Development of Non-Cesiated Magnetically Enhanced External RF Antenna based Negative Hydrogen Ion Source

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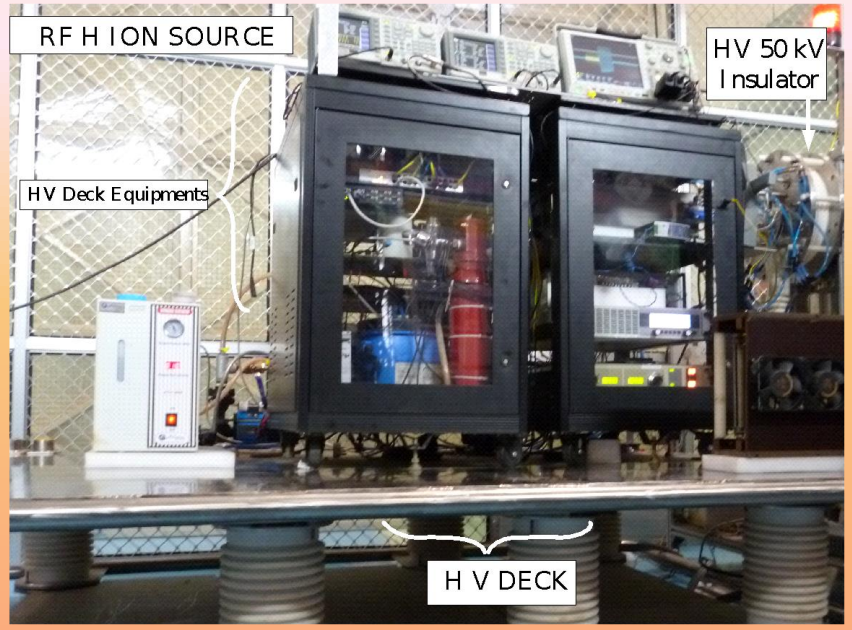
Planned Presentation

* Negative Hydrogen Ion Source Setup Description
  - HV Deck Equipment description
  - Ground Side Equipment description
  - Details for hydrogen Plasma generation and beam extraction
  - Enhancement of RF power coupling using Ni-Zn Ferrite core
* 2 MHz RF Source
  - SiC-MOSFEF based 2 MHz variable amplitude rectangular generator
  - SiC-MOSFET Full-Bridge Inverter and Gate driver Boards
  - Series Resonant Components and RF transformer isolation matching network
  - Setup for testing RF Source and matching network at rated power
  - Experimental test results
* PC control and Measurements
  - PC based control Scheme
  - GIU based user interfacing for main equipments
  - Ion Beam spot and diversion measurement
  - Pepper Pot Emittance measurement
* Ion Beam Measurements
  - Water cooled Biased Faraday Cup
  - Ion beam current measurement results
* Conclusions and future work
  - Acknowledgement
  - References

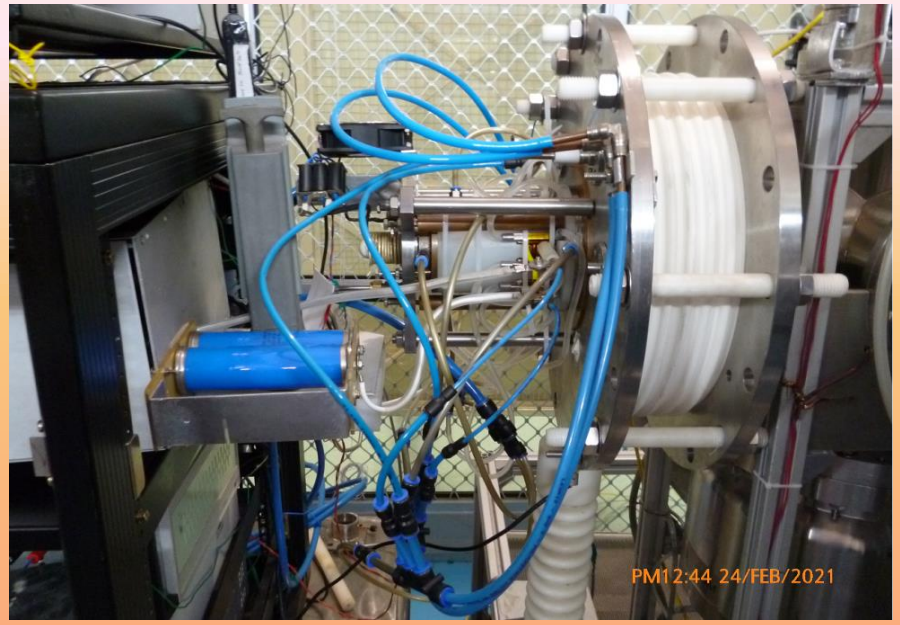
Negative Hydrogen Ion Source Test Setup

Negative Hydrogen Ion Source Test Setup



High Voltage Deck (50 kVDC) Equipment's for Hydrogen Plasma Generation.

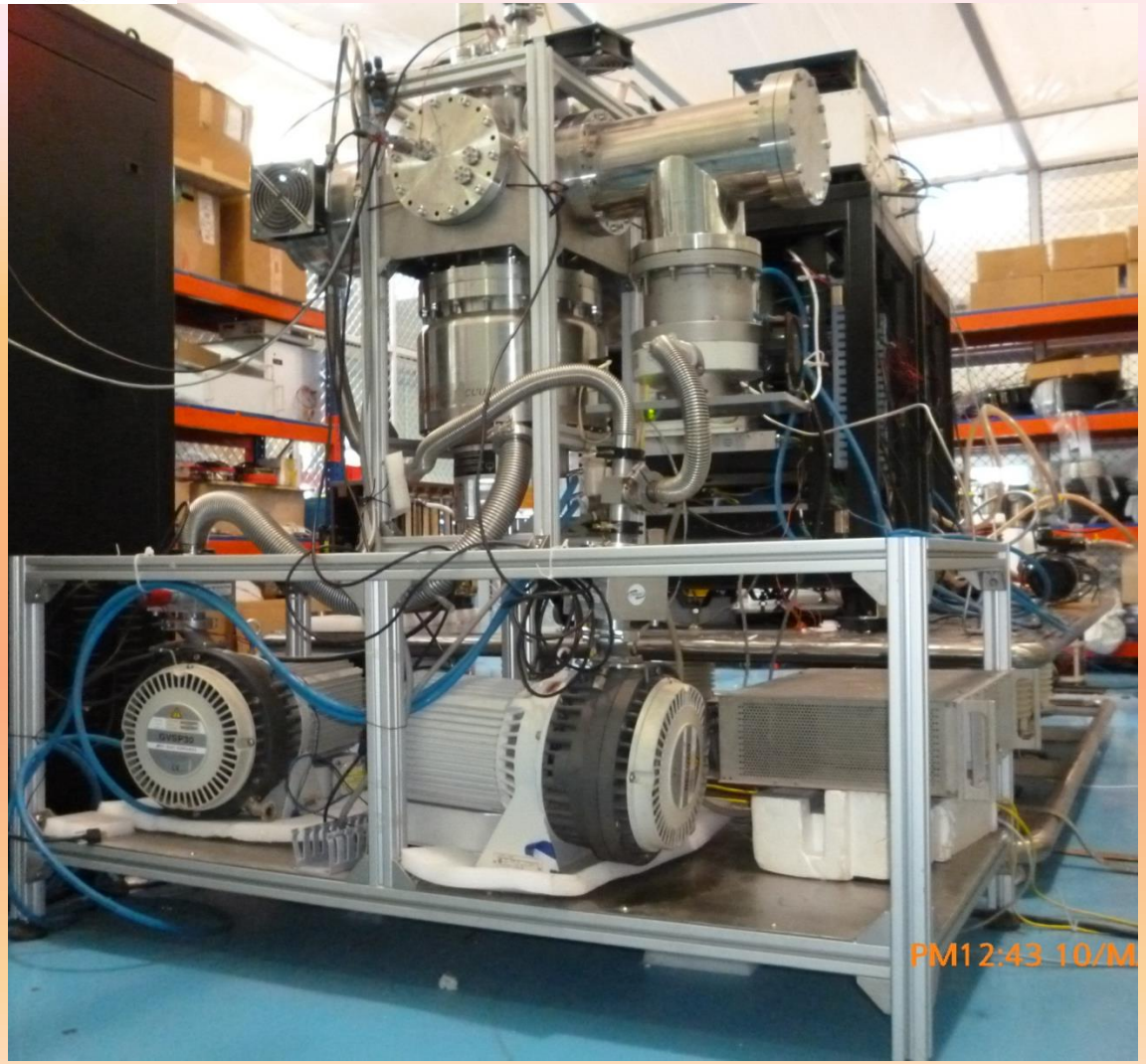
- Hydrogen Generator
- Mass flow controller
- 13.56 MHz, 1 kW Pulsed RF source and DC source
- 13.56 MHz, RF antenna, Matching network
- 2 MHz, 30 kW Pulsed RF Source and its DC source
- 2 MHz, External RF antenna and Matching network
- 10 kVDC, 1 Amp extraction Power Supply
- Programmable delay and pulse generator unit
- Function generator, oscilloscope, Network switches
- DM water cooling system (radiator, pump, tank etc.)
- Single phase AC power distribution with switches



