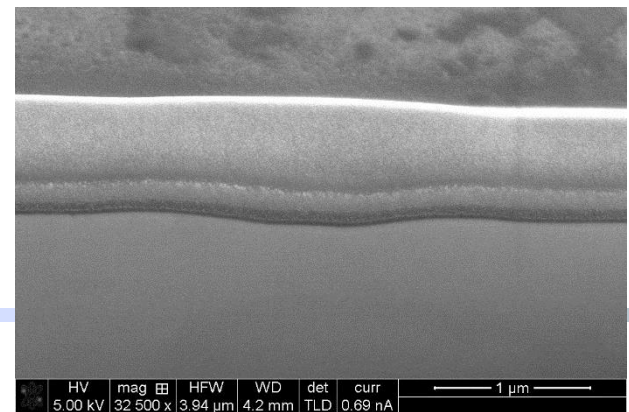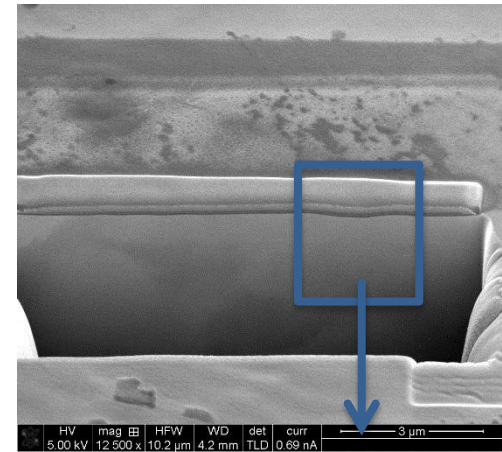# Comparison with a RF sample: depressions on the surface

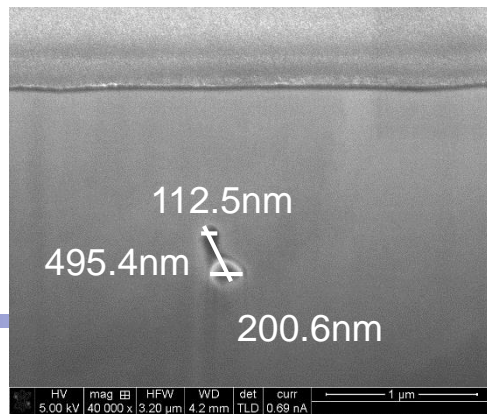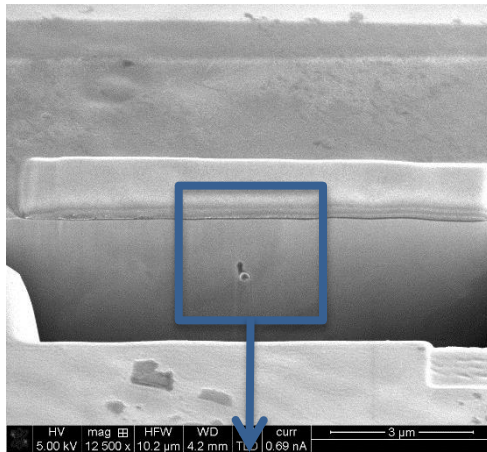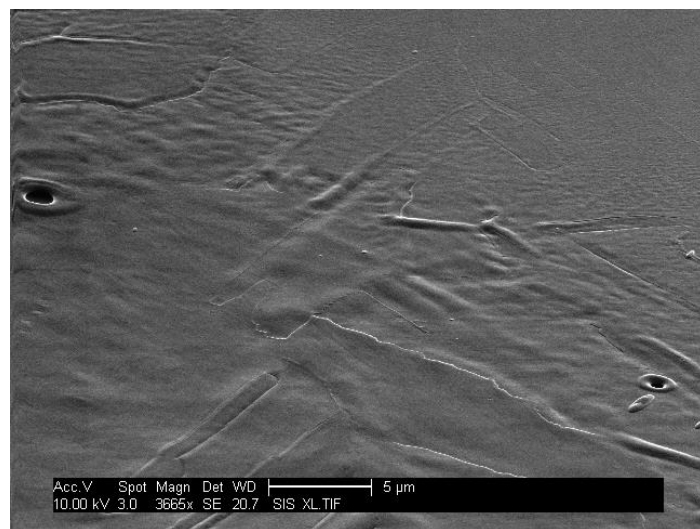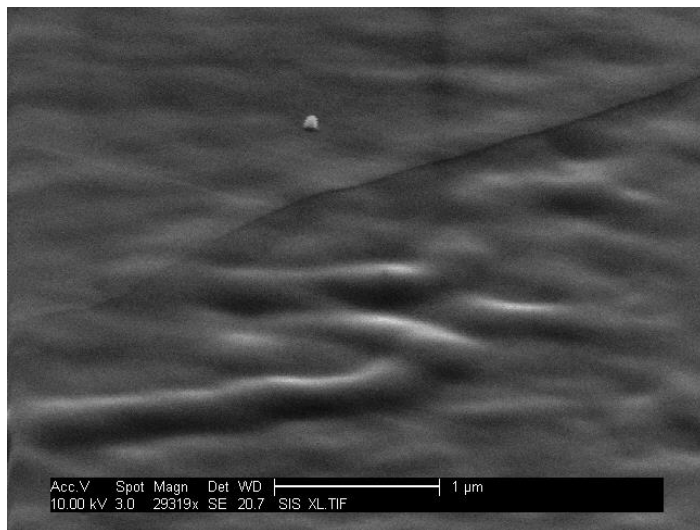DC sample 49   RF sample 23

