8th International symposium on Negative Ions, Beams and Sources (NIBS'22)

Progress in the development of negative ion beam source in KOREA

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CONTENTS

01

INTRODUCTION

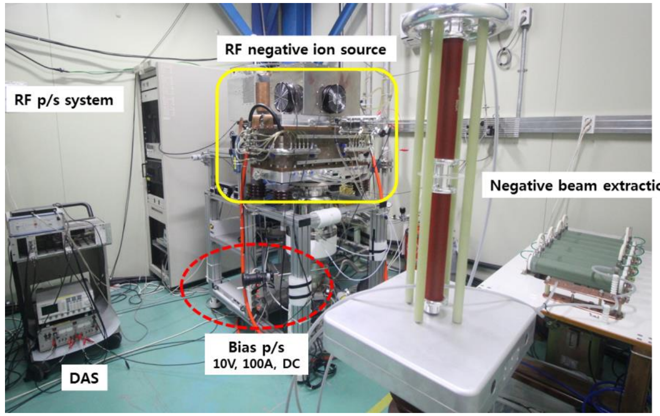
한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

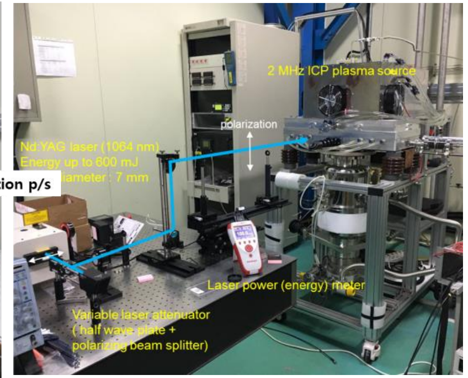
1. INTRODUCTION

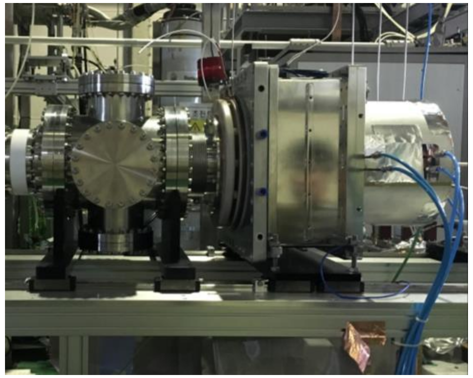
R&D program for Key Technologies of Non-procurement ITER systems

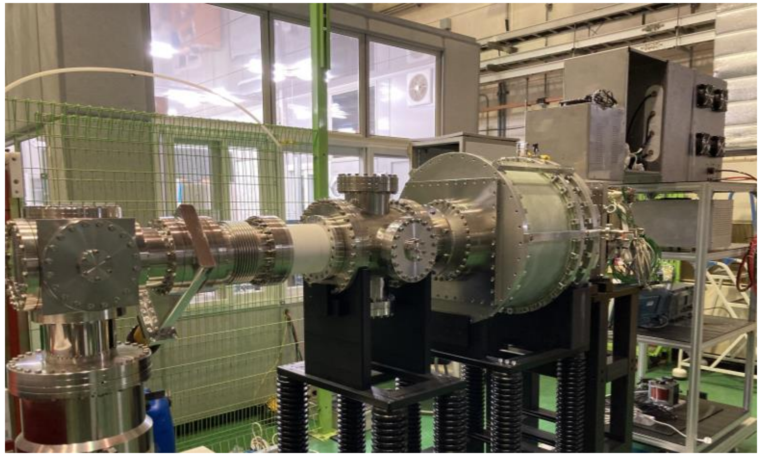
→ To obtain know-hows and technologies required for design and construction of ITER non-procurement items. (~ 15 R&D tasks per year)

'12~'15 Basic Technology Research	'16~'19 Technology R&D		'20 ~ '24 Technology development
Literature study and development a Cs-free negative ion beam source (KAERI)	Diagnostics & Design (KAERI)	Cs-seeded negative ion beam source (KFE)	System upgraded to a pulsed negative ion beam source (KFE)









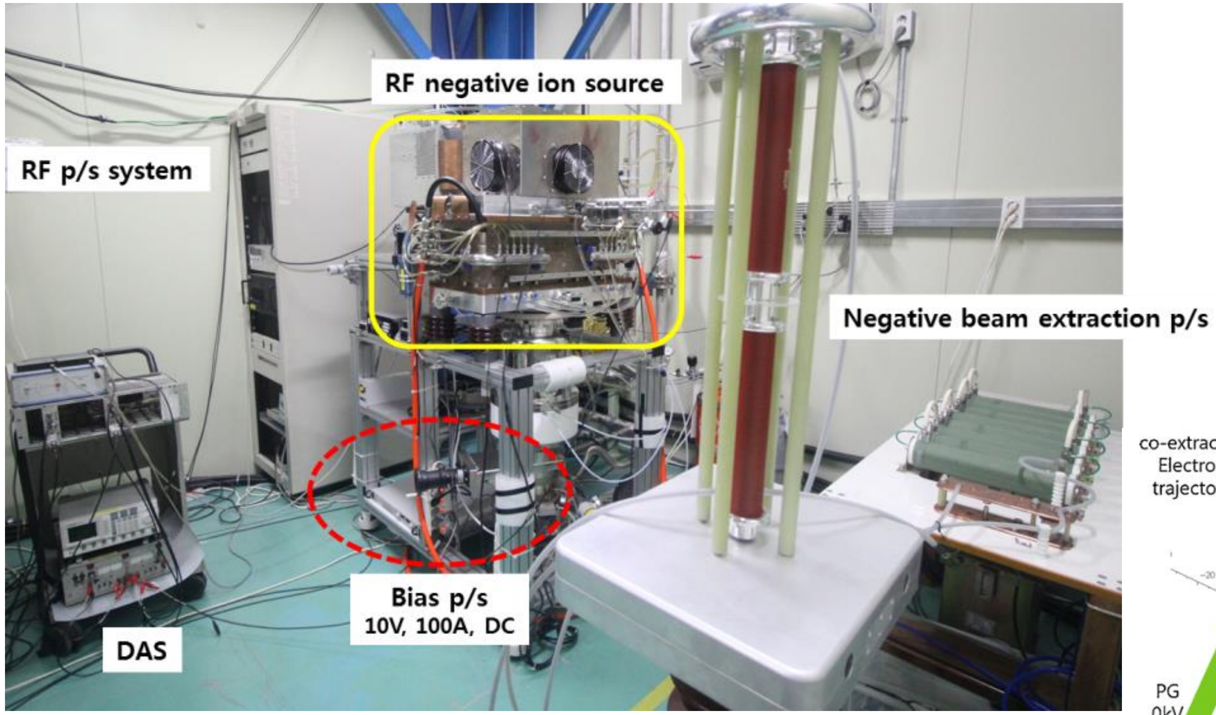
- Transitional phase from Cs-free to Cs (KAERI → KFE)

