Nonlinear saturation of the ion-electron Buneman instability in a spherical positively pulsed gridded IEC device.

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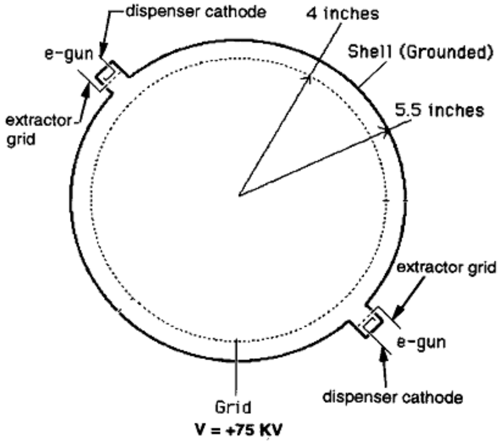
Talk outline

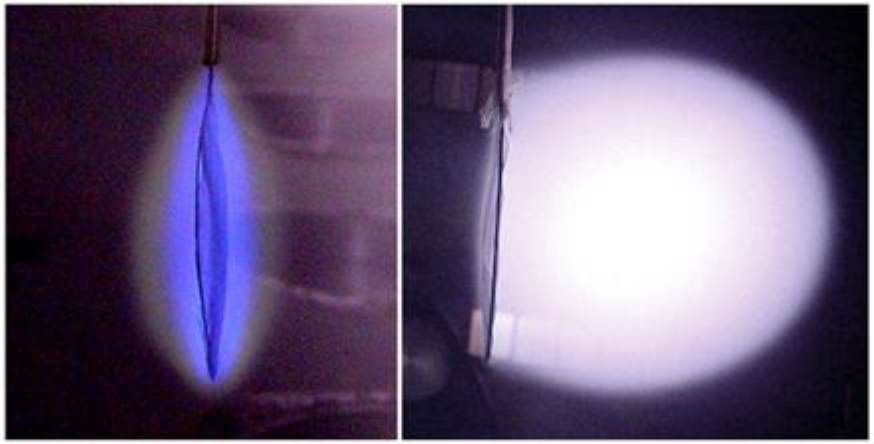
- Positive spherical gridded discharges
- Experiment and setup
- Series ballast resistance
- Results and primary findings
- *Current and beam driven and electrodynamic instabilities*
- *Buneman ion-electron two stream instability*
- Concluding remarks and future work

Existing work on positive spherical discharges



Periodically oscillating plasma sphere[27]

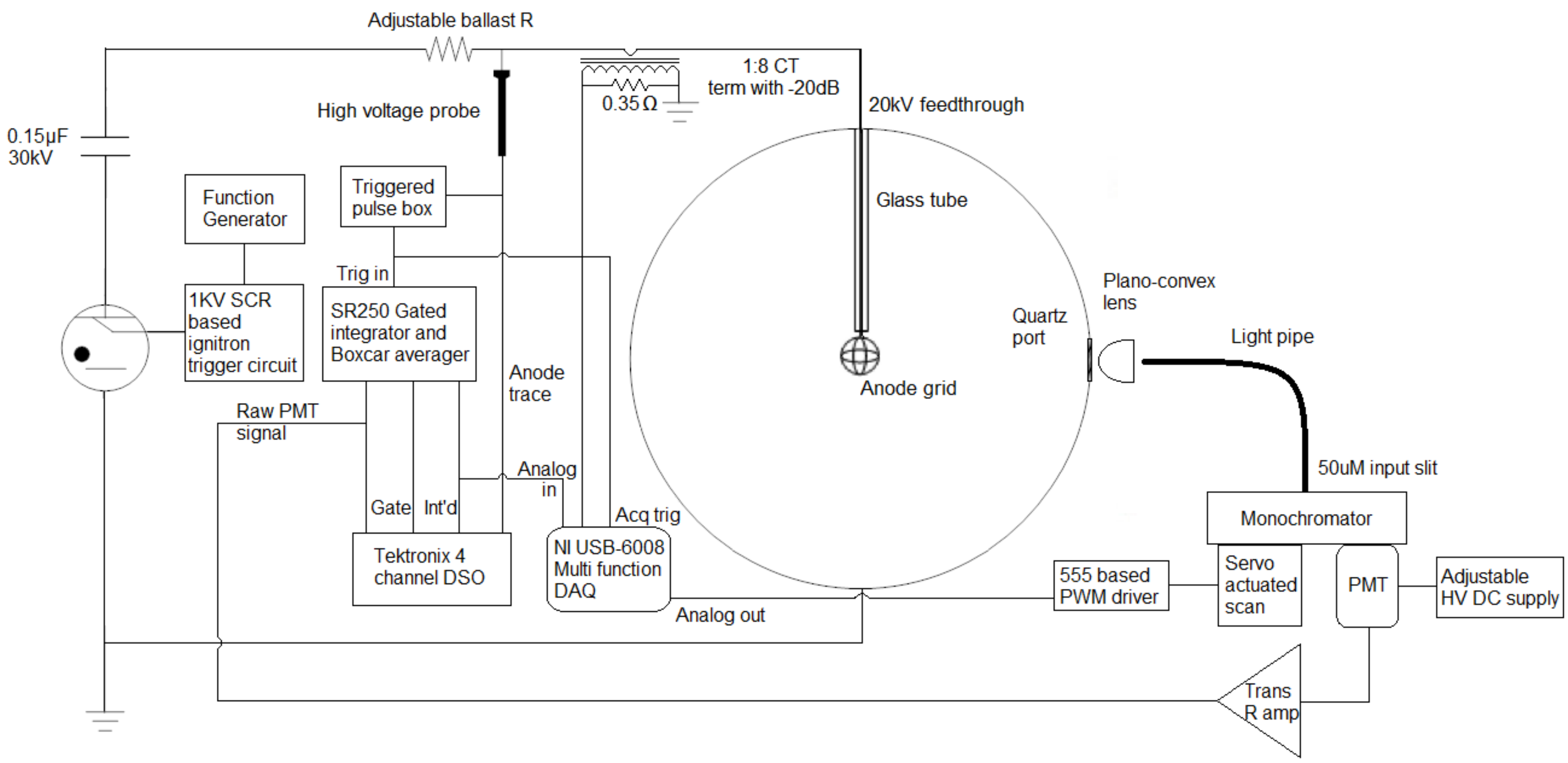
(1998)
J. Park and R. Nebel



R. L Stenzel's work on "fireball discharges" from Dynamics of fireballs (2008)[12] and Transit time instabilities in an inverted fireball (2010)[13]

