Control of Electron Energy Distribution Functions Using Dual Tandem Pulsed/CW Plasma Sources

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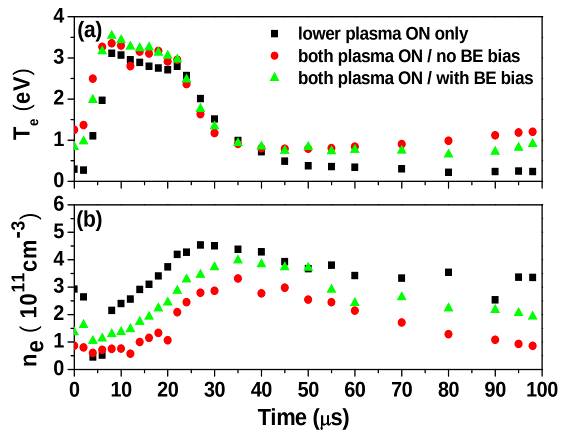

Fig. 1. a) Langmuir probe measurements of T_e. ▪: lower plasma ON (case 1); ●: both ON no bias (case 2); ▲: both ON, +60 V bias (case 3). b) n_e. for 3 cases.

Using dual tandem inductively coupled plasma (ICP) sources separated by a grid, we were able to control the electron energy distribution (EEDF) in a pulsed Ar ICP by injecting species from an adjacent continuous plasma. The electron temperature T_e of the EEDFs in the afterglow were controllable by the use of a biasable boundary electrode (BE) at one end of the upper, injection plasma source. Measured T_e are shown in Fig. 1a for: (1) only the lower plasma (main ICP) is ON, (2) both plasmas are ON, and the boundary electrode is grounded, and (3) both plasmas are ON, and the boundary electrode is biased to +60 VDC. The lower plasma is turned ON (start of activeglow) at t=5 μs and OFF (start of afterglow) at t=25 μs. The afterglow lasts for 80μs. In each case, T_e reaches a quasi-steady state, with: T_e (both plasmas ON, no BE bias) ≈ T_e (both plasmas ON with BE bias) > T_e (only lower plasma ON).

After the lower plasma power is turned OFF, T_e drops within 10 μs and reaches a low, almost constant value for the remainder of the afterglow at 0.21 eV, 0.98 eV and 0.65 eV, for cases (1), (2) and (3). T_e of the upper and lower cw plasmas are 4.5 eV and 3.0 eV, so the upper source has a higher plasma potential, V_p. Only high energy electrons can overcome the potential barrier in the upper plasma and be injected into the lower plasma. When they pass through the grid, they regain energy and move freely in the lower plasma. Energetic electrons that can overcome the potential barrier of the lower plasma are also injected into the upper plasma making electron injection bidirectional. When the lower plasma is OFF, T_e cools and electrons do not have enough energy to overcome the potential barrier and be injected from the lower to the upper plasma. Nevertheless, hot electron (and an equal flux of positive ion) injection still occurs from the upper to the lower plasma, causing T_e in the afterglow to increase from 0.21 to 0.98 eV. Simulations predict a similar, though less dramatic effect. With both plasmas ON and positive bias on the boundary electrode, (case 3), V_p is raised, as positive bias drains electrons from the plasma, so that all but the very high energy electrons remain confined in the plasma. Since a much smaller number of high energy electrons from the upper plasma are allowed to enter the lower plasma compared to case 2, T_e in the afterglow of the lower plasma drops from 0.98 eV to 0.65 eV. This bias-selected T_e control could offer important advantages for controlling gas dissociation and ionization in plasmas.

