Preliminary results from the cryogenic pulsed dc system

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Cryo DC pulsed system

Motivations

Why DC system?

High field measurement with kHz repetition rate, μs DC pulses
Conditioning process kept as close to RF as possible
The same material treatment

- Information about breakdown physics and electrode damage
- Conditioning within days not months
- Easier for post-mortem analysis

DC system at CERN

Why cryo?

Better understanding of RF conditioning process:
- why the achievable gradient increases?
- why there is an ultimate limit in conditioning process?

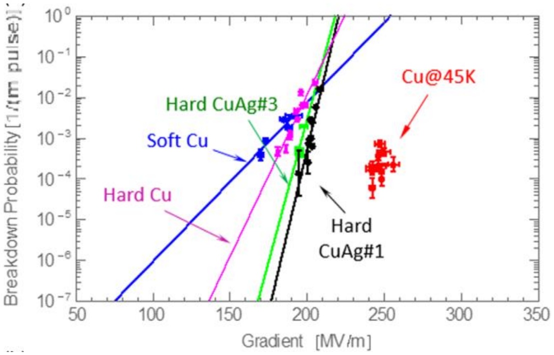
Theoretical models:
- Have strong dependence on temperature
- Agree within the range of currently available data
- Include different temperature-dependent terms

K. Nordlund and F. Djurabekova,
Phys. Rev. ST Accel. Beams 15, 071002 (2012)

E. Engelberg, Y. Ashkenazy and M. Assaf
Phys. Rev. Lett. 120, 124801 (2018)

Experiments at SLAC

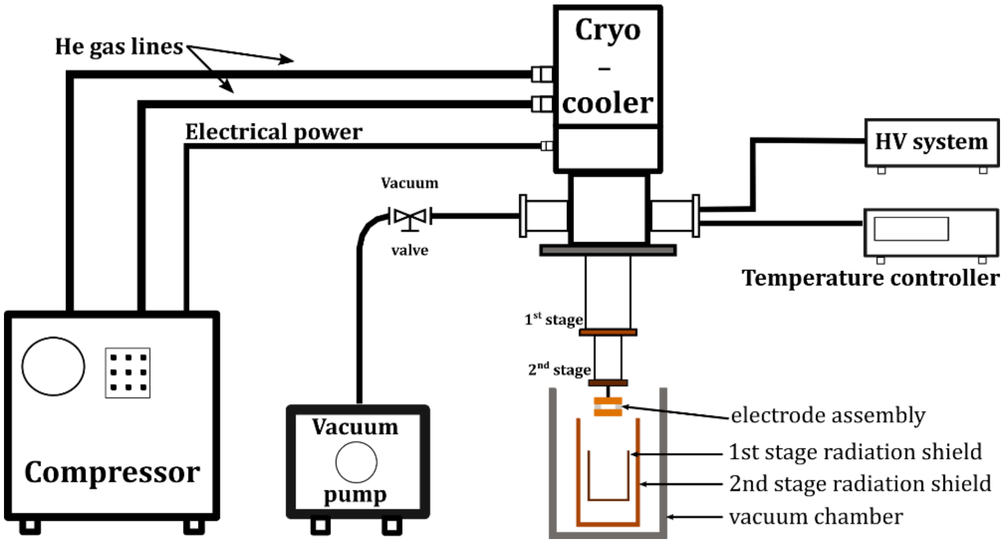
RF structure processed to 250 MV/m, $2 \cdot 10^{-4}$ /pulse/m with 150 ns



Cahill et al., Phys. Rev. Accel. Beams. **21** 102002 (2018)

Cryo DC pulsed system

Setup



Setup

2-stage pulse-tube type cryocooler (CRYOMECH PT415)

Compressor with inverter →

- ➢ variation of the compressor frequency
- ➢ changes cooler capacity and the electrical input power

More flexible operation and wider temperature range.

The nominal performance 1.5W @ 4.2K at second stage

Conditioning with MARX generator

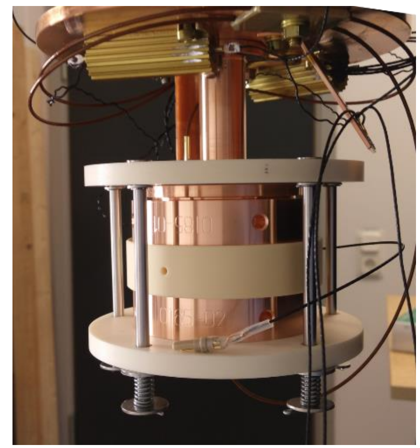
1 µs pulses, 10Hz to 6kHz, up to 10 kV

Field emission with Megger MIT525

Step or ramp mode up to 5 kV

Current range:0.01 nA to 3 mA

Current accuracy: ±2%



OFE Hard Cu electrodes: 60 mm diameter, 60 µm gap maintaned by ceramic spacer

Gap change monitored with:

- ➢ Direct capacitance measurments during cool-down
- ➢ Voltage and current from Marx's power supply

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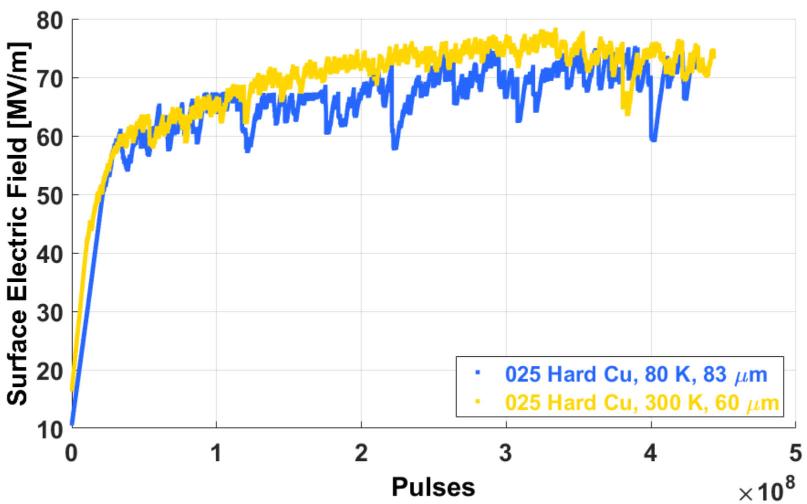
Setup in operation since March, preliminary results

Preliminary results

First conditioning curves → 300K vs 80K

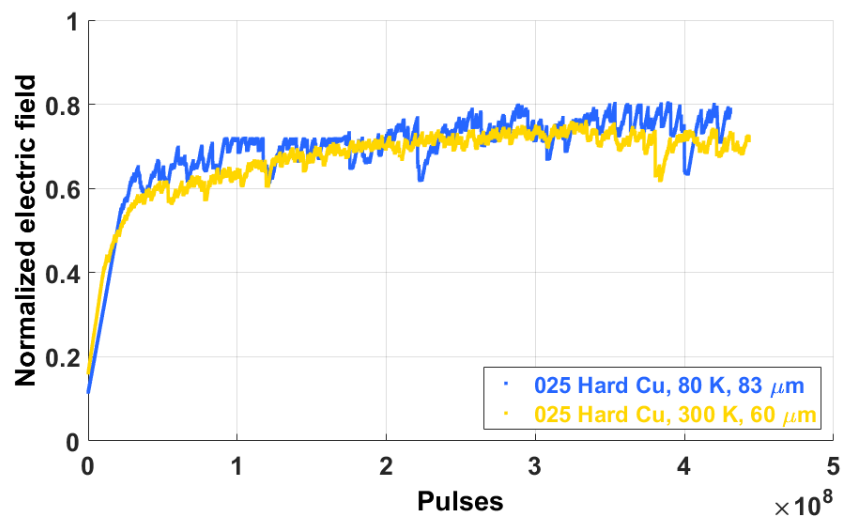


$$E_s = \frac{V}{d}$$

Very little difference in behaviour between two temperatures

<u>Suspicion:</u>

Outgassed and contaminant gases collected on the coldest surface (electrodes)



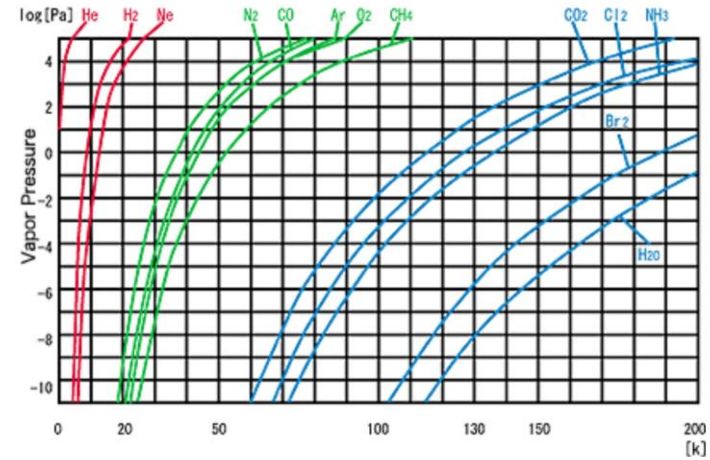
$$E_{norm} = \left(\frac{V}{V_{max}}\right) \times \left(\frac{d_{max}}{d}\right)^{0.7} (*)$$

