Pulsed High Power Helicon Plasma Source

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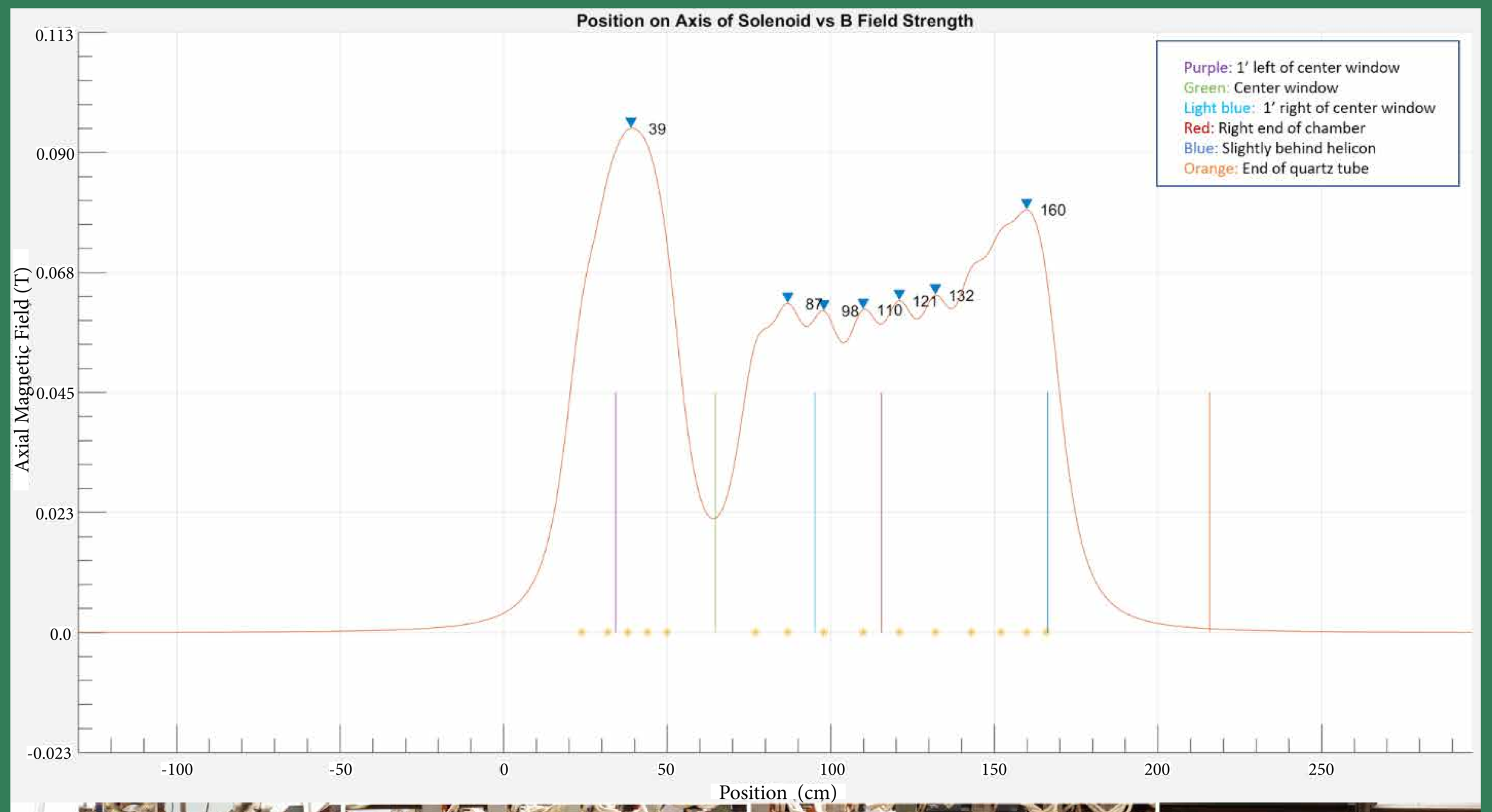
EAGLE HARBOR TECHNOLOGIES

