On the energy dependence of DC sparks

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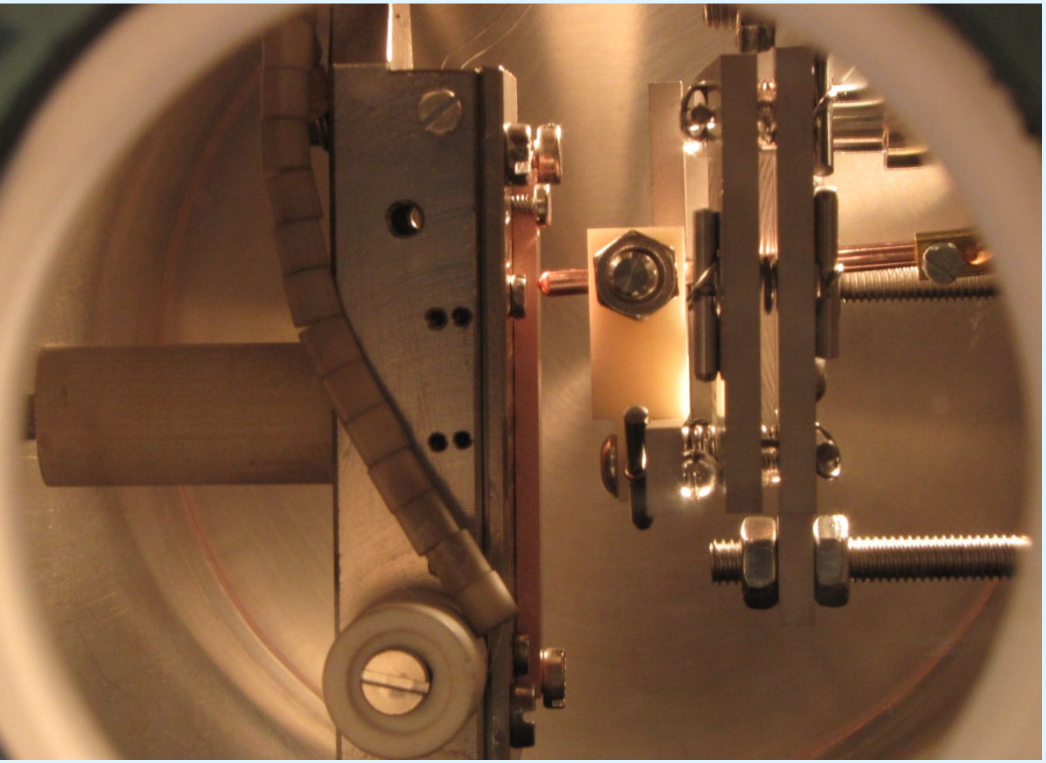
Outline

- DC spark setup
- Energy dependence of breakdown properties for Cu and Mo
  - How do breakdown field and other quantities change?
- A collection of other results
  - Evolution of ß without breakdowns
  - The effect of an oxide
  - Can lattice structure influence E_{BRD}?

Exploring DC sparks

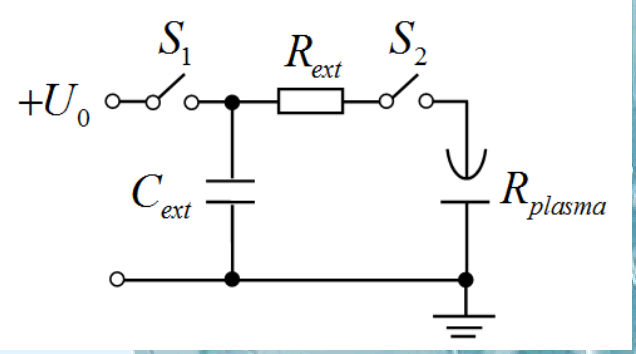


Why DC sparks?

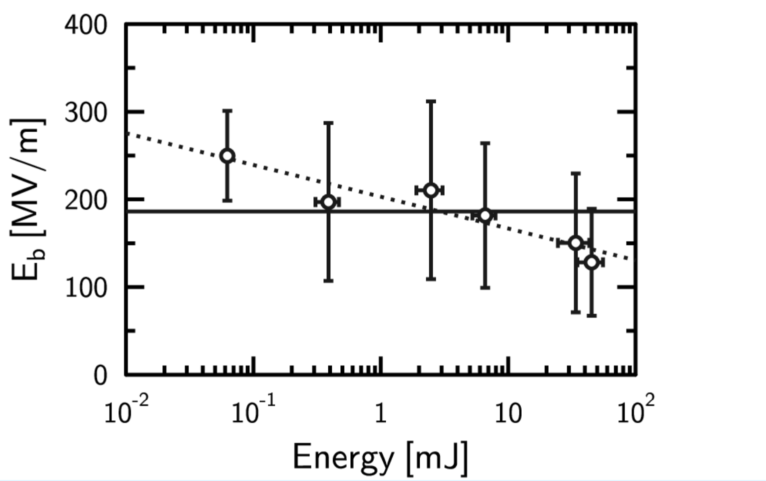
- Allows to study breakdowns on a *fundamental* level
- *Simple and fast* testing of materials, surface treatments etc.

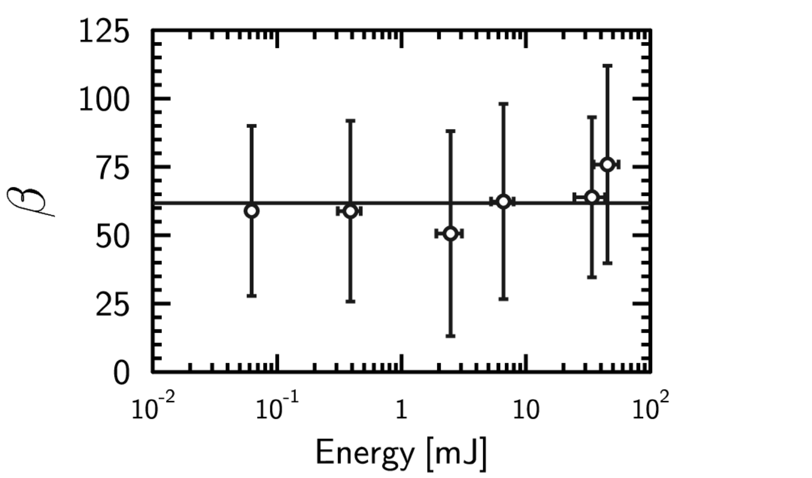
Why energy dependence is interesting...

