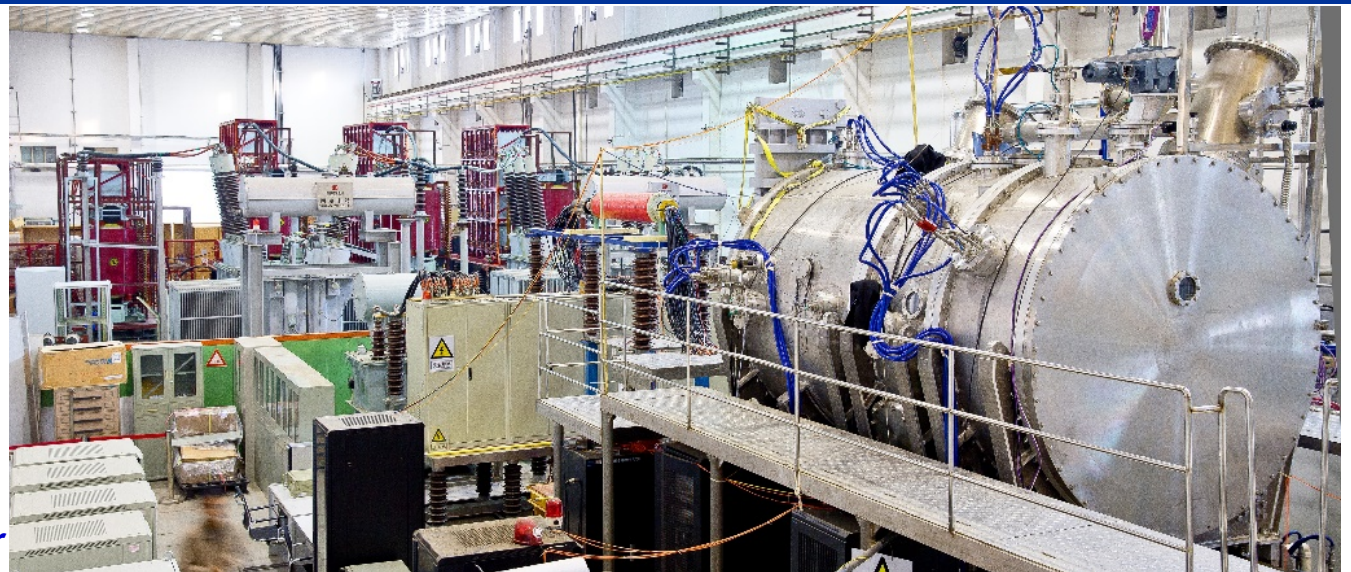
Performance of Radio frequency Ion source for neutral beam injector

Yahong Xie, Chundong Hu*, Caichao Jiang, Jianglong Wei, Yumin Gu, Lizhen Liang, Yongjian Xu, Qinglong Cui, Shiyong Chen,Yuanlai Xie

Neutral beam Injection Division , Institute of Plasma Physics, CAS

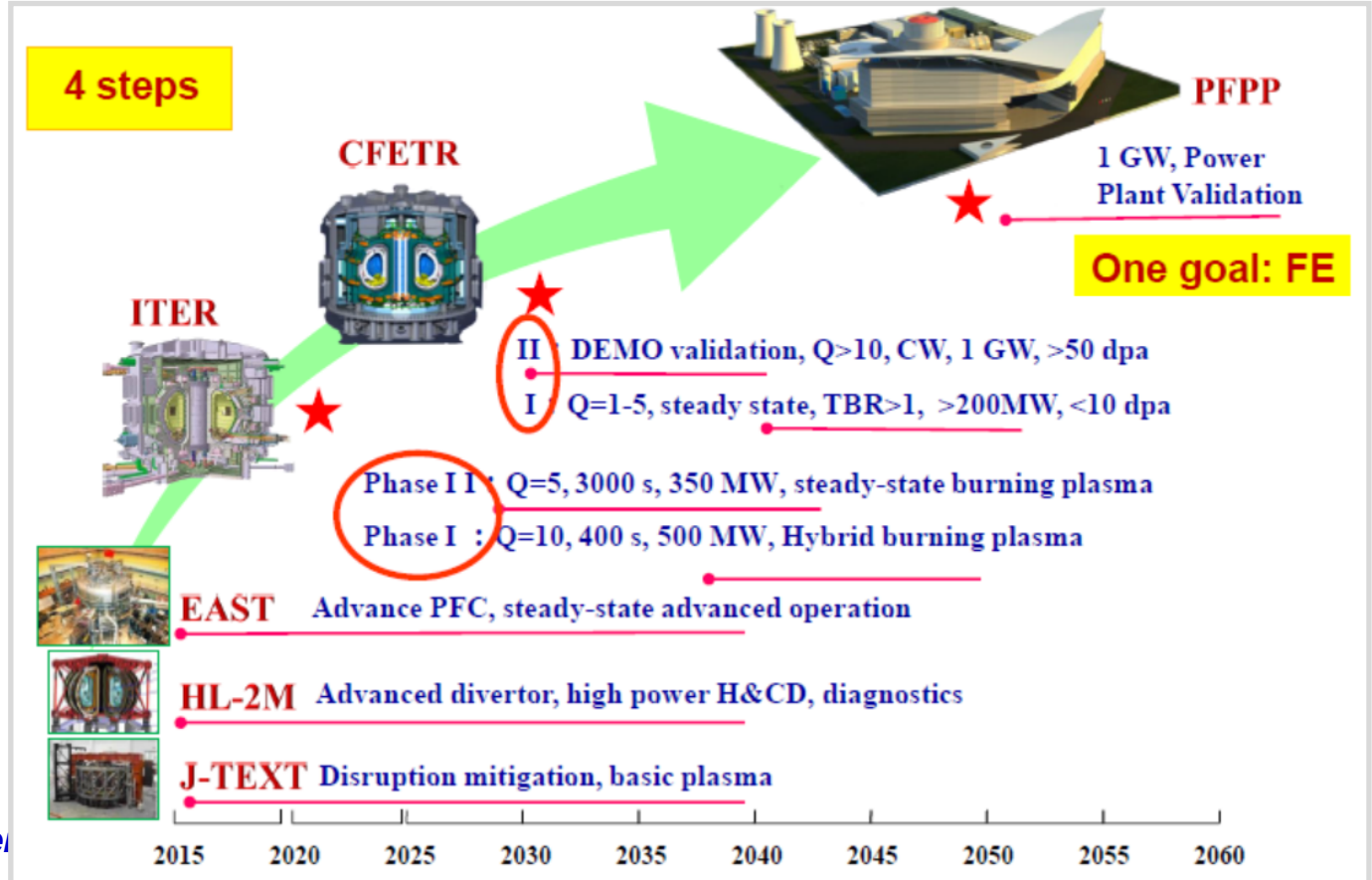


Outline

- Introduction
- R&D of RF plasma generator
- Preliminary results of negative ion extraction
- Future plan and summary

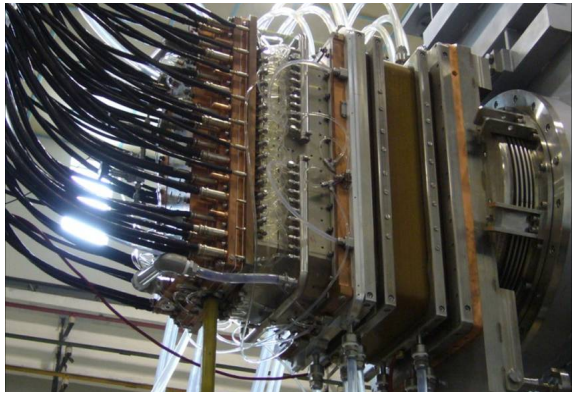
MFE development pathway in CHINA

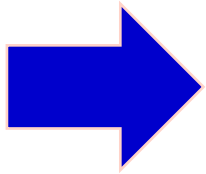
- The construction of the China Fusion Engineering Test Reator (CFTER) for magnetic fusion energy research is proposed
- The negative ion source based neutral beam injector is a key tool for plasma heating and current driver

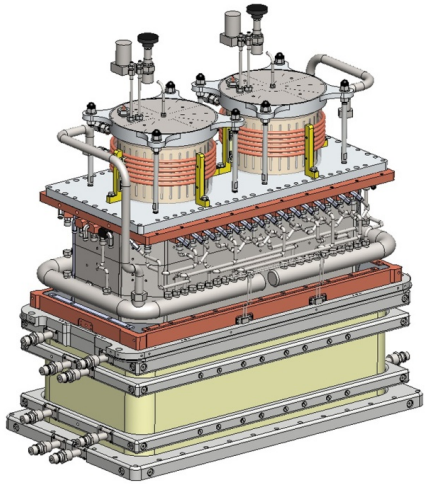


Background of development of RF NIS

- Two positive neutral beam lines were developed for EAST tokamak in the last ten years
- Negative ion source is new research area in ASIPP
- RF ion source will be better compare with arc based source when be operated with long pulse (no filament, no contamination)
- The basic physical and engineering issues for development of RF ion source







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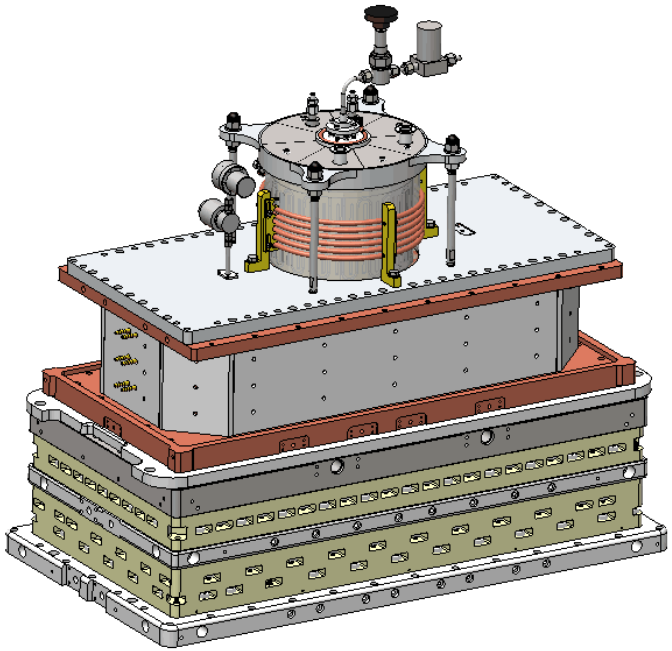
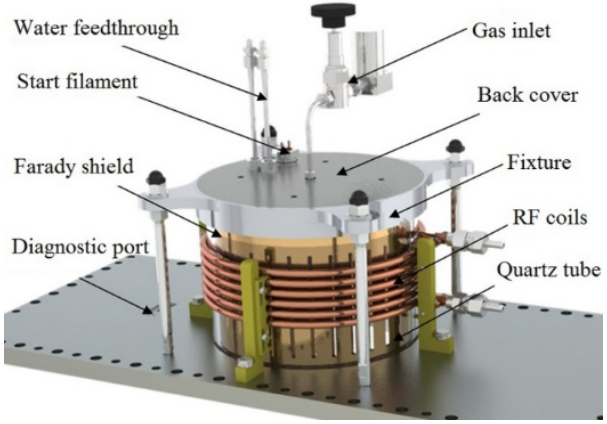
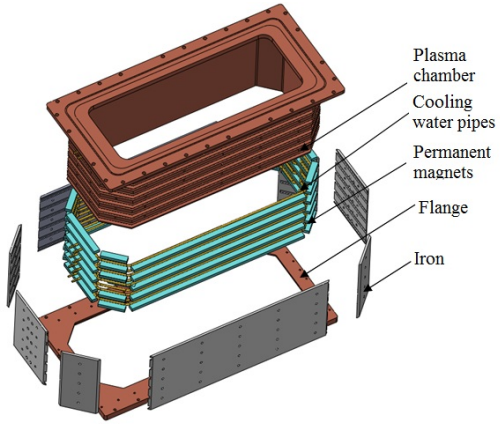
R&D of RF ion source

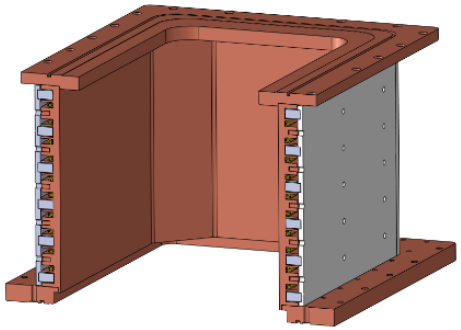
Specifications of RF source

Items	specifications
RF power coupling type	Inductive coupling
Antenna type	External antenna
Dimensions of driver	D=210mm; H=120mm
Number of antenna	6(OD=6.5mm, ID=4mm)
Start filament	D=0.2mm, L=80mm