External RF Antenna Based Negative Hydrogen Ion Source

- 13.56 MHz External RF antenna based Pulsed Ignitor
- 13.56 MHz RF transformer based matching network
- Forced air cooling for ignitor
- 2 MHz external RF antenna covered with C-type ferrite and series resonant matching network
- Water cooling for both 2 MHz RF antenna and ferrite
- Main Plasma chamber (ALN) with water cooling jacket
- Water cooling for plasma electrode and flange in between the plasma chamber and ignitor
- Extraction electrode with water cooling
- 50 kVDC isolation ceramic insulator

Negative Hydrogen Ion Source Ground Equipments

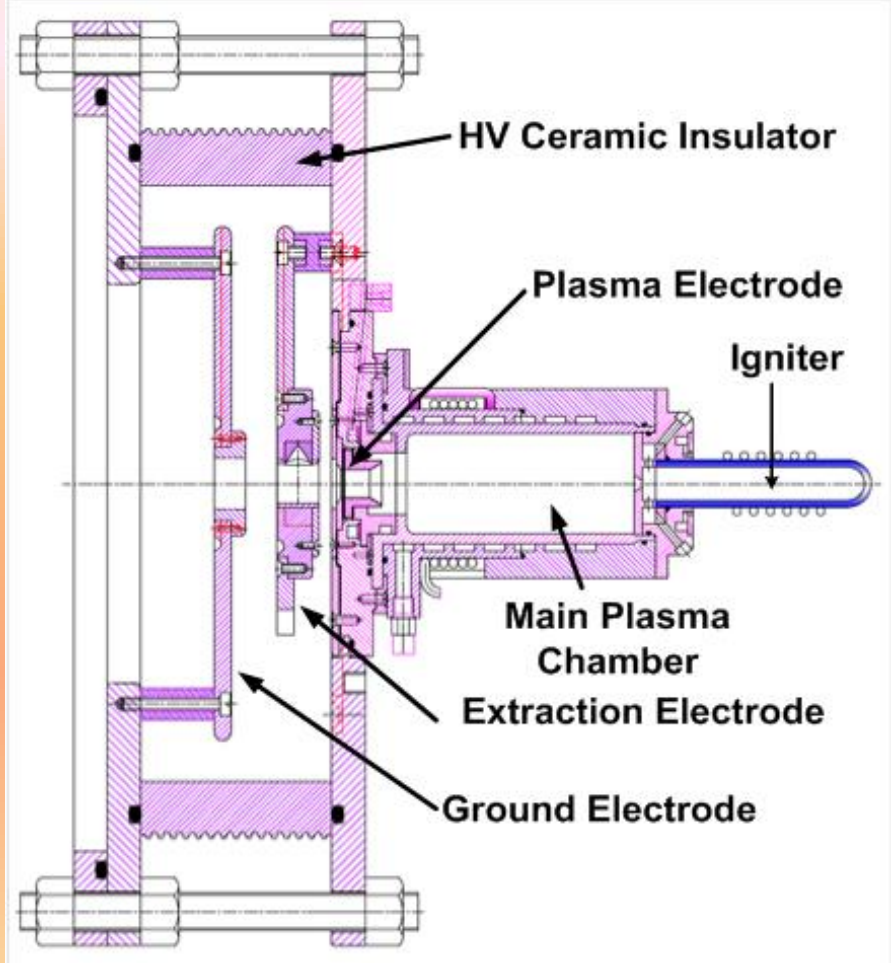


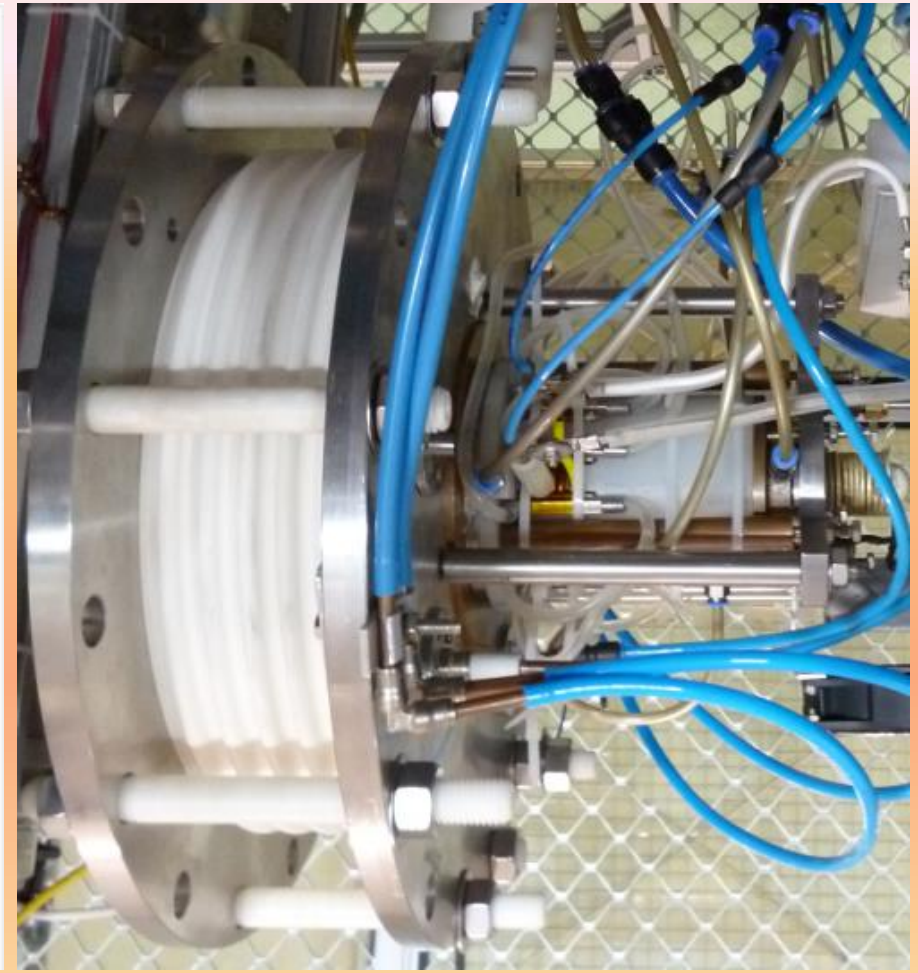
- Multi port Extraction (vacuum) Chamber
- Turbo Molecular Pumps (500 LPS X 2 Nos. + 1800 LPS X 1 Nos.)
- Roughing scroll pumps
- Water cooled biased Faraday cup
- 50 kVDC Acceleration power supply
- Terminator and biasing power supply for Faraday cup
- Oscilloscope for current measurement
- Water cooling arrangement for TMP and Faraday cup (Radiator, pump and water tank)
- Network switches and fiber optical communication modules
- Pepper Pot emittance monitor
- Timing and delay generator
- Vacuum measurement gauge
- Single phase AC power distribution with interlocking contactor and switches
- PC for monitor and control

Ground Side Equipment's for Vacuum Generation, Acceleration and Ion Beam Current Measurement.

