Resistivity Measurement of Metal Surfaces to Track Down Dislocations Caused by Surface Conditioning

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Introduction

Surface Conditioning:

- If the surface of two electrodes are conditioned (high electrical fields are applied repeatedly on the electrode surface), the resistance to electric breakdowns increases.
- The acceptable electrical field can be increased by 4 to 5 times. After this limit, more conditioning does not help.

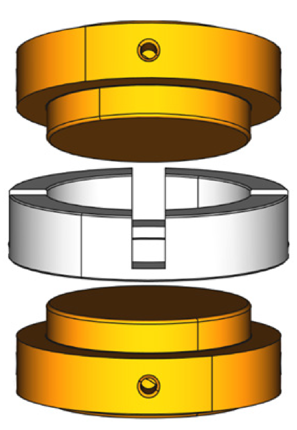
Possible explanation:

- High electrical fields create stress inside the electrodes
- The mobile dislocations just underneath the surface move to the surface
- Once they reach the surface, they create sharp features, which amplify the local electrical field → more breakdowns
- The breakdowns create more dislocation, which interfere with each other's movement and the probability for each dislocation to reach the surface decreases
- Because there is always a small probability for one of the many dislocations to reach the surface, there is a limit to how much the acceptable electric field can be increased [1]

As more dislocations are created, the surface resistivity should increase.

Our aim is to test this theory by measuring the surface resistivity of the electrodes during the conditioning process.

Cryogenic Experimental Set-Up



At temperatures of a few degrees Kelvin, the resistivity is given only by the scattering of the electrons off the lattice defects → **there is a huge benefit in making measurements at cryogenic temperatures!**

The measurement will be done at the cryogenic conditioning systems in Uppsala [2].

The set-up consists of two metal electrodes separated by an alumina spacer, with a distance between them of 60 μm, with variable temperature controlled down to few Kelvin.

The system will be **conditioned** using **DC voltages**, reaching field strengths of 150-200 MV/m.

The surface resistivity will be calculated from the quality factor of a resonating system containing the two electrodes.

The existing setup will be extended for the resistivity measurements with an **RF system inducing a resonating mode** to measure the quality factor.

The method

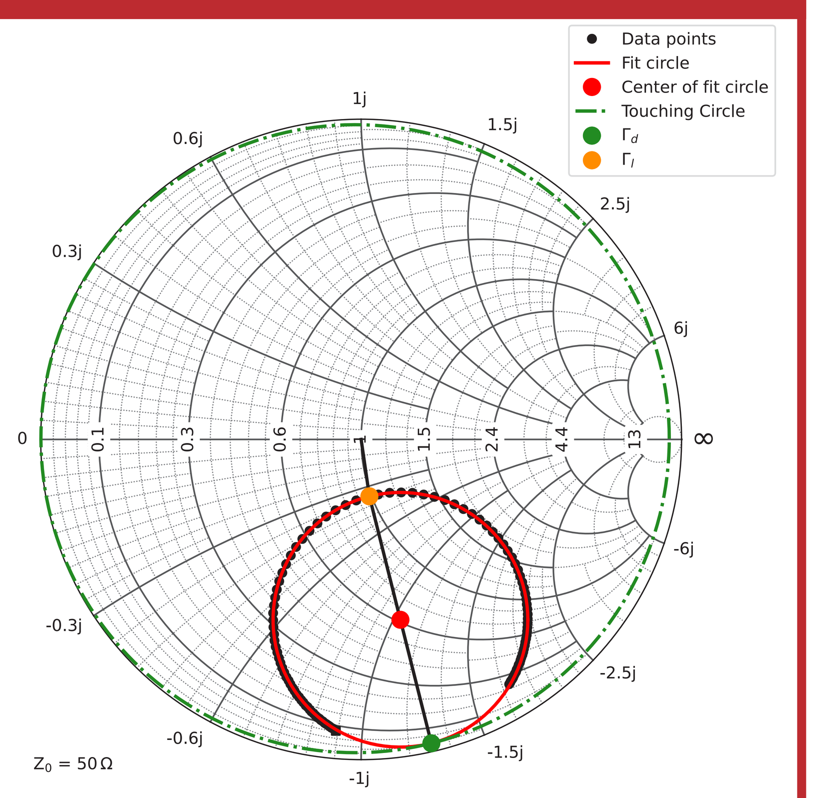
The **quality factor** is obtained by fitting vectorial data obtained from a vector network analyzer (VNA).