(*) $V \sim k \cdot d^{\alpha}$,factor α = 0.7 from A. Maitland, J. Appl. Phys. **30** (1961) and measured at CERN DC system

Improved cooling procedure

Special cooling to prevent adsorption of gasses on electrodes

1) Cool down and stabilize at intermediate temperatures
2) When stable warm up electrodes
3) Gases leave electrodes and condense on colder surface (rad shield)
4) Repeat at next intermediate temperature



Temperatures to consider:

120K - H_2O, CO_2,NH_3

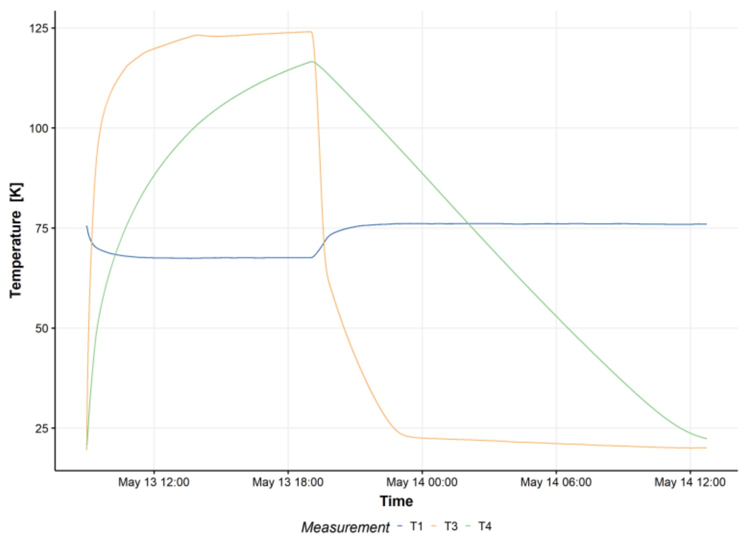
50K – CH_4, O_2, CO, N_2

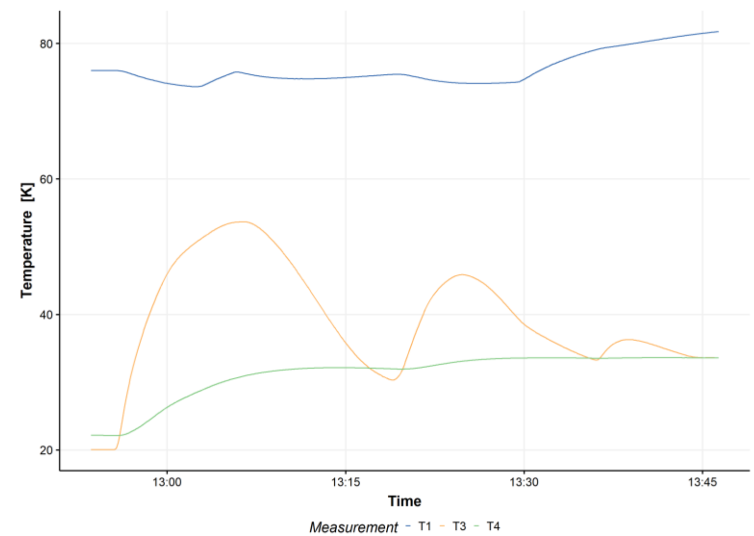
20K – H_2

Blue (T1)
1^{st} stage

Orange (T3)
