Manipulation and Interrogation of Dynamic Plasma Discharges

E. V. Barnat[(a)], J. Franek[(b)], S. Nagomi[(b)], M. Koepke[(b)], V. Demidov[(b)], A. Friss[(c)] and A. Yalin[(c)].

(a) Sandia National Laboratories (evbarna@sandia.gov)
(b) West Virginia University (c) Colorado State University

A central goal of the Plasma Science Center is the ability to (predictively) control and manipulate a plasma discharge to generate desirable interactions (e.g., electron generation, photon generation) while minimizing or eliminating undesirable interactions (e.g., gas heating or plasma instabilities). Dynamically generated and manipulated plasma discharges offer a unique way to envision such a goal. Recent research has focused on the use of a "double pulse" discharge that is used for both generating and manipulating the plasma discharge. Collaborative interactions with partnering institutions are utilizing this discharge system to implement and benchmark advanced plasma diagnostic techniques capable of interrogating challenging plasma systems like the one described in this highlight.

The "double pulse" discharge utilizes two high voltage pulses (hundreds of volts in amplitude and microseconds in duration) to generate a plasma discharge (first voltage pulse) and then to manipulate the plasma discharge into a desired state (second pulse). The amplitude of the first pulse and the delay of the second pulse control the electron densities while the amplitude of the second pulse heats the electrons via the applied electric field induced in the discharge. (See Fig. 1.) Through such manipulation, control over energy deposition into the plasma is realized, as illustrated by selective excitation of the Ar($1s_5$) metastable state over ionization. (See Fig. 2.)

Collaborative efforts underway at Sandia center on the utilization of the discharge for plasma diagnostic development. Partners a West Virginia University (M. Koepke) are utilizing measurements of optical emission emanating from the Ar($3p_5$) (419.8 nm) and the Ar($3p_9$) (420.1 nm) to assess the electron densities, metastable densities and effective values of E/N during the initiation of the plasma with the use of a simplified collisional-radiative model. Likewise, partners at Colorado State University (A. Yalin) are assessing the use of the plasma in furthering a FES funded project on Cavity Enhanced Thomson Scattering for electron density measurements on high pressure plasma discharges.

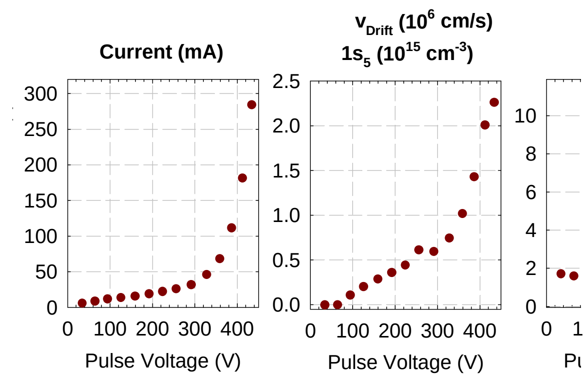


Figure 1 – Measured response of the current (left) and the heating of the electrons (right) as a function of amplitude of the second voltage pulse.

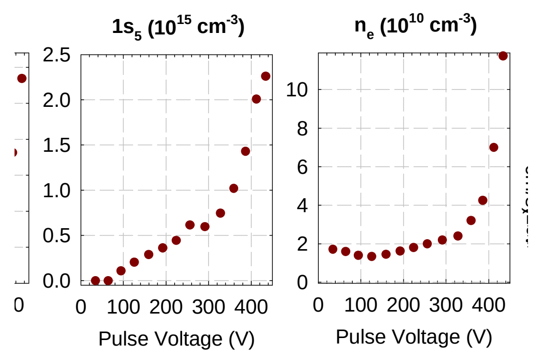


Figure 2 – Selective heating of the Ar($1s_5$) metastable state over ionization.