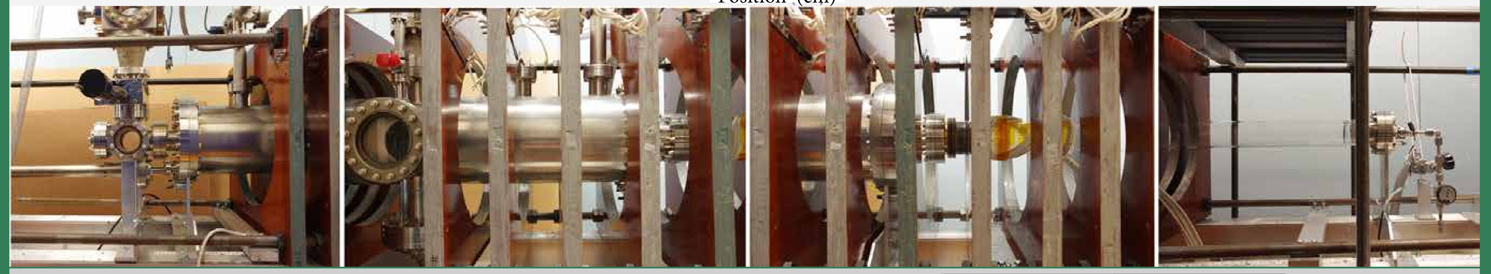
Introduction

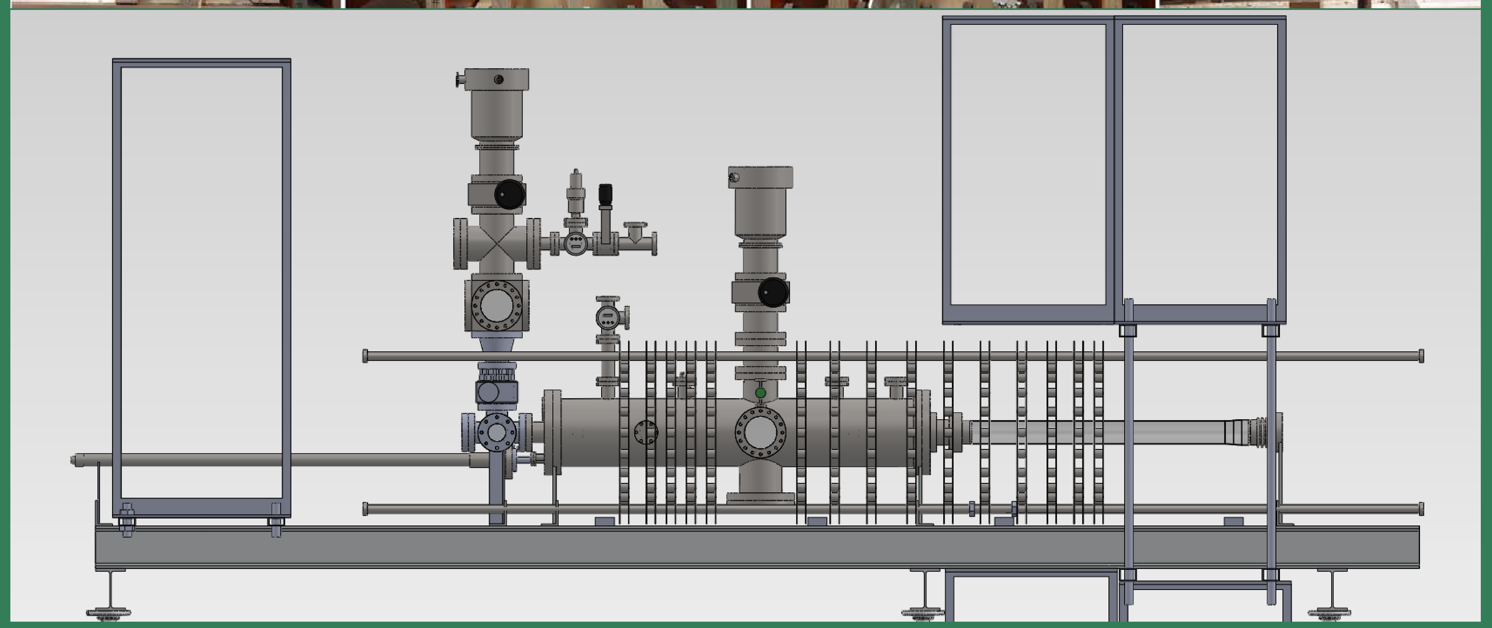
Eagle Harbor Technologies, Inc. (EHT) has developed a high power helicon plasma source for testing a repetitively pulsed, high power RF system for plasma heating. This system is built on the work of multiple SBIR programs including the development of a SiC MOSFET full-bridge and electrodeless plasma source. This full bridge drives a series resonant load, which allows for a low-cost way to produce large antenna currents in excess of 2.5 kA at 1 MHz. The resulting plasma has been characterized over a wide range of magnetic field strengths and input power levels. We will present Langmuir probe data showing plasma density and electron temperature over a range of plasma parameters.