FIB at a depressions site

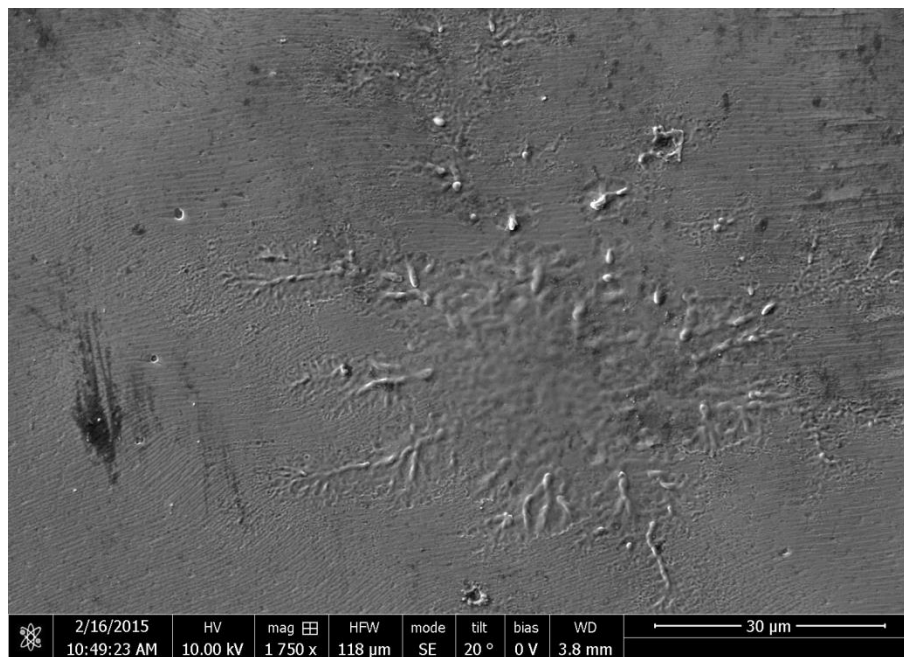During FIB process: two different stages of progress – no distinct sub-surface features

