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Technical Report
Preventing Air Gap Breakdown
Rev -

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Discussion:
It is traditional for disk capacitors of bulk non-linear materials made from PZT, Barium Titanate, PMN-PT, etc. to have electrodes that stretch from edge-to-edge on both sides of the disk. As it turns out, Mother Nature designed non-linear materials so that air breaks down at just about the electric field necessary to saturate their hysteresis loops. The breakdown occurs through the air around the edge of the disk although it is also possible in some cases that surface conduction by the dielectric material between electrodes at the edge may contribute. In either case, a burn mark appears where the breakdown occurred and that burn mark most likely will cause the next breakdown to occur at that spot at a lower voltage. Thus, once a single air-gap breakdown has occurred around the edge of a disk capacitor, the sample cannot reach that voltage again.

Air actually has a high breakdown field. Helium has a lower breakdown field that easily demonstrates the air-gap breakdown effect. Below is the plot of an unpassivated bulk PZT disk capacitor having electrodes to the edge on both sides of the disk. The loop was acquired in air at room temperature. The sample just barely saturated at 1400 volts.

10 second Hysteresis Loop in Air

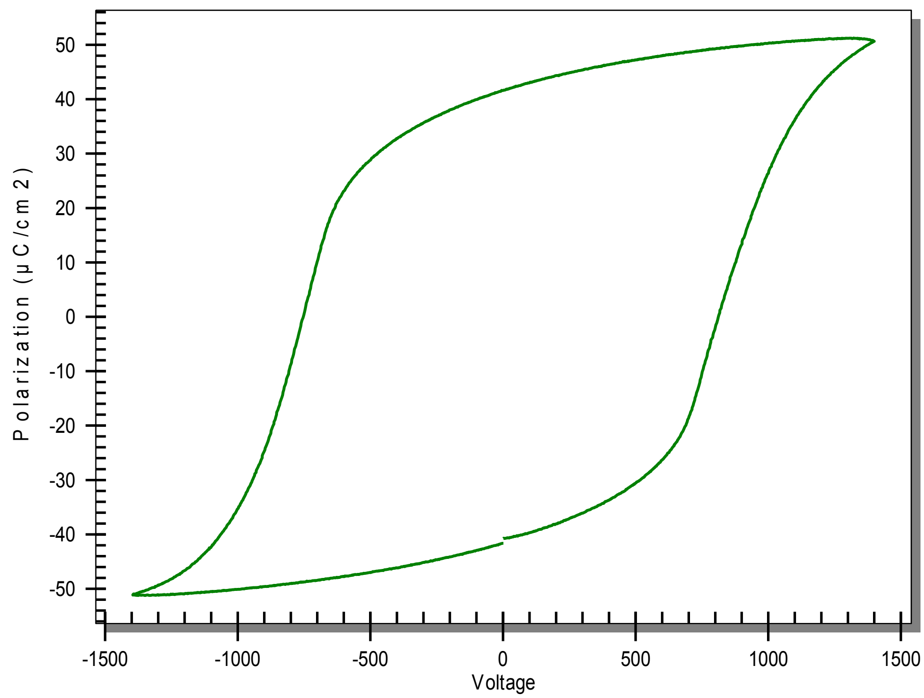

Figure 1

Figure 2 is the same sample under the same test conditions at 300 K and 800 Torr in helium. The temperature 300 K is essentially room temperature but 800 Torr is slightly above standard atmospheric pressure.

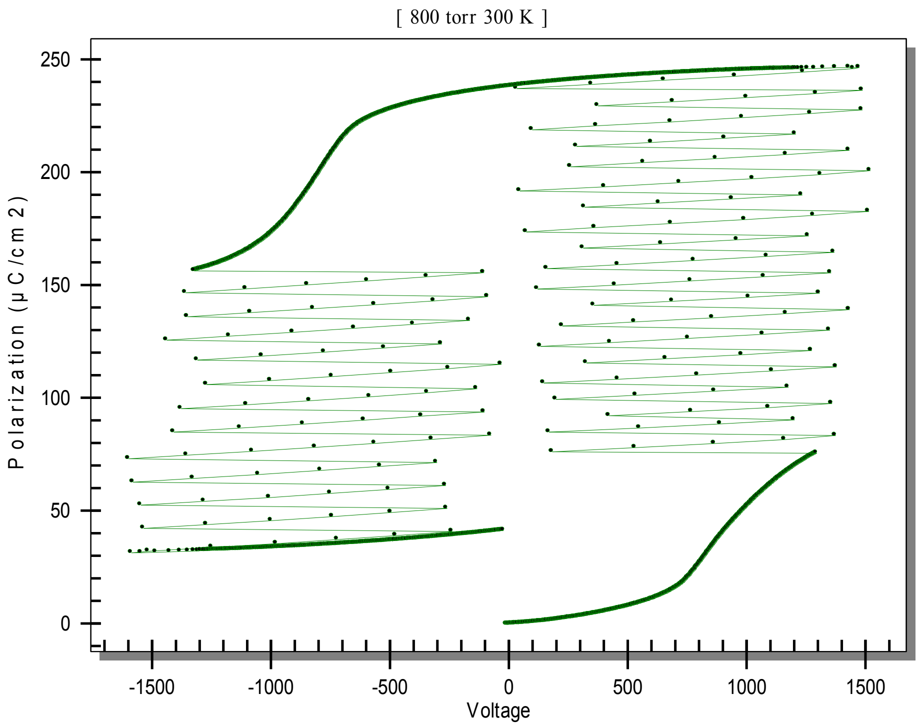

Figure 2

Multiple breakdowns occur during the test. The measurement points in the plot above show the temporal trend of the voltage. The zigzag pattern was produced by the high current flow of breakdown. Figure 3 plots the current versus time that created the hysteresis loop in Figure 2.