1. INTRODUCTION (CONT.)

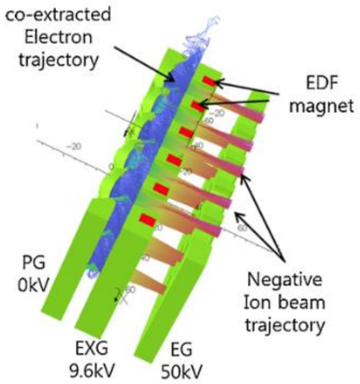
’12~ ’15

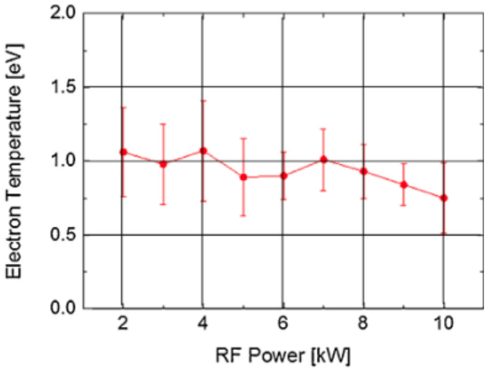
1st phase Basic Technology Research

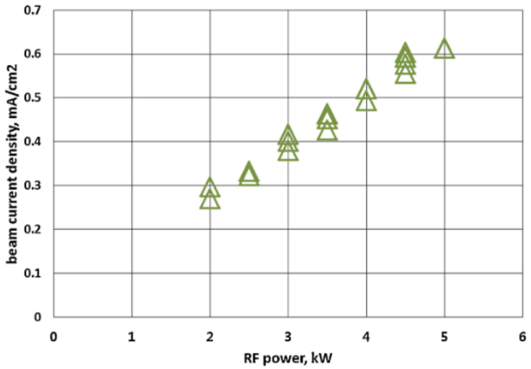
Literature study of ITER NBI technologies and Development of a Cs-free negative ion beam source (KAERI)



- Cs-free
- 2 MHz, 10 kW RF P/S
- 10 kV, 4 A / 60 kV, 1 A HV DC P/S for extraction and acceleration (grounded plasma generator)
- Faraday shield (4 mm thickness for CW operation)
- Plasma start at high pressure with Ar gas mixing







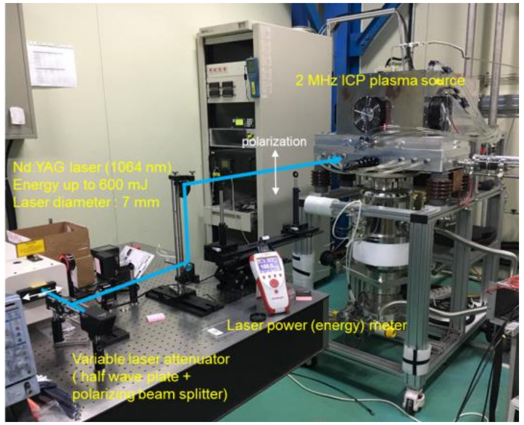
[1] S. H. Jeong, T.-S. Kim, M. Park, D.-H. Chang, B. Jung, S.-R. In, and K. W. Lee, Fusion Eng. Des. 109–111, 186–191 (2016).

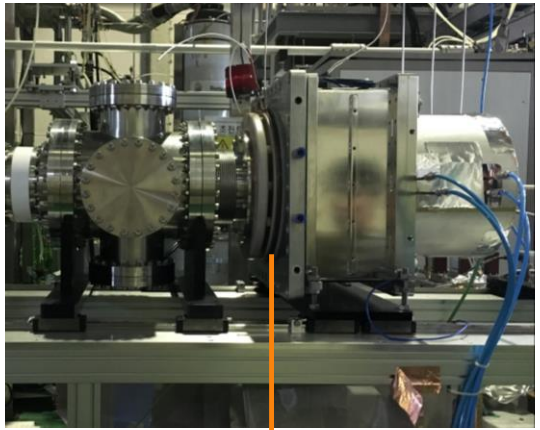
1. INTRODUCTION (CONT.)

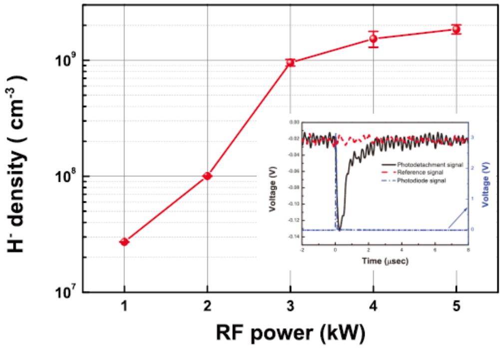
’16~’19
Technology R&D

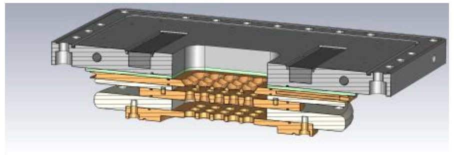
Development of a new Cs-seeded negative ion beam source (transition from KAERI to KFE)

Diagnostics & Design (KAERI)	Cs-seeded negative ion beam source (KFE)