112.5nm
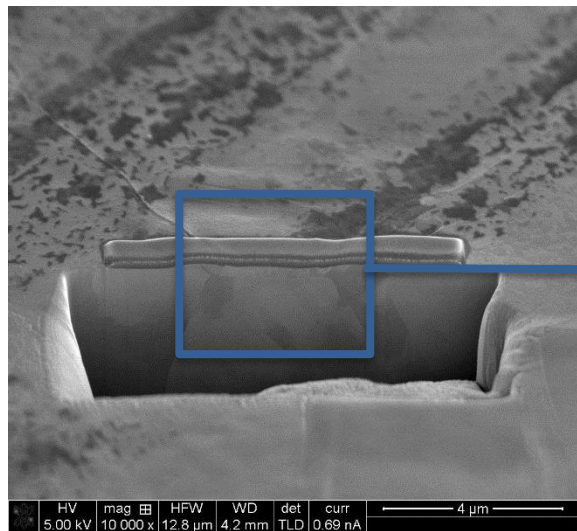
495.4nm

200.6nm

Comparison with a RF sample: branch patterns

DC sample 49

RF sample 23

176.46nm

434.58nm

-
6nm
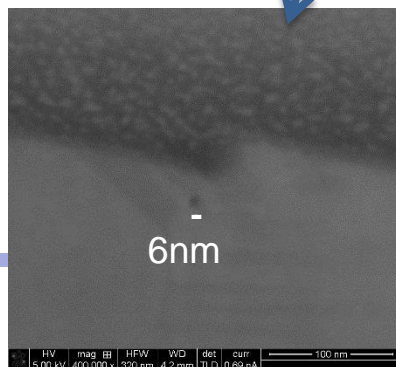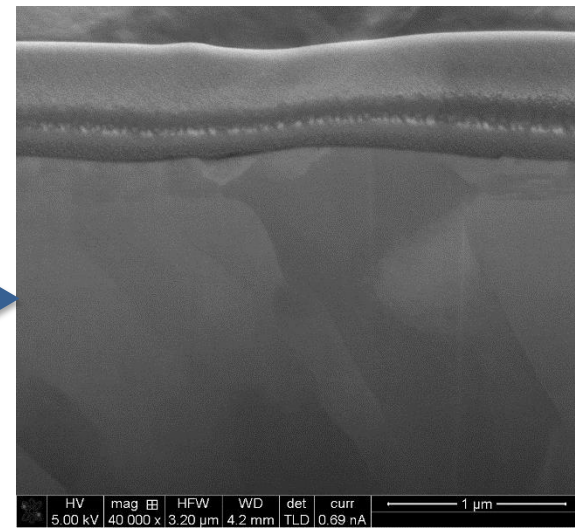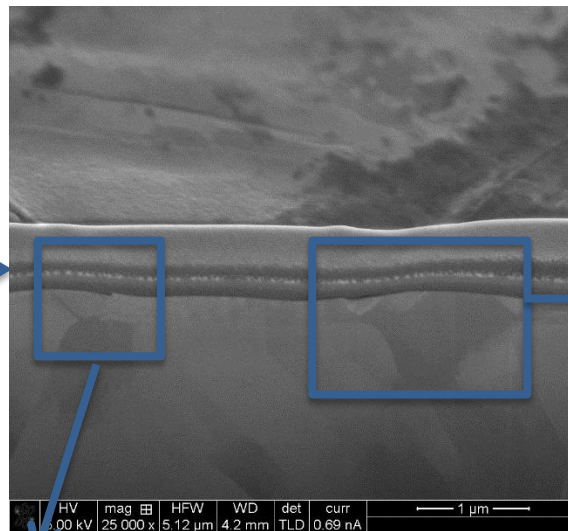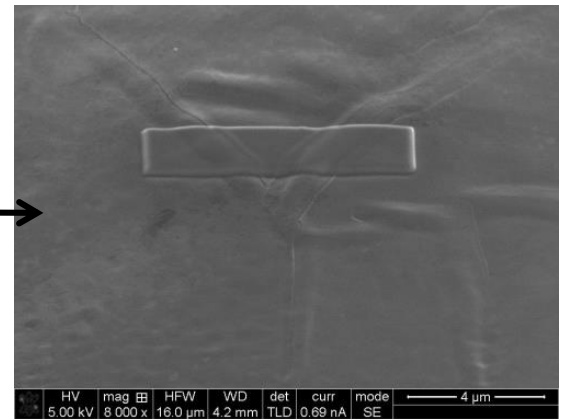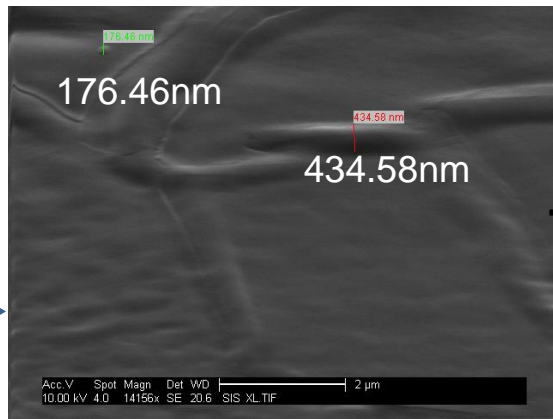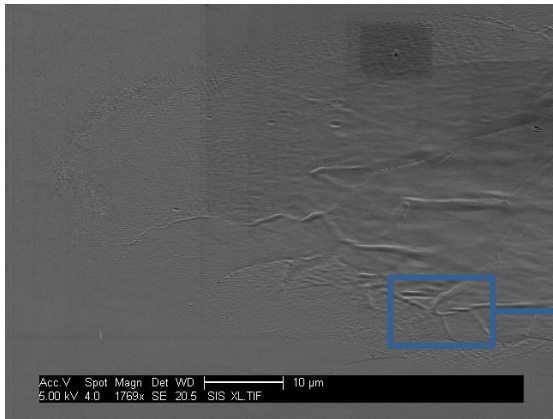
Laser Ablation – a brief overview