RF Hydrogen Negative Ion Source Assembly

RF Ion Source Assembly

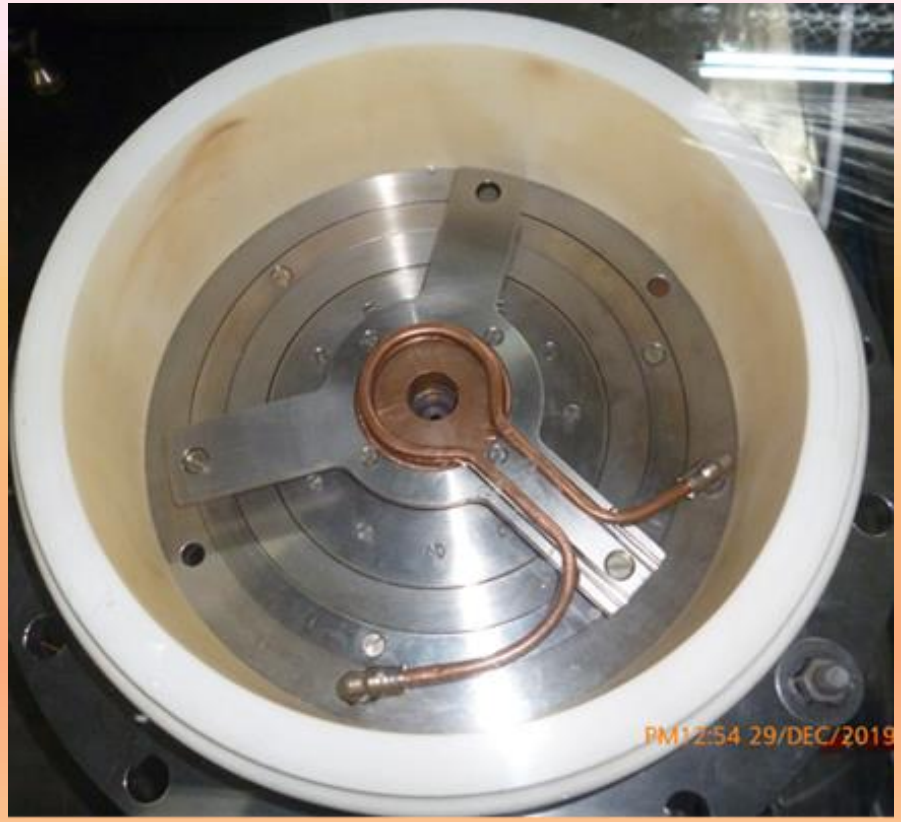




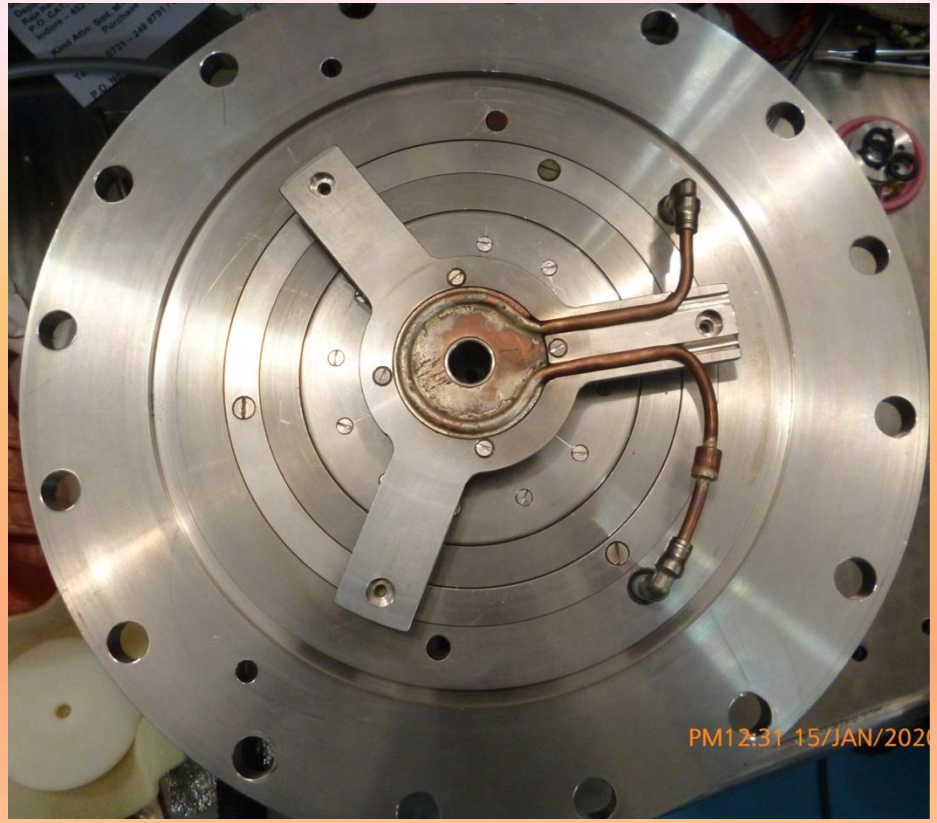
2D-CAD drawing of Hydrogen Plasma Generator with Three Electrodes and RF Ion Source Assembly

Extraction Electrode with Water Cooling Arrangement

Extraction Electrode with Water Cooling Arrangement



Before Brazing

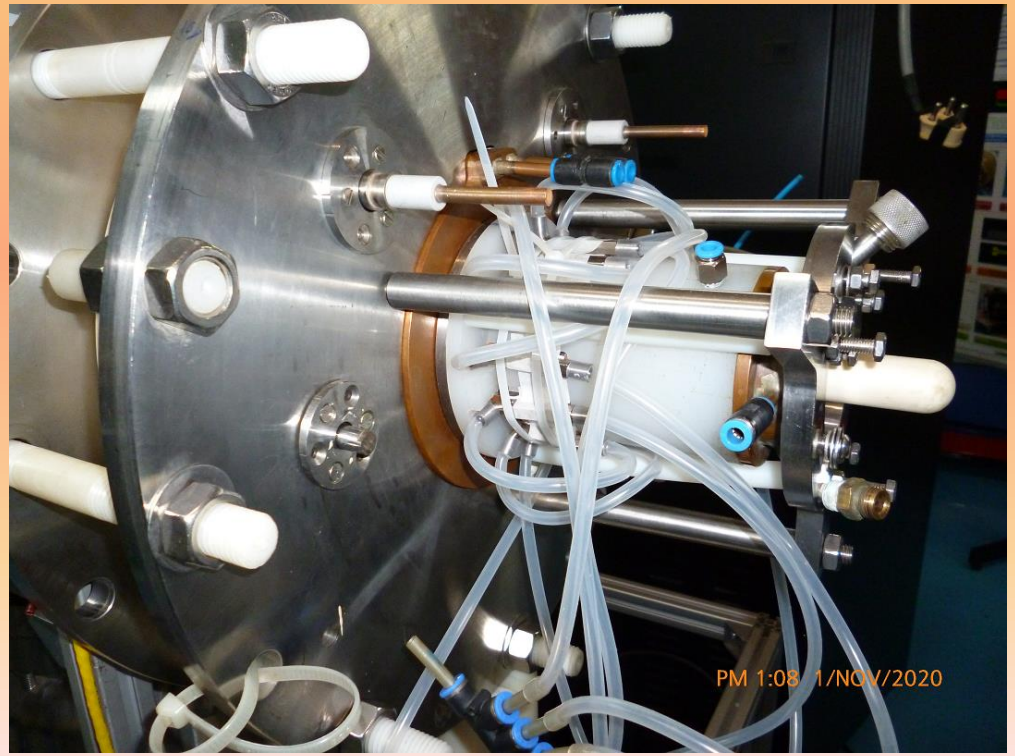


After Brazing

Extraction electrode was tested in open atmosphere with water cooling (LCW) at +15 kV DC.

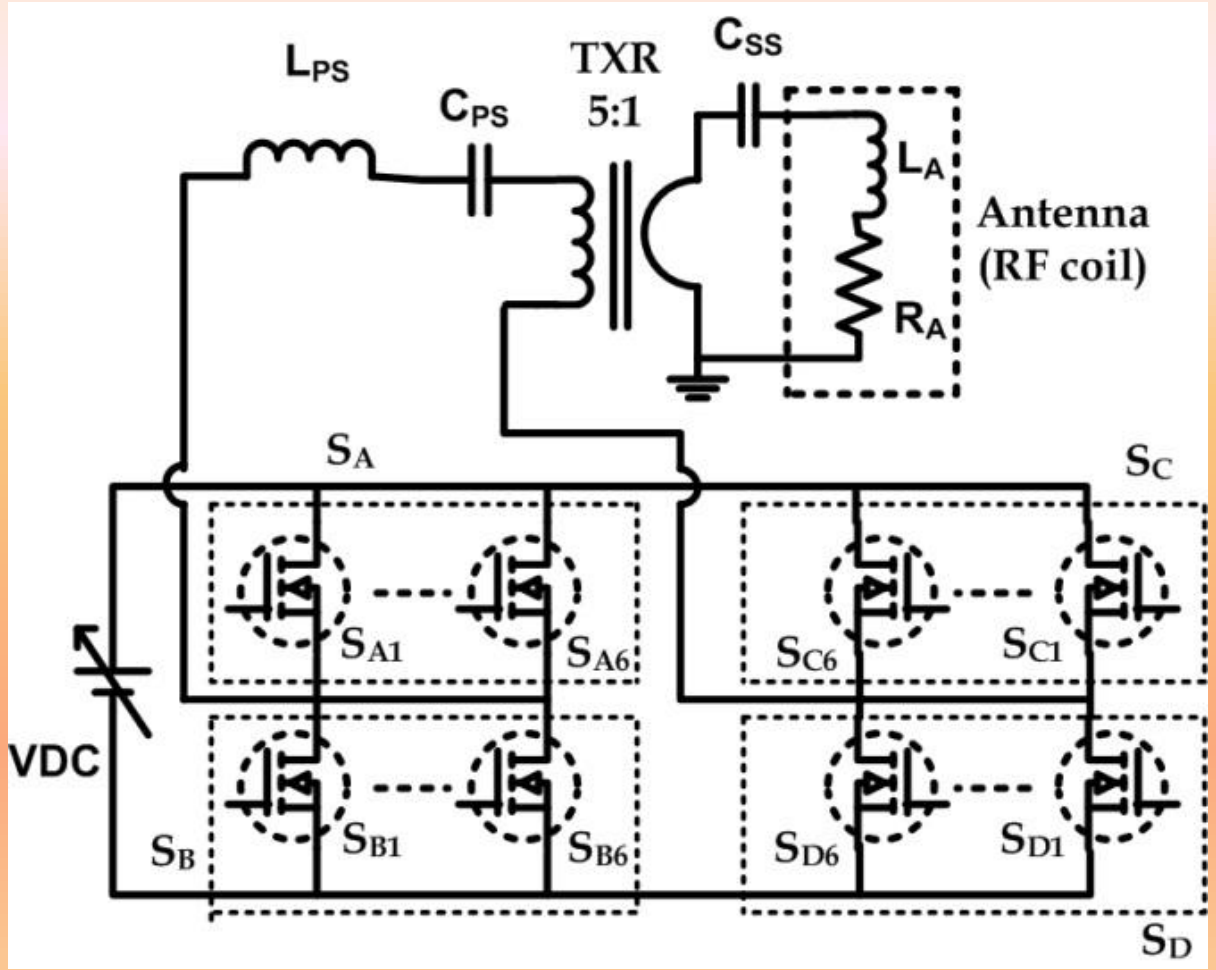
Ni-Zn C-Type ferrite core, water cooling tube, Main Plasma Chamber and 2 MHz RF Antenna

Ni-Zn C-Type ferrite core, water cooling tube, Main Plasma Chamber and 2 MHz RF Antenna



