Elucidating the Mechanism by Which Ball Plasmoids are Stabilized Using Emission Spectroscopy

Amber N. Rose,[1] Scott E. Dubowsky,[1] Nick Glumac,[2] Benjamin J. McCall[3]

[1] Department of Chemistry, University of Illinois at Urbana-Champaign
[2] Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign
[3] Departments of Chemistry and Astronomy, University of Illinois at Urbana-Champaign

Introduction

Ball lightning is a unique, naturally-occurring atmospheric phenomenon associated with thunderstorms [1]. Although ball lightning has been known to exist since the Middle Ages, it still lacks a complete physical and chemical explanation regarding its formation and lifetime. Considered to be laboratory analogues of ball lightning, ball plasmoids are the result of water-based plasma discharges performed in air. They are produced by a high voltage, high current discharge above the surface of a weakly conductive electrolyte. Plasmoids have a definite spherical shape and are not constricted to a power source, as are regular plasmas. Based upon recombination rates expected for a plasma of this type, the plasmoids should dissipate in about a millisecond- but like ball lightning, they are observed to last for hundreds of milliseconds [2].

Instrument Setup

- High voltage, capacitive discharge system
- Electrode: tungsten rod (cathode) insulated with an alumina tube and a copper ring (anode) placed perpendicularly to cathode
- Setup contained in a 5-gallon bucket of weakly conductive electrolyte (deionized water, conductivity set using concentrated HCl)