DOE Center for Control of Plasma Kinetics

Highlight

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

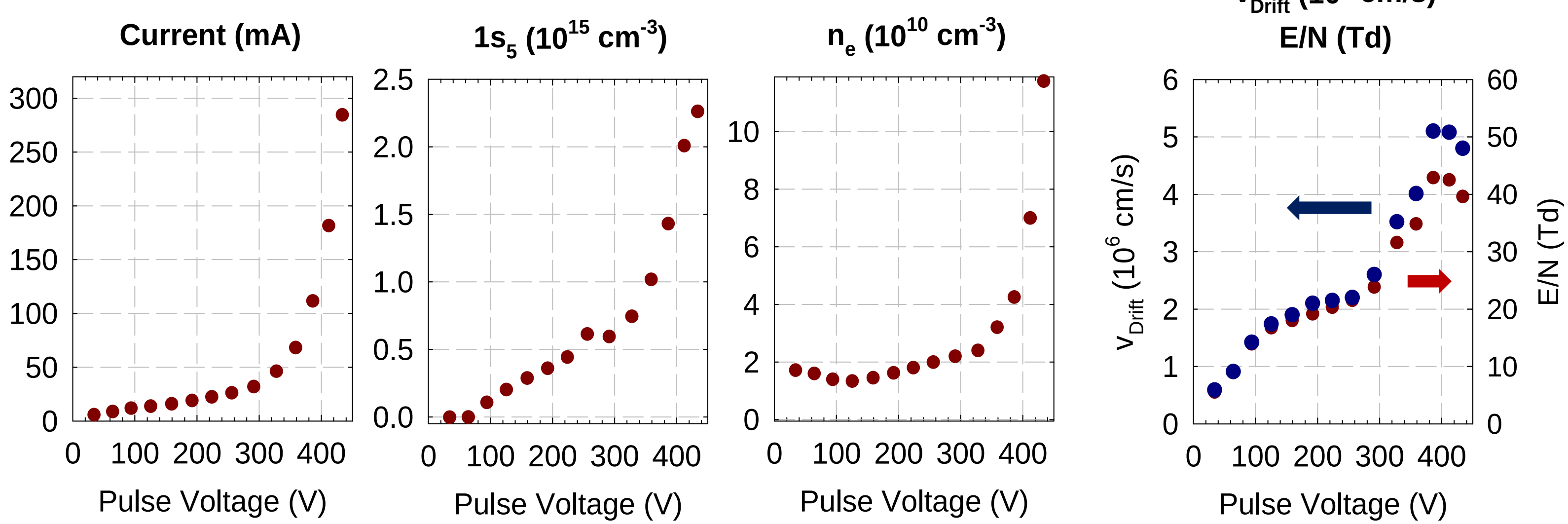
Department of Energy Plasma Science Center

MANIPULATION AND INTERROGATION OF THE DYNAMICS PLASMA DISCHARGES

- **A double pulse plasma is utilized to control plasma generation and electron heating. The first voltage pulse generates plasma and the second voltage pulse controls electron heating by manipulating E/N.**
- **Hosting collaborating institutions (West Virginia University, M. Koepke; Colorado State University, A. Yalin) have utilized this plasma system to further DOE funded research goals.**

Time averaged parameters

5 μs average, 10 μs after pulse is applied



- **Manipulation of the plasma species is controlled through application of a second voltage pulse.**

Mode Transition of Hall Thruster Discharge Plasma

Kentaro Hara and Iain D. Boyd

(a) Department of Aerospace Engineering, University of Michigan
kenhara@umich.edu; iainboyd@umich.edu)

The mode transition of the discharge oscillation in Hall Thrusters between the discharge oscillation mode, often called the breathing mode, and stable mode has been studied using a 1D hybrid-direct kinetic (DK) simulation and experiments[1]. The DK simulation solves the kinetic equations to obtain the velocity distribution functions (VDFs) directly in discretized phase space. In comparison to existing particle methods, there are two advantages of using the DK simulation: (1) time averaging techniques are not needed since there is no statistical noise that arises due to the use of macro-particles; and (2) ionization events are captured every time step in every phase space bin whereas particle methods cannot capture ionization in detail due to computer memory restrictions.

The predicted mode transition agrees with experiments in terms of the mean discharge current, the amplitude of the current oscillation, and the breathing mode frequency. (See Fig. 1.) Stabilization of the breathing mode is associated with reduced electron transport that suppresses the ionization process. The balance between Joule heating and the other energy loss mechanisms stabilizes the global plasma oscillation and hence the discharge current oscillation. We found that there is a strong correlation between the emitted light intensity and the discharge current.

