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HIP

Dislocation mediated response of Cu surface before and after a breakdown event

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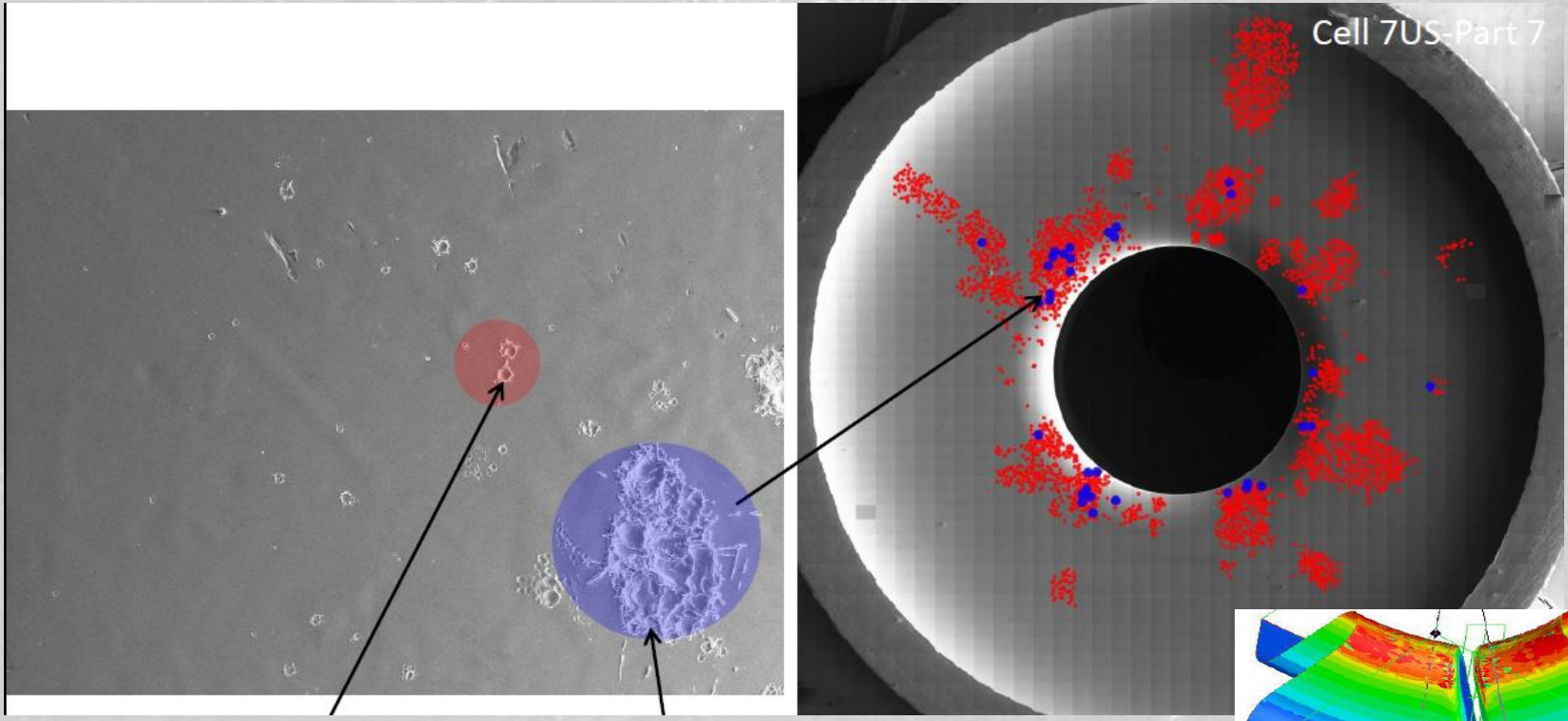
Outline

- Dislocations in metal surface after the breakdown
- Dislocations in metal surface before the breakdown

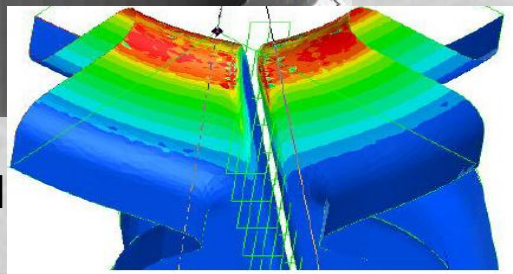
Problem: no metal withstands nominal accelerating gradients (~150 MV/m)

- Interaction of high gradient electromagnetic fields result in frequent breakdown events



