Electrode-less Plasma Source: Phase II Update

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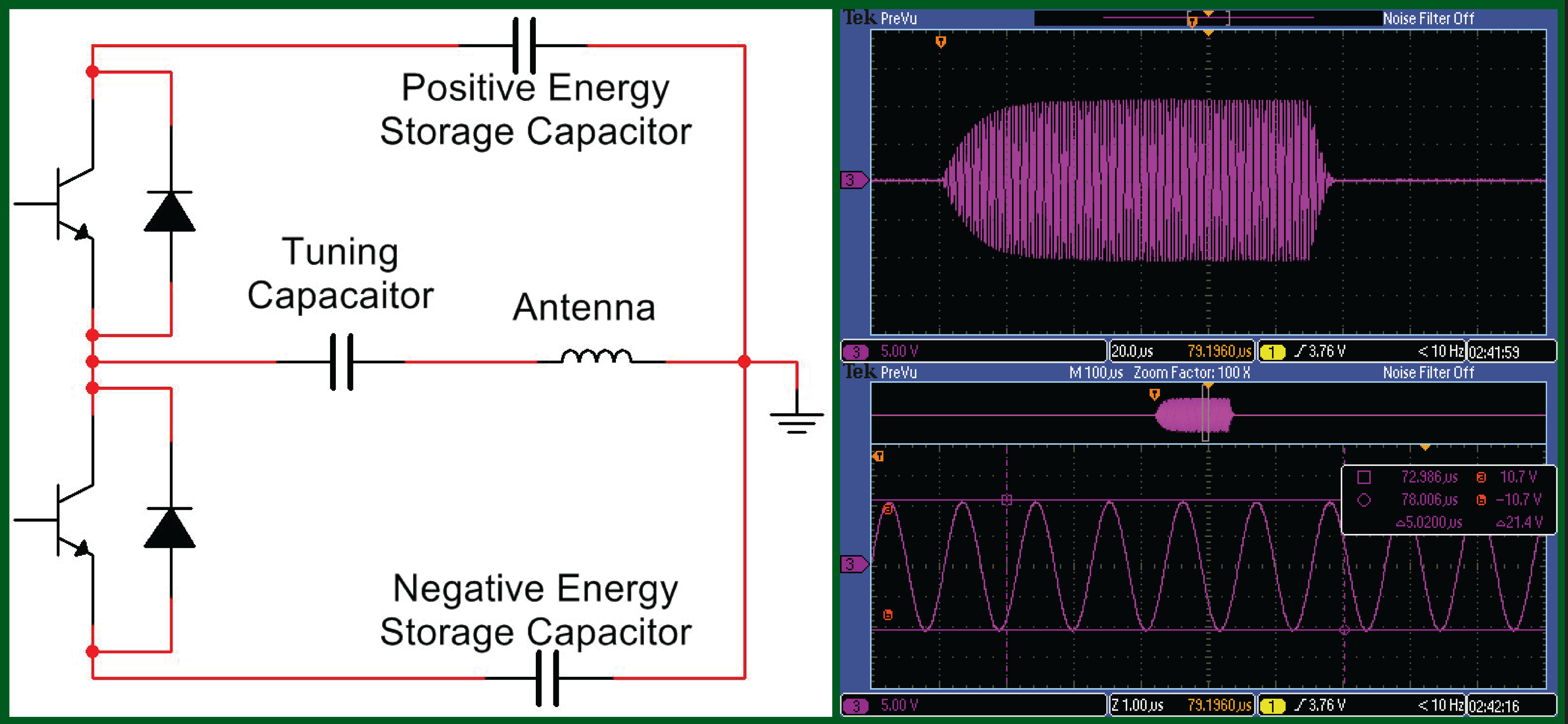
Abstract:
Eagle Harbor Technologies, in collaboration with the University of Washington, has developed a low-impurity, electrode-less plasma source (EPS) for start-up and source plasma injection for fusion science applications. In order to not interfere with the experiment, a pre-ionizer/plasma source must meet a few critical criteria including low impurity production, low electromagnetic interference (EMI), and minimal disruption to the magnetic geometry of the experiment. This system was designed to be UHV compatible and bakable. Here we present the results of the EPS Phase II upgrade. The output plasma density was increased by two orders of magnitude to >10^{17} m^{-3} in hydrogen with no magnetic field injected. EPS system integration with the HIT-SI experiment has begun. EHT has also developed a high particle flux device, which is being used to quantify the low impurity production of the EPS source.