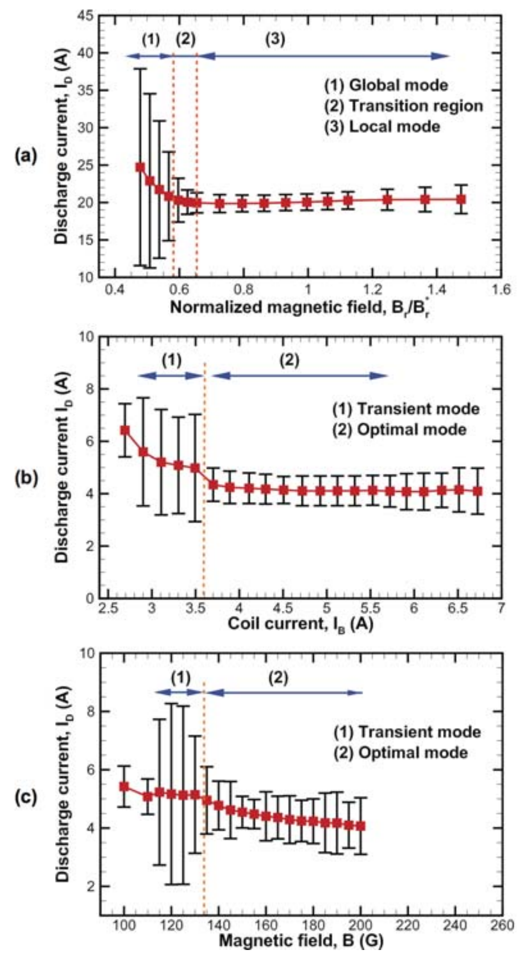


Figure 1 – Discharge current vs. magnetic field. Red symbols are the mean discharge current and error bars show the standard deviation. (a) Experimental results for the H6 thruster, (b) Experimental data for the SPT-100 thruster. Reproduced from Ref. 2, (c) Numerical results for the SPT-100 thruster

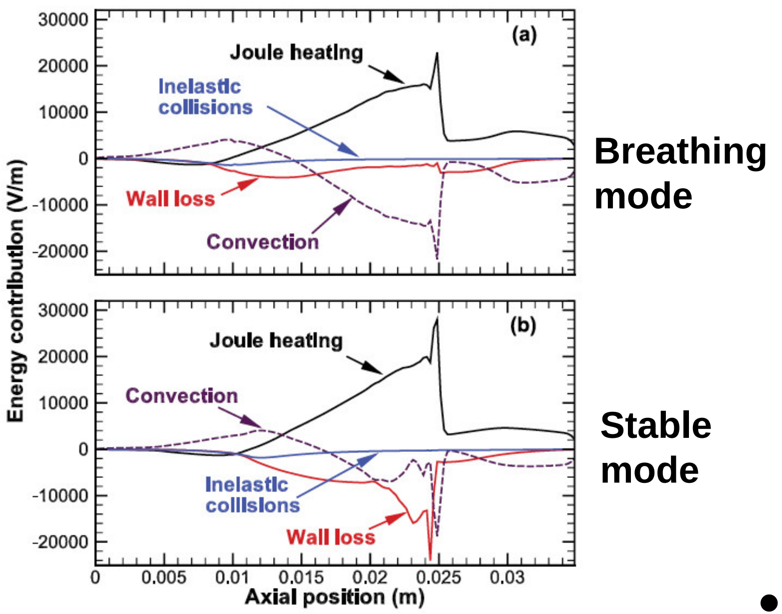
References

[1] K. Hara, M. J. Sekerak, I. D. Boyd, and A. D. Galimore, J. Appl. Phys. **115**, 203304 (2014)

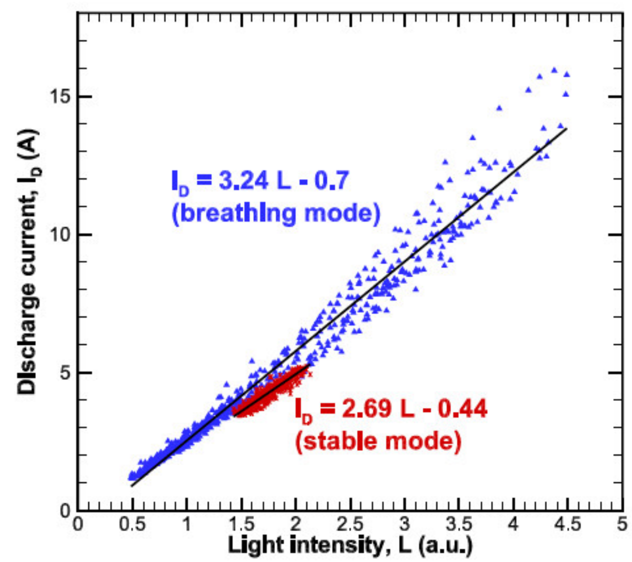
[2] N. Gascon, et al., AIAA 1999-2427, Los Angeles, CA, (1999).

MODE TRANSITION OF HALL THRUSTER DISCHARGE PLASMA

- **Transition of discharge oscillation mode in Hall thruster was numerically studied using a 1D hybrid-direct simulation code, and experimentally investigated using a high-speed Langmuir probe and ultra fast camera.**
- **Results indicate that discharge oscillation is stabilized due to reduced electron transport (heat convection) and increased wall effect (thermal energy).**
- **Correlation between discharge current and light intensity is shown for the first time.**



- **Electron energy balance**



- **Light intensity (excited state atom density) vs. discharge current**

HIGHLIGHT

UNIVERSITY OF MICHIGAN

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics