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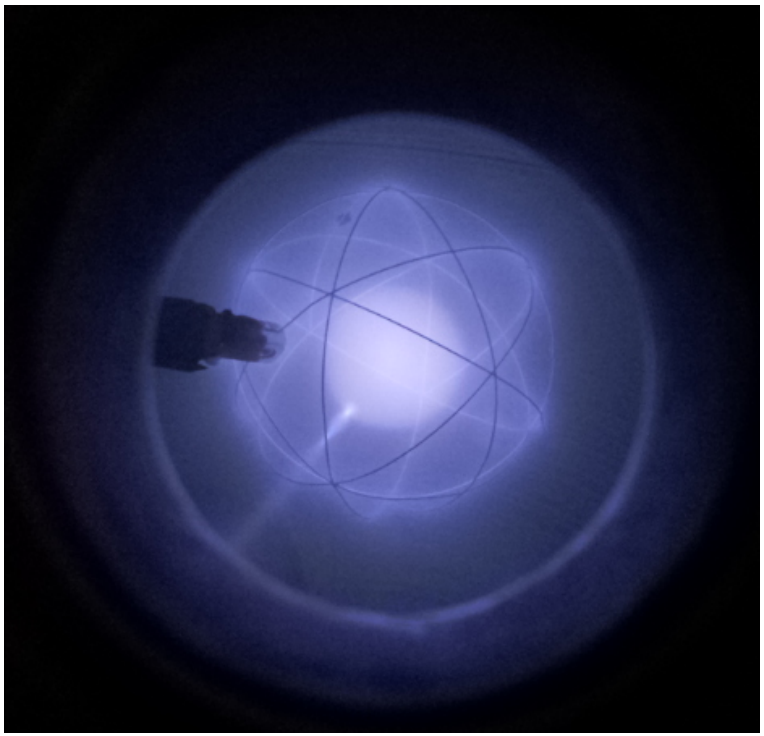
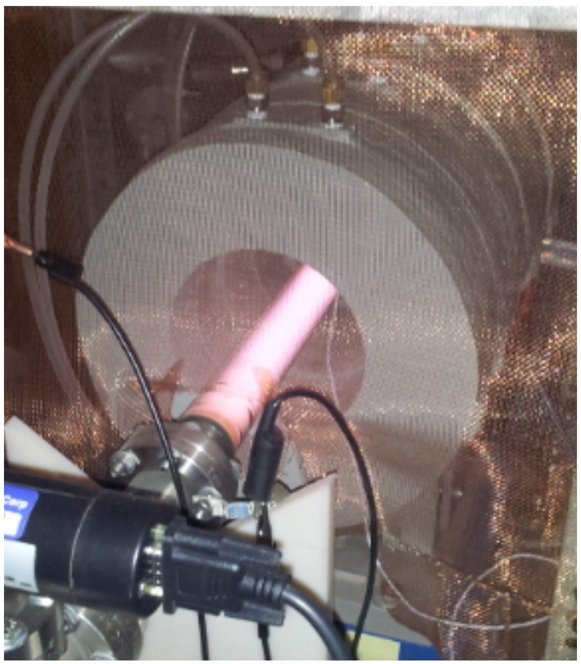
IEC:



- IEC at UIUC modified into a space thruster.
- IEC has several modes. The mode that is shown here is “jet” mode.

Helicon:



- A type of RF discharge in the presence of an axial magnetic field.

- Helicons are a high density plasma source (10^{17} m^{-3} – 10^{18} m^{-3}).

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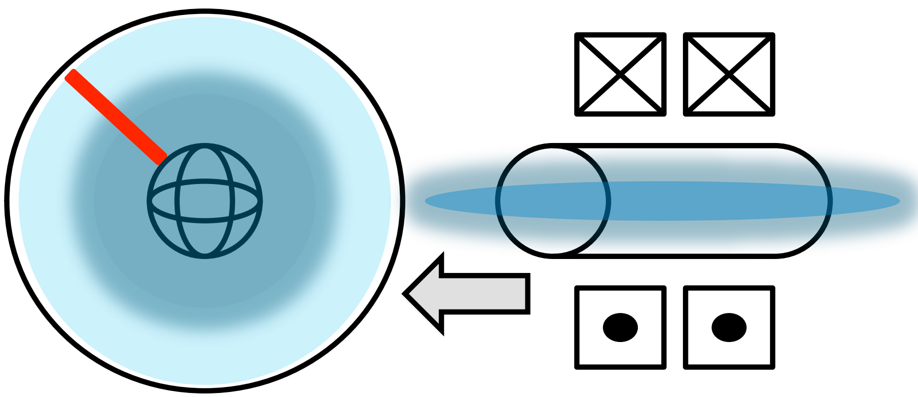
What is HIIPER?

