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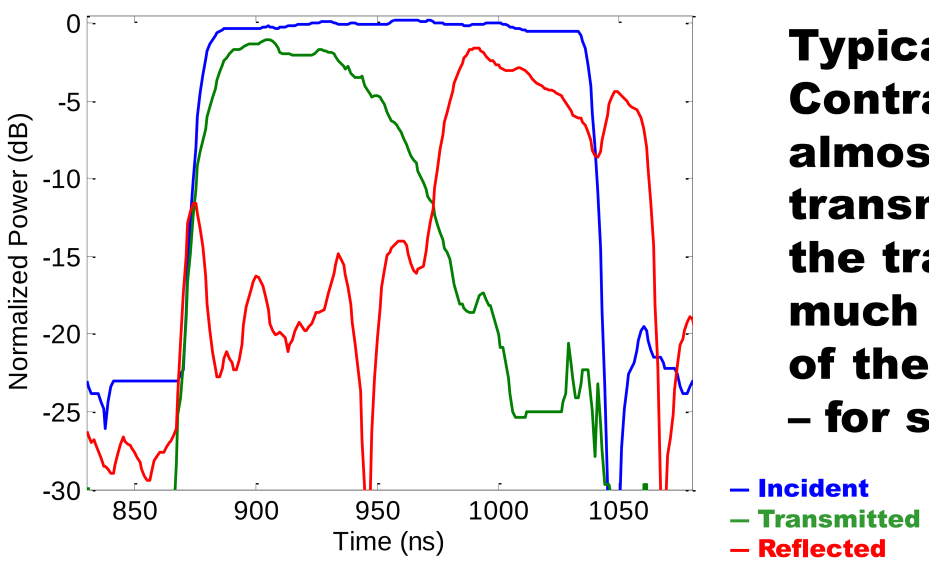
PLASMA INTIATION IN VACUUM ARCS – Part 2: Measuring

BREAKDOWNS IN RF CAVITIES

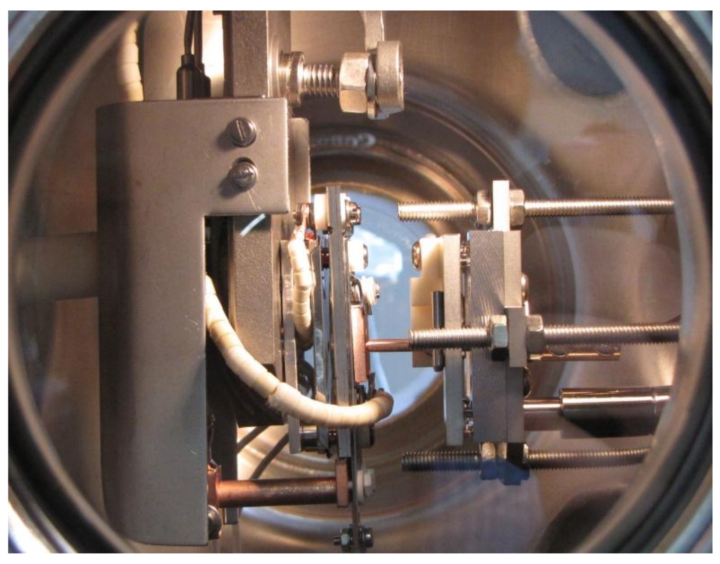
Vacuum arcs can be detected in different ways in the high-gradient RF accelerating cavities: **(i)** through the RF signal, **(ii)** via Faraday-cup measurements of electrons and ions, **(iii)** by detecting the light emission of the arc via spectroscopy, etc. Locating the discharge is possible as well.



Typical RF signal of a breakdown. Contrary to usual operation, when almost all incident power is transmitted, due to the breakdown, the transmission is obstructed and much of the power is reflected. Some of the overall energy might be 'missing' – for so far unknown reasons.

DEDICATED DC TESTING

Several DC devices have been developed at CERN, KEK, and the Uppsala University to investigate vacuum arcs. The two DC setups at CERN allow us to measure e.g. the breakdown properties of different materials. With some setups, *in situ* SEM measurements can be done, too.