The VNA sends an RF signal in the cavity and measures the reflected signal

If the real and imaginary parts of the reflection coefficients for frequencies near the resonance frequency are plotted in the complex plane, we obtain a circle

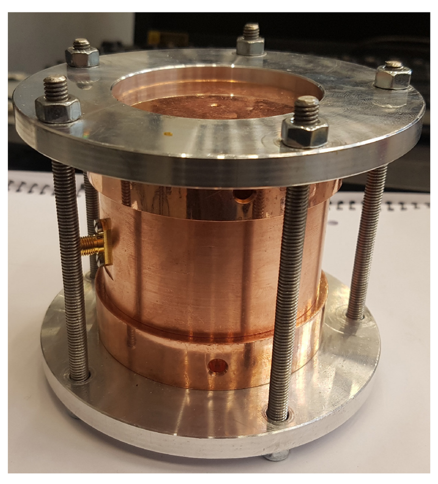
The diameter of the circle is related to the coupling factor Better coupling → Larger circle

To make the fit, a Python fitting routine, based on Kajfez's iterative algorithm, described in [3], was developed. The program takes into account the losses in the transmission line.



Testing the method

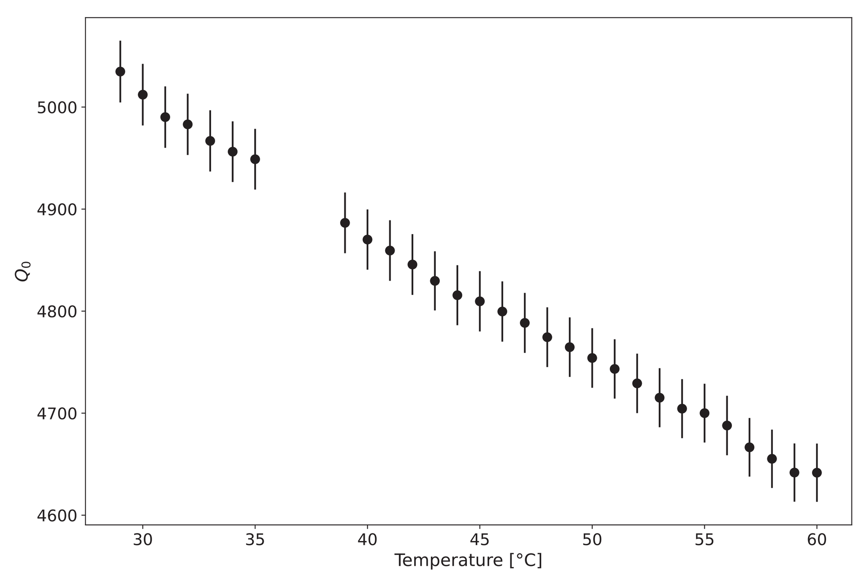
To test this method of measuring the surface resistivity of the electrodes, we have created a resonant system using the two electrodes and a copper cylinder → this system acts as a cylindrical cavity.

