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Observation of Beam Current Fluctuation Extracted from an RF-driven H⁻ Ion Source

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ABSTRACT

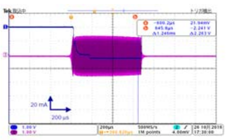
In J-PARC, peak H^- current of several tens mA is produced from a cesiated hydrogen plasma generated by a solid-state RF amplifier with the frequency of 2 MHz. In case of the high-intensity H^- beam extracted from the ion source, the plasma density in the source chamber is so high that the ion sheath around the beam extraction area follows the RF oscillation. Because the ion plasma frequency defined by the ion density is much higher than the driving frequency. The potential fluctuation of the plasma is combined with the driving RF electric field and causes motion of charged particles in the plasma some changes. As a result, the H^- beam extracted from the source plasma also fluctuates. The beam current signal from a Faraday cup was measured by a spectrum analyzer. A powerful frequency component at 2 MHz which is as same as that of the RF amplifier was also observed after the acceleration of RFQ linac located at the downstream of the ion source.

Introduction

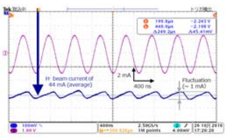
Leung *et al.* initiated to develop a 1.8 MHz RF-driven high-intensity negative hydrogen (H^-) ion source for Superconducting Super Collider (SSC) in the end of 1980s [1]. At the present time, H^- ion sources equipped with 2 MHz RF-driver are employed to produce the H^- beam with the beam current of several tens mA at the accelerator facilities in the world [2-4].

In J-PARC, an investigation of **the effect due to RF discharge for a high-intensity H^- ion source upon the extracted beam** was initiated. The **beam current fluctuation synchronized with the frequency of the RF driver** for producing a high-density pulsed plasma was observed.

Beam current fluctuation measurement

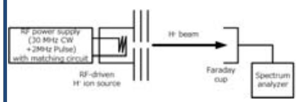


(a) Overall waveforms in a macro pulse

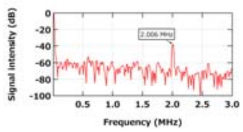


(b) Expansion of Figure 1(a)

Figure 1. Waveforms of H^- beam current measured by a Faraday cup and a signal of 2 MHz RF forward wave for plasma production in the H^- ion source.



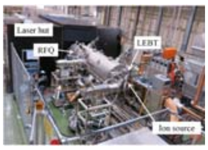
(a) Schematic drawing of the experimental setup.



(b) Frequency spectrum of H^- beam.

Figure 2. Frequency spectrum of the H^- beam measured by a Faraday cup located at the downstream of the H^- ion source.

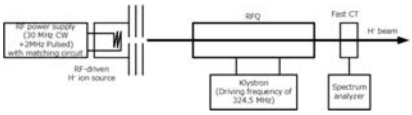
Photograph of a spectrum analyzer for the measurement.



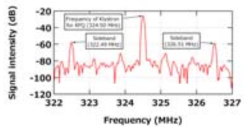
Photograph of a test bench equipped with the RF-driven H^- source and an RFQ linac (Referred from Ref. [5]).

At a test bench for development of the ion source, the H^- beam extracted from the ion source was measured by a Faraday cup located at the downstream of the ion source. The waveforms of the measured H^- beam and a signal of RF forward wave for plasma production are shown in Fig. 1. The H^- beam was extracted while the high-power pulsed RF power was output. As shown in Fig. 1(b), it is found that the **H^- beam signal was fluctuated**. In order to confirm the fluctuation frequency, the H^- beam signal cable was connected to a spectrum analyzer. The frequency spectrum of the H^- beam is shown in Fig. 2. **A powerful frequency component as same frequency of 2.006 MHz as the RF amplifier was observed**.

A test bench equipped with the RF-driven H^- source and an RFQ linac installed for the J-PARC linac till 2014 spring [5] was employed for observation of the H^- beam current fluctuation. The experimental setup is shown in Fig. 3(a). The H^- beam was measured by a Fast Current Transformer (FCT) located at the downstream of the RFQ. The frequency spectrum of the measured H^- beam by the FCT is shown in Fig 3(b). **Around the frequency of the klystron for driving the RFQ, two sidebands were observed**. The difference between the klystron frequency and the sideband frequency was 2.010 MHz. The resolution of the spectrum analyzer is approximately 6 kHz and it is found that **the sideband component was caused by the RF-driver for the ion source**.



(a) Schematic drawing of the experimental setup.



(b) frequency spectrum of H^- beam around the klystron RF frequency.

Figure 3. Measurement of frequency spectrum of the H^- beam measured by a Fast Current Transformer located at the downstream of the RFQ.

Discussions

It is found that the **H^- beam with the beam current of several tens mA extracted from the RF-driven H^- ion source has a frequency component as same frequency as the RF driver** for the plasma production. The frequency component remains after passing through the following RF accelerators. In the source plasma, the H^- ion density around the sheath region is estimated approximately 2×10^{15} m^{-3} according to an assumption that the extracted H^- beam current density is equal to the ion saturation current in the plasma. The **ion-plasma frequency**, which is a criterion whether the ion sheath follows the RF oscillation, is defined by the ion density. In the high-density RF-driven H^- ion sources, there is **a possibility that the driver frequency is much lower than the ion-plasma frequency**.

At the KEK-PS (Proton Synchrotron) which was shut down in 2005, a surface-plasma-type H^- ion source (BLAKE) was employed to deliver the H^- beam with the nominal beam current of 25 mA (maximum 41 mA) and the duty cycle of 0.5 % [6]. **A directly fast-chopped H^- beam was successfully produced in the BLAKE ion source by modulating the converter bias voltage with the frequency of 2.2 MHz** [7]. The reason of successful beam chopping was that **the modulation frequency was lower than the ion-plasma frequency**, and **the ion sheath between the converter surface and the plasma followed the RF modulation**.

In the J-PARC RF-driven H^- ion source, **the ion sheath around the beam extraction area follows the RF oscillation as the same reason** as described above. The **potential fluctuation of the plasma is combined with the driving RF electric field** and **causes motion of charged particles in the plasma some changes**. As a result, the H^- beam extracted from the source plasma also fluctuates.

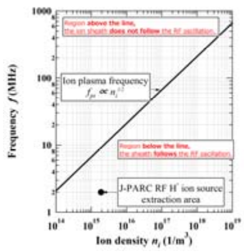


Figure 4. Ion plasma frequency plotted as a function of the ion density.

SUMMARY and PERSPECTIVE

The fluctuation of high-intensity H^- beam extracted from the H^- ion source by RF discharge was observed. This is caused by the frequency of the RF driver less than the ion-plasma frequency and the ion sheath follows the RF oscillation. The beam may be also exhibited some fluctuation to the transverse motion as well. To further clarify this high frequency oscillation of the beam extraction sheath, a measurement system using a time-resolved highly sensitive emittance monitor in order to observe the real-time beam fluctuation in the phase space will be prepared.

Acknowledgements

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