# Emissive Probe Measurement of Sheath Potential with Secondary Electron Emission in a Low-Density Xenon Plasma

**Alexander C. Englesbe, Kapil U. Sawlani, and John E. Foster**
Department of Nuclear Engineering and Radiological Sciences, University of Michigan

## Project Motivation – Hall-Effect Thrusters

Hall thrusters are a subset of crossed-field devices in which the electrons execute an azimuthal $E \times B$ drift, while the ions are unmagnetized and are accelerated out of the device by the axial electric field, producing thrust. The experiments in this study investigate a single aspect of Hall thruster physics – the emission of secondary electrons due to plasma-surface interaction. In order to better understand this phenomenon, a high-accuracy laser-induced fluorescence technique is to be developed for use in a low-density plasma, where the yield of secondary electrons is enhanced by irradiation with a low-energy electron beam.

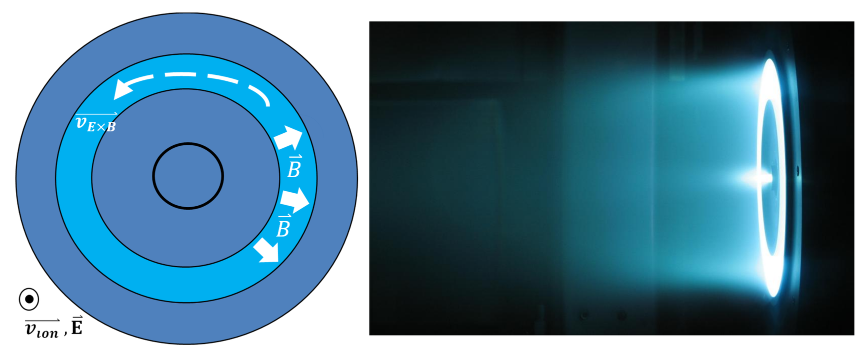

Figure 1: *Left* – A diagram a Hall thruster from the rear. *Right* – A Hall thruster in operation at JPL.

## Secondary Electrons and the Sheath

Secondary electron emission (SEE) from the thruster channel affects the electron energy distribution (EEDF) function of the main discharge plasma, and therefore has the potential to influence ionization efficiency. In order for secondary electrons to enter the plasma, they must traverse the sheath. SEE can alter the sheath potential, and therefore affect energy transfer to the wall. The EEDF is self-consistent with the plasma-wall interaction, thus we can infer the attributes of former and their consequences for thruster operation by investigating the latter.

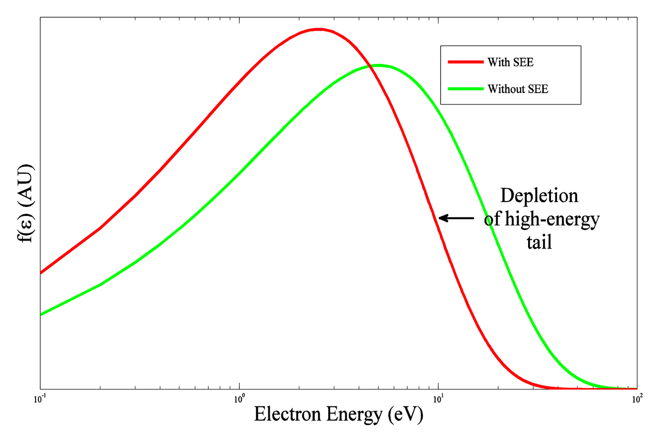


Figure 2: A qualitative demonstration of the effect of secondary electron emission on a Maxwell-Boltzmann EEDF.

## Experimental Setup and Plasma Source Characterization

The experiments take place in a cylindrical filament-driven multipole ring-cusp plasma source. The measurements of the plasma properties and sheath potential are made in the field-free region (|B| ~ a few Gauss). The magnetic field effects present in a Hall thruster are not considered in this experiment so that the secondary electron behavior can be isolated.

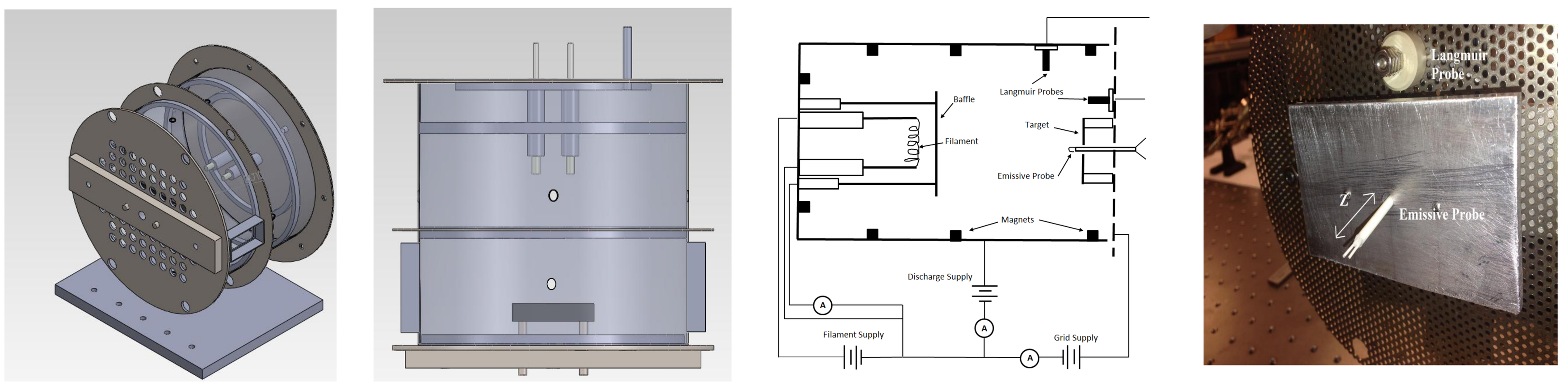

Figure 3: *Left* – A model of the plasma source. *Middle, left* – The model viewed from the top showing the position of the target and filament holder. *Middle, right* – A circuit diagram of the experiment. *Right* – A photograph demonstrating the operation of the emissive probe diagnostic.

The source is operated at densities of $10^7$-$10^8$ $cm^{-3}$ in order to maximize the sheath thickness ($\lambda_D$ ~ 0.1 cm, sheath thickness ~1 cm) which allows for the sheath potential to be spatially resolved with an emissive probe. Figures 4 and 5 show the rough trends in the plasma properties as a function of the operating conditions. The thick sheath condition is achieved by maximizing the grid voltage, and minimizing the filament current, gas flow rate and discharge voltage.

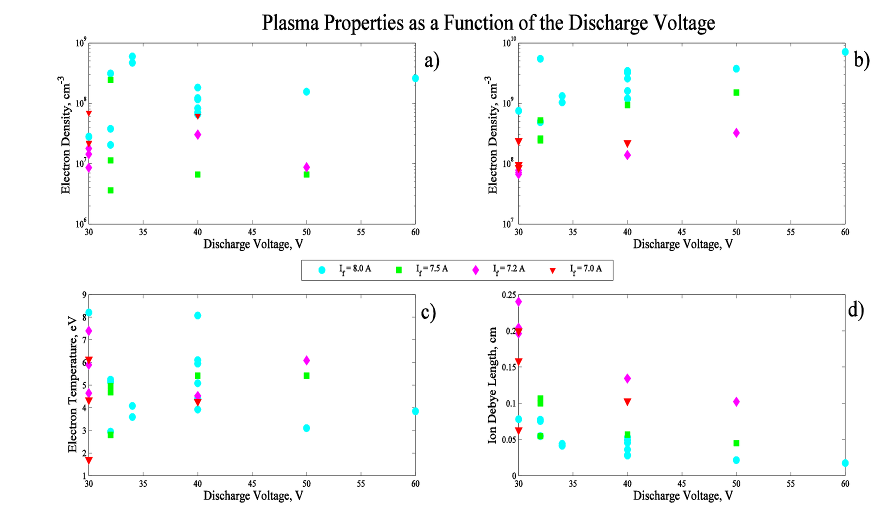


Figure 4: *a)* Electron density, *b)* ion density, *c)* electron temperature, and *d)* Debye length as a function of the discharge voltage. The different markers correspond to the filament current, $I_f$.

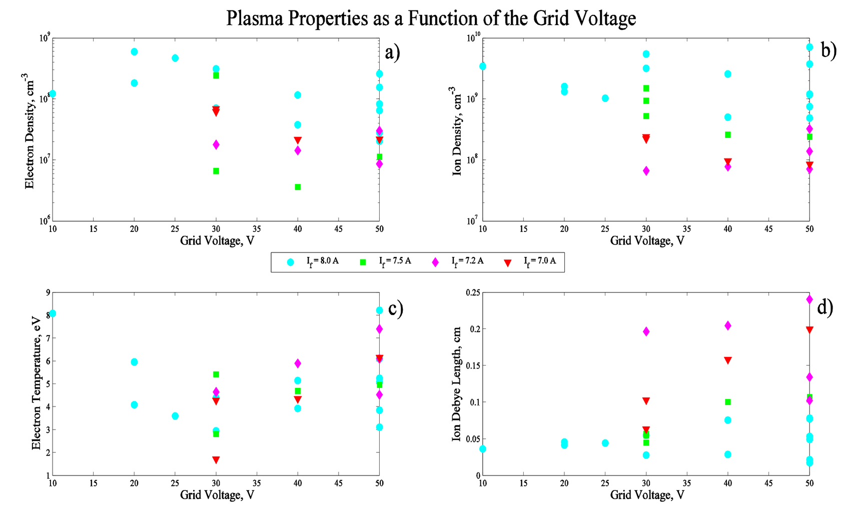


Figure 5: *a)* Electron density, *b)* ion density, *c)* electron temperature, and *d)* Debye length as a function of the grid voltage. The different markers correspond to the filament current, $I_f$. In general, the discharge voltage has a greater effect on the plasma properties.

## Emissive Probe Results

Secondary electron emission generally reduces the difference between the plasma potential and the sheath potential at the wall[1]. Translating an emissive probe through a thick sheath while sampling the local plasma potential gives an estimate of the sheath potential as a function of position. Comparison of these sheath potentials between different test conditions allows us to draw conclusions about the factors determining SEE yield.

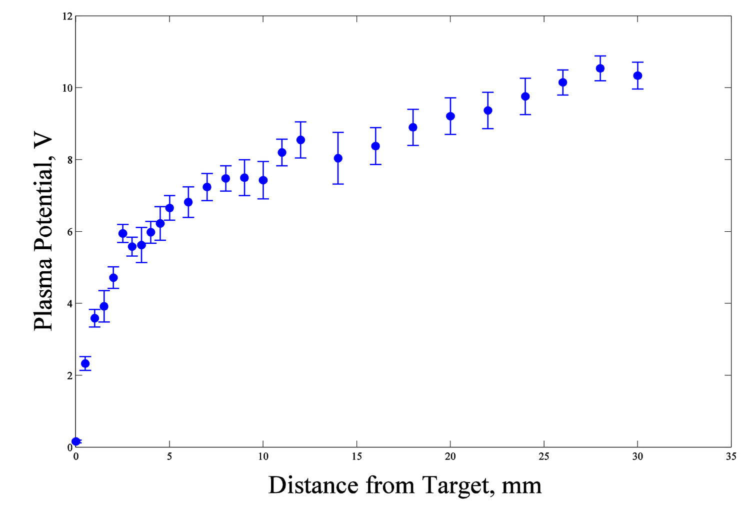


Figure 6: The sheath and pre-sheath are resolved in a plasma with electron beams having energies of about 55 eV, a temperature of a few eV, and a density of about $7 \times 10^8$ $cm^{-3}$.

## Sheath Potential Measurement with Laser-Induced Fluorescence

The sheath potential structure may be inferred with high accuracy using a non-perturbative diagnostic such as laser-induced fluorescence (LIF). The LIF measurements will be performed using a Sacher Lasertechnik Lynx-100 laser, which has a maximum output power of 25 mW at 670 nm. The Xe II LIF scheme due to Severn[2] will be used in a xenon ion velocimetry measurement similar to that of Lee and colleagues[3]. The amount of Doppler broadening of the velocity distributions is related to the local electric field.

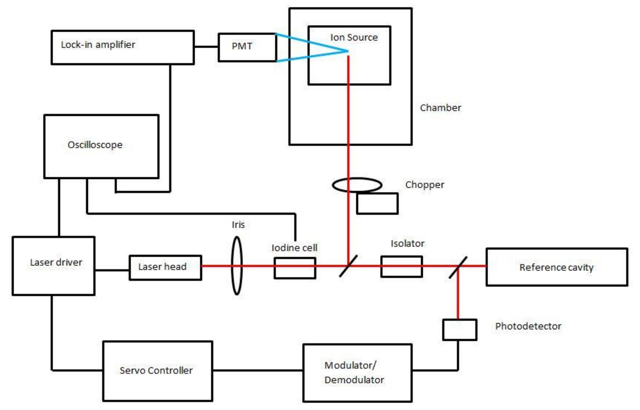

Figure 7: Schematic of planned LIF diagnostic setup.

## References

1. G.D. Hobbs & J.A. Wesson. "Heat Transmission Through a Langmuir Sheath in the Presence of Electron Emission", Culham Laboratory Report CM-R61, 1966.
2. G.D. Severn, D.A. Edrich, & R. McWilliams. "Argon ion laser-induced fluorescence with diode lasers", *Review of Scientific Instruments*, Vol. 69, No. 1, 1998.
3. D. Lee, N. Hershkowitz & G.D. Severn. "Measurements of $Ar^+$ and $Xe^+$ velocities near the sheath boundary of Ar-Xe plasma using two diode lasers", *Applied Physics Letters*, Vol. 91, 041505, 2007.

## Acknowledgements

-The presenter is grateful for support from the NASA Michigan Space Grant Consortium.
-This project is sponsored by the Air Force Office for Scientific Research.

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