OVERVIEW EXPERIMENTS DC SPARK SYSTEM 2010

Rocío Santiago Kern
VSC Meeting 3rd December 2010

Outline

- CLIC Project
- Need of a DC-Spark System
- Basic Concepts
- DC-Spark System: Schematics
- Experiments: Influence of purity, hardness and surface finish of materials in the breakdown parameters
- DC-Spark System Revision: Noise Sources
  - a) Electrical
  - b) Mechanical
  - c) Physical
- Future Plans
- Video
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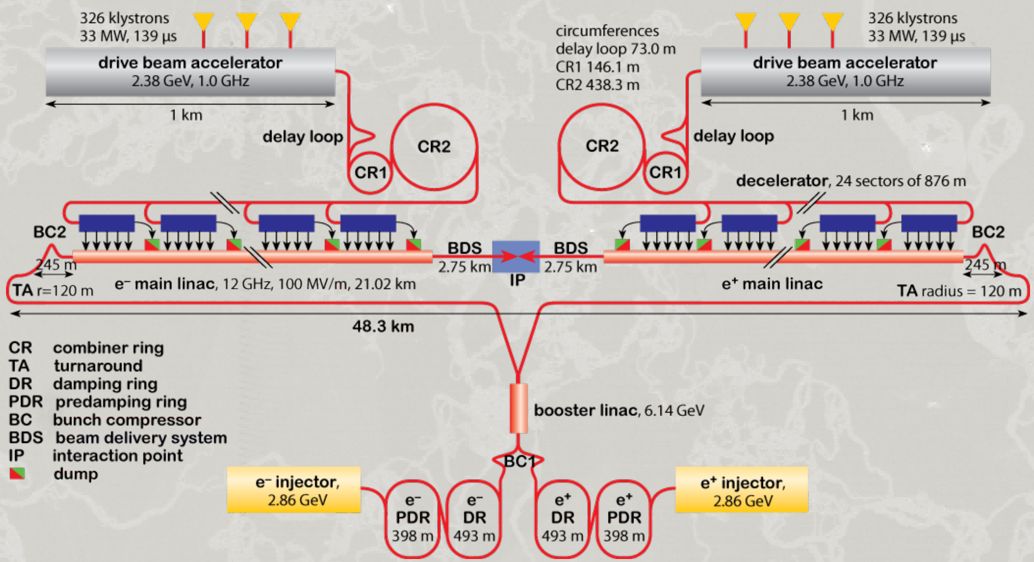
CLIC Project

The CLIC project aims at building a Compact LInear Collider which will operate in the TeV range, with parameters:

- RF frequency of 12 Ghz
- **High accelerating gradient** (100 MV/m)
- **Low breakdown rate** (BDR < 10^{-7} m^{-1})
- **Low structure modification after breakdown**



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Need of DC-Spark System

The main reasons to use a DC-Spark system are to:

- Allow testing of several materials and
- Surface treatments
- Study breakdown conditions (electric field, energy, temperature,…)

as a cheap and effective alternative to RF tests.

BUT when generalising from DC to RF, we need to consider:

- In DC small areas of material (about Ø 0.5 mm) are conditioned, while in RF is the complete cavity
- In RF, BDR not only depends on the material, but also on the pulse length, repetition rate,…

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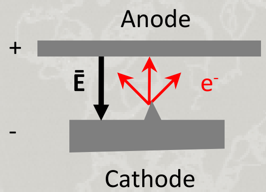
Basic Concepts

Field Emission (FE) [1]



Emission of e^- from the microprotusion to the anode

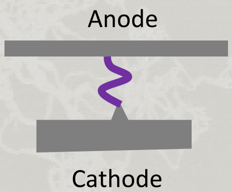
The **field enhancement factor ß** enhances the electric field at the tip of the microprotusion by an amount:

$$E_{local} = \beta E$$

Where **ß**= **ß**(I,V,d,ø)

- I: FE Current
- V: Applied voltage
- d: Gap distance
- ø: Work function

Breakdown



Avalanch of e^- from the microprotusion to the anode: temporarily shortcircuited

Possible Causes:

- Field induced stress
- Ionization of:
  - a) Cathode surface atoms
  - b) Desorbed gas at anode
  - c) Molten protrusions at anode