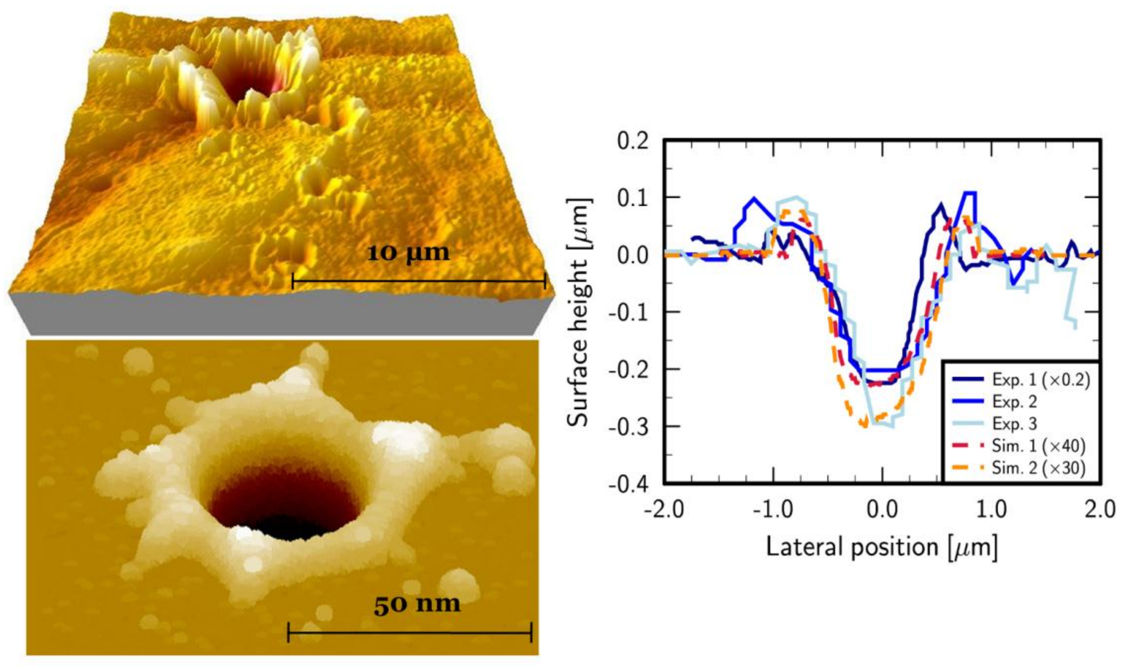


With our upgraded DC setup, we can heat or cool samples in the temperature range of ~ 80 – 1200 K. A repetition rate of up to 1 kHz allows to test BDRs down to 10^{-7}.

Soon we will also be able to determine the current-voltage curves of vacuum arcs during the early phase of plasma initiation.

CRATER STUDIES

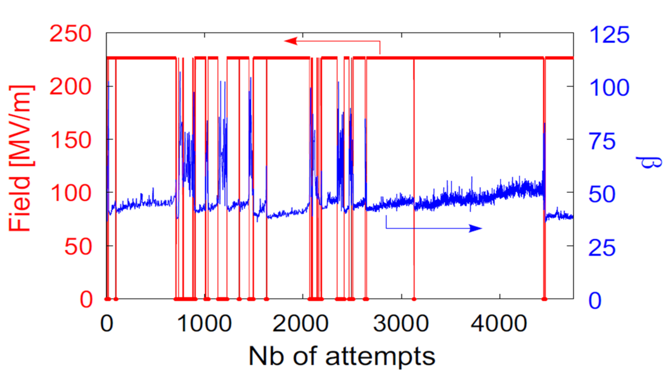
There are several ways to benchmark our theory with measurements. Perhaps the most direct link can be found for the surface damage. We compared molecular dynamics simulations of the crater formation due to plasma impact [5] to experimental results.



Measured (upper left) and simulated (lower left) arc craters. Although simulations are limited to smaller scales, the crater depth-to-width ratio (right) is universal in the investigated range.

ARE BREAKDOWNS DETERMINISTIC?

Parallel breakdown rate and field enhancement factor measurements with the DC setup indicate that Cu breakdowns might occur deterministically when the local electric field of ~10 GV/m is exceeded [7]. Hence, the experimentally and the theoretically found plasma build-up criteria confirm each other.



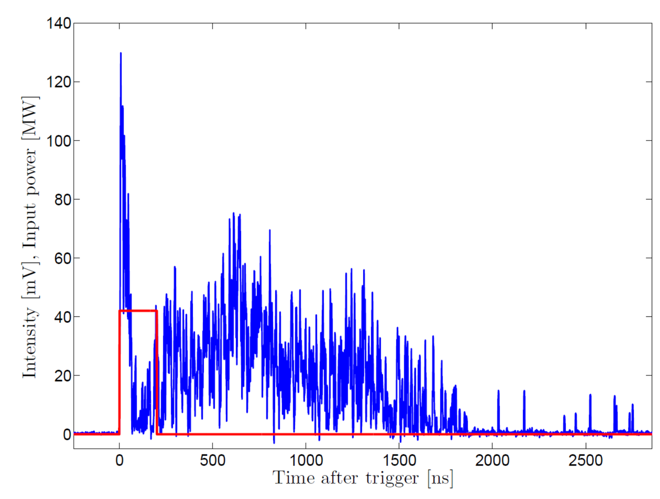
Measurements with Cu suggest that the field enhancement factor grows until a threshold local field is reached and an arc forms.

