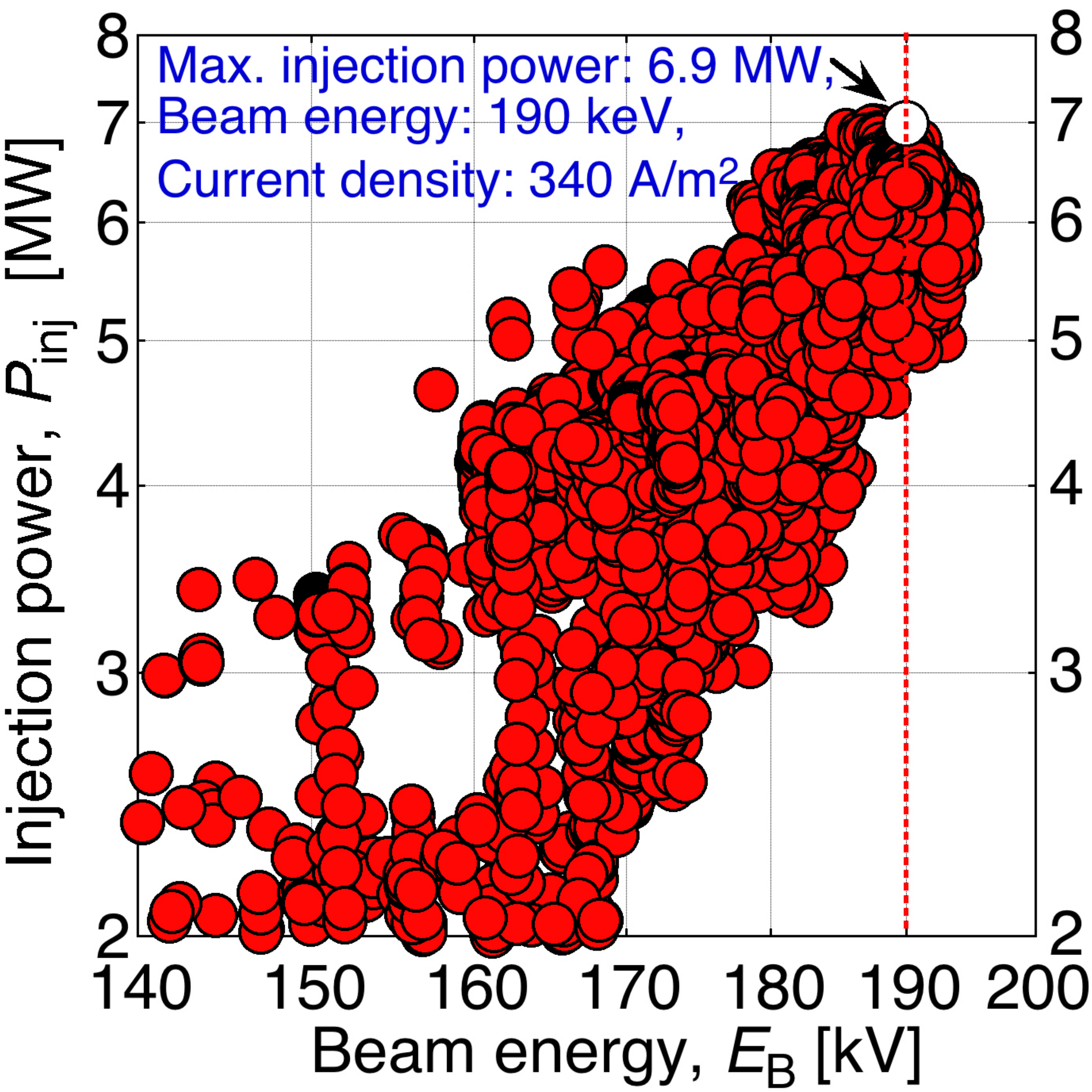
First measurement of the flow reversal of negative ions