- The DC setup has been designed to match the energy lost in RF structures during breakdown (we store ≈1J in a capacitor)
  - However, it can be that only a *fraction* of this energy is consumed by the breakdown itself
  - Also, if we know the breakdown behaviour of materials as a function of energy, we can *optimise* our structures
- Lowering the energy available ↔ changing the capacitor

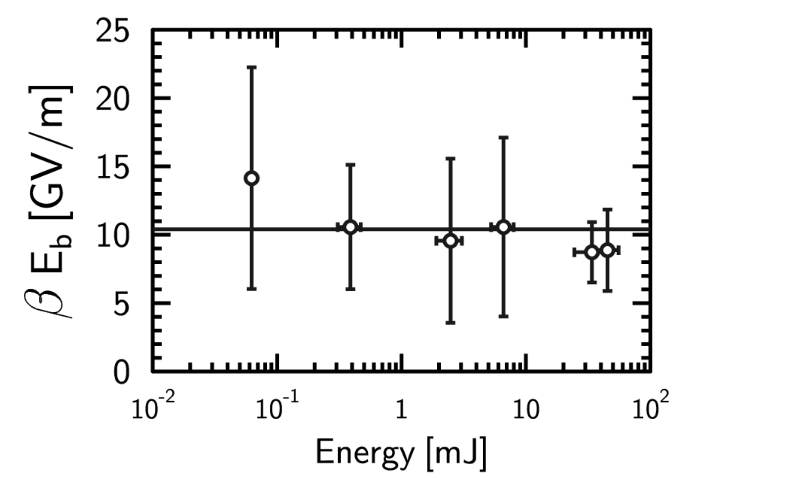


E_{BRD}, ß and E_{LOC} for Cu as a function of energy

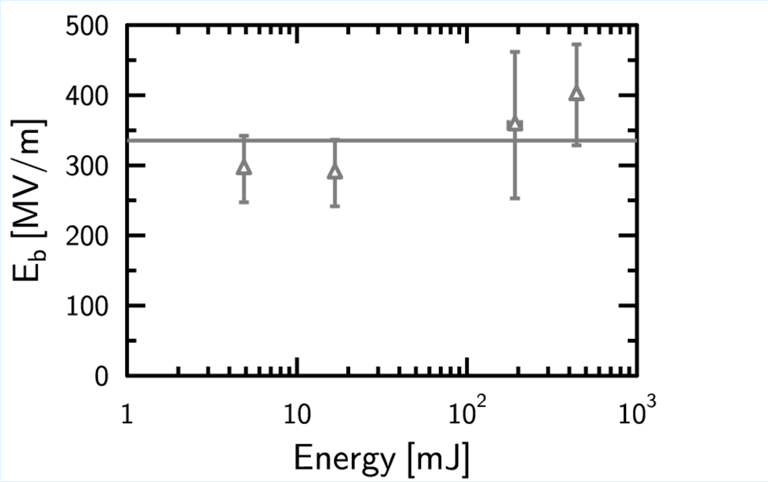


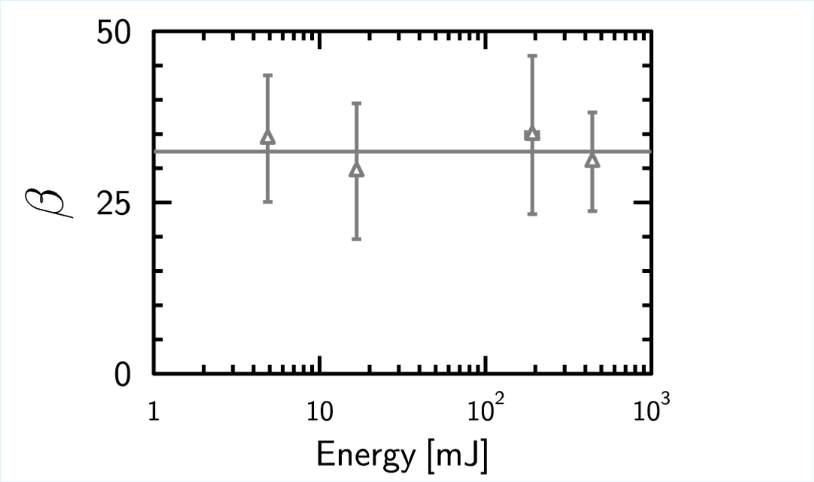


- E_{BRD} increasing with decreasing energy (less deconditioning is possible)
- ß and E_{LOC} remain constant
- E_{BRD} =190 MV/m, ß=62, E_{LOC} =10.4 GV/m