Sample 38 FE of 64Mv/m
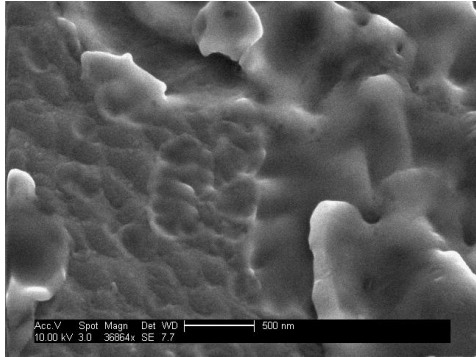
Features created by a Ti:sapphire laser, λ = 800 nm, 65-fs pulses, 1 mJ/pulse, 1-kHz repetition rate
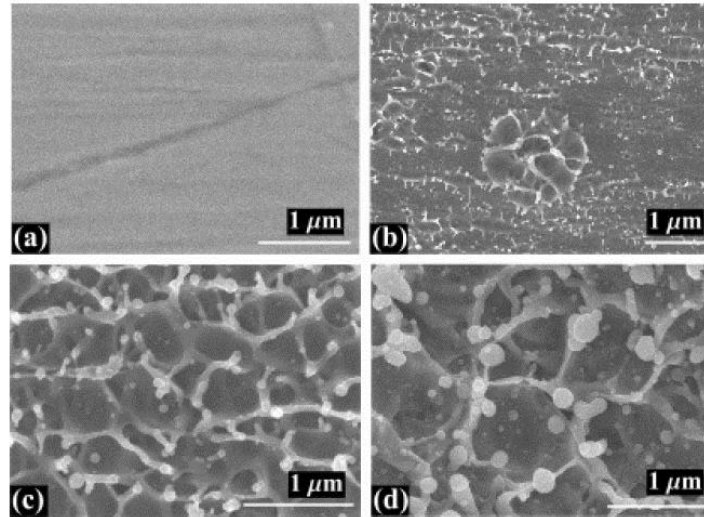
SEM images of nanoscale structures in the center of the irradiated spot on copper following ablation at *F = 0.35 J/cm2. (a) Sample surface before irradiation. [Note, this figure* does not show the same spot on the sample as in (b)], (b) surface after one-shot ablation featuring random fine nanostructures in form of nanoprotrusions, nanocavities, and nanorims,(c) after two-shot ablation, (d) after 1000-shot ablation.