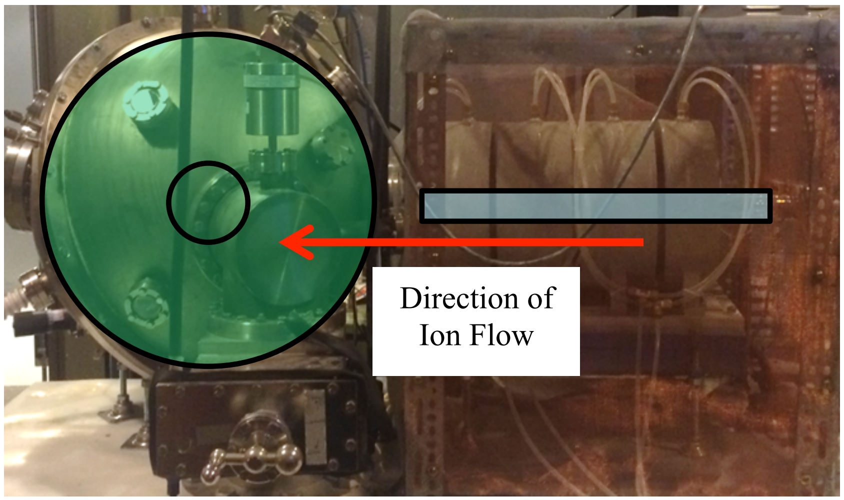


Helicon Injected Inertial Plasma Electrostatic Rocket (HIIPER)

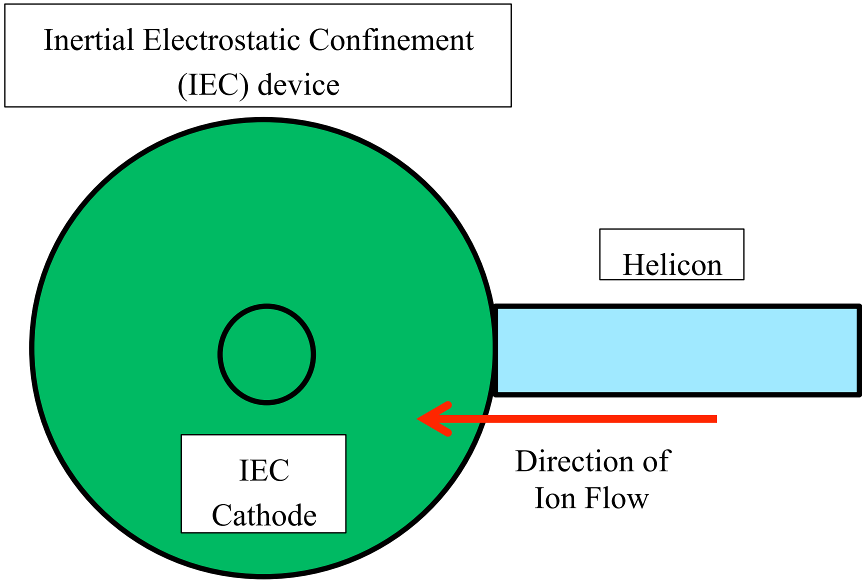
Helicon plasma injected IEC combination

What is HIIPER?

