SAND2016-9930C

Exceptional service in the national interest

Sandia National Laboratories

Experimental Study of a Pulsating Anode Spot in Helium

B.T. Yee[1], E.V. Barnat[1], B.S. Scheiner[2], S.D. Baalrud[2], and M.M. Hopkins[1]

[1]Sandia National Laboratories, Albuquerque, NM, USA
[2]University of Iowa, Iowa City, Iowa, USA

Introduction

Anode spots are double layers which form around positively biased electrodes immersed in plasma. As seen in figure 1,

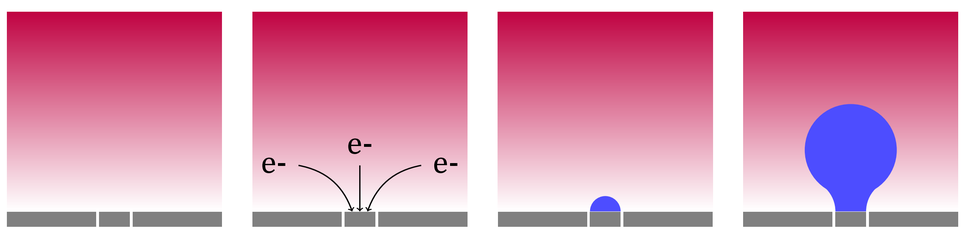


Figure 1: Conceptual drawing of the formation of an anode spot with each frame representing an increase in anode voltage relative to the plasma. In the first frame, the center electrode is below the plasma potenial and a typical ion sheath is present. In the second frame, the anode is just above the plasma potential causing it to collect electrons and form an electron sheath. The bias is then increased further, leading to excitation at the face of the anode. Finally, for a high enough bias, ionization occurs and the spot expands outward.

the positive bias accelerates electrons toward the electrode, resulting in a region of excitation and ionization. For sufficiently high ionization, a secondary plasma expands out from the anode with a higher potential and density than the host plasma.

In many cases [1, 2, 3, 4, 5] these spots have been found to oscillate; undergoing collapse and reignition at frequencies of 10s of kHz. While the Langmuir condition [6] represents a well-known constraint on the stability of double layers, the cause of these oscillations has not been definitively identified. Likewise, there is no clear set of conditions for the formation of a non-oscillatory anode spot.

Experiment

Experiments were conducted in a modified GEC reference cell. In place of the lower electrode was a disc-shaped electrode embedded in a grounded guard ring. In place of the upper electrode was a long cylindrical nipple with rare earth magnets placed about the periphery to form a multipole confinement scheme. A sketch of the setup used can be seen in figure 2. At the end of the nipple is a hollow cathode source. Helium was used in all cases and pressures ranged from 20 mTorr to 50 mTorr.

Typical biases for the anode ranged from 50 to 100 V. The input was buffered with a 100 μF capacitor in order to prevent voltage droop during spot formation. The spot was observed with an ICCD camera fitted with a narrow bandpass filter centered at 390 nm. Current and voltage measurements were made at the anode. Bulk plasma properties were measured using a Langmuir probe and an emissive probe.

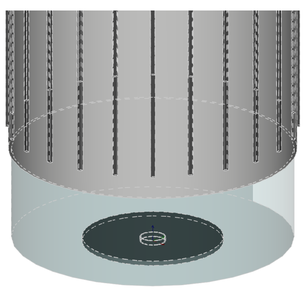
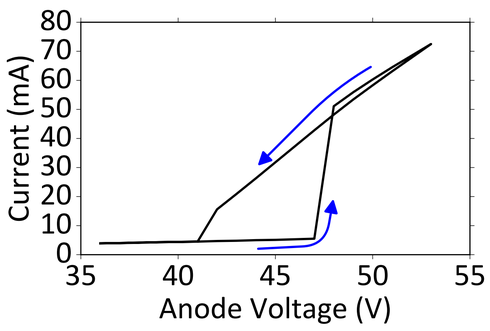


Figure 2: A 3D representation of the spot formation region with the multipole confinement device located above.

