Comparative studies of rf and dc breakdowns

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Motivation

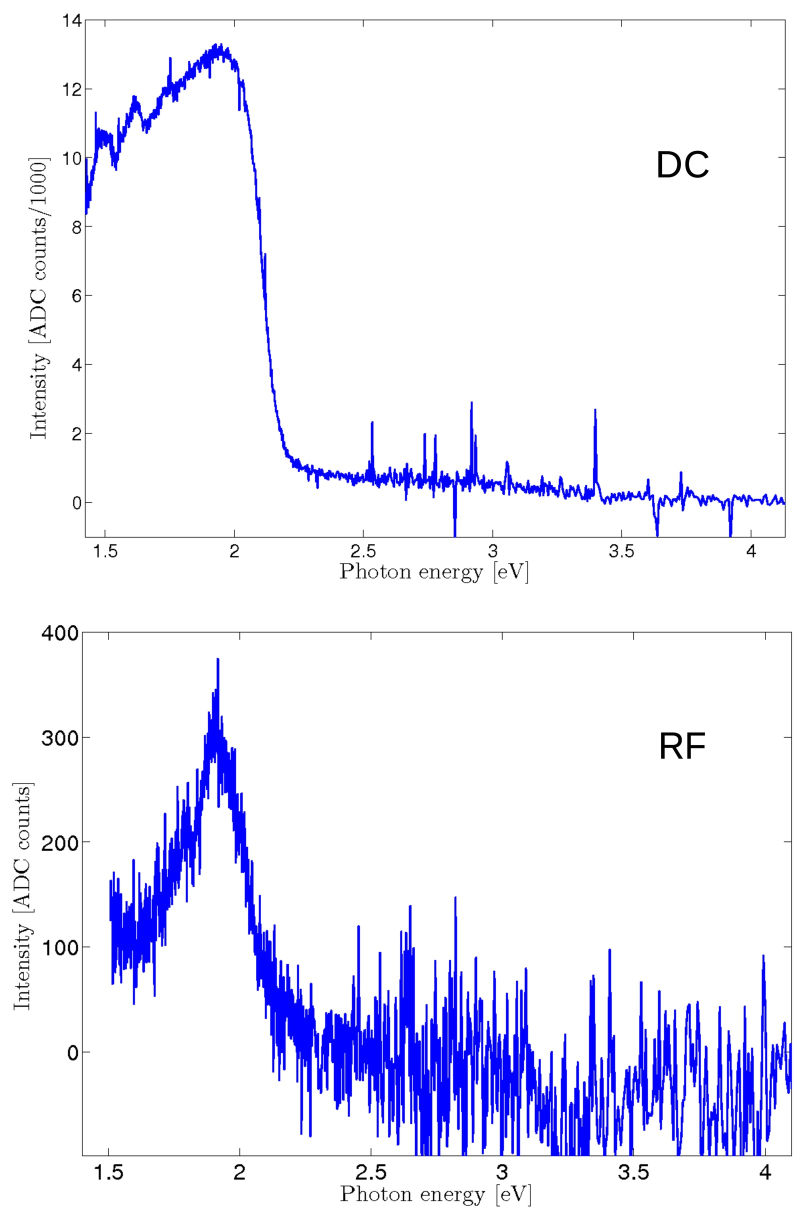
An essential part of the CLIC project is the development of n.c. accelerating structures with a loaded gradient of 100MV/m and a breakdown rate of less than $4{\cdot}10^{-7}$/pulse. For this, structure materials, machining and surface treatment techniques are tested in rf and dc for breakdown resistance. Even though dc tests offer higher test throughput at reduced costs compared to rf tests, the applicability of dc results to new rf designs is unknown. This work therefore focuses on comparing experimentally the physics of rf and dc breakdowns.