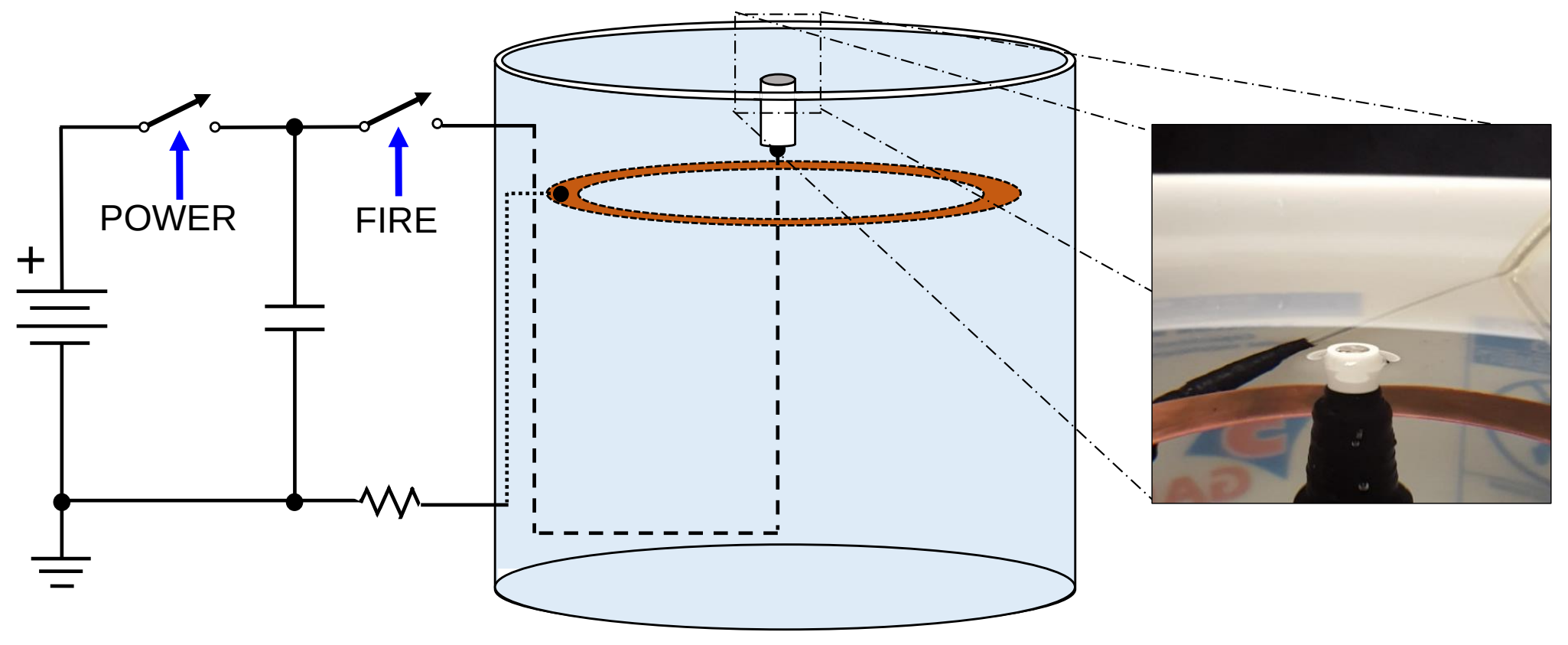


Figure 1. Simplified circuitry and electrode setup used to produce a plasmoid.

Variable Parameters:

- Capacitance (870 μF and 1700 μF)
- Voltage (5,000-8,000 V)
- Height above cathode (0, 10, 20, 30, 40 cm)

