Coaxial Vacuum Gap Breakdown for Pulsed Power Liners

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P³ PULSED POWER PLASMAS GROUP

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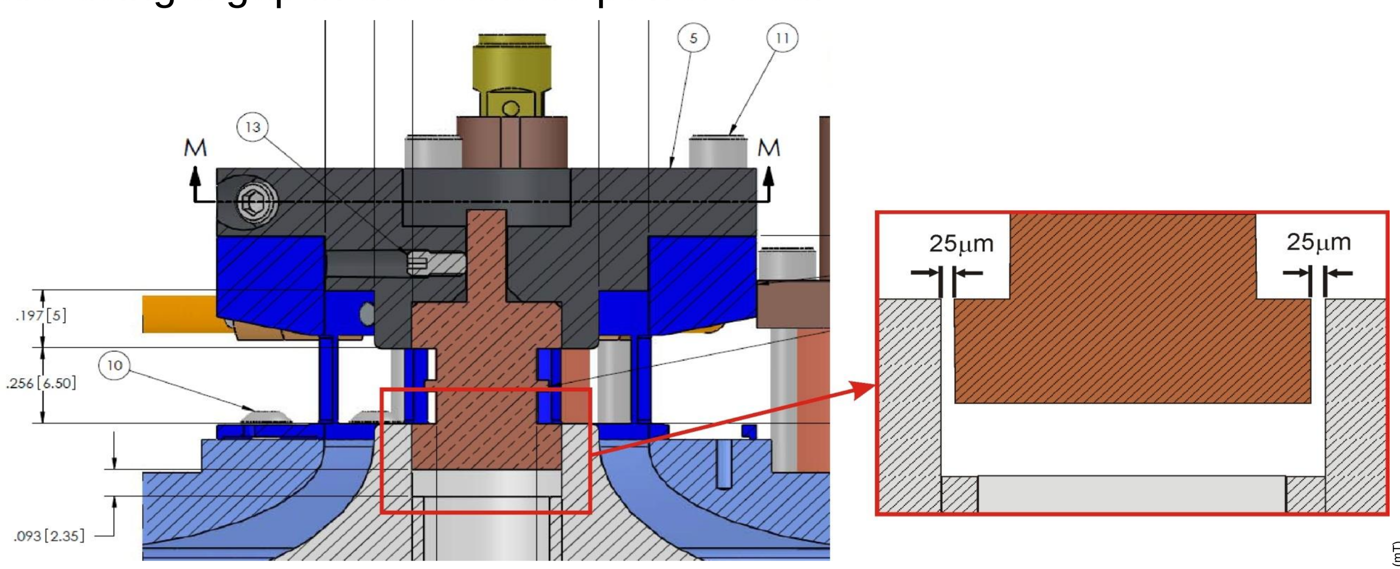
Introduction

This work is motivated by the need to better understand the mechanisms by which breakdown occurs in a coaxial gap over a few nanoseconds to a few microseconds at 10's of kV at gap sizes up to 1mm. We are specifically interested in the breakdown about the azimuth, and the influence such symmetry might have.