Conditioning: succesive breakdowns in order to “clean” the surface

Saturated breakdown field E_{sat} : stable electric field achieved after conditioning

$$\text{Breakdown Rate (BDR)} = \frac{\#\text{breakdowns}}{\#\text{attempts}}$$

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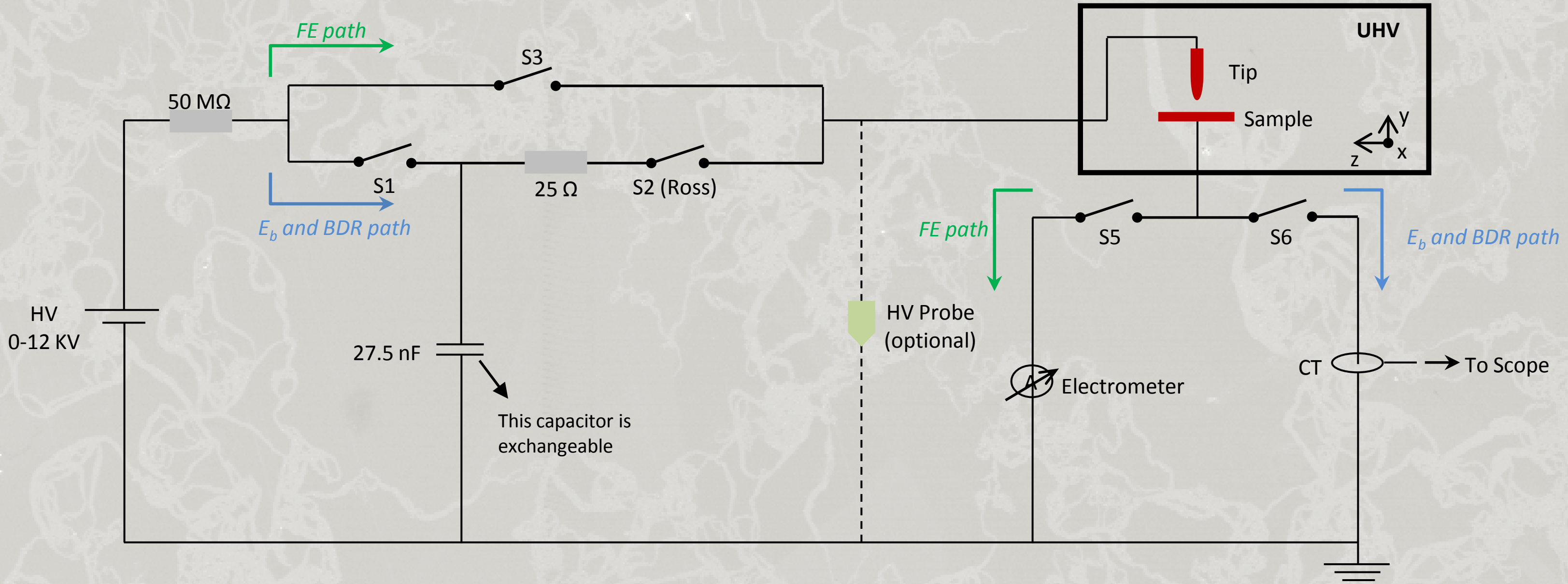
DC-Spark System: Schematics

Available at CERN are two DC-Spark Systems [2], with characteristics:

- Voltage Range 2 kV - 12 kV
- Gap 20 µm
- Two modes of operation:
    a) Field Emission (FE) → from pA to nA
    b) Conditioning and BDR → 100 A app.



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Experiments: Influence of purity, hardness and surface finish

Experiments regarding the **influence** of **purity**, **hardness** and **surface finish** have been carried out in Cu samples.

