The Cs-free Negative Hydrogen Ion Source Project at KAERI: A New Concept Multi-Pulsed Ion Source

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Poster Session 2

ABSTRACT: Due to reliability issues in using Cs for efficient hydrogen negative ion production in ion sources for NBI systems in fusion research, many researchers have explored Cs-free alternatives to Cs for a future DEMO NBI system. KAERI recently launched a new project in collaboration with Seoul National University in order to identify an efficient Cs-free negative ion source based on the volume production mechanism, not only for fusion application, but for other applications (e.g., semiconductor, space propulsion, and accelerator). In this project, we attempt to improve efficiency of the volume negative ion source by introducing plasma pulsing. The plasma pulsing, which is also called temporal filter, refers to a method of modulating power that sustains the plasma and consequently the electron energy. Supplying negative ions at high densities by the pulsing is, however, inherently transient and its duration is short. In view of a future DEMO, a significant drawback of the pulsing is being unable to continuously supply the negative ions to an extraction system. To remedy the drawback, and consequently to develop a novel promising Cs-free alternative, we devised a multi-pulsed ion source. The multi-pulsed ion source included more than two plasma sources and magnetic filters operates with an alternating pulsing sequence of the plasma sources. The temporal and magnetic filters named spatiotemporal filters may enable this ion source to continuously supplying the negative ions, leading to the development of the efficient Cs-free negative ion source. In this presentation, the overview of the Cs-free negative hydrogen ion source project at KAERI, the new ion source concept, and its preliminary experimental results are presented and discussed in detail.

Introduction

Motivation

- ❑ A new concept negative ion source and related method are required
  - as **an alternative to Cs-seeded negative ion sources** for a future **DEMO NNBI**.
    : Inherent drawbacks of Cs usage challenge RAMI requirements [1].
    → The new source should be "**Cs-free**" as well as **efficient**.
  - for contributing to the development of an **advanced etching** using negative ions for **semiconductor manufacturing** by adding controlled variables
    → "available for **temporal shaping** of the negative ion density".
  - to be applied to a **neutralizer-free gridded ion thruster** for space propulsion [2].
    → "**high negative ion-to-electron density ratio**".
- ❑ The aim of this research project is to develop a new negative ion source with the characteristics mentioned above.
- ❑ We have started with the **volume negative ion source using plasma pulsing** [3].

Fundamentals

✓ **Why Pulsing (or temporal filter)? Plasma pulsing (after-glow) is favorable for the volume production of H⁻ ions.**

- ❑ The volume production mechanism of H⁻ ions is a **sequential** two-step process [4, 5]:

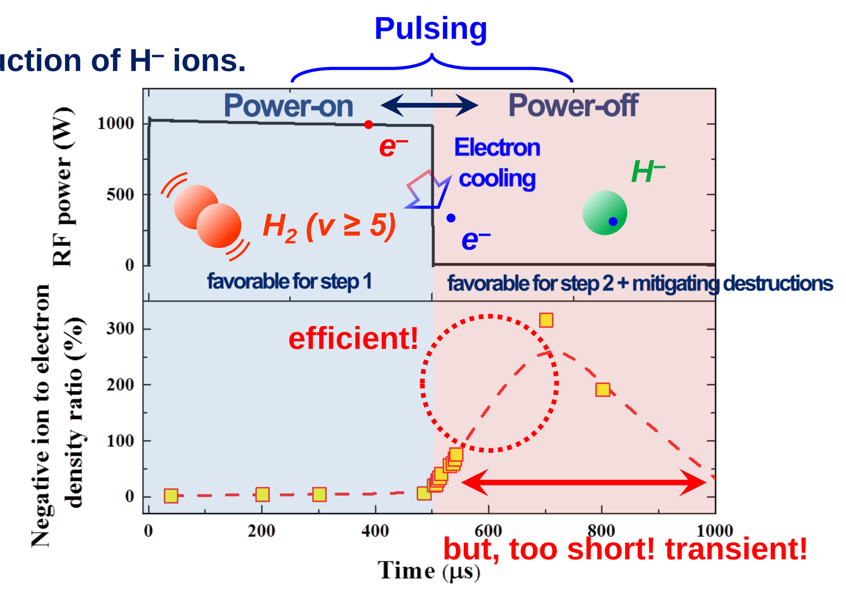
  [step 1] high-energy $e^- + H_2 \rightarrow e^- + H_2(v \geq 5)$

  [step 2] low-energy $e^- + H_2(v \geq 5) \rightarrow H + H^-$

- ❑ The **high-energy electrons in step 1 are also involved in the destruction** mechanism of H⁻ ions [4, 5]:

  high-energy $e^- + H^- \rightarrow 2e^- + H$

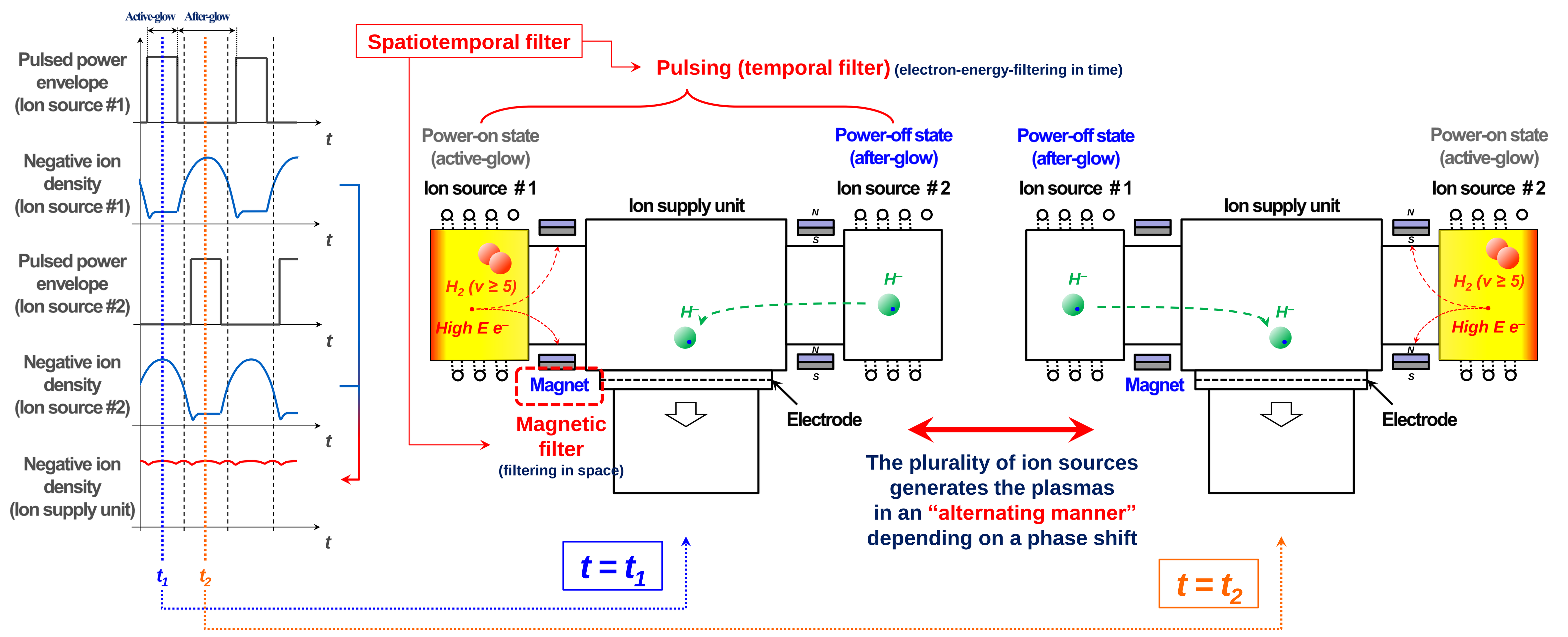
- ❑ CW plasmas simultaneously provide high- and low-energy electrons, leading to both the production and destruction of H⁻ ions.
- ❑ But, **pulsed plasmas** can "**sequentially** " offers high- and low-energy electrons in accordance with the volume production mechanism while also lowing the destructions of H⁻ ions.



method for continuously supplying the negative ions ?

Multi-pulsed Ion Source System for Continuously Supplying Negative Ions

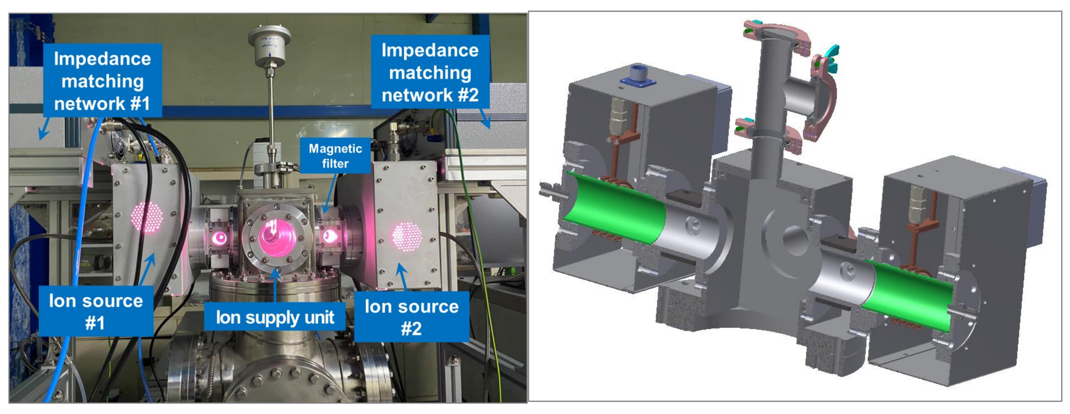
Schematic diagram illustrating working principle of the multi-pulsed ion source system



- ❑ With this configuration using **the plurality of ion sources**, when one ion source in **the active-glow state** supplies a relatively small amount of negative ions to the ion supply unit, a state of a plasma in another ion source can be switched to the after-glow state in order to **compensate for the amount of negative ions supplied**. Accordingly, **the total amount of negative ions** supplied from the plurality of ion sources to the ion supply unit can be **kept constant at high densities**.
- ❑ The **active-glow state** producing a large number of highly vibrationally excited molecules (**negative ion precursors**) is indispensable for generation of H⁻ ions in the next state
- ❑ The **magnetic filter** may restrict a **high-energy electron group** generated in an ion source in the active-glow state from **entering the ion supply unit** where the H⁻ ions are abundant, **blocking their destruction**.

Overview of apparatus

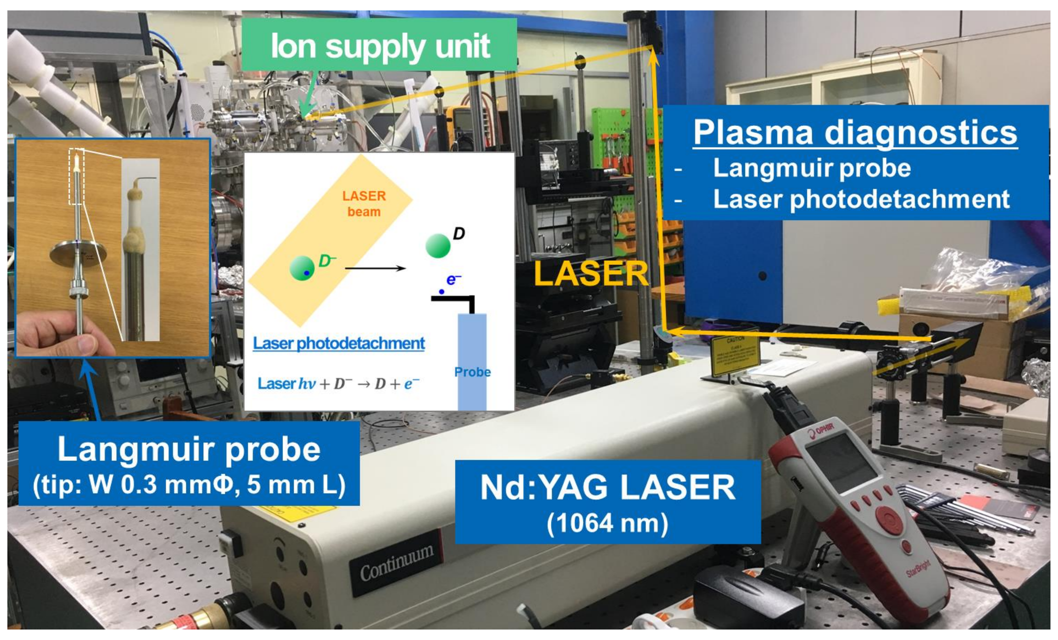
- ❑ **KOMPASS** (**KO**rea atomic energy research institute **M**ulti-**P**ulsing-**A**pplied ion **S**ource **S**ystem) for **experimental proof-of-concept**
  - **KOMPASS model I**
    - A **crude** one for a quick and brief proof-of-concept exp.
    - Filament-driven **DC** arc ion source type
    - Characteristics of the two ion sources are not identical.
    - **Retired**
  - **KOMPASS model II**
    - RF-driven ion source type (ICP type)
    - 13.56 MHz, 800 W, 0.2 ~ 5 kHz (pulsing)