Ball Plasmoid Overview

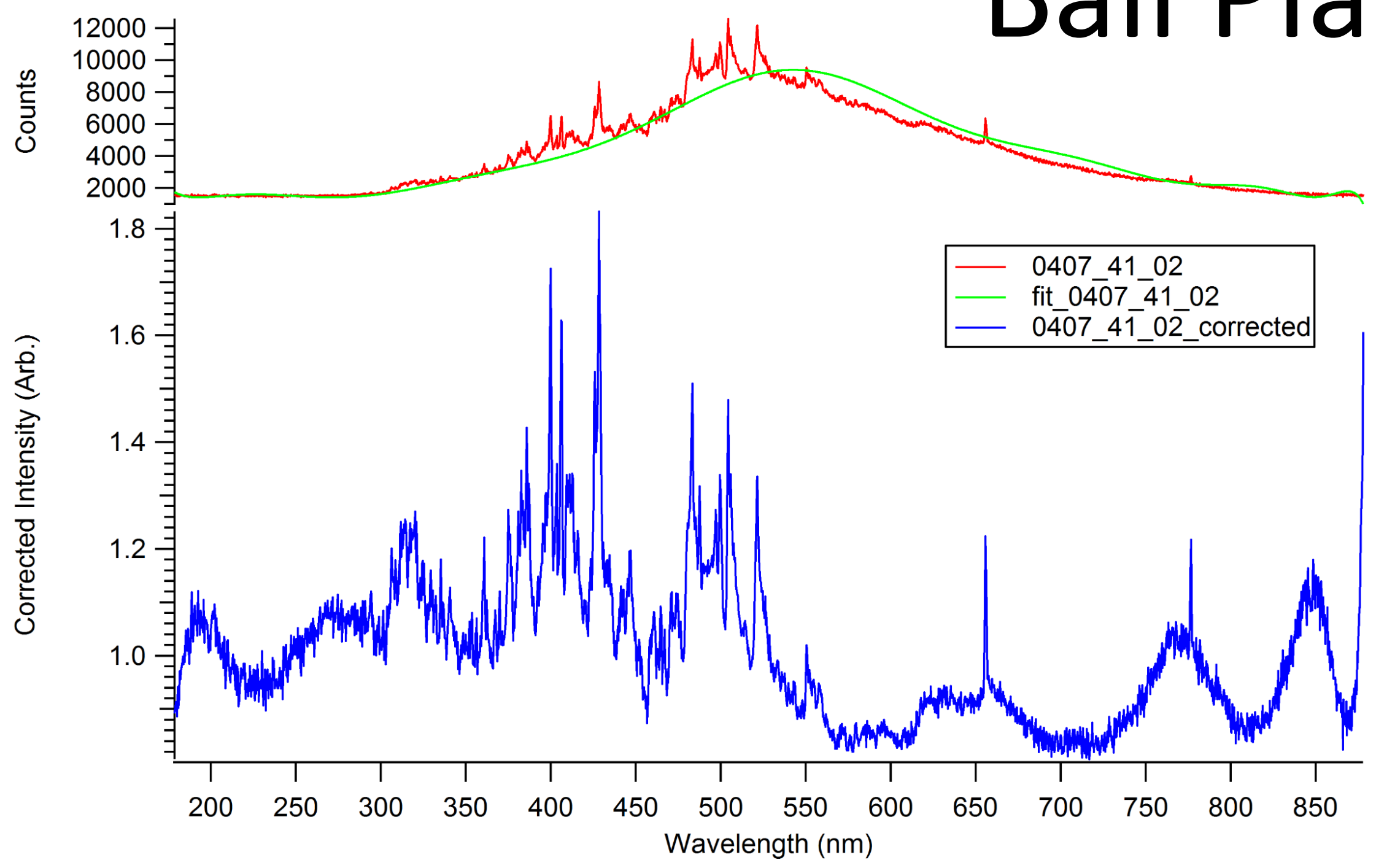
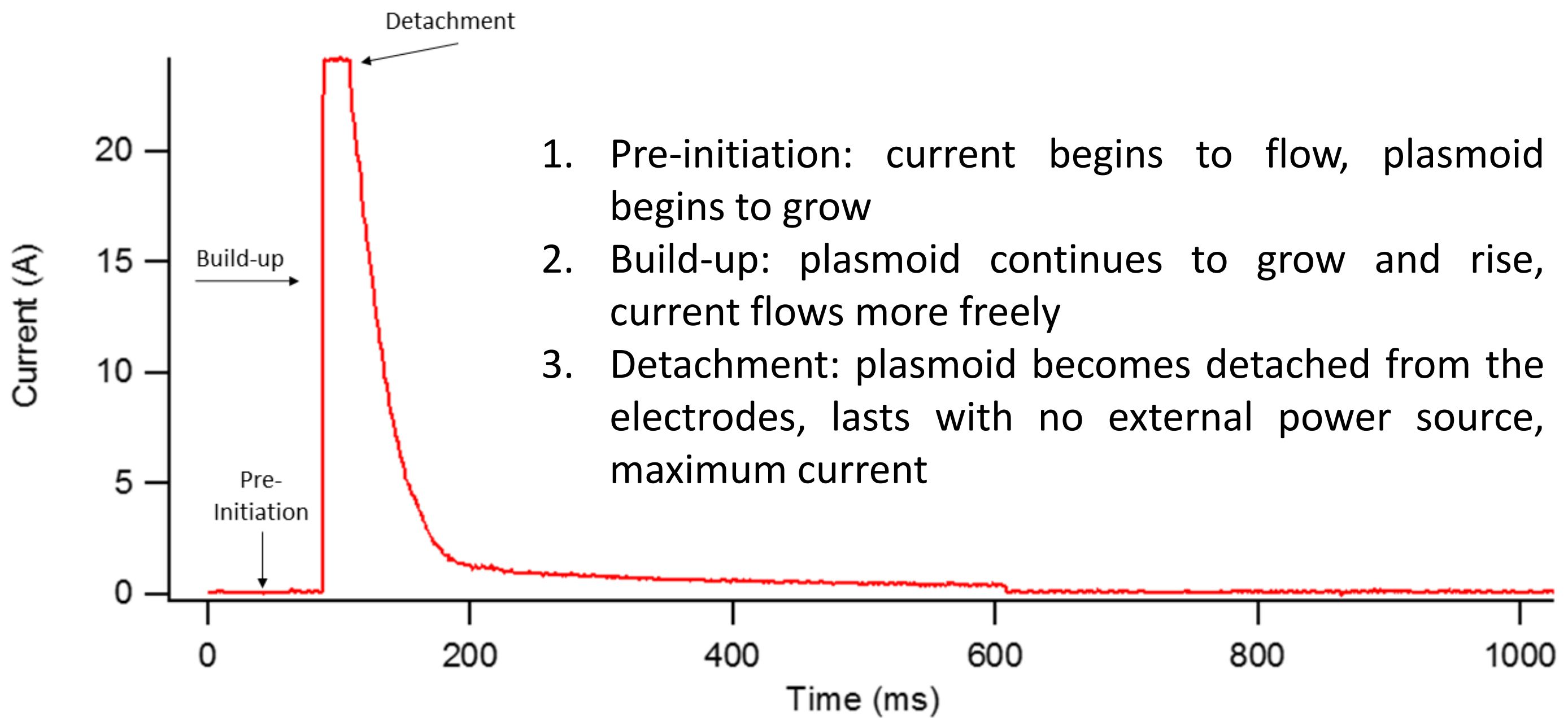


Figure 2. A characteristic emission spectrum (red) of a plasmoid (8 kV, 300 μS) with a corrective fit (green) applied (blue).