The main goals are:

- Identify energy needed in a pulse to create similar features on the surface
- Finding clues for pre-breakdown surface evolution

Citation
A.Y. Vorobyev, Chunlei Guo, "Femtosecond laser nanostructuring of metals," Opt. Express **14,** 2164-2169 (2006); http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-14-6-2164

> The laser in use: Ti:Sa laser, λ=800nm, maximum pulse energy of 30mJ, 60-fs pulses

LASER

RF
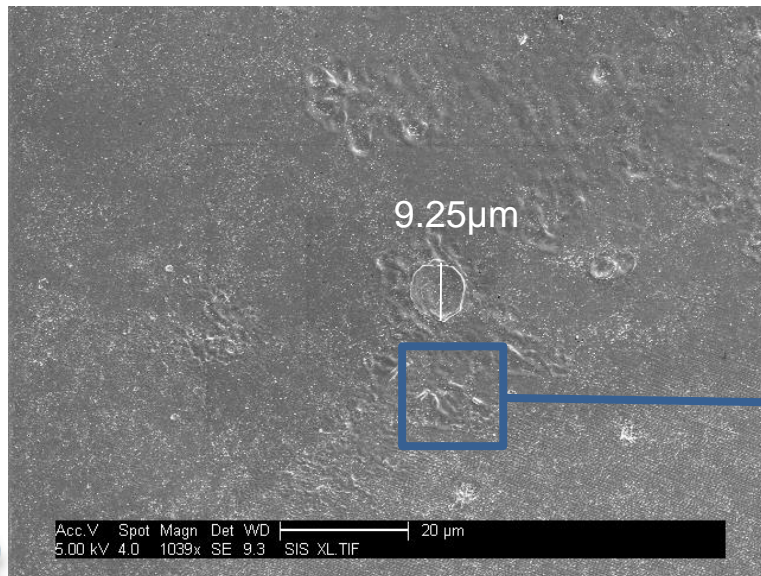
More images of similarities (with a DC sample)