EPS Power Supply Upgrade:

In the first year of the Phase II program, the antenna power supply has been upgraded. The new power supply is a resonant half bridge configuration constructed from the EHT Integrated Power Modules, which were developed with the support of a DOE SBIR Phase I and II program: *A Robust Modular IGBT Power Supply for Innovative Confinement Concepts* (Poster UP8.00035). The antenna is the inductor in the series LC network, and the tuning capacitance is selected so that the resonant frequency is ~1 MHz. The IGBT switches are driven at the resonant frequency. Since this is a high Q system (>50), high voltage developes across the inductor, thus high current is driven in the antenna. This system has been robustly operated with several antenna configurations.

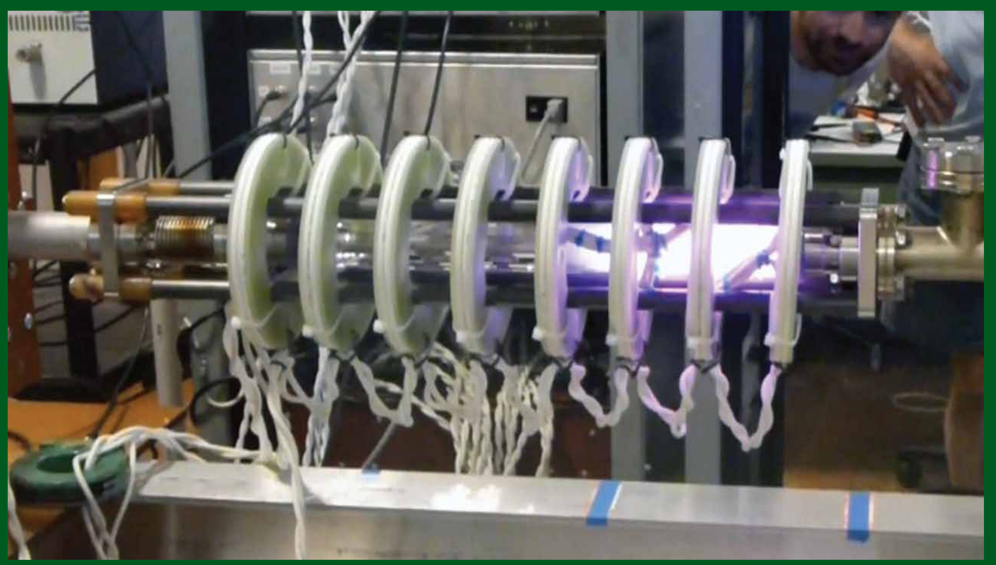


Left: Circuit diagram showing the EPS antenna resonant half bridge power supply. Right: Antenna current profile for 100 µs shot: Full waveform (Upper) and zoomed in scale (Lower). The current in the antenna is 1.7 kA.

The EPS system requires four power supplies for the antenna, magnet coils, seed plasma generator, and puff valve. All four power supplies are designed around the versions of the EHT Integrated Power Module and are fiber optically isolated from the control computer, which allows for high speed triggering with noise immunity. All four power supplies fit into a single rack along with the energy storage for the antenna and magnet supplies. A fiber optically isolated charge/dump unit is also included. Final versions of these supplies have been designed, constructed and tested. They are currently three systens in operation at EHT, HIT-SI, and the Advanced Propulsion Laboratory at the University of Washington.

EPS for HIT-SI3

The EPS performance from Phase I testing showed promising results as a pre-ionizer for HIT-SI and other small-scale concept exploration experiments. The primary goal of Year 1 of the Phase II program was to upgrade the EPS system and characterize the plasma. The upgraded EPS is shown on the right. There were three primary upgrades:

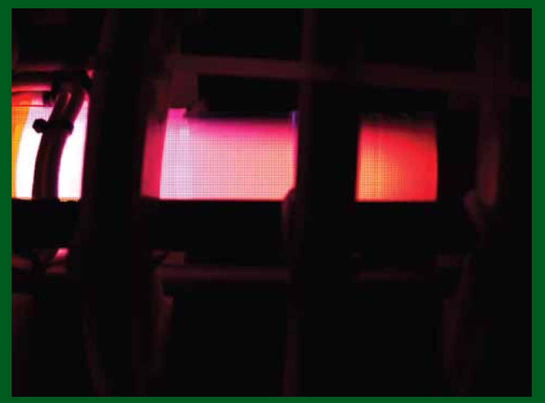


Laboratory testing of Phase II EPS generating hydrogen plasma prior to transfer to HIT group.

1. Magnetic Field: In the Phase II, the solenoid was replaced with eight coils with a larger radius, which resulted in a more uniform field in the radial direction. The current is pulsed so field does not penetrate through the flux conserver into the main chamber.