1. Pre-initiation: current begins to flow, plasmoid begins to grow
2. Build-up: plasmoid continues to grow and rise, current flows more freely
3. Detachment: plasmoid becomes detached from the electrodes, lasts with no external power source, maximum current

Figure 3. A current profile of a plasmoid discharge shown in Figures 2 and 4. Phases of the discharge are labelled [3]. (Note: current sensor is saturated at detachment).

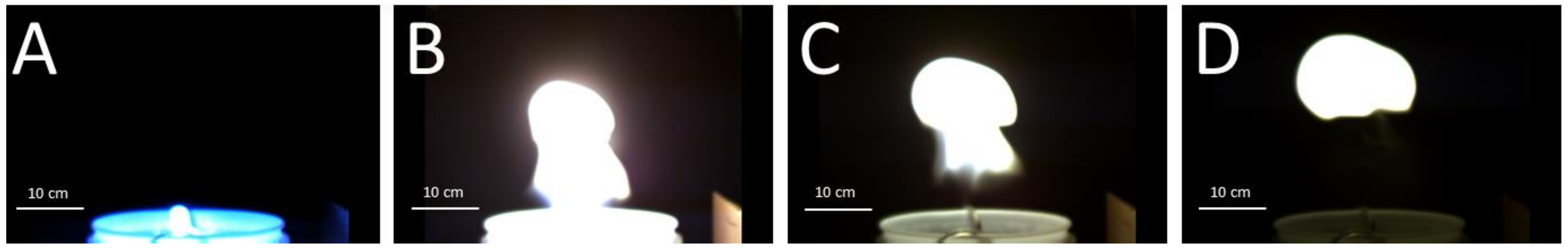


Figure 4. Images of the different phases of a plasmoid discharge (8 kV, 300 μS), obtained using a high speed camera (1 ms exposure time, 85.3 fps). [A] pre-initiation, [B,C] buildup, [D] detachment.

Emission Spectroscopy

Optical emission spectroscopy (OES) is a diagnostic technique that can be used for the identification of emitting species and determination of rotational temperatures. We performed OES using an Ocean Optics Jaz spectrometer. Using this technique, we have observed a much richer plasmoid chemistry than has previously been observed.