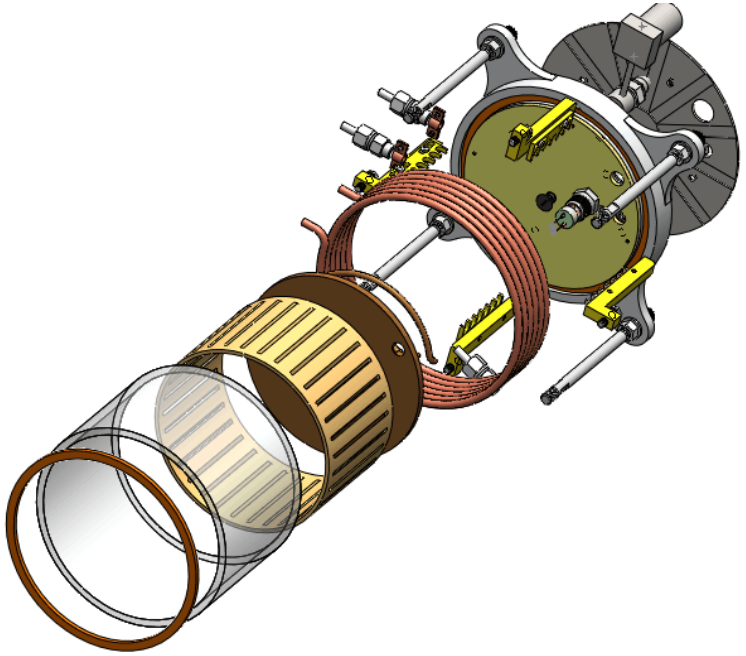


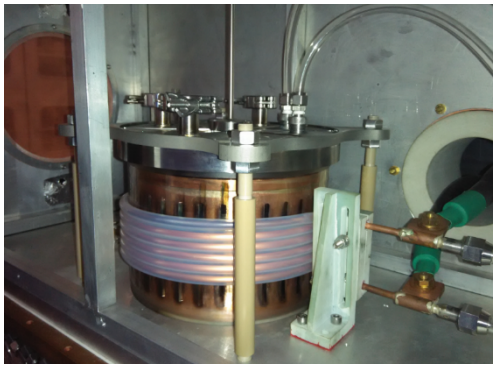


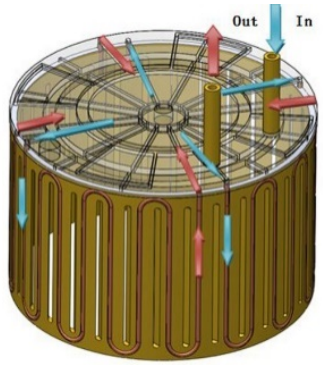
R&D of RF ion source

Sizes of RF driver

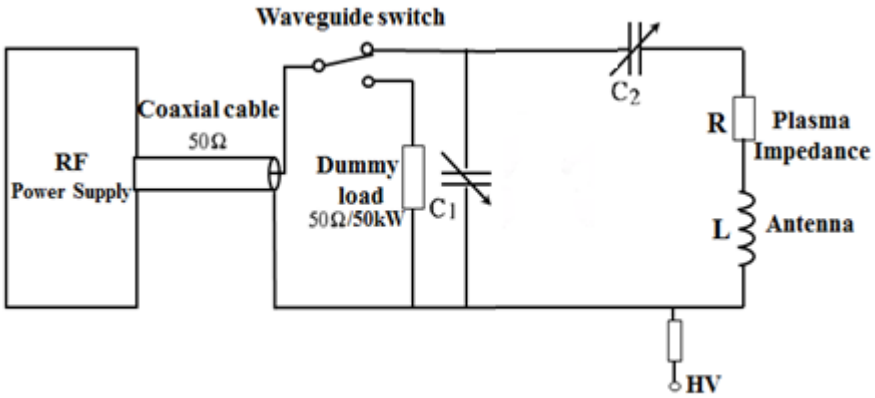
Item	specifications
faraday shield	ID=200mm height = 140mm thickness = 4 mm
Size of quartz	ID=210mm height = 156mm thickness = 8 mm
Expansion area	Length=650mm, height= 260mm, depth= 240 mm



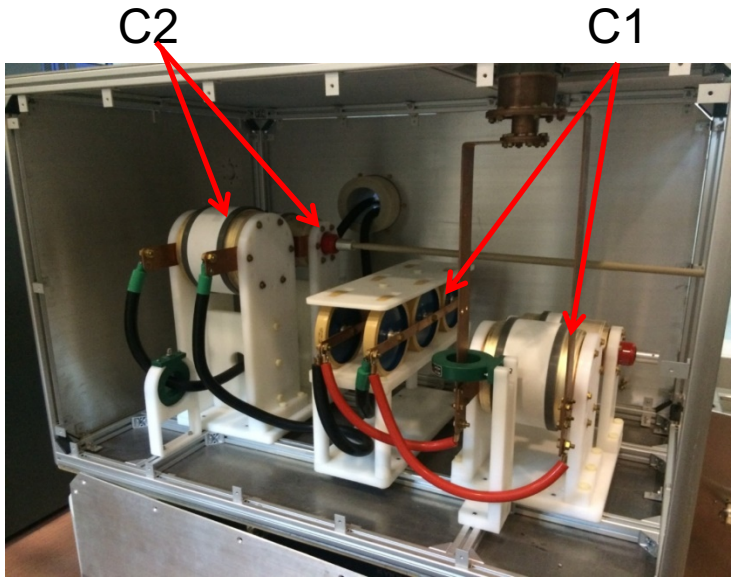


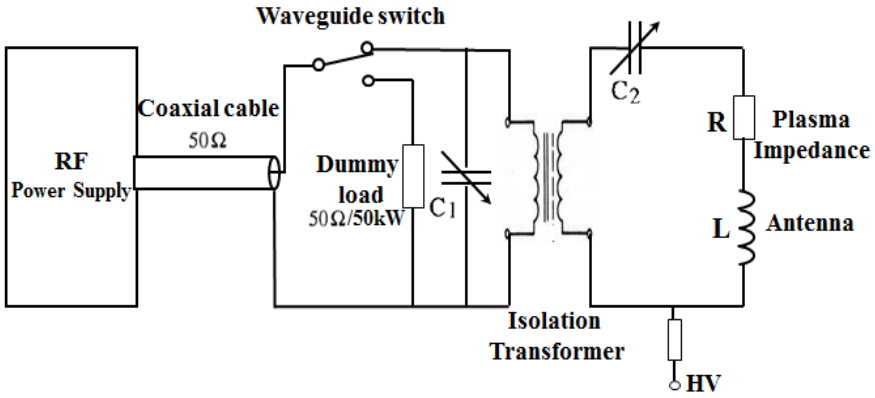


RF ion source matching network

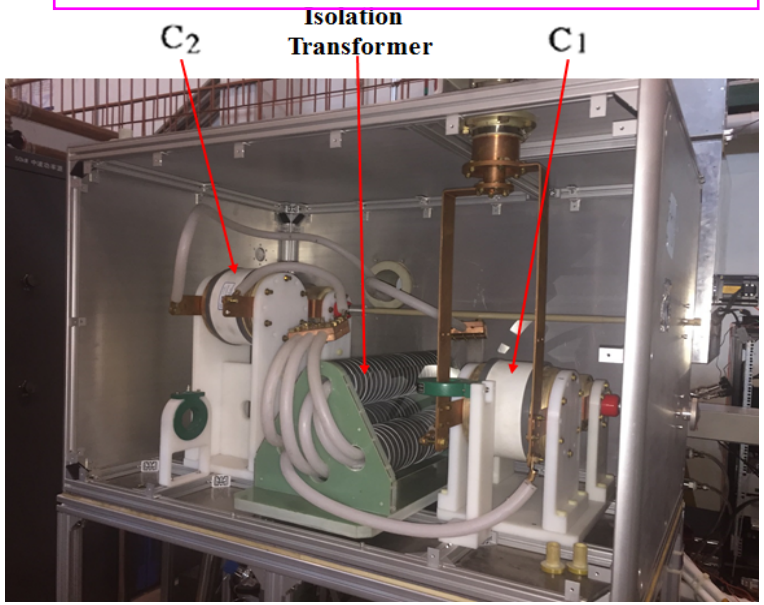


C2=1.5nF±0.5nF C1=8.5nF~11nF





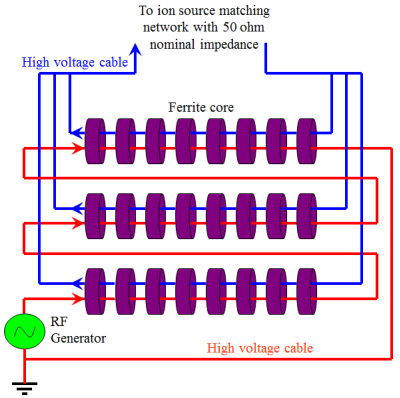
C2=2.65nF±0.5nF C1=1.1nF~5nF

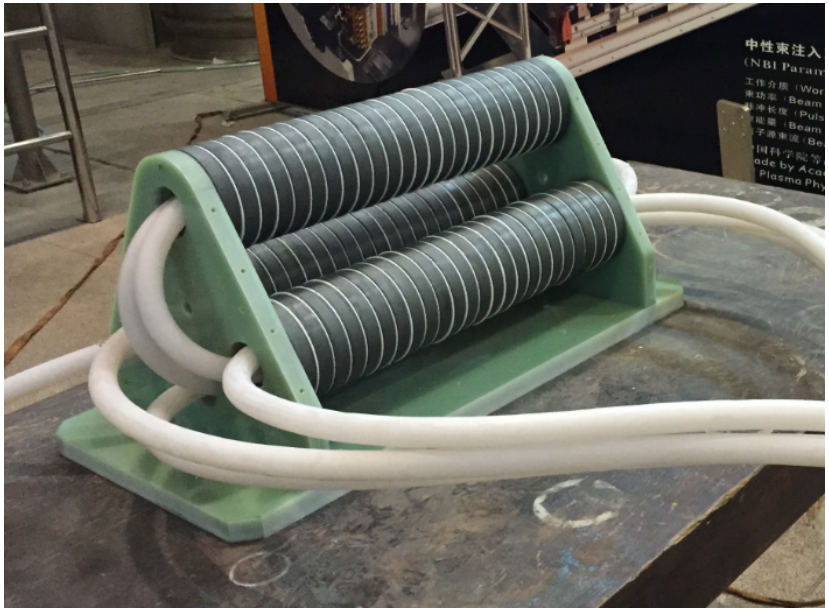


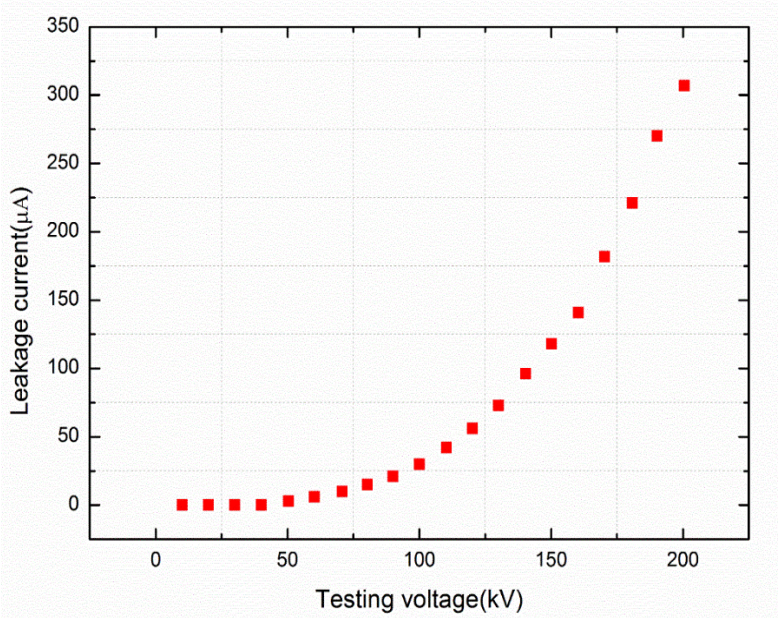
Details please see P1-30 on Monday, September 3

HV transformer

- HV transformer was designed and developed
- The HV holding was tested with 200keV