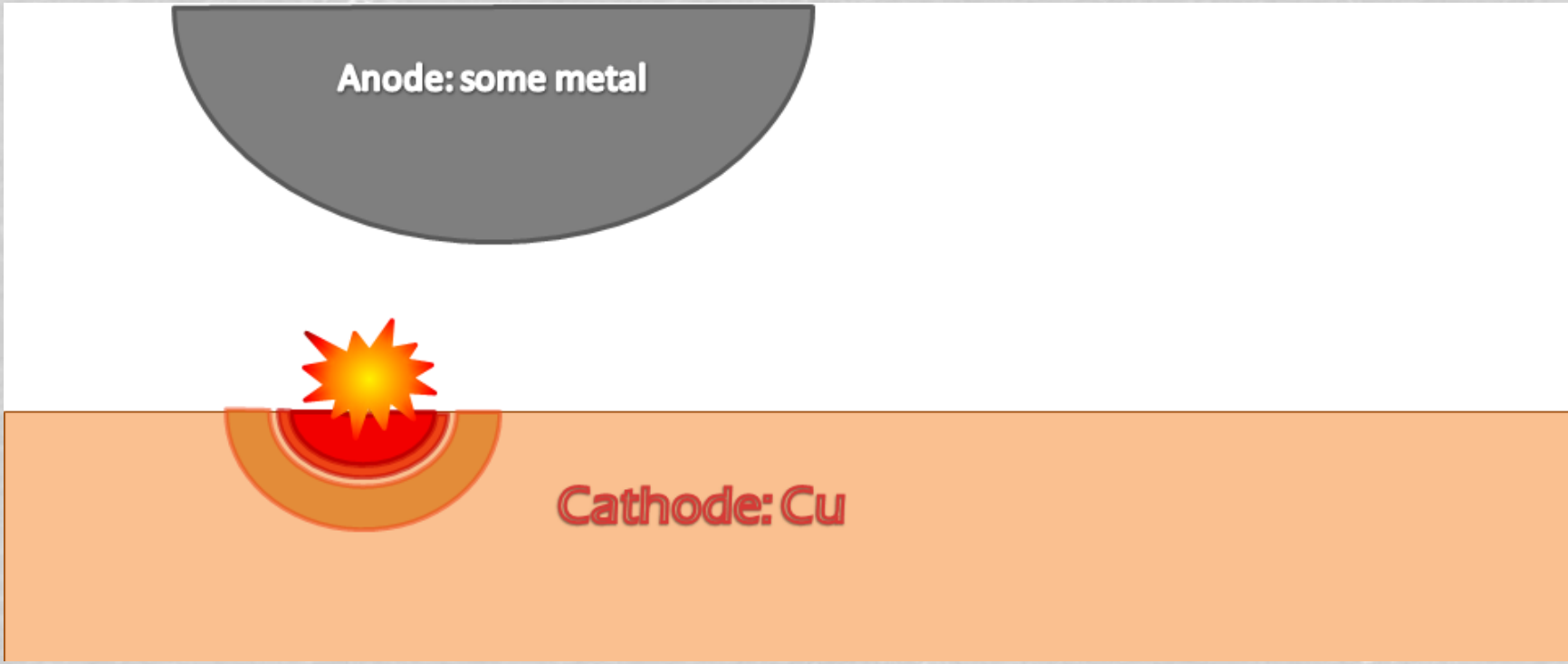
Courtesy of M. Aicheler, CERN

Macroscopic electomagnetic field near irises

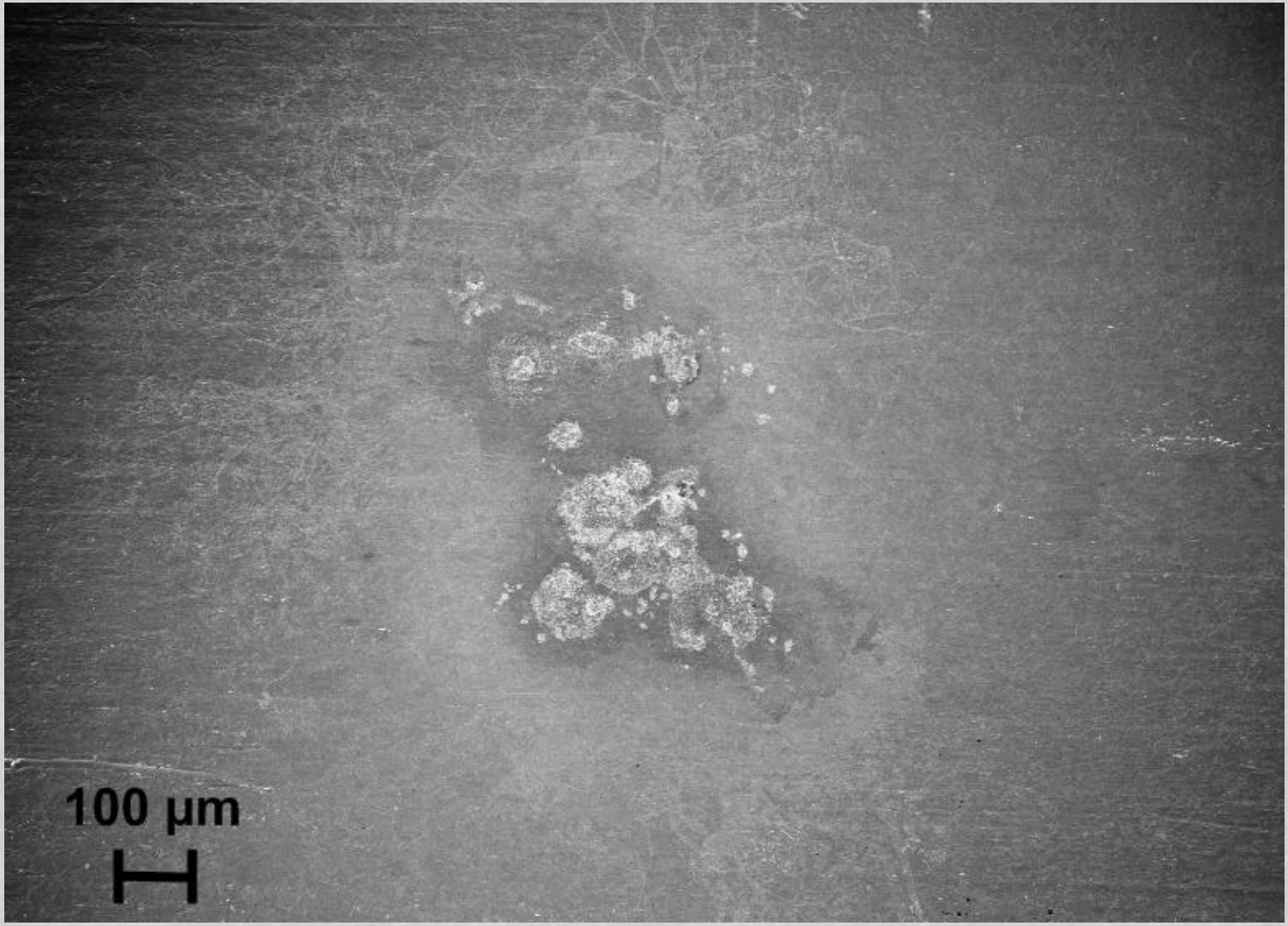


Electric “shock” for metal surface

- Schematically a breakdown effect can be seen as follows



Zooming in the surface damage



High resolution SEM: new features called "flowers" or "spaghetti"

- The halos seen around the breakdown spots were well identified in HR-SEM as the dense network of white lines (in SEM images) of uncertain origin

Fine "flowers" are a plastic response of surface on a sparking strike

Dislocations!

- The "flowers" spread well beyond the actual breakdown spots

100 µm

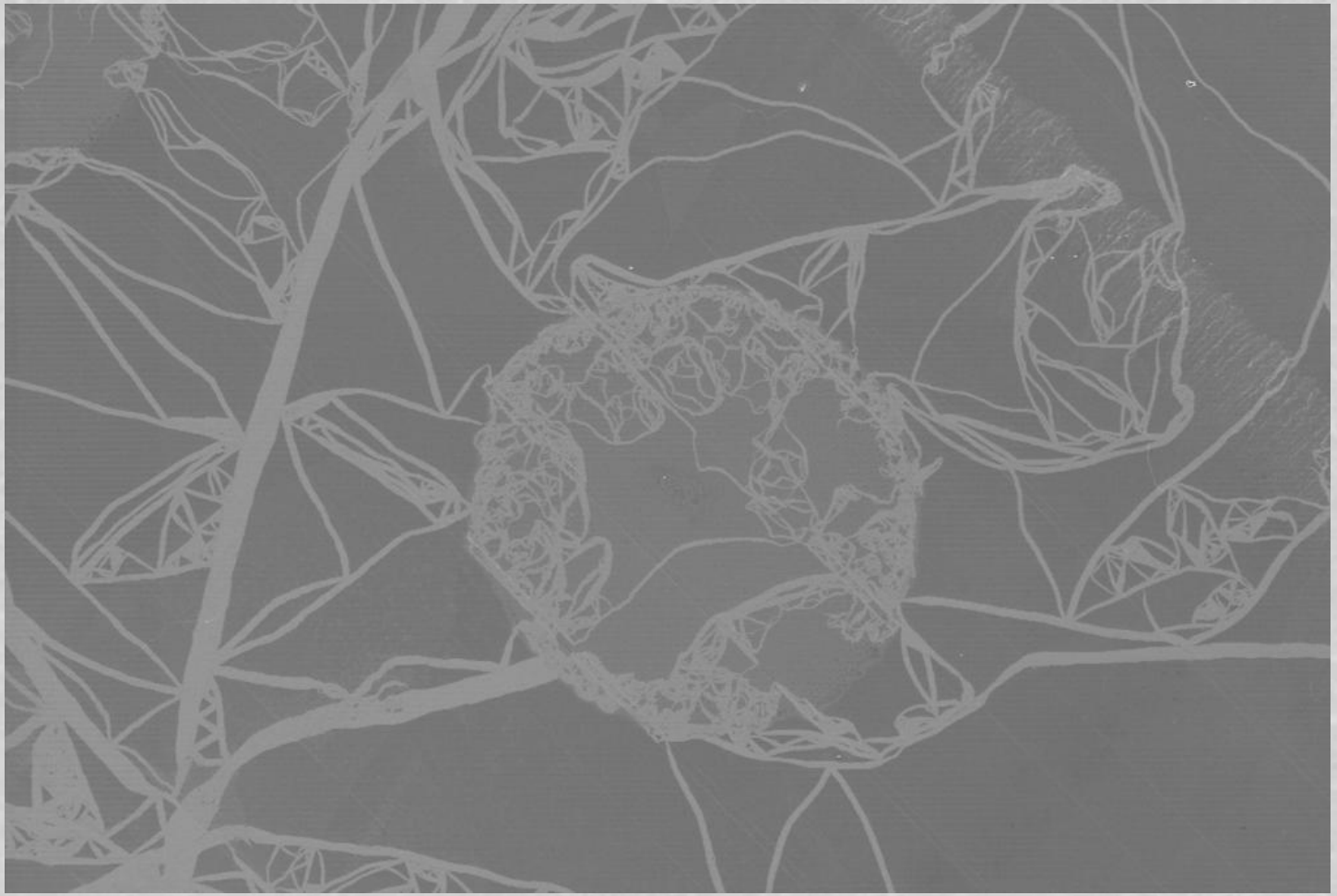
EHT = 3.00 kV
WD = 5.9 mm
Mag = 50 X
Signal A = InLens