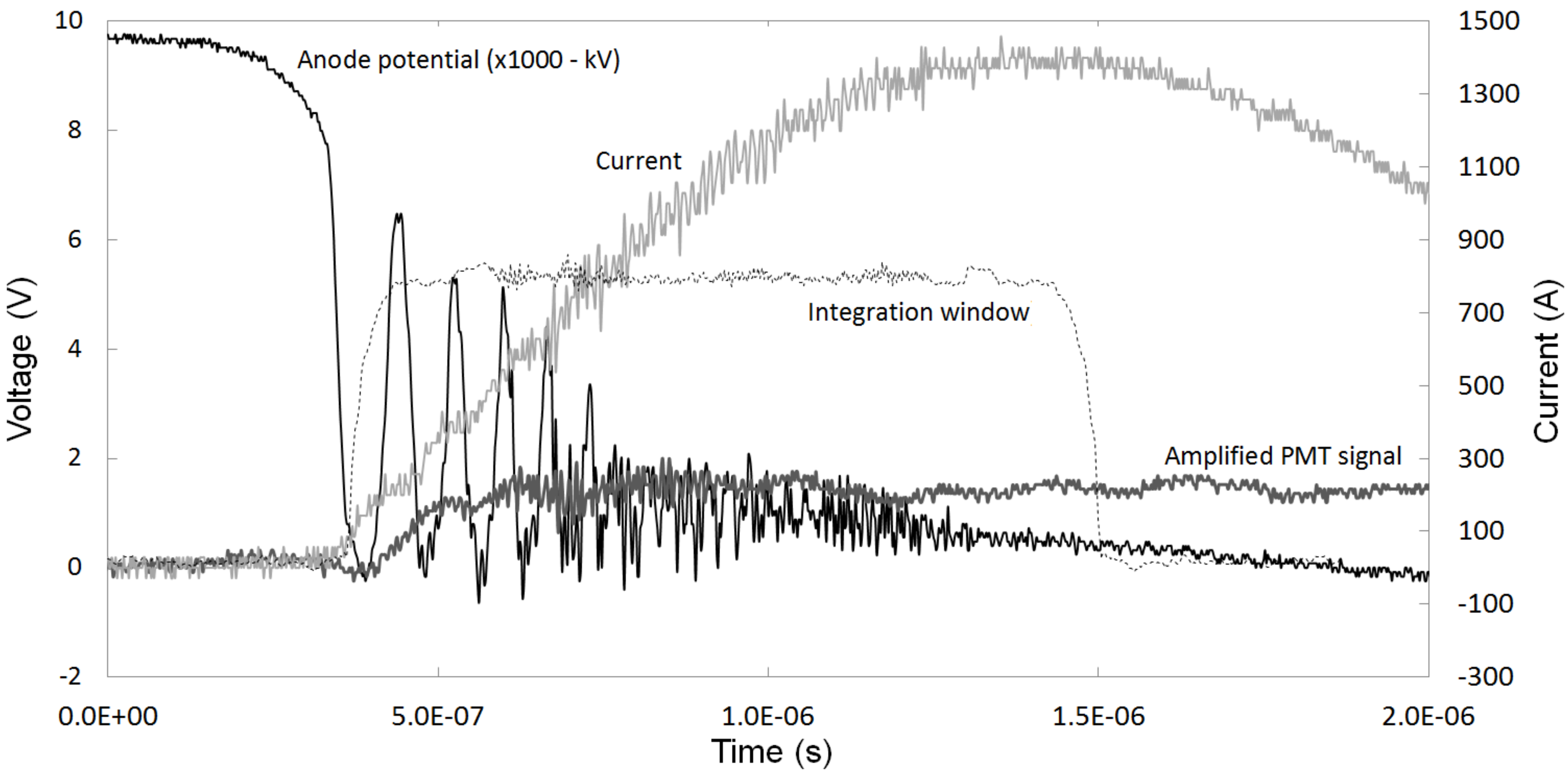
- Elmore et al. [3] 1959
  - Reversed polarity electron confinement
- Pops[26-29] 1998-2007
  - Virtual cathode IECF
- Stenzel's fireball[12-18] 2001 -
  - Positive glow discharges
  - Potential relaxation instability
- Theoretical works[16,30]

Experimental setup



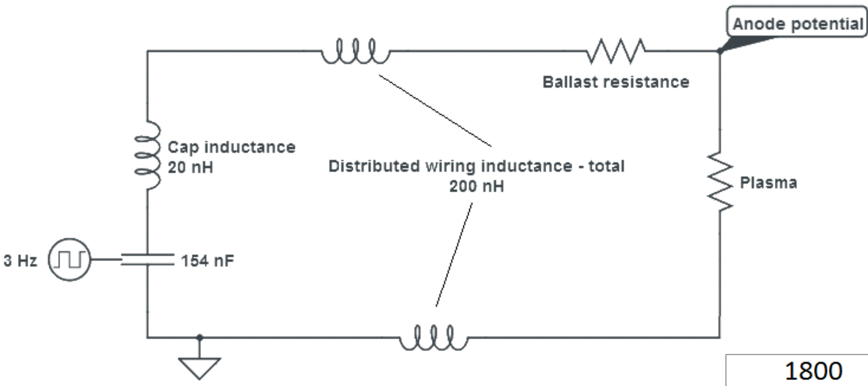
Experimental setup featuring Labview automated optical spectrum recording, current (transformer) and voltage trace recording.