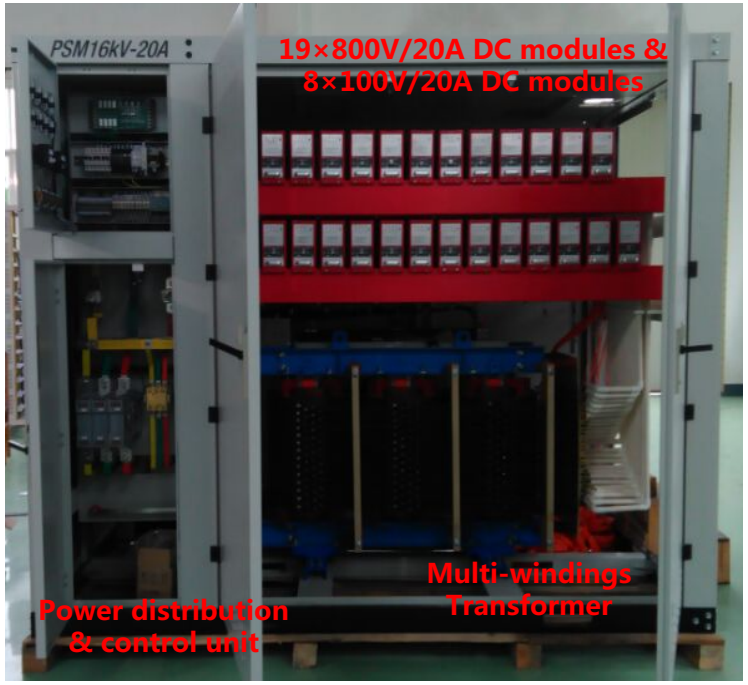


The test results of HV holding

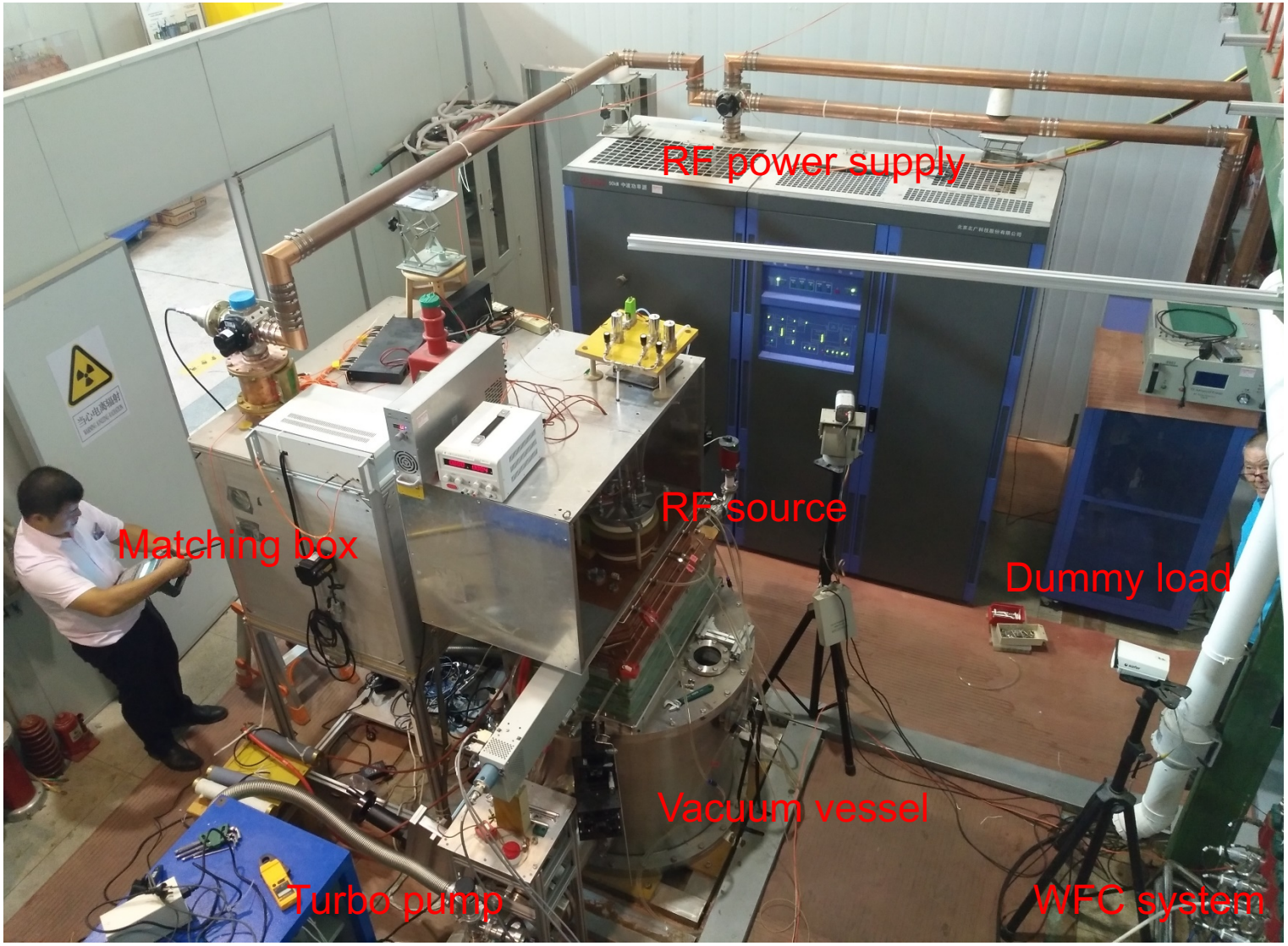
Power supply

- RF power supply
  - Solid state, 50kW@1MHz,
  - 100kW@1MHz (will move to lab. soon)
- Beam extraction power supply
  - PSM type
  - 16kV@20A


50kW@1MHz RF P.S.

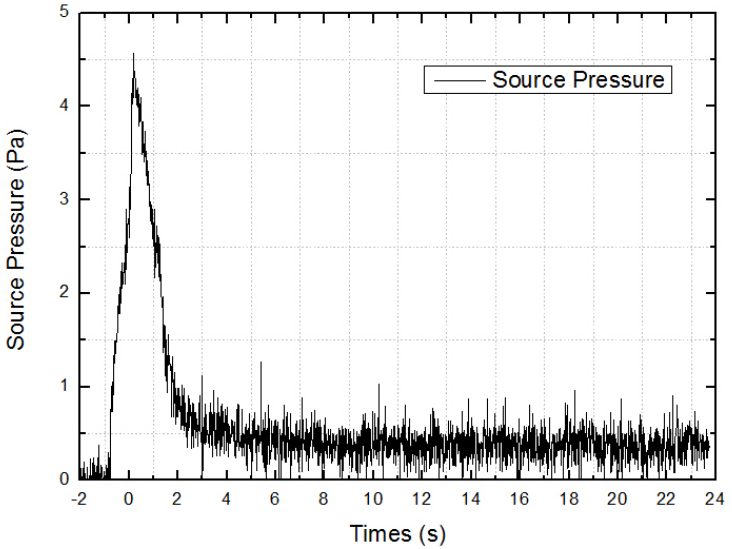


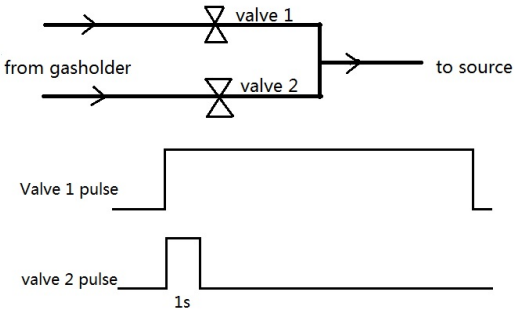
RF ion source test bed

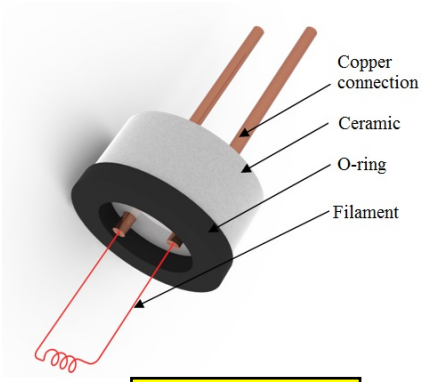


RF plasma generation

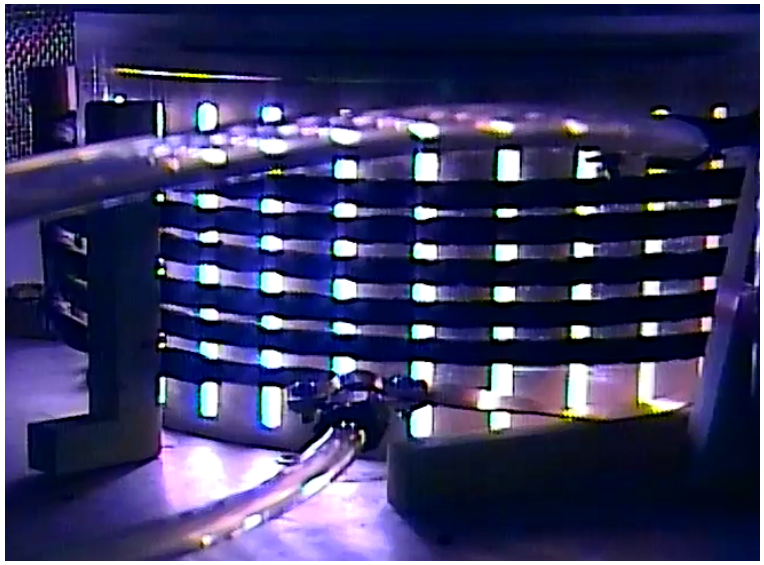
- Plasma was not easy to be generated with Faraday shield
- Start filament was used to plasma generation
- Gas was controlled to help of plasma ignition