Experimental Setup

The helicon antenna (14 cm length) is wrapped around a 7 cm diameter quartz tube, which is connected to a dump chamber (18.4 cm in diameter and 114 cm in length). The system is complies with UHV standards and can reach a base pressure of 3 x 10^8 Torr with the use of two turbo pumps.



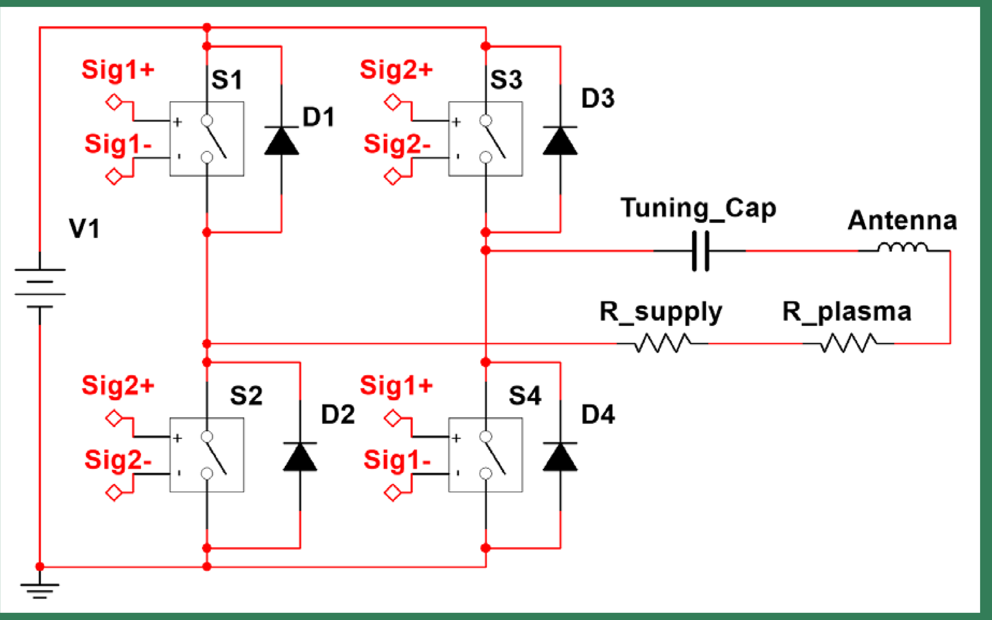


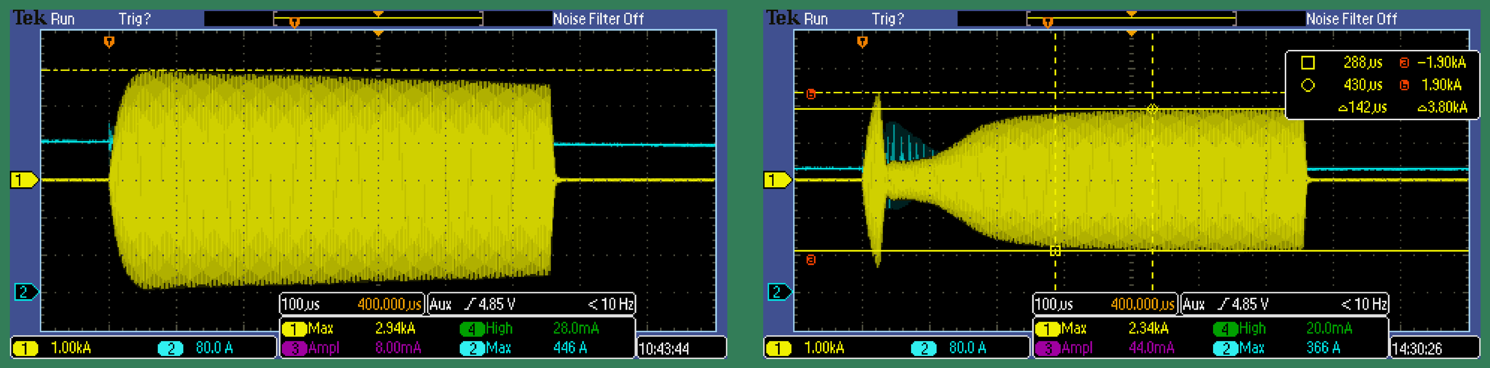


Top: Axial magnetic field strength as a function of distance. Notable chamber features are marked as colored lines. Center of coils are mark with yellow stars on B = 0 line. Middle: Montage of vacuum chamber. Bottom: CAD drawing of vacuum chamber, magnets, pumps, and empty equipment racks.

Helicon Power System

The helicon antenna is part of an RLC circuit that is driven by a SiC MOSFET-based full bridge at its resonant frequency (909 kHz), which allows large currents to be generated in the antenna. This power system was developed with support of a DOE SBIR.