7N-LG-Cu (45)
Spot #2

P. Alknes EN/MME
Date :24 Mar 2010
Time :21:36:33

CERN

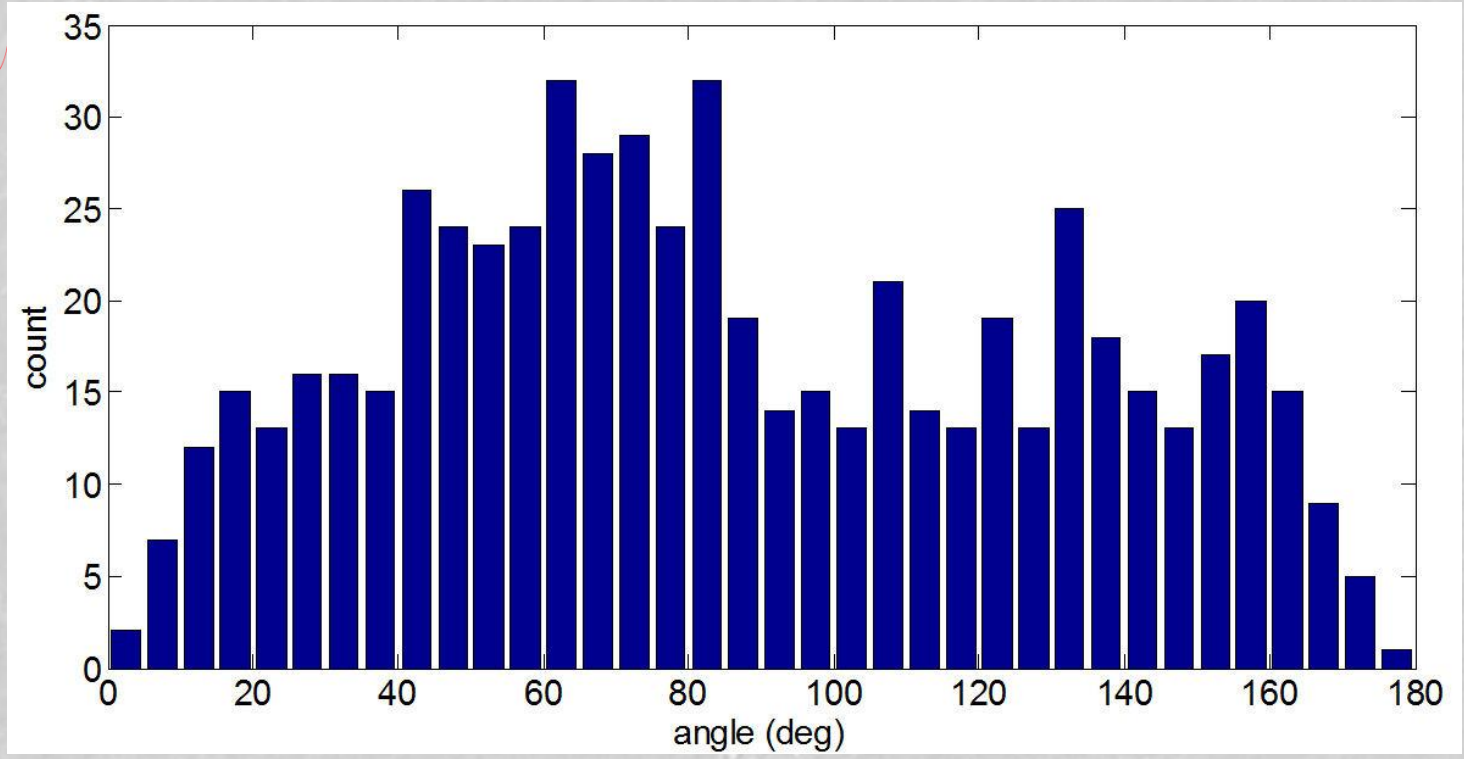
Zoom in one part where the lines look the clearest



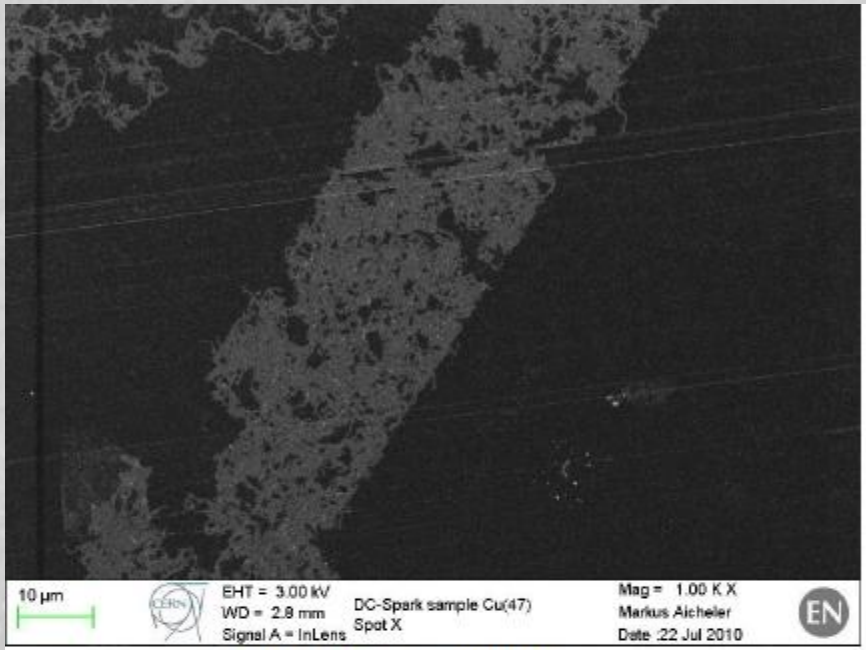
Filtered view

- Filter out the undistinguishable areas to reduce the unnecessary noise in the analysis

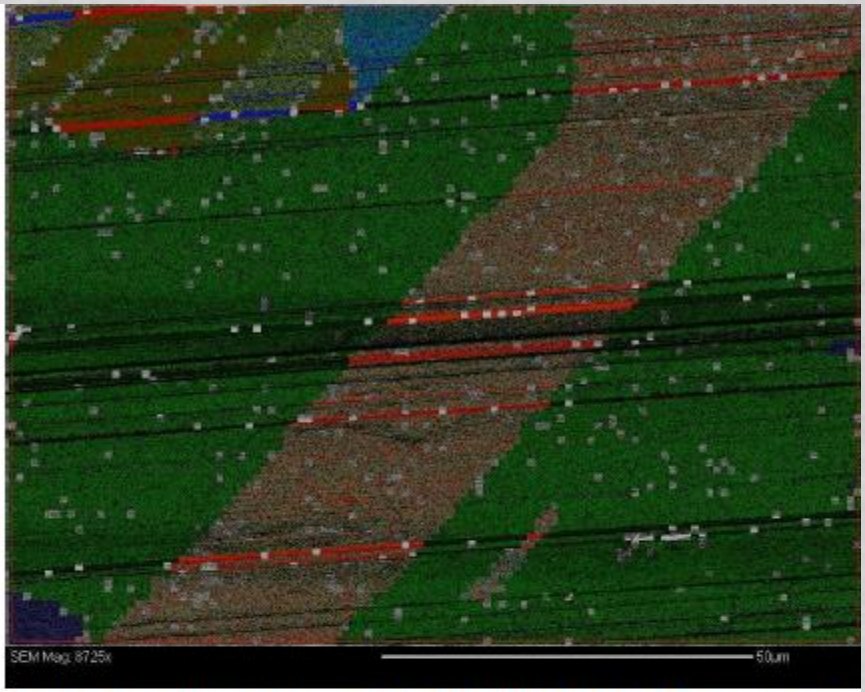
Angle distribution gives a peak at 60°



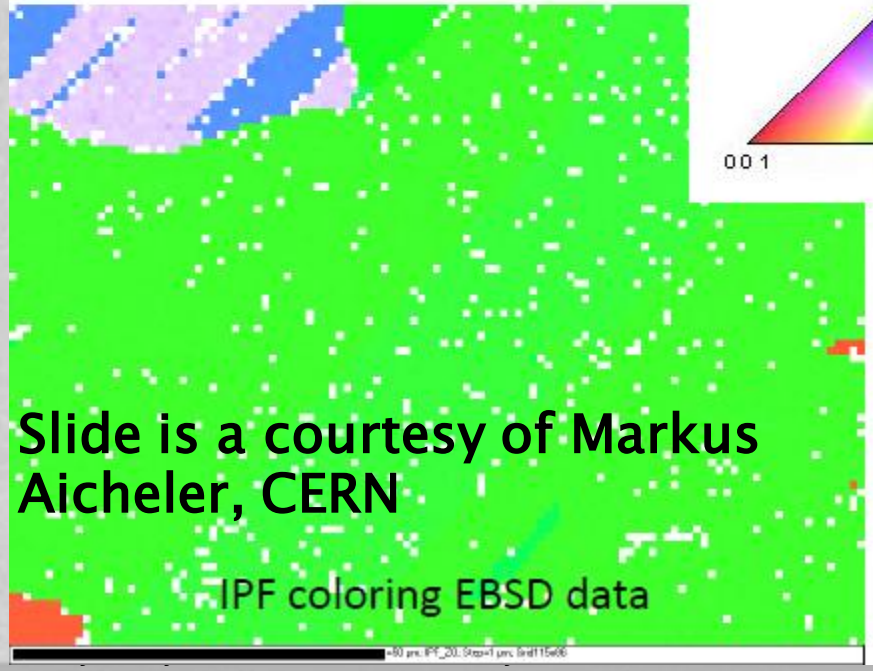
- Peak at 60 degree indicates a dislocation origin of the white ”worms” features. The most straightforward thought is that the slip planes intersect each other on Cu {111}-surface at 60°.