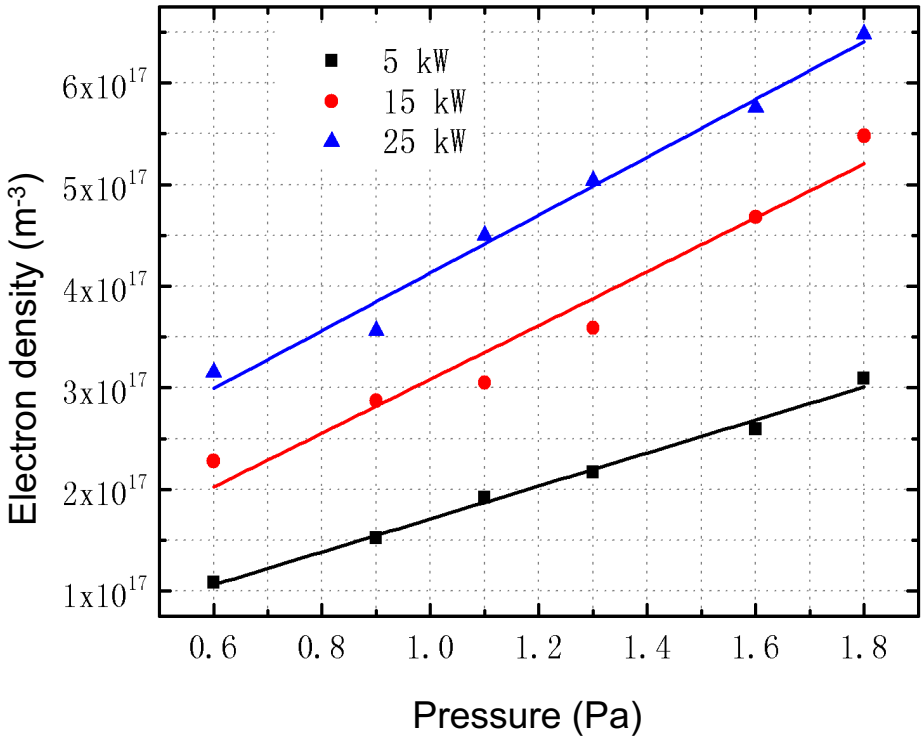


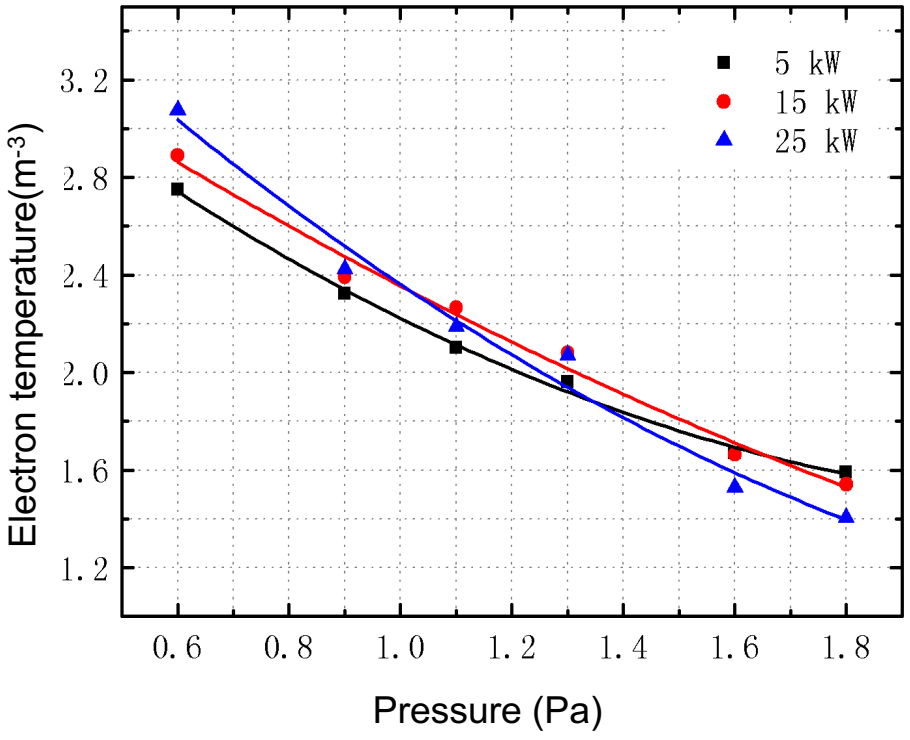


Start filament



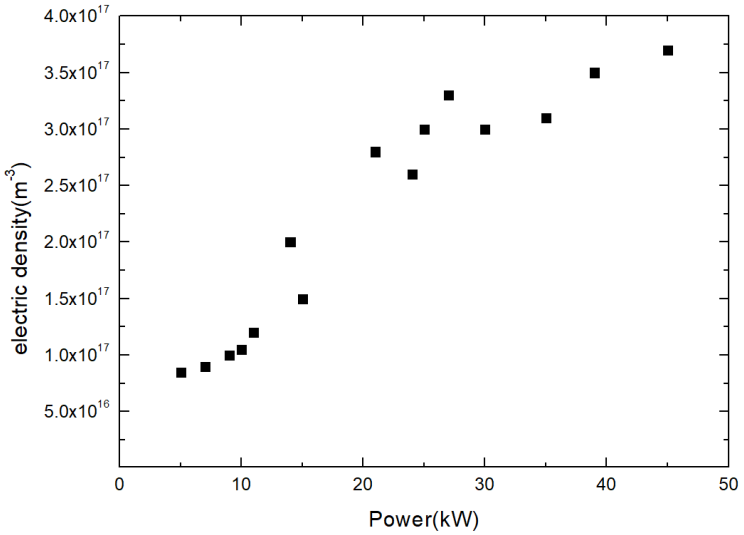
Plasma parameters measurement

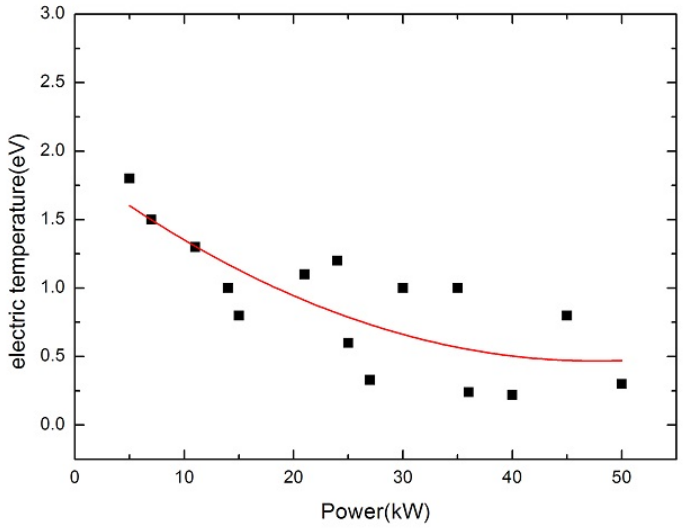


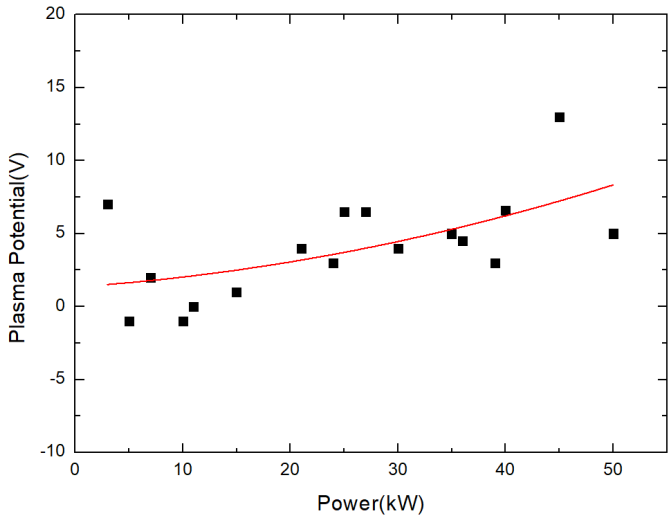


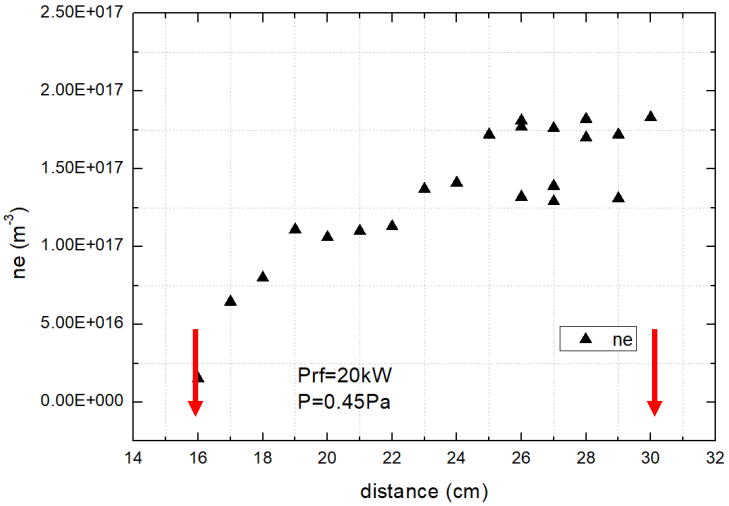
Electron density and temperature as a function of pressure

Plasma parameters measurement





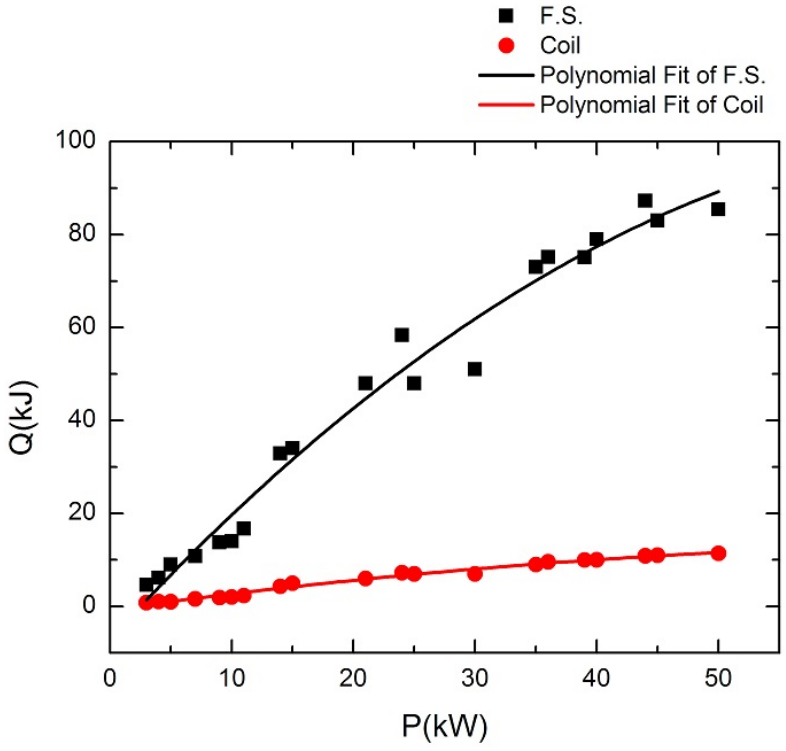




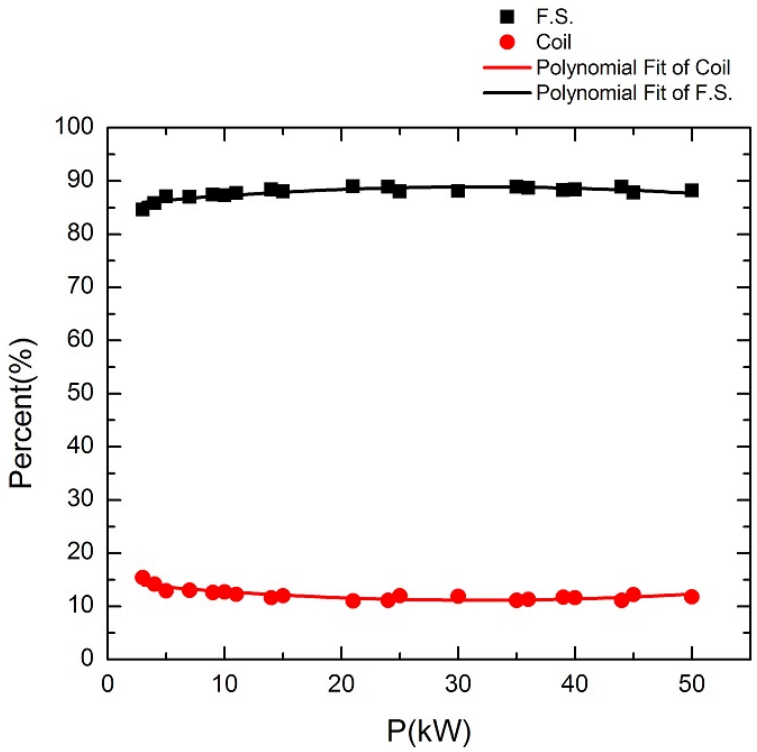
Parameters measurement in the bottom of expansion area

The power lose on the F.S and coil

- About 40% of RF power deposited on FS and coil which measured by WFC
- 88% of measured heat on FS and 12% on Coil



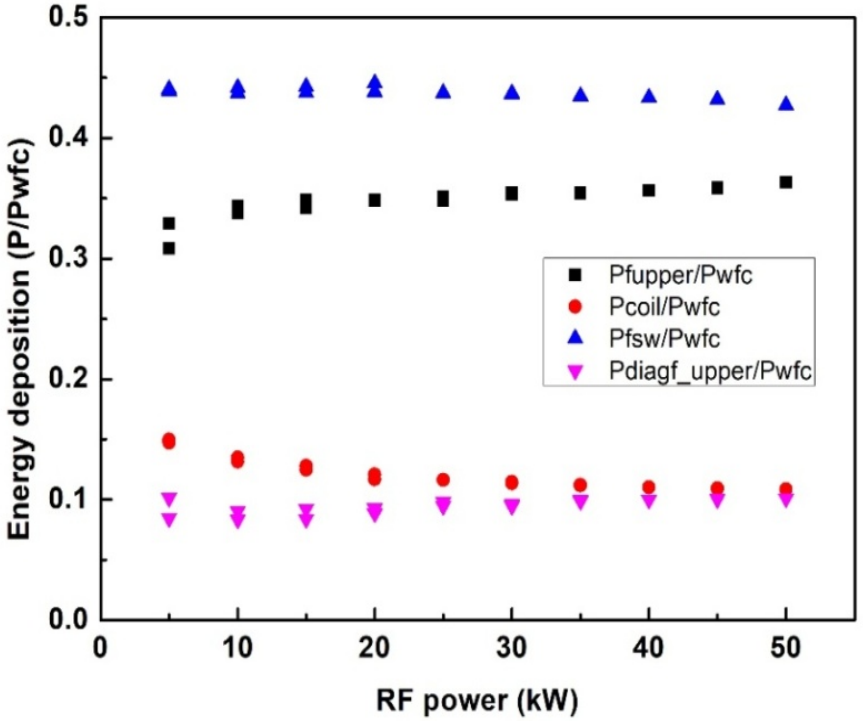
Heat deposition as function of RF power(5s)