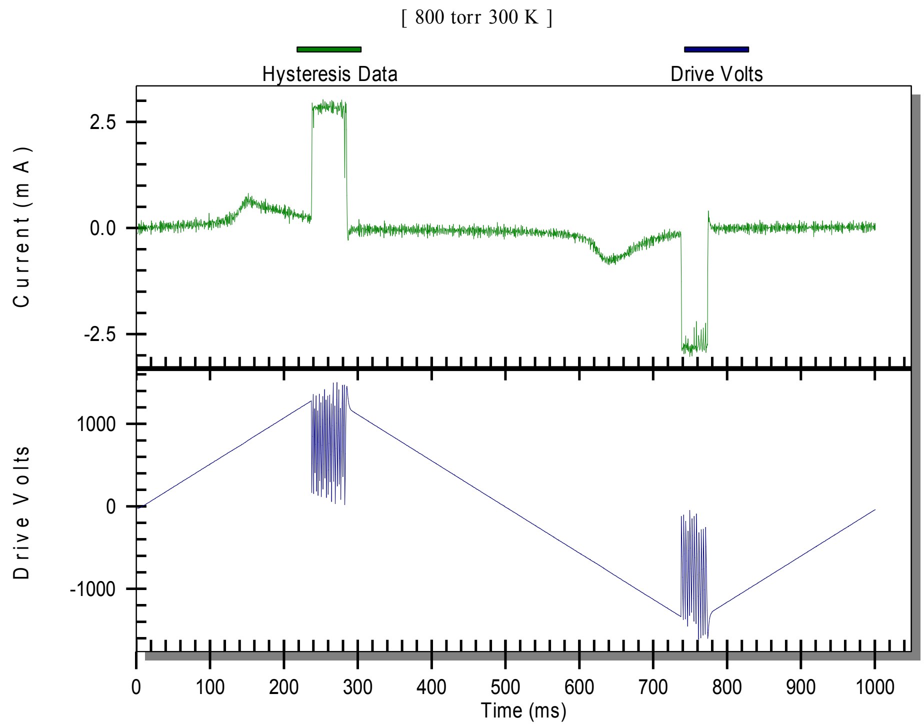

Figure 3

Of interest are those points where breakdown occurred. Each time breakdown started, the current surged to just above 2 mA. This is above the current limit for the high voltage amplifier (HVA) driving the sample. The HVA could not maintain its output voltage above that current. The amplifier's output voltage dropped when the breakdown began, stopping the breakdown. The HVA immediately began charging up to its assigned voltage. When the breakdown voltage was again reached by the HVA, the pattern repeated itself. This situation resulted in an oscillation until the triangle-wave stimulus started down and reached an assigned value below the air-gap breakdown voltage. Since Radiant testers record the voltage across the sample during a test, each breakdown and subsequent re-charge is visible in the plot. The sample itself showed no physical damage from the multiple breakdowns, indicating that these were air-gap breakdowns.

Submerging the sample in oil increases the breakdown voltage for the disk capacitor simply by replacing the air at the edge of the capacitor with the oil that has a higher breakdown field. Using oil is a messy business. It is also not possible to use oil in some test situations such as with elevated temperature. There is another technique for increasing the air-gap voltage above the highest intended test voltage: use asymmetrical electrodes on the disk capacitor.

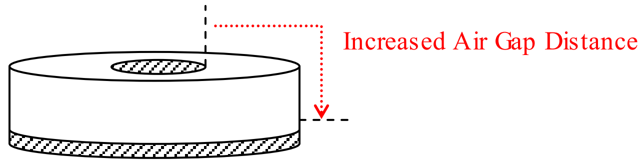

Figure 4

The increased distance between the edges of the two electrodes increases the voltage necessary to break down the air along the top surface of the disk and then around the edge of the disk.

> Recommendation: The sample electrode geometry should allow for voltages of at least **2 times higher** than the air-gap breakdown voltage for traditional disk capacitors at room temperature in air. A simple rule of thumb for air-gap breakdown is that it will occur at a voltage just above saturation voltage for the sample in air at room temperature. For tests in helium at lower temperatures, increase the air-gap-to-sample-thickness ratio to at least **five times** higher or maybe larger.

To achieve a *5 times* increase in air gap breakdown voltage, the geometry of the sample electrodes would have to be as below.

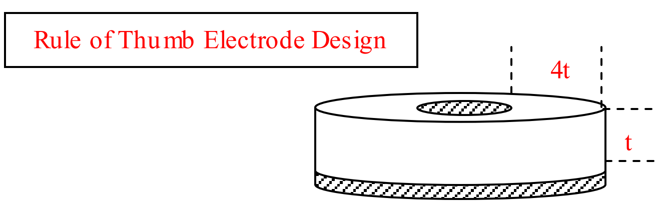

Figure 5