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Highlight

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems
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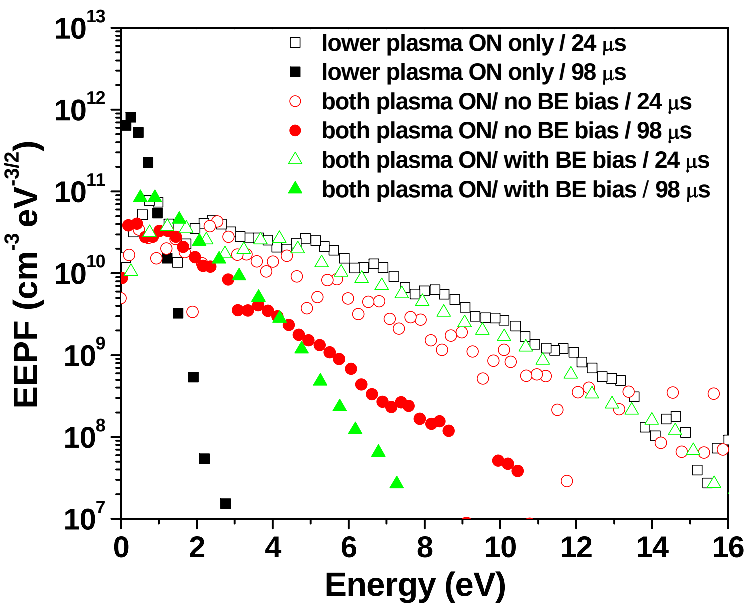
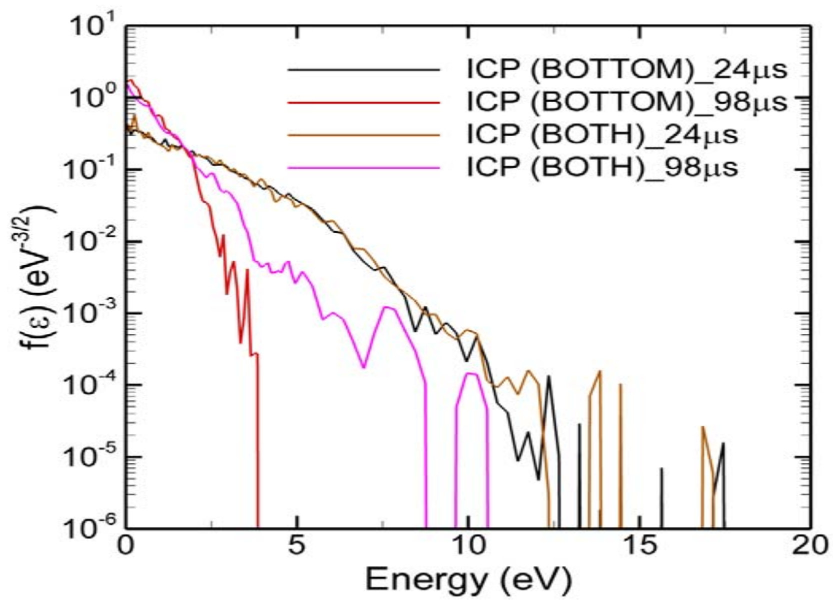
CONTROL OF ELECTRON ENERGY DISTRIBUTIONS USING DUAL TANDEM PULSED/CW PLASMA SOURCES

- **Pulsed lower Ar ICP with and without injection of species from a cw upper Ar ICP with Boundary Electrode (BE) grounded or biased at +60 VDC.**
- **Plasma injection has little effect during the ON period but heats the EEDF during the OFF period. With +60 V BE bias, the high energy electrons are lost and low energy electrons enhanced.**





- **Measured (left) and simulated (right) EEPFs with and w/o upper plasma power and +60V on BE.**

Time-averaged Characterization and Predictive Control of the Electron Energy Distribution Functions (EEDFs) in Hall Thruster Plasmas

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Ions, accelerated to high velocities, in the low temperature plasma (LTP) inside Hall-effect Thrusters (HETs) are the thrust-producing constituent. With the continuing push for more efficient use of propellant in HETs,[1] predictive control of the EEDFs is needed. The ability to tailor the EEDF would allow electrons with energies that contribute to ionization to be increased. However, predictive control of the EEDFs in LTP devices is a challenging problem in plasma physics due to the complex electromagnetic interactions that take place in the actual system. Improved Hall-effect Thruster (HET) efficiency would allow more rapid repositioning of communication satellites and decrease their maintenance costs. In addition, this pursuit will allow us to obtain a deeper understanding of the underlying physics in the operation of these LTP devices.