Plasma oscillations



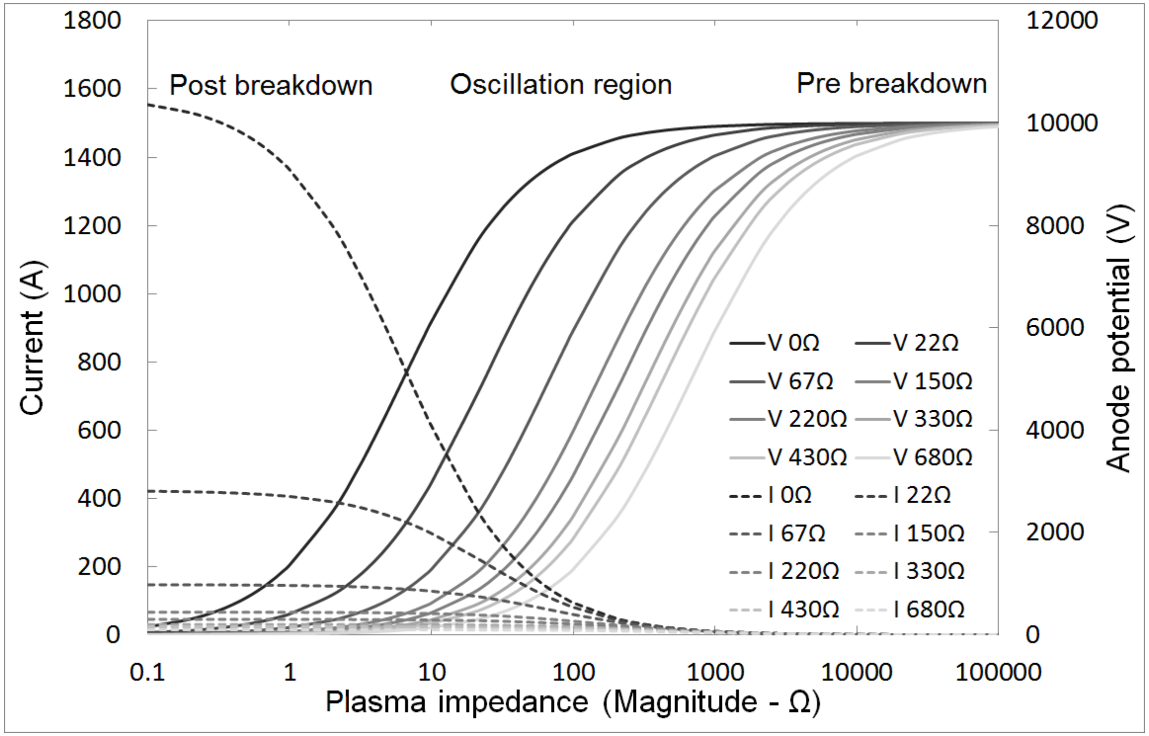
A typical collection of traces for a 36mTorr hydrogen plasma at 10kV