Antenna current for a vacuum shot (left) and plasma shot (right). The flat top current is 2.94 kA and 1.9 kA for the vacuum and plasma shots, respectively.

At resonance, the impedance the power system drives reduces to the pure resistance of the supply or supply + plasma, which allows a simple way to calculate power deposited into the plasma. The calculation assumes that the inductance change due to the plasma is small compared to the antenna. Comparing the driving and ring down frequency validates this assumption.

$$R_{supply} = \frac{4}{\pi}\left(\frac{V_{drive}}{I_{antenna}}\right)_{vacuum} = \frac{4}{\pi}\frac{550\ V}{2.94\ kA} = 238\ m\Omega$$

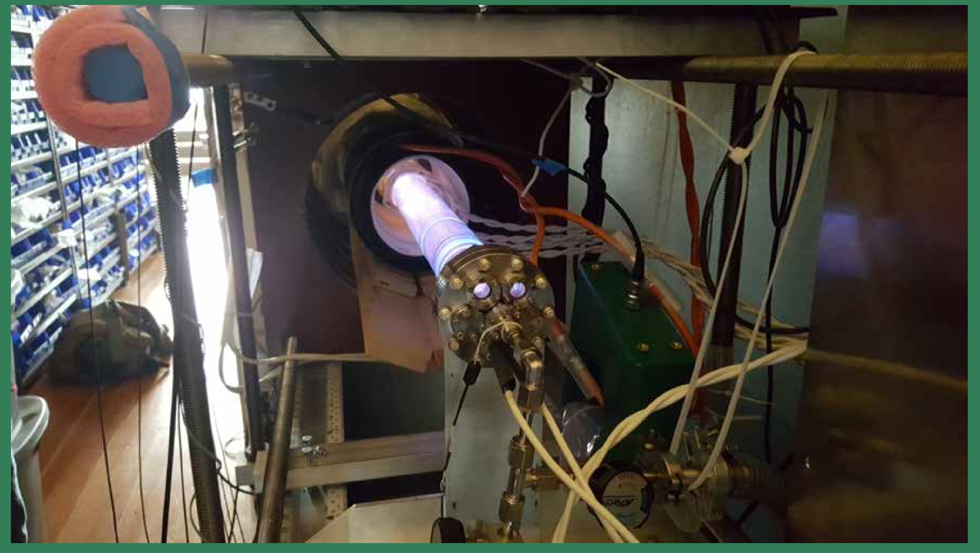
$$R_{total} = \frac{4}{\pi}\left(\frac{V_{drive}}{I_{antenna}}\right)_{plasma} = \frac{4}{\pi}\frac{550\ V}{1.9\ kA} = 368\ m\Omega$$