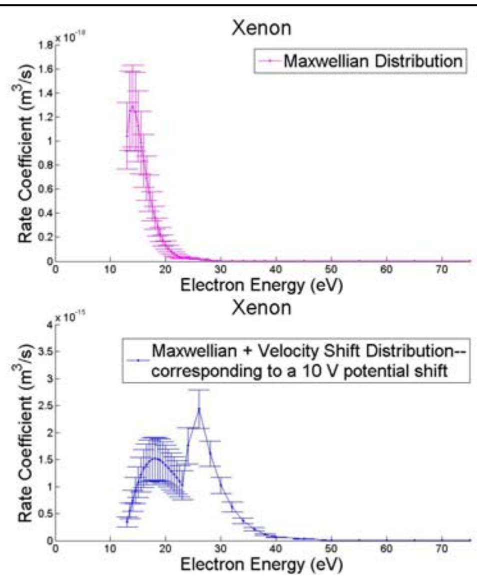


Fig. 1 – Example of how the form of the EEDF affects calculated reaction rate constants for the reaction: $Xe + \tilde{e} \rightarrow 2e + Xe^{+}$

A PEPL-designed hollow cathode is being used as the test cell for exploratory EEDF control experiments. These smaller scale experiments, using the electron-producing component of a Hall thruster, will give us a good indication of the effectiveness of a gas mixing method for EEDF control.

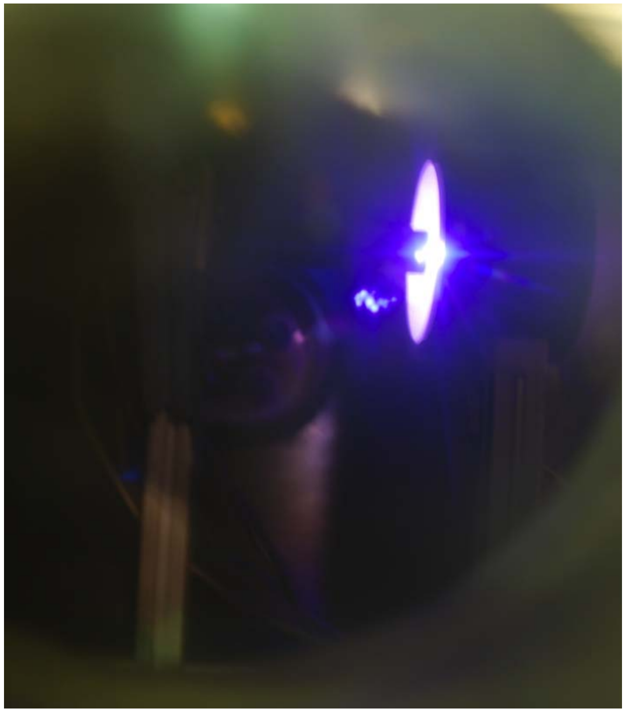
Calculations to estimate the increase in ionization that could result for various gas mixtures are currently being carried out. These calculations will guide the choice of auxiliary gas and the ratios used to focus the experiments and decrease test time. With the calculations completed thus far for standard electron impact ionization, shown in Fig. 1, it is apparent that the form of the EEDF has a significant affect on the reaction rate constant for ionization. This underlines the importance of the EEDF characterization component of this research. Having the correct form of the EEDF will allow accurate simulation of the optical spectral data which will allow more definite conclusions to be drawn about the effect of the gas mixing method on ionization.

References

[1] J. A. Linnell, "An Evaluation of Krypton Propellant in Hall Thrusters," Ph.D. Dissertation, Aerospace Engineering Dept., University of Michigan, Ann Arbor, Michigan (2007).

TIME-AVERAGED EEDF MEASUREMENTS TOWARDS PREDICTIVE EEDF CONTROL IN HETs

- **Project Goals:**
- **Characterize the time-averaged Electron Energy Distribution Functions (EEDFs) of Hall-effect Thrusters (HET) plasma**
- **Develop schemes to predictably tailor the EEDF to increase HET efficiency**
- **Exploratory test cell EEDF control experiments using the electron-producing component of a Hall thruster, the hollow cathode**
- **Use test cell to determine the ratio of an auxiliary gas that maximizes the increase in ionization of the main propellant gas, xenon or krypton**



- **Hollow cathode operated in triode mode with an external cylindrical anode. Here the cathode is running on krypton gas.**

PLSC_0813 ***HIGHLIGHT***

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