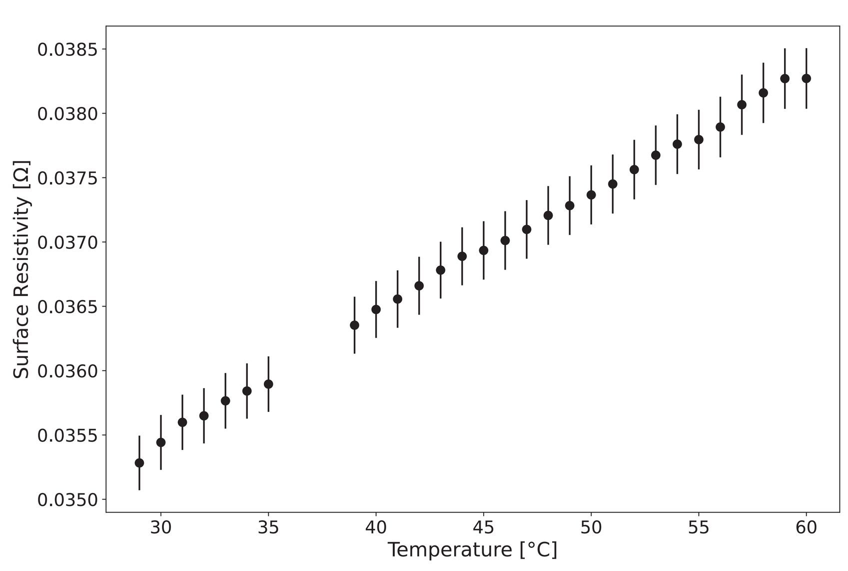


The quality factor depends on many other factors, such as the contact between the different parts of the cavity or the state of the surface → the **absolute value** of the surface resistivity **can't be reliably calculated**.

We showed that once the cavity is in a stable configuration, **it is possible to resolve small changes (0.3%)** in quality factor with high repeatability [4].

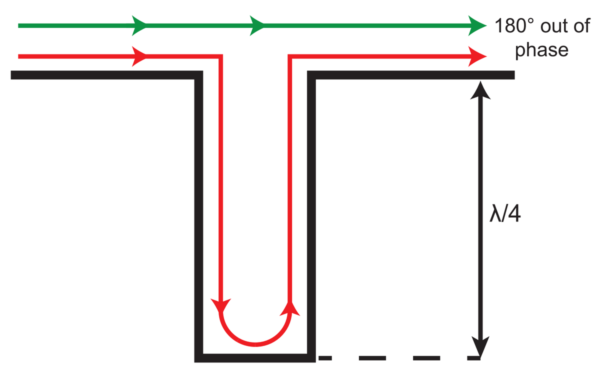
The observation of the relative changes in the resistivity would be a first proof of the formation of defects under the surface during conditioning.





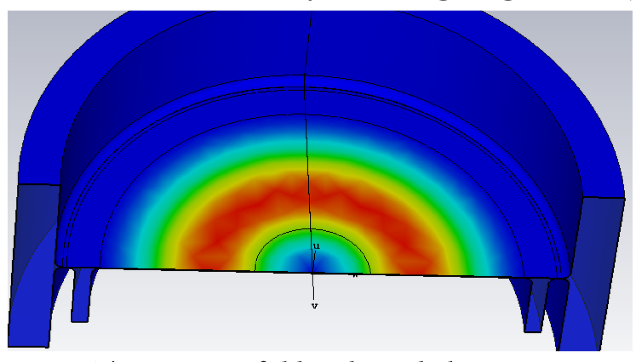
Simulations and Future Plans

The next step is to modify the electrode system in such a way that it forms a resonant system in order to make in-situ measurements.



The working proinciple of a choke

An idea proposed by J. Paszkiewicz and S. Calatroni is to modify the bottom electrode by making a groove (choke [5]) at the edge of the electrode that will contain the resonant modes between the electrodes without the need of a side wall.