LASER

1.6μm

0.95μm

Acc.V Spot Magn Det WD
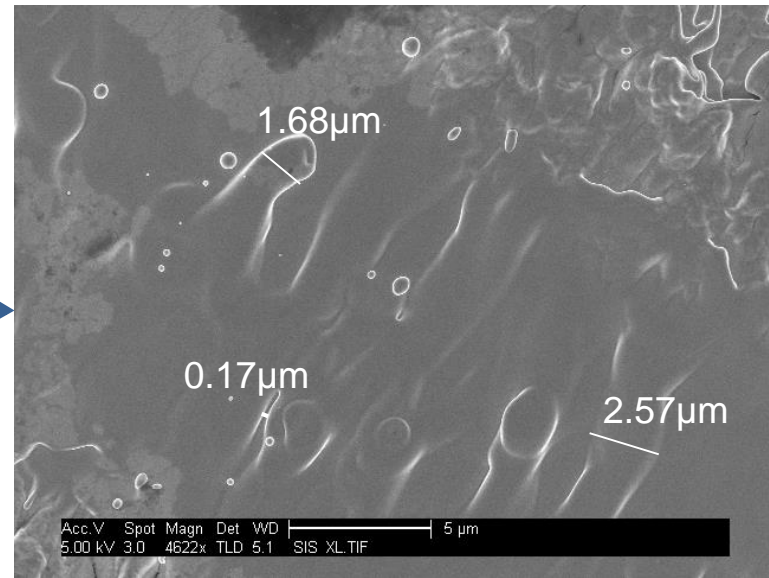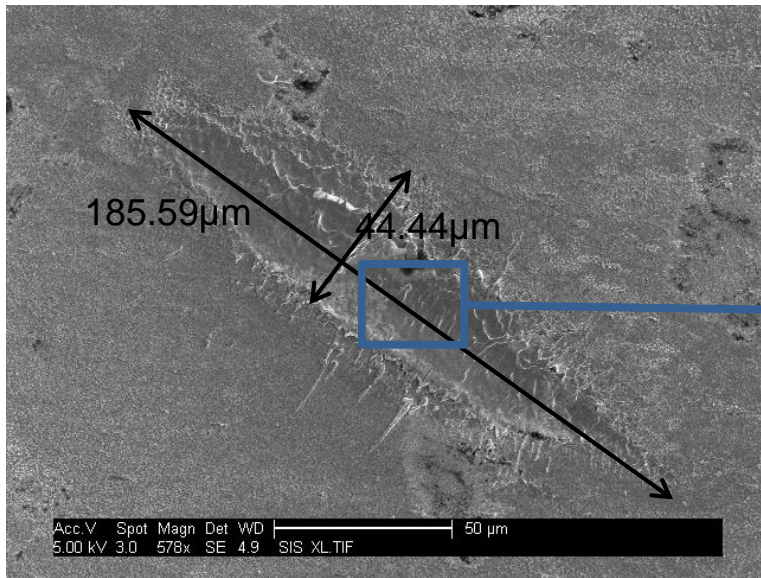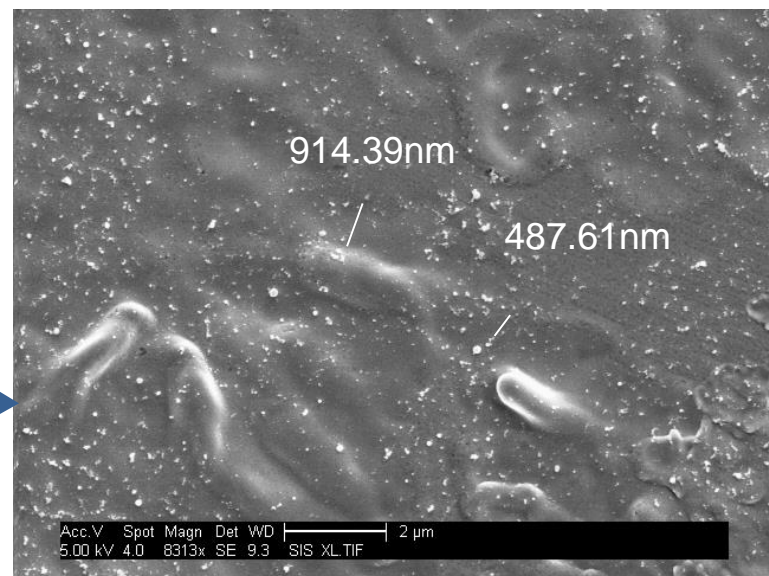5.00 kV 3.0 3927x SE 4.8   SIS XL.TIF   5 μm

138.41nm

495.49nm

777.68nm

Acc.V Spot Magn Det WD
5.00 kV 3.0 7854x SE 4.8   SIS XL.TIF   2 μm

DC

HV   curr   WD   det mode mag ⊞   20 μm
5.00 kV 50 pA 4.1 mm ETD SE 2 400 x   Cu square Ion-milling