The role of series ballast resistance

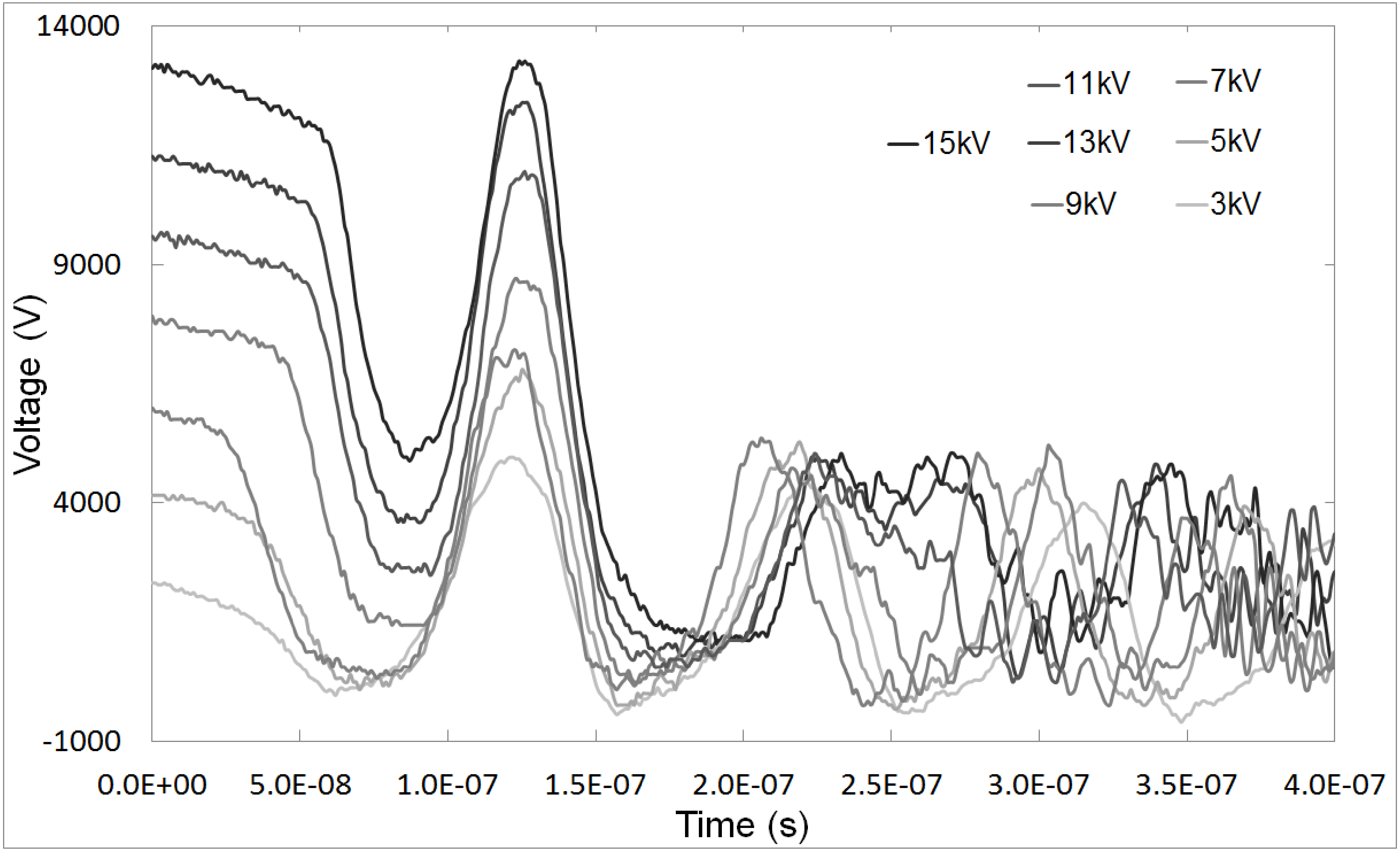


- L primary factor in I when $R_b = 0$
- X_L at 5MHz = 7Ω
- $R_b > 0$, Substantially lower I and F

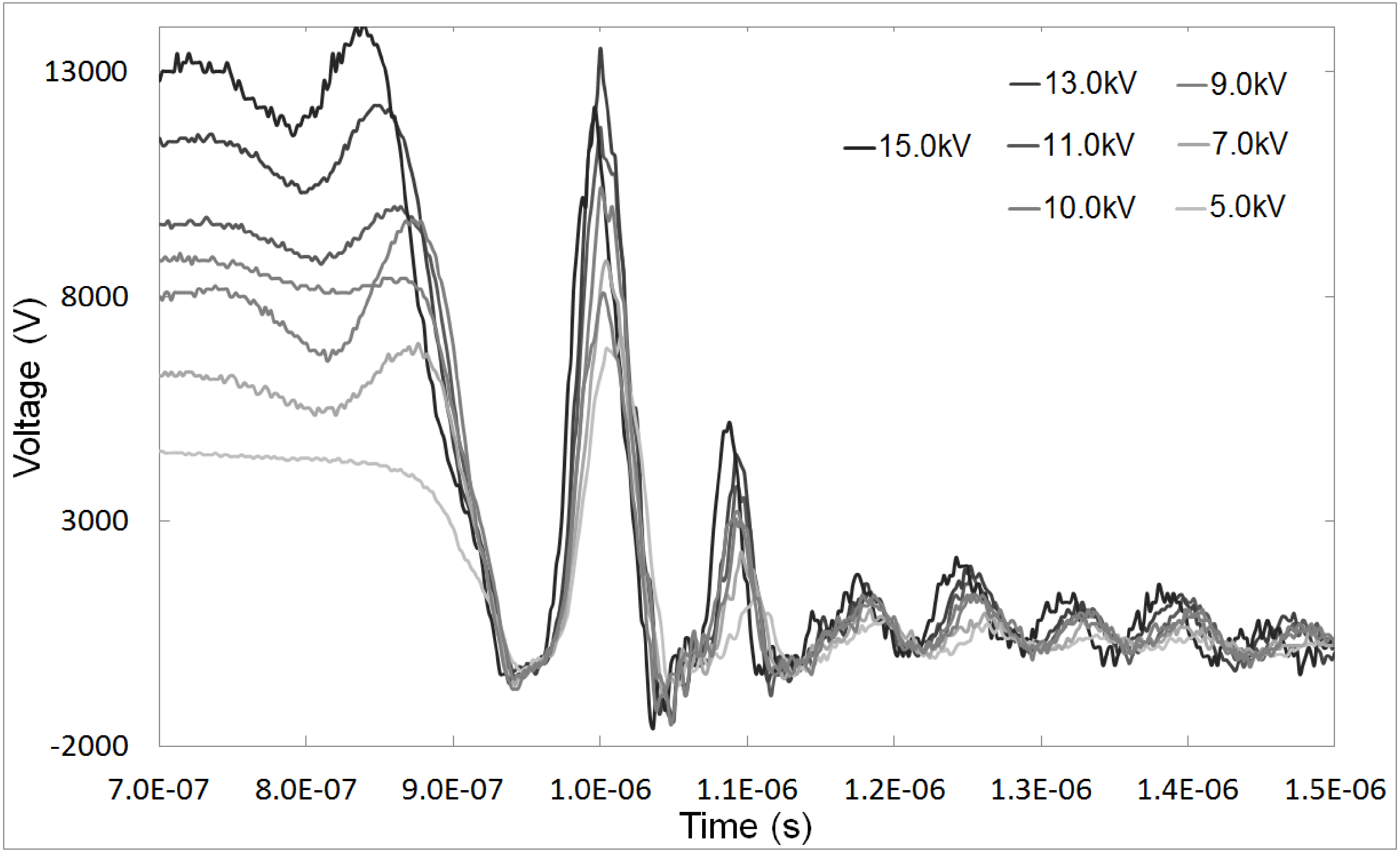
- The current and anode potential as a function of ballast resistance.
- Oscillation between the Spitzer resistivity and anomalous resistivity
- Extends experiment regime below Paschen breakdown requirement