SEM InLens 0° Tilt

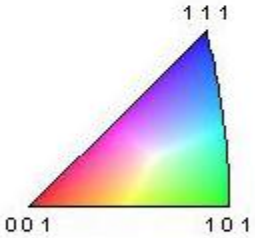


SEM back scatter 73° Tilt with EBSD overlay

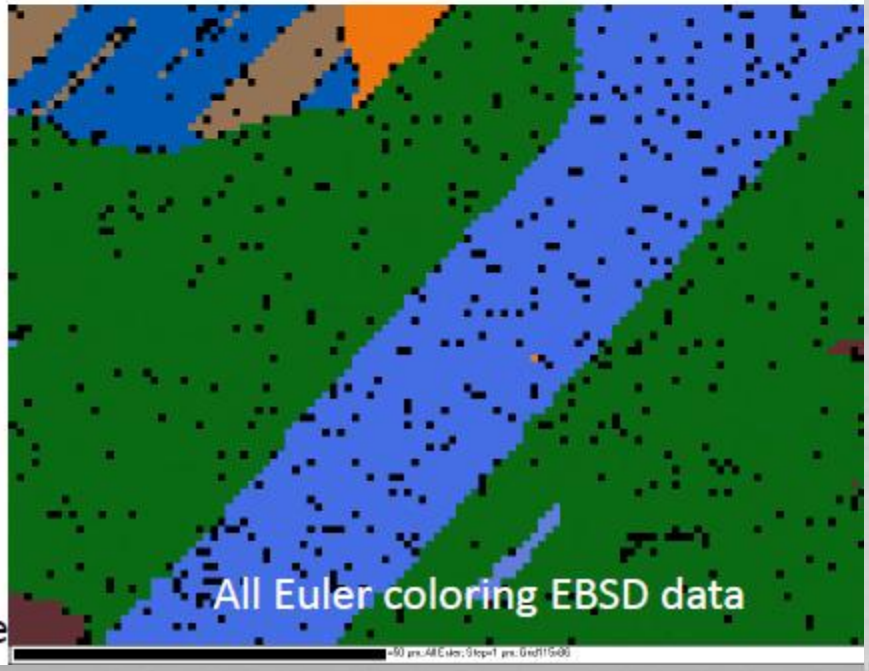


Slide is a courtesy of Markus Aicheler, CERN

IPF coloring EBSD data

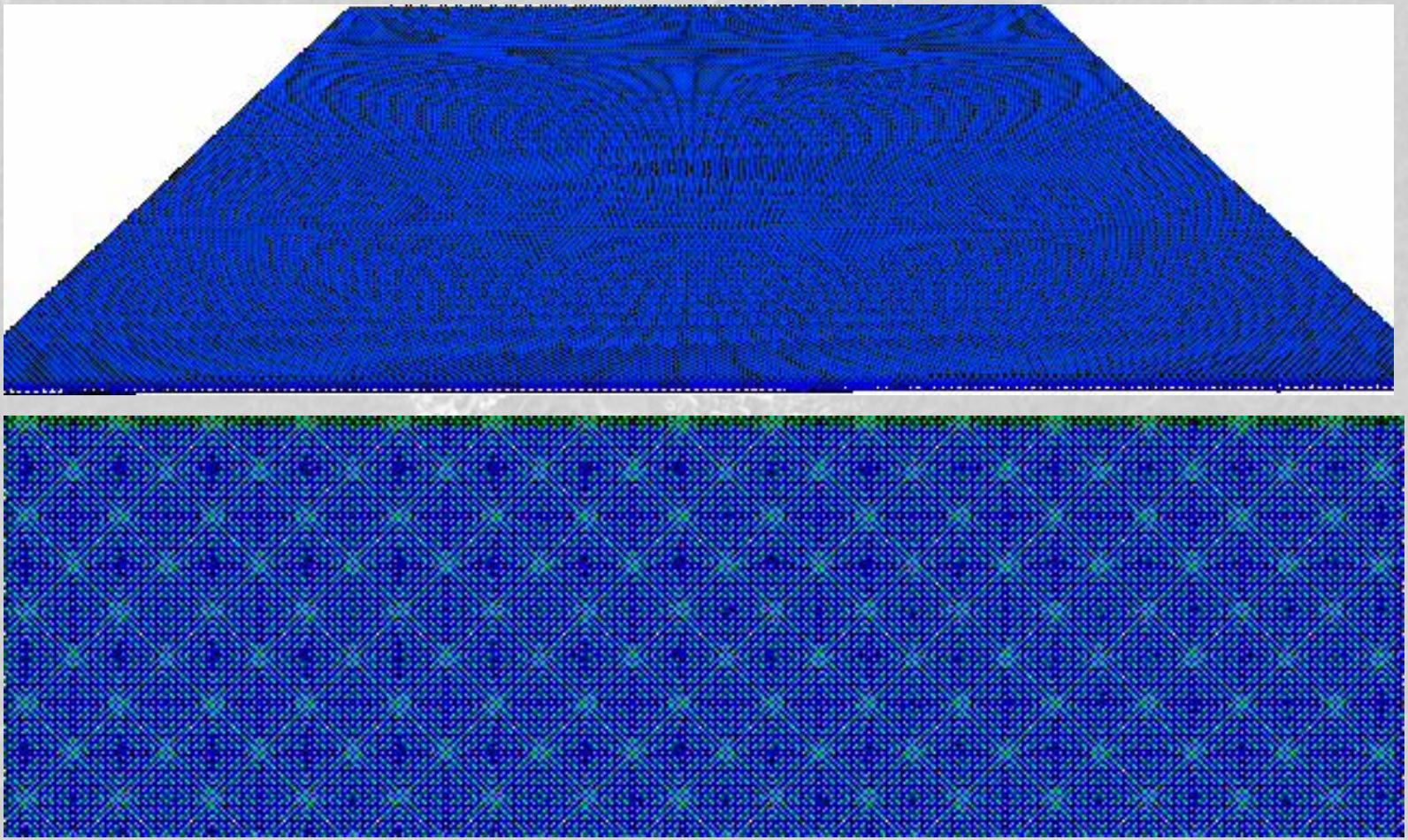


M. Aiche



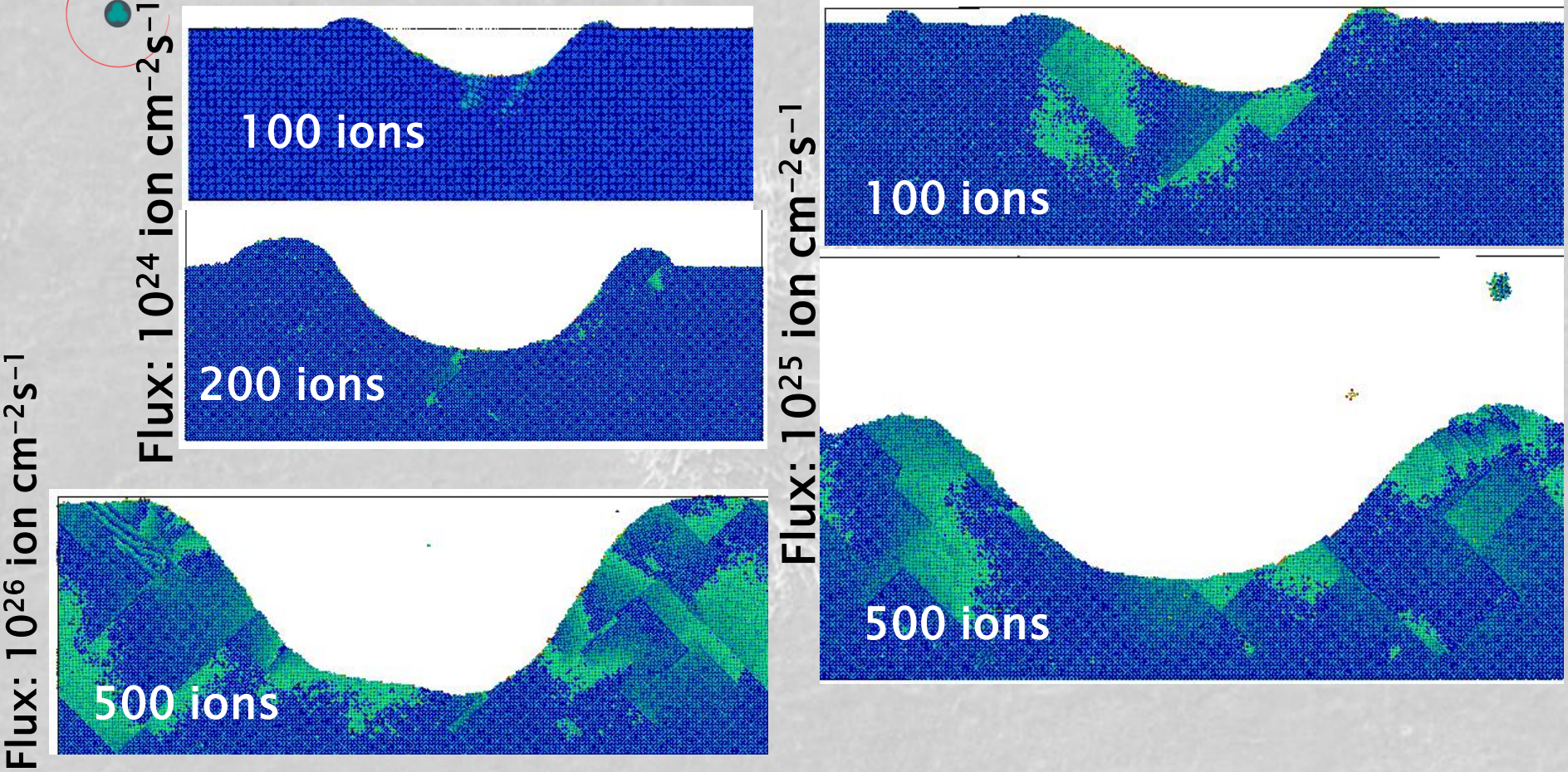
All Euler coloring EBSD data

Plasma impacts: Arc-MD simulations



- The impact of 200 ions with the flux of 10^{24} ions $cm^{-2}s^{-1}$
- Energy of ions 6 keV at RT

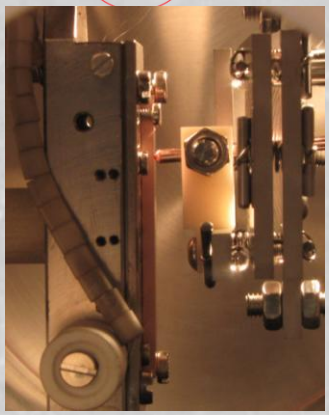
Changing fluxes



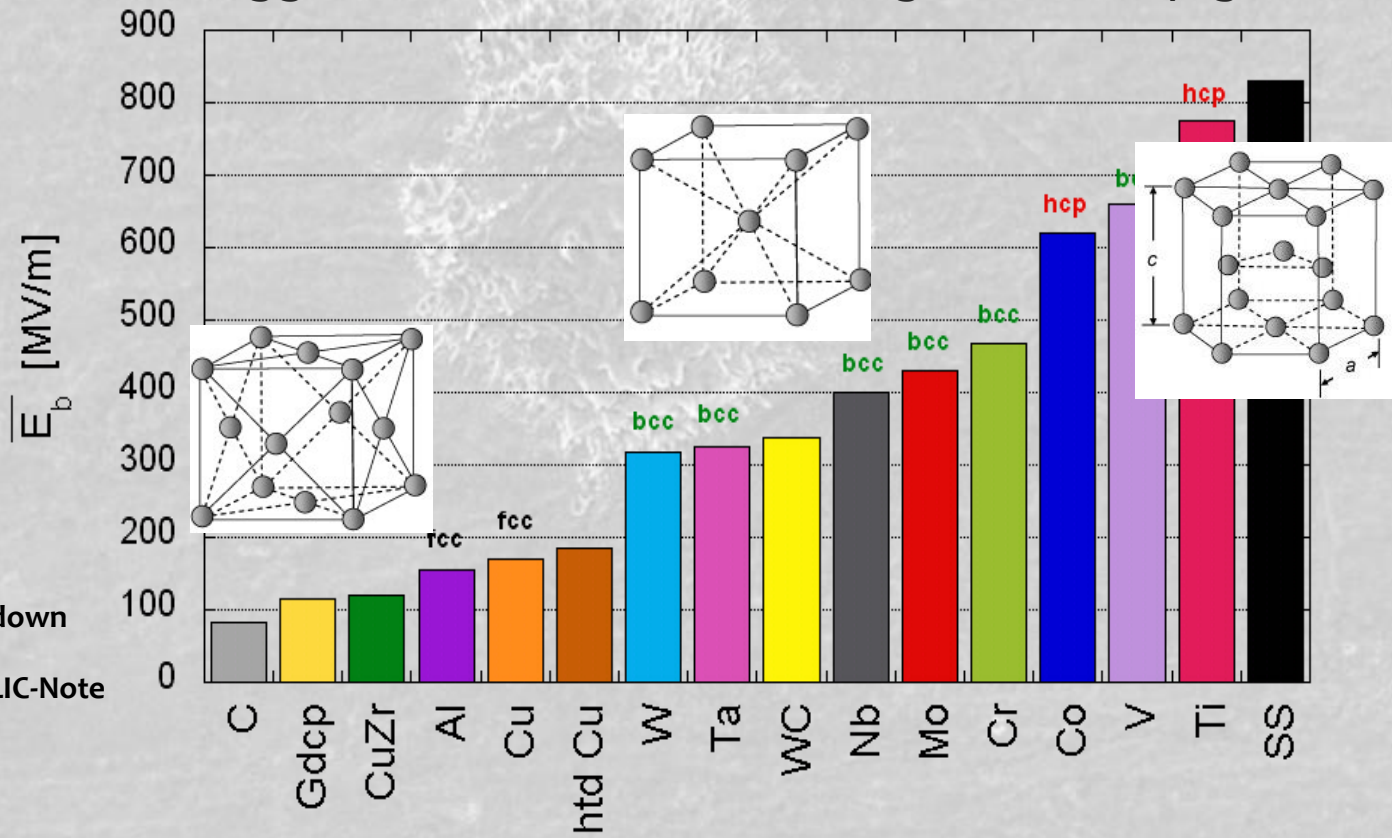
- Plastic deformations under the craters formed by plasma ions with different fluxes

Correlation with crystal structure

- Experiments on the critical field for electric breakdown very well correlate with the crystal structure
  - Suggestive of a dislocation origin of the tip growth

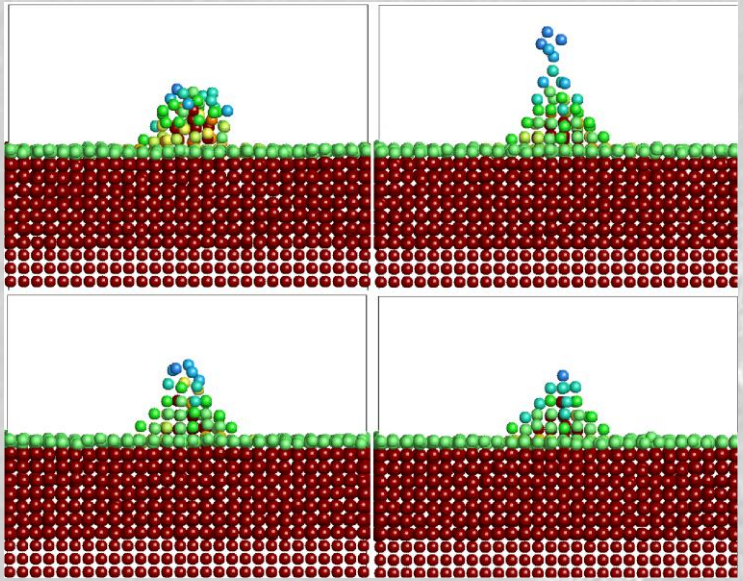


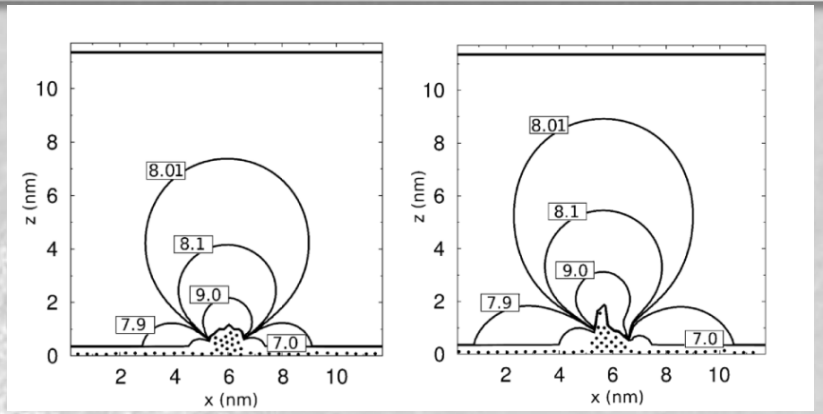
CERN DC station



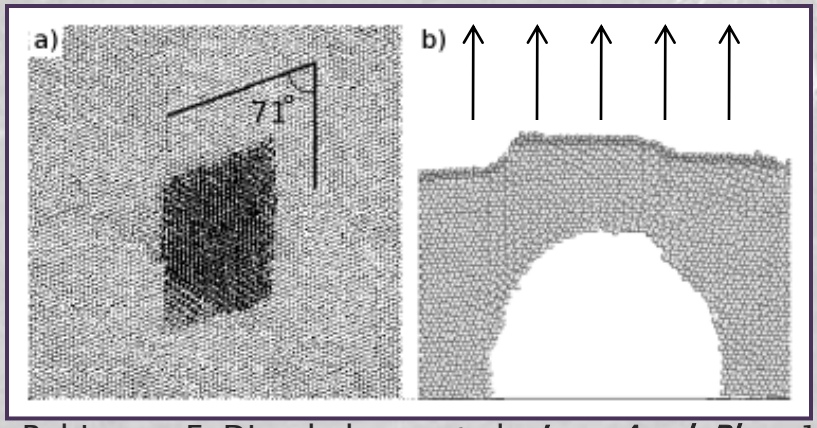
A. Descoeudres, F. Djurabekova, and K. Nordlund, DC Breakdown experiments with cobalt electrodes, CLIC-Note 875, 1 (2010).