EG : 6 kV
AG : 50 kV

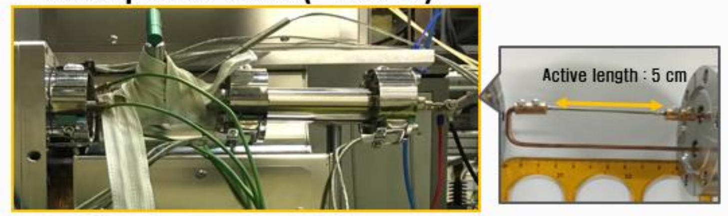
- H^- density measurement by laser photo-detachment (KAERI)
- 2 MHz, 10 kW RF P/S (KFE)
- Glassman P/S (30 kV, 100 mA/ 40 kV, 100 mA)

Cs-free

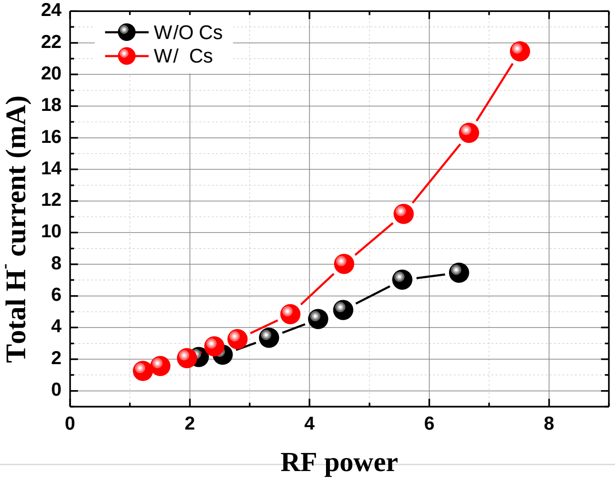
- $n_e \sim 2 \times 10^{17}$ m^{-3} , Te ~ 10 eV (driver region) for 6 kW RF , 0.3 Pa
- $n_e \sim 2 \times 10^{16}$ m^{-3} , Te ~ 1 eV, $n_{H-} \sim 2 \times 10^{15}$ m^{-3} (extraction region)

- Beam extraction with Cs injection by a Cs dispenser

- **Cs dispenser oven (~ 250 °C)**



- Cs dispenser : 2-hour lifetime
- Controlled by the current
- SID for the Cs evaporation rate measurement



[2] Park M, Na B, Kwak J G, Kim T S, Jung B, Huh S R and Jeong S H 2021 Phys. Plasmas 28 023505

02

KFE pulse operational negative ion beam source

KFE
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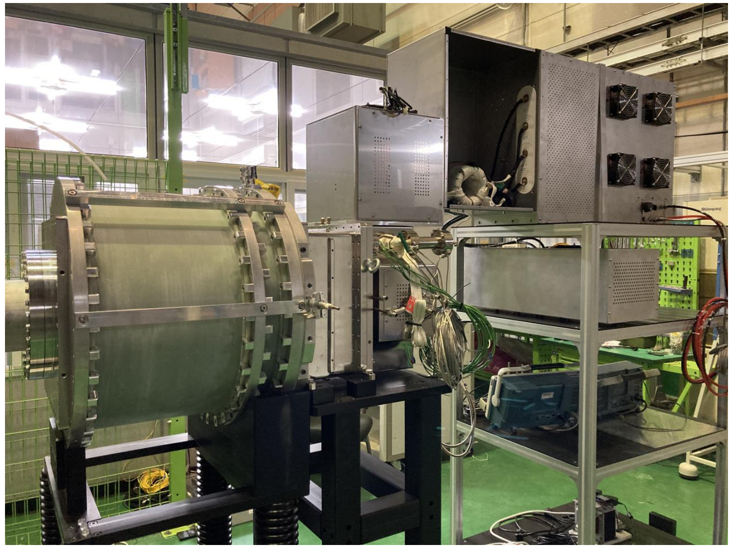
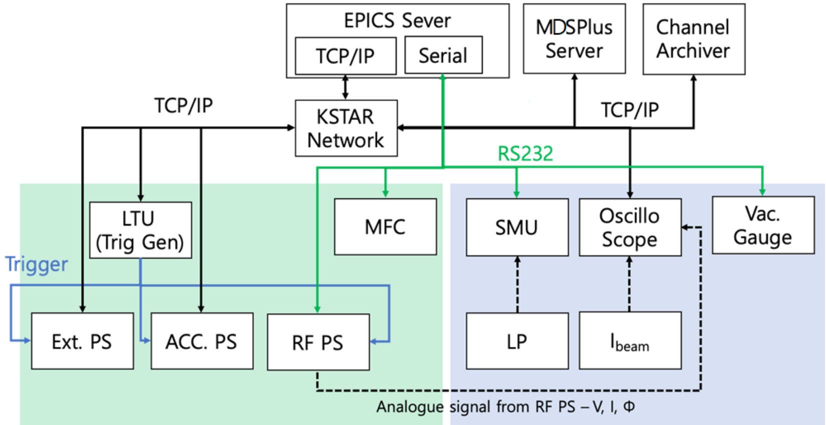
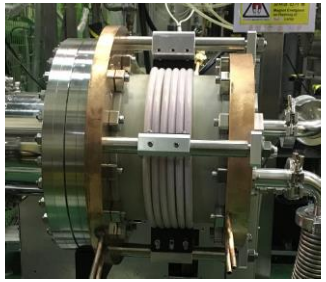
2. A negative ion beam source for pulse operation