$$R_{plasma} = R_{total} - R_{supply} = 130\ m\Omega$$

$$P_{total} = \frac{1}{2} I_{antenna}^2 R_{total} = 0.5(1.9\ kA)^2(368\ m\Omega) = 0.66\ MW$$

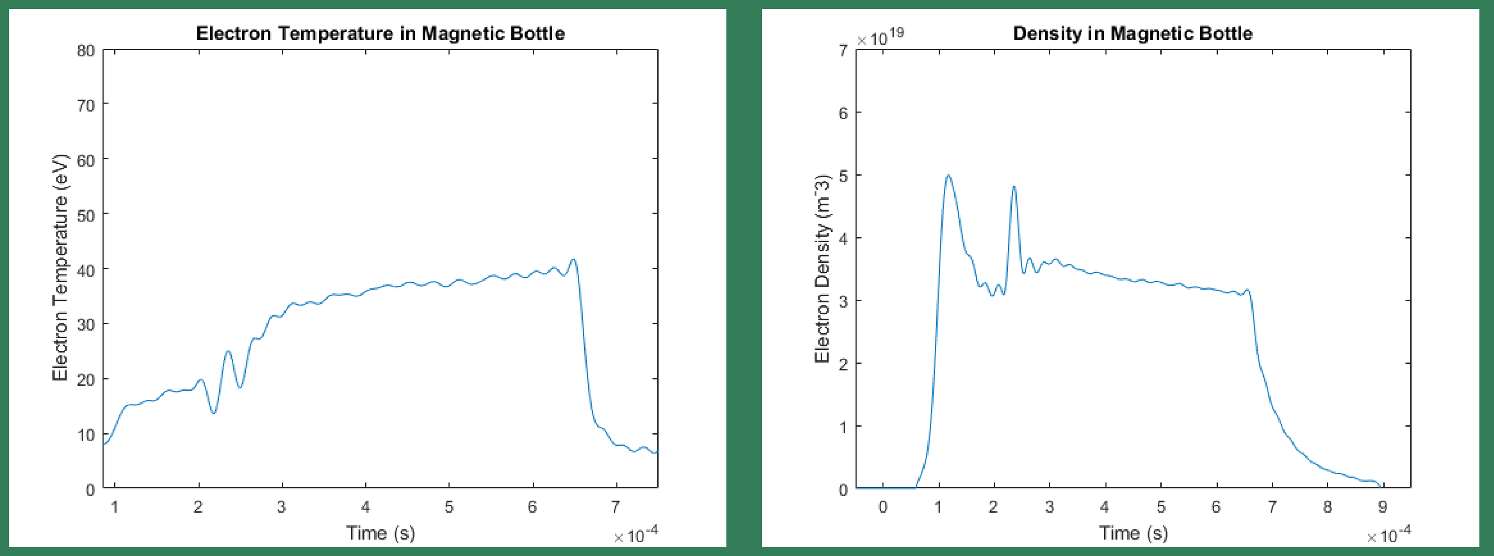
$$P_{plasma} = \frac{1}{2} I_{antenna}^2 R_{plasma} = 0.5(1.9\ kA)^2(130\ m\Omega) = 0.23\ MW$$