HV   curr   WD   det mode mag ⊞   10 μm
5.00 kV 50 pA 4.1 mm ETD SE 5 000 x   Cu square Ion-milling
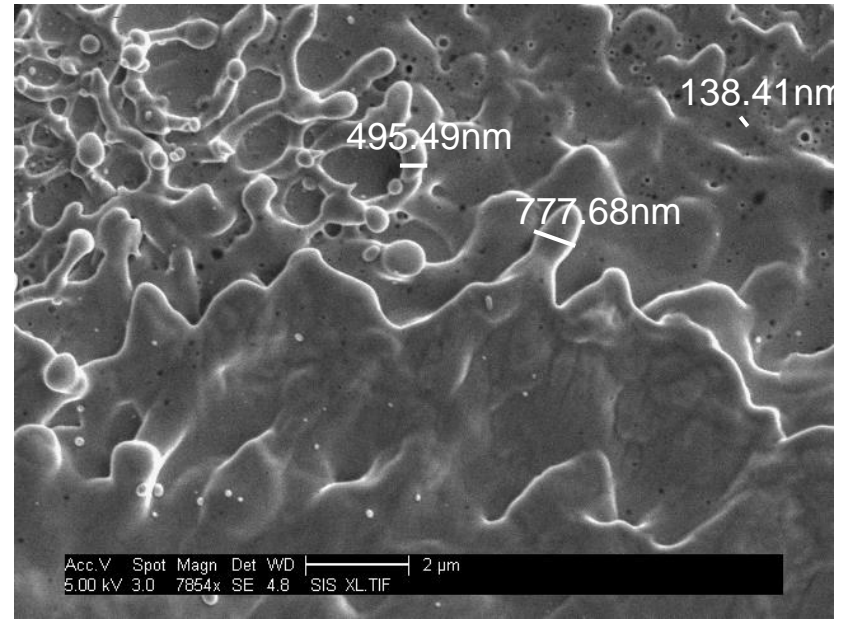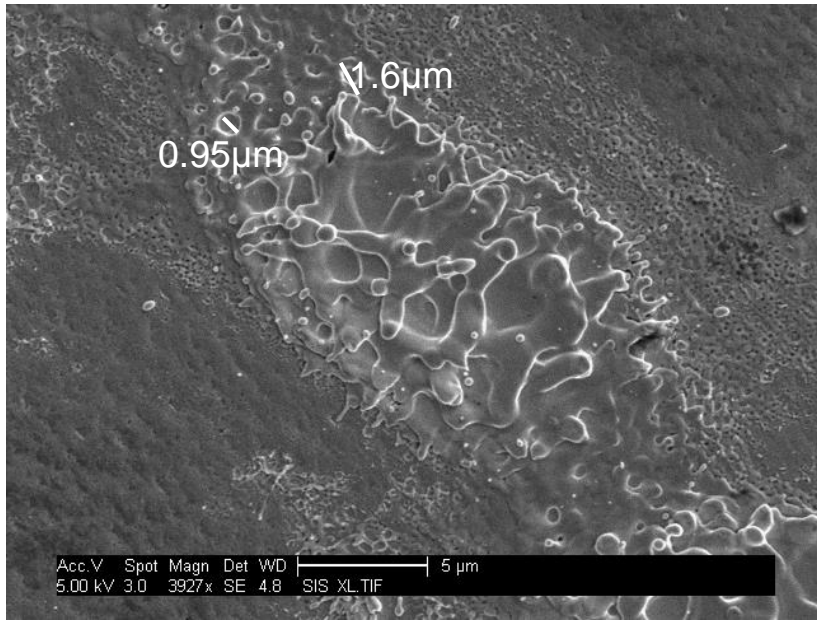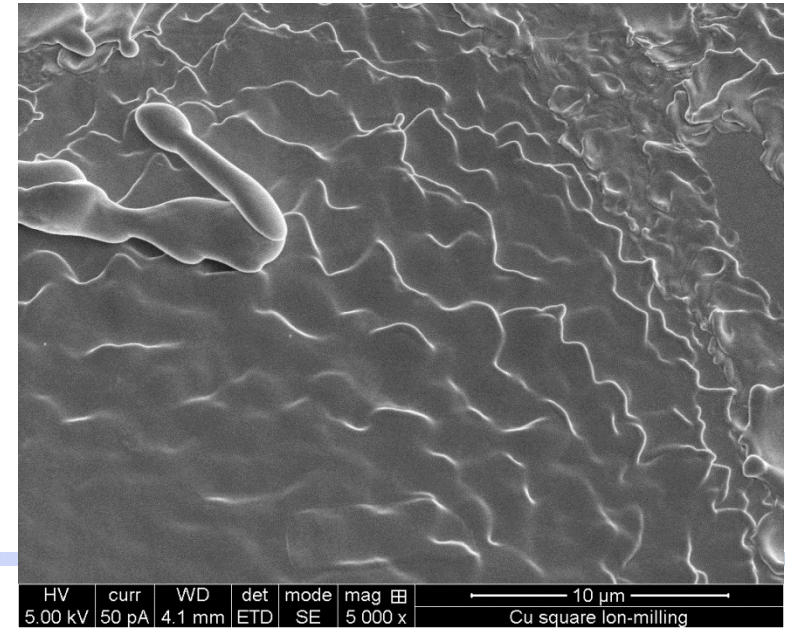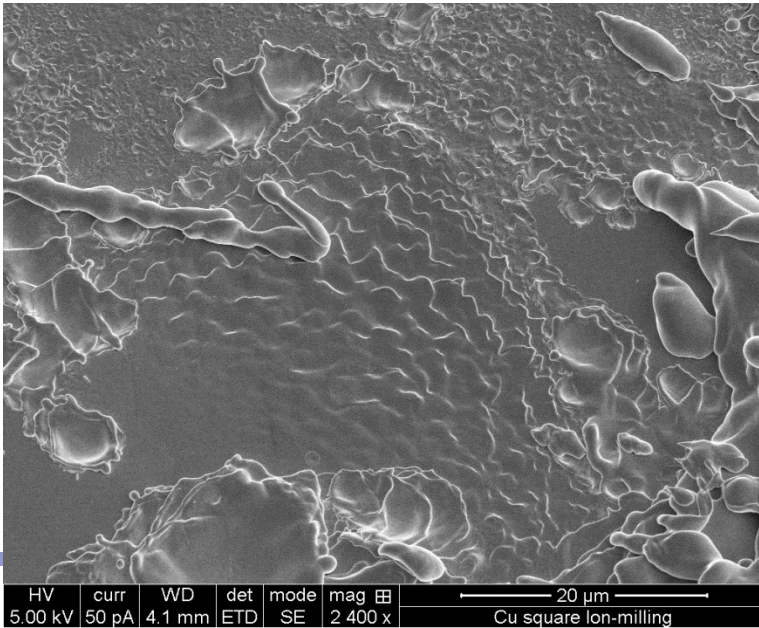
Conclusions