Experimental approach

Breakdowns are fast transient, randomly occurring microscopic plasma phenomena, occurring on surfaces exposed to electric fields of several 100MV/m in vacuum. The approach chosen for experimental access are time-resolved and integrated optical spectroscopy to gain insight into the breakdown plasma processes. The experiments took place in the CERN dc setup, the CTF2 30GHz structure test area at CERN and in the 12GHz structure test area ASTA at SLAC [1,2].

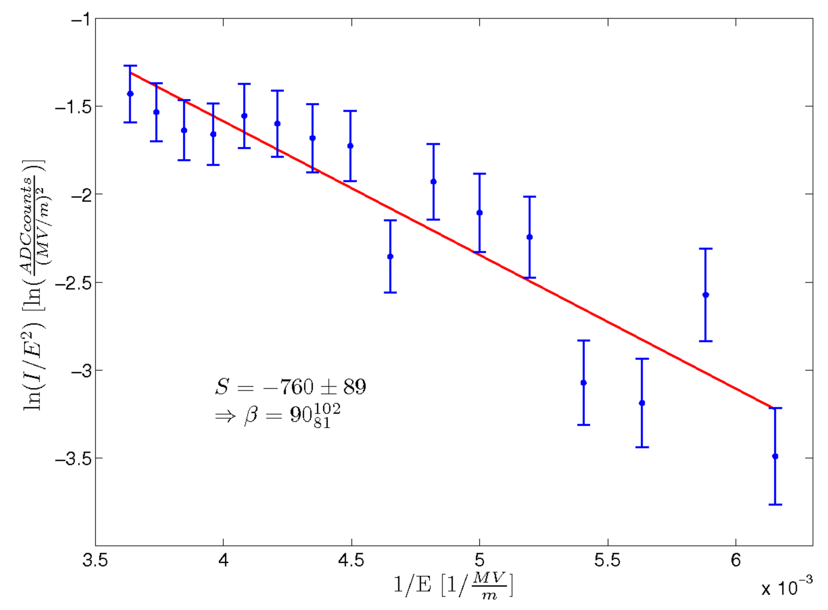
Observation of OTR light

During normal operation, that is, when the structure respectively gap can sustain the applied fields without breakdown, light emission has been observed and identified as optical transition radiation created by the field-emitted electrons when impacting on the structure respectively sample surface.



OTR spectrum in dc and rf. Shoulder at 2.1eV created by Cu interband transition.