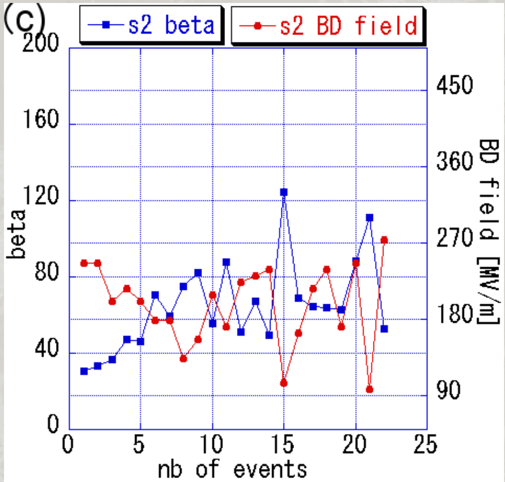
In total, three different Cu samples have been tested:

- **OFC Class 1**: standard Cu sample
- **7N-LG**: high purity Cu with large grain size. Two different surface finish:
  a) Diamond turning (standard)
  b) Surface etching (2 μm)
- **6N-HIP**: also high purity Cu hardened by Hot Isostatic Pressure (HIP)

All samples were manufactured at KEK

Experiments: Influence of purity, hardness and surface finish

Data analysis: **Beta** and **Breakdown field**



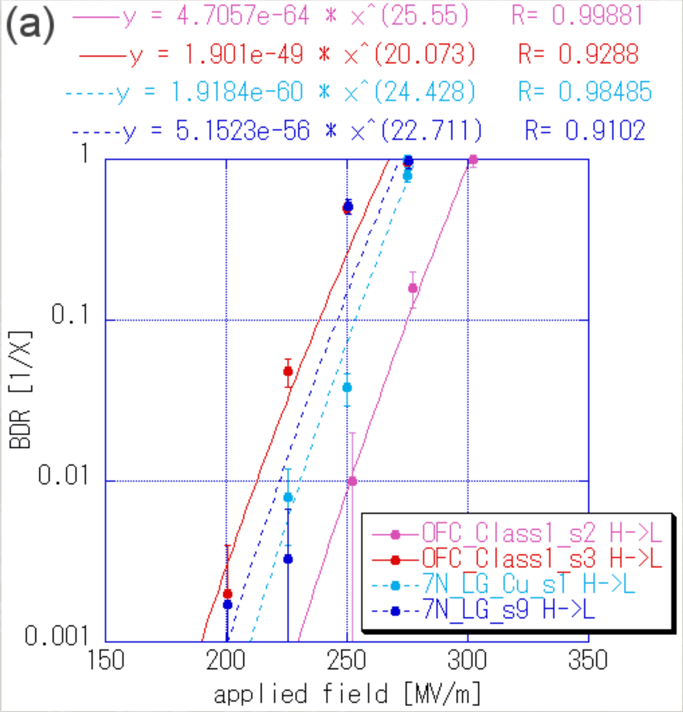
K. Yokoyama

The analysis of such data gives information about the conditioning process, the electric saturated field, the local electric field,…

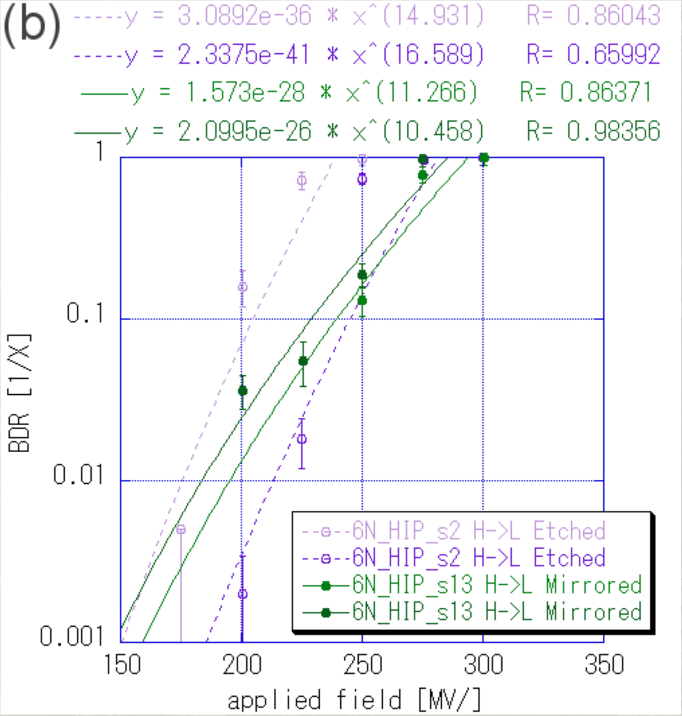
Such analysis gave a **dependence of** the **surface finish** wrt breakdown field parameters, but **not** so in the case of the **purity** of the material

Experiments: Influence of purity, hardness and surface finish

BDR comparison



OFC-Class1 and 7N-LG



6N-HIP

K. Yokoyama

Experimentally

$$BDR \propto E^{\alpha}$$

$\alpha_{OFC} = 26$

$\alpha_{7N\text{-}LG} = 23$

$\alpha_{6N\text{-}HIP,mirr} = 11$

$\alpha_{6N\text{-}HIP,etched} = 15$

Therefore, the **hardness** of the sample **does affect** the BDR: hardened Cu sample registers less breakdowns

Experiments: Influence of purity, hardness and surface finish

Summary of results:

- Regarding breakdown properties, they are affected by:
    a) Hardness of material
    b) Surface finish
- BUT they are not affected by its purity

However, these results should be corroborated by having more statistics. Studies regarding surface treatments are planned

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DC-Spark Systems: Revision

• The first DC-Spark setup has been working for some time now

• It has almost exhausted all its possibilities, so a revision and an optimisation of such system is mandatory.

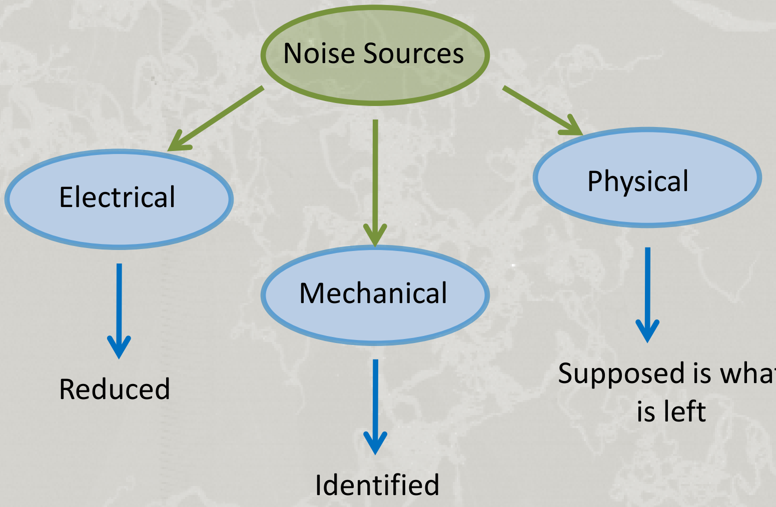
•The second setup is an improvement of the first one, but it will also benefit from the same process

• The optimisation process will also help to accurately estimate the errors in the measurements

DC-Spark Systems: Noise Sources

There are three types of possible noise sources:

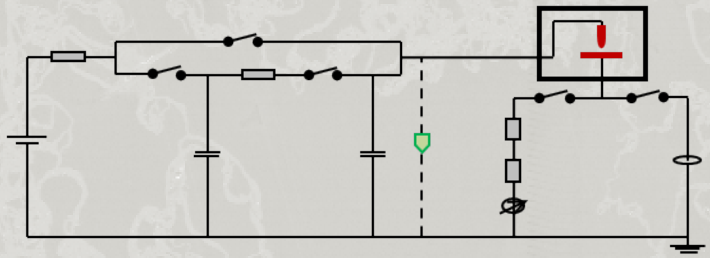
- **Electrical noise**: originates in electrical components present in the circuit, such as resistors, capacitors, cabling…
- **Mechanical noise**: comes from resonance frequencies of the chamber itself
- **Physical "noise"**: given by variations in the sample/cathode surface



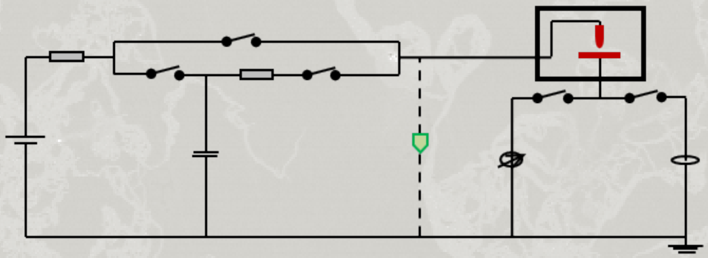
DC-Spark Systems: Electrical Noise

For the **electrical noise**, the following steps have been taken:

- Take overshoot capacitor out
- Change electrometer settings (damping, filter, range,…)
- Avoid ground loops
- Shield HV cabling



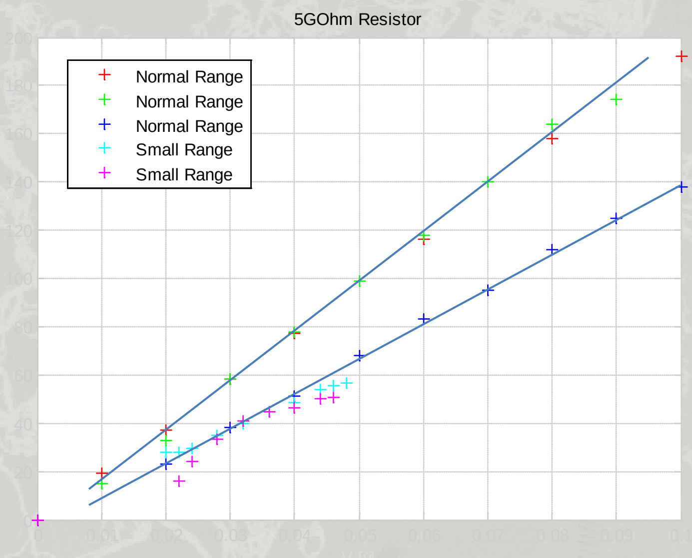
Before changes



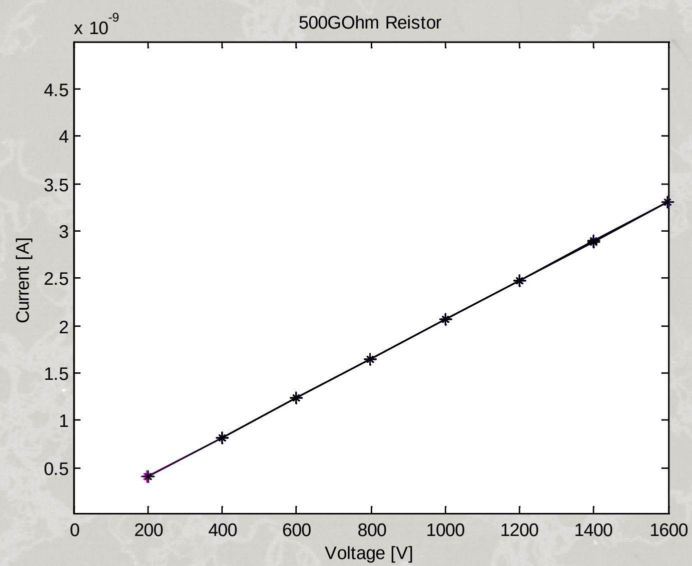
After Changes

DC-Spark Systems: Electrical Noise

To test the improvement in reducing the electrical noise, an external resistor of 5 GΩ and 500 GΩ was placed instead of the cathode and anode. The same setup was used, i.e. same cabling, power supply, electrometer,…



Before changes



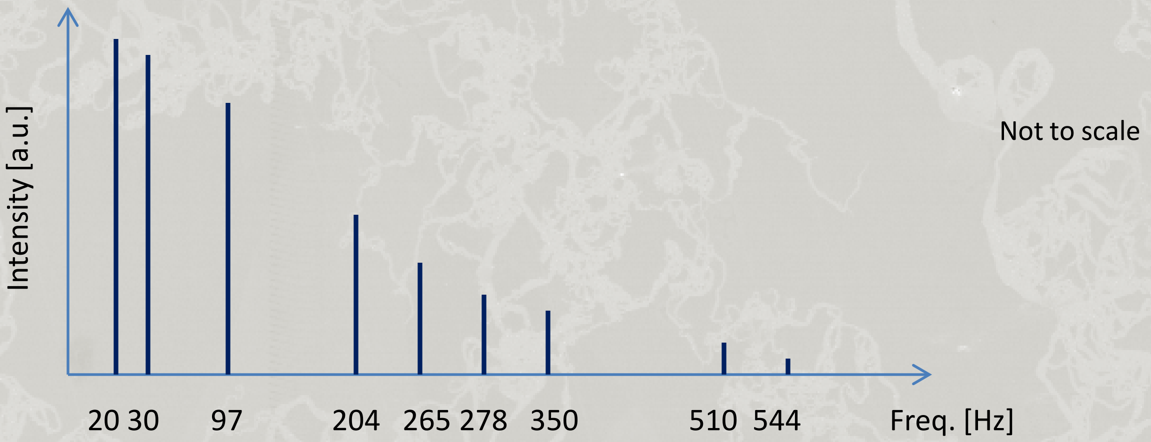
After Changes

DC-Spark Systems: Mechanical Noise

For the **mechanical noise**:

- A ceramic piece pushes on the rear side of the sample holder to give stability
- BUT The sample holder's arm is quite long (about 70 cm)
- Any small perturbation in the sample's or tip's holder adds mechanical noise

The **resonance frequencies** were identified using a pulse generator and a loudspeaker. The identified resonant frequencies are:

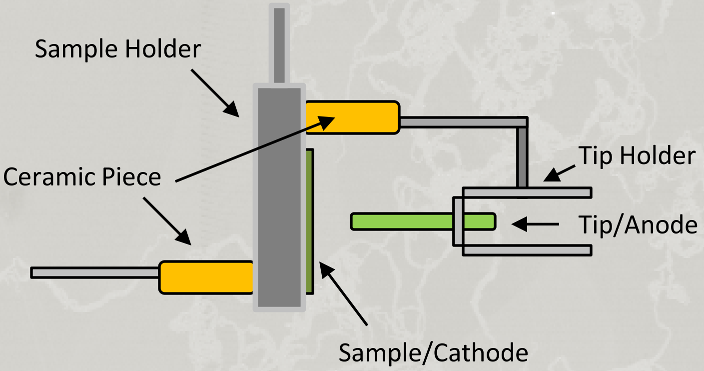


DC-Spark Systems: Mechanical Noise

In order to filter out mechanical noise in an effective and computable way:

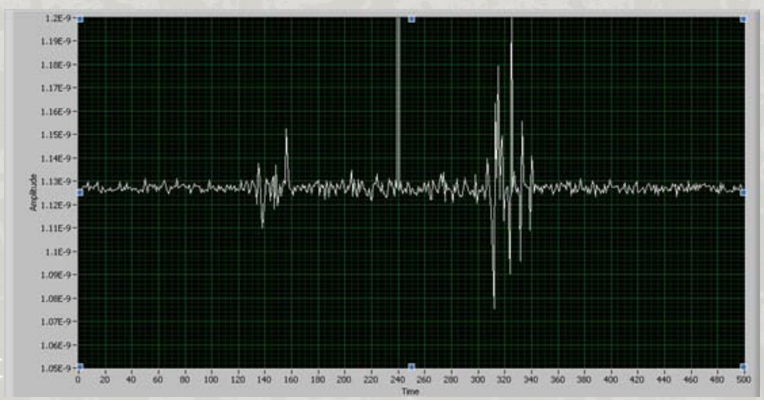
- Read the data as fast as possible to at least 100 Hz
- With an FFT get rid of all the resonant frequencies
- Convert to time domain
- Choose the data from the new set

The problem is that there is no possibility of reading data at 100 Hz with the present electrometer, BUT one way of reducing the mechanical noise is by increasing the stability of the sample's holder. One way to do this would be by pushing the sample from the rear and the front side.

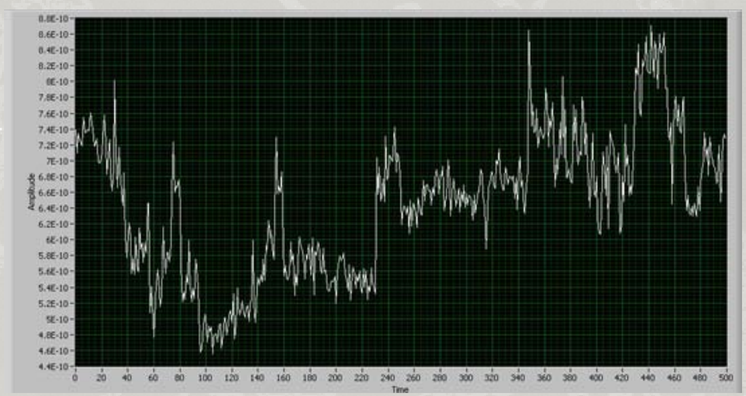


Once the other noise sources have been identified and reduced, we can assert that the only noise source left is solely due to **variations in the sample's surface**

In this case we can analyse the results knowing that changes in sets of data (hysteresis curves, repeatability,…) are due to a physical change of the surface: build-up or extinction of microprotrusions



Normal setup, with 500 GΩ external resistor instead of gap



Normal setup, with sample and tip

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Future Plans

Dislocation mechanisms:

- It has been suggested that microprotusions appear because of the presence of dislocations in the crystal lattice.
- Experimentally, some growth mechanisms are hindered at elevated temperatures (> 400 K)
- At low temperatures (< 80 K), dislocations do hardly move

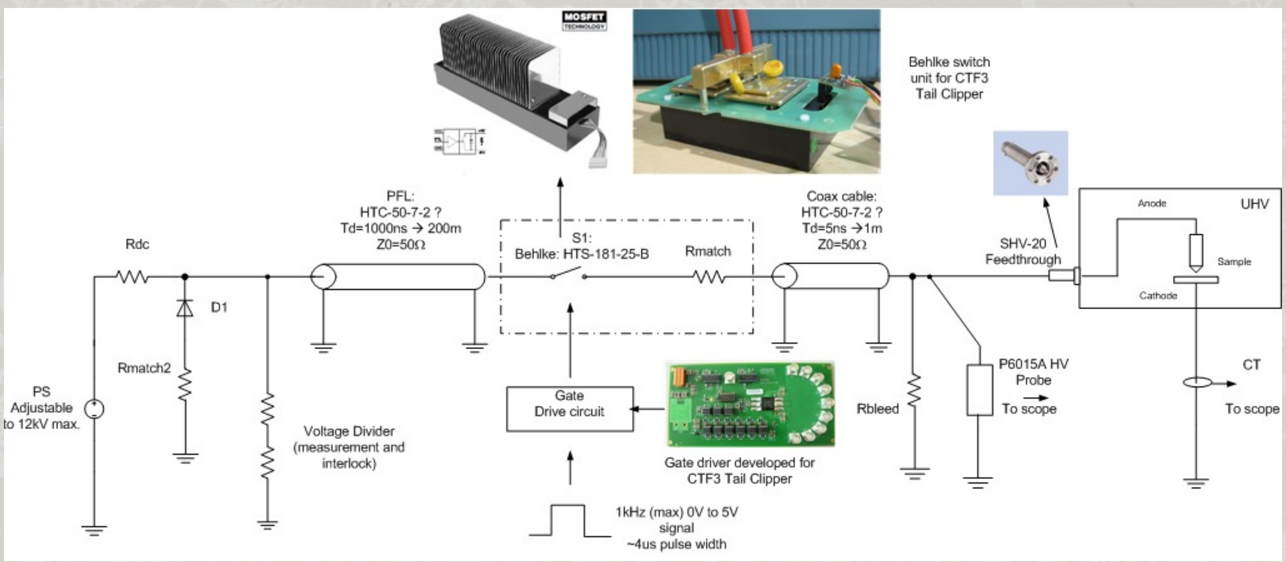
➡ Install a temperature-controlled sample holder, with the possiblity of setting temperatures ranging from -200°C to 1000°C

Future Plans

High repetition rate for BDR measurements:

In order to have BDR of the order of 10^{-7} [m^{-1}] and below, which is not possible to measure in RF but is a feasability requirement for CLIC, the DC-Spark system needs to increase its repetition rate

→ Install fast HV MOSFET switches



Future Plans

Breakdown properties of surface treatments on single crystal Cu materials:

Because RF cavities are chemically treated, study what step(s) in the process vary these parameters and by how much

Develope a non-contact gap measurement:

- Experimentally from FE current and Beta
- With two microscopes at 180° placed at the viewports
- …

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References

[1] K. L. Jensen et al.: *Electron emission contributions to dark current and its relation to microscopic field enhancement and heating in accelerator structures*, Phys. Rev. ST Accel. Beams **11**, 081001 (2008)

[2] M. Kildemo: *New spark-test device for material characterization*, Nucl. Instrum. Meth. A **530**, 596-606 (2004)

[3] K. Yokoyama et al.: *Breakdown characteristics in DC spark experiments on Copper focusing on purity and hardness*, LINAC10 paper.

Thank you for your attention

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