spacer between electrodes

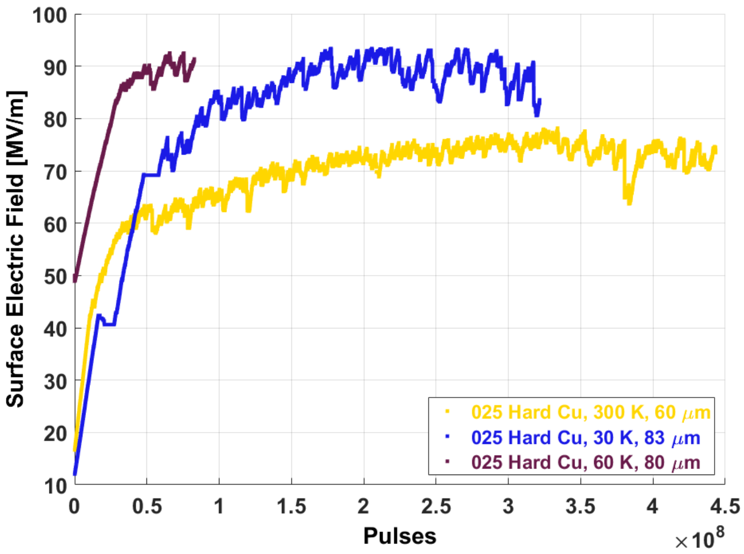
Green (T4)
2^{nd} stage rad shield

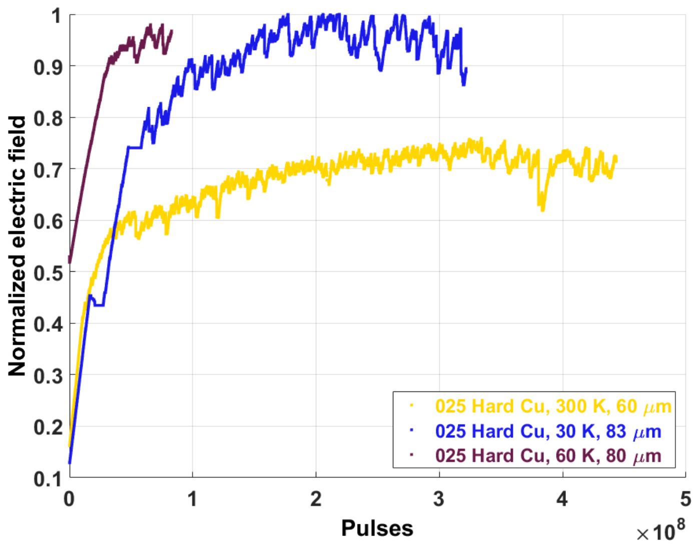




Preliminary results

Conditioning curves → 300K vs 30K and 60K





$$E_s = \frac{V}{d}$$

$$E_{norm} = \left(\frac{V}{V_{max}}\right) \times \left(\frac{d_{max}}{d}\right)^{0.7}$$

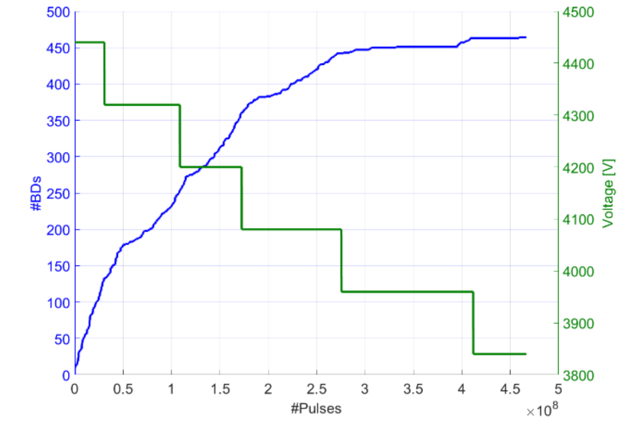
Around 20% increase in achieved gradient

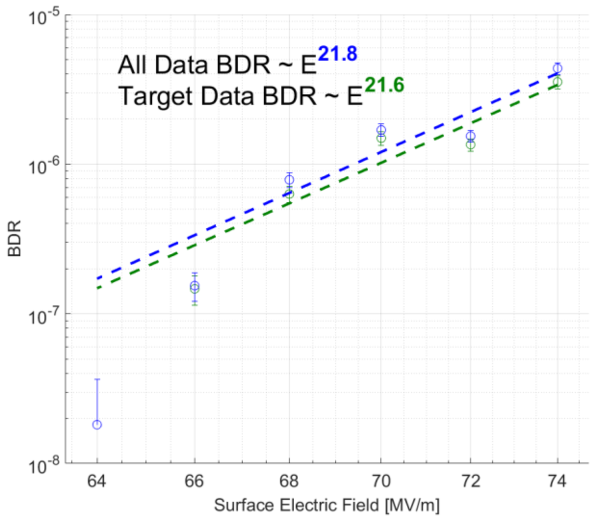
Surface re-condition quicker after each cycle

Breakdown rate

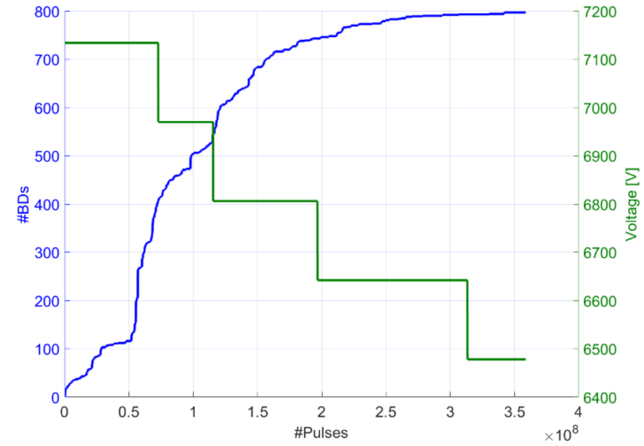
runs at constant field (flat mode) with recovering after BD