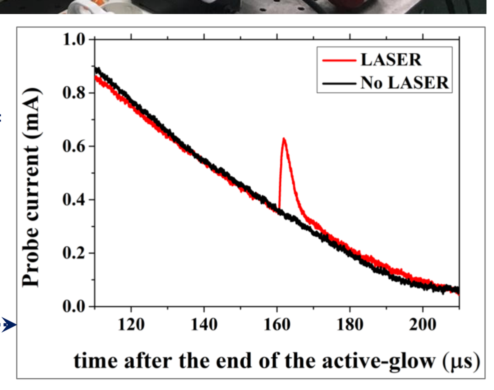
    - **On hold** due to difficulty in interpreting data obtained from the RF compensated Langmuir probe diagnostics
      : In the early afterglow, a displacement current through a capacitor is induced, resulting in a distortion of the probe data → model III
  - **KOMPASS model III**: an elaborate one for the proof-of-concept
    - Filament-driven **DC** arc ion source type: **distortion-free**
    - **In progress**

Preliminary Experimental Results

Plasma diagnostics

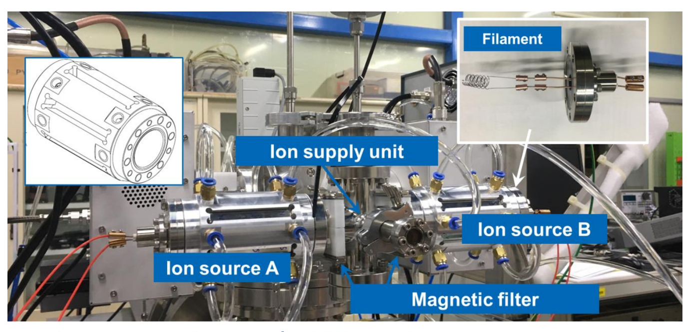


- ❑ **Langmuir probe** measurement (**Boxcar** acquisition method)
  - The probe is placed at the center of the ion supply unit.
- ❑ **Time-resolved and probe-assisted laser photodetachment** technique

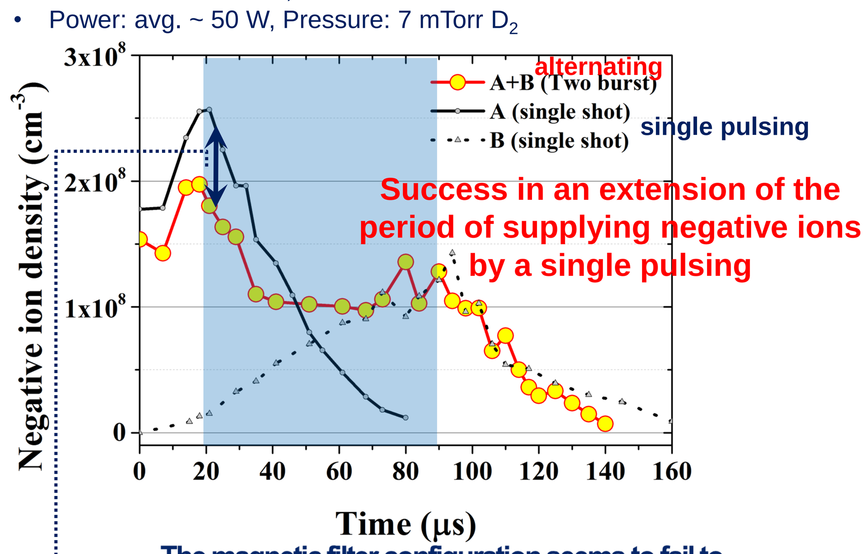


Preliminary experimental results (KOMPASS model I and III)