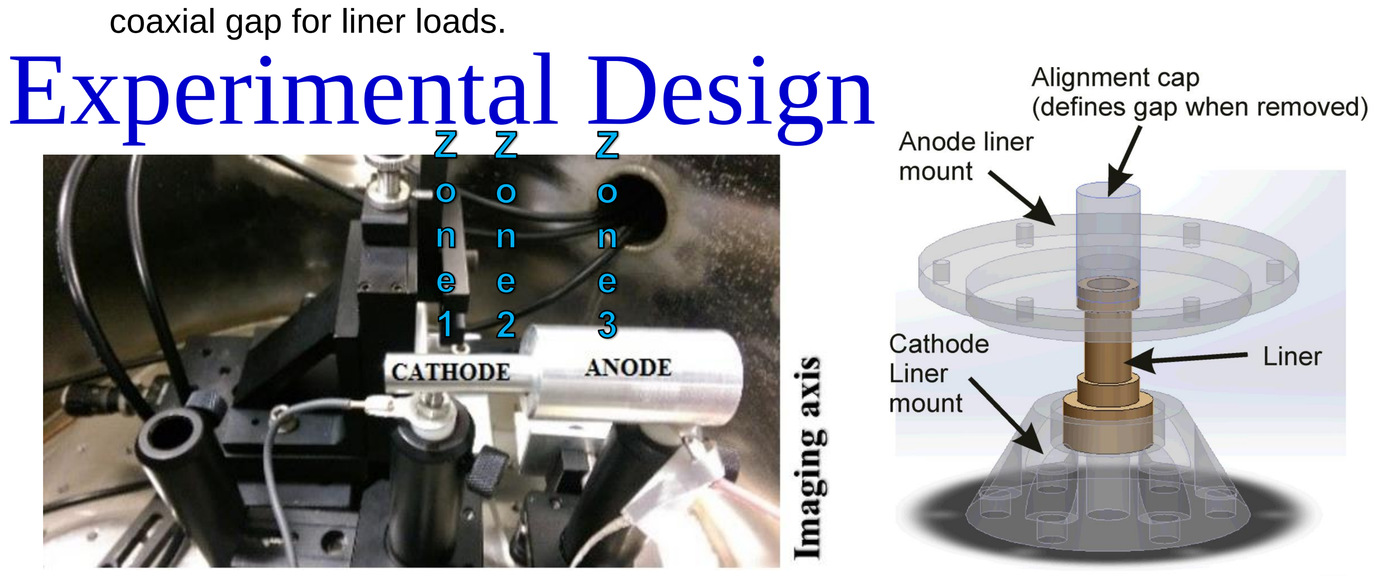
We are developing an experimental system to provide a means of analysis of the mechanism and influences of a coaxial gap.

Relevant to MagLIF (Magnetized Liner Inertial Fusion) experiments conducted on the Z-Machine (et all) at Sandia National Laboratory, Which are using a gap in the cathode power feed.



- Image of ~26 MA Z- Machine (Sandia National Laboratory), which uses the coaxial gap for liner loads.

Experimental Design



- Experimental parameters: UCSD; V ~25kV, 340 A,
- T_{rise}~100ns, p~10^{-5}Torr. Cornell; ~1.05 MA, T_{rise}~100ns p~10^{-5}Torr.
- Material : Aluminum, not highly polished.
- Cobra liner shots: 600 μm gap Al Liner- 400 μm Al Wire placed placed inside gap to force single azimuthal breakdown position.
- Gap current measured with Pearson coil model 6585 (1.5ns risetime)
- Time integrated axial imaging (DSLR)
- Axial gated optical emission views (10ns exposure)
- Magnetic field measurements (B-dot probes)

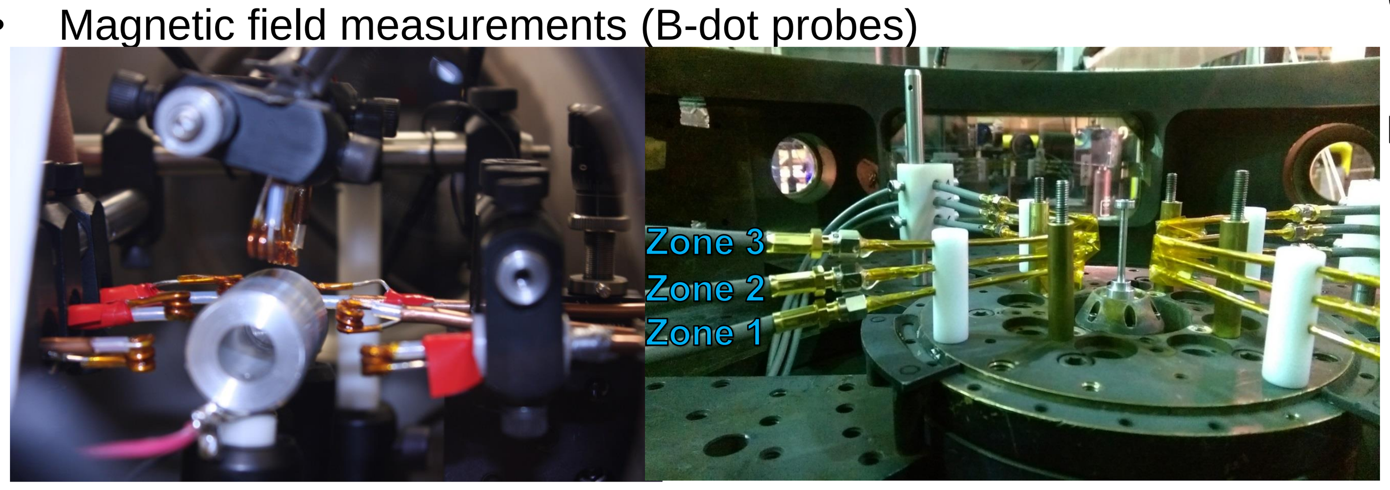


Figure 1 : Mounted B-dot probe positions

Breakdown triangulation:

Can use $R = \frac{\mu I}{2\pi B}$, for each peak B-field value to estimate the corresponding distance from break down. The R value corresponds to the distance the breakdown is from the probe (Figure 2). (Rev. Sci. Instrum. **86**, 073503 (2015))

- With the 3 calculated R values we are able to Triangulate the position the breakdown has occurred at. Which in this case occurs on the left side.

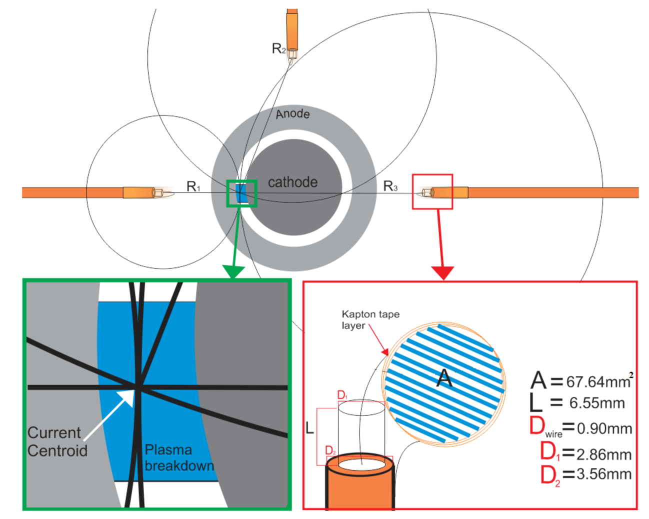
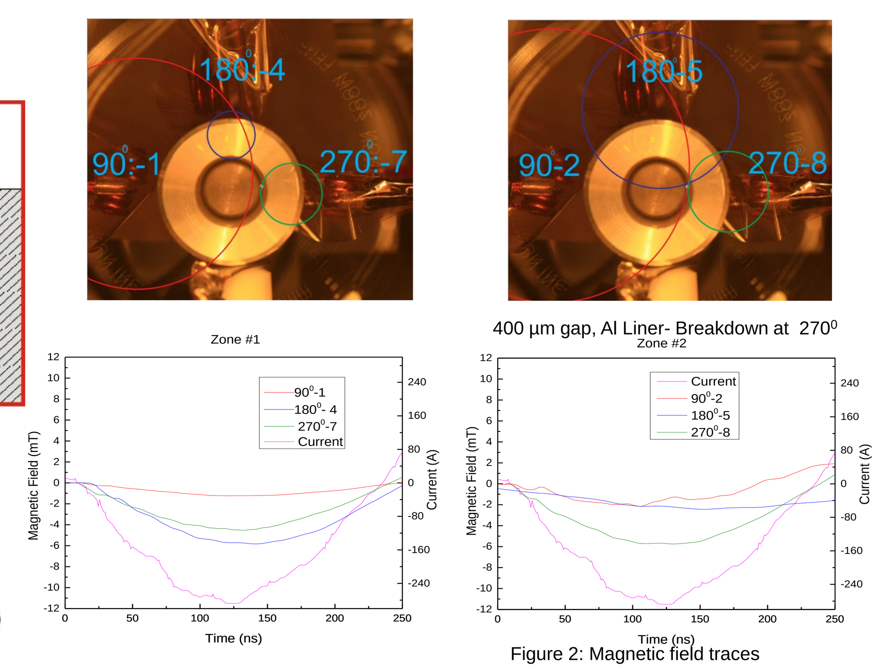