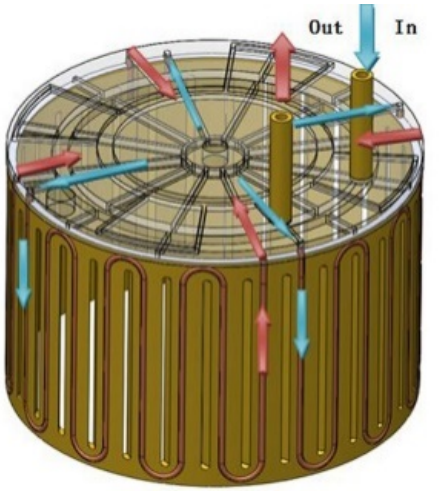


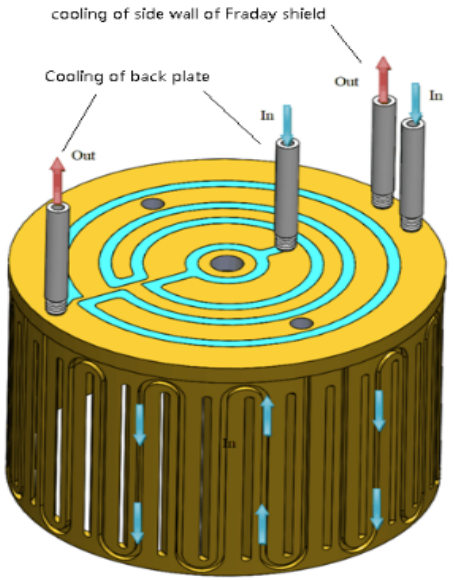
Heat deposition of FS and coil

Long pulse RF plasma generation tests

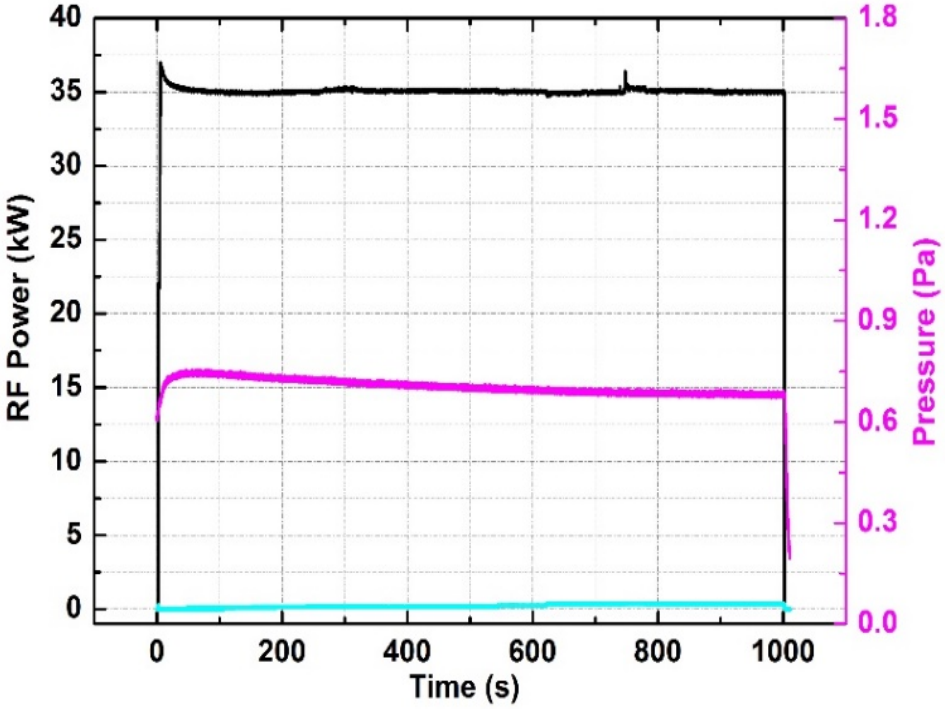
- The heat loading on FS was huge, especially the side wall of FS
- The cooling of FS was optimized for long pulse operation test



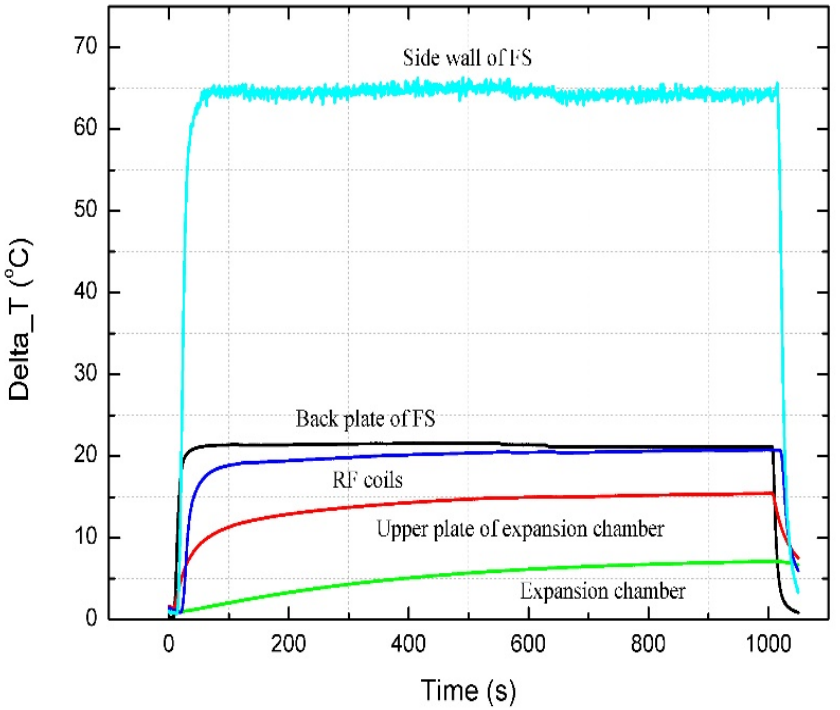




Long pulse RF plasma generation tests



Waveform of plasma generation(35kW &1000s)



Temperature rise of each components of source

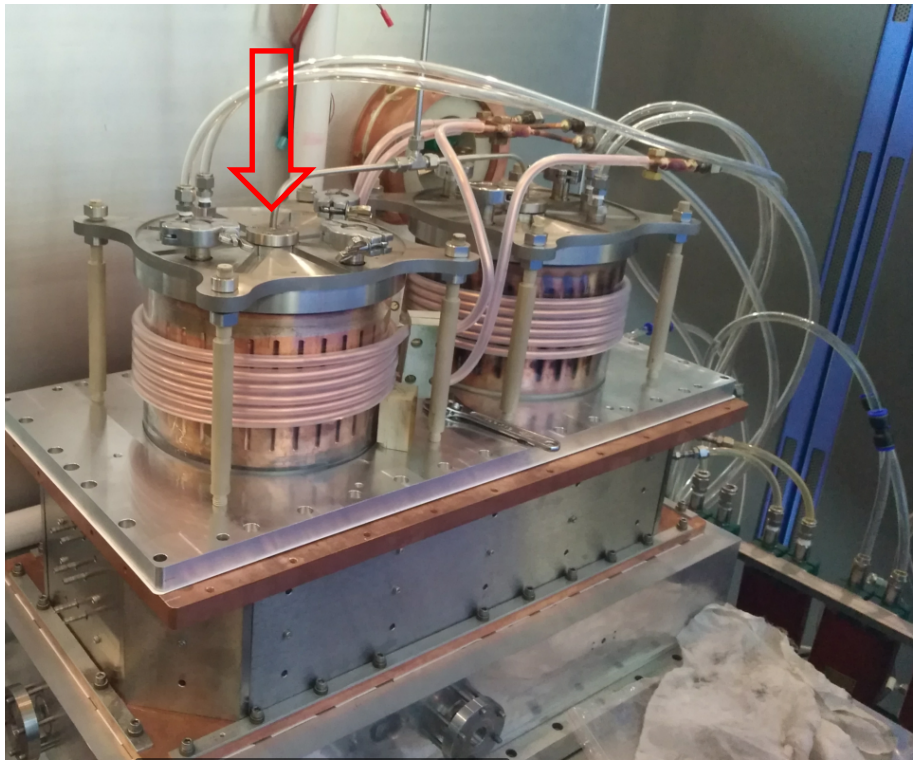
Long pulse RF plasma generation tests

- Heat deposited on the FS was huge
- Structure and cooling should be optimized

Item	Side wall of FS	Back plate of FS	coils	Upper plate of EC	Body of EC
Flow rate(L/h)	140	270	119	274	239
Maximum temperature rise (℃)	64	21.3	20.7	15.4	7.2
Deposited power (kW)	10.48	6.72	2.8	1.52	4.58
Percentage	40.1%	25.7%	10.7%	5.8%	17.6%

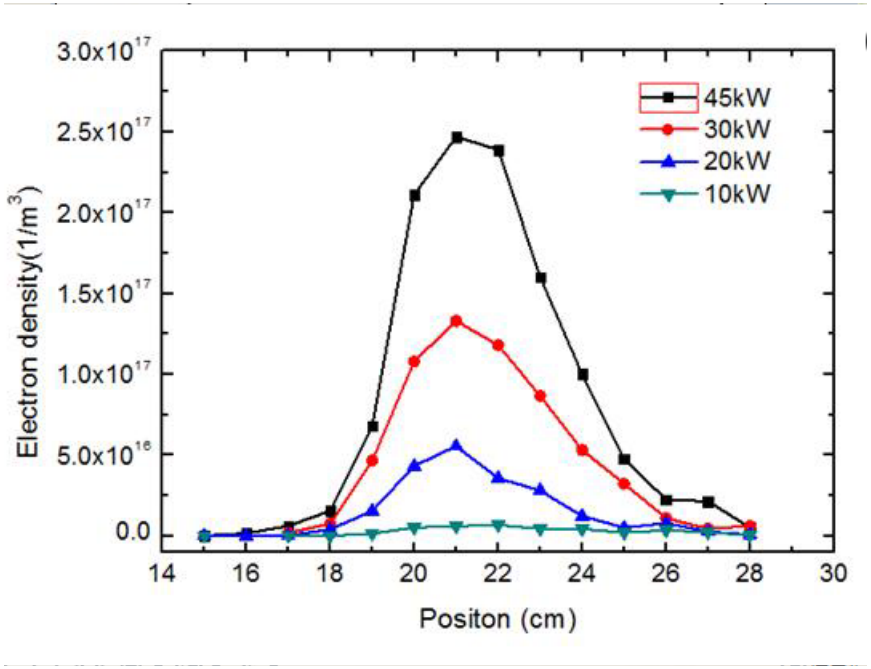
Plasma discharge with double drivers

- Plasma generation with two drivers was tested
- The coils was connected in series
- Plasma was generated with RF power of 50 kW
- Langmuir probe was installed in the bottom of expansion chamber

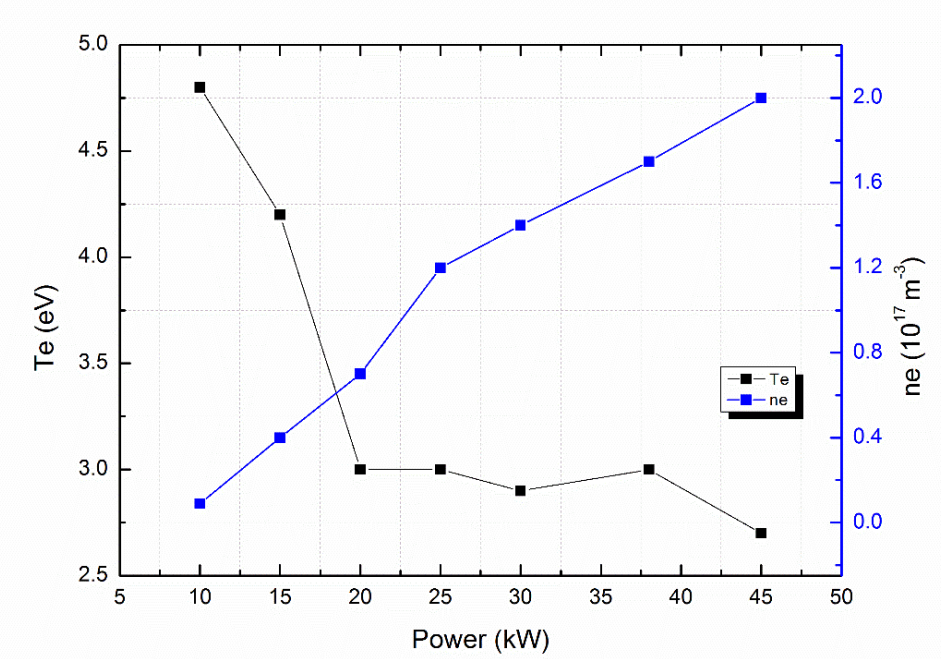


Plasma parameters measurement

- The profile of electron density was strange, may be due to the probe tip parallel to gas pump direction



