# Cathode versus Anode Breakdown Features in Cryogenic Conditioning


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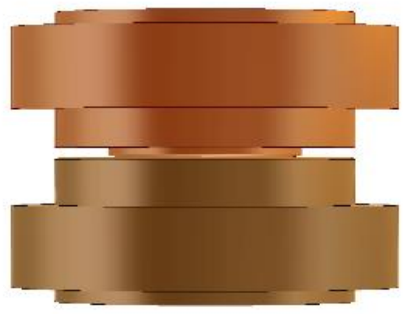
## Cryogenic discharge system

Pressure value:
@ room temperature: < 1e-7 mbar
@ cryo temperatures: ~ 5e-9 mbar
Temperature: **typical 30 K**, min 5 K
Electrodes material: **copper**



Electrodes and gap:
60 mm diameter cathode
40 mm diameter anode
**Gap:** 40 or 60 $\mu m$ at warm,
i.e. **59 or 79 $\mu m$ at cold**.

High voltage generator: Pulsed DC
**Up to 12 kV**, pulse width **1 $\mu s$** (up to 1 ms)
Rep rate: **1 kHz** (up to 6 kHz)

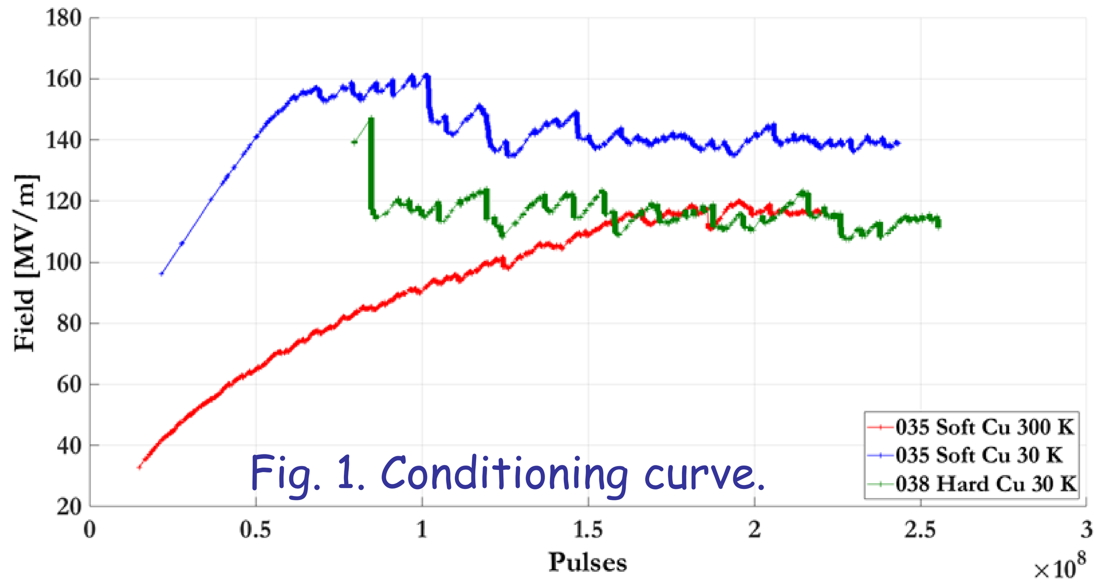
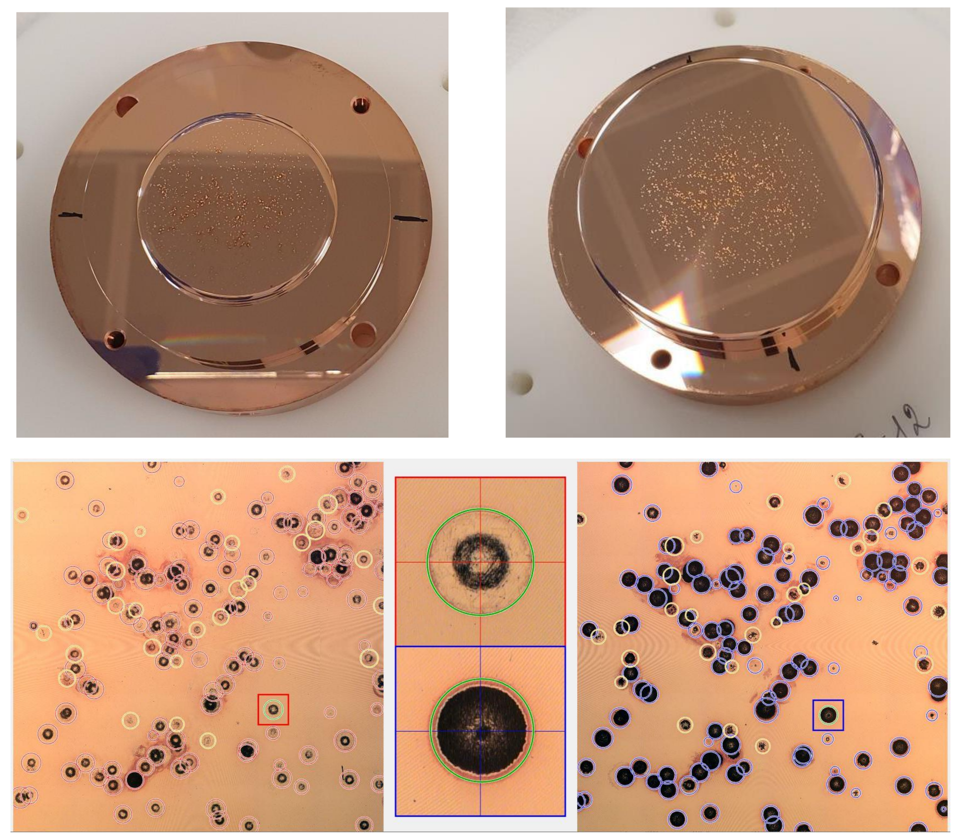