Electrodynamics–molecular dynamic model+ study of a void under tensile stress





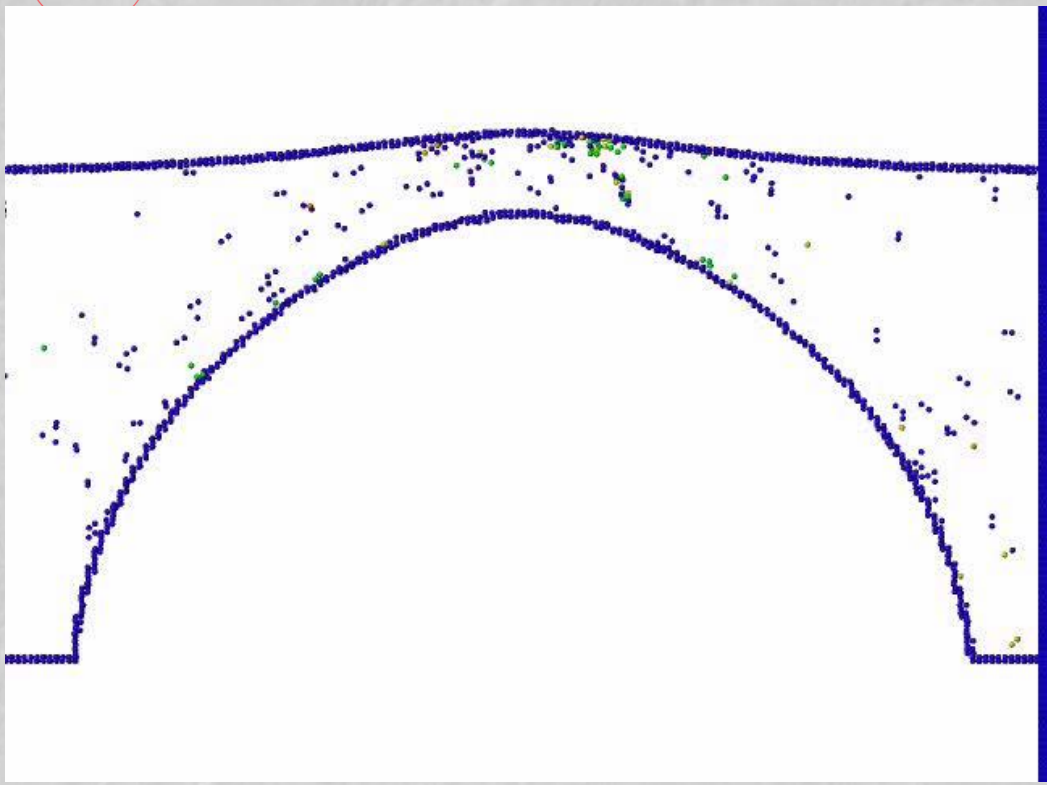
Details in F. Djurabekova, S. Parviainen, A. Pohjonen and K. Nordlund, PRE 83, 026704 (2011).

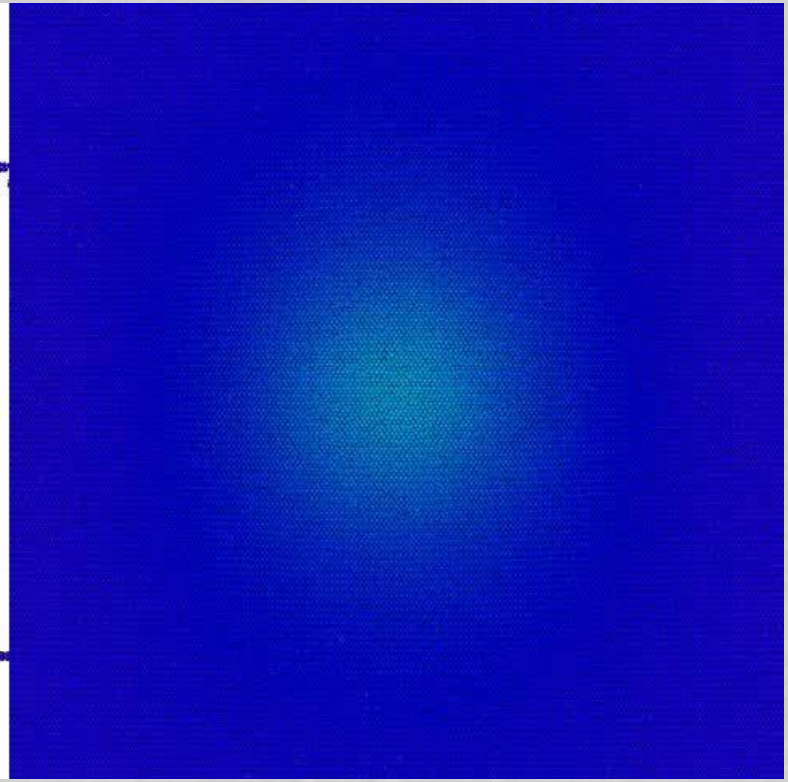


A. Pohjonen, F. Djurabekova, et al., *Jour. Appl. Phys.* 110, 023509 (2011).

- ED–MD model follows the evolution of the charged surface.
- The dynamics of atom charges follows the shape of electric field distortion on tips on the surface
- We also studies the dislocation dynamics on a void burrowed near the surface in Cu held under unilater tensile stress

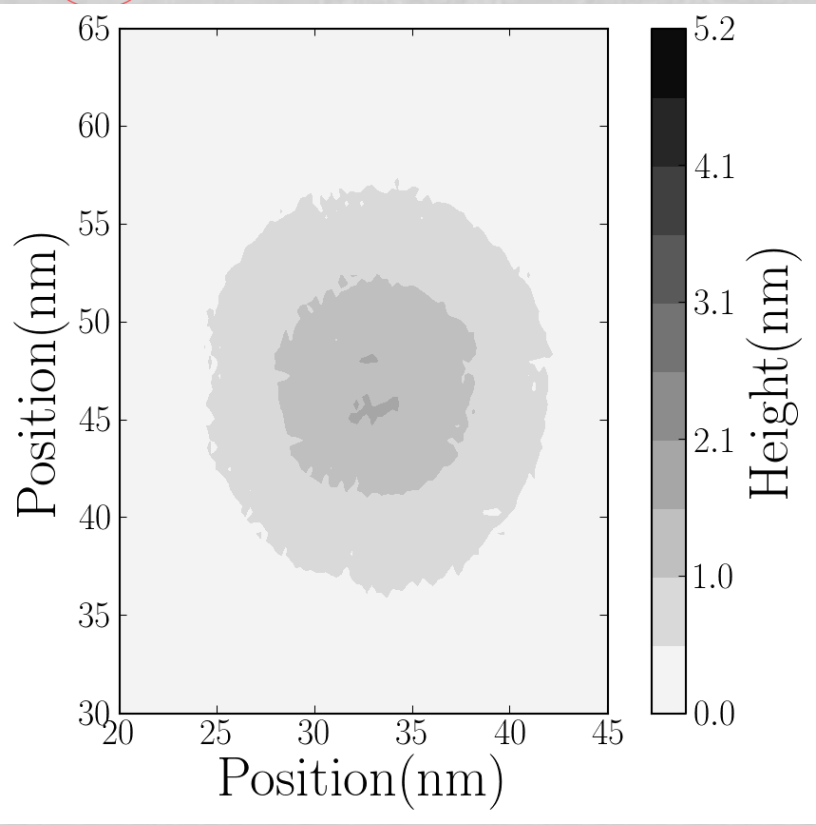
Back to simulation with assumed voids under surface