2. Power Supplies: The four power supplies were upgraded as described to the right.

3. Seed Plasma Generator (SPG): The SPG provides seed electrons to improve the shot-to-shot repeatability of the EPS discharge. The components were carefully selected to ensure UHV compatability and bakability.

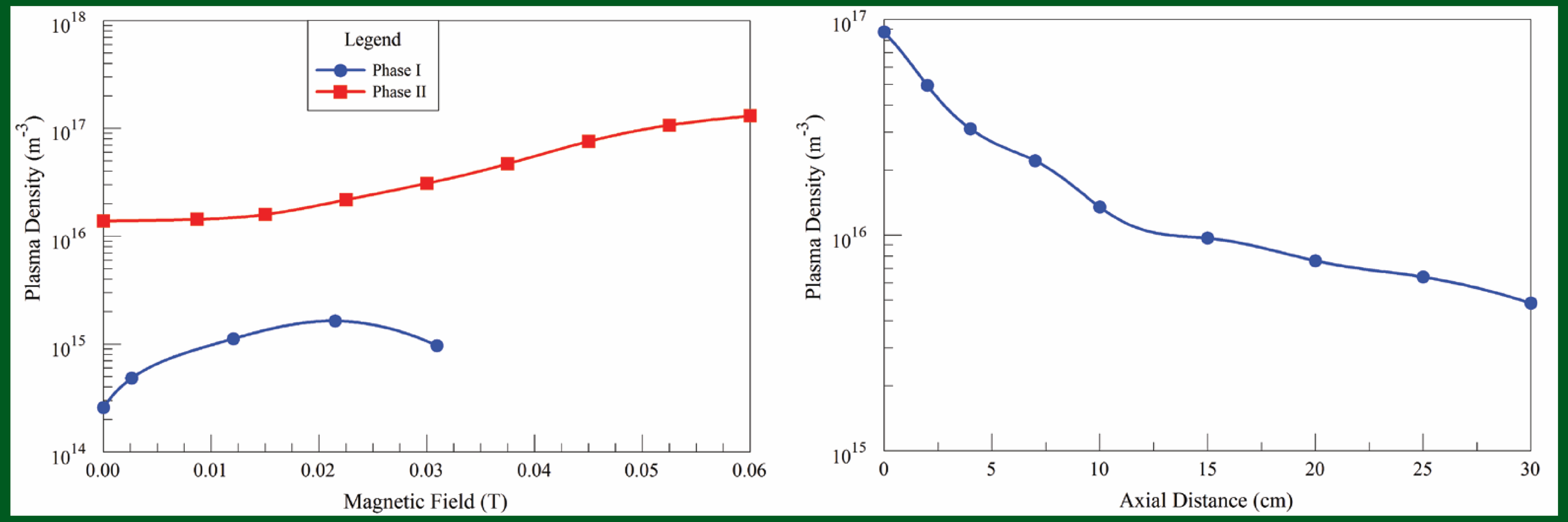


EPS plasma under the antenna.

After the completion of the upgrade to the EPS, the system was tested. The system parameters were optimized to produce the highest density plasma in the main chamber. To get to the main chamber, the plasma must pass through a flux conserving flange, which prevents the EPS magnetic fields from interferring with the magnetic configuration of the fusion plasma.

The left figure below shows the plasma density measured at the exit of the EPS as a function of magnetic field strength. Even though the magnetic field does not penetrate into the main chamber through the flux conserving flange, the plasma density increases with magnetic field strength. This figure also shows a direct comparison of the Phase I and Phase II data. In Phase I, the plasma density peaks at 1.6 x 10^{15} m^{-3} using hydrogen. However, with the upgraded EPS, the maximum density has increased by almost a factor of 100 to over 10^{17} m^{-3}. In Phase I, the EPS would not function at magnetic field strengths above 30 mT due to power limitations of the EPS antenna supply. Once the system was upgraded, it could be operated at field strengths up to 60 mT, with significant improvements in plasma density. This data demonstrates the importance of the upgraded EPS antenna supply.