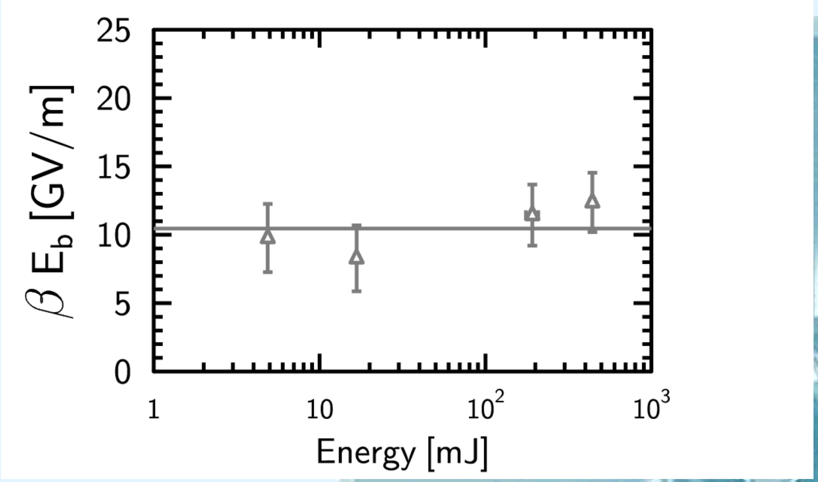


E_{BRD}, ß and E_{LOC} for Mo as a function of energy



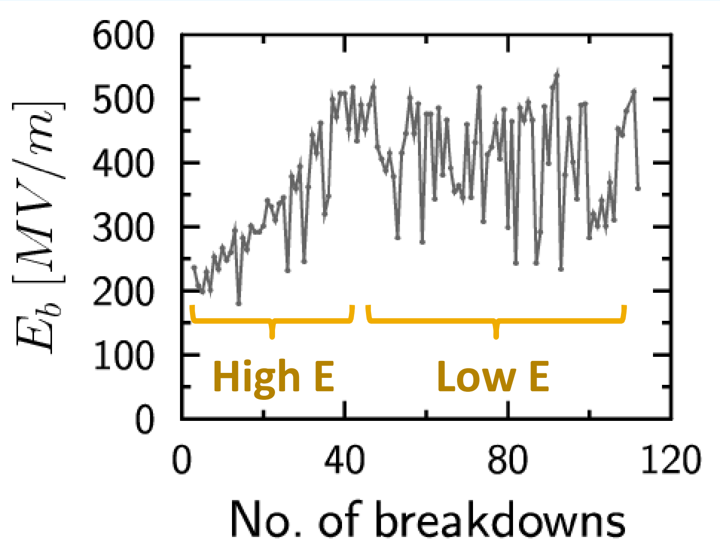


- E_{BRD} seems to decrease with decreasing energy (less conditioning possible)
- ß and E_{LOC} remain constant
- E_{BRD} =350 MV/m, ß=34, E_{LOC} =11.3 GV/m



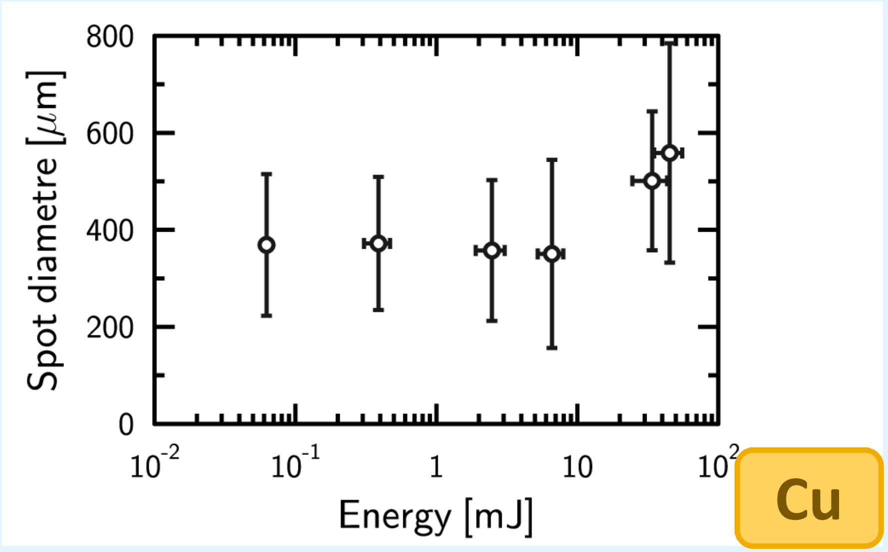
How conditioning effects E_{BRD}

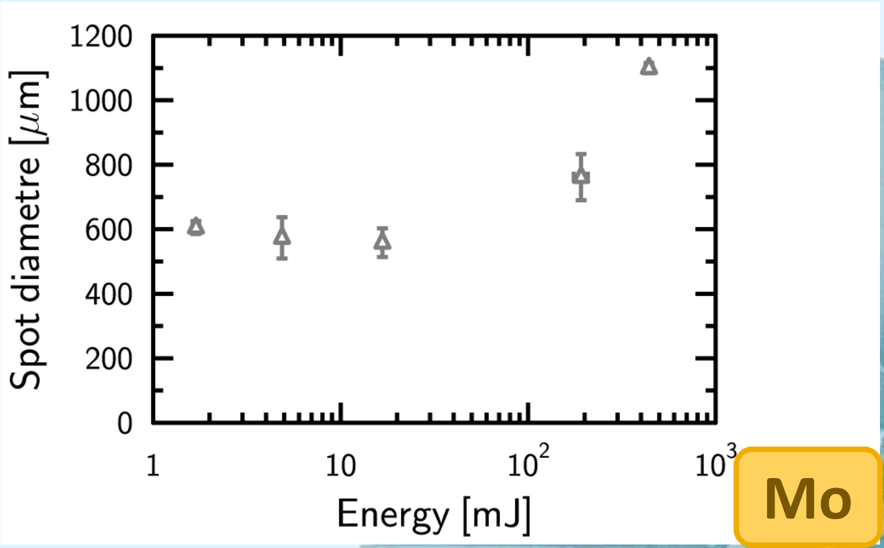
- Conditioning time remains the same, however,
  - With less energy available for the breakdown, less (de-)conditioning can be achieved $\Rightarrow$ E_{BRD} changes
- This was confirmed by preconditioning tests
  - By preconditioning with higher energy, higher E_{BRD} can be reached (for Mo)



Energy scaling of the spot size

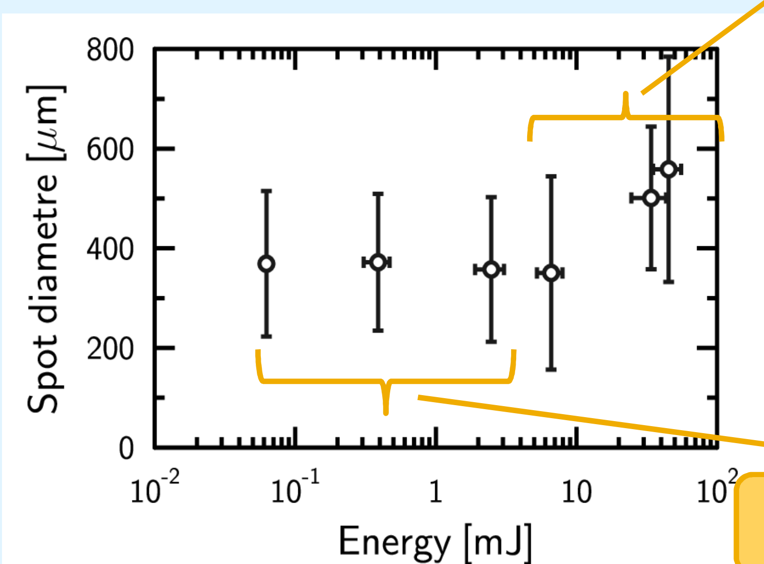
- Also the diameter of the damaged area depends on the energy available
  - Area mostly determined by the conditioning phase
  - Decreases with decreasing energy; saturates below a given threshold