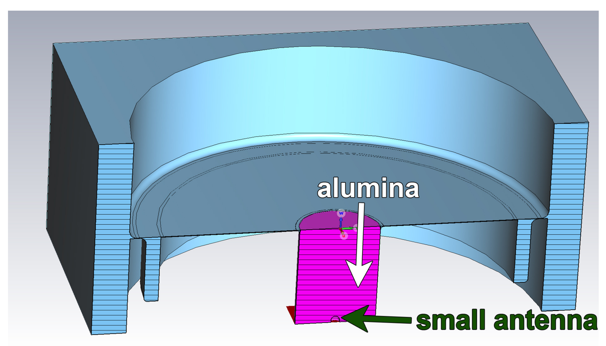


The magnetic field in the 1-choke cavity

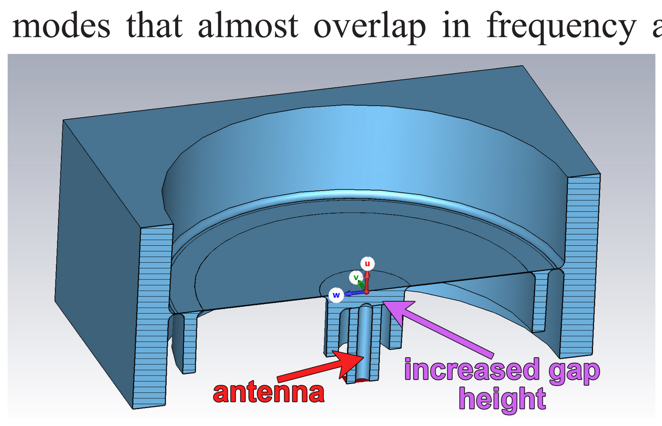
We have explored this possibility in multiple CST Microwave Studio simulations [6].

In order to couple to this mode, we need to introduce an antenna through an opening in the center. The tip of the antenna cannot be placed too close the surface of the top electrode because there will be electrical discharges through the antenna. But as the antenna is moved out, the coupling to the mode becomes weaker and weaker.

A possible solution is to fill the opening with alumina to create a cylindrical waveguide. This allows us to put the antenna far away from the top electrode. But, in this geometry, the simulations show two resonant modes that almost overlap in frequency and we cannot extract information about the quality factor for any of these modes.