TIME-TO-BREAKDOWN

RF cavity tests have shown that short pulses are not likely to produce breakdowns in RF. Most of the breakdowns were found to occur between 8 and 60 ns after the peak field [8], suggesting that the timescale of plasma initiation should be $\lesssim$ 10 ns. This is also consistent with cathode spot observations that estimate the lifetime of a field emitter to 1 – 10 ns [9]; which is the typical timescale used in our simulations.

VACUUM ARCS THAT 'ENLIGHTEN'

With optical spectroscopy, the light emission of the plasma can be observed in both DC and RF environments. The extraction of plasma temperature and density is non-trivial since the investigated discharges are transient and occur on a small length and timescale.



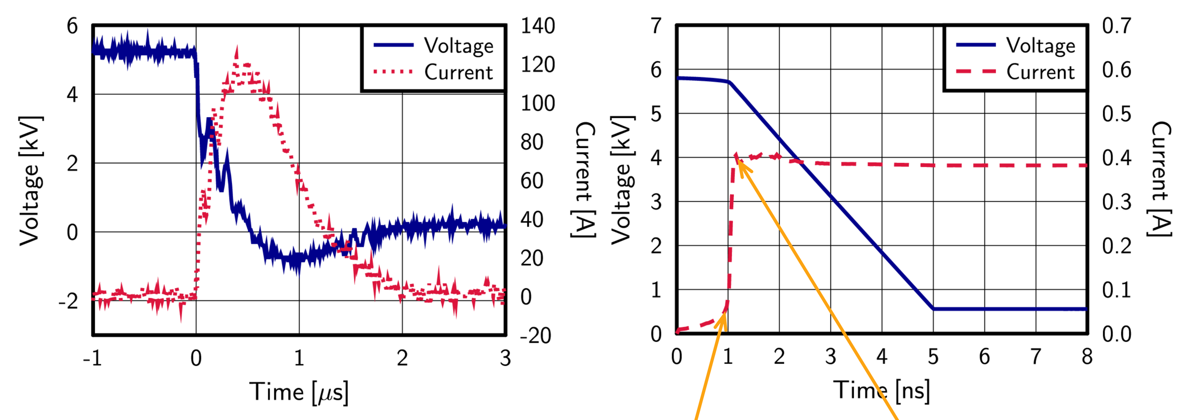
Time-resolved spectroscopy of breakdowns could reveal important details of the plasma build-up.

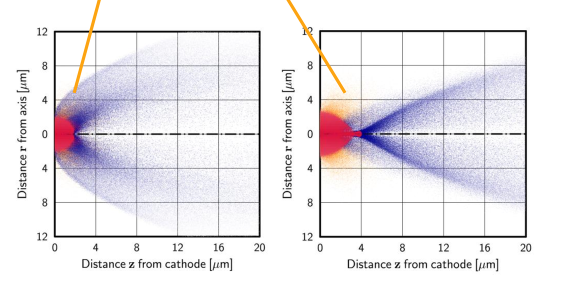
A figure from [6].

For some breakdowns, a high-intensity short-lived emission peak was observed; was it the plasma initiation that we witnessed?

RISE TIMES

Another direct comparison between theory and measurements can be made via current-voltage characteristics. In simulations, we implemented the electric circuit that is used in DC experiments to simulate the plasma response. However, an upgrade of the measurement system is required in order to resolve the first 10 ns of the arc.

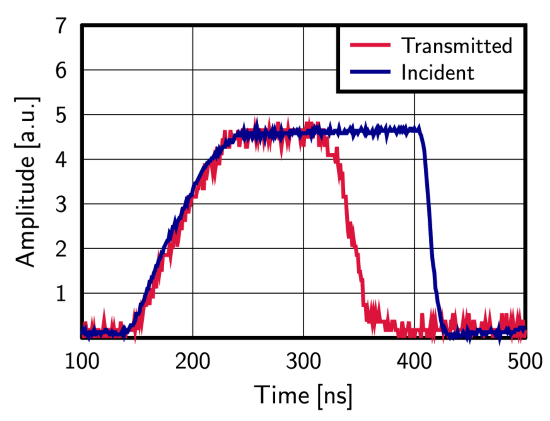




Measured (top left) and simulated (top right) current-voltage curves of DC vacuum arcs in Cu.

Simulations are limited to the plasma initiation phase. Higher-bandwidth measurements that can resolve the onset are now underway.

Interestingly, the rise times extracted from RF measurements and spectroscopy all point towards a plasma initiation of the order of 1-10 ns. Our simulations demonstrate that this is indeed feasible.



Latest measurements suggest rise times of less than 20 ns in CLIC RF structures.

T. Higo (2012)

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