'20~ '24
Technology development





200 keV / 0.5 A negative ion beam



- I.D : 200 mm
- H :150 mm
- T : 5 mm

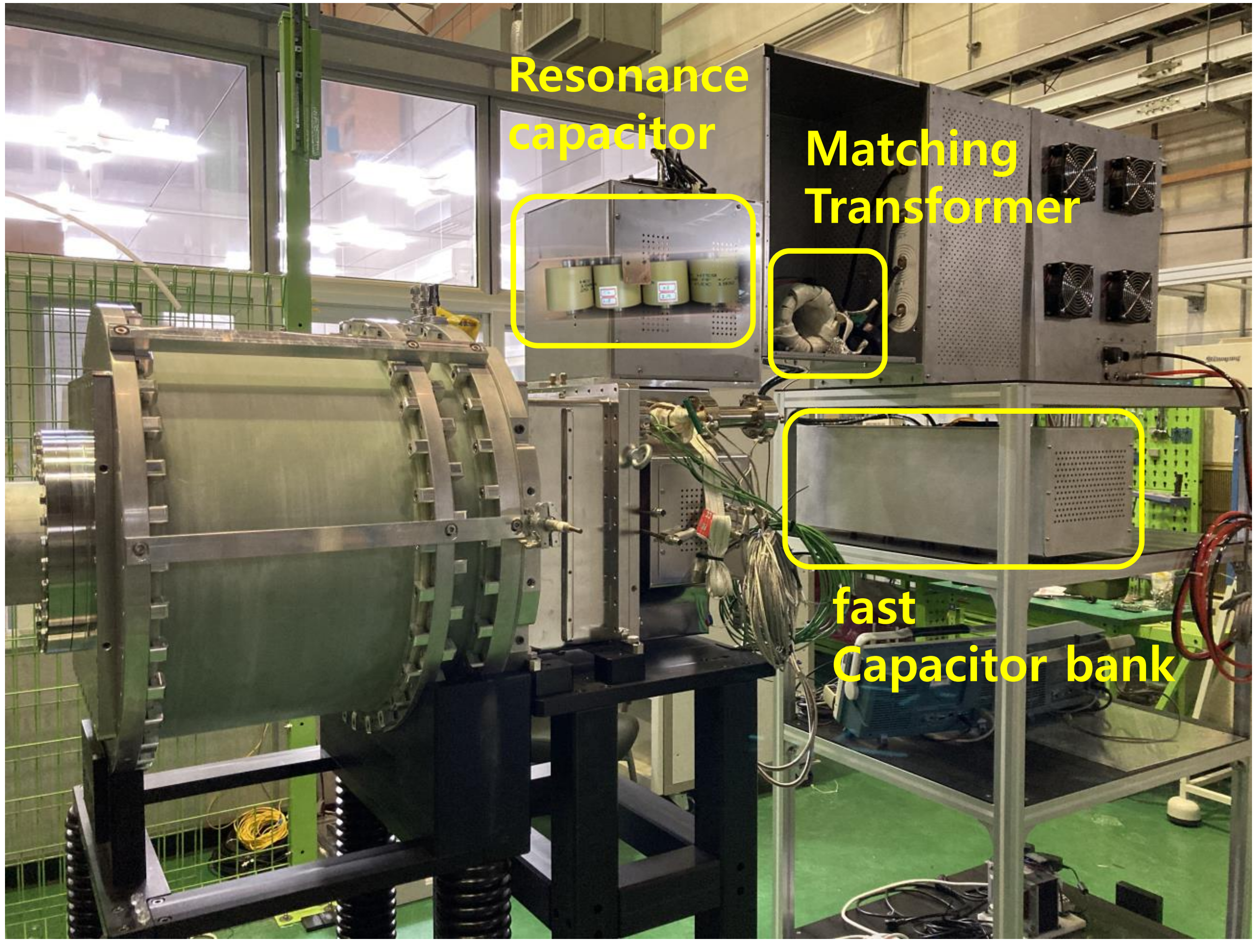
- Plasma source
  - 6- turn ICP source with AlN (w/o Faraday shield)
  - 400 kHz / 50 kW RF power supply
  - Hot filament for thermionic electrons used for plasma start-up
- Beam acceleration system
  - 3-grid system for 200 keV beam energy
  - 200 kV / 0.5 A H^- beam (100 kW, H^- current density j = 13 mA / cm^2)
- Pulse operation
  - To obtain higher density plasmas free from heat load issues
  - RF and DC power supplies are synchronized by a trigger unit

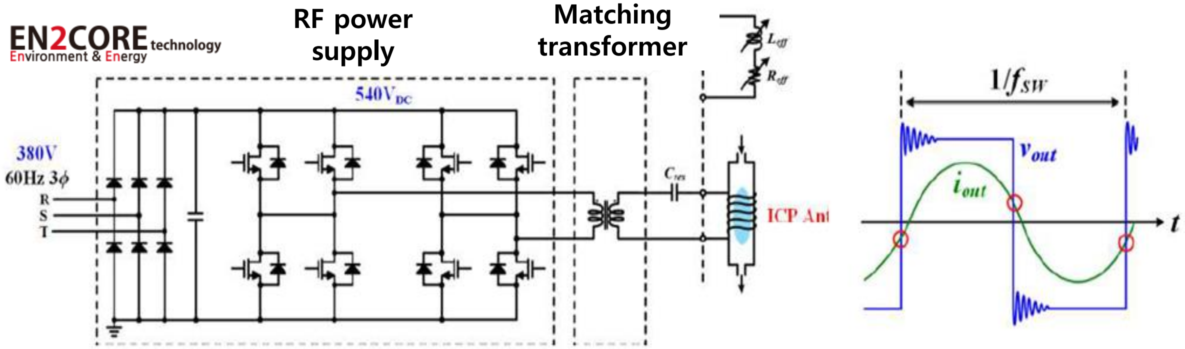
2. A negative ion beam source for short-pulse operation (cont.)

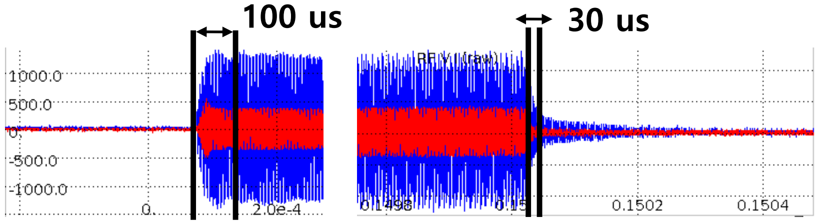
'20~ '24
Technology development

- 400 kHz , 50 kW RF power supply
  : Full-bridge series resonance invertor

Very fast high power delivery to plasma







- RF voltage and current waveforms

- Deliver high power RF to plasma very fast (fast rise and fall !)
- Maximize the power by frequency adjustment for the resonance
- load impedance ~ 4.2 ohms → matching transformer needed
  (8 : 6 step-down, the resistance of the secondary circuit < 4.2 Ω)