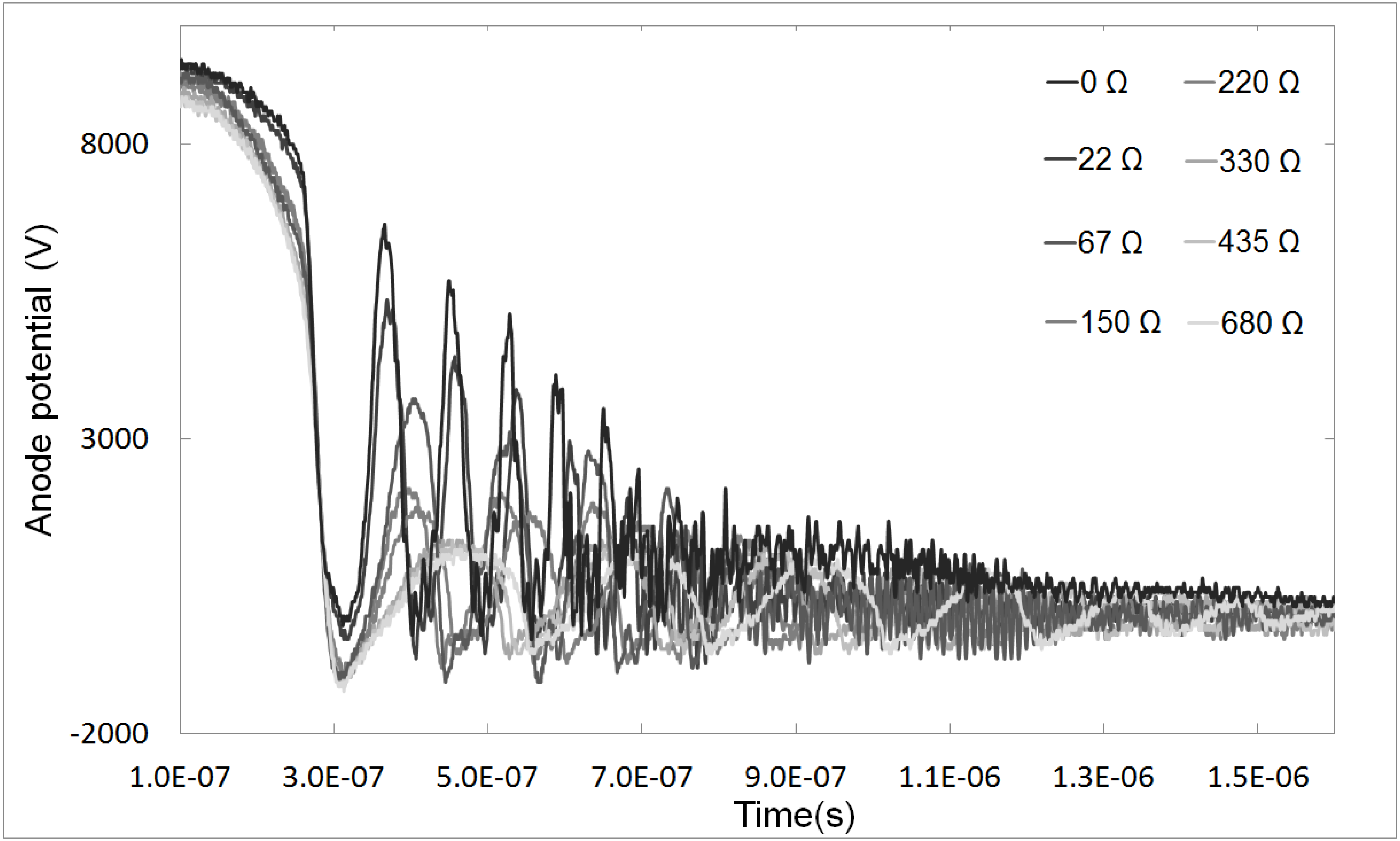
Oscillations in hydrogen as a function of varying peak anode potential



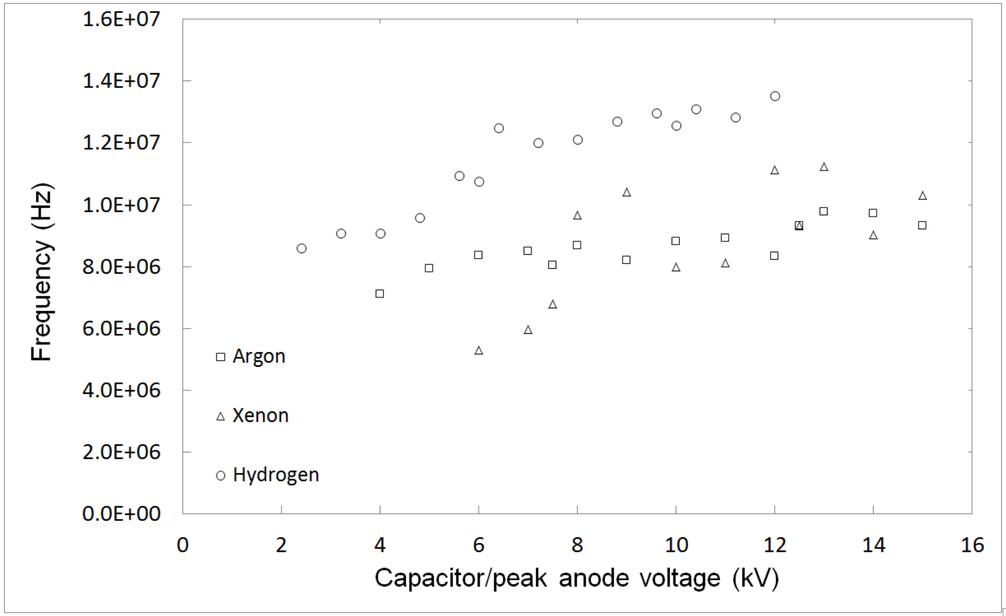
Oscillations in Argon as a function of varying peak anode potential