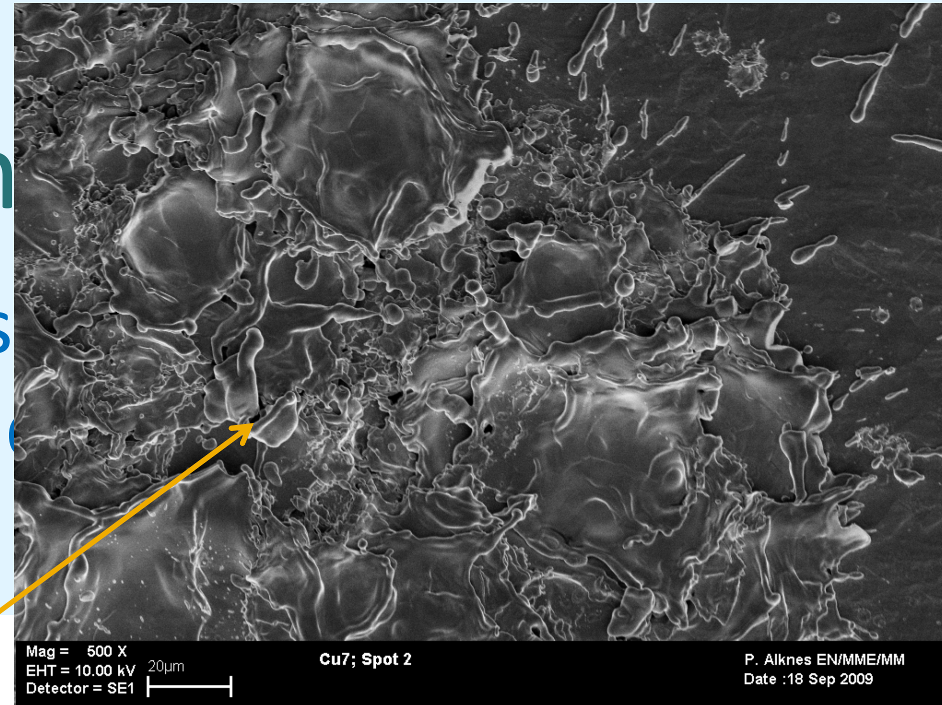


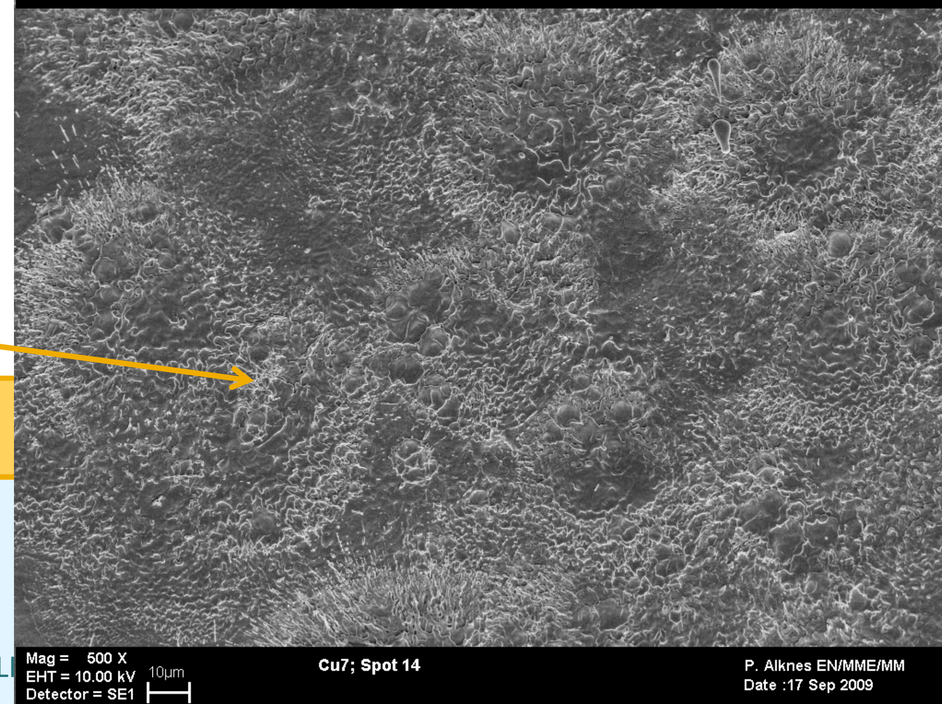


Saturation

• Below a given thres
sufficient to create



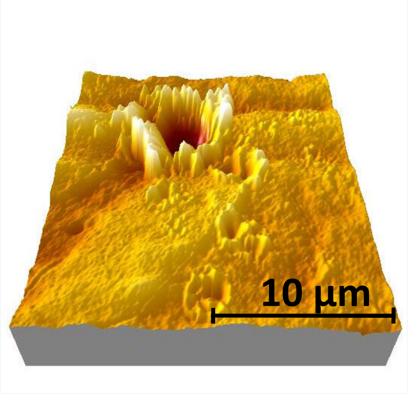


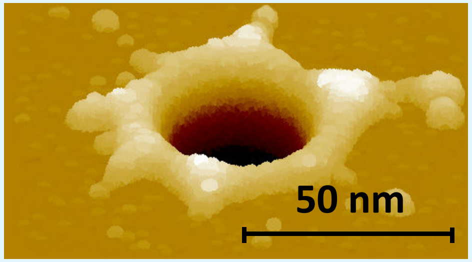


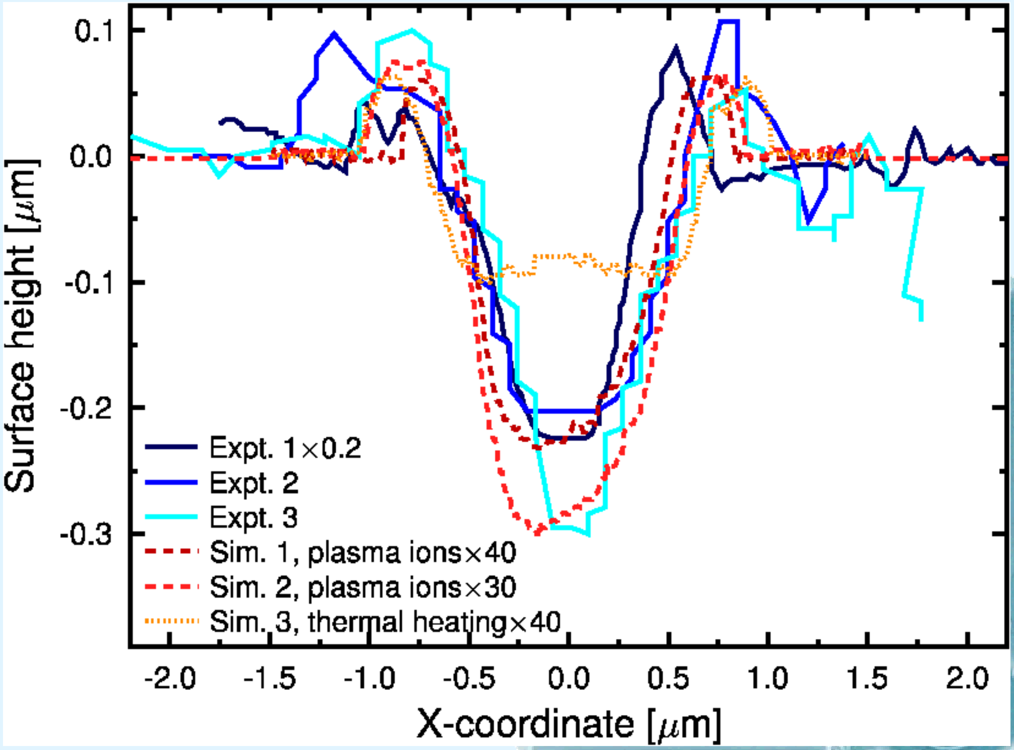
Crater rim size [atoms]

Scaling of single craters in Cu

- Depth to width ratio is independent of dose
  - Both experiments and simulations gave the same aspect ratios