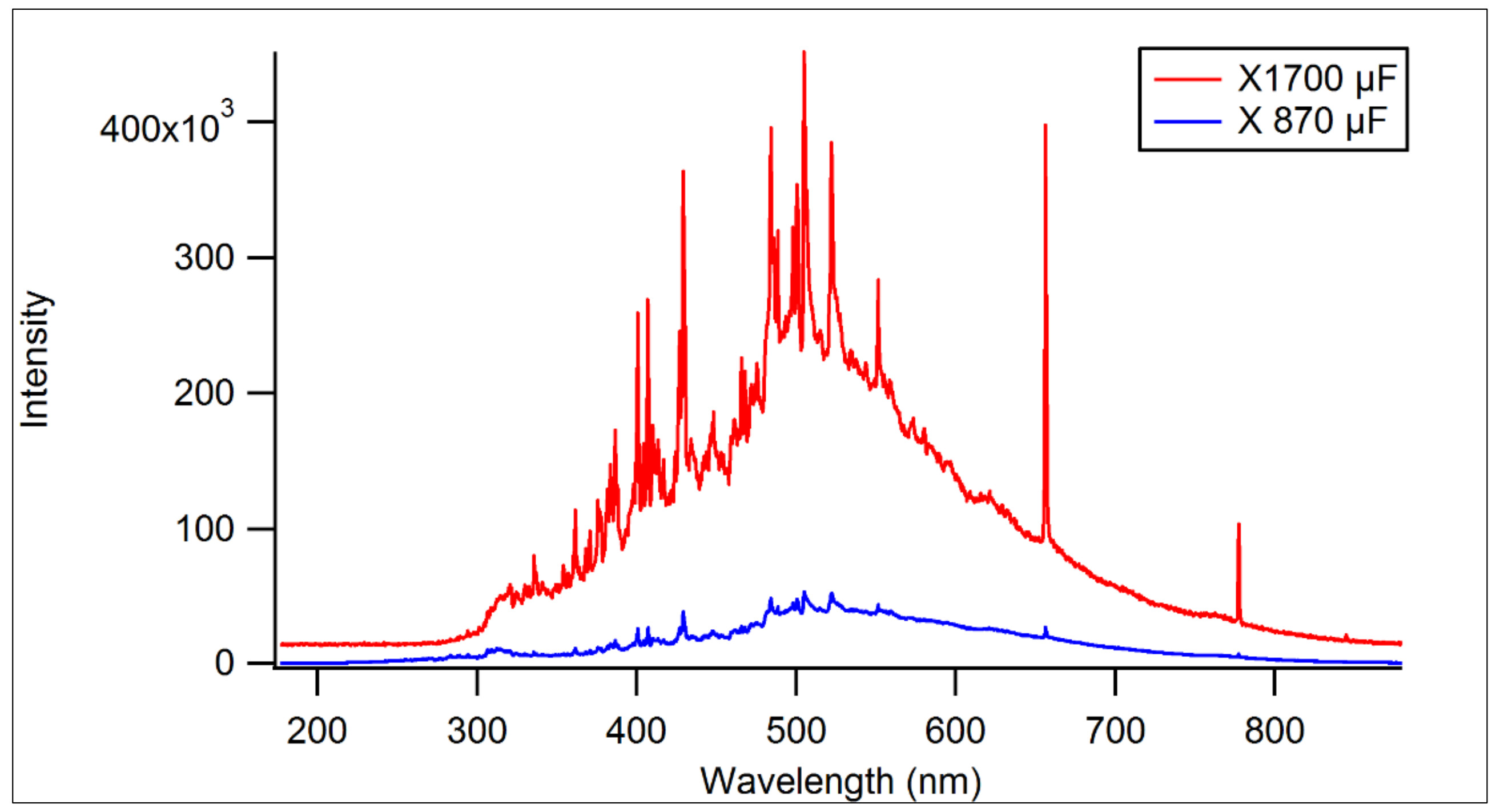


Figure 5. An example emission spectrum from a ball plasmoid discharge, comparing intensities at different capacitances (8 kV, 200 μS).