Fig. 1. Conditioning curve.



**Experimental procedure:**

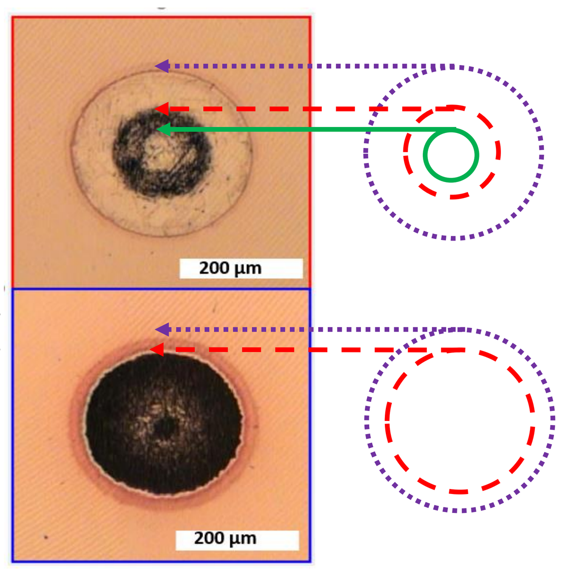
CERN:
1. Sample preparation.

Uppsala:
2. HV conditioning in cryo temperature.
3. Imaging with light microscope.
4. Data processing: match anode and cathode based on surface features, measure the features sizes (semi-automatic), analyze the results.

Jerusalem:
5. Post-mortem analysis with Light and SEM microscopy. Future plans: TEM for subsurface morphology.