- Applied SEM+FIB to identify pre-BD events

  → as of now no identifiable pre-BD features. But are we at the right location?

  Possible observations of pre-BD near the BD site?

- BD sites show rich collection of features – similar to those observed at RF

Future plans and goals

• Using additional samples – identify pre-BD areas

• Once these are identified - analyze also using TEM (identify modifications of cellular structure

• Via similarity to laser ablation features – identify energies of BD events
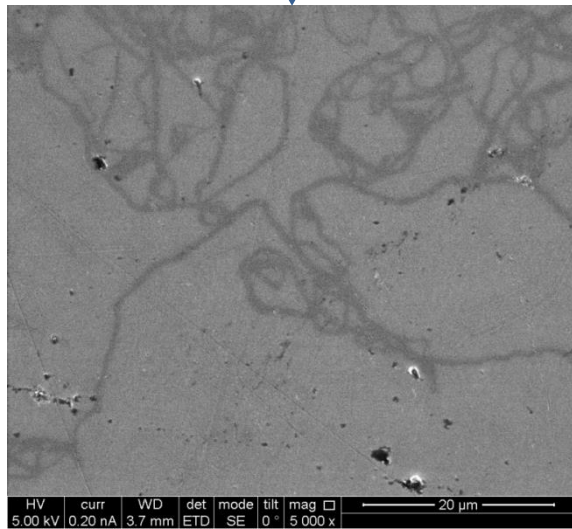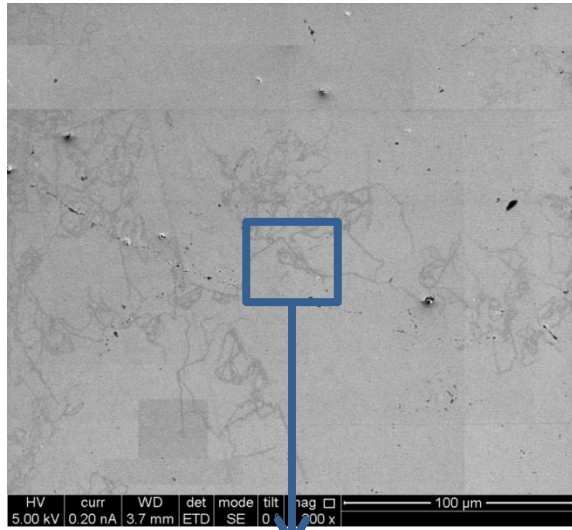
Thank you very much for your attention!

Spare slides

Heat treated and polished – BD effects

Wormlike features - all over the sample	Splashes