Electrostatic PIC simulation of low temperature plasma in cusp-shaped magnetic field for deuterium ion source

Woongil Ji[1], Bin Ahn[1], Jaewook Kim[2], Y.-C. Ghim[1]
[1]Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology
[2]Korea Institute of Fusion Energy
e-mail (speaker): jiwoongil@kaist.ac.kr

Understanding the detailed behavior of ion source plasmas in neutral beam injection(NBI) system is essential for improving the efficiency of plasma heating in magnetic confinement fusion devices such as KSTAR. In particular, the cusp magnetic field, commonly implemented in NBI ion sources, plays an important role in enhancing ion confinement and increasing ion density. However, comprehensive modeling of ion source remains challenging due to the complex interplay between charged particle kinetics, collisional process, and magnetic confinement.

Particle-In-Cell (PIC) simulation has become a powerful tool for investigating complex plasma dynamics. PIC simulation enables kinetic modeling of microscopic plasma behaviors by computing particle trajectories and electromagnetic fields self-consistently. In this study, we utilized WarpX, an advanced open-source PIC simulation code that employs various advanced algorithms[1].

To address the lack of detailed understanding of NBI ion source plasmas, we performed the 2-D electrostatic PIC simulations using WarpX to investigate deuterium plasma behavior in cusp field. The magnetic field is computed by Finite Element Method Magnetics (FEMM)[2], a software for solving electromagnetic problems using the finite element method, based on NBI ion source geometry of KSTAR. We obtained electron-deuterium collision data from LXCat[3], an open-access online platform that provides data of necessary collision cross sections. The data includes the cross section of elastic scattering, ionization, and excitation as a function of electron incident energy. The collision cross section data and magnetic field data were implemented into a stochastic collision model within WarpX.

To simulate the DC characteristics of ion source plasma, the simulation was performed under varying bias voltages and magnetic field strengths. The results include the resulting ion density distributions and ion species ratio under varying operational conditions. This approach can support the understanding of plasma behavior in ion source of NBI system and the design optimization of NBI systems for KSTAR and other magnetic fusion devices.

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References

[1] WarpX. *WarpX Documentation.* https://warpx.readthedocs.io/
[2] FEMM. *Finite Element Method Magnetics.* https://www.femm.info/
[3] LXCat. *Low Temperature Plasma Data Exchange Project.* https://us.lxcat.net/