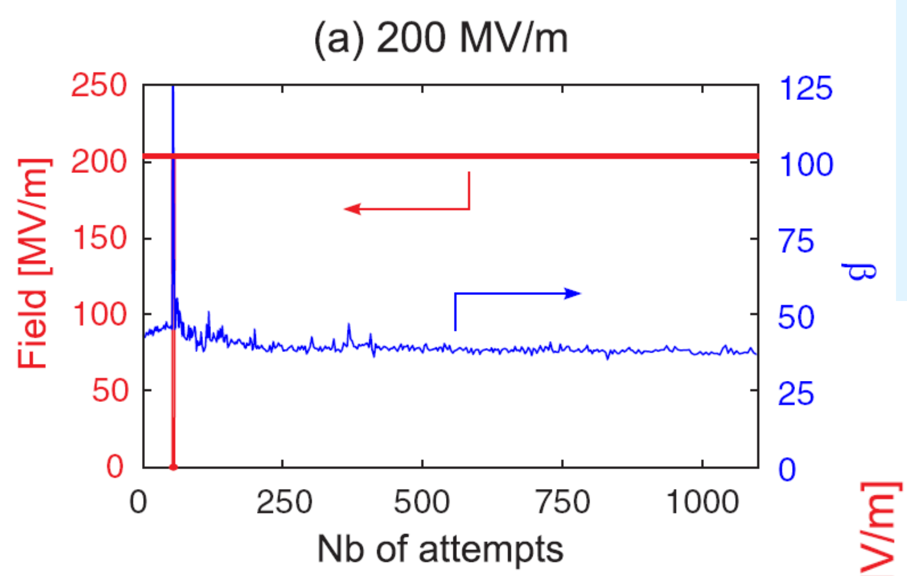




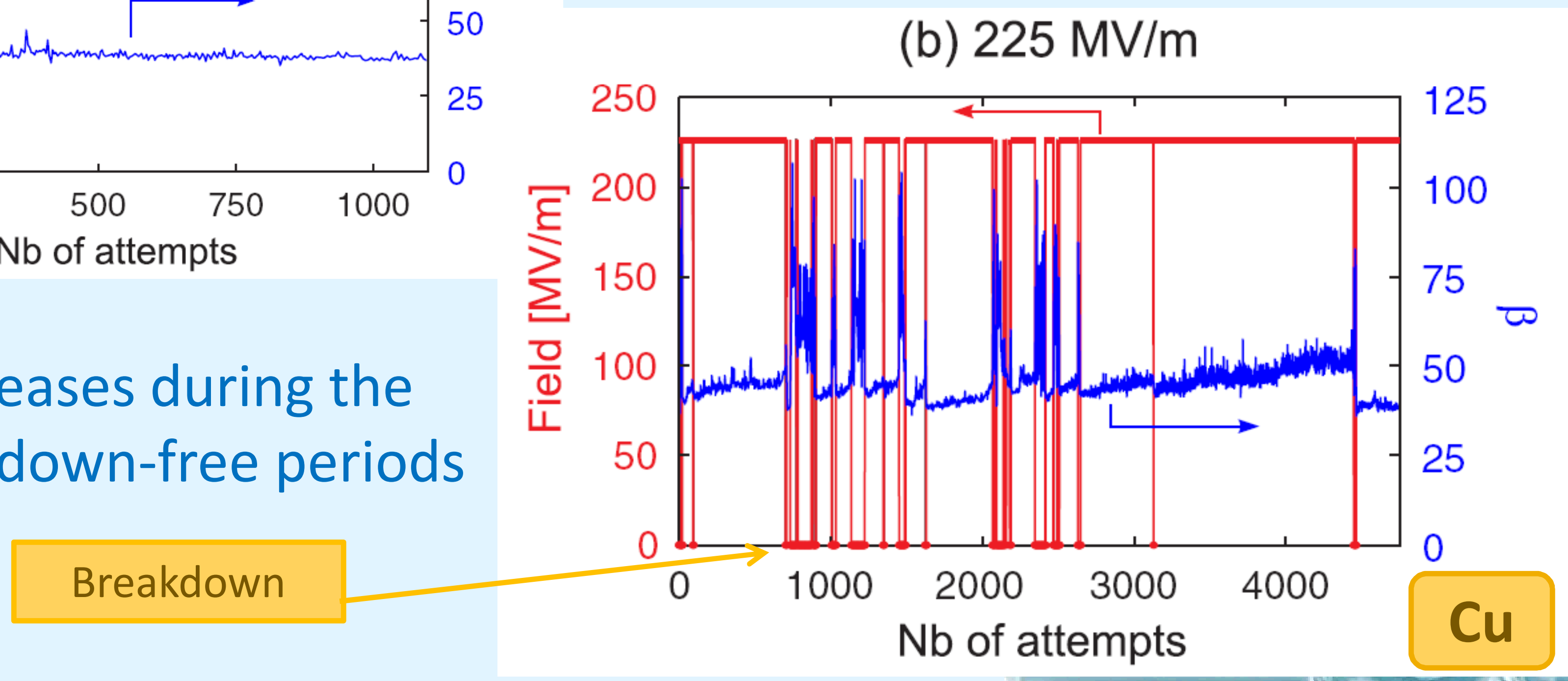


Other breakdown phenomena

The evolution of ß during breakdown rate measurements

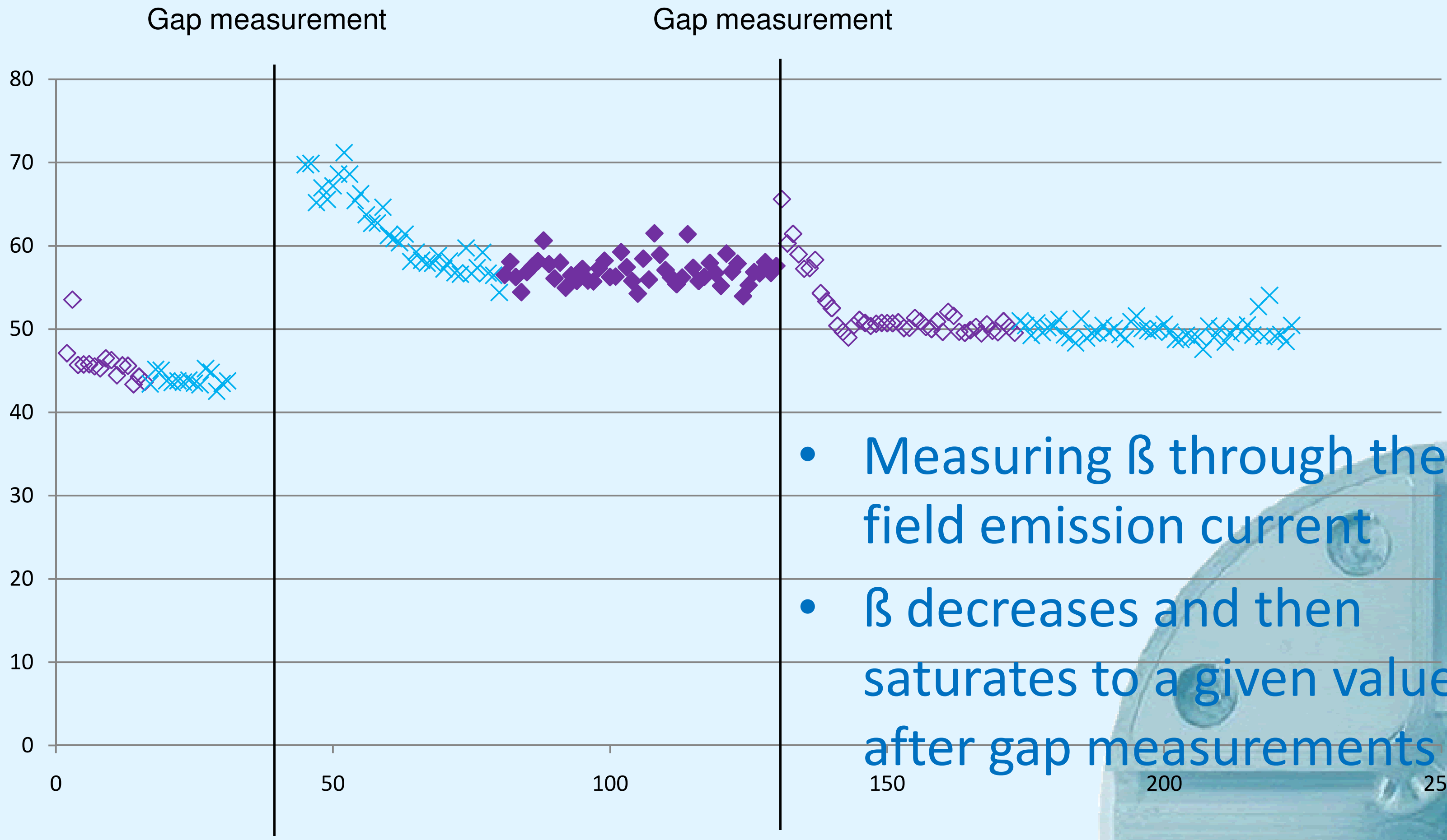


- 200 MV/m: BDR = 4×10^{-3}
- 225 MV/m: BDR = 0.11



- ß increases during the breakdown-free periods

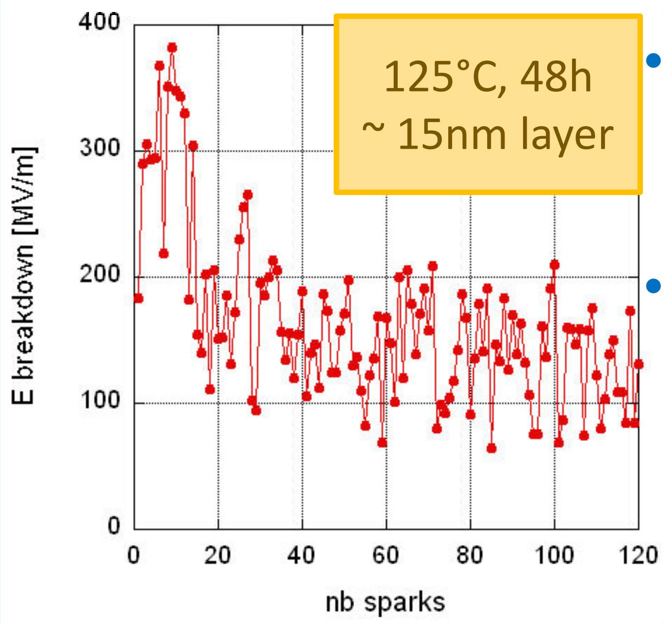