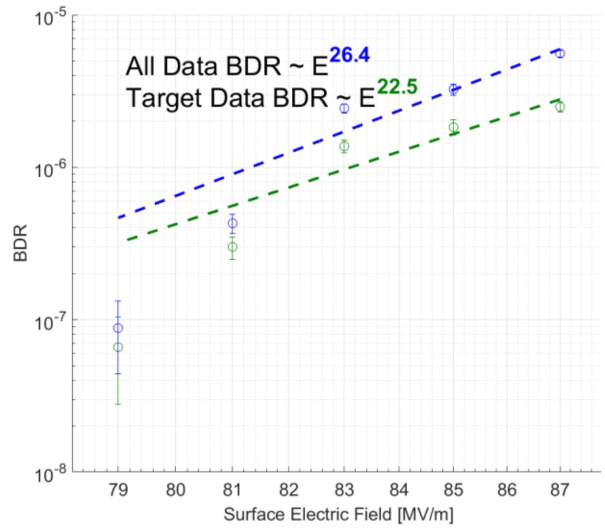
Flat mode → room temperature





Flat mode → 30K





Power law fit

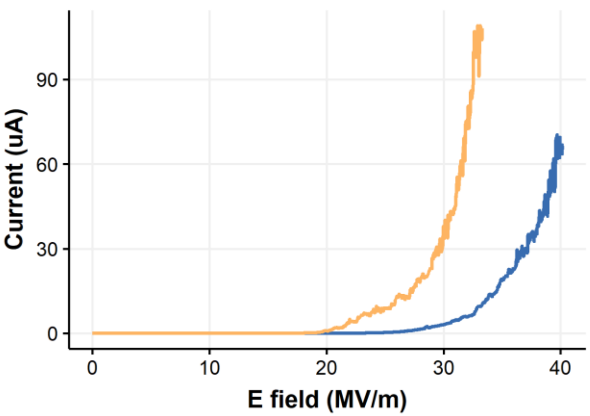
$$BDR \propto E^{30}\tau^5$$

Preliminary results - field emission

Field emission at two temperatures 300K and 30K

Ramping voltage with rate 100V/minute → stopped when breakdown detected

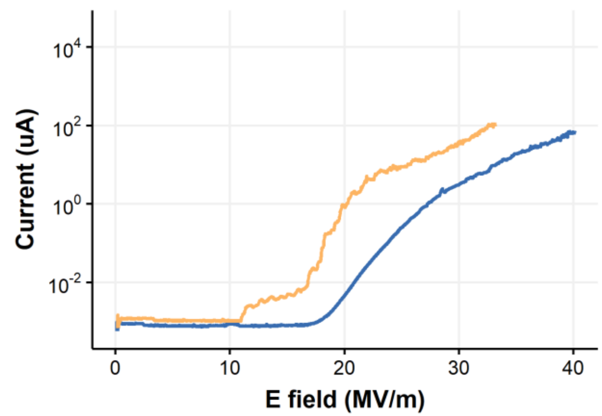
Current - Field



Orange → 300K

Blue → 30K

Current – Field – log scale