Results and Discussion

After exceeding a threshold bias (which depends on pressure and electron density) spot formation was readily observable. The spot mode was identified by hysteresis in the I-V curve for the anode, and its physical appearance as seen in figure 3.



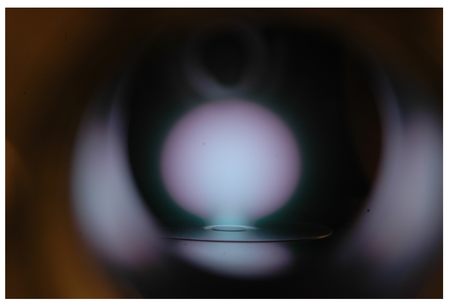


Figure 3: On the left, a plot of the hysteresis of the I-V curve for the anode, indicating spot formation. On the right, a full color image of a spot.

For the present system, there was essentially no set of parameters which yielded a non-oscillatory spot. An exception to this is for a short time after pumping the chamber down from atmosphere. Under these conditions, in which one expects a larger proportion of impurities, a stable spot was able to form.

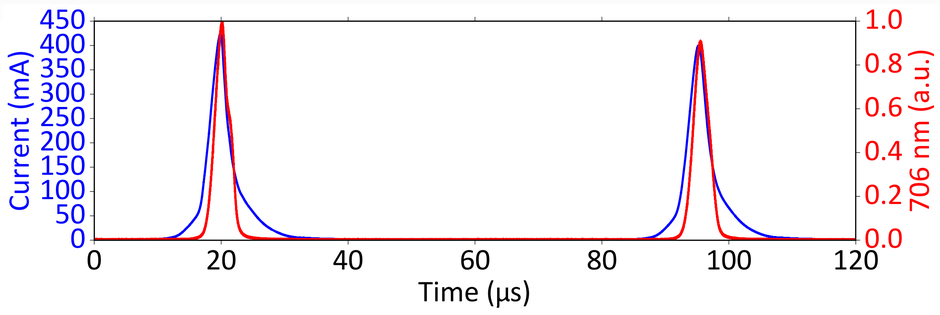


Figure 4: The averaged waveforms for the ac-coupled current and the emissions from the 706 nm transition of helium for an oscillating spot.

Figure 4 shows typical current and light emission waveforms for an oscillating spot in helium. The timing of these waveforms corresponds to the ICCD images presented in figure 7. The continued current collection after the cessation of light emission indicates a significant reduction in the potential drop between the electrode and the spot. This would be consistent with previously observed spot behavior which places its potential at approximately one ionization potential above that of the host plasma.

The oscillation period for the spot varies with electron density, neutral gas pressure, and anode bias. This can be seen in figure 5 which show the frequency as a function of anode bias.

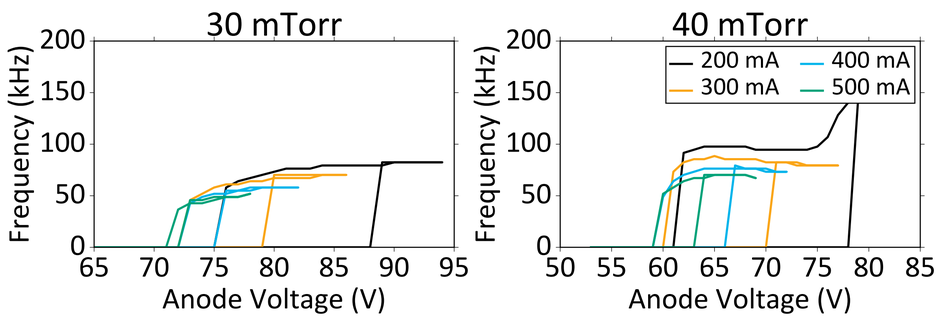


Figure 5: Frequency of spot formation for different neutral pressures and different anode biases at a variety of discharge currents (electron densities).