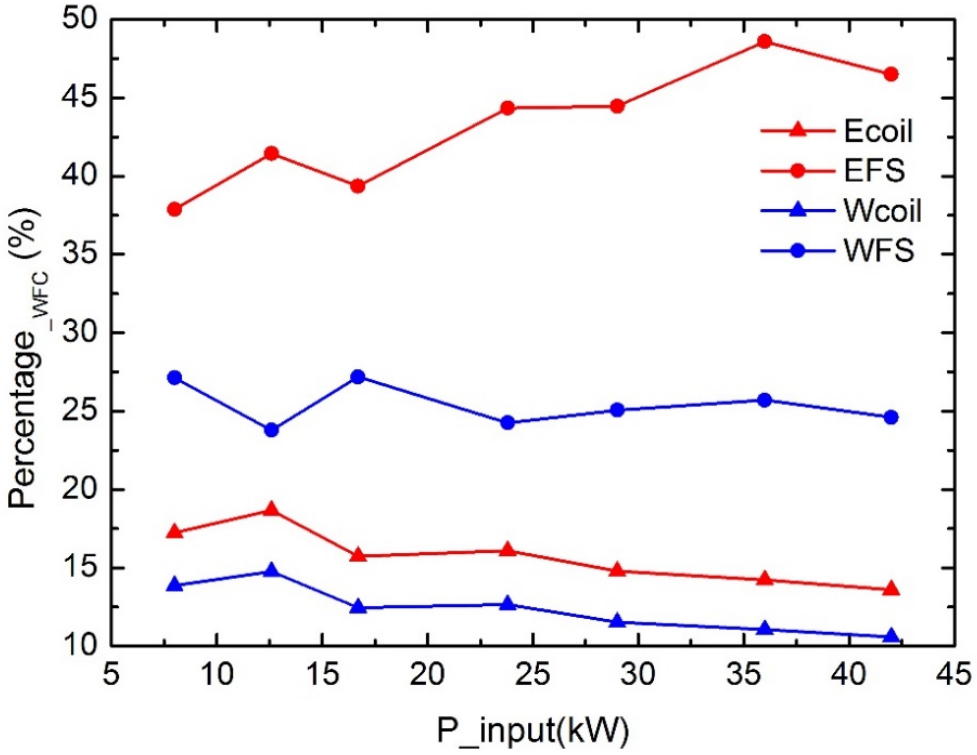
Electron density vs probe position



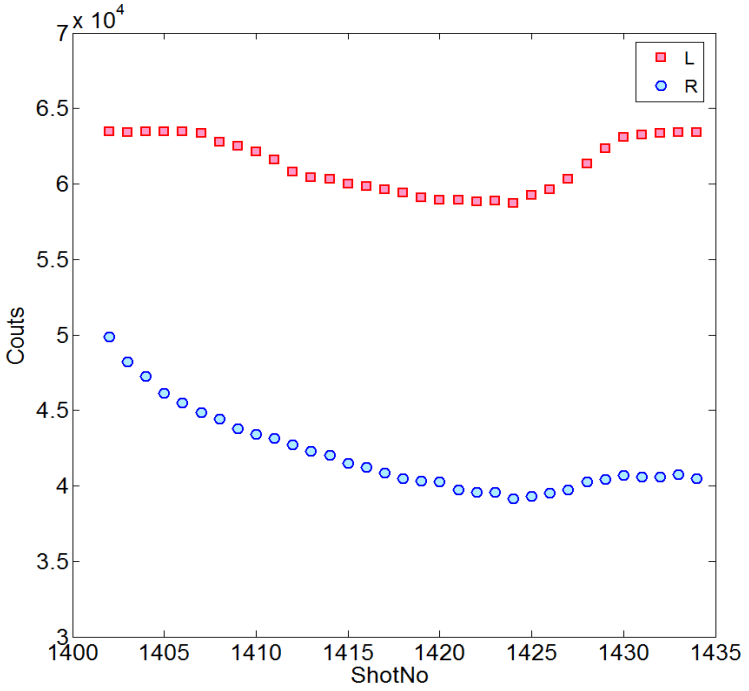
Electron density and temperature vs RF power

Plasma parameters measurement (cont.)

- Heat load on the drivers and intensity of Hα in drivers were measured
- The RF power loading on two drivers was different



Heat deposited on the coils and FS



Intensity of Hα in driver

Outline

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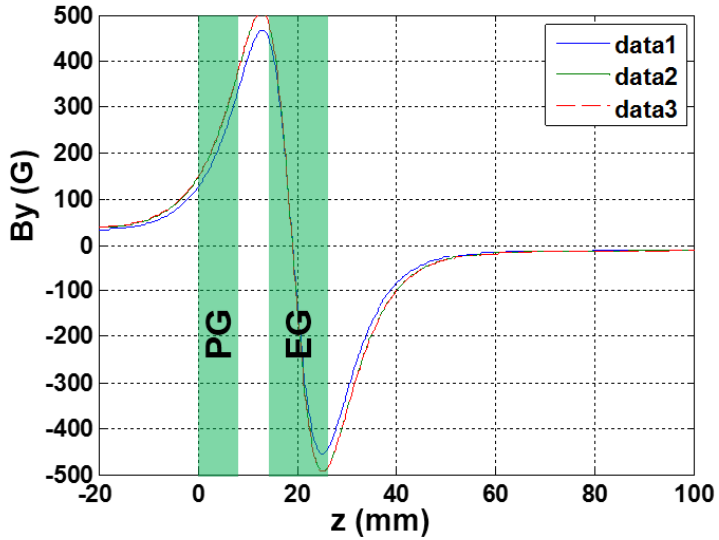
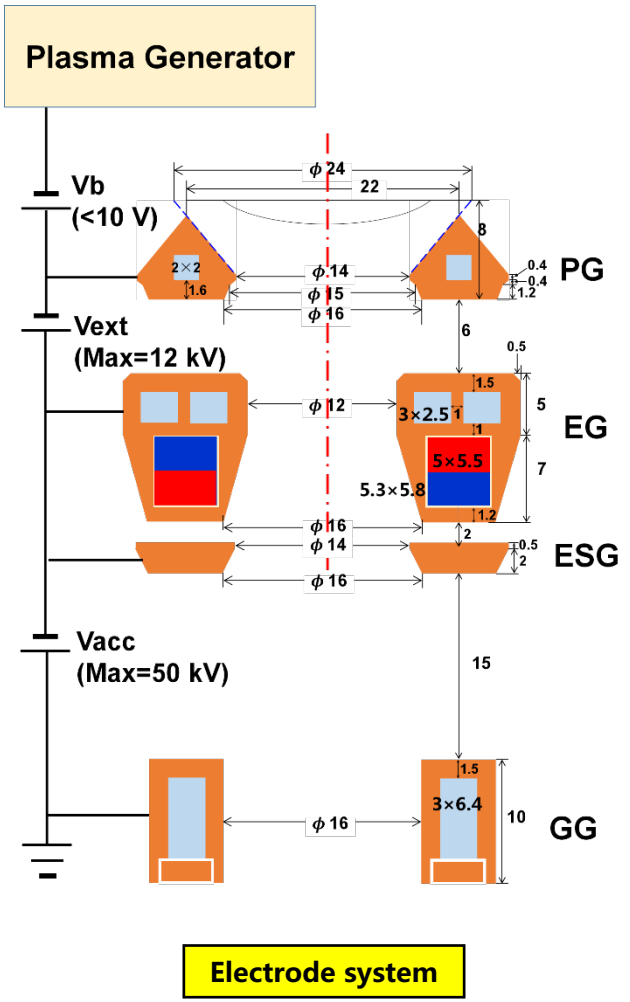
Negative ion extractor and accelerator

- **2** segments, **5×6 beamlets** for each, aperture separation **22mm and 20mm**
- Center of electron suppression magnetic field **~500G**
- Electron Suppression Magnet: **5mm×5.5mm**(cross section), **SmCo**, **1 T**