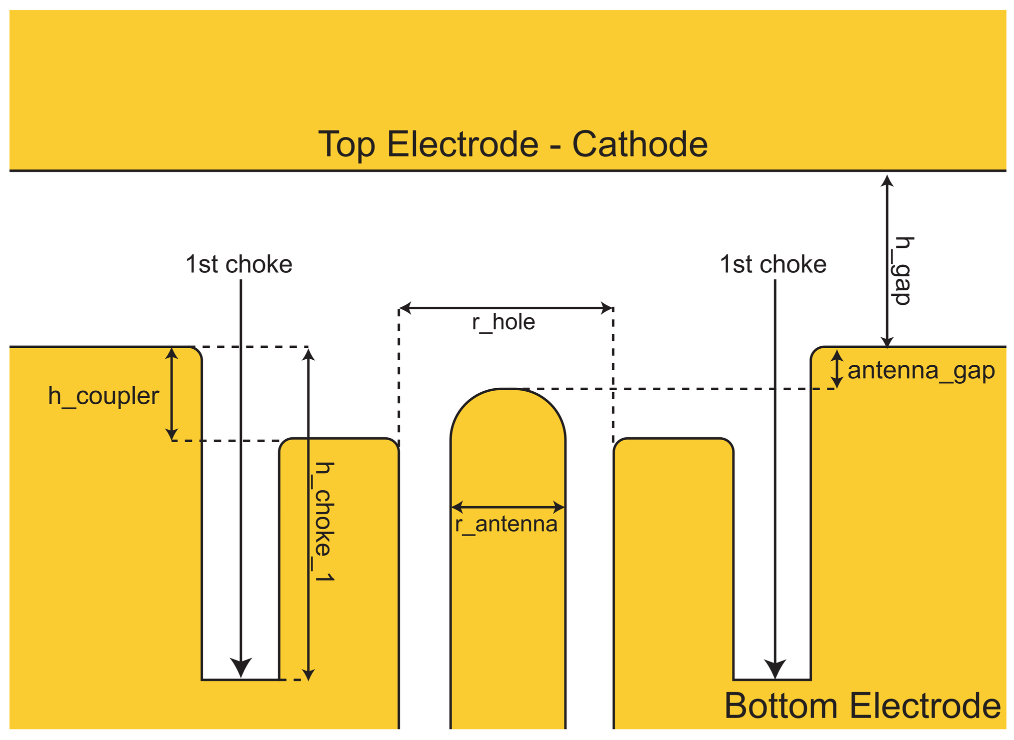


1-choke cavity with alumina waveguide

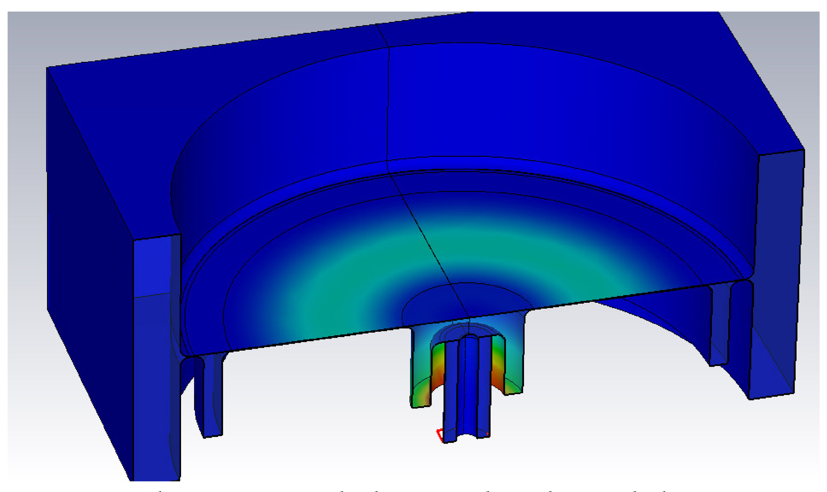


2-choke cavity with antenna

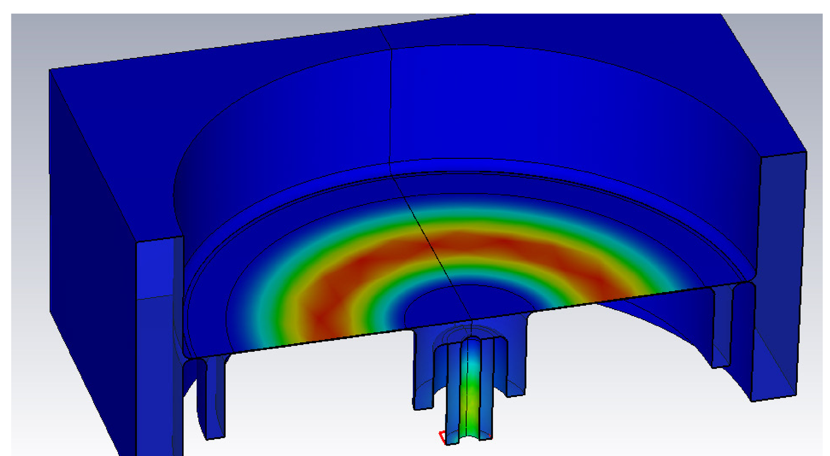
Another possible design is to use two chokes. The additional choke will block the mode from entering the opening through which the antenna is placed. The gap size will be increased in the center, such that the choke effect is spoiled slighlty and the signal can enter between the two chokes.