The evolution of ß without breakdowns



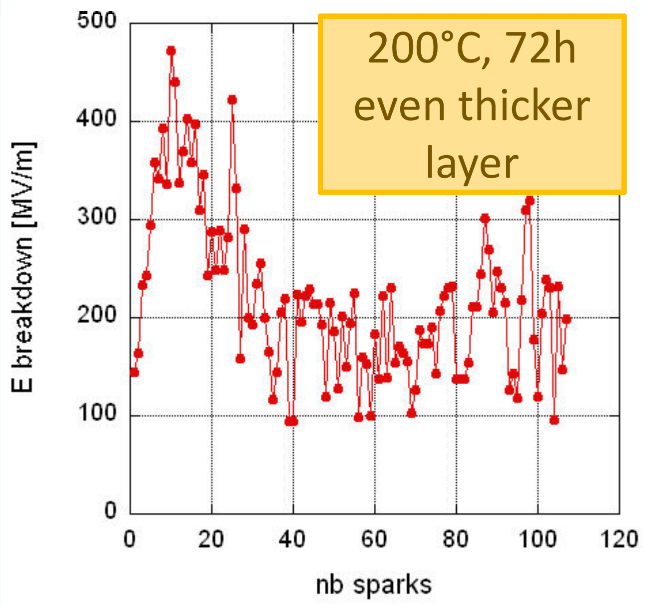
- Measuring ß through the field emission current
- ß decreases and then saturates to a given value after gap measurements

The oxide layer of Cu

- An oxide layer has been grown on Cu, which was thicker than the natural oxide layer
