Multi-modal oscillations in a spherical positive polarity Inertial Electrostatic Confinement device

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1. Abstract

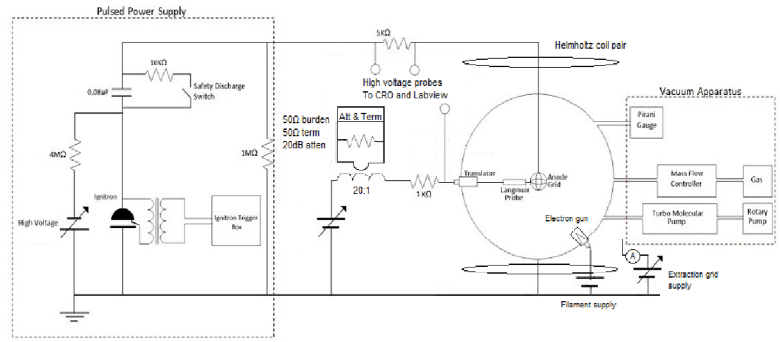
A pulsed, positive-polarity gridded inertial electrostatic confinement device is being investigated experimentally primarily using a single Langmuir probe and some preliminary optical diagnostics. Large amplitude oscillations are observed in the anode voltage and current, as well as the probe current. An emergent tri-modality in the character of the oscillations has been observed, which is highly sensitive to chamber pressure and peak anode voltage. The canonical oscillatory mode as observed by Tuft et al [1] is most sensitive and is stochastically subject to minor fluctuations in seemingly invariant experimental parameters, as localised discharges or arc spots induce the more dominant oscillatory modes. This mode features a prominent potential well, which is observed as a sharp, radially dependent fluctuation in the floating potential.

It has been found that the induction of this oscillatory mode is sensitive to the value of a series ballast resistor, whose function is to facilitate the initial application of a high voltage to induce breakdown, and to dynamically limit the current supplied to the plasma by allowing the anode voltage to sag during the low impedance regime of the discharge transient.

A preliminary analysis yields the hypothesis that the canonical oscillatory mode is the result of coherent ion oscillations within a harmonic potential well formed by a region of uniform negative space charge within the centre of the device.

The induction of the second and third oscillatory modes is likely to involve an asymmetric point convergence of electrons and subsequent ion oscillations. This hypothesis is confirmed by the inference of the formation of a stronger virtual cathode (as observed by a higher oscillatory frequency), an inability to measure any strong potential well within the anode area, a non uniform spatially resolved optical intensity profile, a weaker susceptibility to a perturbing magnetic field, and most importantly, the presence of these oscillatory modes when a solid spherical anode is used in place of the gridded anode. We propose that these oscillatory modes are similar to those associated with the discharge phenomenon commonly referred to as the "fireball" [2][3][4].

A thorough study of these oscillatory phenomena is pending the development of an accurate transient Langmuir probe theory and subsequent data analysis, as well as the implementation of fast optical instruments to collect spatially resolved intensity and wavelength data to infer time resolved ion energies and rough density distributions. The influence of an electron gun facilitating the formation of a non neutral plasma is also being investigated, as it is expected that this line of research will yield some convergence with the POPS [5] project.



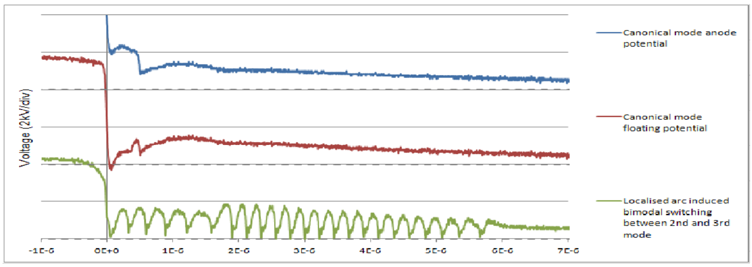
The experimental setup comprises of a pulsed high voltage power supply, a Langmuir probe on a linear stage and associated current measurement circuitry, a Helmholtz coil pair capable of producing a uniform field at the anode centre, a filament electron gun with extraction grid, and an orthodox set of vacuum apparatus.