December 9 2016



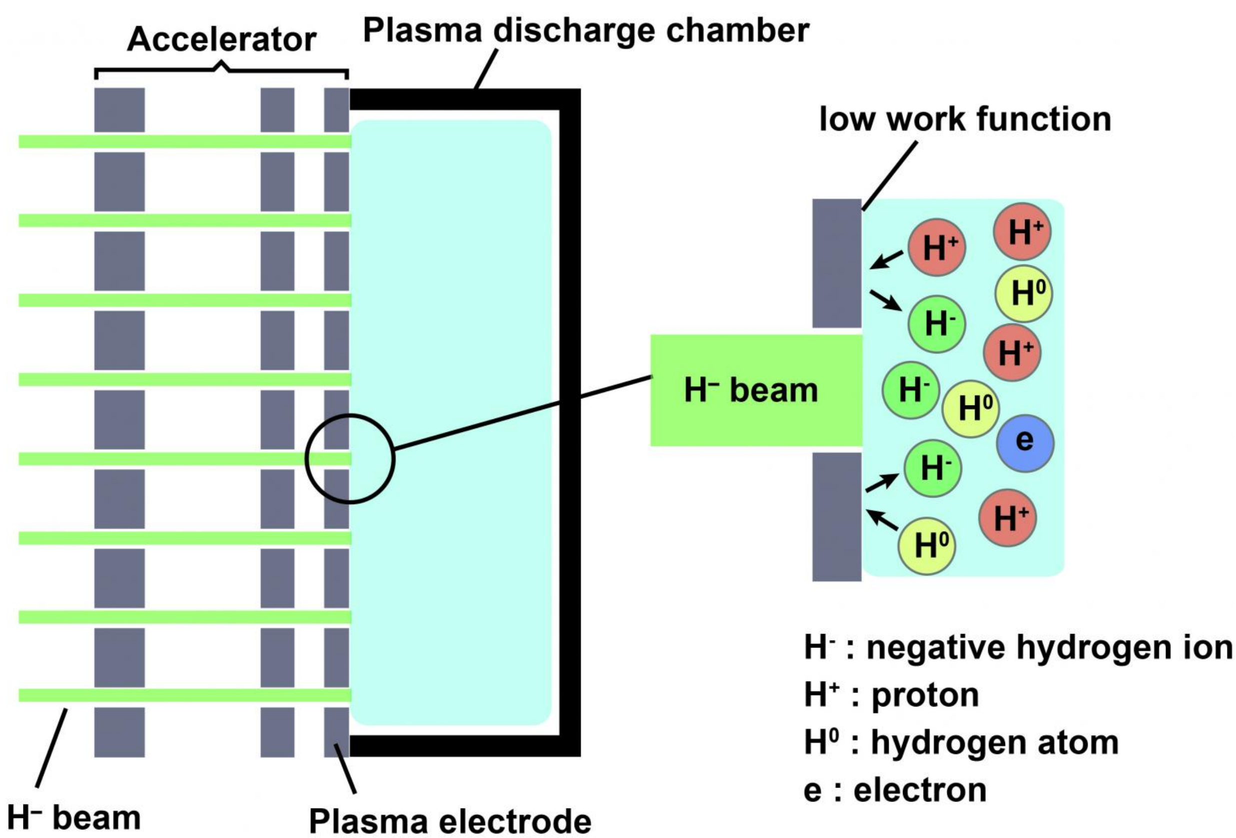
The current density reached 340 A/m2 at the maximum injection power. This value is comparable with the target of the ITER NBI. Credit: Dr. Masashi Kisaki

The National Institutes of Natural Sciences National Institute for Fusion Science (NIFS) has succeeded in revealing the flow of negative hydrogen ions using a combination of infrared lasers and electrostatic probes in the ion-source plasma, which generates a negative-hydrogen-ion beam. This is the first time in the field of fusion research that the detailed ion flow, which changes direction and moves toward the beam direction in the ion source, has been demonstrated experimentally.