The parametrisation for the coupler of the 2-choke cavity

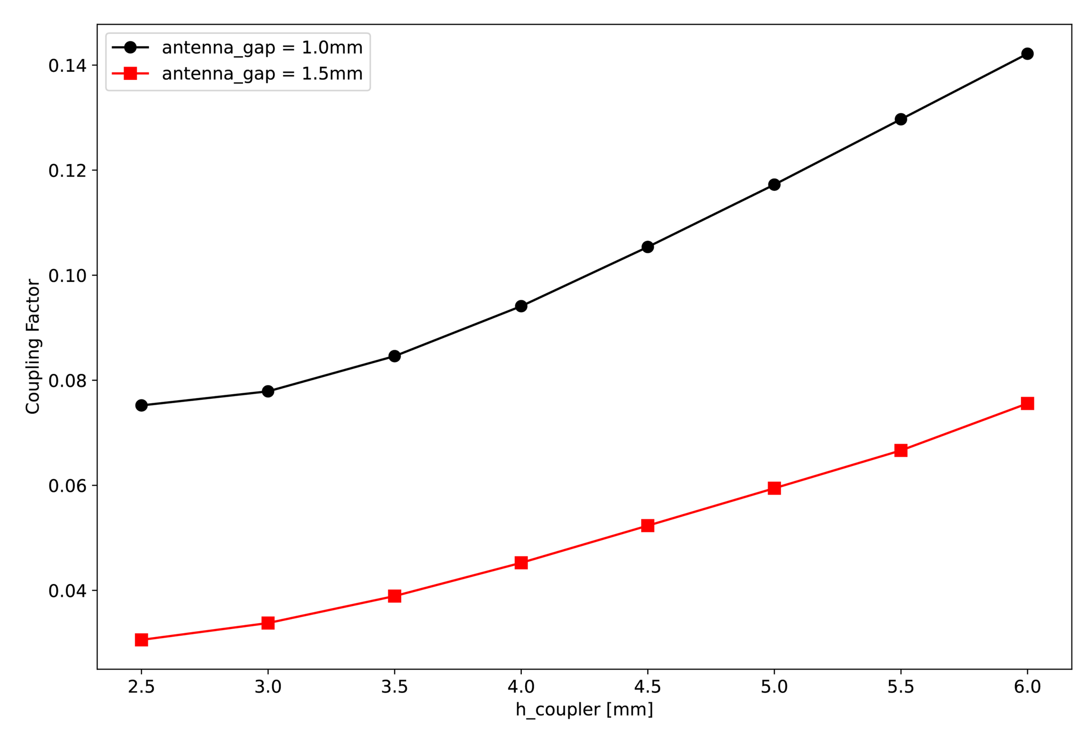


The parasitic mode that extends in the 1st choke



The resonant mode of interest

The same problem persists: the existence of two modes overlapping in frequency.



The parasitic mode can be shifted to higher frequencies by decreasing the depth of the 1st choke, from 10 mm, to 7 mm.

The next step is to improve the designs by trying to obtain better couplings and by finding better ways to remove the parasitic mode.

Using the improved design, we will be able to follow the changes in the surface resistivity of the modified electrodes during the conditioning, in cryogenic conditions, and thus test whether or not the dislocation hypothesis is true.

References

[1] E. Z. Engelberg, Y. Ashkenazy, and M. Assaf, "Stochastic model of breakdown nucleation under intense electric fields," Physical Review Letters 2018-mar 20 vol. 120 iss. 12, vol. 120, mar 2018.

[2] J. Eriksson, M. Jacewicz, and R. Ruber, "Cryosystem for dc spark experiments: Construction and acceptance tests," Uppsala University, FREIA, Tech. Rep.2019/02, 2019.

[3] D. Kajfez, "Random and systematic uncertainties of reflection-type Q-factor measurement with network analyzer," IEEE Transactions on Microwave Theory and Techniques, vol. 51, no. 2, pp. 512–519, 2003.

[4] Coman, M.-G., Feasibility Study of Resistivity Measurement of Metal Surfaces to Address Potential Dislocations Caused by Surface Conditioning. Dissertation, 2022. http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-479445

[5] T. U. Shintake, "The choke mode cavity," Japanese Journal of Applied Physics, vol. 31, no. Part 2, No. 11A, pp. L1567–L1570, nov 1992

[6] CST Studio Suite, "CST Microwave Studio," 2008. http:// www.cst.com