7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Basic Research on Negative Ion Source for Fusion Using FA, RF and Hybrid Ion Sources

H. Nakano[1,2], K. Tsumori[1,3], K. Nagaoka[1,4], K. Takahashi[5], K. Ikeda[1], Y. Takeiri[1], E. Rattanawongnara[3], M. Osakabe[3], W. Kraus[6] and P. Veltri[7]
[1] National Institute for Fusion Science, National Institutes of Natural Sciences, [2] Graduate School of Engineering, Nagoya University, [3] Graduate University for Advanced Studies, SOKENDAI, [4] Graduate School of Science, Nagoya University, [5] Graduate School of Engineering, Tohoku University, [6] Max-Plank Institute for Plasma Physics, [7] ITER Organization
e-mail (speaker): nakano.haruhisa@nifs.ac.jp

Negative hydrogen ion sources are utilized for neutral beam injectors (NBIs) for fusion devices, large accelerators for particle physics and material physics, and accelerators for medicine. High ion-beam current density, low divergent beam, and long lifetime are required in all fields. The negative ion source for the NBI is large-scaled, has multi-beamlets to obtain tens amperes of total beam current, and utilizes negative deuterium ion beam due to the use of one of the same kinds of fusion fuels: deuterium and tritium. Isotope effects are known in the negative hydrogen ion source. Co-extracted electron current with negative ion from ion source plasma increases in deuterium operation [1], and should be less than the current of negative ion beam in ITER requirements. The large co-extraction electron current delivers extra electric consumption in a fusion system where power efficiency is important. The elucidation of the physics of isotope effects is one of the key issues to develop the negative deuterium ion source with a low co-extracted electron current ratio. The radio frequency (RF) discharge to generate the ion source plasma is appropriate for long lifetime, which is one of the important elements in fusion because the equipment becomes radioactive. Negative ion sources for the NBIs have been realized with filament-driven arc (FA) discharge [2], and are been developing with RF discharge for the ITER. The beam divergence of the RF negative ion source for the fusion has been larger than the ITER requirement so far. The larger beam divergence also reduces the electric power efficiency of the NBI as well as beam injection efficiency to fusion plasma. The realized FA-negative ion sources, on the other hand, have lower beam divergence. Clarifying the physics mechanism of the beam divergence difference between the RF and the FA ion sources contributes realization of the low divergent beam from the RF ion source. In this paper, the isotope effects in the negative ion source and the influence of the RF oscillation in the ion source plasma on beam property are presented.

Investigation on the isotope effects has been conducted with the research and development negative ion source in National Institute for Fusion Science (NIFS-RNIS), which is an FA ion source [1]. Although the line-averaged density of the negative deuterium ion in the vicinity of plasma-beam boundary grid electrode (PG) in the ion source plasma increased by a factor of 1.3 of that of the negative hydrogen ion, the line-averaged electron density enhanced threefold in the deuterium operation. This is a direct reason for the co-extracted electron current increase in deuterium operation. Since higher plasma density in deuterium operation was also observed in the plasma production region which is upstream of the plasma-beam boundary region, plasma production processes would cause higher electron density in the vicinity of the plasma-beam boundary. This is supported by simulation studies [3]. The isotope effect also appeared in the negative ion density response in the vicinity of the PG boundary to the application of the beam extraction field [4]. This can be partially explained by the Larmor motion of the negative ions emitted from the PG surface which is the main negative ion production area.

To investigate the influence of the RF oscillation on the negative ion beam property, RF perturbations were applied to ion source plasmas in the FA negative and positive ion sources. The RF perturbation in the negative ion source plasma caused oscillations on not only beam width, which is related to beam divergence but also beam axis position [5], while the RF perturbation in the positive ion source plasma oscillated ion beam only at the peripheral region [6]. This indicates that sheath in the ion source plasma with a high negative ion density ratio to electron can affect ion beam formation. Further investigation on the influence of RF plasma on the beam property in large-scaled negative ion source will be conducted with FA/RF hybrid negative ion source modified from the NIFS-RNIS, collaborated with ITER organization and Max-Plank Institute for Fusion Science [7].

References

[1] H. Nakano et al., Jpn. J. Appl. Phys. 59, SHHC09 (2020).
[2] K. Tsumori et al., Fusion Sci. Tech. 58, 489 (2010).
[3] T Shibata et al., J. Phys.: Conf. Ser. 2244 012002 (2022); R. Kato et al., J. Phys.: Conf. Ser. 2244 012035 (2022).
[4] H Nakano et al, J. Phys.: Conf. Ser. 2244 012046 (2022).
[5] K. Nagaoka et al., 8th International Symposium on Negative Ions, Beams and Sources, 2-7 October 2022, Padova, Italy.
[6] K. Takahashi et al., New J. Phys. 21, 093043 (2019).
[7] K. Tsumori et al., 20th International Conference on Ion Sources, 17-22 September 2023 Victoria, BC, Canada.