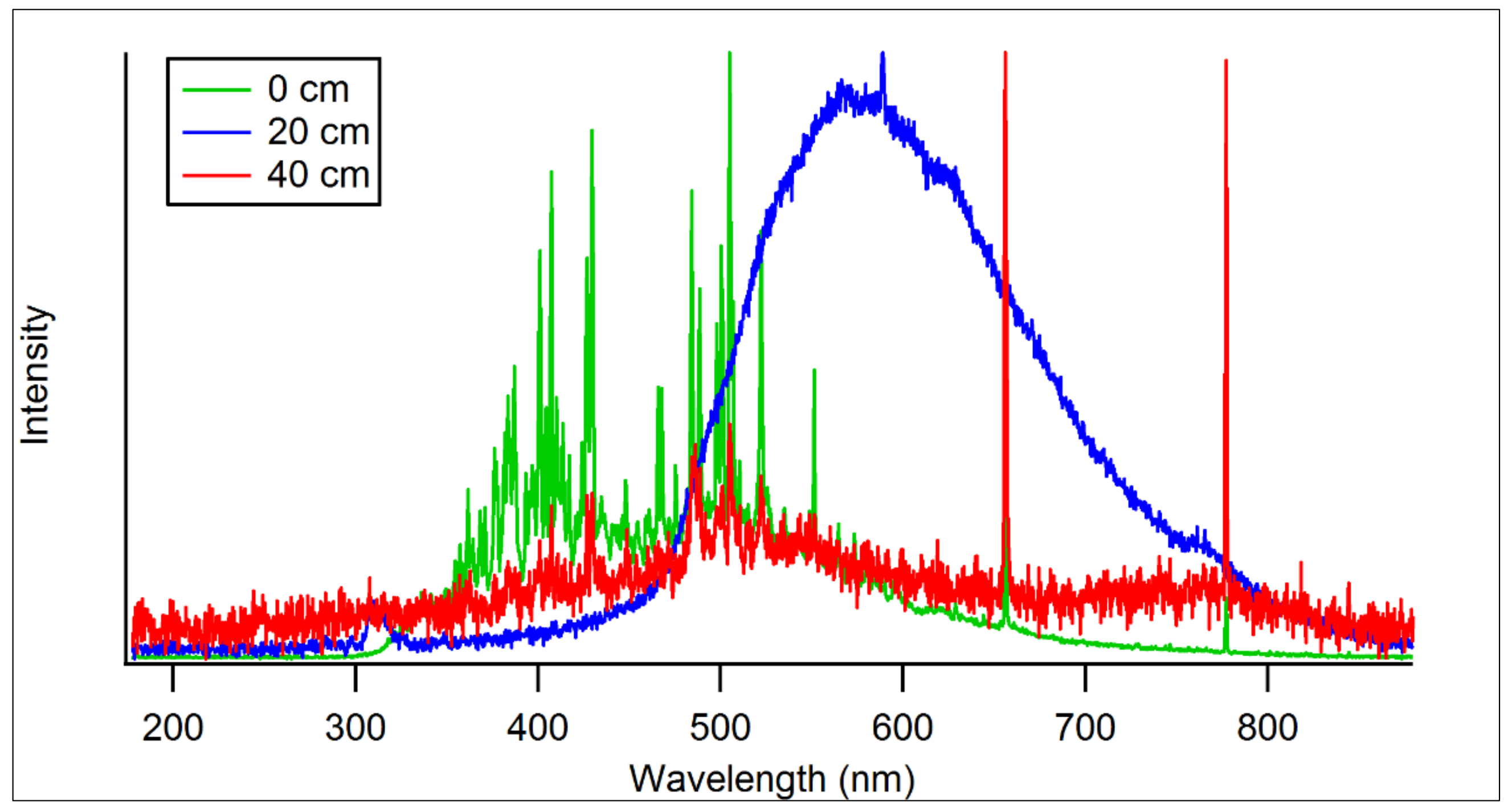


Figure 6. A series of spectra obtained at various heights above the cathode (7 kV, 300 μS) (note: the comparison is qualitative.

Results

Table 1. Rotational temperatures of various species across the lifetime of a plasmoid (7 kV, 300 μS, 870 μF).

Spectrum	OH [K]	NH [K]	AlO [K]
1	-	-	900 ± 200
2	7200 ± 900	4000 ± 800	600 ± 100
3	6400 ± 800	-	-
4	5100 ± 700	-	-
5	4900 ± 700	-	-

Dashes represent an unphysical fit or no emission from the species.

Table 2. Rotational temperatures of various species across the lifetime of a plasmoid (7 kV, 300 μS, 1700 μF).

Spectrum	OH [K]	NH [K]	AlO [K]
1	-	-	1000 ± 200
2	9000 ± 1000	300 ± 100	700 ± 100
3	7200 ± 900	3400 ± 800	1200 ± 200
4	6500 ± 800	-	-
5	5200 ± 700	-	-
6	5300 ± 800	-	-
7	-	-	-

Dashes represent an unphysical fit or no emission from the species.

Table 3. Atomic and molecular species that have been identified from plasmoid emission spectra.

	Species
Atomic	W (I), H_β, N (II), H_α
Molecular	OH (A-X), NH (A-X), N_2 (C-B), AlO (A-X), N_2 (B-A)