## Light Microscopy at Uppsala

Typical



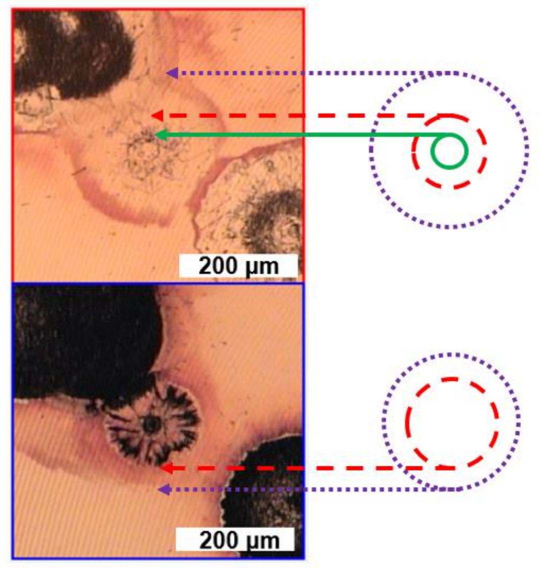

A typical round-shape anode BD is composed of **a reflective central part ($rc_a$)** surrounded by **a wavy circumference ($w_a$)** surrounded by **a thin lighter ring ($tlr_a$)**.

A typical cathode feature has **a wavy dark major part ($w_c$)** and a **thin lighter ring ($tlr_c$)**.

Table 1. Ratio between sizes of typical BD features.

| Ratio name | Number |
|---|---|
| $tlr_a/w_a$ | 1.98 ± 0.38 |
| $tlr_c/w_c$ | 1.21 ± 0.29 |
| $w_c/w_a$ | 1.7 ± 0.54 |
| $tlr_c/tlr_a$ | 0.99 ± 0.08 |

Star-like




**Star-like BD features are found only on cathode side!**

Anode / Cathode

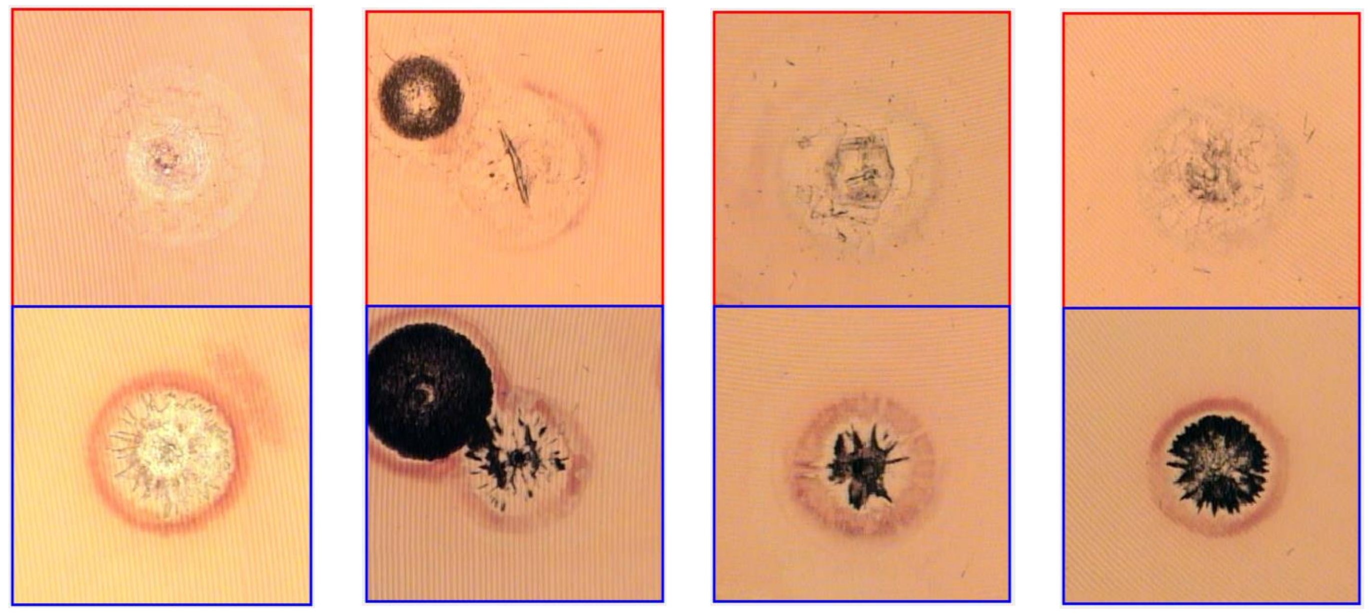


Figure 2. Examples of star-like BD features.
Breakdown sites are matched with anode on top and cathode below.