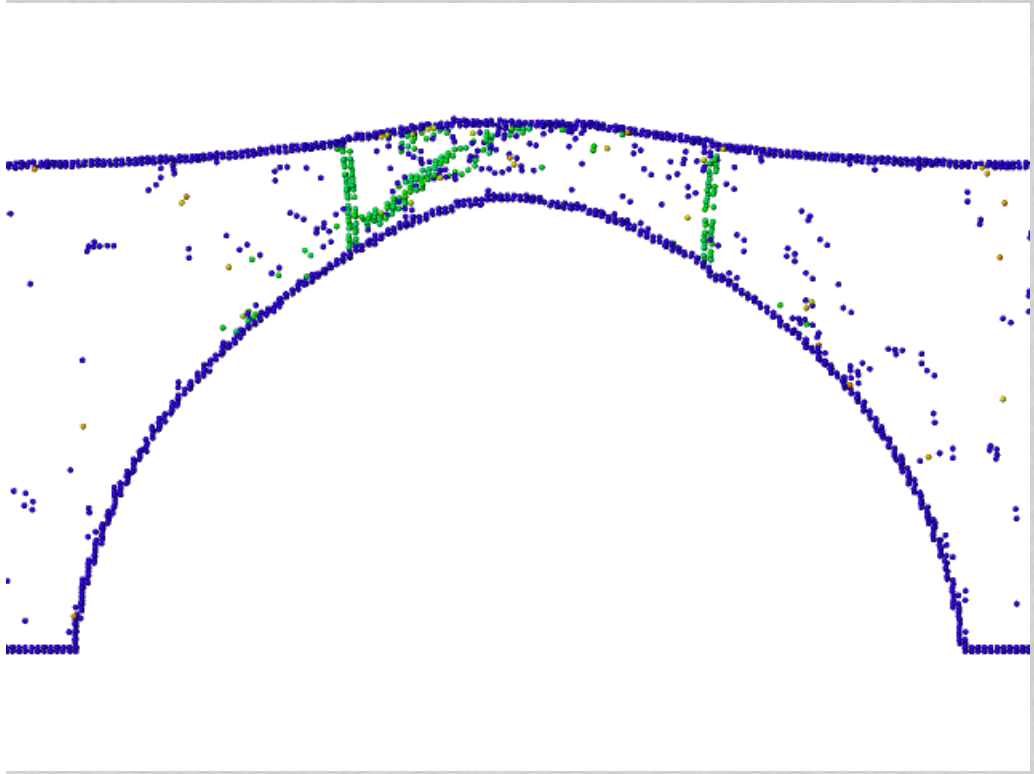




- We have now finished the analysis of the behavior of a void under tensile stress due to the electric field (Simulations now done with the hybrid ED-MD code, where the electric field effect is accounted explicitly)

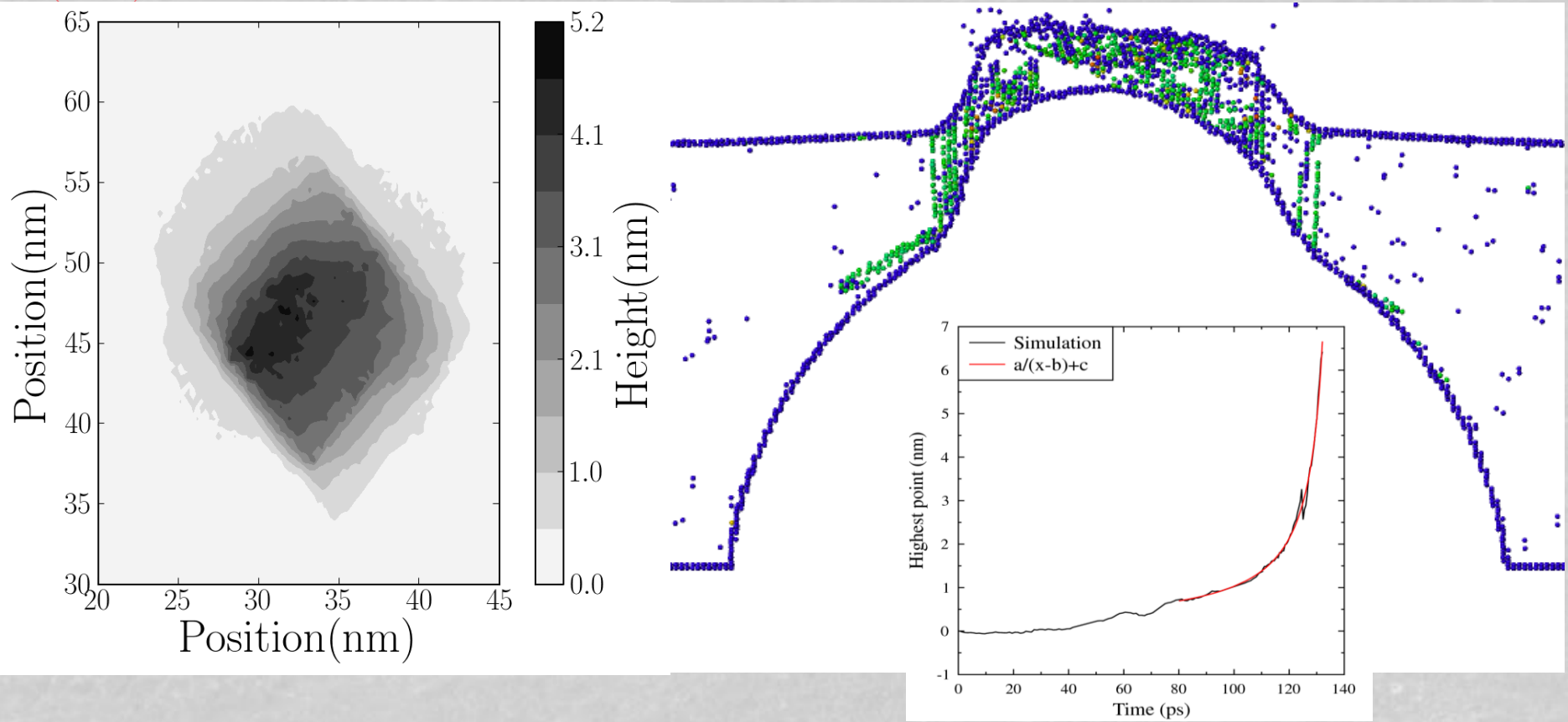
Initial plastic deformation





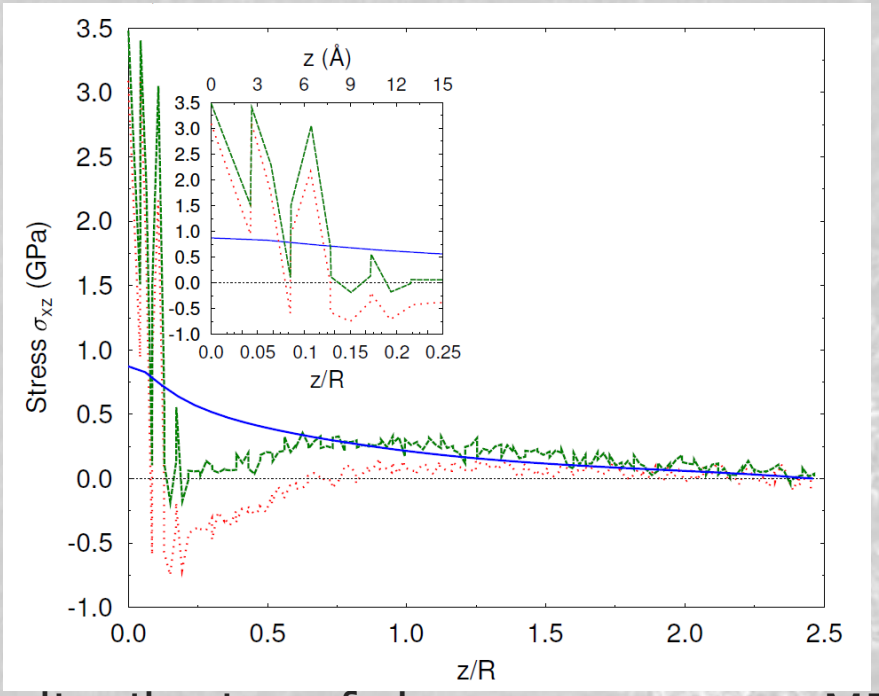
- the top view and a slice of the system at time t = 114 ps when the first bump has formed

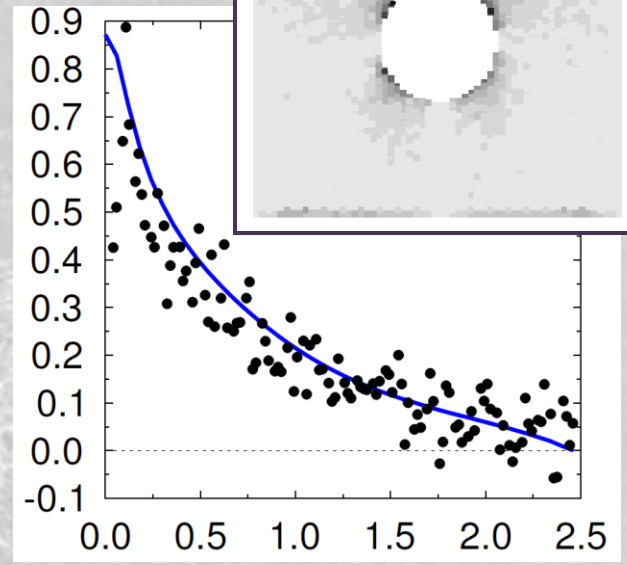
"Catastrophic"growth of a protrusion at the void



. the top view and a slice of the system at time t = 130 ps when the fully developed protrusion is clearly visible.

