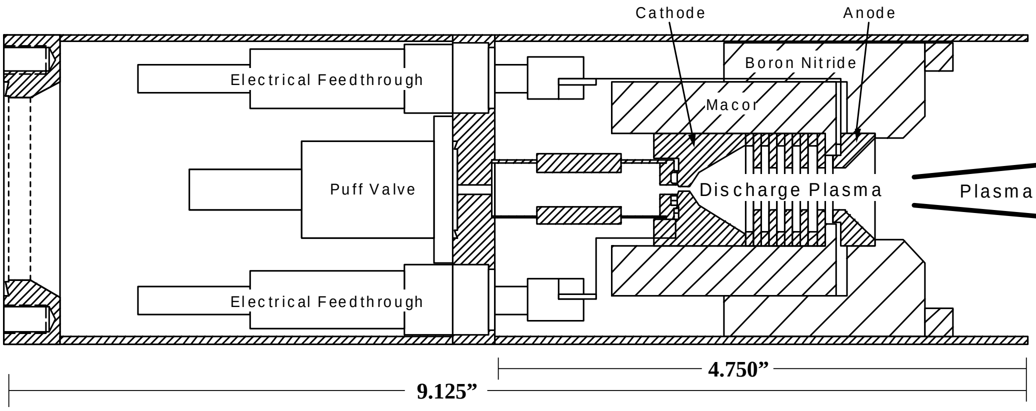
Magnetized Cascade Arc Source for Ionization and Fuelling in TCSU

Paul Melnik, H.Y. Guo, K.E. Miller
Redmond Plasma Physics Laboratory, University of Washington

Abstract

An easily translatable, ultra-high vacuum compatible, magnetized cascade arc source has been designed and constructed to inject a directional plasma beam that will be used as source plasma for RMF driven FRCs in the TCSU experiment. In addition to providing initial background plasma, the arc source can also be run during FRC sustainment to provide steady state plasma fuelling. The deuterium plasma produced by the arc source is tied to the external axial magnetic field lines, providing an ideal pre-ionization source for FRC formation. A 3 kJ, IGBT controlled power supply has also been built and is used for initial breakdown and arc sustainment. Plasma densities of 10^{20} m-3 and electron temperatures of 15 eV are anticipated from the device that is currently being tested. Results from these tests and performance during preliminary operation of the TCSU experiment will be reported.

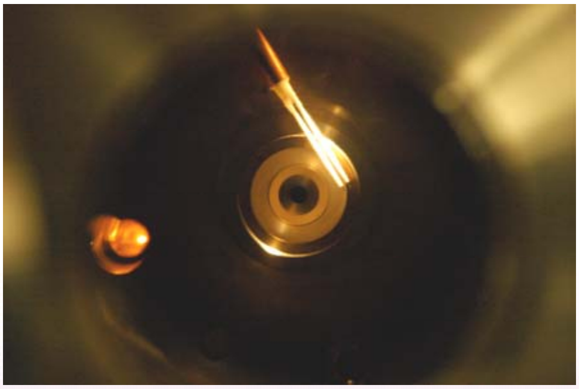
Schematic of the MCAS to be used on TCSU

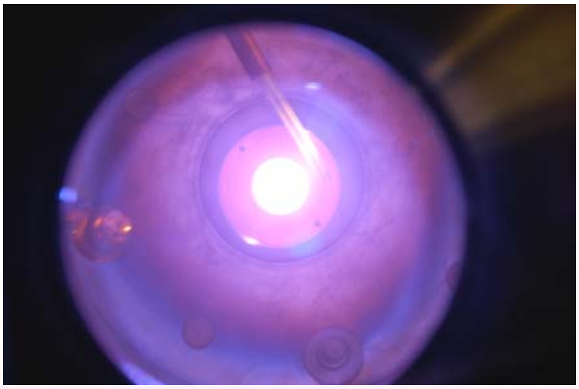


SS Pipe
ID = 2.620”
OD = 2.750”