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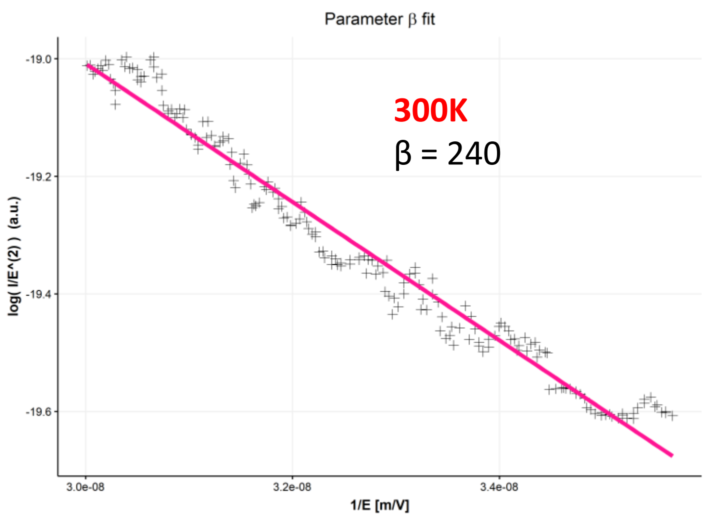
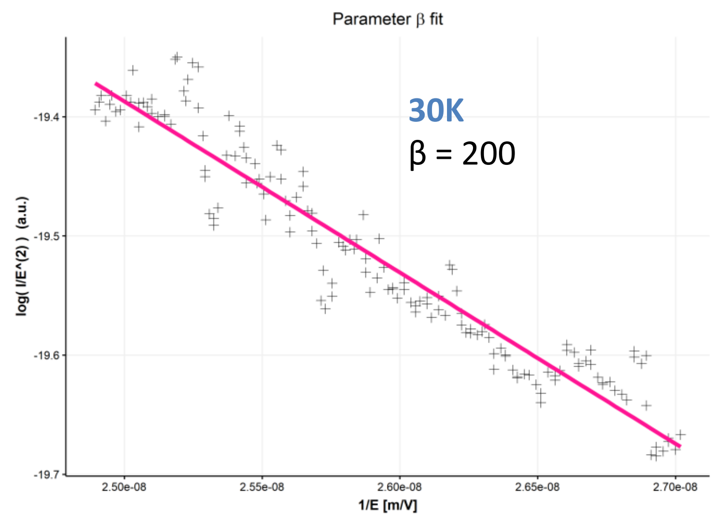
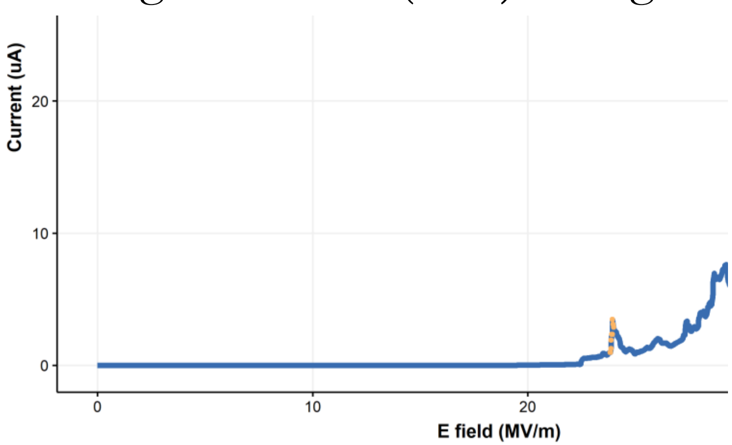
Preliminary results - field emission

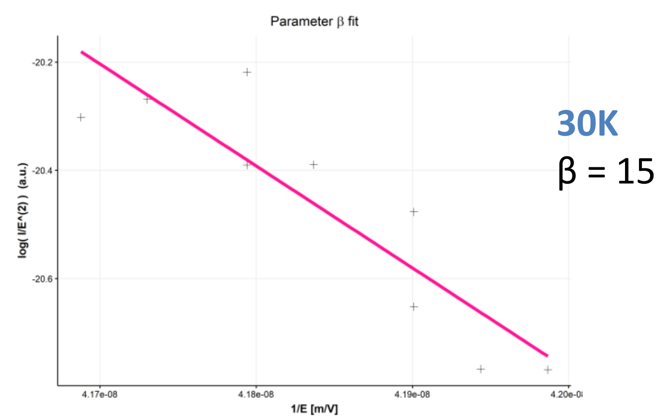
Fowler-Nordheim enhancement factor at two temperatures 300K and 30K





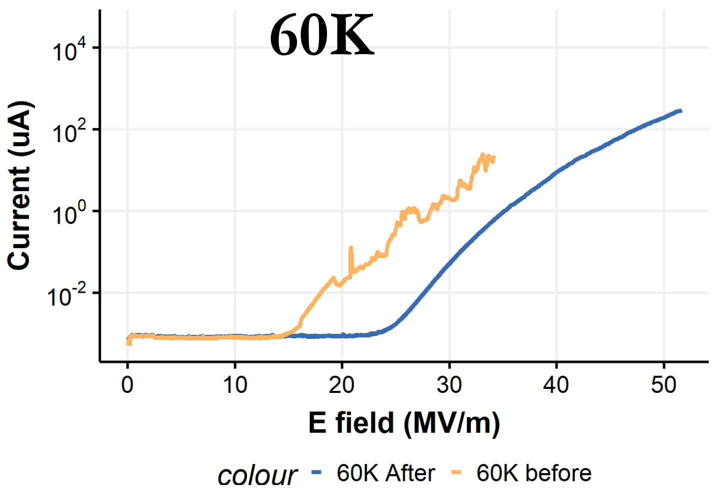
”Single” emitter (30K) – single burst of current during ramping



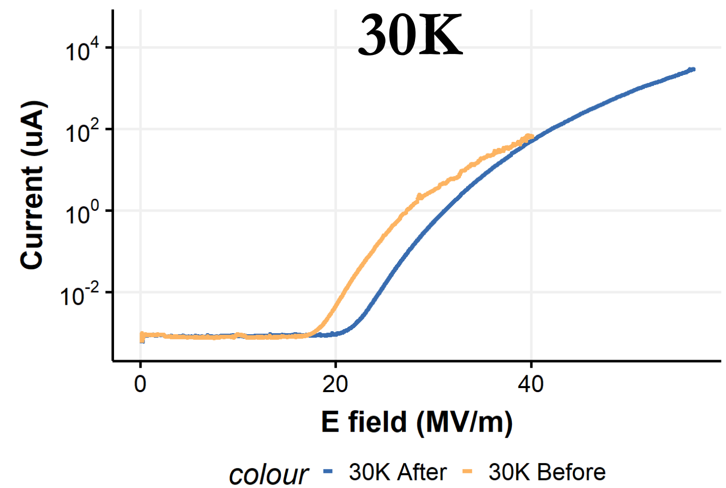


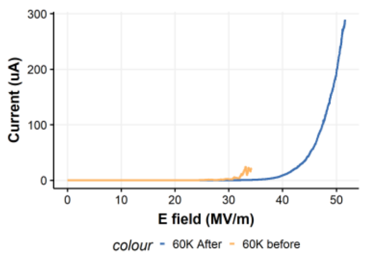
Preliminary results - field emission

Field emission at 30K and 60K→ before and after conditioning at 30K and 60K

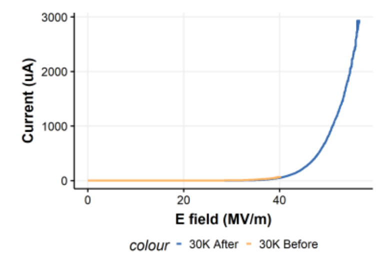


← log scale →





← linear scale →

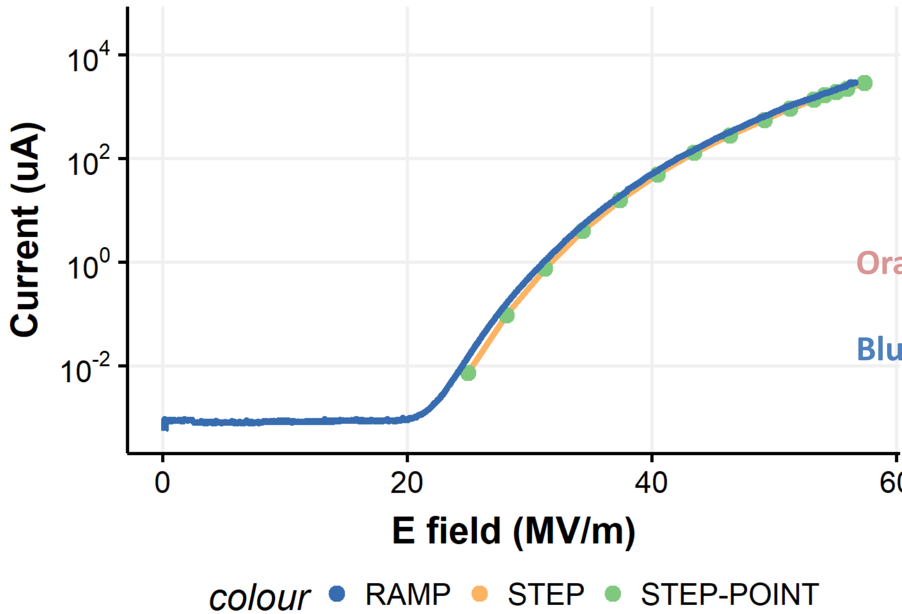


Very high, stable current drawn, > 10W in power!
No breakdown – highest voltage reached

Preliminary results - field emission

Field emission at 30K → after conditioning at 30K

Current – Field → log scale



Orange → step

Blue → ramp

Different procedure for field emission (data at 30K):

Ramp → 100V/minute **vs**

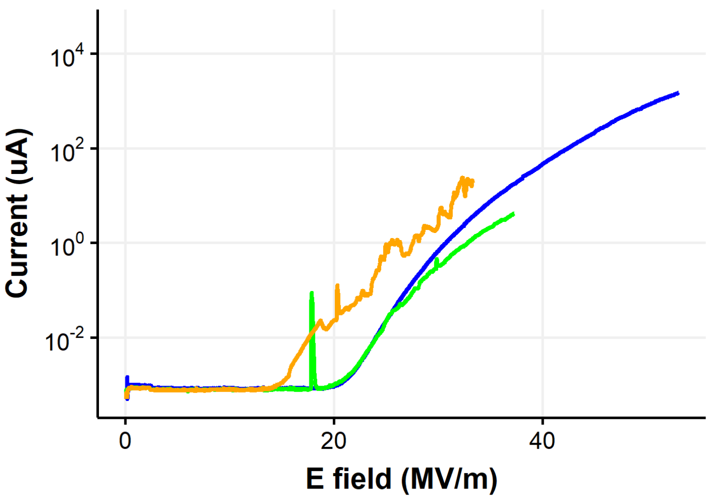
Step → 250V/100V steps, for 1 minute

No significal difference → the same large current

Preliminary results - field emission

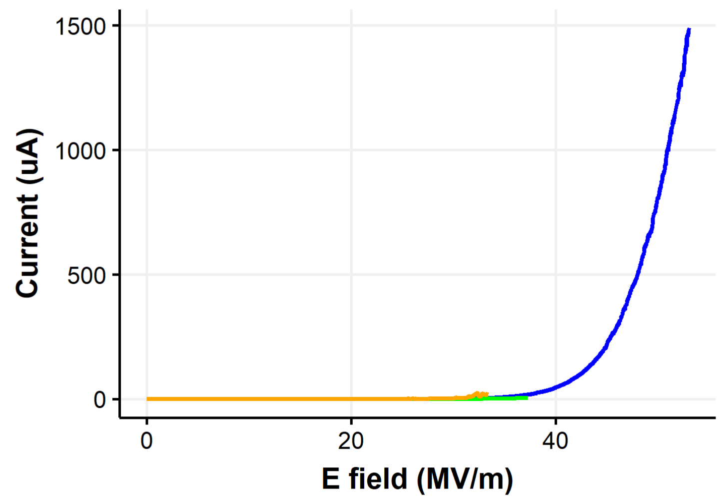
Field emission at 3 temperatures 30K, 45K and 60K after conditioning at 30K

Current – Field → log scale



Blue → 30K
Green → 45K
Orange → 60K

Current – Field → linear scale



"Quiet" surface at 30K, no fluctuations and very high, stable current, no breakdown
"Wakes up" with increased temperature, fluctuations,
field emission scan ends with breakdown at much lower currents

Summary

- Successful construction and commissioning of the cryo DC system
  - First set of electrodes Cu tested
  - Operation in wide temperature range down to ~20K
  - Set for field emission and BDR measurements
- Preliminary results indicate:
  - Higher (~20%) gradient can be reached at 30K/60K wrt 300K
  - Material "calms down" significantly at cryo temperatures

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Thank You for attention!

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New Derivation of the Vacuum Breakdown Equation Relating Breakdown Voltage and Electrode Separation

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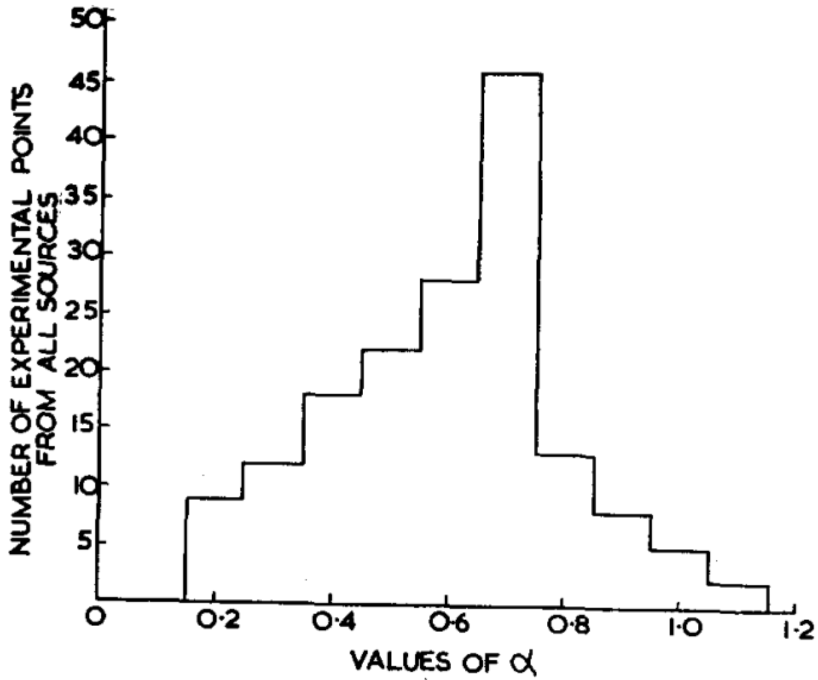

FIG. 1. Distribution of values of α obtained from publications relating to plane or near-plane geometry.