HIIPER Configuration



Representative model of the HIIPER



Schematic of HIIPER

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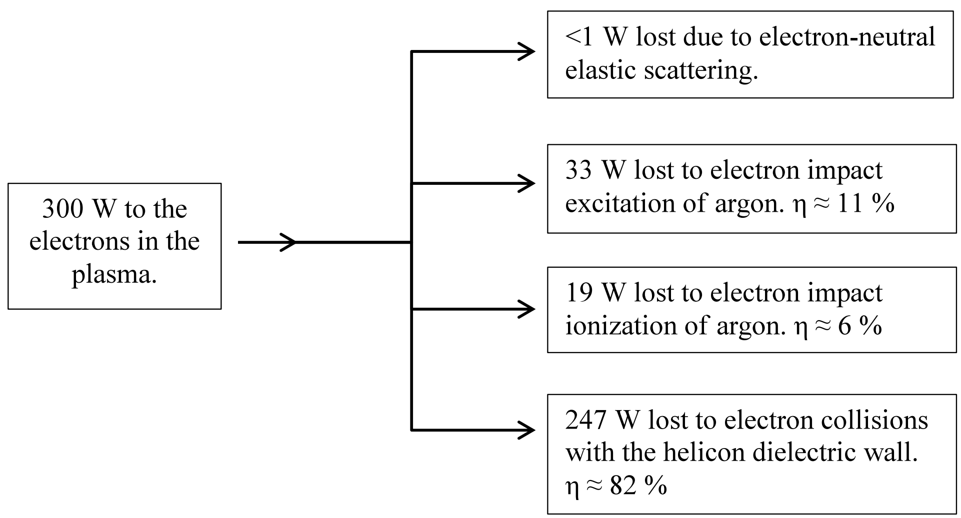
Analysis of Helicon

Distribution of power to the different reactions in a helicon plasma

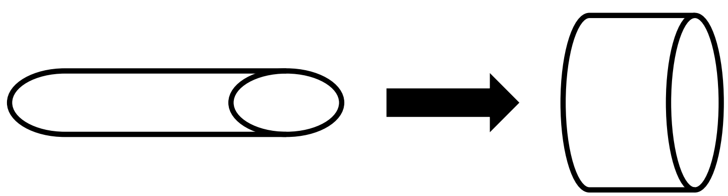


Analysis of Helicon

Lessons from the analysis:

- Minimize surface area of the dielectric tube without minimizing plasma volume.
- Decrease height of cylinder and increase radius.

$$S = 2\pi r H$$
$$V = \pi r^2 H$$



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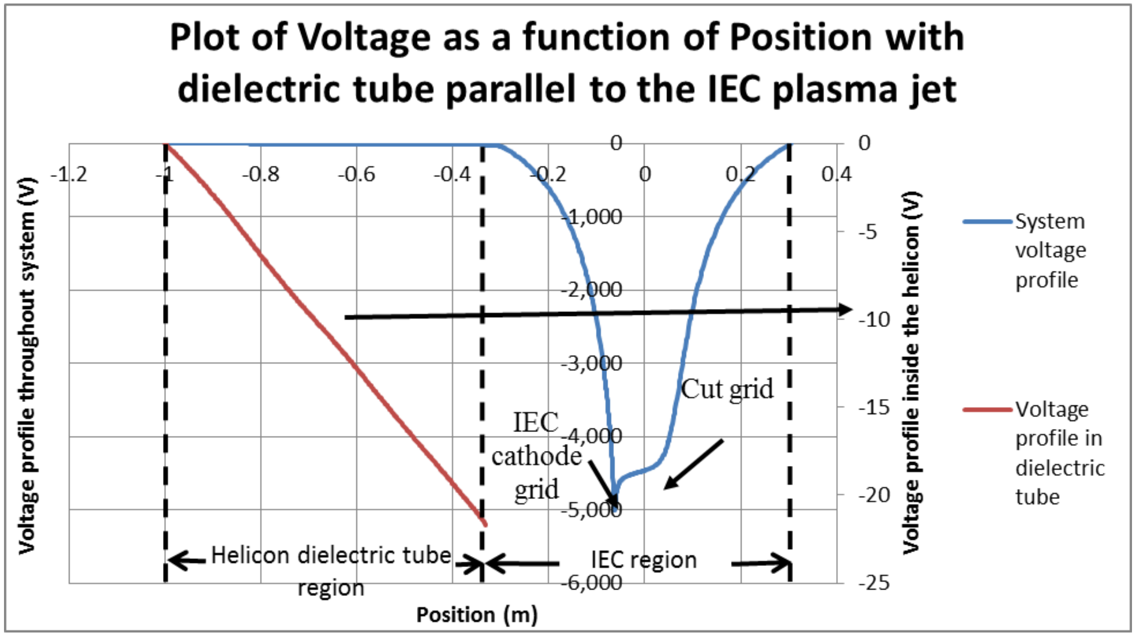
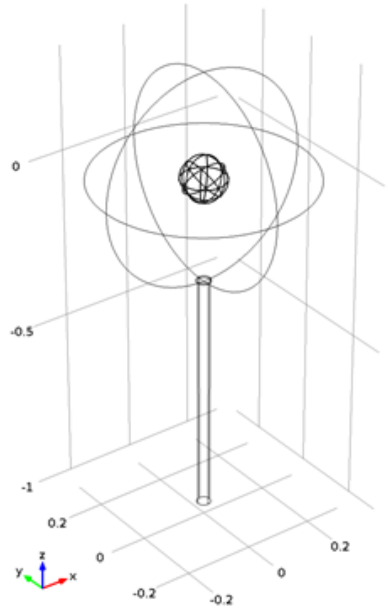
Coupling of the helicon and the IEC