The 1kΩ ballast resistor in series with the Langmuir probe serves to limit the probe current to protect the power supply, and to reduce the perturbative effect of the probe on the plasma. The Langmuir probe current is sensed through a 20:1 step down current transformer, which is shunted and terminated by 50Ω, and attenuated by 20dB. Its transfer function is approximately flat in the oscillatory frequency regime and was designed with a transfer ratio of 1V/mA.

A series of interchangeable anodes of various sizes have been manufactured, taking the form of three orthogonally spot welded rings. Some solid anodes were also fabricated to help investigate the third modal double layer oscillations that can form around any positively pulsed conductor within a low density plasma [2][3][4].

Experiment independent variable	Operating range	Nominal value
Peak anode voltage	0v - 20kV	12kV
Gas pressure	1μTorr - 150mTorr	18mTorr
Gas type	Hydrogen, Helium, Argon	Hydrogen
Applied magnetic field	0G - 9G	0G
Filament current	0mA - 50mA	0mA
Cathode size & type	Transparent & Solid 10mm - 17mm	Transparent 17mm
Anode ballast resistor	0Ω-10kΩ	5kΩ
Applied probe bias	0V - 5kV	0V (floating)

3. Selected results

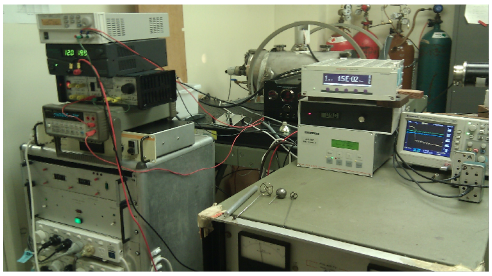


This plot shows three traces; A typical low amplitude trace of the anode potential for a canonical spherical plasma oscillation (4.5kV, 20mTorrr), the floating potential during this oscillation, which experiences a slightly negative excursion near the discharge onset, and a trace of a bifurcation between the two dominant modes of ion oscillation that occur at comparable frequencies (8kV, 20mTorr). It is worth noting that the peak floating potential depth is not entirely representative of the effective attractive potential well experienced by an ion within the gridded area. It was determined that the oscillations are strongly sensitive to magnetic fields (units of Gauss), and such the relocation of the Pirani gauge resulted in stronger oscillatory behaviour.

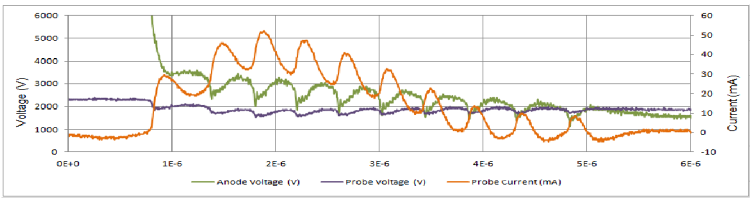
A first order approximation of the well depth can be derived from the oscillation frequency, by assuming a uniform space charge distribution and subsequent harmonic oscillator ion dynamics.

$$V_0 = \frac{\omega^2 R^2 m_i}{2e}$$

Potential well depths have been determined to be of the order of ~100V, which shows good agreement with preliminary Langmuir probe measurements of the spatial plasma potential profile.



4. Biased transient Langmuir probe measurements



Thus far our cursory Langmuir probe data analysis has involved the composition of a conventional probe IV curve by selecting a point in time, referenced to a trigger on the falling edge of the anode voltage (green).

Over the course of many pulses, the applied supply voltage was adjusted. For each supply voltage, the true probe voltage and probe current were measured at this fixed point in time relative to the discharge onset.

This methodology implies that our plasma is invariant over successive pulses, which is a shortcoming of this approach. Jitter in the timing of the plasma oscillations relative to the falling edge, the perturbative nature of the probe with increasing probe bias voltage and the generally stochastic nature of the plasma ensure that successive measurements aren't hugely consistent.

Our analysis thus far has not taken into account any transient slewing due to particle mobility, nor does it account for dynamicism in the sheath size and intrinsic circuit phase shift.

5. Conclusion

Preliminary measurements of anode potential, transient probe voltage and probe current have been collected over a wide parameter space. A thorough understanding of the tri-modal nature of the observed plasma oscillations is pending further analysis. Future work includes the installation of additional electron guns to form a more electron rich plasma, the pulsing of the gun extraction potential in the presence of a DC biased grid, which is more akin to the POPS experiment, and theapplication of direct RF excitation to explicitly excite and phase lock oscillatory modes.

6. References

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