Generation of Novel EEDFs in a Tandem Plasma Reactor

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Control of electron energy distributions is one of the most important and challenging issues in low temperature plasma science and technology. Several approaches have been investigated, including pulsed plasma power [1], dual frequency operation [1] and ultrahigh frequency operation.[2] Here we introduce a new approach. Energetic particles (electrons, positive ions, negative ions, photons, fast neutrals, metastables, or combinations) from a tandem plasma are injected into the main plasma, to influence the EEDF of the main plasma. The two plasmas are separated by a grid, and have separate control of the power and to some extend gas composition.

By applying a positive bias to a boundary electrode on the tandem plasma, we raise its plasma potential and expel positive ions through the grid with an energy equal to the bias voltage. This ion injection increased the plasma density in the main Ar plasma beneath by 22% for 80 eV ions, with an onset at 30 eV, close to the threshold energy for ion-impact ionization of Ar. Preliminary EEDFs in the center and near the far edge of the lower plasma are shown in Fig. 1 for: (a) main (lower) power only, (b) tandem power only, and (c) both sources powered. With only main ICP power, the EEPF is bi-Maxwellian with a cooler tail due to inelastic collisions. With only tandem source power, the center EEPF is again bi-Maxwellian, with a small enhancement of the high energy tail over that with just lower plasma power. Near the edge, however, the tandem plasma dramatically affects the low-energy region, which becomes depleted of electrons, and the high energy tail, which is greatly enhanced. This "transfer" of electrons from <5 eV to > 7 eV could suppress VUV light from conversion of Ar 1s5 to 1s4, while enhancing ionization out of the 1s5 state, lowering the VUV flux to ion flux ratio bombarding the substrate, thereby favoring ion-assisted over photo-assisted etching. More experiments are needed to understand such effects, but the first results are encouraging and intriguing.

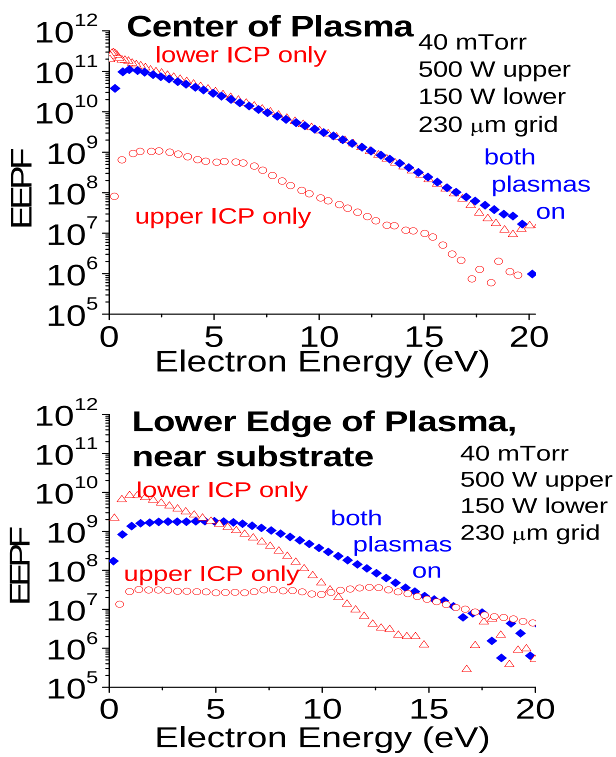


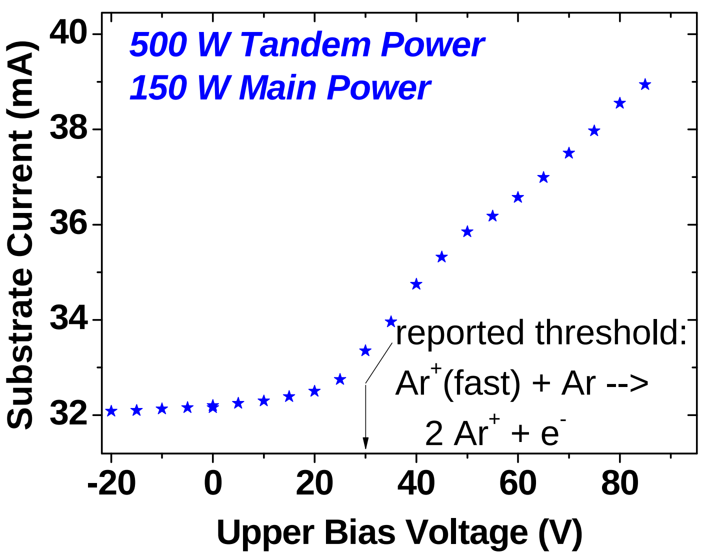
Fig. 1. EEPFs of Ar plasmas in the downstream chamber, near the center and at the far edge. The grid is grounded.

References

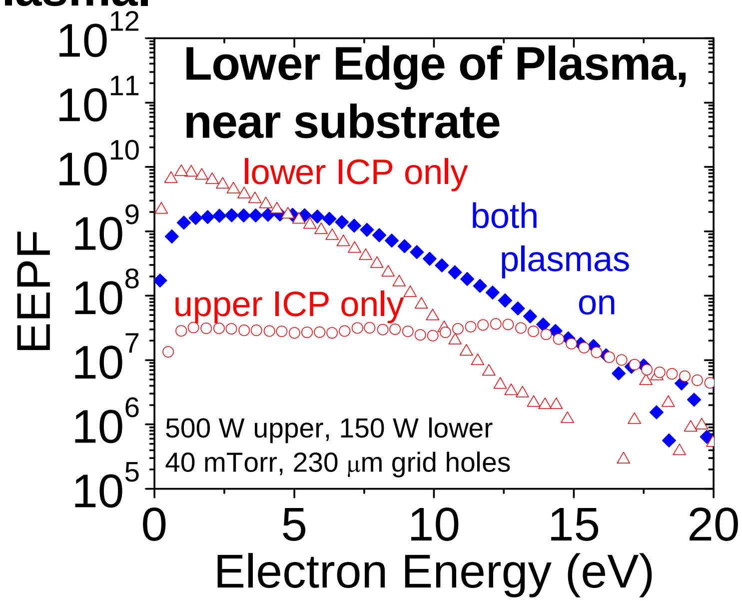
[1] S-H. Song and M. J. Kushner, Plasma Sources Sci. Technol. **21**, 055028 (2012).
[2] M. V. Malyshev, V. M. Donnelly, and S. Samukawa, J. Appl. Phys. **84**, 1222 (1998).

GENERATION OF NOVEL EEDFS IN A TANDEM PLASMA REACTOR

- Energetic particles (electrons, ions, photons, fast neutrals, metastables, or combinations) from a tandem plasma are injected into the main plasma, to boost the charge density and influence the EEDF of the main plasma.
- Injecting energetic (+) ions increases plasma density, suggesting fast ion and neutral impact ionization.
- Tandem plasma injection dramatically "transfers" electrons in the EEDF from <5 eV to > 7 eV at the edge of the main plasma.



- 80eV Ar^+ injection raises plasma density 22%



- EEDF modification with Tandem plasma

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HIGHLIGHT

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Control of Plasma Kinetics

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

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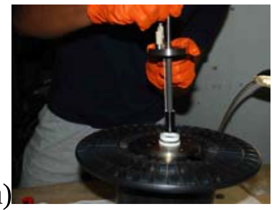
a) 

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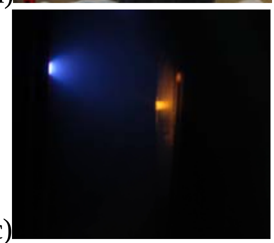
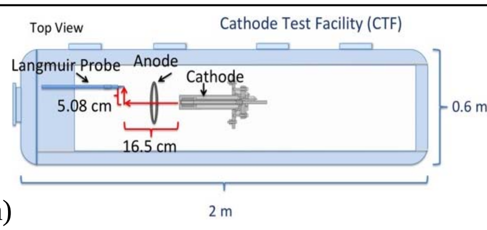
c) 

Fig. 1 – a) Assembly of the hollow cathode. b) Fully assembled cathode. c) Cathode operating in triode mode with external annular anode.

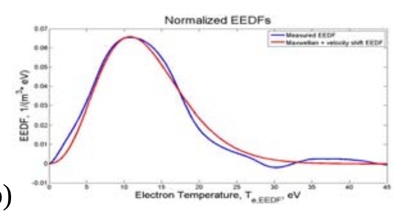
Ions, accelerated to high velocities, in the low-temperature plasma (LTP) inside Hall-effect Thrusters (HETs) are the thrust-producing constituent. With the continued push for more efficient use of propellant in HETs,[1] predictive control of the electron energy distribution functions (EEDFs) is needed. The ability to tailor the EEDF would allow the population of electrons with energies that contribute to ionization to be increased with the most efficient use of input power. 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.

A specially designed hollow cathode is being used as the test cell for exploratory EEDF control experiments. These smaller scale experiments will verify the effectiveness of proposed EEDF control methods. The design, optimization and testing of the hollow cathode have been completed this year. (See Fig. 1.) For the current tests, the cathode is being operated in triode mode with an external annular anode to permit operation for extended periods for taking data.

The EEDFs are calculated using measurements from a specially designed dual Langmuir probe system. The drifting plasma of hollow cathodes causes their EEDFs to fit a Maxwellian with an energy around 1-eV plus a 10^6 m/s velocity shift profile instead of the 5-eV estimated when assuming the EEDF is a pure Maxwellian. (See Fig. 2.)



a)



b)

Fig. 2 – a) Schematic of the cathode, anode and Langmuir probe in the Cathode Test Facility (CTF); b) Characteristic EEDF of the hollow cathode plasma is best described by a drifting Maxwellian distribution.

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.

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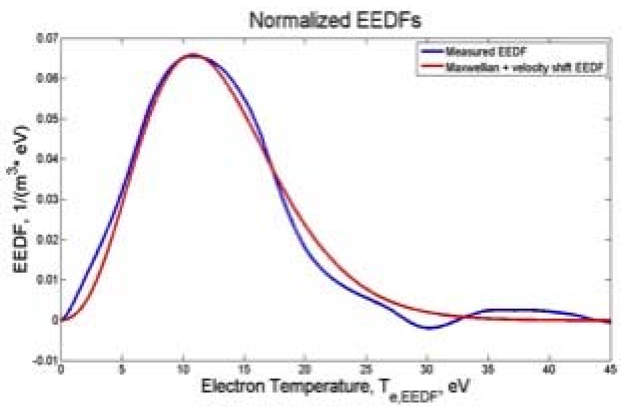
MEASURING THE EEDF USING AN ADVANCED LANGMUIR PROBE SYSTEM

- **Time-averaged EEDF Test Cell Measurements**
  - **Hollow cathode with external annular anode serves as test cell**
  - **Investigate potential EEDF control methods**



- **Hollow cathode EEDFs are best fit to a 1-eV Maxwellian + 10^6 m/s velocity shift**
- **Current tests will produce maps of plasma characteristics and EEDFs to characterize cathode plume, and allow comparison between potential EEDF control techniques.**

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