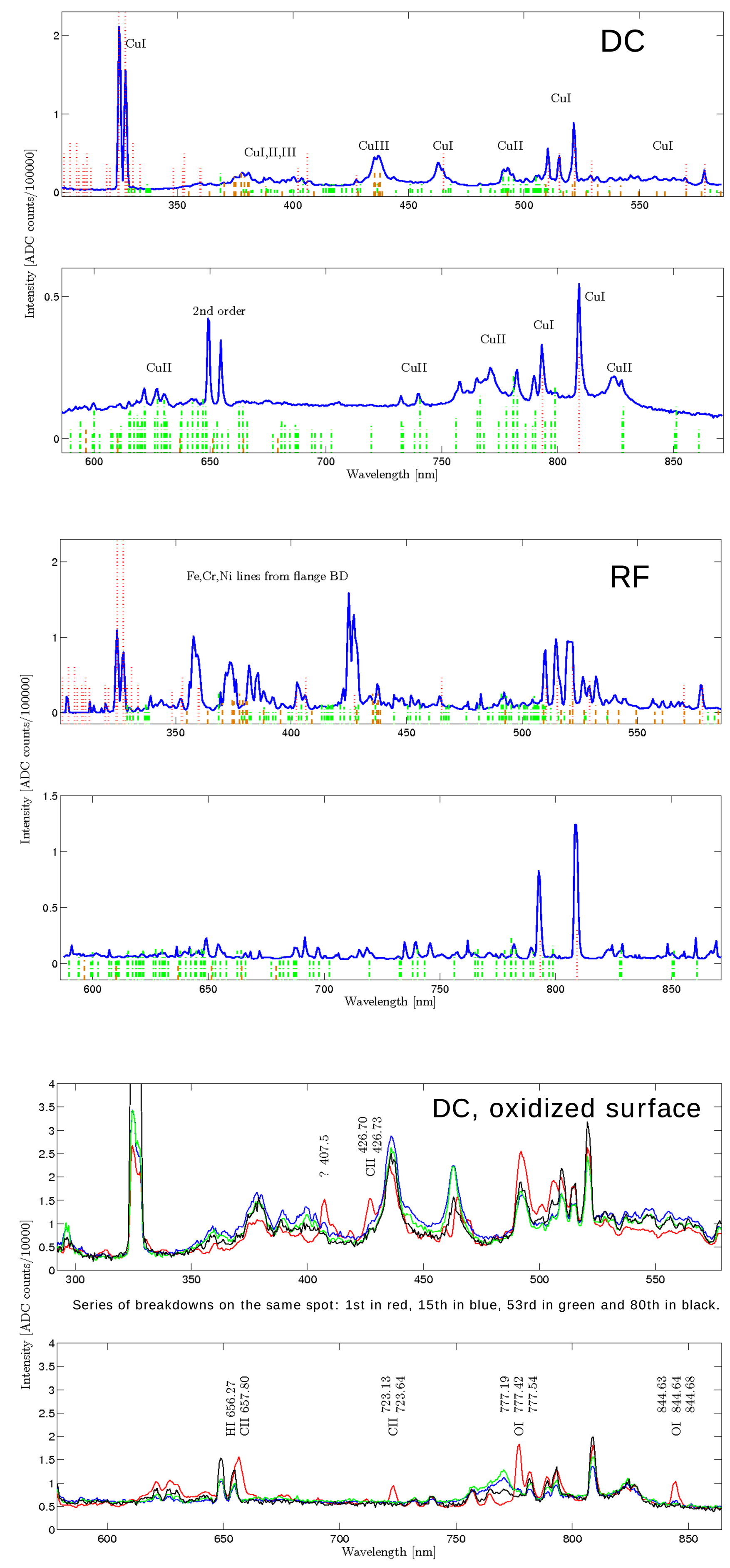
The OTR intensity is linearly proportional to the current and can be used to measure the field enhancement factor β of the field emitters on the surface at voltages which are not accessible to standard instrumentation.



Example of a β-fit using OTR light intensities.

Time-integrated spectroscopy

The light emitted by breakdowns in rf and dc has been analyzed: No elements other than the sample bulk material ions were found, either on conditioned nor on unconditioned samples except on artificially oxidized surfaces.

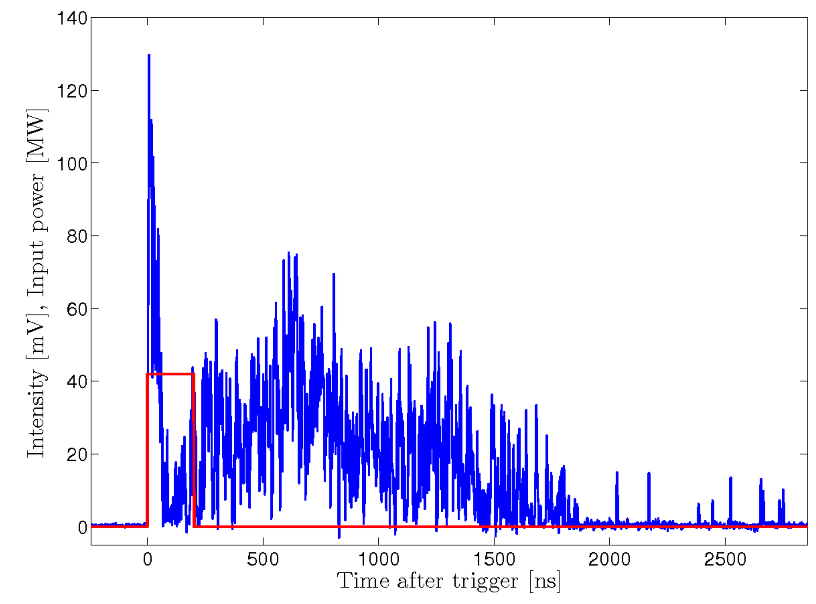


Breakdown spectrum in dc and rf on Cu. Removal of CuO layer (~ 150nm) due to conditioning.