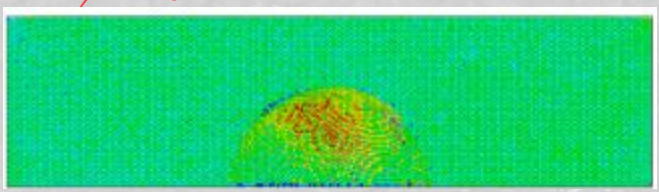
Deeper view on atomic level stress MD vs FEM



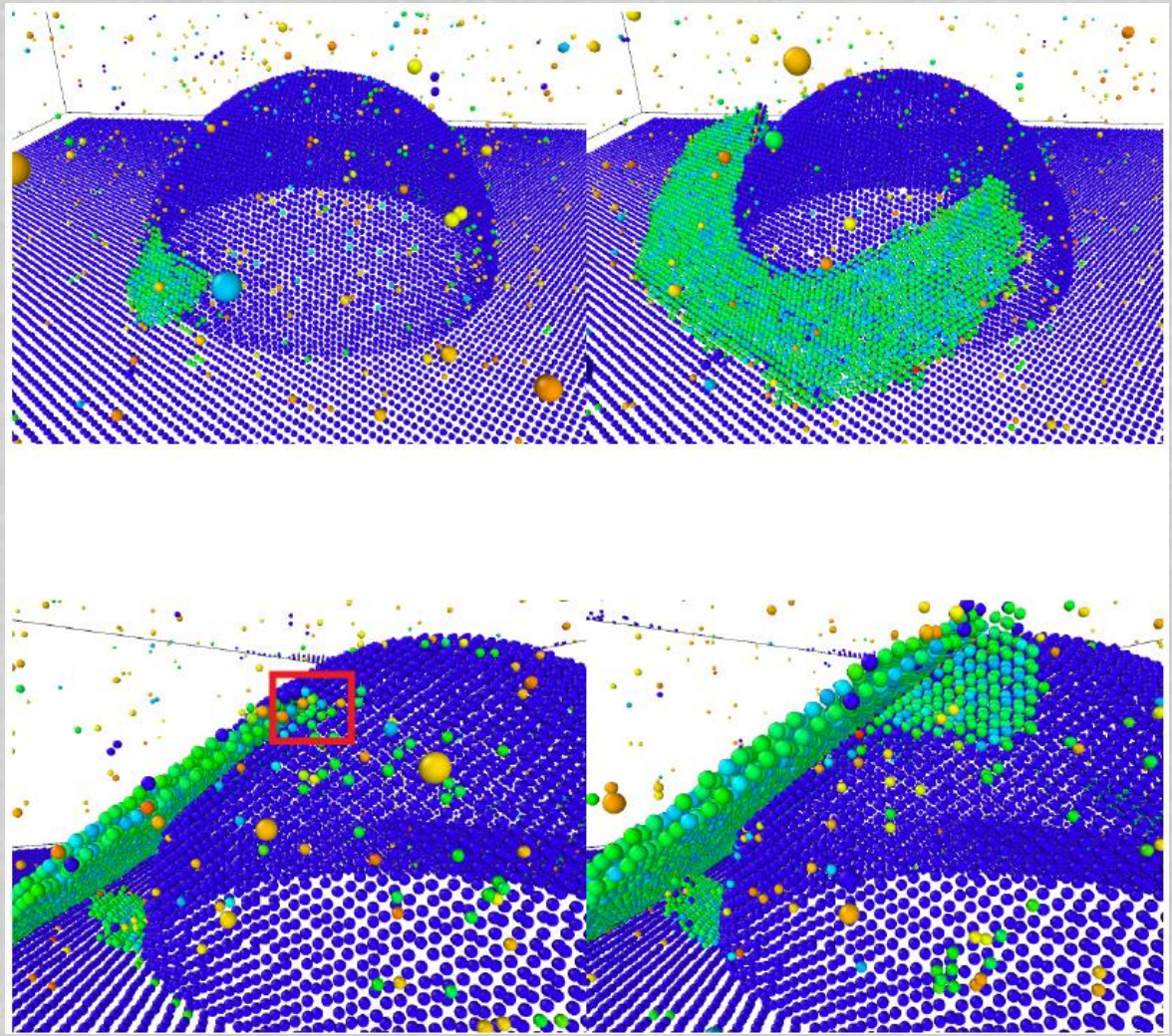


- The distribution of shear stress σ_{xz} on MD simulations along a line (directed in z-direction) starting from the point of maximum shear on void surface and ending on the material surface for a void located at depth H = 2R. b) A detailed view of the atomic level stress near the void surface shows an alternating pattern caused by the surface stress. c) The difference between the simulation results with external stress and pure surface stress corresponds to the analytical result.

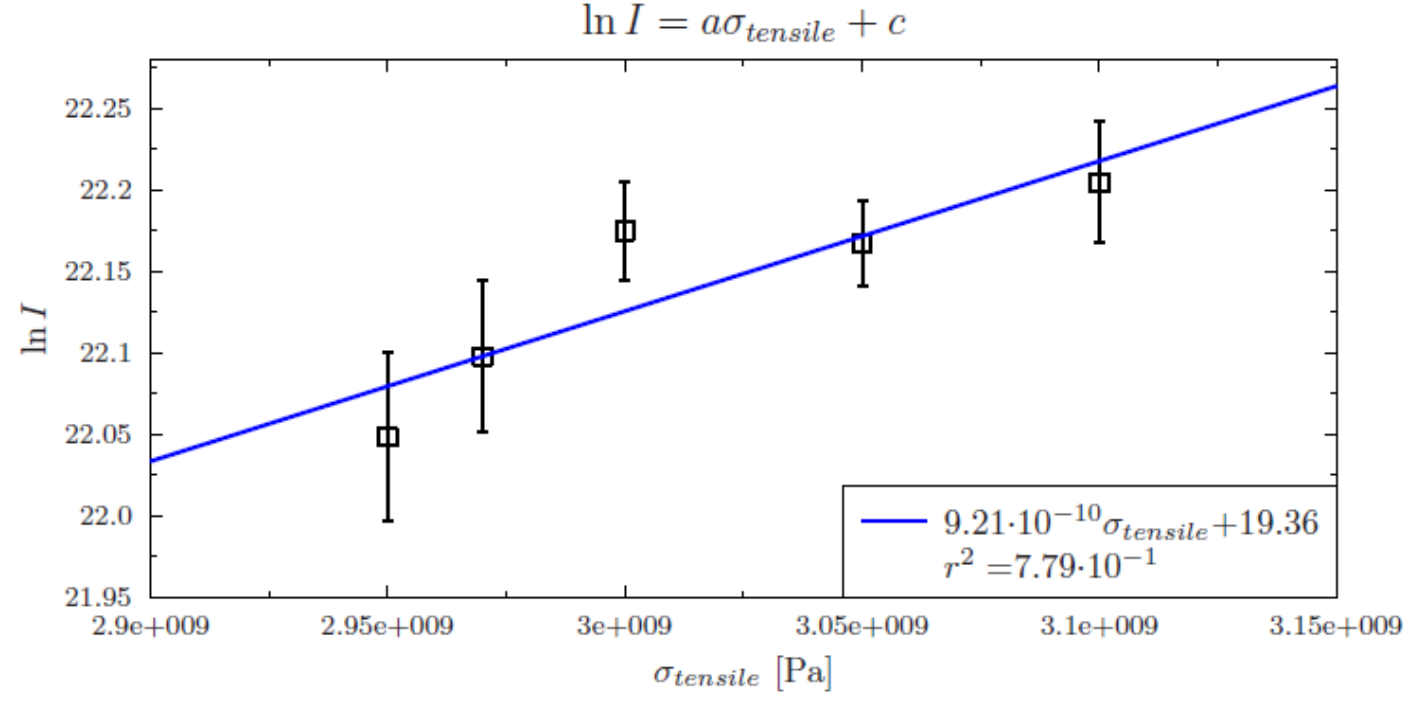
Zoom in at the dislocation nucleation spot



- Trying to analyze the nucleation event, we constructed the half void
- First at random : nucleates a dislocation in the slip plane not perpendicular to the surface.
- Second, almost pre-determinedly in 5 ps the : dislocation in perpendicular to the surface slip plane appears in all simulations.



Quantitative result



- Analyzing the dislocation nucleation rate at fixed temperature and within a small range of stresses we can obtain the effective activation volume to be $2.2b^3$ and Gibbs free energy Q(3 Gpa, 575 K) = 0.5 eV. Both values well agree ($1..10b^3$ and 0.2 eV) with data from

Ting Zhu, Ju Li, Amit Samantha, Ausint Leach, and Ken Gall. Temperature and strain-rate dependence on surface dislocation nucleation. *Physical Review Letters*, 100(2), 2008.

Summary

- We pursue the studies of mechanical properties of Cu surface under electric field.
- We also noticed that the dislocations are activated after the breakdown has taken place.
  - This may also contribute in the clear lattice structure correlation with the maximum electric field, which the surface can tolerate before breaking down
- The coupling of dislocation model and electric field effect resulted in “catastrophic” protrusion growth, which was not observed previously, but intuitively in line with field emission measurements from flat copper surfaces.
- We also start obtaining some quantitative data to be able to estimate the relevance of the process to the real situation

Next MeVARC – 2013

Chimonix – A place for the next meeting!

5 – 7 November, 2013

Thank you for your attention!