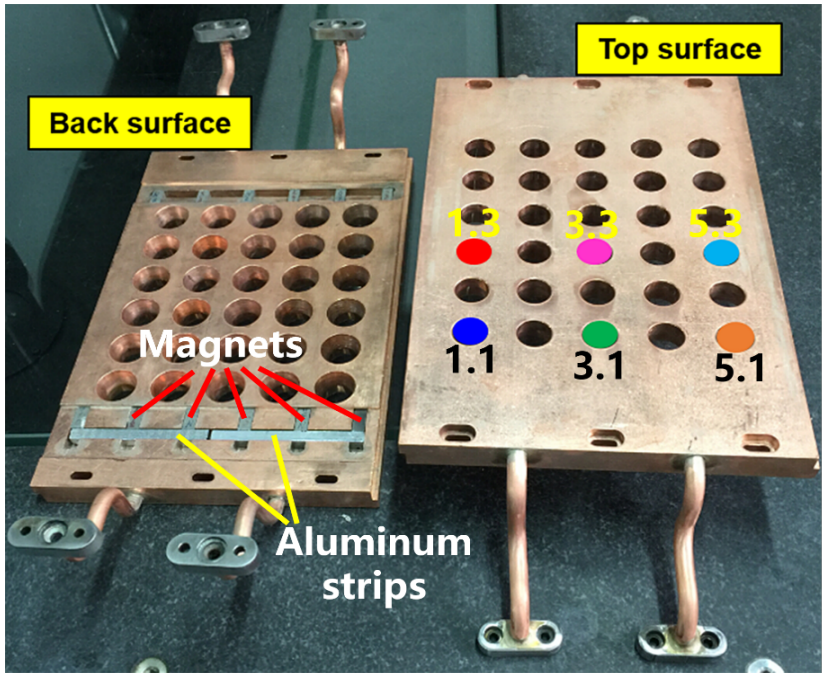


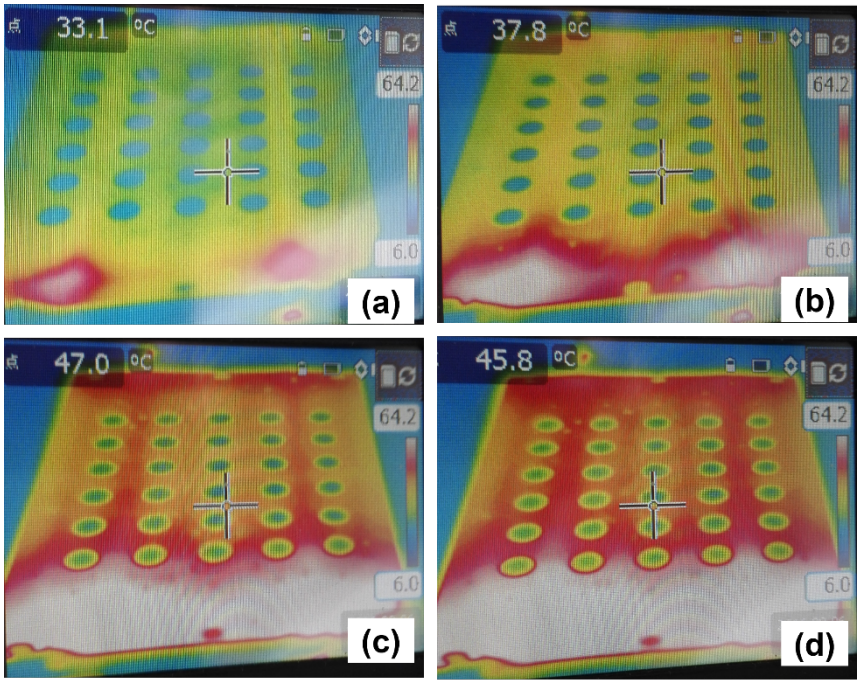
Center B_{ESM}

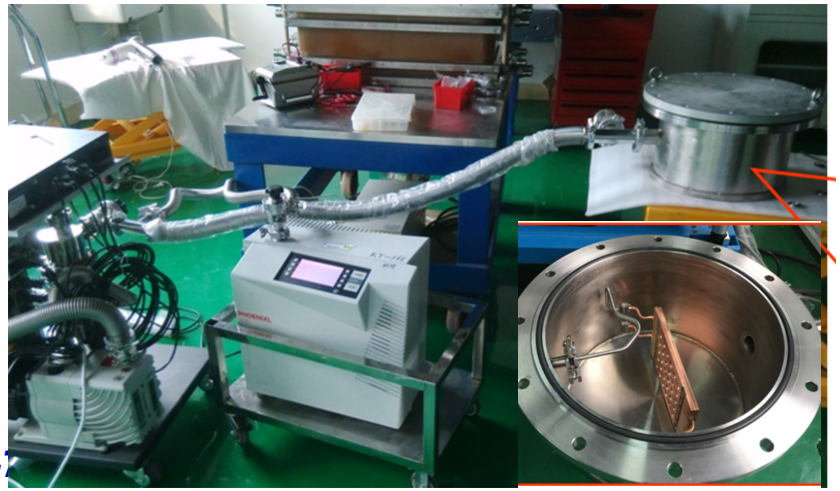


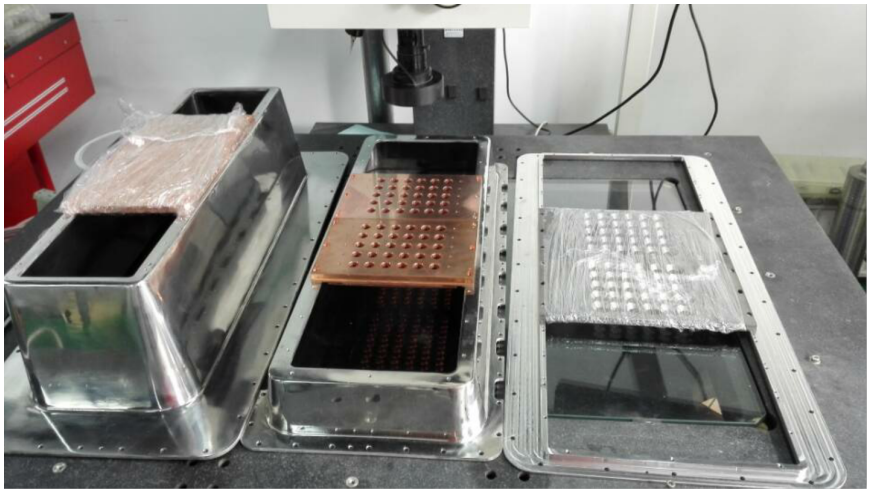
Electrode system

Negative Ion Accelerator



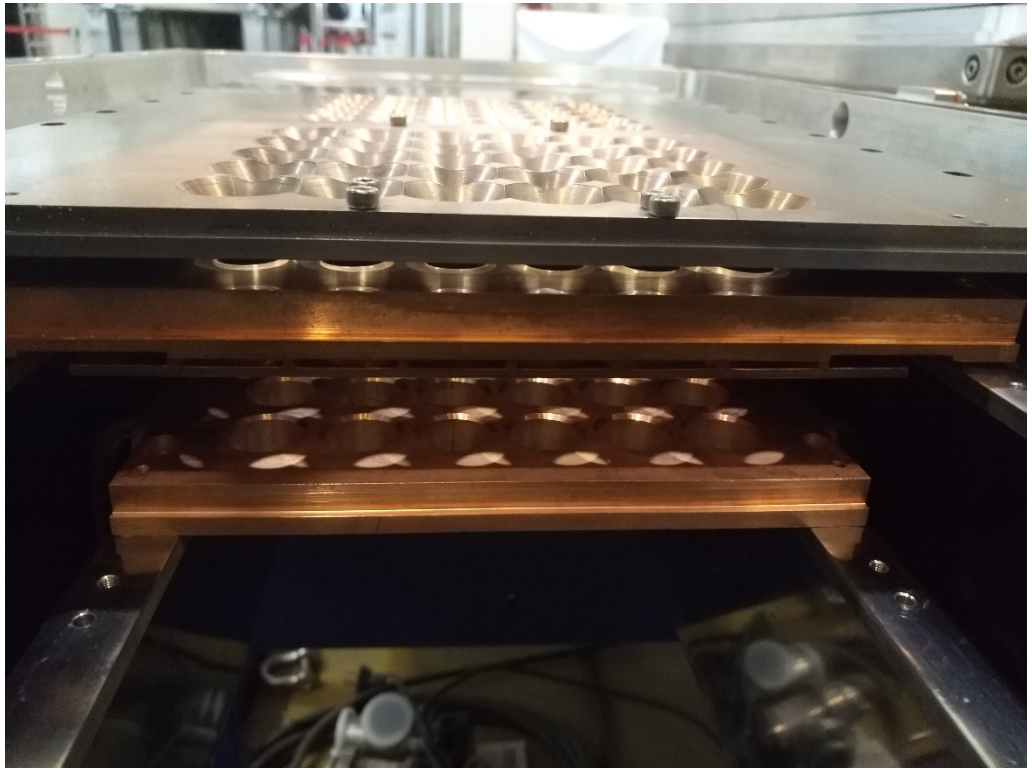


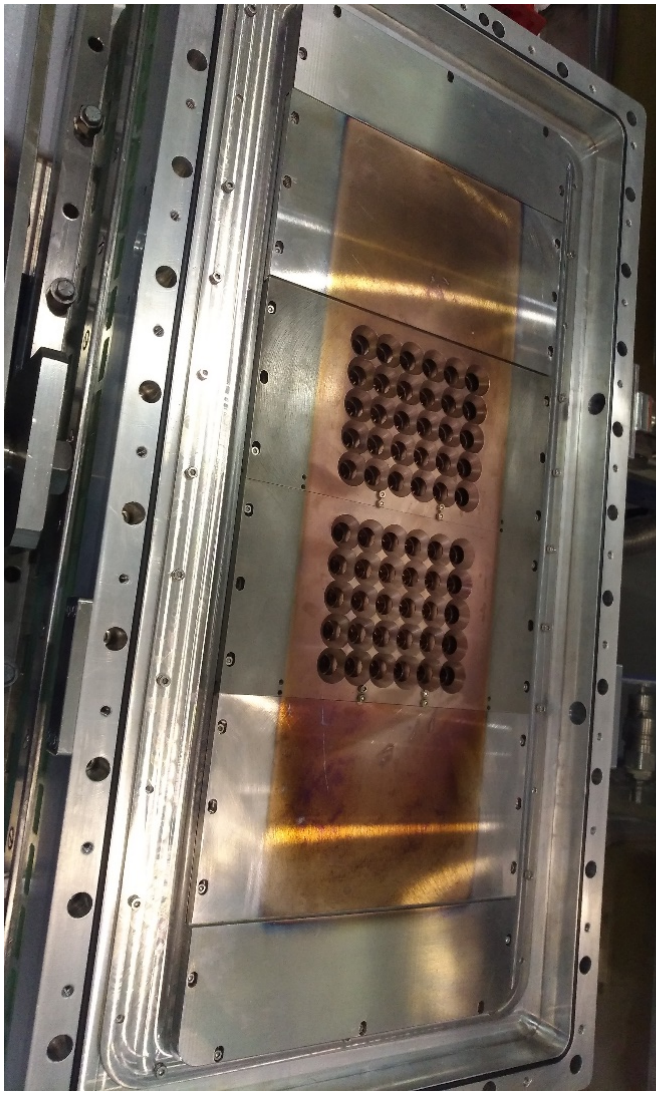




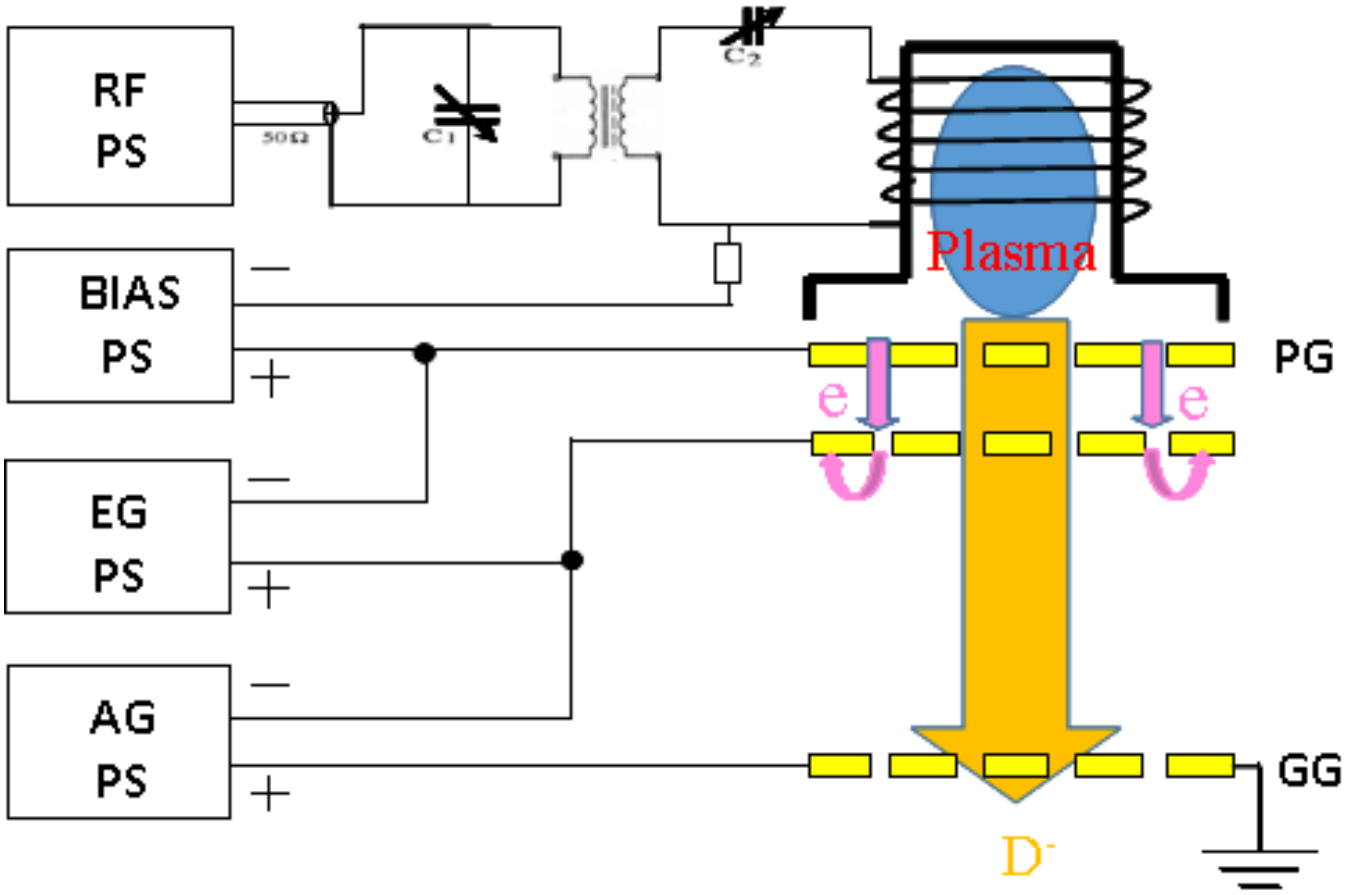
Assemble of Accelerator

- Plasma grid (Mo) without water cooling
- Two pieces of accelerators were installed in the middle of source