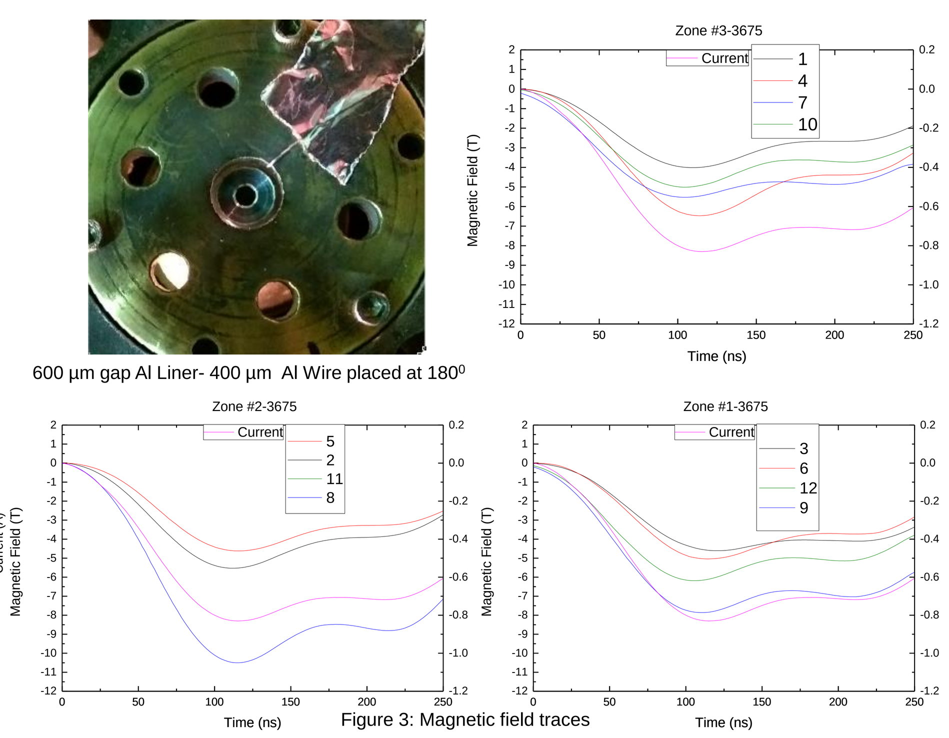
Figure 2 : Triangulation diagram

Experimental Results



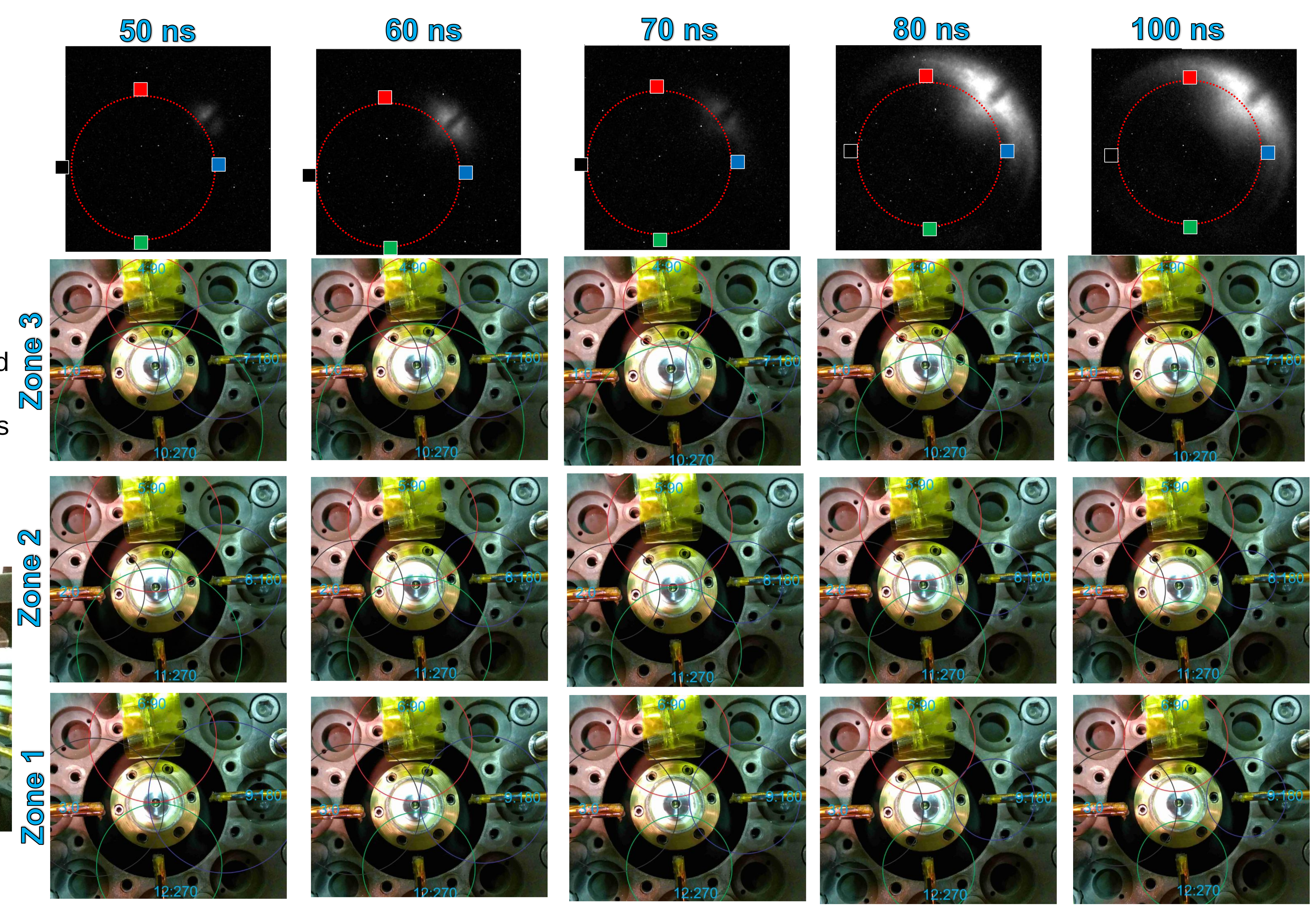
400 μm gap, Al Liner- Breakdown at 270⁰

Figure 2: Magnetic field traces



600 μm gap Al Liner- 400 μm Al Wire placed at 180⁰

Figure 3: Magnetic field traces



600 μm gap Al Liner- 400 μm Al Wire placed at 180⁰
Magnetic Feld Evolution Matrix

Experimental Summary

Coaxial:

- Random breakdown about the azimuth, when parallel.

B-dot Measurements:

- The largest magnetic field strength is measured on the probe(s) closest to where breakdown occurs (as seen in the integrated DSLR images compared to dB/dt signals).
- Able to accurately determine location of breakdown based on B-field strengths.
- Able to follow the evolution of the magnetic field.

Breakdown Mechanism

The power-feed gap is 25μm – 1000μm, and initially at vacuum (< 5x10^{-5} torr) and room temperature. The load voltage is applied cross this gap which causes electron and/or plasma emission, closing the gap and allowing the main drive current pulse to flow.

Two possible mechanisms by which such an initiation can occur:

Thermionic emission: estimated by the Dushman-Richardson formula.

$$j_T = A_0 D T^2 \exp\left(-\frac{e\varphi}{kT}\right) \qquad (\text{A}/cm^2)$$

- Since Liner and cathode are both initially at room temperature, contribution is negligible.
- Electrode skin depth (order of 100 μm for initial pulse, and 1mm subsequent pulse) coupled with the short pulse width (~70 μs) means temp change due to Ohmic heating is of order a few Kelvin.

Field emission is likely the dominant mechanism. As estimated by the Fowler-Nordheim formula.

$$j_F = 6.2x10^{-6}\frac{(\varepsilon_F/\varphi)^{1/2}E^2}{\varepsilon_F+\varphi}\exp\left(\frac{-6.85x10^7\varphi^{3/2}\zeta}{E}\right) \qquad (\text{A}/cm^2)$$

- Proportional to the work function of the metal surface and the applied electric field.
- Metal surface purposely not polished, results in field enhancement.
- Expect number of channel to be dependent on gap voltage (c.f. rail gap breakdown)

Improvements

- Increased spatial resolution in optical imaging to determine if multiple breakdowns are sequential or coincident
- Investigating various surface finishes and/or electrode materials.
- Investigating how magnetic field evolve time varies with electrode length

Future Work

- Implementation of electrode conditioning (~0.1 Hz).
- Further analysis of multiple breakdowns using the b-dot array.

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