  - Higher initial E_{BRD} and conditioning last longer
  - Has also a different E_{LOC} as the naturally oxidised Cu

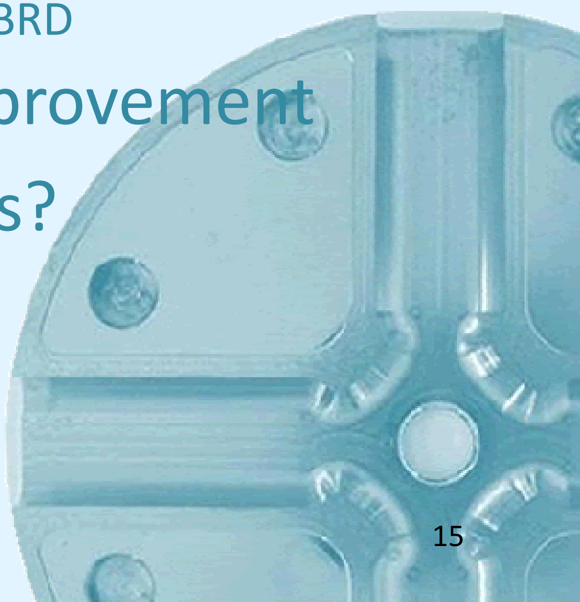


- During conditioning, E_{BRD}=350-500 MV/m in both cases
- This lasts only for 15-20 sparks (left case) or 20-40 sparks (right case)

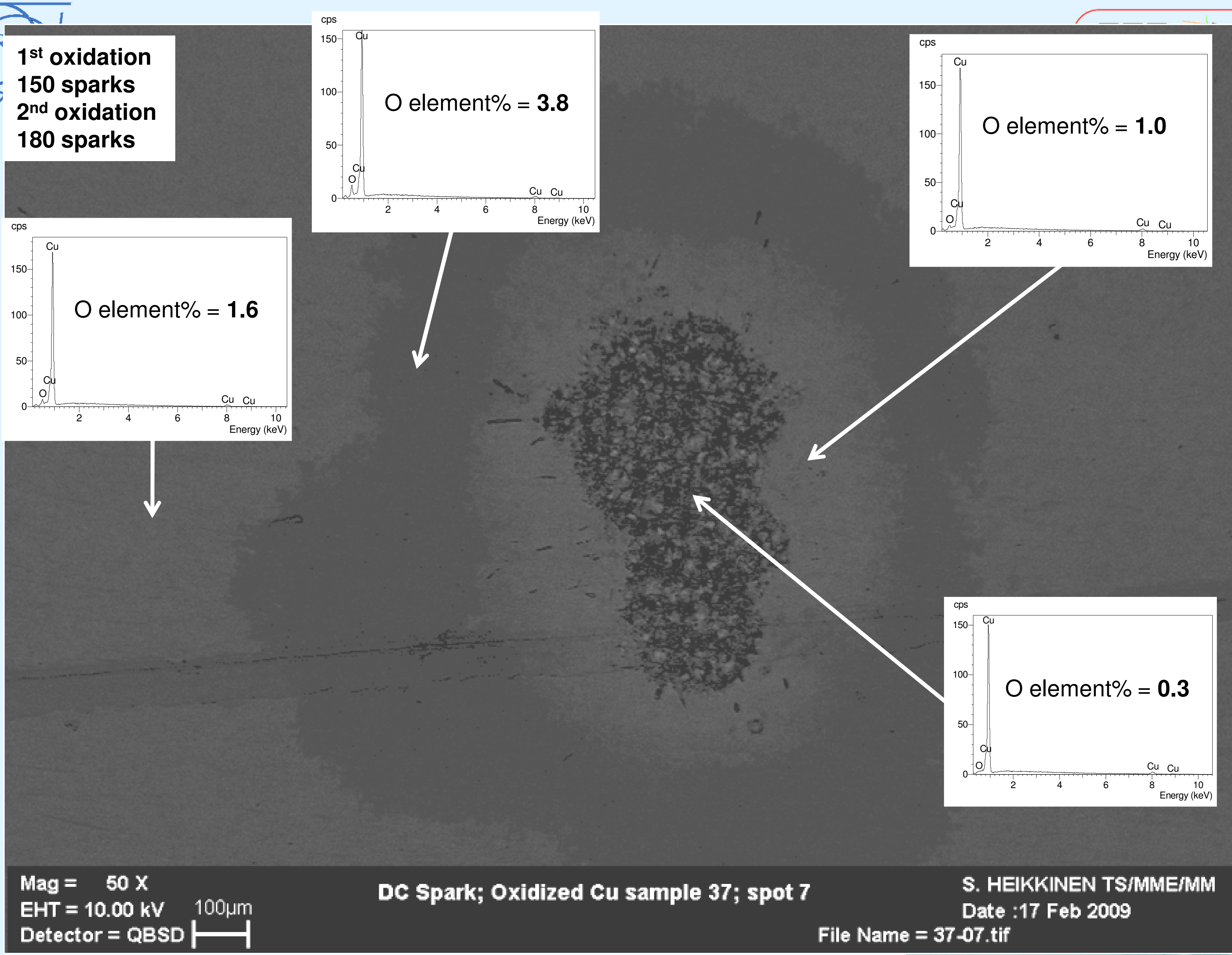


Can reoxidation recover E_{BRD}?