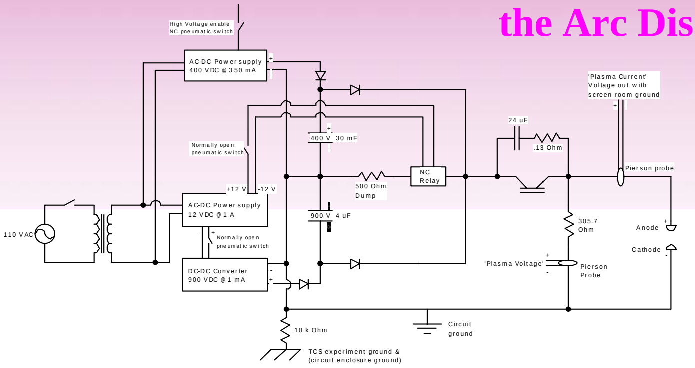
Discharge chamber
ID = .376”
Length = .785”

The plasma gun (MCAS) to be used on TCSU was designed to be used in a clean, ultra-high vacuum environment. The plasma gun was also designed to be translatable and as robust as possible. A cross-sectional view of the plasma gun is shown above. The cathode and washer stack fit inside a Macor, or machinable glass ceramic, sheath and the anode is held in place by a Boron Nitride ferrule. All of the components are contained within a stainless steel pipe and are compressed using a retaining ring. This robust design not only makes it easy to change the dimensions of the plasma discharge chamber but the anode and cathode are easily replaced also. The electrode material is chosen to have the lowest possible electrical erosion rate but must still be machinable. All arc discharges to date with this plasma gun have been made using Molybdenum but Carbon electrodes and washers have been made and will be tested shortly. More exotic materials such as Silver Tungsten alloys may be used also.





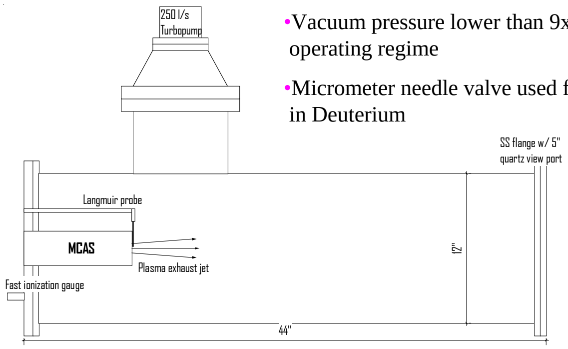
A 3 Kilojoule, IGBT Controlled Power Supply is used to Form and Sustain the Arc Discharge



A 3 kilojoule, IGBT (integrated gate bi-polar transistor) controlled power supply has also been built and is used for initial breakdown and arc sustainment. The use of IGBTs makes it possible to vary the plasma discharge time from as little as 100 microseconds to over 15 milliseconds. As seen above, a 900 volt potential is applied across the anode and cathode for initial breakdown. This initial voltage is supplied by high voltage 4 microfarad capacitors. After the initial breakdown is achieved the 30 millifarad capacitors supply the charge necessary for arc sustainment. The IGBTs are protected by a 24 microfarad snubber circuit. A Stangenes probe is mounted inside the power supply enclosure to measure the plasma discharge current. The plasma voltage is measured using a high resistance voltage divider.

The Plasma Gun has been Operating within a 90 Liter Vacuum Chamber

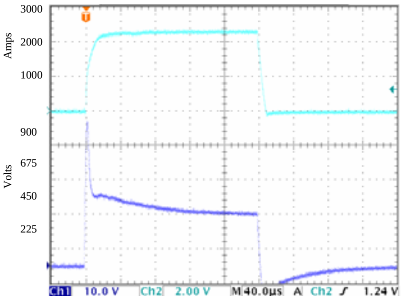
- Test chamber equipped with a double Langmuir probe and fast ionization gauge
- Coaxial and side quartz viewing ports provide excellent plasma observation



- Vacuum pressure lower than 9×10^{-8} Torr insure a quality operating regime
- Micrometer needle valve used for fast ion gauge calibration in Deuterium
- Imacon camera used to elucidate arc formation and uniformity
- Schematic of vacuum test chamber shows relative position of MCAS, Langmuir probe, and fast ion gauge