Background to the Research

The Neutral Beam Injection (NBI) is a method for increasing the plasma temperature and driving currents in magnetically-confined fusion plasmas by injecting neutral hydrogen/deuterium beams. As the plasma size increases, higher beam energy is necessary to deposit neutral beams at the core region of the confined plasma. The neutralization efficiency of positive hydrogen/deuterium ion beam accelerated with conventional NBI steeply decreases with energy of more than 100 keV. On the other hand, negative hydrogen/deuterium ion beams sustain the energy-independent neutralization efficiency of ~60 %. Consequently, negative-ion-based NBI are indispensable for recent large-scale plasma confinement devices. In order to construct negative-ion-based NBI with energy of 190 keV, NIFS researchers have successfully pioneered development of the negative ion sources.

Two significant improvements have been brought to the NIFS negative ion source. One is enhancement of the negative-ion current by optimizing the magnetic configuration for plasma confinement in the ion source. The second improvement is the development of an original beam accelerator equipped with the slot-aperture electrode, whose beam transparency is two times higher than the conventional circular-aperture electrode. Combining these two innovative ideas, the world's highest beam injection performance has been achieved with the beam power of 6.9 MW at the beam energy of 190 keV, as shown in Fig. 1.



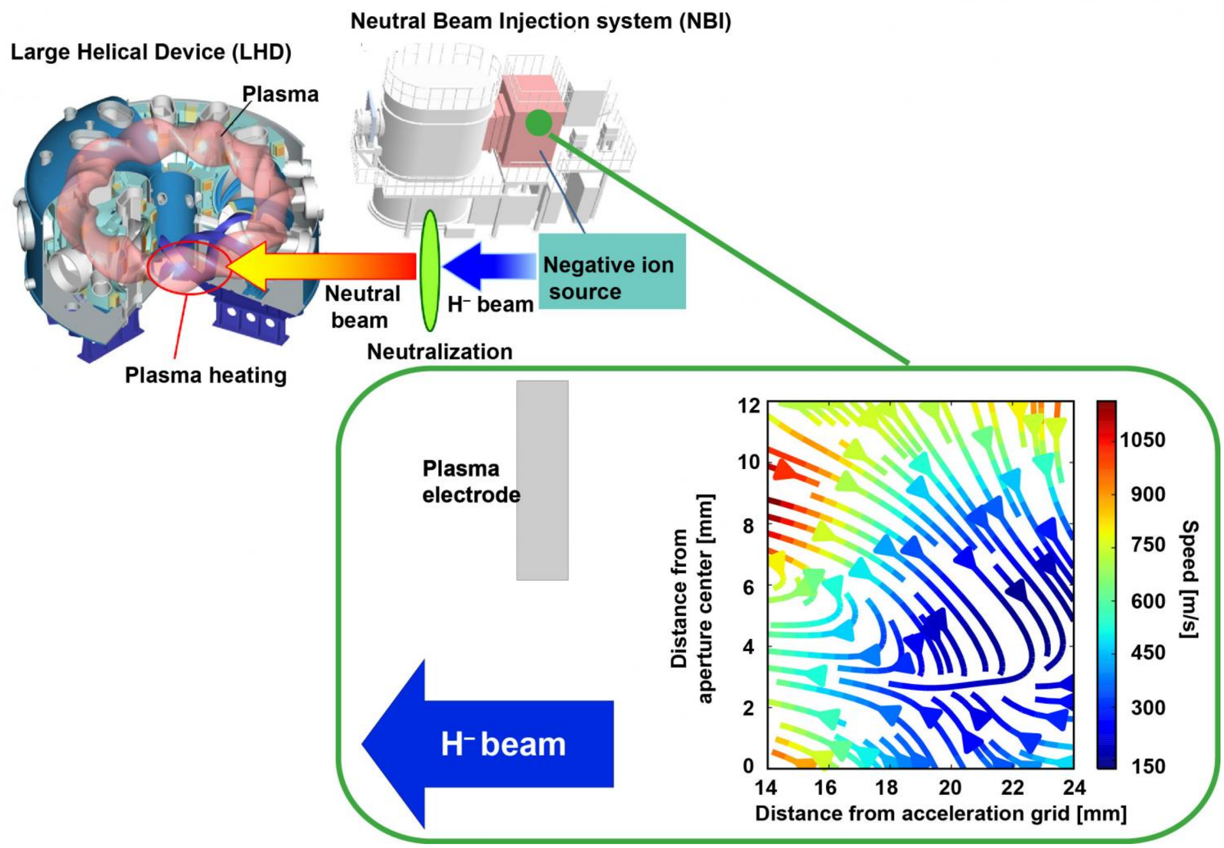
The work function of the electrode surface becomes low with introduction of the cesium into the ion source, and the negative hydrogen ion production is enhanced. Credit: Dr. Masashi Kisaki

Further investigation, however, is required to achieve higher performance and stability for advanced negative ion source to be adopted for future fusion devices. In addition, the ion-source size is too large for applying a trial-and-error approach. Scaling approach is not applicable either, because the mean free path of an electron is much shorter than the actual ion source for NBI and an ion source with the size smaller than the mean free path has different characteristics. These conventional developments become difficult for achieving significant progress in performance. For this reason, the NIFS NBI group has initiated research that focuses upon the behavior of negative hydrogen ions inside the ion-source plasma.

In the case of the negative ion source, the small amount of cesium is injected into the ion source and the cesium-adsorbed surface of the so-called "plasma electrode" become activated to transfer the electron to hydrogen atoms and hydrogenous positive ions that are colliding on the surface. As shown in Fig. 2, these particles are converted to negative ions on the surface and are recoiled opposite to the beam direction. The mechanism of how the negative hydrogen ions change the direction of their velocity and are extracted as a beam has not been clarified. Moreover, it also has not been clarified from which part of the surface of the plasma electrode the negative hydrogen ion is extracted as a beam. To this point, regarding the processes concerning the beam production through the extraction of negative hydrogen ions, although many simulations have been conducted, because numerous physical processes are related to this issue we still have not obtained results that will help explain the experimental results.

Research Results

In the large negative hydrogen ion source at NIFS, various types of diagnostics are available for measuring negative hydrogen ion density, electron density, and other quantities. These physics quantities can be measured spatially and temporally in detail. The behaviors of negative hydrogen ions can be clarified under the beam extraction. Heretofore, these behaviors had been difficult to measure experimentally.



Negative hydrogen ion flow changes its direction toward the electrode aperture when the beam is extracted. Credit: Dr. Masashi Kisaki

Accompanying the beam extraction, the spatial flow distribution of the negative hydrogen ions was investigated by measuring the flow of negative hydrogen ions with the use of a compound-type electrostatic probe with four needle-type electrodes irradiated by laser pulse.

These operations were conducted at numerous places, and, during the beam extraction, we investigated how the flow of negative hydrogen ions changed. In the results of that investigation, it was clarified experimentally that the negative hydrogen ions generated at the plasma electrode move far from the electrode, subsequently make a U-turn, and flow toward the beam extraction hole where the beam extraction field is applied (See Figure 3). This feature of the negative ions has never been observed before this experiment. Clarifying the detailed configuration of the negative hydrogen ion flow is a valuable result for both physics and technology research.

This research result was reported at the 26th International Atomic Energy Association (IAEA) Fusion Energy Conference held in Kyoto, Japan from October 17-22, 2016. In addition to achieving success in improving the performance of the negative hydrogen ion source, we clarified experimentally detailed physical phenomena related to negative ion source plasma by using numerous diagnostics to investigate negative ion source plasma from numerous directions. These results were comprehensively evaluated, and received the NIBS Award at the 5th International Symposium on Negative Ions, Beams and Sources held in Oxford, England from September 12-16, 2016.

Significance of the Research

By applying the method developed in this research, measurement of the negative ion flow at places still closer to the plasma electrode is possible for clarifying more detailed mechanism of the negative ions extracted as a beam. The result provides a guideline to improve the performance of the negative ion source as well as an important contribution to the simulation field related to ion-source plasma. The negative ion beams are widely utilized not only in fusion research but also in medical applications, particle physics, and propulsion for spacecraft. The ripple effects of these experimental results and the newly developed diagnostic methods in this research are expected to contribute to these research developments.

Provided by National Institutes of Natural Sciences