Voltage profile of HIIPER with biased IEC grid with no plasma (helicon tube aligned with grid asymmetry)

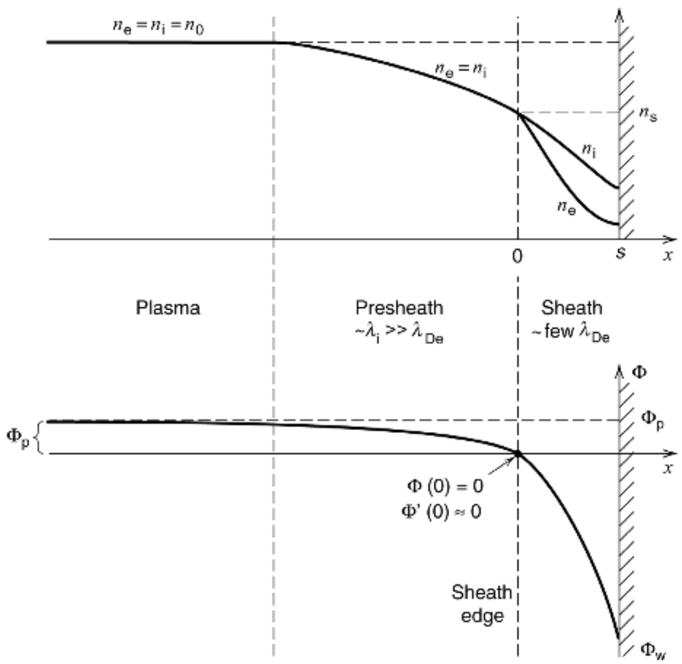


Drawing of the helicon tube aligned with the grid asymmetry

(Chen, 2013)



Coupling of the helicon and the IEC



(Lieberman, 2005)

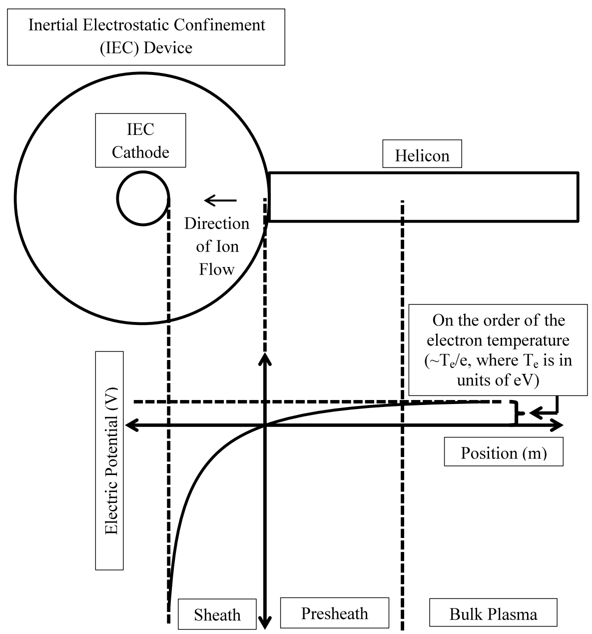
Model of the IEC-Helicon interface similar to a DC plasma sheath.

Description of the model:

- The “bulk plasma” region is in the helicon.
- The sheath region is in the IEC.

Coupling of the helicon and the IEC

Schematic model of the Helicon-IEC interface



Coupling of the helicon and the IEC

Ion flux approximated by the following equation:

$$\Gamma_i = \mu_i n_i E - D_a \nabla n_{\mathrm{i}}$$

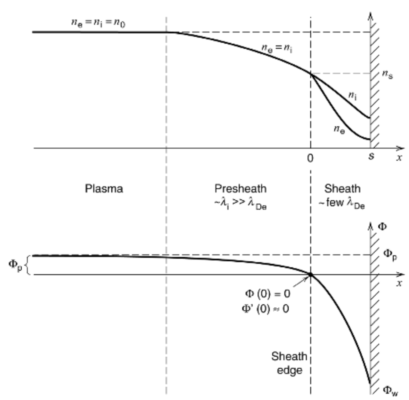
μ_i: ion mobility
n_i: ion number density
D_a: ambipolar diffusion coefficient
E: electric field

(Chen, 2006)

Coupling of the Helicon and the IEC

$$\Gamma_i = \mu_i n_i E - D_a \nabla n_{\mathrm{i}}$$

How do we find the variables to this equation?

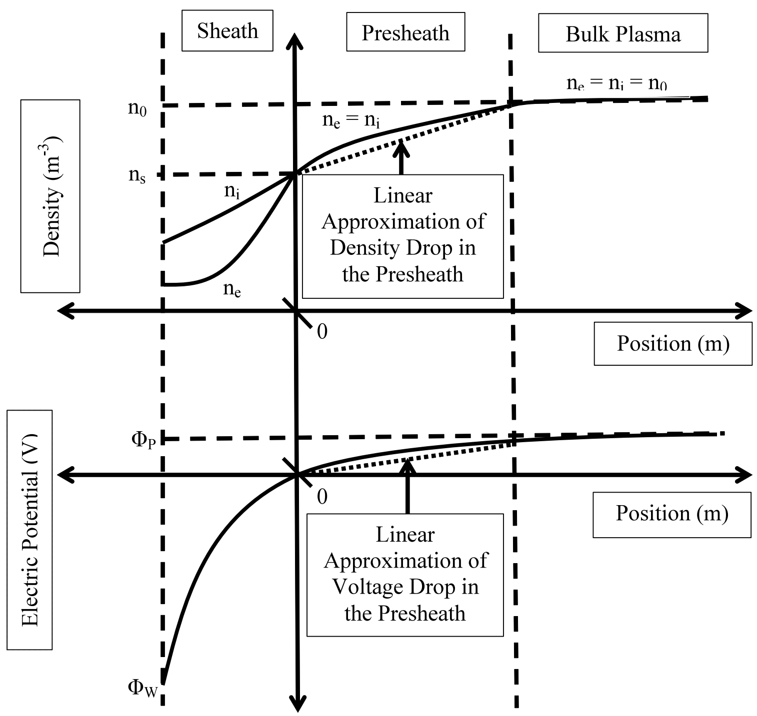


(Lieberman, 2005)

Conditions in the sheath vary drastically. For example:

- quasi-neutrality does not hold
- most of the voltage drop occurs in the sheath

Coupling of the Helicon and the IEC



Conditions to determine the variables in the ion flux equation are less erratic in the presheath.

Coupling of the Helicon and the IEC

The different properties of the presheath can be determined from various diagnostics, for example:

Langmuir Probe:

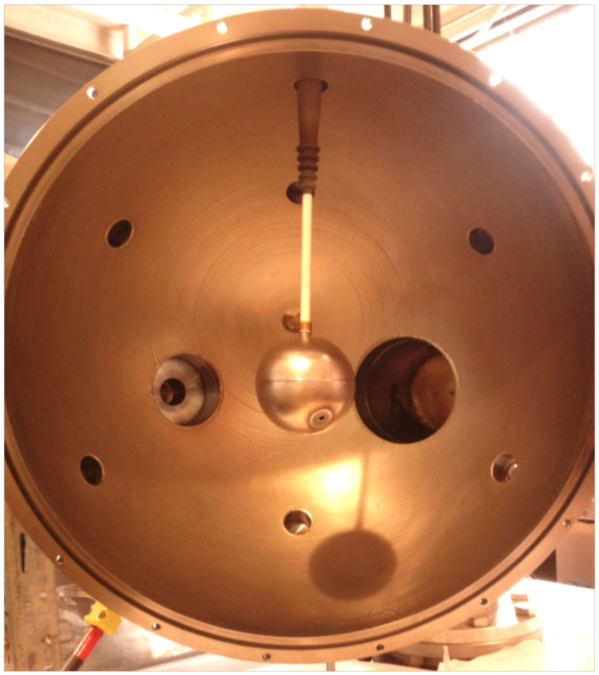
- Electron temperature in the helicon
- Electron density in the helicon

