Application of 3D code IBSimu for designing an H⁺/D⁺ extraction system for the Texas A&M facility upgrade

T. Kalvas¹, O. Tarvainen¹, H. Clark², J. Brinkley² and J. Årje¹

1. Department of Physics, P. O. Box 35 (YFL) FI-40014 University of Jyväskylä, Finland
2. Texas A&M University, Cyclotron Institute, College Station, TX 77843, USA

Model for negative ion plasma extraction

A negative ion plasma extraction model has been implemented in the three dimensional ion optical code IBSimu. The simulation is started in the extraction from the potential well at \( U=0 \) V, where negative charges are born. The electron and negative ion propagation is calculated using standard ray-tracing techniques and their space charge \( \rho_{\text{ET}} \) is deposited on a mesh. Positive charges are taken in account using analytic formulations. The self-consistent solution is found by Vlasov iteration using Newton-Raphson on the non-linear Poisson equation

\[
\nabla^2 U = \frac{-\rho_{\text{ET}} + \rho_{\text{h}}}{\epsilon_0},
\]

where the space charge of fast positive ions flowing from the bulk plasma is described by the virtual cathode process

\[
\rho_{\text{ET}} = \rho_{\text{h}} \left( 1 - \frac{eU}{E_i} \right).
\]

The space charge of the thermal ions trapped in the potential well is

\[
\rho_{\text{h}} = \rho_{\text{h0}} \exp \left( -\frac{eU}{kT_i} \right).
\]

The sheath model is compatible with multiple thermal ion species and magnetic fields at the extraction.

Validation with SNS extraction

The plasma model was tested using the widely simulated extraction of the SNS ion source in cylindrical symmetry and in full 3D. In the simulation shown, 38 mA of H⁺ beam was extracted with 230 mA e⁻ beam dumped by the magnetic filter.

The results achieved are consistent with earlier studies and experimental observations from SNS ion source with the exception of more aberration-free emittance patterns in simulations.

Texas A&M University H⁺/D⁺ extraction design

An extraction system was designed for a filament-driven cesium-free multicusp ion source installed at the Texas A&M University Cyclotron Institute. Up to 1 mA of ion beam is extracted with a variable final energy ranging from 5 keV to 15 keV. Tens of milliamps of electron beam is dumped at fixed 6 keV energy into the water-cooled puller electrode containing a permanent magnet dipole filter. The ion beam is tilted to about 4° angle. The beam is accelerated to final energy after the puller while the focusing is adjusted using a decelerating Einzel lens.

The extraction is capable of handling both H⁺ and D⁺ beams with the same electrode configuration using roughly the same voltages. This is possible because the differences in electron to ion beam ratio and plasma density affect the ion beam tilt angle to counteract the bending difference between the species. Beam angle exiting the extraction is almost independent of hydrogen isotope and energy.

Experiments

The ion source was installed in the injection line of the K150 cyclotron at TAMU with additional focusing elements and diagnostics. The extraction system proved to function as predicted by the simulations made for both H⁺ and D⁺. Optimal transmission to the first Faraday cup was found very close to simulated electrode voltages. The slight variation in beam angle with changing energy and species is corrected with an XY steering magnet after the extraction.

The H⁺ current of 1 mA was reached with 100V, 12.7 A arc. The the e⁻/H⁺ ratio was 25 (5 with 2 V plasma electrode bias). With deuterium 285 µA was measured with 10 A arc. Beam currents of 25 µA of H⁺ and 15 µA of D⁺ have been measured at energies 30 MeV and 20 MeV respectively in the first FC after the cyclotron.

Overall, the experimental work done with the source shows that the design process has been a success.

Contact the corresponding author via email at taneli.kalvas@jyu.fi