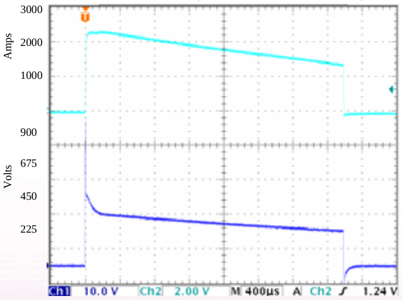
The MCAS Discharge is Reproducible Under Different Conditions

Current and Voltage for a 200 µs arc discharge

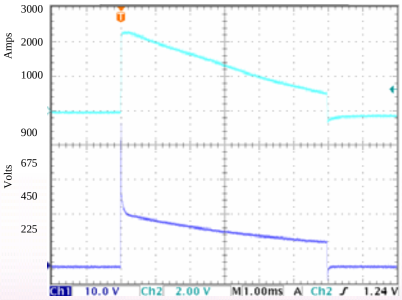


- Plasma Discharges of 200 µs, 3ms, 6ms, and 14ms are shown
- Current and voltage decay times are always uniform
- Droop in the Stangenes probe is evident in discharges of 6 ms or more. Another current measuring device will be installed shortly.
- Quality design and construction of plasma gun eliminates extraneous arcing and insures repeatability.

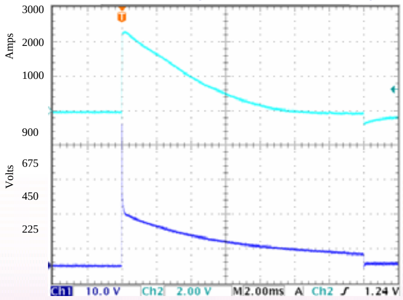
Current and Voltage for a 3 ms arc discharge



Current and Voltage for a 6 ms arc discharge

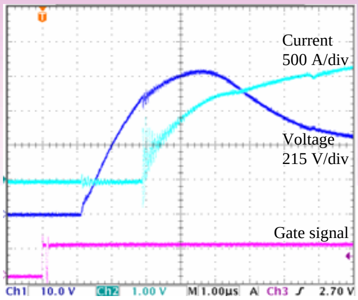


Current and Voltage for a 14 ms arc discharge

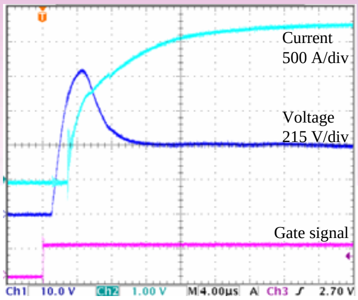


MCAS Breakdown Always Occurs Approximately 3 μs After Gate Signal

Current, voltage, and trigger 1μs per division



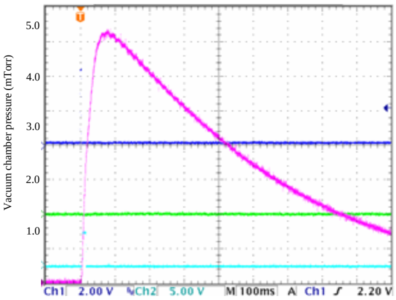
Current, voltage, and trigger 4μs per division



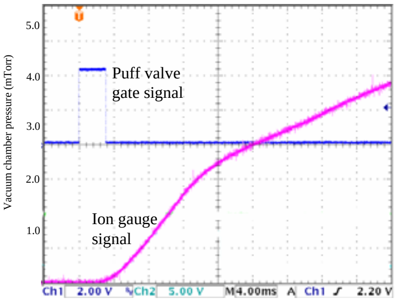
- Voltage ramp up occurs roughly 1.2 μs after input gate due to delay in IGBT trigger electronics.
- MCAS breakdown occurs roughly 3 μs after input gate when there is approximately 750 to 800 volts across the electrodes.