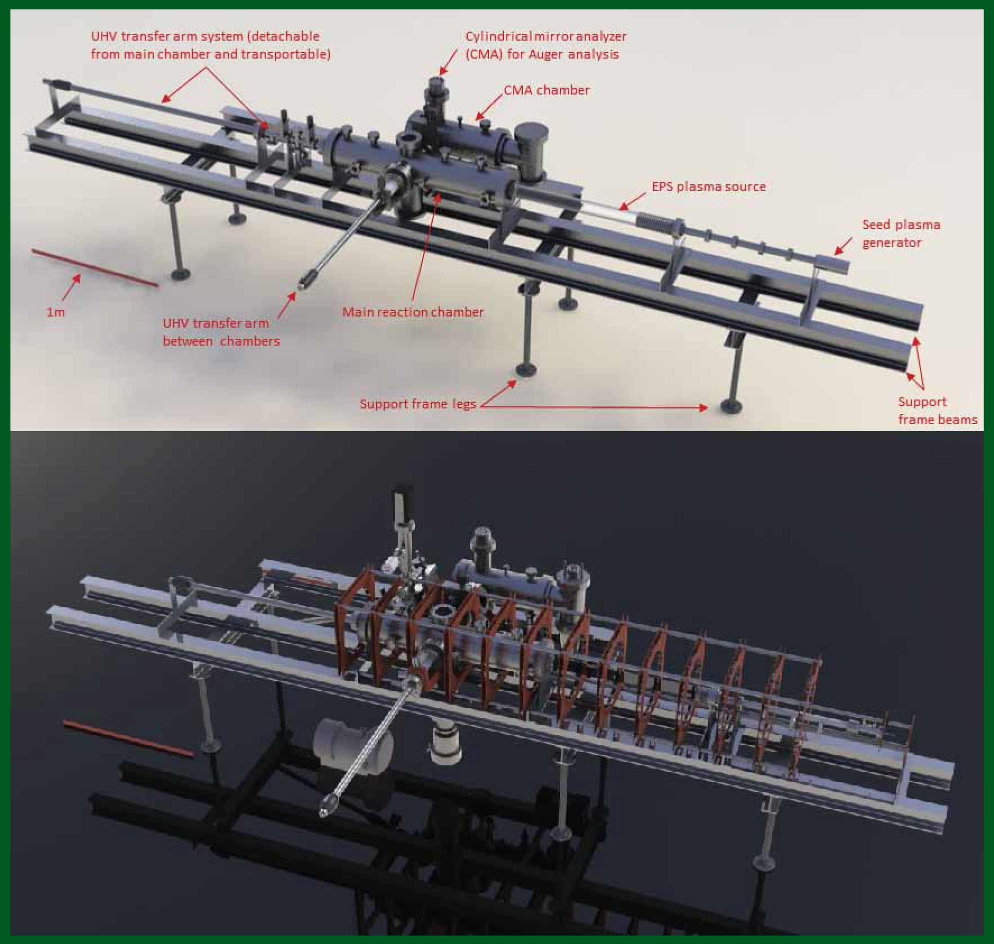
The right figure below shows the plasma density as a function of axial distance from the exit. This shows the plasma propogates a sufficient distance to reach the injectors for use



Left: A comparison of plasma density from the Phase I and II EPS antennas as a function of magnetic field strenght. Right: Plasma density as a function of distance from the EPS-main chamber junction.

Impurity Study System:

The second major goal of the Phase II program is to design and build a high density/flow rate version of EPS and demonstrate the system as a low impurity source. In this case, the magnetic field from the EPS is allowed to penetrate into the main chamber. The system was designed so that witness plates could be exposed to the plasma and then transferred to the cylindrical mirror analyzer (CMA) for analysis. In addition, the samples can be transferred to the University of Washington under vacuum to preserve sample quality, where they can be studied with X-ray excited electron spectroscopy, a 2D mapping high resolution X-ray photoelectron spectroscopy system, Raman spectroscopy, Magic Angle Spinning NMR, and a TEM/Selected-area-diffraction system, as well as both visible and near-infrared photoluminescence microscopy. Schematics of the vacuum system showing the transfer arms, CMA, EPS and magnets are shown above.



Schmatics of the material science chamber and EPS showing the key sections and transfer arms (upper) and the magnet sizes and locations (lower).

The high density/flow rate EPS with hydrogen plasma under the antenna.

Construction of the material science chamber, magnet coils, high density/flow rate EPS, and associated power supplies has been completed. The vacuum system was designed to UHV standards and has reached a base pressure of 5 x 10^{-8} torr prior to baking the system. The high density/flow rate EPS has has been successfully tested with argon and hydrogen (shown at left).

Future Work:

During Year 2 of the Phase II program, EHT has three primary objectives:

1. Assist the HIT-SI group with final integration and operation of the EPS system.

2. Characterize the control parameters of the high density/flow rate EPS source to optimize the output for high density, high flow rate, and high speed plasma production.

3. Utilize the material science capabilities at EHT and the UW to demonstrate the low impurity nature of the EPS system.

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