Emissive Probe:

- Length of the presheath

Coupling of the Helicon and the IEC

Spherical Langmuir Probe



Calculation from the model previously described compared with experiment:

- Spherical probe used to mimic the potential profile of the spherical IEC grid
- Spherical probe biased to -3000 V, this would put the probe in the ion saturation region
- Ion current collected at a specific voltage bias

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Conclusions:

The geometry of the helicon dielectric tube plays an important role in plasma formation efficiency which affects flow rate

- Shorter length
- Larger radius

Conclusions:

Presheath measurements can be used to estimate the ion flow from the helicon to the IEC.

- Plasma density and electron temperature in the bulk plasma can be determine from a RF-compensated Langmuir probe

$$\Gamma_i = \mu_i \cancel{n_i} E - D_a \nabla n_\mathrm{i}$$

Conclusions:

- Density drop in the presheath can be determined from the Boltzmann relation

Boltzmann Relation: $n(V) = n_0 e^{\frac{e(V-V_0)}{Te}}$

- Voltage drop in presheath on the order of the electron temperature in eV divided by elementary charge
- Length of the presheath determine by emissive probe

$$\Gamma_i = \mu_i n_i E - D_a \nabla n_i$$

Conclusions:

Mobility and ambipolar diffusion coefficient can be determine from:

- The ion temperature (approximately equal to the neutral gas temperature)
- Neutral gas density (from pressure)
- Mean free path of neutral gas atoms (given the temperature range it can approximated as hard sphere collision)
- Electron-ion collision frequency (given in (Chen, 2006))

$$\Gamma_i = \mu_i n_i E - D_a \nabla n_\mathrm{i}$$

Conclusions:

RF FWD: (W)	Calculated Ion Flow Rate: (s^{-1})	Measured Ion Flow Rate: (s^{-1})	Error (%)	Normalized Error
30	9.37×10^{15}	1.78×10^{16}	47	0
60	1.27×10^{16}	2.70×10^{16}	53	-0.13
90	1.46×10^{16}	3.54×10^{16}	59	-0.26
120	1.70×10^{16}	4.21×10^{16}	60	-0.28
150	1.87×10^{16}	4.77×10^{16}	61	-0.30
180	1.99×10^{16}	5.39×10^{16}	63	-0.34
210	2.14×10^{16}	5.85×10^{16}	63	-0.34
240	2.32×10^{16}	6.28×10^{16}	63	-0.34
270	2.37×10^{16}	6.83×10^{16}	65	-0.38
300	2.67×10^{16}	6.86×10^{16}	61	-0.30

Calculation are based on experimental measurement (e.g. Langmuir probe) and several approximations

Conclusions:

Agreement between experimental and calculated results are thought to be reasonable given errors associated with many theoretical and experimental comparison for plasmas.

The present measurement shows that the ion flow rate can be increased by shortening the presheath length by decreasing the helicon tube length and the distance of the high density plasma in the helicon from the IEC.

Conclusions:

The goal of the improved flow rate into the IEC can be achieved by careful design of the helicon geometry combined with the optimization of the helicon-IEC coupling region.

Future Work

Calculations were determined from previous experimental data and information

Perform new diagnostic measurement (e.g. emissive probe measurements) such as mapping the potential profile from the helicon into the IEC to reconfirm results

Consider a inverted helicon design to increase ion density and hence flow rate to the IEC (Masters, 2010).

Acknowledgment

- NPL Associates
- Air Force Research Lab
- National Systems
- NASA

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B. C. Masters, "Development and Characterization of Conventional and Inverted Helicon Plasma Sources," University of Illinois at Urbana-Champaign, Urbana, 2007.

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