Helicon Antenna and Hydrogen Plasma

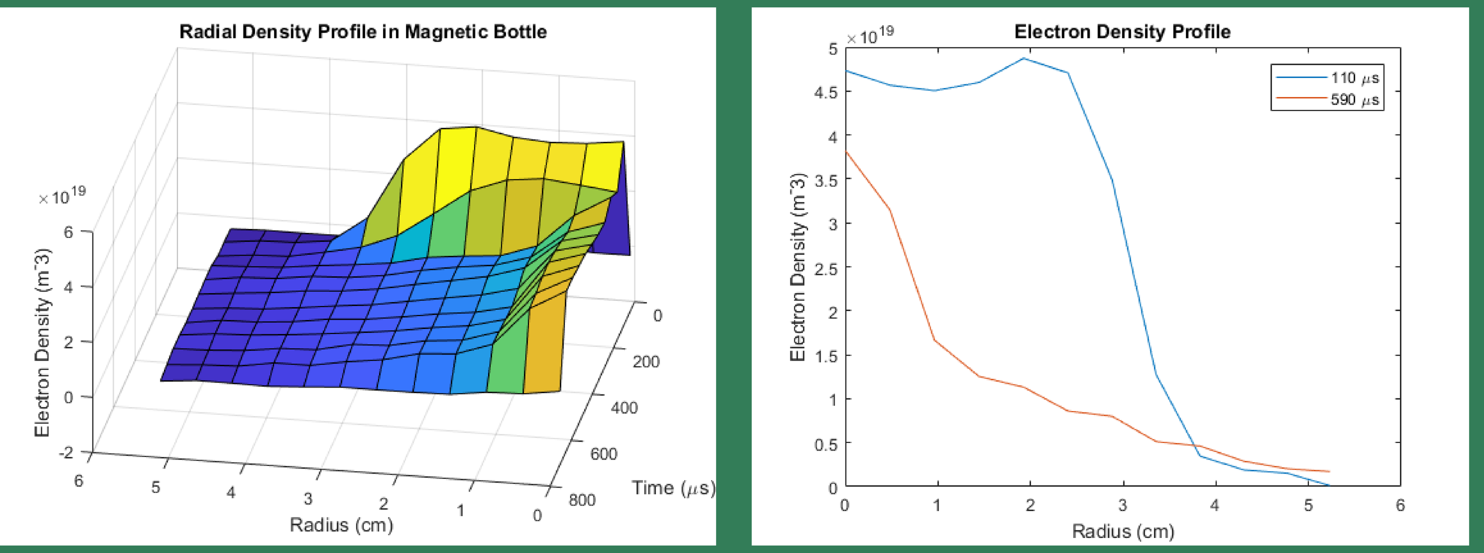


Initial Langmuir Probe Data

The plasma was investigated using a double Langmuir probe. The probe was inserted from the end of the chamber and could be moved axially along the dump chamber. The probe can also be rotated to obtain a radial profile of plasma density. Probe voltage was provided by a capacitor charged with batteries. The probe current was measured use a Pearson probe connected to a floating oscilloscope. The probe voltage was swept to obtain an IV curve, which was used to calculate the electron temperature and plasma density.



Left: Electron temperature as a function of time as measured near the low point in the magnetic bottle. Right: Plasma density as a function of time at the same location.



Left: Radial profile of electron density as a function of time. Right: Radial electron density profile at two time slices. Plots show initial ionization followed by a compression of the plasma profile into a narrow beam.

Conclusion

EHT has constructed a helicon system that can deposit hundreds of kilowatts into the plasma. The SiC MOSFET full bridge enables this high power deposition. Using a Langmuir probe, an initial characterization of the plasma has been conducted. The probe shows an electron temperature between 10 - 40 eV and an electron density of 3.5 x 10^{19} m^3 in the magnetic bottle for hydrogen plasma. The radial profile shows an initial ionization followed by the formation of a beam in steady state.

Future work will investigate more magnetic field and gas parameters. For other applications, argon plasmas will be investigated.

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