- Ni-Zn C-type Ferrite core 12 Nos.
- Copper cooling tube
- Copper plate
- Ferrite core, copper plates and tube assembled together with thermal conducting EPOXY.
- Flexible silicon rubber tube for water line (Four parallel and three in series) water lines connected with flexible
- 2 MHz external RF antenna, Extraction electrode, Plasma electrode, plasma chamber and flange in between plasma chamber and igniter chamber are water cooled.
- DM water cooling arrangement is provided for all major heat generating components
- RF Antenna inductance at 2 MHz without ferrite core ~ 3.3 uH and with ferrite core ~ 4.3 uH (30% improvement in inductance)

2 MHz pulsed RF Source Circuit Diagram

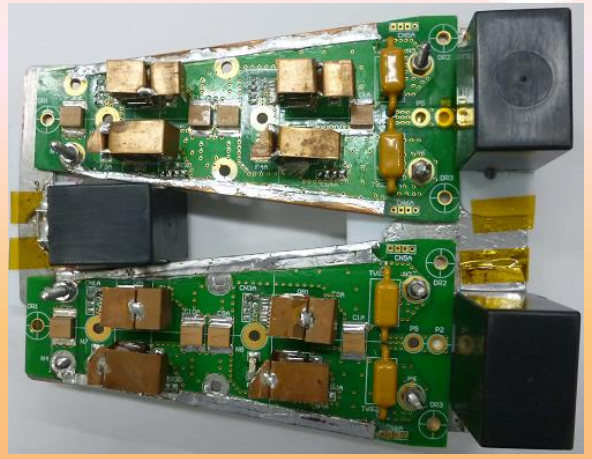


24 Nos. of SiC-MOSFETs are used in full-bridge configuration, which generates 2 MHz rectangular variable amplitude voltage pulses, two series resonant components converts this pulses to sine wave current in RF antenna. A step down isolation transformer (5:1 turns ratio) is used for current amplification.

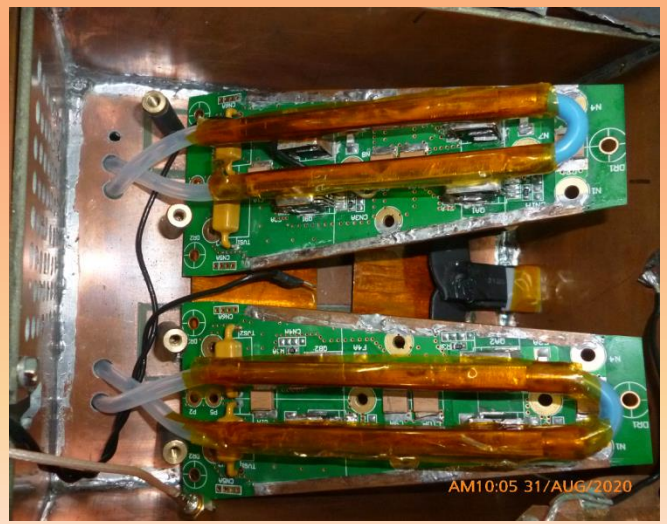
Water Cooled 2 MHz RF Source

2 MHz RF Source Driver Card

2 MHz RF Source Inverter Card



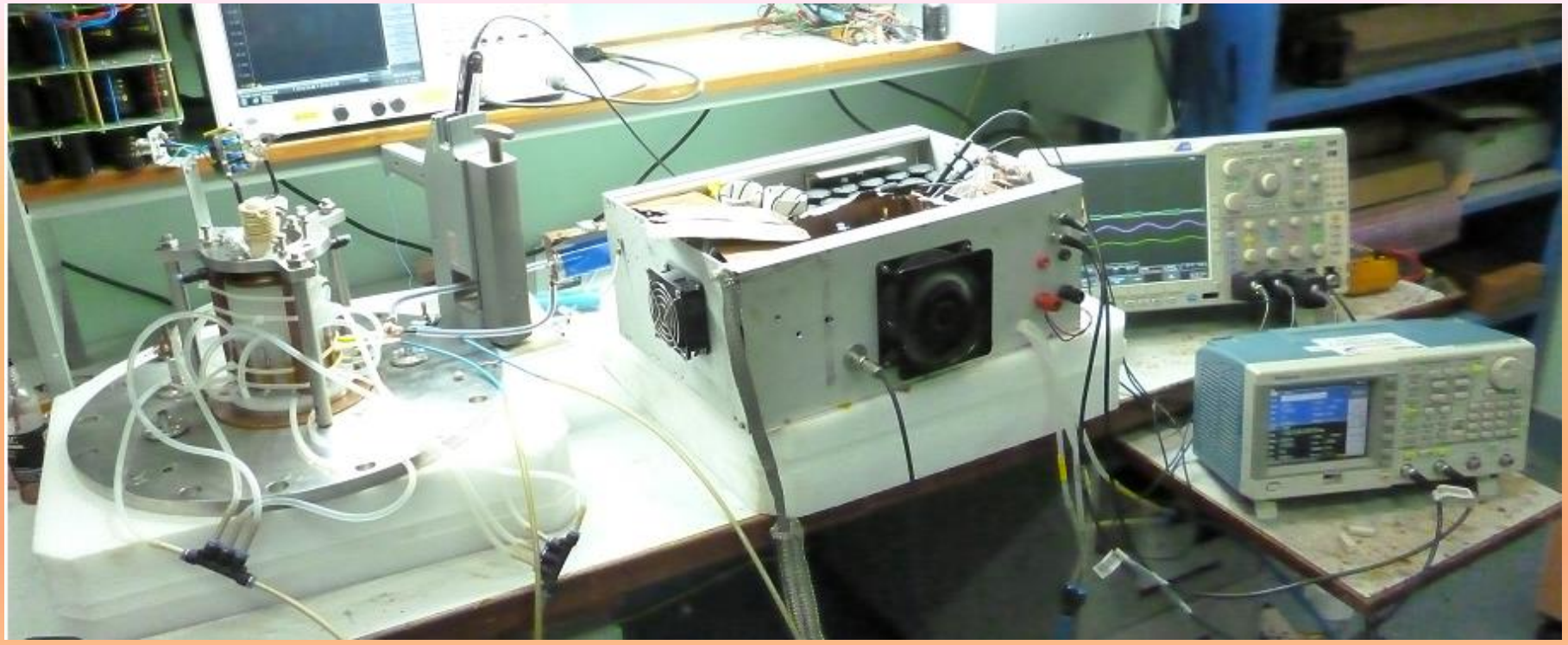
2 MHz RF Source Inverter Card and Filter Capacitor.



2 MHz RF Source Switching Device with Water Cooling Arrangement

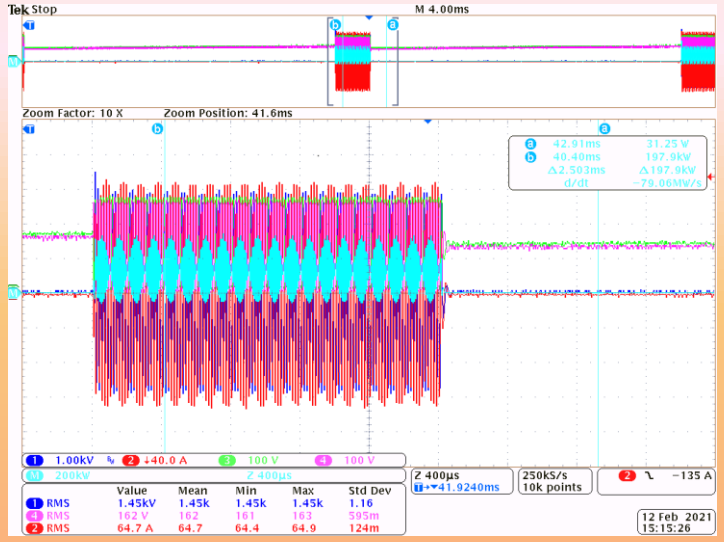
2 MHz RF Source Series Resonant Components.

2 MHz RF Source, Ferrite and Antenna

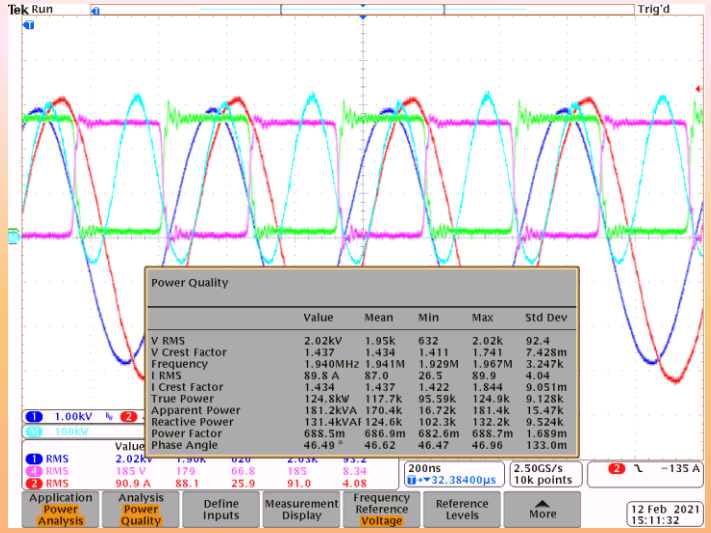


Full RF power testing of 2 MHz RF source, ferrite core and Antenna at 2 ms pulse width at 50 Hz repetition rate with water cooling arrangement.