These lower frequency oscillations, corresponding to a timescale comparable to an ion transit time, are not the only dynamics present. This can be seen in figure 6

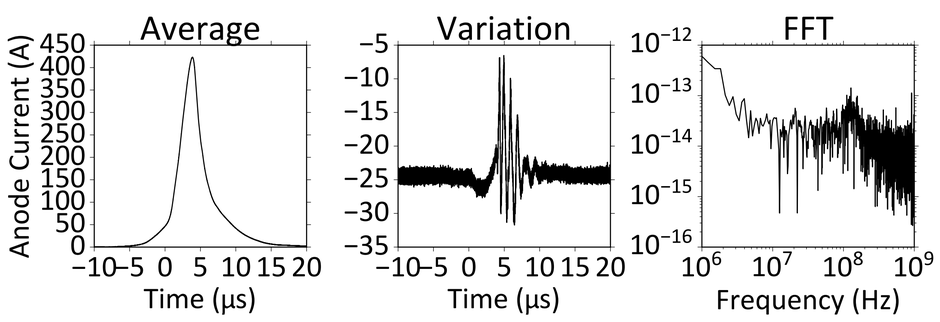


Figure 6: Several frames illustrating the various dynamics of the oscillating anode spot. The first plot shows the waveform averaged over 100 periods, while the second plot shows the variation from this mean for a single shot. The third frame contains an average of the FFTs for these variations.

which shows the average waveform, the variation from this average in a single period, and an average of FFTs of these variations taken over 100 periods. Two additional components are readily apparent. The first are oscillations around 1 MHz, likely related to streaming instabilities [7]. The second may be related to an electron transit instability, akin the principle of operation for vircators [8].

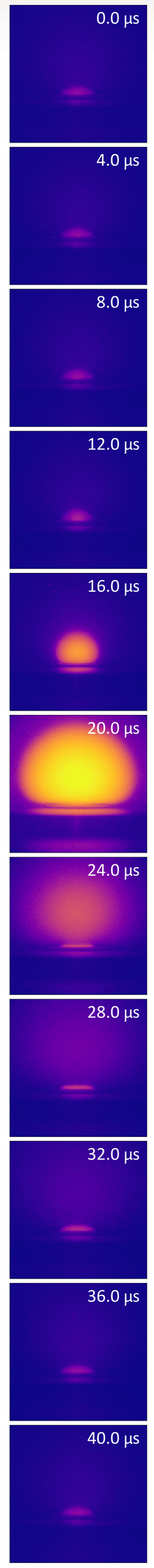


Figure 7: Log-scaled images of the light intensity from the 390 nm transition in helium over the course of one spot period.i

References

[1] K. G. Emeleus, *Int. J. Electron.*, vol. 52, no. 5, pp. 407–417, 1982.

[2] B. Song, N. D'Angelo, and R. L. Merlino, *J. Phys. D. Appl. Phys.*, vol. 25, p. 5, 1992.

[3] C.-S. Yip, G. D. Severn, and N. Hershkowitz, *Plasma Sources Sci. Technol.*, vol. 22, no. 6, p. 065002, 2013.

[4] R. L. Stenzel, J. Gruenwald, C. Ioniţă, and R. Schrittwieser, *Plasma Sources Sci. Technol.*, vol. 21, no. 1, p. 015012, 2012.

[5] M. Sanduloviciu, C. Borcia, and G. Leu, *Phys. Lett. A*, vol. 208, no. 1-2, pp. 136–142, 1995.

[6] I. Langmuir, *Phys. Rev.*, vol. 33, no. 6, pp. 954–989, 1929.

[7] B. Scheiner, S. D. Baalrud, B. T. Yee, M. M. Hopkins, and E. V. Barnat, *Phys. Plasmas*, vol. 22, no. 12, 2015. [Online]. Available: http://dx.doi.org/10.1063/1.4939024

[8] R. L. Stenzel, J. Gruenwald, B. Fonda, C. Ionita, and R. Schrittwieser, *Phys. Plasmas*, vol. 18, no. 1, p. 012105, 2011.

Acknowledgements

This work was supported in part by the Department of Energy Office of Fusion Energy Contract DE-SC0001939.