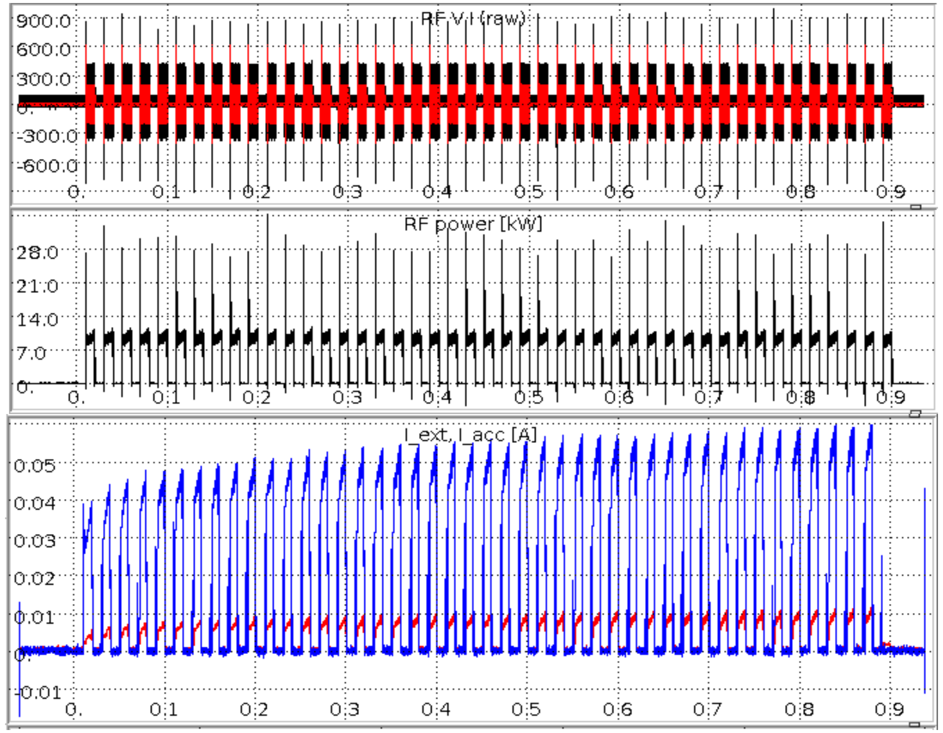
2. A negative ion beam source for short-pulse operation (cont.)

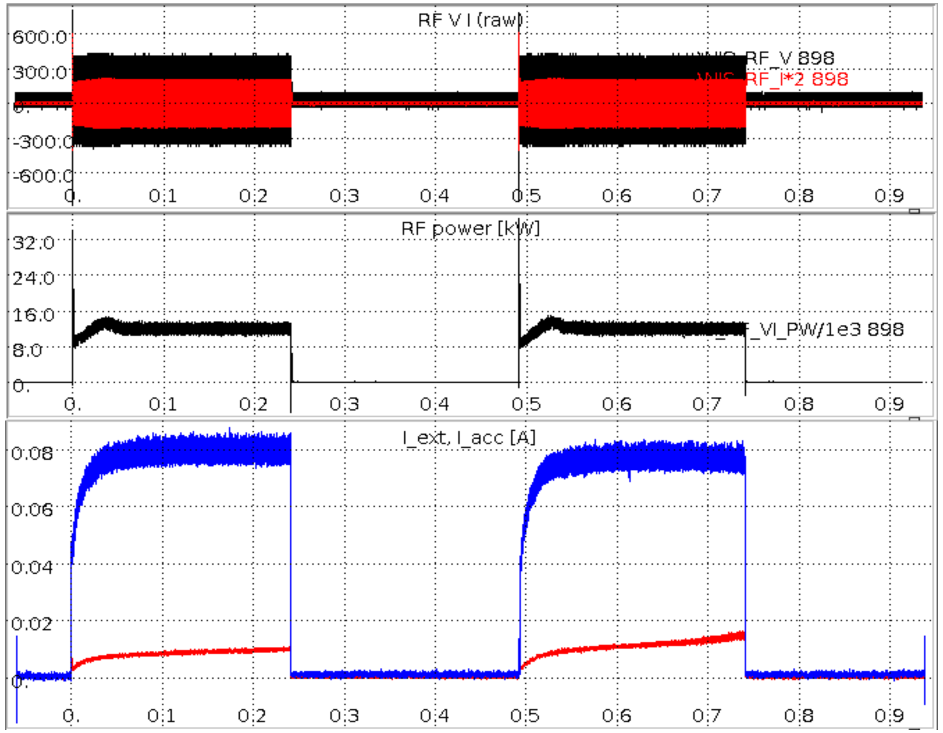
RF V & I

RF power

Beam current (w/o biasing)

(I_e^- , I_H^-)





- RF power can be modulated by an external pulse signal. (Fast rising and falling of the RF power)
- For consecutive short pulses, gradual increase of co-extracted electrons as well as negative ions are observed.
- For longer pulses, co-extracted electrons are saturated quickly.
- This may be due to the change of the AlN surface temperature. (H recombination coefficient of dielectrics)
- No Faraday shield and AlN is directly exposed to the plasma.

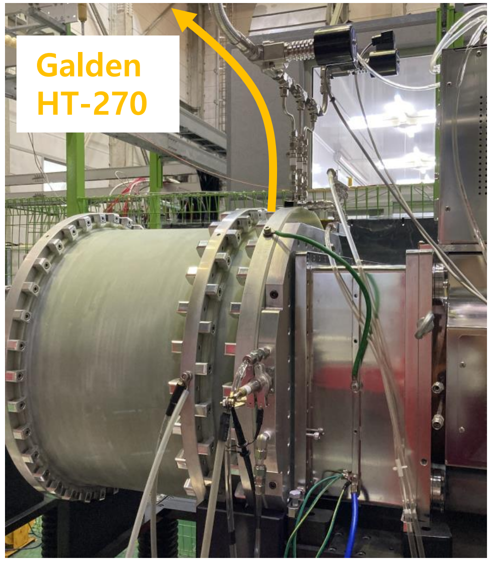
$$\gamma_{rec} = \exp(-E/RT)$$

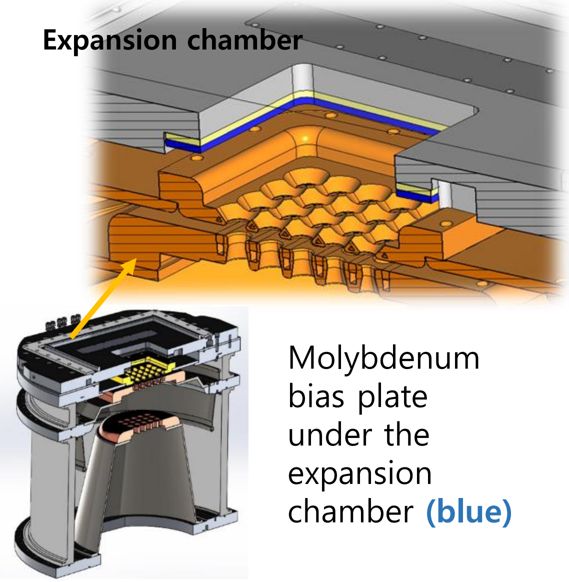
E : activation energy for the H recombination (16 kJ/mol)