Oscillations in Hydrogen as a function of Rb at 10kV fixed anode potential

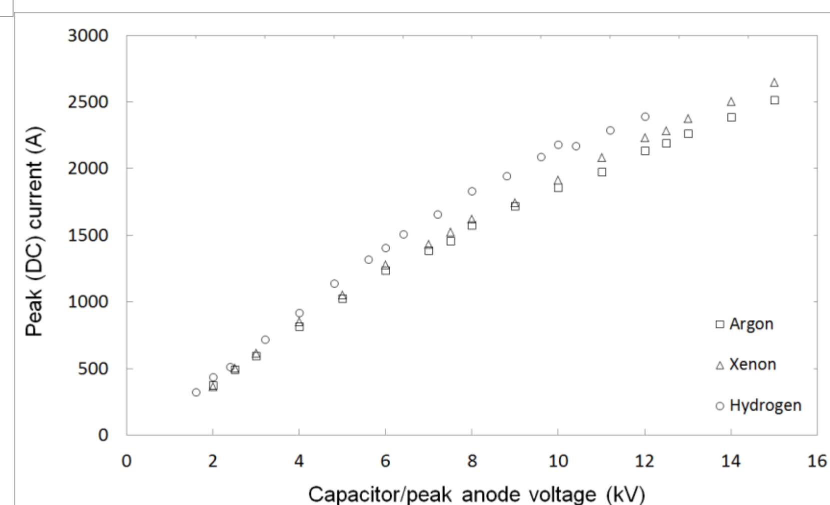


Frequency and current data for Rb = 0W

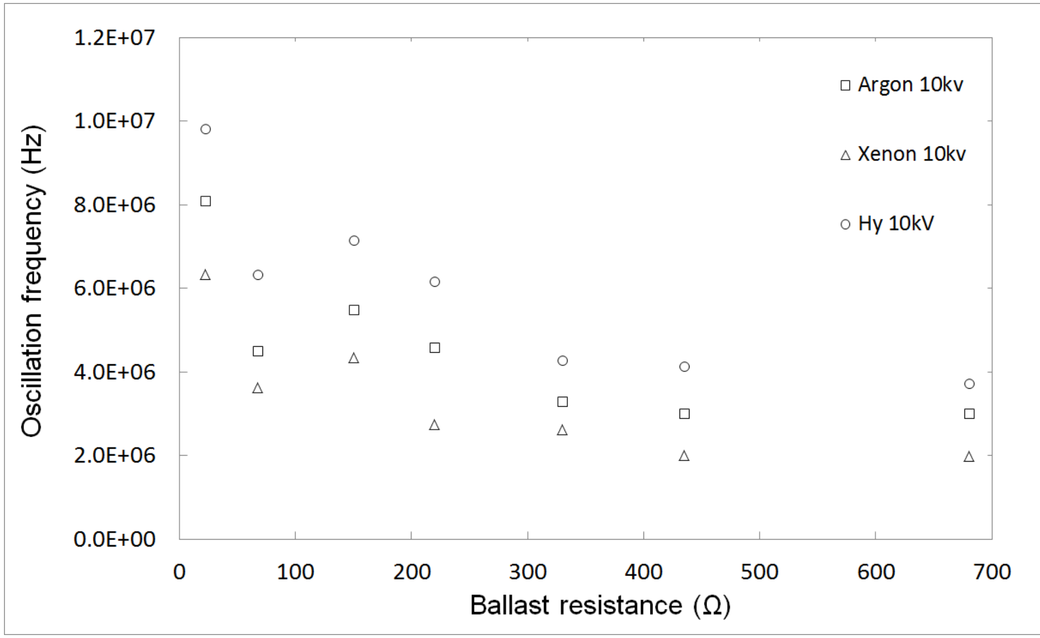


- Oscillation frequency is somewhat mass independent
- Oscillation frequency is somewhat anode potential independent
- No clear monotonic trends

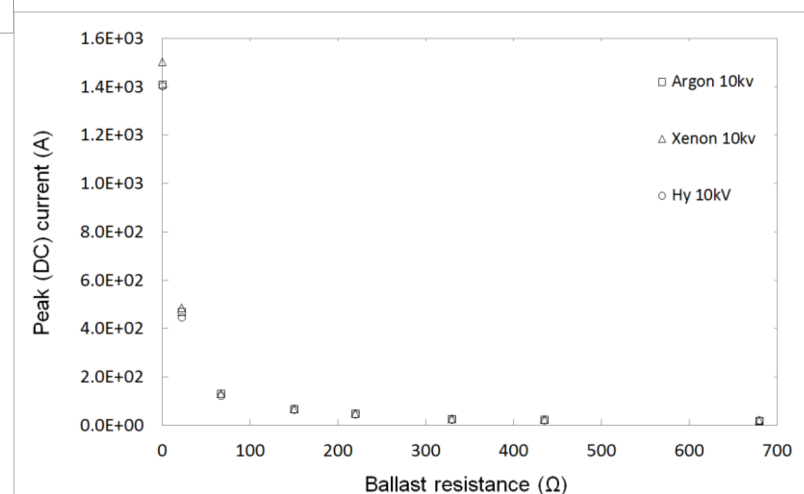
- Current almost linearly increases as a function of increasing anode potential
- Current is mostly ion mass independent