A Fast Ion Gauge has been used to Determine Plasma Discharge Timing

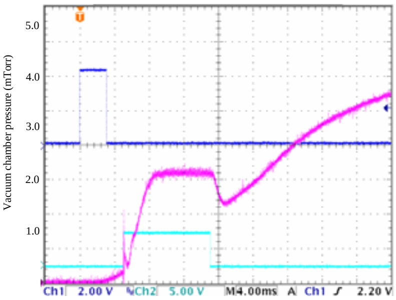
Vacuum chamber pressure vs. time



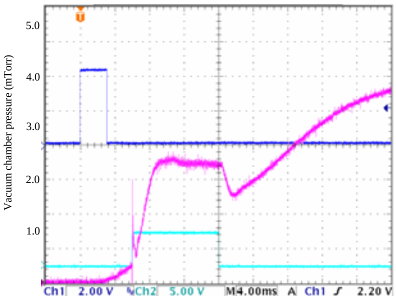
Vacuum chamber pressure vs. time



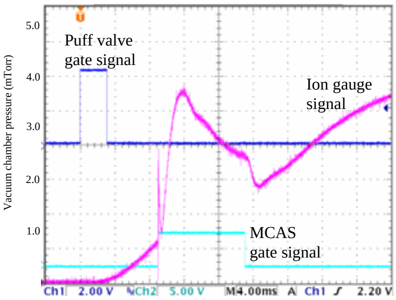
Vacuum chamber pressure vs. time (5 ms delay)



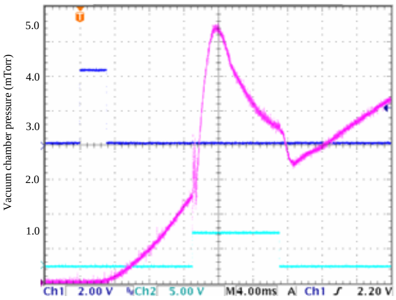
Vacuum chamber pressure vs. time (6 ms delay)



Vacuum chamber pressure vs. time (9 ms delay)

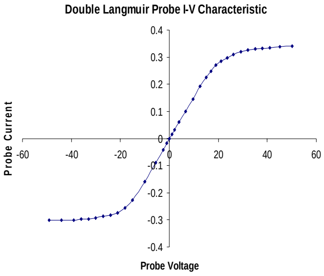


Vacuum chamber pressure vs. time (13 ms delay)



The graphs above show the fast ion gauge response to various plasma conditions. The top left graph shows the pressure in the chamber for a 3 ms gas puff at 100 ms per division resolution. The top middle graph shows the ion gauge response at 4 ms per division resolution. The other four graphs are all at 4 ms per division resolution and show 10 ms MCAS discharges at various delay times. With the fast ion gauge and the future help of a spectrometer we can determine the correct discharge delay time and discharge pulse time to minimize the impurity content.

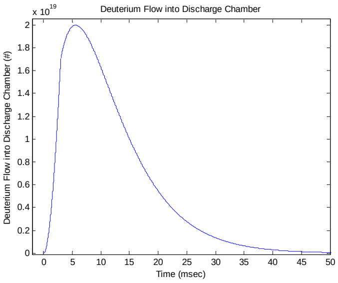
A Double Langmuir Probe has Measured n and T_e



- A Double Langmuir probe was used to find T_e and n
- Probe was positioned in plasma exhaust approximately 1.4” from anode on axis
- Probe tips are Tungsten
  probe tip length is .150”
  probe tip diameter is .020”

- Graph above shows a shot to shot Langmuir probe sweep for a 400V discharge formed 6 ms after gas puff gate signal.
- Usual double probe analysis $\left.\frac{dI}{dV}\right|_0=\frac{e}{kT_e}\frac{i_{1+}\bullet i_{2+}}{i_{1+}+i_{2+}}$ **reveals T_e as 9.83 eV**
- Bohm ion saturation current $I_{i+}=.61eA_s n\sqrt{\frac{kT_e}{M_i}}$ **finds n = $3.34\text{x}10^{19}$ m^{-3}**

Flow Analysis to Determine Mass Flow Rate and Ionization Fraction



- Solving simple volume filling equation

$$\frac{dp}{dt}+\left(\frac{\tau A_o a}{V}\right)p=\left(\frac{\tau A_v a}{V}\right)p_v$$

to determine plenum fill pressure

- Use plenum pressure p(t) to determine mass flow rate through cathode orifice
- At a valve pressure of 28 psig the maximum MCAS flow rate is approximately $1.37\text{x}10^{22}$ #D_2/s
- Preliminary power balance shows the ionization percentage to be approximately 30% with large error bars.