## SEM and Light Microscopy at Jerusalem

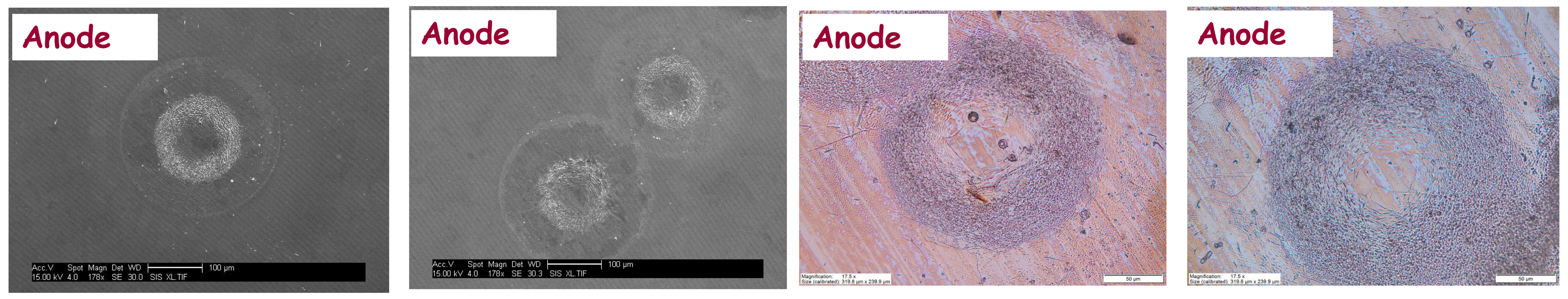



Fig. 3a. Examples of BD features on anode.

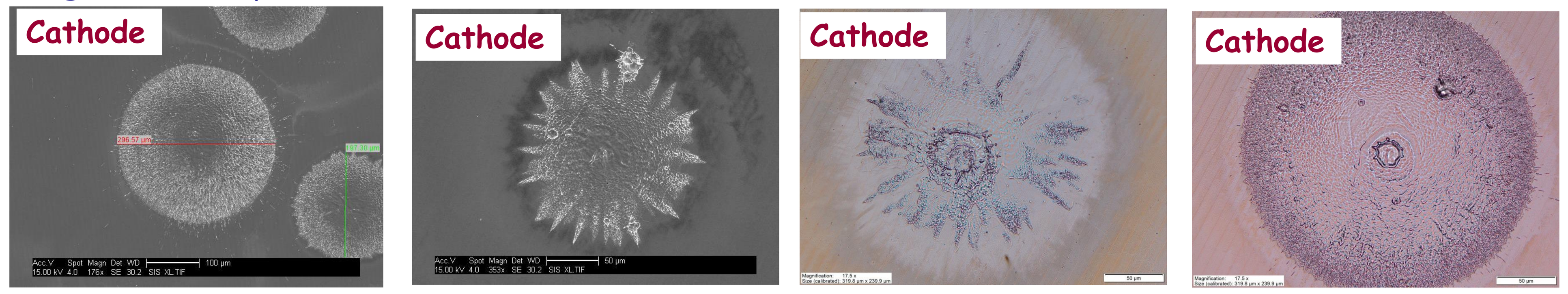



Fig. 3b. Examples of typical and star-like BD features on cathode.

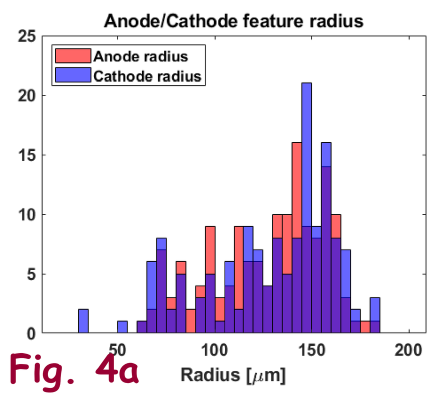



Fig. 4a

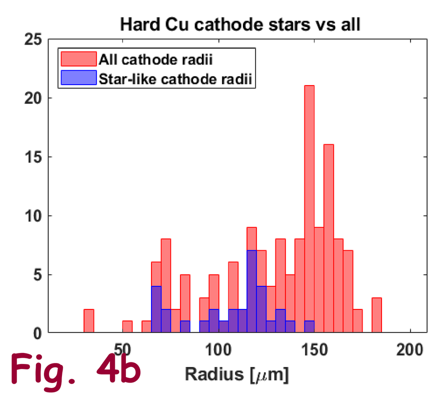



Fig. 4b

Fig. 4a. Radii for thin lighter rings for anode and cathode (i.e. $tlr_a$ and $tlr_c$).

Fig. 4b. Radii for thin lighter rings for typical cathode BD features (in red) and star-likes (blue).

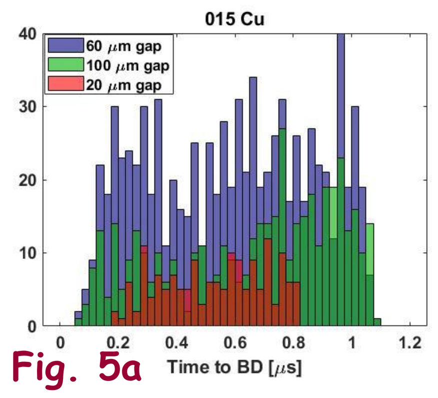



Fig. 5a

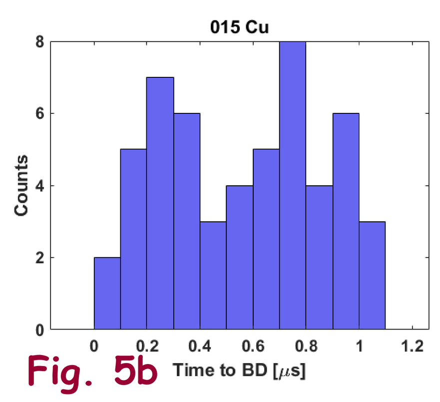



Fig. 5b

Fig. 5a. Time to BDs for all BDs at room temperature.

Fig. 5b. Time to BDs for star-like BDs at room temperature.

## Main results

- Cathode and anode BD spots have different morphology:
  - the cathode has a deeper crater and, typically, the machining traces are destroyed by the BD. At the outer parts, in star-like BD spots traces remain visible.
  - the anode BD features usually have a reflective central part, a wavy deep circle and a shallow halo. The machining traces are destroyed only under the wavy circle.
- BD features have characteristics radii and demonstrate similarity in radii ratios for anode and cathode.
- We identified a quarter of the BD spots as star-like after HV dc test @ 30K (26%, 37 from 145 BD spots in the analysed region). The inter-electrode gap size was 79 $\mu m$.
- During the room temperature test less than 2% (8 from 485) of star-like BDs are found for the test with 100 $\mu m$ gap between electrodes and none for the test with smaller gap.
- Star-like features were found only on cathode side with radii smaller than typical BD spot.
- The BD voltage for 95 % star-like BD features is 10 - 40% lower than expected BD voltage for the same conditions
- Distribution of Time to BD for star-like BDs looks similar to the typical BDs.

## Outlook

Data demonstrate self-similarity between spots and variation in shape distribution with lowering the temperature of the surface.
Observed features may be used to constrain future plasma models for BD and spot evolution.
Future plans include:

- tracing the correlation between shape and field conditions;
- quantifying features such as the amount of material deposited in spots and jets, as well as crater depth and amount of eroded material.

## References


1. M. Jacewicz, J. Eriksson, R. Ruber, S. Calatroni, Ia. Profatilova, W. Wuensch, Phys. Rev. Applied 14 (2020) (http://doi.org/10.1103/PhysRevApplied.14.061002).
2. Ia. Profatilova, X. Stragier, S. Calatroni et al. Instrum. Methods Phys. Res. A 953 (2020) (https://doi.org/10.1016/j.nima.2019.163079).



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