Frequency and current data for 10kV

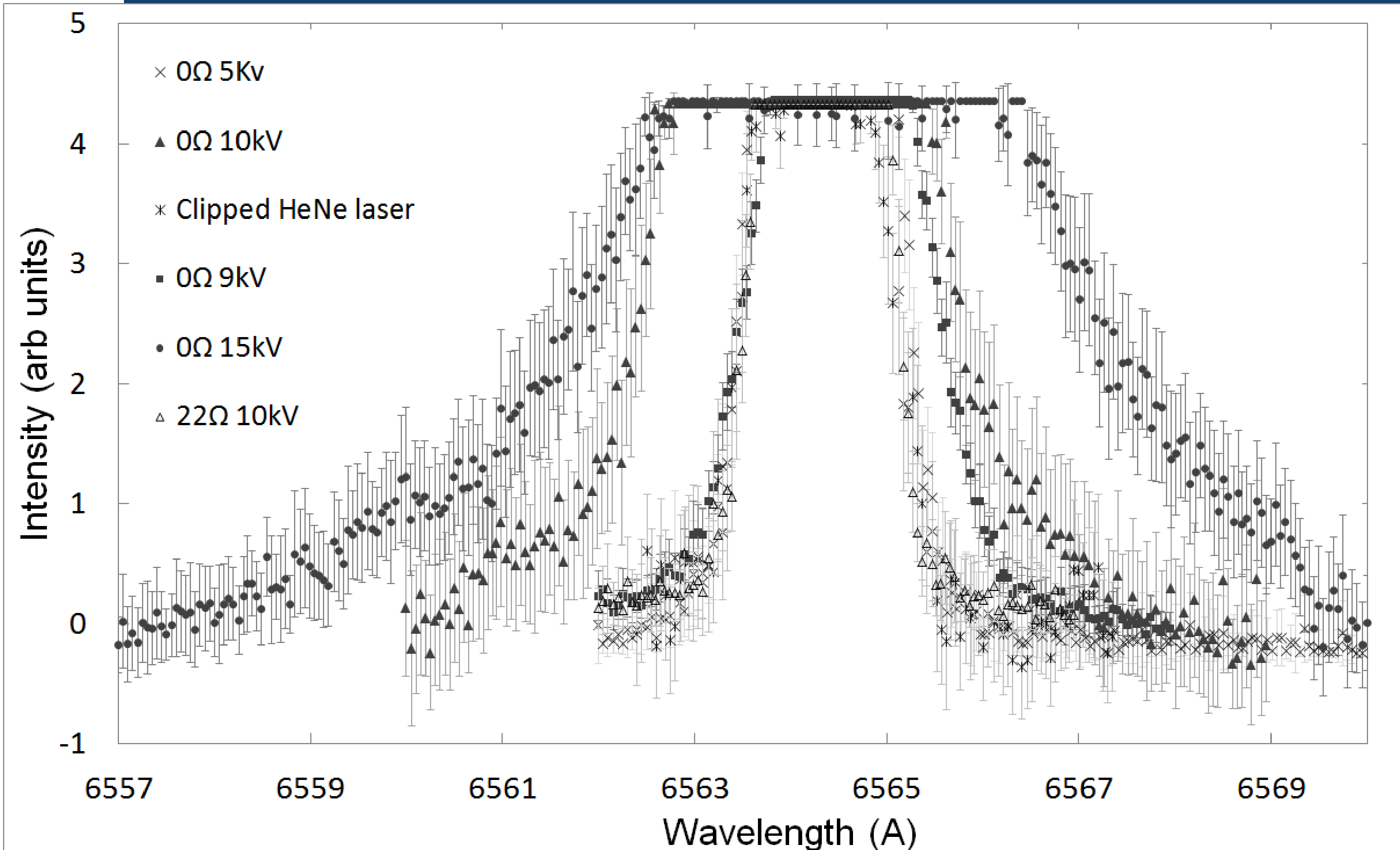


- Mass dependent splitting in frequency occurs
- Oscillation frequency strongly decreases with increasing ballast resistance



- Current hyperbolically decreases as a function of increasing anode potential
- Current is again mostly ion mass independent

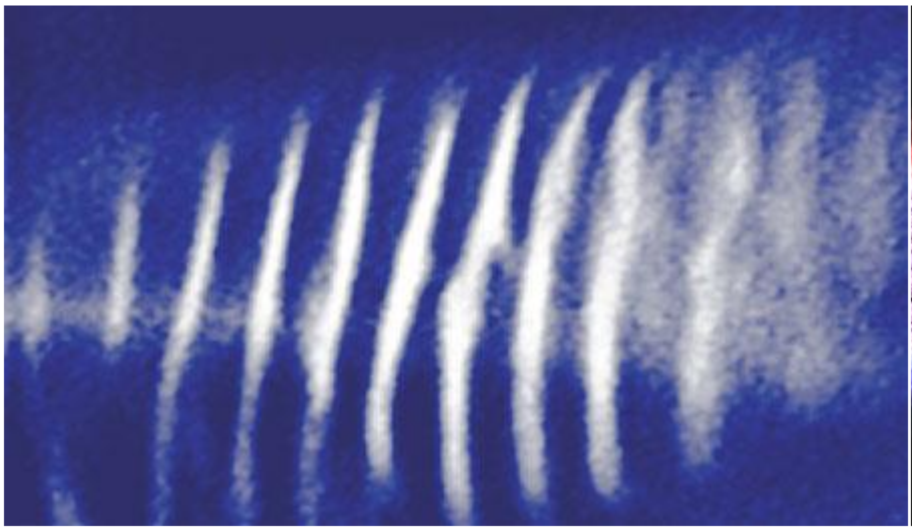
Doppler broadened Hydrogen alpha spectra at large anode potentials

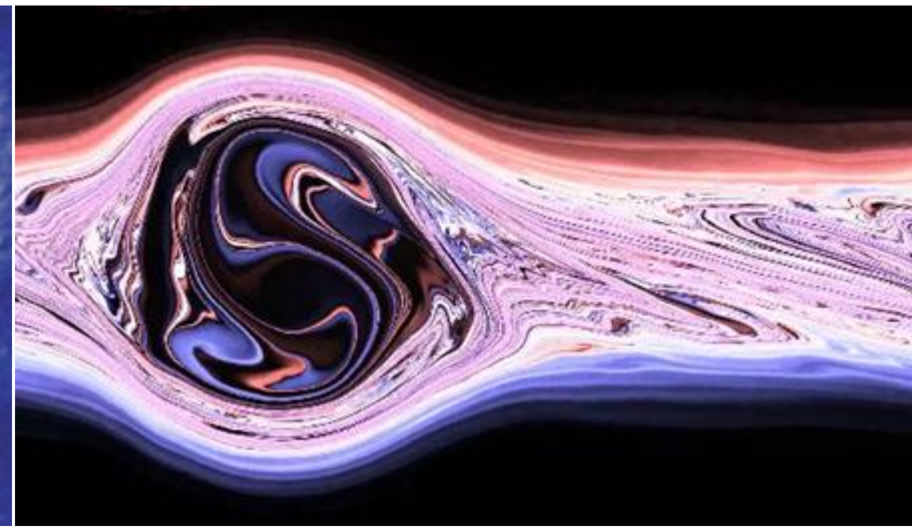


Instabilities in an unmagnetised plasma

Ion acoustic wave

Buneman instability





Dusty acoustic wave visualisation
R. Merlino and J. Goree 2004

Buneman instability simulation
S. Earle 2008

Current driven instabilities - Buneman instability

- Spherical ion acoustic wave[36]

$$v = \frac{\omega}{k} = \sqrt{\left(1 + \frac{2i}{k^2 r}\right)\frac{\gamma K_b (T_i + T_e)}{m_i}}$$

- Criteria for excitation:

- $T_e >> T_i$
- Vdrift > Vsound
- Does not preclude Buneman instability from forming

- Linear Buneman instability[38]

$$1 = \left(\frac{\omega_{pi}}{\omega}\right)^2 + \frac{\omega^2{}_{pe}}{(\omega - kV)^2}$$

- Criteria for excitation:

- $V_{drift} > V_{thermal}$
- Can lock into Buneman mode before T_e increases
- Avalanche current -> sharp increase in V_{drift} before electron thermalisation

Conclusions and future work

- A pulsed positive polarity IEC device has been studied in Hydrogen (36.5mTorr), Argon (9.5mTorr) and Xenon (1.5mTorr) at varying anode potential (5-15kV) and ballast resistance (0-680Ω).
- Large amplitude ion oscillations occur within a microsecond of the discharge onset.
- Data suggests the Buneman instability is responsible for oscillations.
- Nonlinear and saturated Buneman instability theory is very incomplete, with no closed form solutions in spherical geometry. Known effects are virtual cathode trapping and ponderomotive ion motion.

- Time resolved, broadband current data would be useful.
- Transmissive microwave electron density measurements without homodyning requirement – fast/cheap oscilloscopes are required.

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References

1. W. M. Nevins, Physics of Plasmas (1994-present) **2** (10), 3804-3819 (1995).
2. T. H. Rider, Physics of Plasmas (1994-present) **2** (6), 1853-1872 (1995).
3. W. C. Elmore, J. L. Tuck and K. M. Watson, Physics of Fluids (1958-1988) **2** (3), 239-246 (1959).
4. R. W. Bussard, Fusion Technol. **19** (2), 273-293 (1991).
5. M. Carr, D. Gummersall, S. Cornish and J. Khachan, Physics of Plasmas **18** (11) (2011).
6. M. Carr and J. Khachan, Physics of Plasmas **17** (5) (2010).
7. M. Carr and J. Khachan, Physics of Plasmas **20** (5) (2013).
8. D. V. Gummersall, M. Carr, S. Cornish and J. Kachan, Physics of Plasmas **20** (10) (2013).
9. N. A. K. Jaeyoung Park, Paul E. Sieck, Dustin T. Offermann, Michael Skillicorn, Andrew Sanchez, Kevin Davis, Eric Alderson, Giovanni Lapenta, eprint arXiv:1406.0133 (2014).
10. C. Tuft and J. Khachan, Physics of Plasmas **17** (11) (2010).
11. R. Bandara and J. Khachan, Physics of Plasmas **20** (7), 10 (2013).
12. R. Stenzel, C. Ionita and R. Schrittwieser, IEEE Trans. Plasma Sci. **36** (4), 1000-1001 (2008).
13. R. L. Stenzel, J. Gruenwald, C. Ionita and R. Schrittwieser, Plasma Sources Sci. Technol. **20** (4), 9 (2011).
14. R. L. Stenzel, J. Gruenwald, C. Ionita and R. Schrittwieser, Plasma Sources Sci. Technol. **21** (1), 11 (2012).
15. R. L. Stenzel and J. M. Urrutia, Physics of Plasmas **19** (8), 10 (2012).
16. K. H. Pae and S. J. Hahn, Journal of the Physical Society of Japan **71** (9), 2169-2173 (2002).
17. R. L. Stenzel, J. Gruenwald, B. Fonda, C. Ionita and R. Schrittwieser, Physics of Plasmas **18** (1), 9 (2011).
18. J. M. Urrutia and R. L. Stenzel, Physical Review Letters **57** (6), 715-718 (1986).
19. O. Buneman, Physical Review Letters **1** (1), 8-9 (1958).
20. O. Buneman, Physical Review **115** (3), 503-517 (1959).
21. O. Ishihara, A. Hirose and A. B. Langdon, Physical Review Letters **44** (21), 1404-1407 (1980).
22. N. Jain, T. Umeda and P. H. Yoon, Plasma Physics and Controlled Fusion **53** (2) (2011).
23. A. Hirose, O. Ishihara and A. B. Langdon, Physics of Fluids **25** (4), 610-616 (1982).
24. O. Ishihara, A. Hirose and A. B. Langdon, Physics of Fluids **24** (3), 452-464 (1981).
25. M. E. Dieckmann, P. Ljung, A. Ynnerman and K. G. McClements, Physics of Plasmas (1994-present) **7** (12), 5171-5181 (2000).
26. B. Edwards, Ph.D. Dissertation, University of Illinois (1980).
27. J. Park, R. A. Nebel, S. Stange and S. K. Murali, Physical Review Letters **95** (1), 015003 (2005).
28. J. Park, R. A. Nebel, S. Stange and S. K. Murali, Physics of Plasmas (1994-present) **12** (5), - (2005).
29. E. G. Evstatiev, R. A. Nebel, L. Chacón, J. Park and G. Lapenta, Physics of Plasmas (1994-present) **14** (4), - (2007).
30. Y. Takeda and K. Yamagiwa, Physics of Fluids B: Plasma Physics (1989-1993) **3** (2), 288-299 (1991).
31. L. Spitzer and R. Harm, Physical Review **89** (5), 977-981 (1953).
32. A. Bogaerts and R. Gijbels, Journal of Applied Physics **86** (8), 4124-4133 (1999).
33. D. B. Melrose, *Instabilities in space and laboratory plasmas*. (Cambridge university press, 1986).
34. I. K. D. M. Gobel, *Fundamentals of Electric Propulsion: Ion and Hall Thrusters*. (John Wiley & sons Inc., 2008).
35. R. Schrittwieser, Physics Letters A **95** (3-4), 162-164 (1983).
36. F. F. Chen, *Introduction to Plasma Physics and Controlled Fusion*, 2nd ed. (Plenum Press, New York, 1984).
37. J. Z. G. Ma, A. Hirose, J. P. St-Maurice and W. Liu, Ann. Geophys. **29** (1), 123-145 (2011).
38. A. Hirose, *Plasma waves: http://physics.usask.ca/~hirose/P862/notes.htm*.