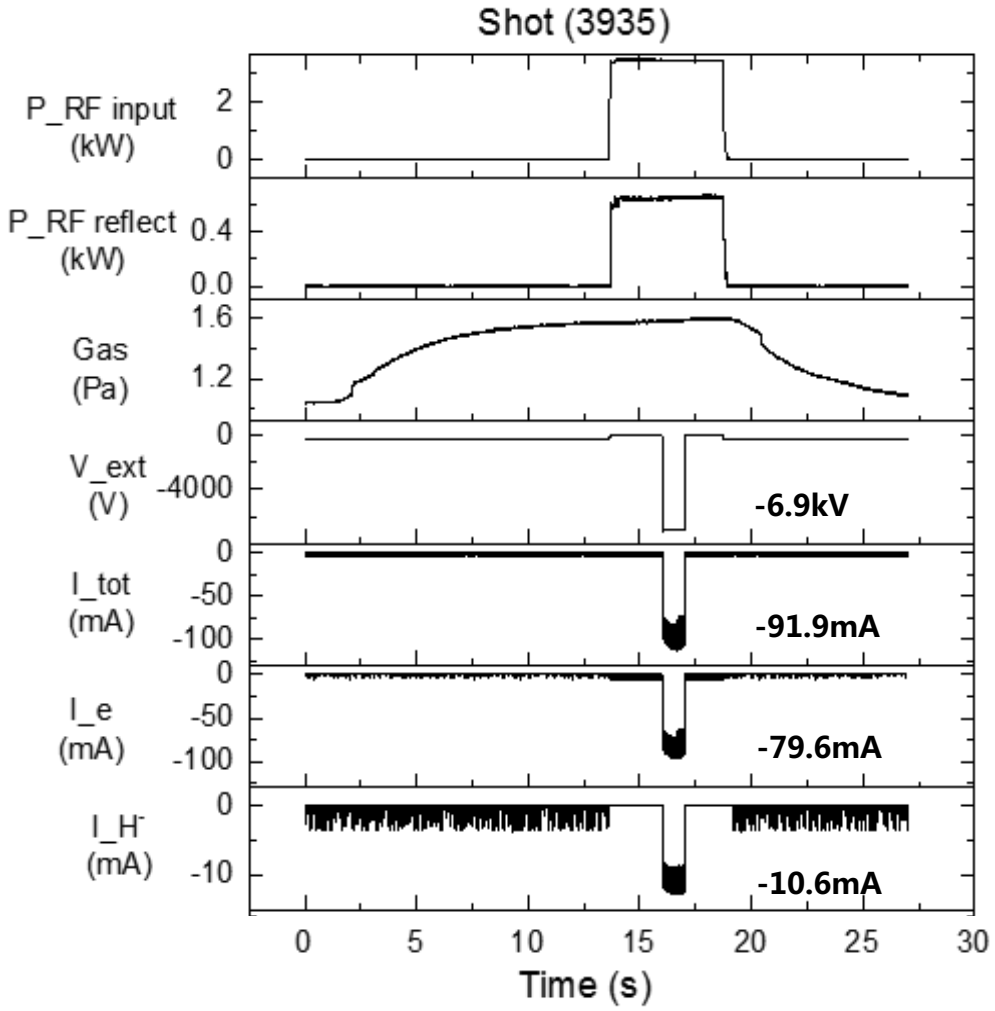
Negative ion extraction

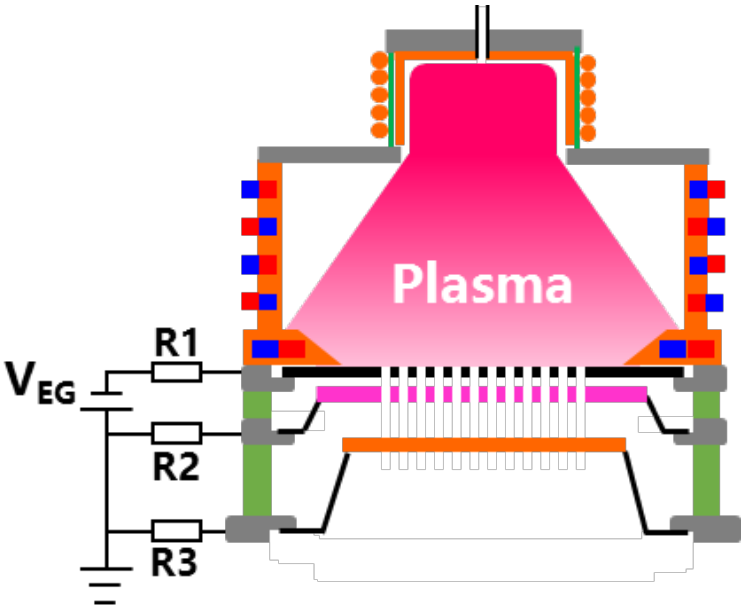


- Topology of power supply

Negative ion extraction exp.

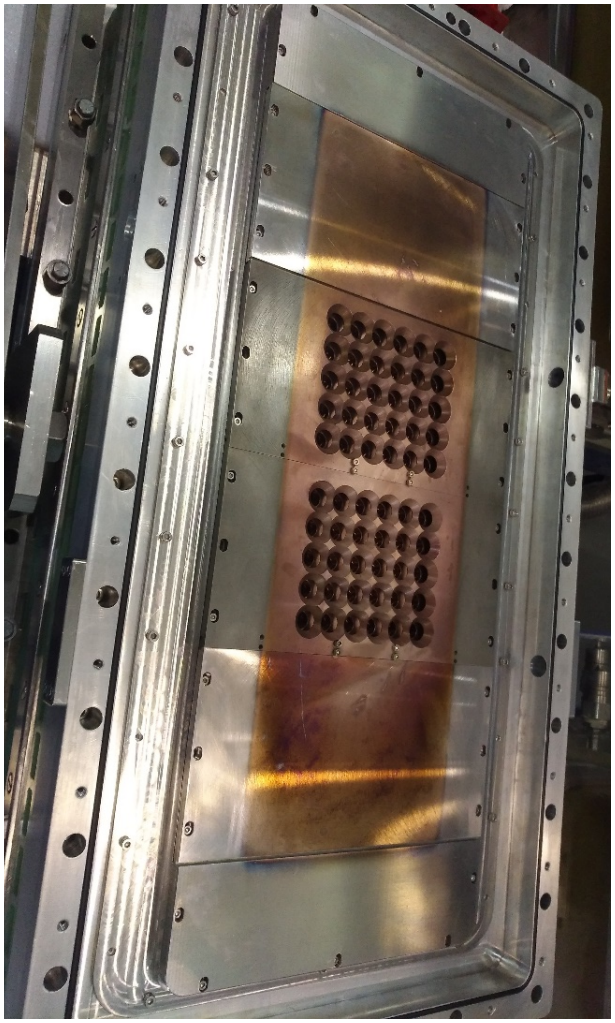
Negative ions extraction (w/o acceleration)

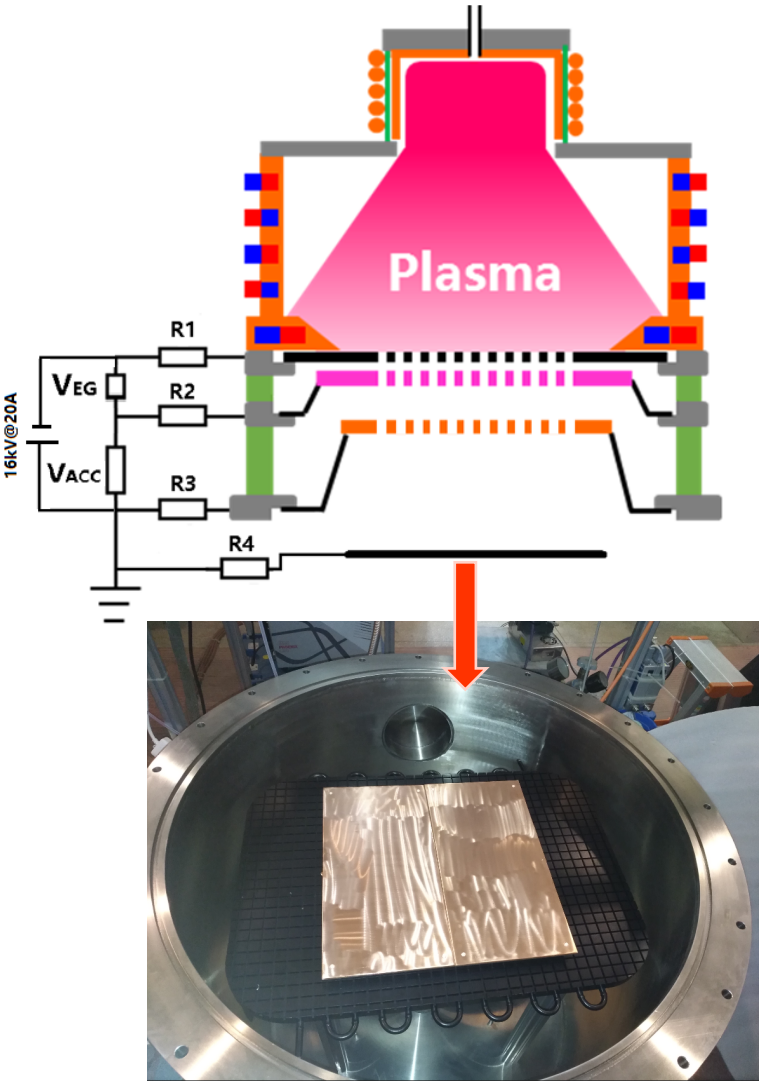




Negative ion extraction exp.

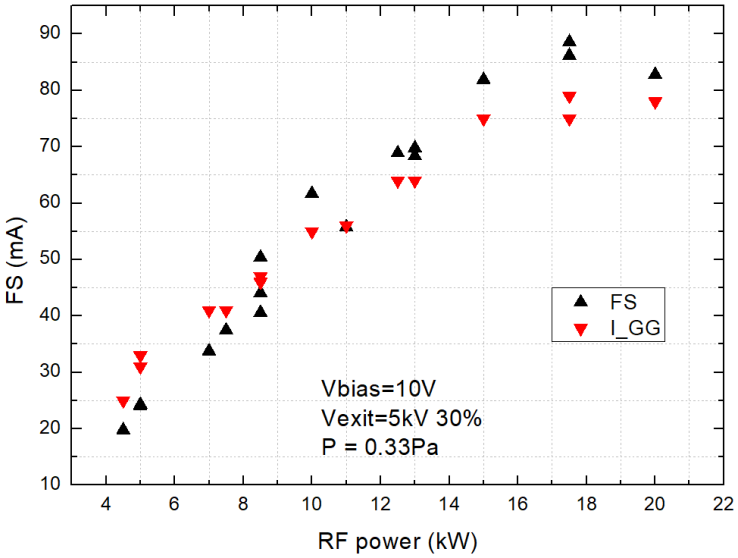
Negative ions extraction (with acceleration)

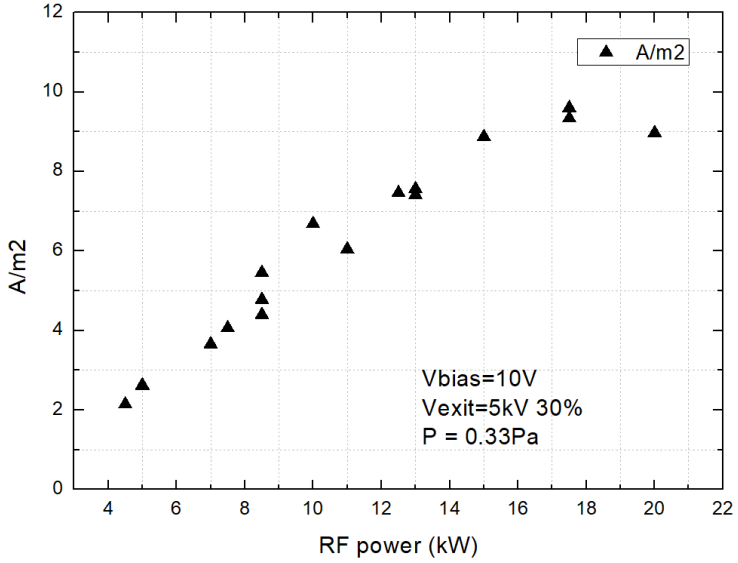


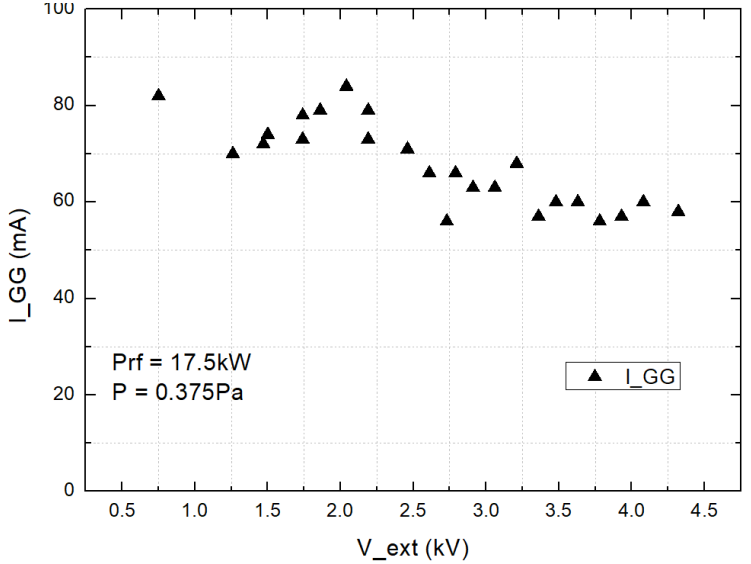


Negative ion extraction exp.

- The negative ion was extracted and accelerated
- The Vext : Vacc = 3:7
- The negative current was measured by Faraday cup with different RF power and extract voltage







Outline

- Introduction
- R&D of RF plasma generator
- Preliminary results of negative ion extraction
- Future plan and summary

Future plan of RF ion source

- **Long pulse plasma generation with high RF power**
  - → stable RF discharge with single driver
  - → stable RF discharge with two drivers
- **Negative ion production**
  - → Free cesium (filter magnetic optimization)
  - → Cesium feed in
- **Negative ion extraction and acceleration**
  - → Extractor tests and optimization
  - → Beam optic study & beam loss study

Summary

- The RF plasma source with single RF driver was designed and preliminary tested
- Long pulse operation of RF plasma source with tested and got 1000s plasma with RF power of 35kW
- The negative ion extractor/accelerator was designed and developed
- The negative ion was extracted and preliminary tested without cesium feed in.
- Cesium will be used and the negative ion source will be tested soon

Thanks for your attention !