2. A negative ion beam source for short-pulse operation (cont.)

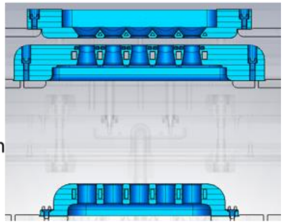
'20~ '24
Technology development

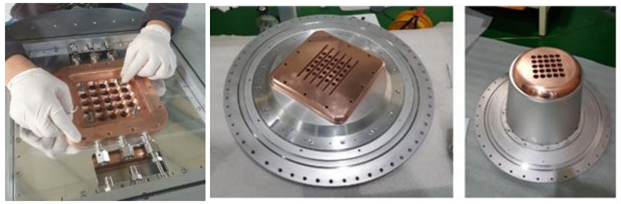
- 200 KeV beam acceleration with stackable DC p/s





Molybdenum bias plate under the expansion chamber (blue)





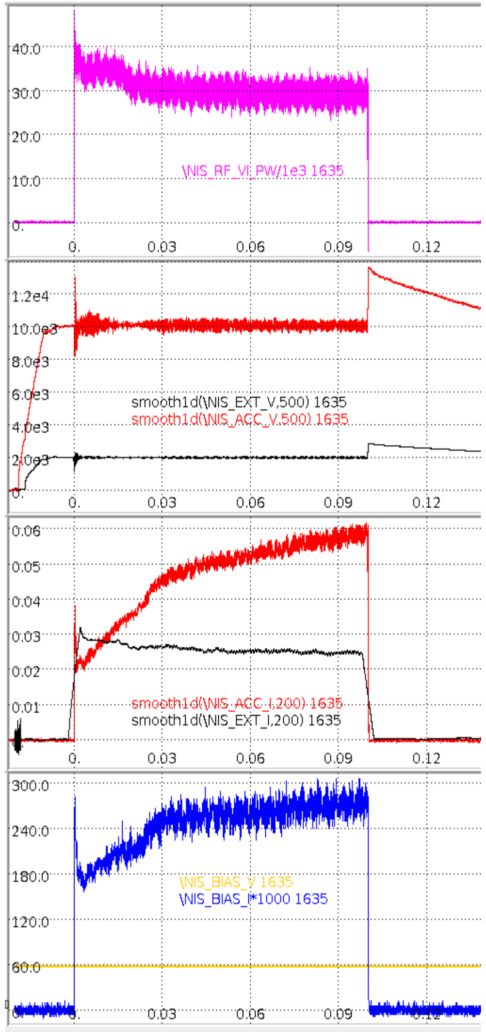
PG EG(9kV) AG (200 kV)

5 x 5 holes with 38.5 cm^2
→ **J~13 mA /cm²** for 0.5 A

- Stackable P/S
(20 kV / 2 A x **6** + 10 kV / 1A x **1**)

- Li-ion battery (26 Vdc, 26 AH)

-100 ms x 400 available with full charge



RF ~ 30 kW

Vacc = 10 kV

Vext = 2 kV

Iacc ~ 60 mA

Iext ~ 25 mA

I_Bias ~ 270 mA
V_Bias ~ 60 V

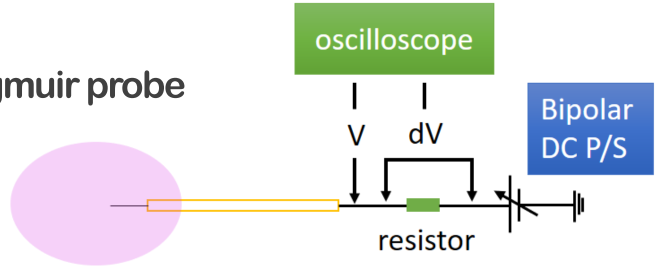
03

EXPERIMENTAL RESULTS

3. Langmuir probe diagnostics

Characterization of high-density low-pressure hydrogen plasmas

- High RF power without a Faraday shield → Severe RF plasma fluctuations → **RF-compensated** single Langmuir probe