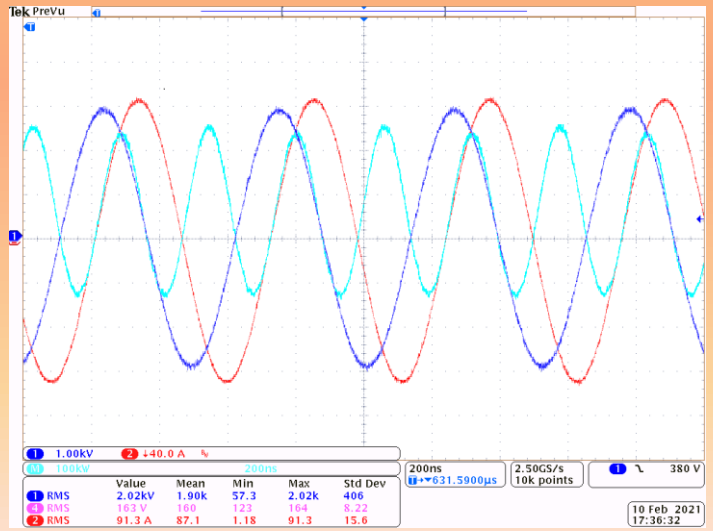
Water Cooled 2 MHz RF Source Testing at 50 Hz repitation rate



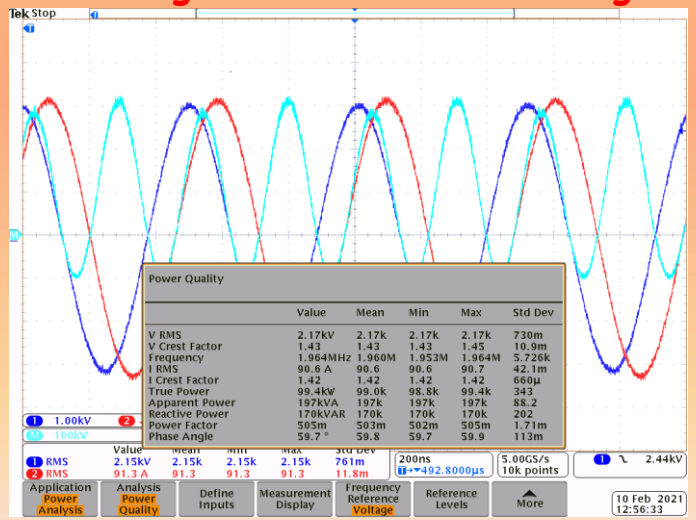
2 ms pulse with 50 Hz repetitions rate



Inverter voltage and RF antenna voltage and current



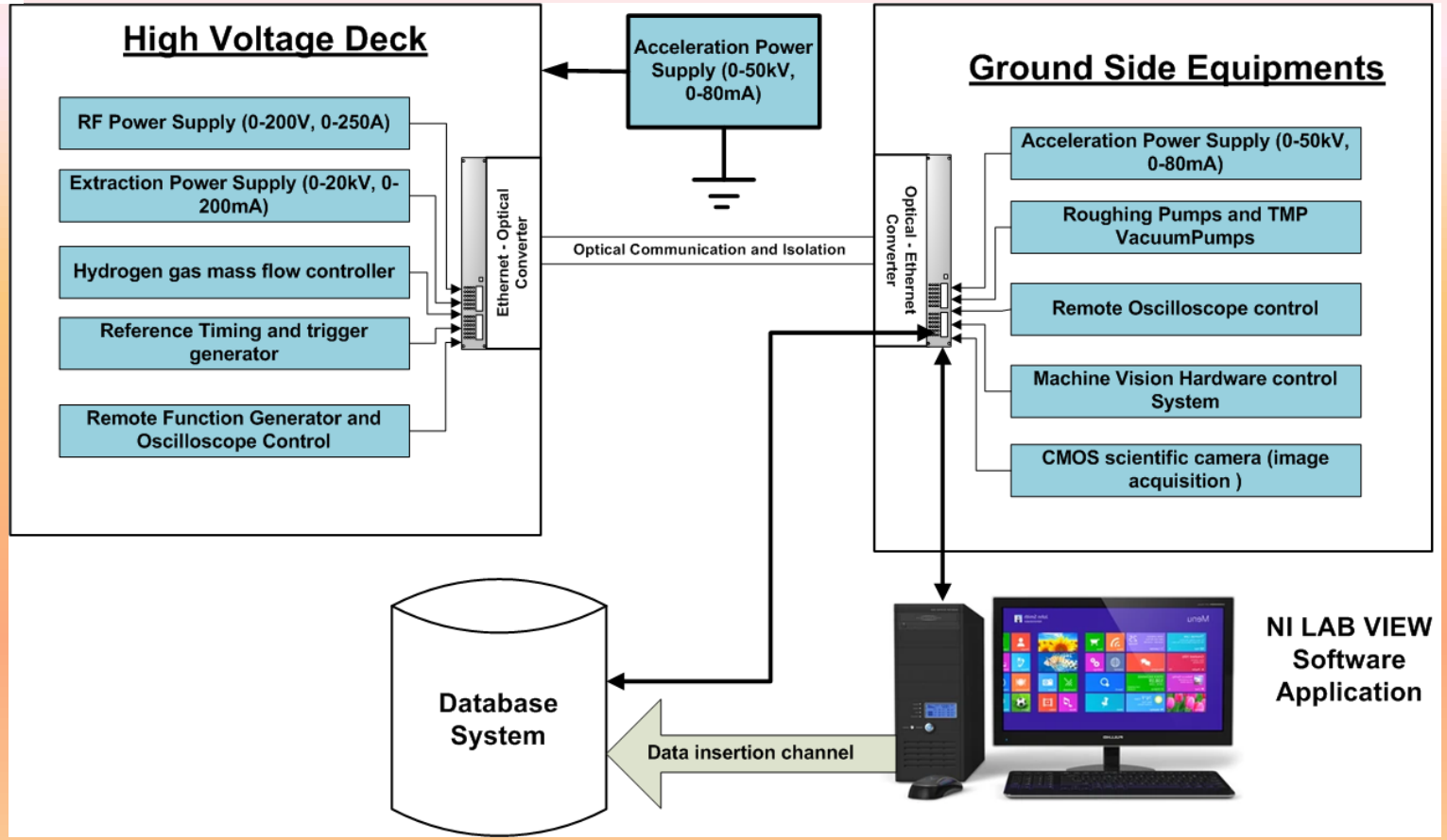
2 MHz RF Antenna voltage, current and power



RF power measurement coupled to plasma

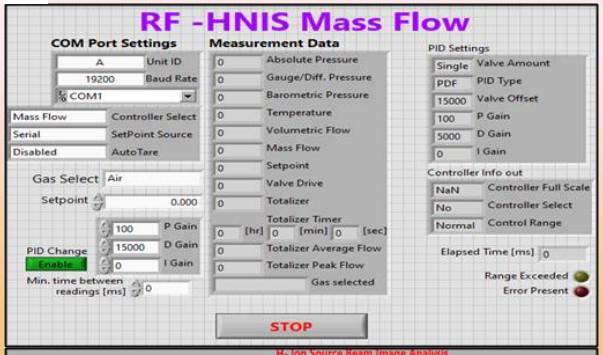
RF Ion Source Computer Control & Measurement

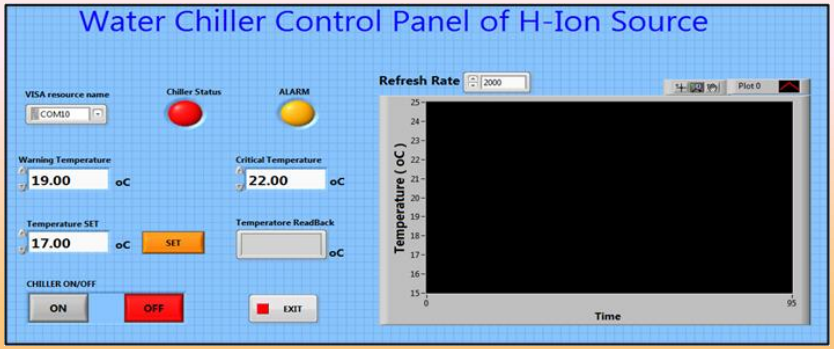
RF Ion Source Controls and Measurements

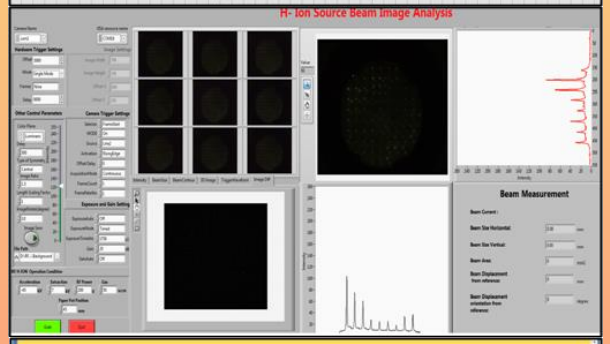


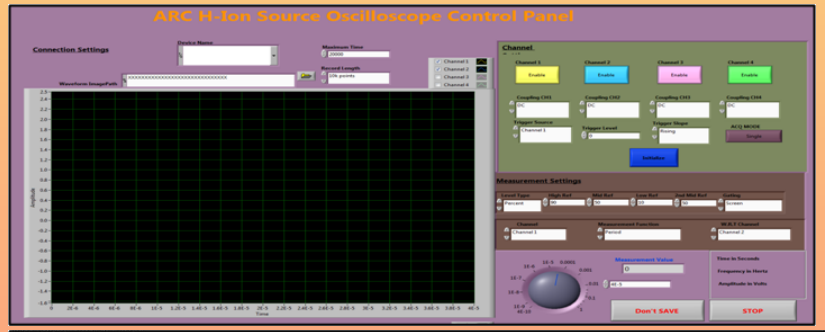
- HV deck equipment's control for hydrogen plasma generation and extraction
- Ground side equipment's acceleration, vacuum and measurement
- Optically isolated control for HV deck equipment's
- Network switches at HV deck and ground side for communication
- MS SQL server for data base system

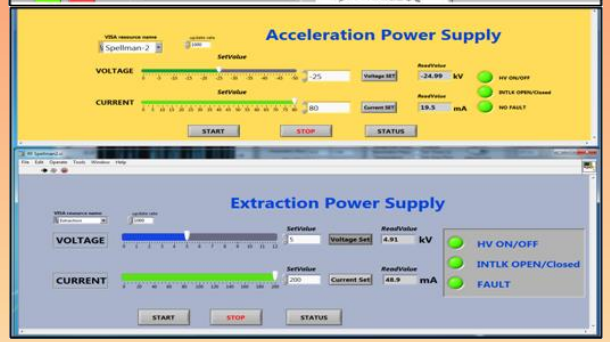
GUI for control of Ion Source

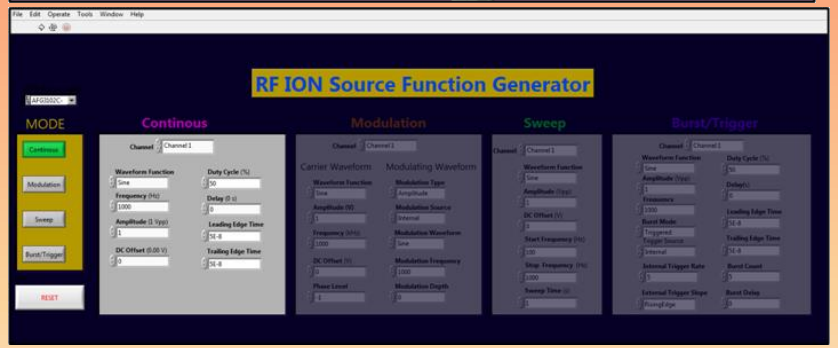






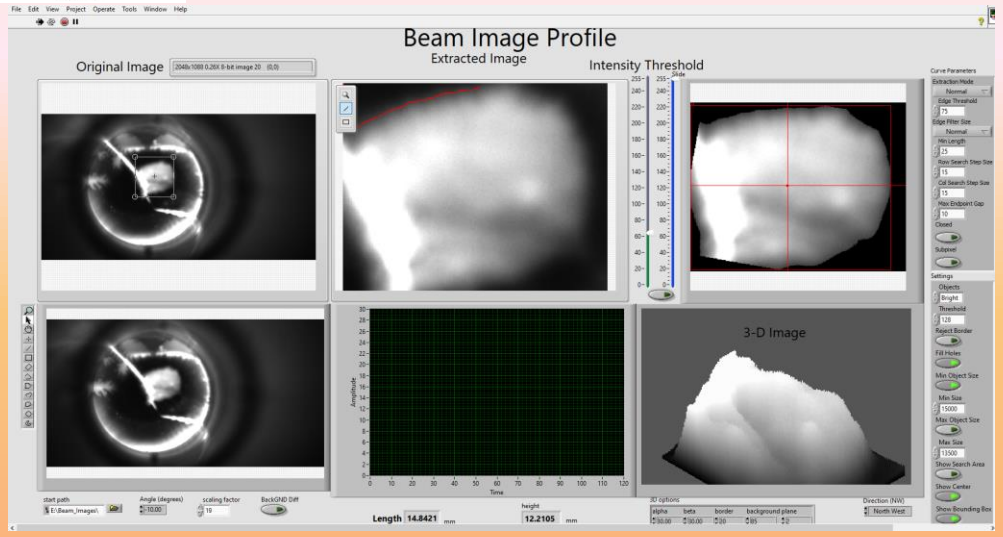




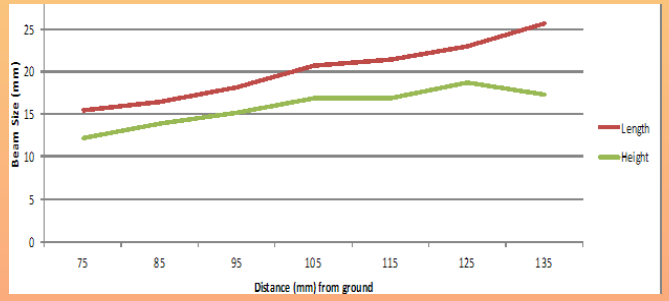


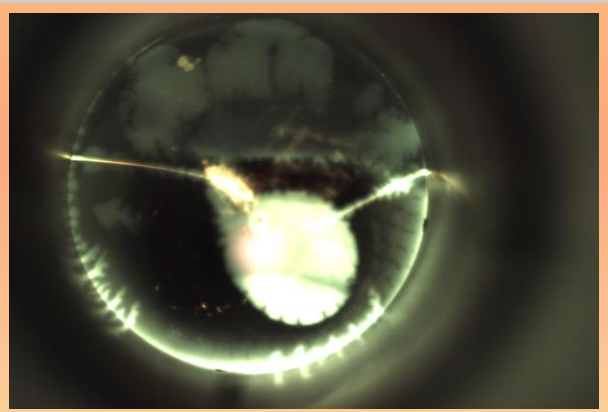
- NI Lab-View based GUI for control and monitor.
- Mass flow controller, extraction, acceleration and RF power controller.
- Monitoring of water cooler, GUI for function generator, DSO, digital delay generator
- Beam imaging with CCD, capture and measurements

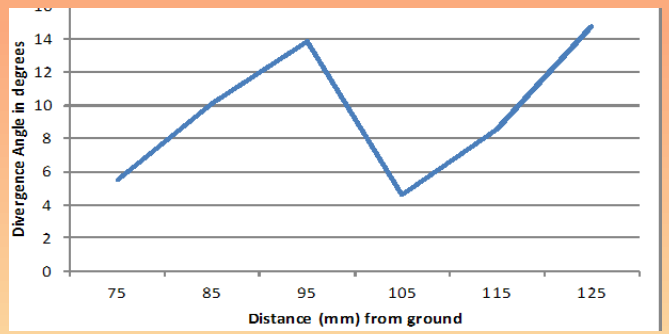
Negative Hydrogen Ion Beam Size Measurements



Distance	Length	Height	TAN Θ	Divergence Θ (degree)
75	15.4211	12.1722		0
85	16.3918	13.8538	0.09708	5.54
95	18.1711	15.1491	0.17792	10.09
105	20.6364	16.8804	0.24653	13.84
115	21.4354	16.8421	0.0799	4.57
125	22.9415	18.7368	0.15061	8.53
135	25.5789	17.3158	0.26374	14.7



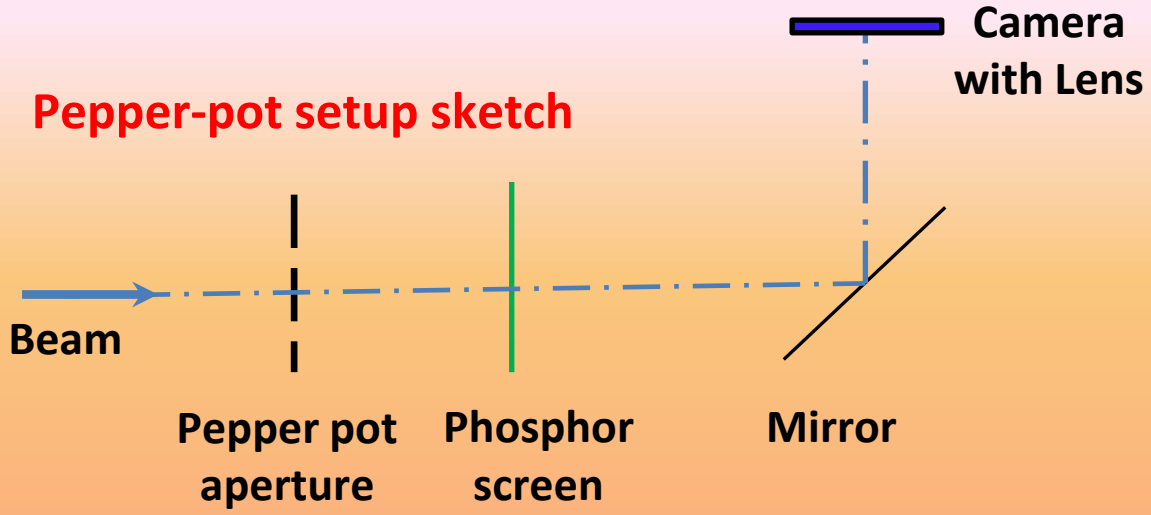


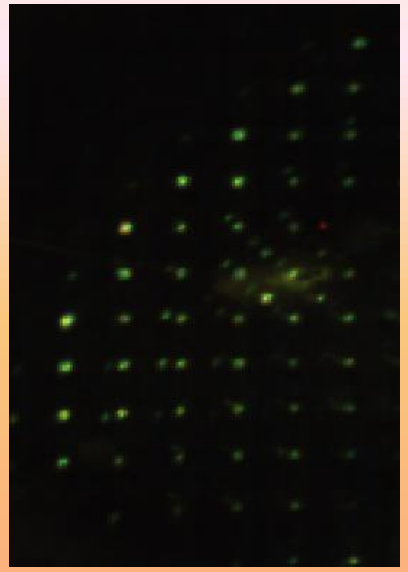


- GUI based image analysis for spot measurement
- GUI can operate portion of image capture for rotation, scaling, X and Y length measurement averaging, intensity profiling etc.
- Processed data exported into excel format for storage.
- Graphs shows beam size in X and Y plane and diversions along the beam axis (Z)

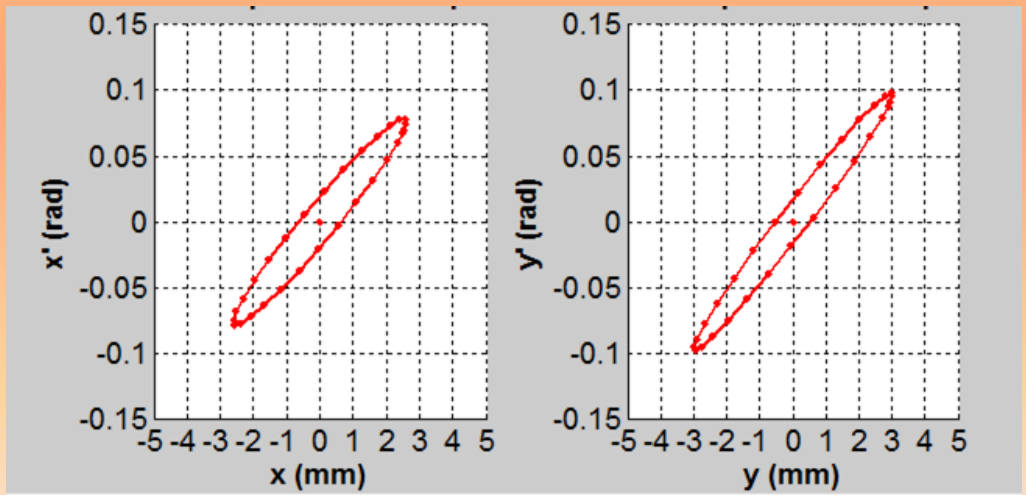
H- Ion Beam Emittance Measurement

Pepper-pot setup sketch



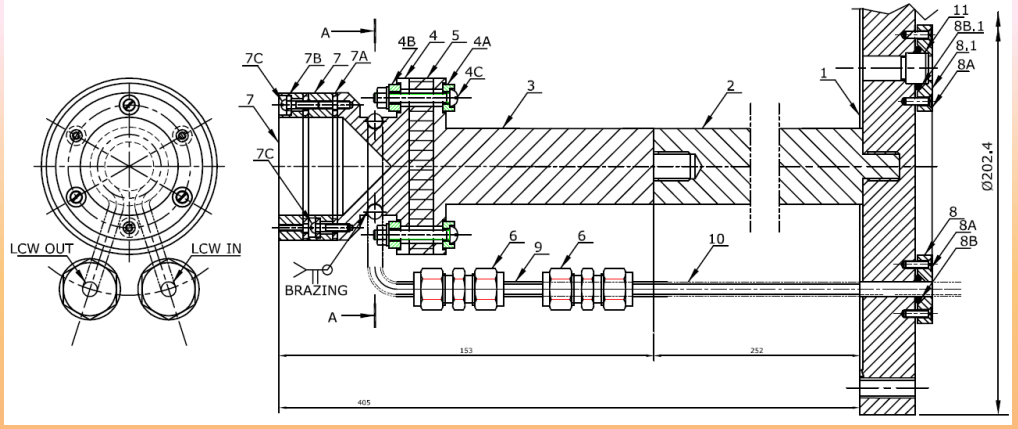


ε_x= 0.48 π mm-mrad	ε_y= 0.50 π mm- mrad
α_x = -3.99	α_y = -5.69
β_x = 0.13 mm/mrad	β_y = 0.17 mm/mrad
γ_x = 0.12 rad/mm	γ_y = 0.18 rad/mm

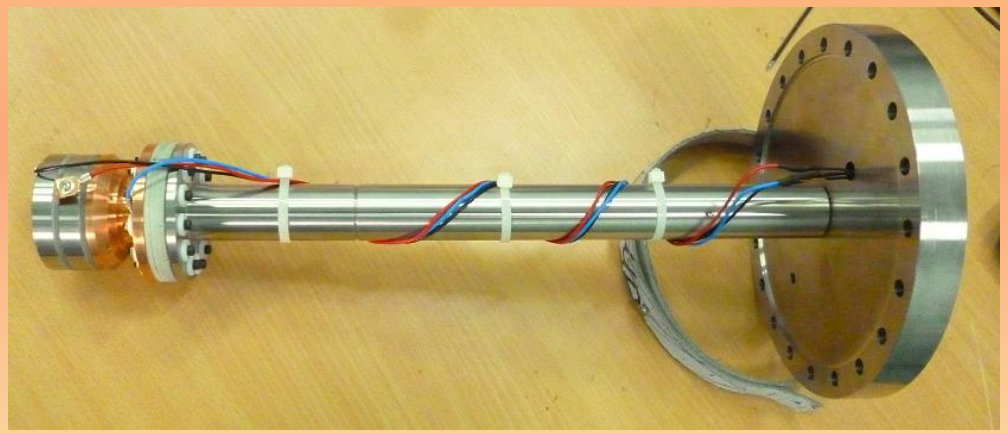


Water Cooled Biased Faraday Cup for Ion Beam Current Measurement

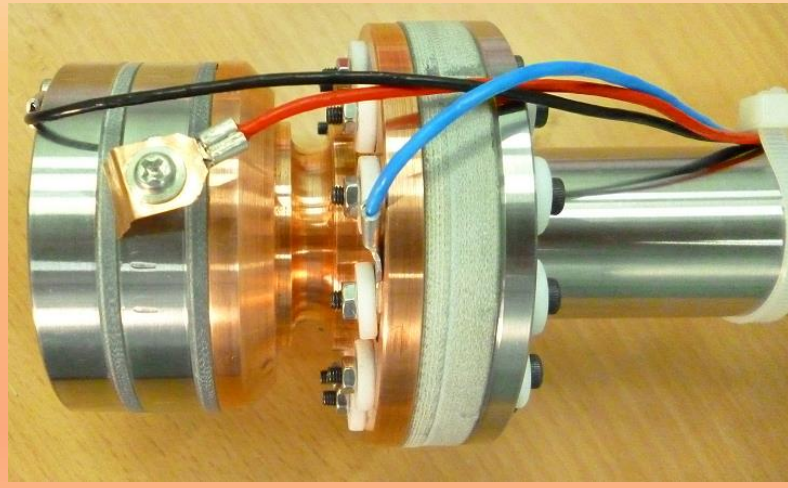
Water Cooled Biased Faraday Cup For Beam Current Measurement



2D-CAD drawing of water cooled biased Faraday Cup



Assembled water cooled biased Faraday Cup



Faraday Cup with Ground and Biasing Electrode

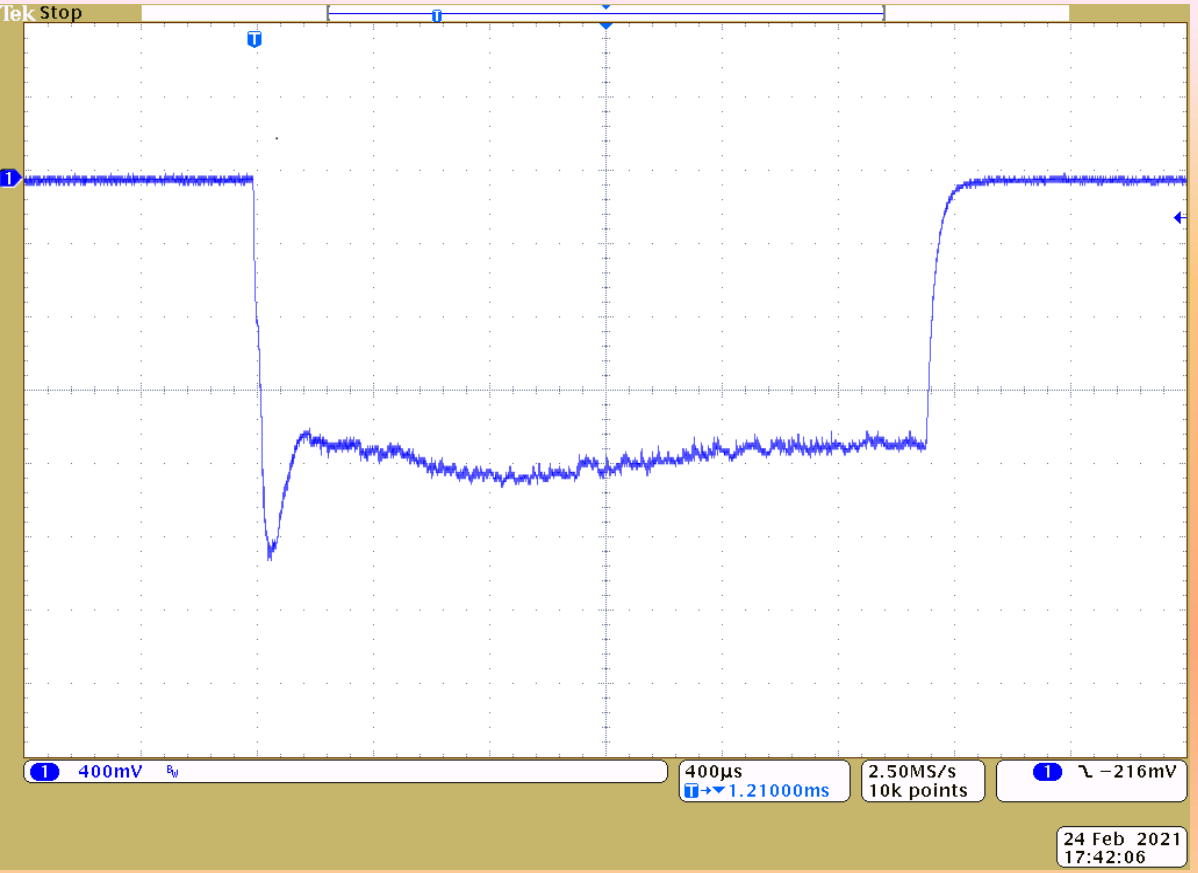
Water cooled biased Faraday Cup

Measured Parameters of Negative Hydrogen Ion Source

High Duty Factor RF H- Ion Source Measured Parameters

Description	Parameters	Parameters
Type	RF based Ion Source (High duty factor operation)	RF based Ion Source (low duty factor operation)
Particles	H-	H-
Beam Energy	50 keV	50 keV
Beam Current (Pulsed)	16 mA	25 mA
Main Plasma Frequency	2 MHz	2 MHz
Igniter Frequency	13.56 MHz	13.56 MHz
Pulse Width	2 ms	2 ms
Pulse Repetition Rate	10 Hz	2 Hz
Duty Factor	2%	0.4%

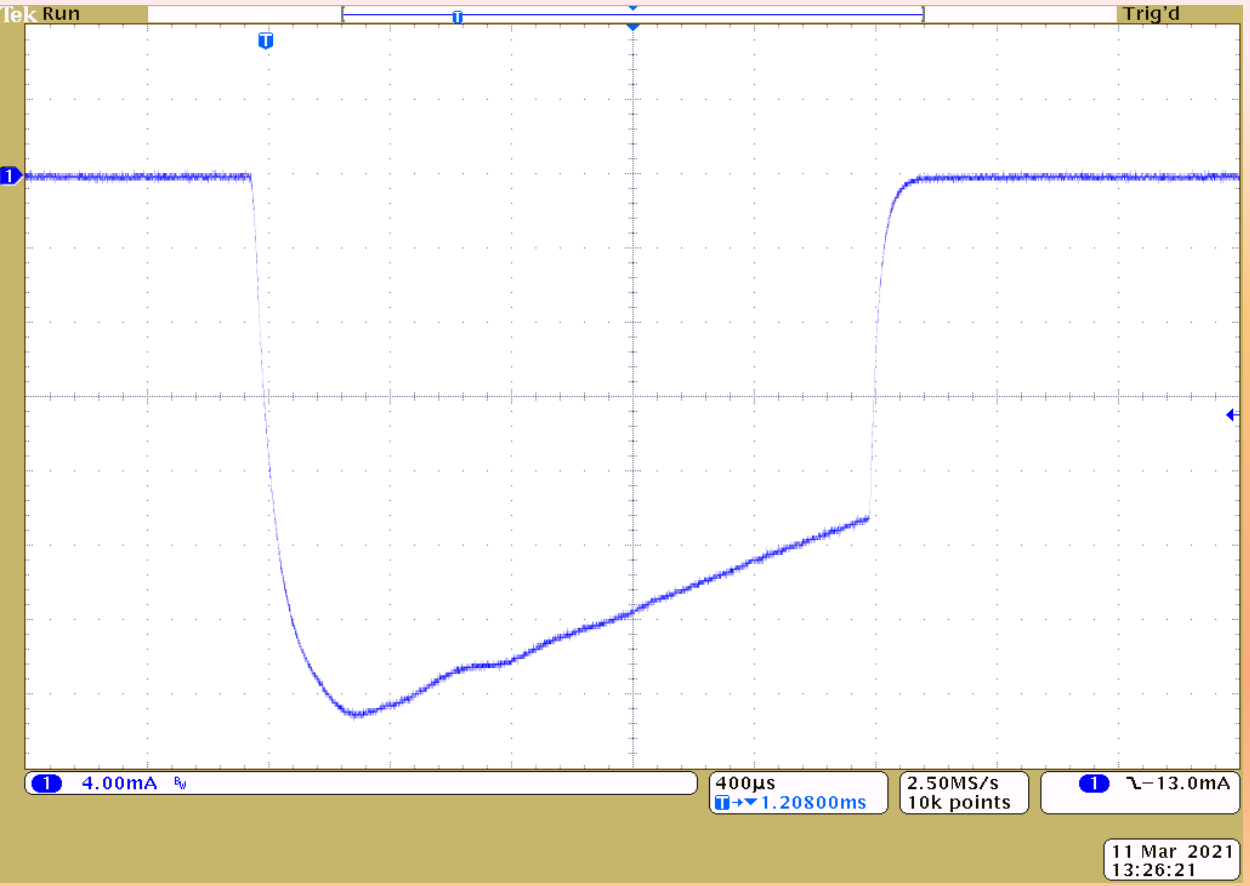
Recorded Beam Current Waveform



- H2 Gas at 28 SCCM
- 2 MHz RF Power ~ 13 KW
- Extraction Voltage 10 kV
- Acceleration Voltage 50 kV

16 mA pulsed beam current with 2 ms pulse width and 10 Hz repetition rate (2% duty factor) beam energy recorded up to 50 keV. This recording was done without water cooling. In future this will be operated at 50 Hz rate with water cooling at high duty factor.

Recorded Beam Current Waveform



- H2 Gas at 30 SCCM
- 2 MHz RF Power ~ 17 KW
- Extraction Voltage 10 kV
- Acceleration Voltage 50 kV

25 mA pulsed beam current with 2 ms pulse width and 2 Hz repetition rate (0.4% duty factor) beam energy recorded up to 50 keV. This recording was done without water cooling. In future this will be operated at 50 Hz with water cooling at high duty factor.

Conclusions

Conclusions & Future Work

- The pulsed RF source, matching network and various power supplies were tested successfully with 2 ms pulse width, at 50 Hz repetition rate (10% duty factor).
- The major heat generating components were water cooled like main plasma chamber, 2 MHz RF source and antenna, plasma electrode, extraction electrode, ferrite cores, Faraday cup. The remaining other components were forced air cooled.
- The mass flow controller, DC and RF sources were operated remotely using computer control
- The measured pulsed (2 ms) negative hydrogen ion current of 16 mA at 10 Hz and 25 mA at 2 Hz at 50 keV beam energy.
- NI Lab-View based GUI developed for remote operation.
- Measurement's of beam currents, emittance, beam size and divergence were carried out at various locations along the beam axis.
- In future testing will be carried out for high duty factor of ~10%.
- Further enhancement of beam current up to ~ 40 mA will be carried out.
- 100 Hours continuous operation of Endurance test will be carried out.
- Further investigation will be carried out to get flat top beam current.

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Shri Sunil Kamthre,

Shri Suman Kumar,

Shri Lakshman Chowdhry

and Shri S. K. Sonawane

during various stages of development of the RF based negative hydrogen ion source.

References

References

[1] M.P. Stockli, R.F. Welton, and B. Han, "Record productions establish RF-driven sources as the standard for generating high-duty-factor, high-current H- beams for accelerators, Rev. Sci. Instrum. 89, 052202 (2018).

[2] R. F. Welton, V. G. Dudnikov, K. R. Gawne, B. X. Han, S. N. Murray, T. R. Pennisi, R. T. Roseberry, M. Santana, M. P. Stockli, and M. W. Turvey, "H− radio frequency source development at the spallation neutron source", Rev. Sci. Instrum. 83, 02A725 (2012).

[3] J. Peters, "New developments in multicusp H− ion sources for high energy accelerators", Rev. Sci. Instrum. 79, 02A515 (2008).

[4] Dharmraj V. Ghodke, R. K. Khare, Rajnish Kumar, Manish Pathak, S. K. Jain, Ajith Amban, K. Murali Krishnan, Kuldeep Kumar Singh, Purushottam Shrivastava and Vijendra Prasad, "Development of external RF antenna based cusp free high duty factor pulsed negative hydrogen ion source", #28, NIBS-2020.

[5] J. Lettry, D. Aguglia, J. Alessi, P. Andersson, S. Bertolo, S. Briefi, A. Butterworth, Y. Coutron, et al, "Linac4 H− ion sources", Rev. Sci. Instrum. 87, 02B139 (2016).

[6] M. P. Stockli, B. Han, S. N. Murray, T. R. Pennisi, C. Piller, M. Santana, and R. Welton, "Recent performance of and plasma outage studies with the SNS H− source", Rev. Sci. Instrum. 87, 02B140 (2016).

[7] J. Lettry, S. Bertolo, U. Fantz, R. Guida, K. Kapus et al et al "Linac4 H− source R&D: Cusp free ICP and magnetron discharge", AIP Conference Proceedings 2052, 050008 (2018).

[8] Manish Pathak, V. K. Senecha, Rajnish Kumar, Dharmraj. V. Ghodke, "Simulation of RF power and multi-cusp magnetic field requirement for H− ion source", NIMA838, 96 (2016).

[9] S. Briefi, S. Mattei, J. Lettry, and U. Fantz, "Influence of the cusp field on the plasma parameters of the Linac4 H− ion source," AIP Conference Proceedings 1869, 030016 (2017).

Thanks

Q & A

For any question

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