Ionization levels up to CuIII have been observed while higher levels can not be observed with this setup. Temperature estimations showed a non-LTE plasma. The total emitted intensity consists of approximately 25% line intensity and 75% continuous background. In rf, the online spectroscopy could reveal a sparking vacuum flange during structure test. It is therefore proposed to be used as standard diagnostic for multi-material structure tests.

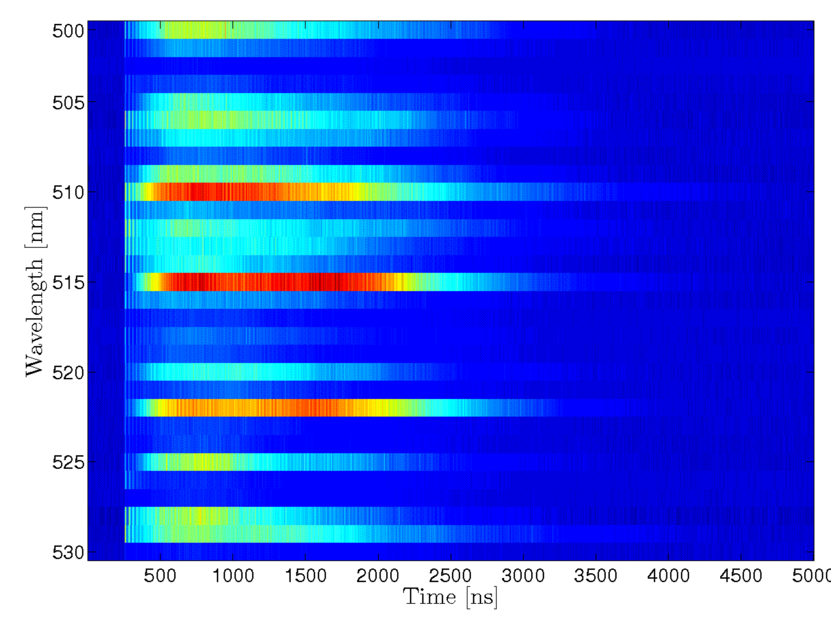
Time-resolved spectroscopy

Time-resolved spectroscopy of the total light emission showed a two-peak structure and a total emission length of several µs both in dc and rf, much longer than the external power input lasts.



Total emitted light intensity (blue) and rf input power (red) of an rf breakdown, the first sharp peak can be attributed to strong OTR.

A wavelength scan of the continuous and line emission revealed longer emission times for the excited lines than for the continuum. This can be explained with an initially high density plasma with heavy spectral broadening which then expands into the vacuum and therefore cools down, leaving recombination as the dominant emission process.



Time resolved wavelength interval of a dc breakdown on a Cu sample.

Conclusion

Dc and rf breakdowns are similar in their optical emission spectra and the corresponding time structure, implying that the underlying physics is the same. No evidence was found for non-sample materials playing important role in the breakdown process. Nevertheless, the optical spectroscopy showed to be a fast analysis tool for failures in multi-material structures. The breakdown plasma is a non-LTE plasma with heavy broadening effects at the beginning. The OTR light observed during non-breakdown operation turned out to be a useful tool for field enhancement factor measurements close to the breakdown limit.

References

[1] A. Descoeudres, Y. Levinsen, S. Calatroni, M. Taborelli, and W. Wuensch. Investigation of the dc vacuum breakdown mechanism. *Phys. Rev. ST Accel. Beams, 12(9):092001, Sep 2009*

[2] S. Calatroni et. al.. The CERN dc spark setup. LC2010 poster session.