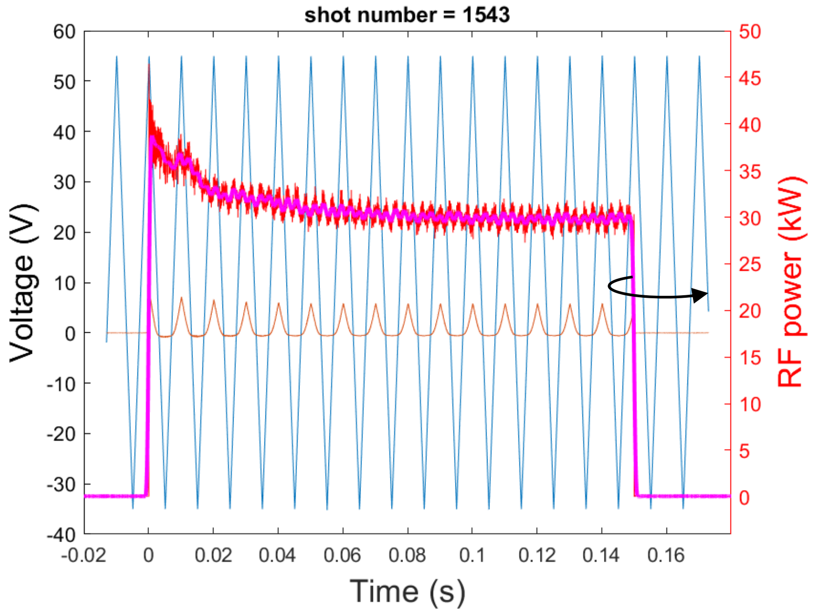


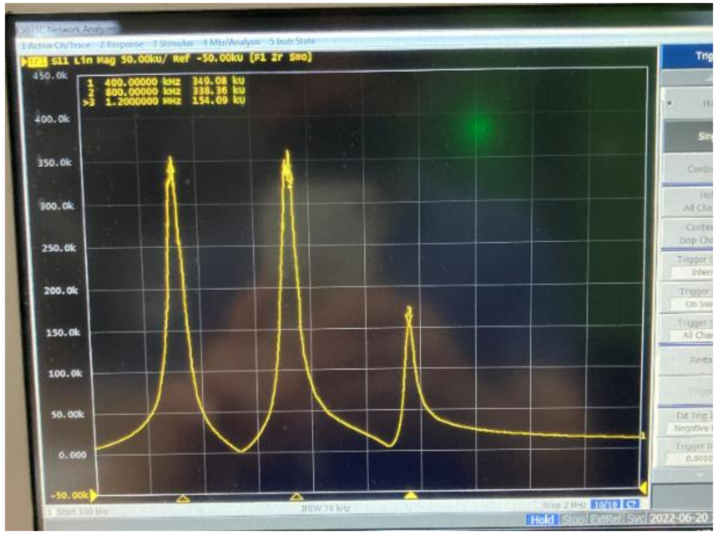
400 kHz, 800 kHz and 1.2 MHz LC parallel resonance filters

Pressurized air inlet (circulation in a coaxial configuration)

Hard anodized cap for enlarging the effective sheath area of the tip

- Voltage sweep frequency = 100 Hz

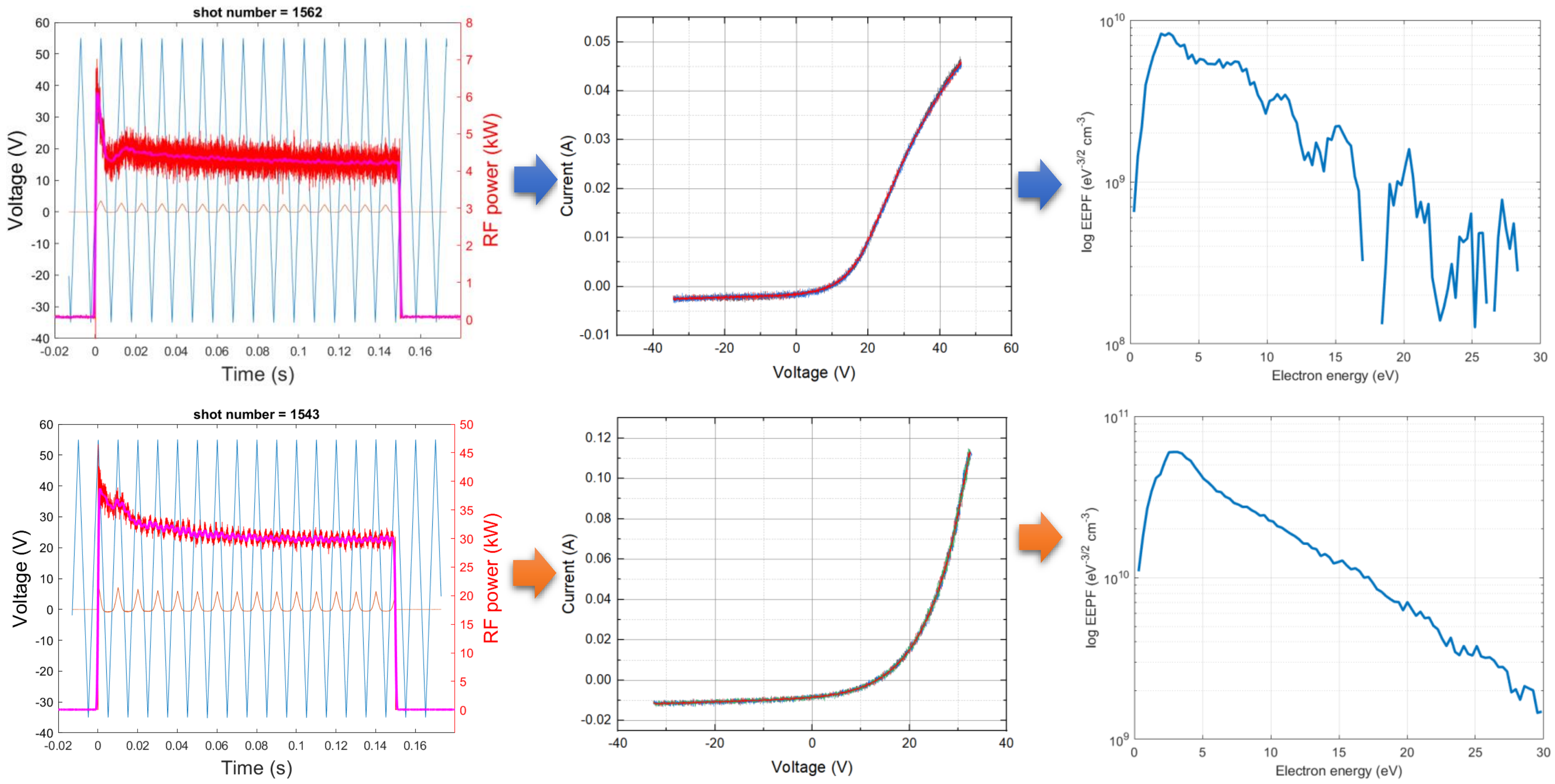




Magnitude of filter impedance at
400 kHz ~ 349 kΩ
800 kHz ~ 338 kΩ
1.2 MHz ~ 154 kΩ

- Raw signals of probe voltage (blue) and voltage difference in measurement resistor (orange) and RF power (red, magenta: smoothed) vs time

3. Langmuir probe plasma diagnostics



→ Take the last 4 IV curves and average them and smoothing again (Gaussian window)

→ Obtain Electron Energy Probability Function (EEPF) from the second derivative of the IV curve (Druyvesteyn formula)

$$f(\varepsilon) = 2(2m_e)^{1/2}(e^3A)^{-1}\frac{d^2I_p}{dV_p^2}$$

→ Electron density (ne) and temperature (Te) calculated with the EEDF

$$F(\varepsilon) = \varepsilon^{1/2} f(\varepsilon)$$

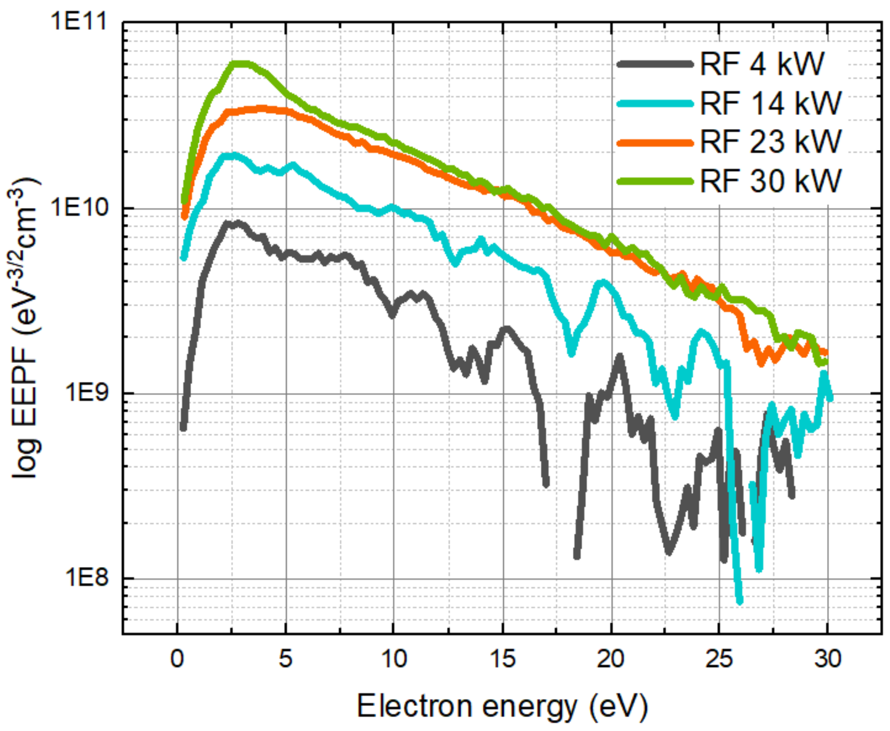
$$n_e = \int_0^\infty F(\varepsilon)d\varepsilon,$$

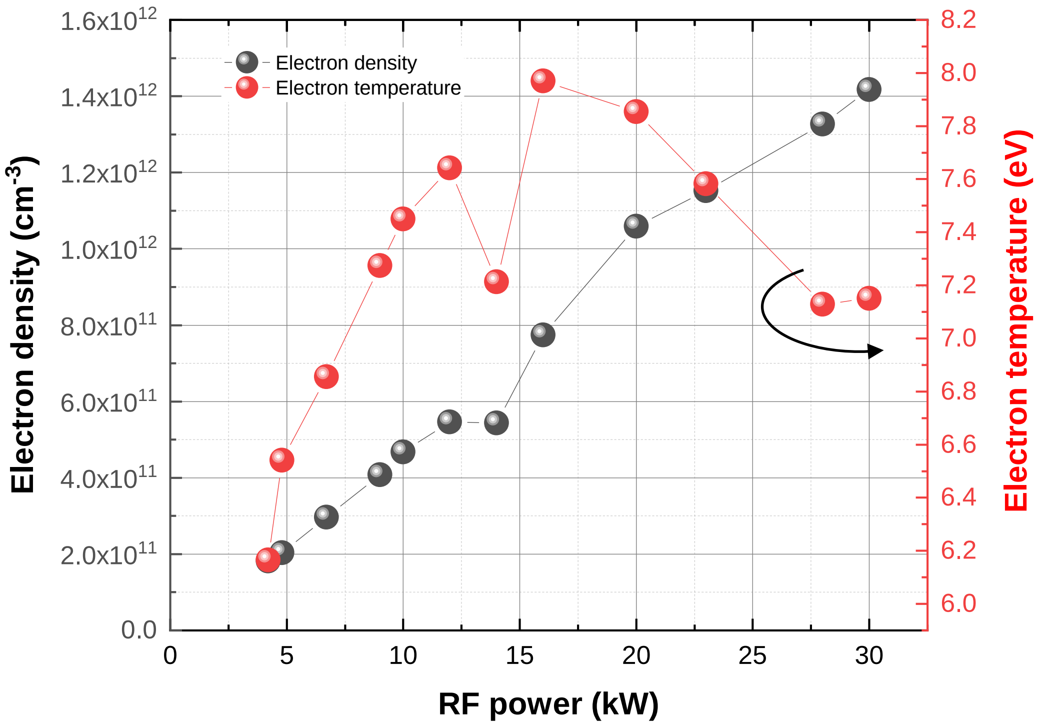
$$T_e = \frac{2}{3n_e}\int_0^\infty \varepsilon F(\varepsilon)d\varepsilon.$$

- At 4 kW RF , noise is rather higher than the case of RF 30 kW.
- EEPF evolves from Maxwellian to Bi-Maxwellian ?

3. Langmuir probe plasma diagnostics

Electron energy probability functions (EEPFs) , electron density and temperature





- The temperature decrease seems due to the EEPF evolution from Maxwellian to Bi-Maxwellian.
- The increase of low energy electron population can be understood as a result of the Ponderomotive force.

04

SUMMARY & FUTURE PLAN

4. SUMMARY & FUTURE PLAN

50 kW / 200 keV pulse operational negative ion beam source

- Cs-seeded by a Cs dispenser and the active control of PG surface temperature by a high-temperature fluid circulation (ready for the Cs conditioning)
- Pulse operational system free from heat-load issues
- Full H-bridge inverter type High power RF supply (400 kHz , 50 kW)
- Stackable battery-type High voltage DC power supply (20 kV / 2 A)

Future plan

- Maximize RF power input by modification of frequency adjustment
- Optimize the beam extraction with Cs conditioning (PG temperature control)
- Increase the beam energy through high voltage conditioning of three grids

Thank you very much for your listening!

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