- A sparked (damaged) surface was reoxidised by heating and was sparked then again
  - Was not able to recover the initial high E_{BRD}
  - Oxidised, smooth surface $\Rightarrow$ high E_{BRD}
  - Oxidised, sparked surface $\Rightarrow$ no improvement
  - Connection to the oxidation process?

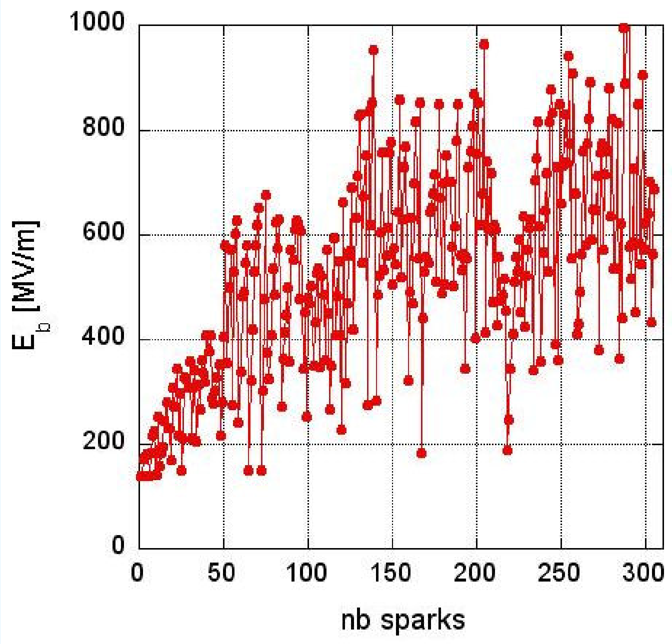


1st oxidation
150 sparks
2nd oxidation
180 sparks

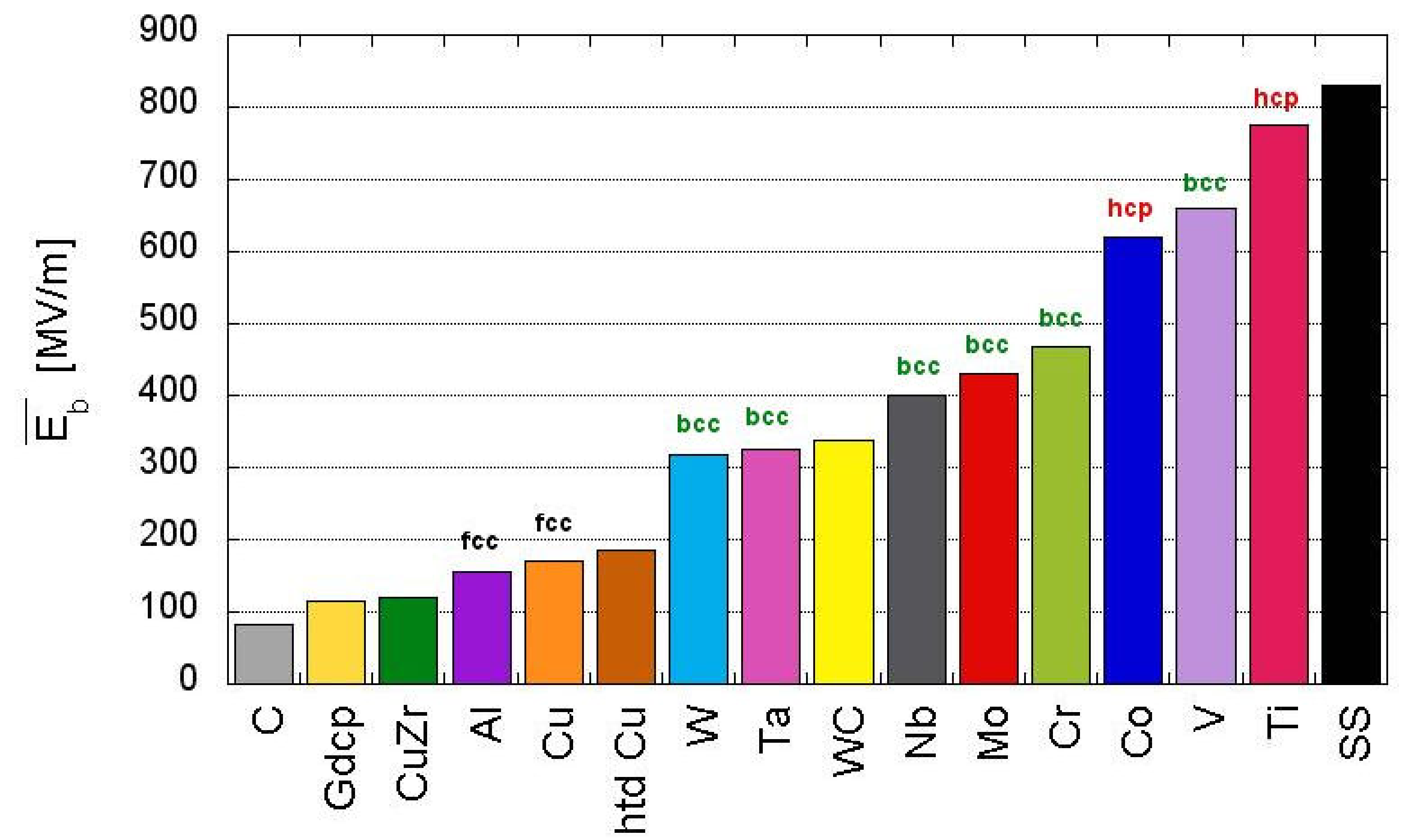


The breakdown field of Co

- Crystal structure can influence the formation of field emitters and therefore, breakdown properties
  - A E_{BRD} ranking of materials by crystal structure was suggested by F. Djurabekova (HIP)
  - We tested Co, which has HCP lattice, and expected a high E_{BRD}
    - Experiments confirmed this



Ranking materials by crystal structure?



Summary

- The energy dependence of breakdown properties is governed by (de)conditioning properties of the material (oxide layer, etc.)
- ß steadily grows when a field is applied (without breakdown events)
- A thick oxide layer on Cu can improve E_{BRD} for a while
- The crystal structure might influence the triggering of breakdowns

Future plans

- Growth of spot size during conditioning
- Oxidised Cu: effect of surface treatments

- Investigation of differently oriented single crystals
- Thermal effects: heating and cooling
- Other materials...

Thank you!