KOMPASS model I

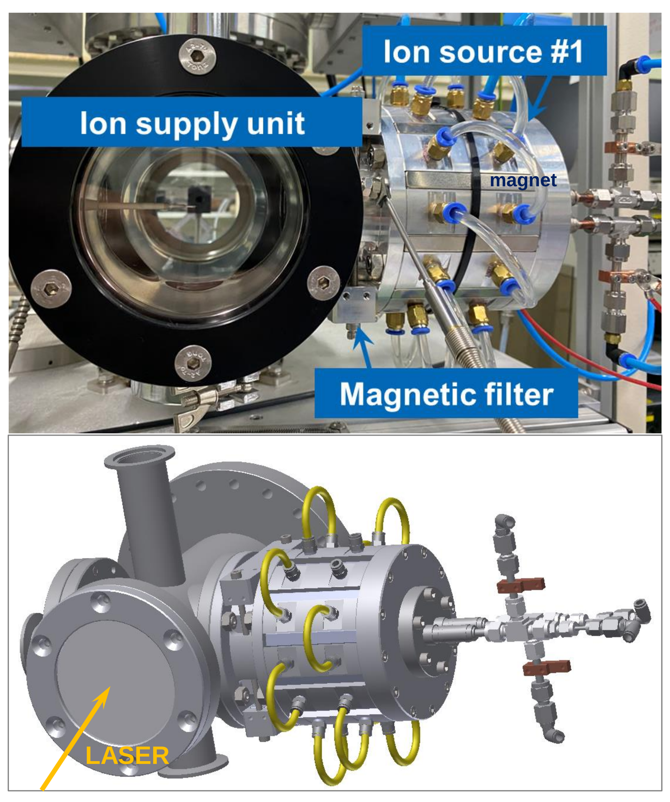


- Ion source: 38 mm Φ, 125 mm L
- Power: avg. ~ 50 W, Pressure: 7 mTorr D_2



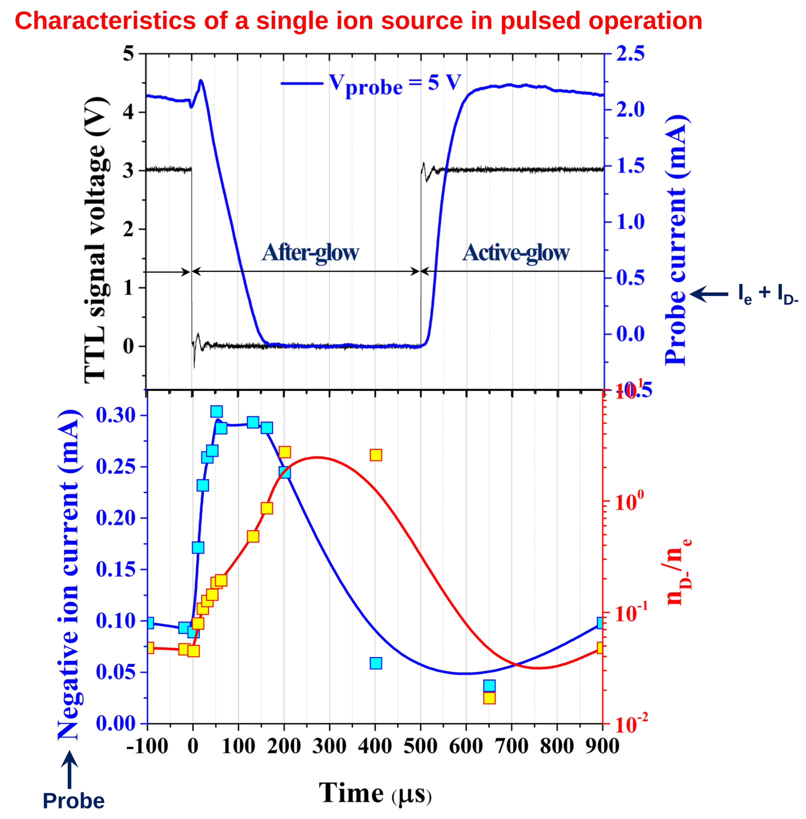
The magnetic filter configuration seems to fail to prevent the destruction of some of negative ions by high-energy electrons .

KOMPASS model III



- Ion source: 80 mm Φ, 125 mm L
- Power: avg. ~ 550 W (pulsing: 1 kHz, duty cycle 50%)
- Pressure: 1 Pa D_2
- Probe: tungsten cylindrical tip → 0.3 mm Φ, 7 mm L

Characteristics of a single ion source in pulsed operation



- ❑ At present, we are getting ready to carry out the proof-of-concept experiment of the KOMPASS model III with two ion sources. The results will be reported soon.

Potential: Even the proof-of-concept experiment is not yet complete and there are still a lot of technical problems to solve, the multi-pulsed ion source system is quite promising for the following reasons: (1) it is efficient for generation of negative ions without Cs usage. It is supposed that the negative ion density per unit of the power delivered to the ion source is fairly high. (2) Due to the nature of the volume production mechanism of H⁻ ions, the negative ion-to-electron density ratio is likely to be high. (3) Compared to the CW operation, the heat load to an RF driver can be greatly alleviated, and (4) In the after-glow, the sheath potential is drastically reduced. This may help one to control the uniform easily.

Future Work: (1) The proof-of-concept experiments with model III and also model II (RF ion source system), (2) Beam extraction test of the multi-pulsed ion source system, and (3) The scale-up

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[1] U. Kurutz *et al.*, Plasma Phys. Control. Fusion **59** (2017) 075008
[2] A. Aanesland *et al.*, IEEE Trans. Plasma Sci. **43** (2015) 321.
[3] S.-R. Huh, Ph.D. dissertation, Seoul National University, Seoul, 2015.
[4] R. S. Hemsworth and T. Inoue, IEEE Trans. Plasma Sci. **33** (2005) 1799.
[5] M. Bacal, Nucl. Fusion **46** (2006) S250.

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