Time-resolved Measurements of Negative Ion Density in a Negative Deuterium Ion Source System using Multi-pulsed Plasma Sources

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1. Introduction

Negative hydrogen/deuterium (H^-/D^-) ion sources are devices that produce H^- or D^- ions and provide ion extraction. They are considered crucial components in many fields, especially particle accelerator applications. Employing charge exchange reactions of H^- ions supplied from the ion sources enables tandem accelerators and cyclotrons to have simple and efficient configurations of accelerating voltage source system and electromagnet system, respectively [1].

Since the discovery of cesiation in 1971, there has been a large amount of research and development activity on surface negative hydrogen ion sources based on the surface production mechanism [2]. The researchers found that the surface negative hydrogen ion source allows efficient formation of negative ions, and thus it became the major type of negative ion source for fusion and accelerator applications.

However, the use of cesium (Cs) has several inherent drawbacks [3]. First, Cs control is difficult due to the complex chemistry and complicated adsorption or desorption dynamics of Cs. Second, Cs may react with impurities, resulting in deterioration of the work function. Finally, Cs may adhere to accelerator stages and lower their voltage holding capabilities. For tackling these issues and achieving a reliable long-term operation, careful Cs management and inconvenient counteracting processes, including the continuous evaporation of fresh Cs and Cs conditioning of the ion source, are mandatory.

These issues have motivated development of a new Cs-free negative hydrogen ion source system using multi-pulsed plasma sources. The purpose of the present research is to develop an efficient negative hydrogen ion source based on the volume production mechanism and to investigate its underlying physics by measuring negative ion density.

2. Ion Source Development

To remedy the drawbacks, a novel Cs-free negative hydrogen ion source system using two pulsed plasma sources has been devised as shown in Fig. 1 [4]. The system is composed of one main chamber, two pulsed plasma ion sources, and two magnetic filters.

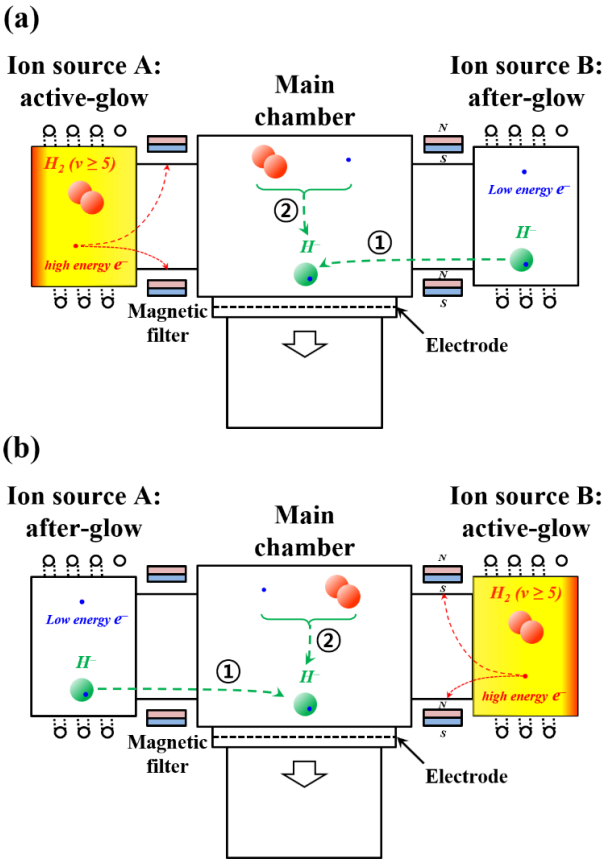

Fig. 1. Schematic diagram illustrating a Cs-free negative hydrogen ion source system using two pulsed plasma sources, and its plasma states at (a) $t = t_a$ and (b) $t = t_b$ in Fig. 2.

The main chamber is located in the center of the system and connected to each of the ion sources. Each of the magnetic filters is installed between the main chamber and the corresponding ion source, resulting in presence of a magnetic field perpendicular to the main plasma flow direction.

A key feature of the system is the alternate pulsing scheme applied to the ion sources. The system switches the ion source plasmas in the after-glow state in an alternating manner, as indicated in Figs. 1 and 2, possibly leading to a quasi-continuous supply of H^- ions to the main chamber. As shown in Figs. 1(a) and 2, at $t = t_a$, the ion sources A and B are in the active-glow state and the after-glow state, respectively.

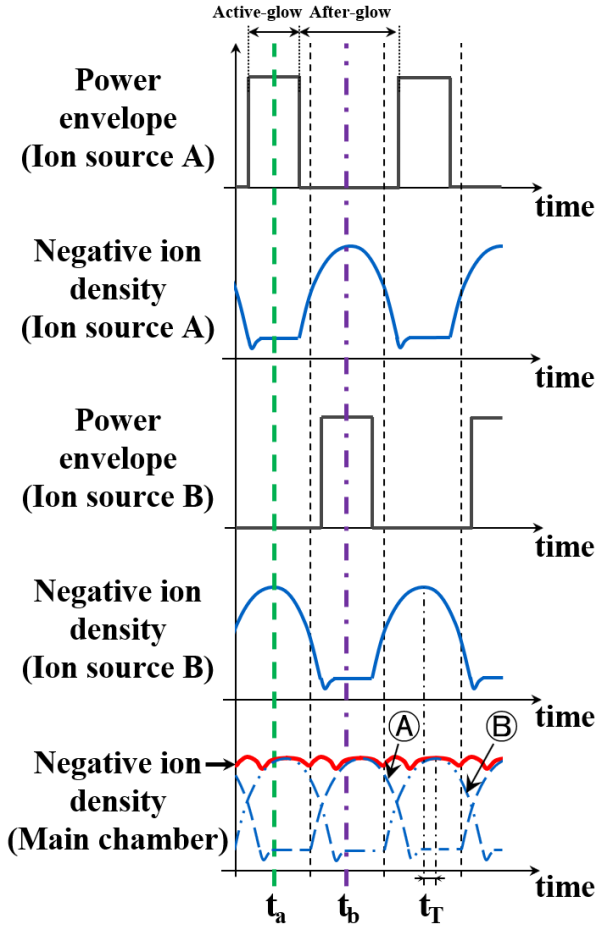

Fig. 2. Schematic diagram representing power modulated in time and temporal variations of H^- ion densities in the Cs-free negative hydrogen ion source system using two pulsed plasma sources illustrated in Fig. 1. Here, t_a is the mid-time of both the power-on period in the ion source A and the power-off period in the ion source B; t_b is analogously defined by switching between the ion source A and B; and t_T is the transport time of the H^- ions or the precursors from the ion sources to the main chamber. Ⓐ and Ⓑ denote supplies of H^- ions from the ion source A and B, respectively, to the main chamber.

At this time, the highly vibrationally excited H_2 molecules produced in the ion source A are supplied to the main chamber. They are for generation of H^- ions during the after-glow period of the ion source A (i.e., at times around $t = t_b$). At the same time, the ion source B supplies a large number of H^- ions to the main chamber (mechanism ① in Fig. 2). H^- ions in the chamber may also be produced from the low-energy electrons and the highly vibrationally excited H_2 molecules (or precursors) flowing from the ion sources (mechanism ② in Fig. 2). The magnetic filter restricts the high-energy electrons from moving from the ion source A to the main chamber, blocking the destruction of the H^- ions in the chamber. As time passes and the H^- ion density in the main chamber decreases, the system switches the plasma states in the ion sources A and B to the after-glow and active-glow states, respectively [see Figs. 1(b) and 2]. In so doing, at $t = t_b$, the ion source A produces and additionally supplies abundant H^- ions to the main chamber by the mechanisms, compensating for the decrease in the H^- ion density in the main chamber. In the meantime, the ion source B produces the precursors of H^- ions in common with the ion source A at $t = t_a$, for the next state. This sequence is alternately repeated. Accordingly, if one adjusts the phase difference between the two power pulses appropriately, the H^- ion density in the main chamber can be continuously maintained at a high value as shown in Fig. 2. In other words, while this system uses pulsing, it can offer a continuous supply of H^- ions, taken as a whole.

In order to explore the characteristics of the Cs-free negative deuterium ion source system using multi-pulsed plasma sources, a device embodying the concept were fabricated as shown in Fig. 3(a).

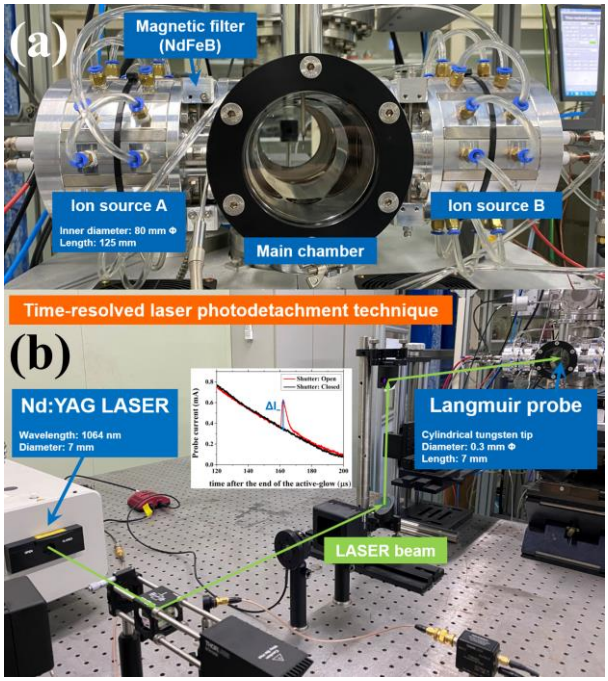

Fig. 3. (a) KOMPASS III embodying the concept of the Cs-free negative deuterium ion source system using two pulsed plasma sources and (b) plasma diagnostic system for measuring negative ion density.

It was named KOMPASS (KOrea atomic energy research institute Multi-Pulsing-Applied ion Source System) III. KOMPASS III has filament-driven DC arc ion sources. The two cylindrical ion sources with detachable magnetic filters made of permanent Neodymium (NdFeB) magnets are identical and have an inner diameter of 80 mm and a length of 125 mm. Each of the magnetic filters was installed in the vicinity of the base of the respective ion source. The two ion sources in KOMPASS III are mounted on the 80-mm inner diameter ports of the main chamber that is a six-way cross. The distance between the ion source base and the

center of the main chamber is 66 mm. All of the experiments in this study were carried out at a fixed peak power of 1100 W for each of the ion sources and an operating pressure of 1 Pa D_2. The pulse repetition frequency and pulse duty cycle were 2 kHz and 50% respectively.

3. Time-resolved Measurement of D^- Ion Density

In order to investigate the temporal behavior of negative charged particles including D^- ions in KOMPASS III, a time-resolved laser photodetachment technique with an uncompensated Langmuir probe was employed [see Fig. 3(b)]. The probe was placed at the center of the main chamber, and its cylindrical tungsten tip has a diameter of 0.3 mm and a length of 7 mm. The distance from the end wall of discharge chamber to the probe position is 111 mm. In the laser photodetachment diagnostics, a pulsed Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) laser (Continuum Surelite II-10) beam with a wavelength of 1064 nm and a beam diameter of 7 mm is injected toward the probe. The tip is aligned parallel to the laser beam axis so that the laser beam detaches electrons from the D^- ions in the vicinity of the probe and then the detached electron current corresponding to the D^- ion density is collected by the tip.

A schematic diagram of the diagnostic system for measuring temporal variations of negative ion density in KOMPASS III is shown in Fig. 4.

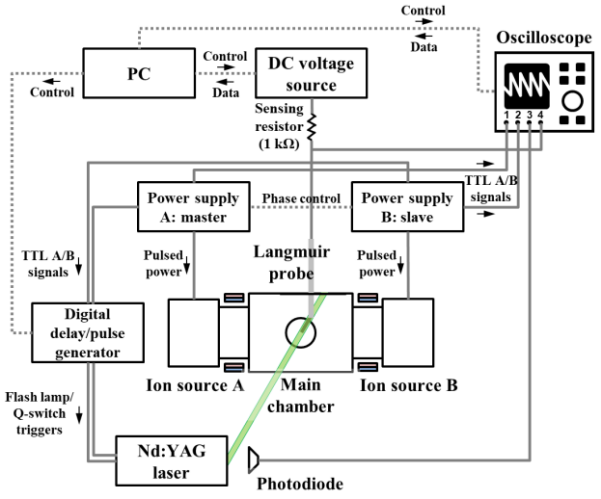

Fig. 4. Schematic diagram of the diagnostic system for measuring temporal variations of negative ion density in KOMPASS III.

Fig. 5 shows power TTL signal voltage levels and temporal variations of electron density, electron temperature, photodetachment signals, and negative ion density in the single and alternate dual pulsing modes of KOMPASS III, obtained using the Langmuir probe diagnostics and the laser photodetachment technique.

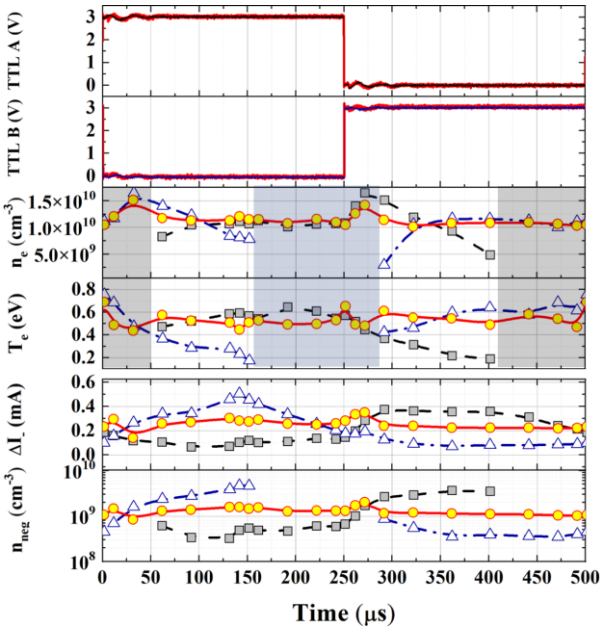

Fig. 5. Power TTL signal voltage levels and temporal variations of electron density, electron temperature, photodetachment signals, and negative ion density in the single (ion source A: dashed line with square symbol, ion source B: dash-dotted line with triangle symbol) and alternate dual (solid line with circle symbol) pulsing modes of KOMPASS III.

Notice that the shaded regions in Fig. 5 indicate ranges under the lower density measurement limit of the boxcar sampling technique. Unlike the single pulsing modes, the alternate dual pulsing can provide a continuous supply of the negative ions. Moreover, its negative ion density is higher than that in the active-glow state of the single pulsing mode. This implies that the multi-pulsed ion source system may have a higher efficiency of the negative ion formation, compared to the conventional CW ion source system equipped with only the magnetic filter.

4. Conclusions

A novel Cs-free negative hydrogen/deuterium ion source system using two pulsed plasma sources has recently developed at Korea Atomic Energy Research Institute. The system operates with two alternate pulsing sequences related to the respective plasma sources, thereby switching the plasmas in the after-glow state in an alternating manner. As a result, the ion source system can offer a continuous supply of negative ions at high densities. This is not possible with conventional single pulsing. In order to understand the physics of the ion source system, the negative ion behavior in the system is experimentally investigated and then compared with that in a single pulsing mode. For experiments, time-resolved Langmuir probe and laser photodetachment diagnostic techniques are employed. It is experimentally

observed that the alternate dual pulsing can provide a continuous supply of the negative ions.

ACKNOWLEDGMENTS

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