Future Directions

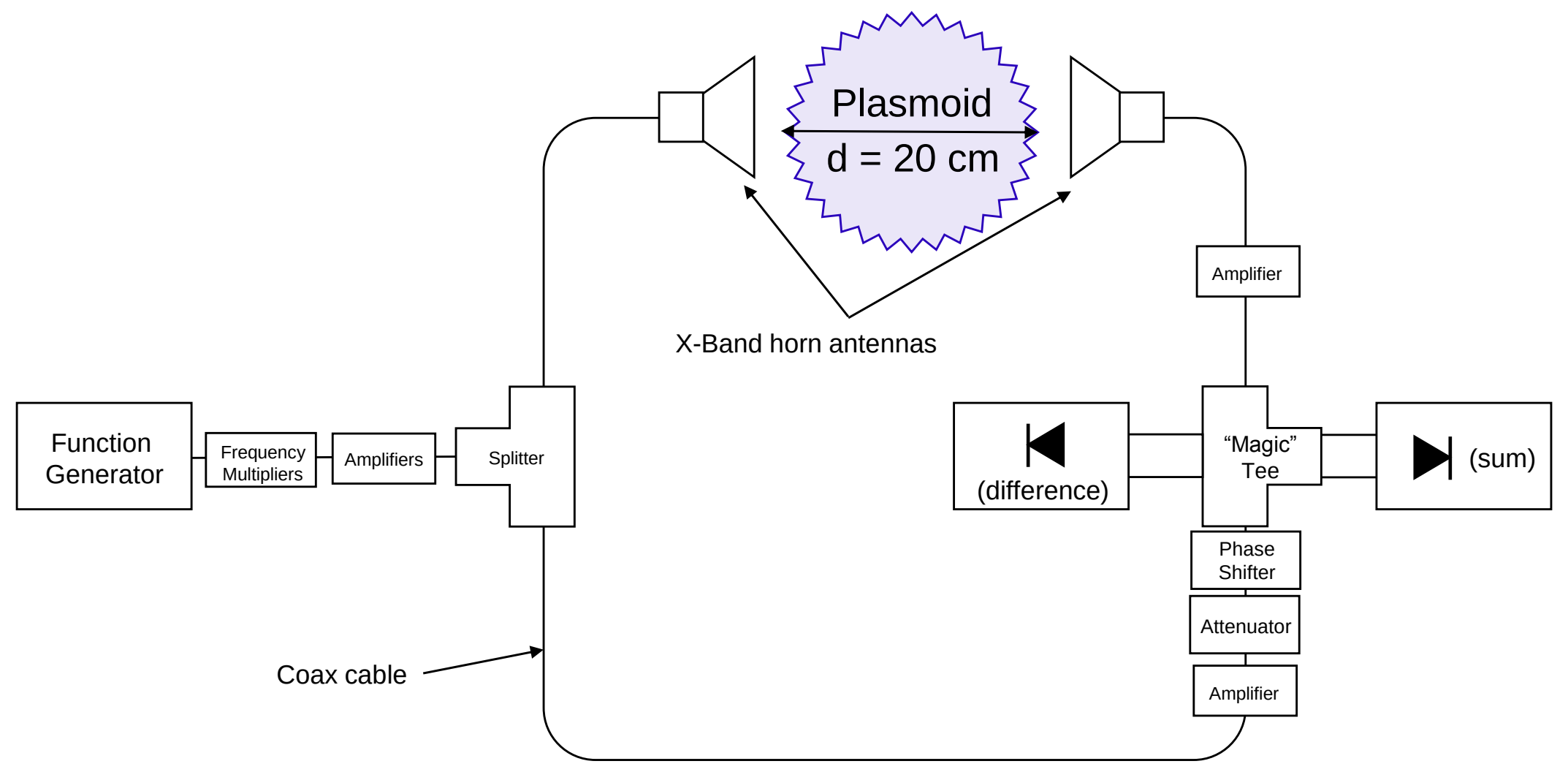


Figure 7. Microwave interferometer design for measurement of electron density of a plasmoid [4].

Microwave interferometry is a technique that can be applied to plasma diagnostics to measure electron density and collisional frequency. In the proposed design (Figure 7), a microwave beam will pass through the plasmoid where it will be attenuated and phase shifted, while another beam will pass through a reference arm. The sum and difference of these two waves, when combined, produce a signal leading to the electron density as a function of time.

References

[1] Dubowsky, S. E.: Friday, D.M.; Peters, K.C.; Zhao, Z.; Perry, R. H.; McCall, B.J. *Int. J. Mass Spectrom.* **2015**, 376, 39-45.
[2] Dubowsky, S. E.; Deutsch, B. Bhargava, R.; McCall, B. J. *J. Mol. Spec.* **2016**, 322, 1-8.
[3] Stephan, K.D.; Dumas, S.; Komala-Noor, L.; McMinn, J. Plasma Sources. Sci. Technol.2013, 22, 2.
[4] Dubowsky, S. E.; Rose, A. N.; Glumac, N.; Eden, J. G.; McCall, B. J. Spectroscopic Diagnostics of Ambient Ball Plasmoid Discharges: Revealing the Underlying Physical Chemistry of Ball Lightening. *Turkey Run Analytical Conference*. **2016**.

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