UPGRADES AND DEVELOPMENTS RELATED TO STABLE ION BEAMS INJECTORS AT INFN-LNL

A. Galatà*, E. Fagotti, P. Francescon, C. S. Gallo, D. Giora, D. Martini, A. Minarello, M. Miglioranza, F. Pasquato, M. Roetta, M. Rossignoli, INFN-LNL, Legnaro, Italy

Abstract

The LNL accelerator complex is equipped with two stable ion beams injectors, employing respectively negative and positive ion sources. In particular, a sputtering-type negative ion source and an Electron Cyclotron Resonance Ion Source (ECRIS) are installed on high voltage platforms, to provide the optimum injection energy in the downstream accelerators. Recently, the two injectors have been object of upgrades and developments, in order to improve the overall safety and reliability of the two systems, as well as the beams available for the users. This contribution describes the work related to the above mentioned activities, the technical choices employed and the latest results on ion beams production.

NEGATIVE IONS INJECTOR

The negative ions injector for the Tandem accelerator is based on a commercial sputtering-type negative ion source [1] installed on a -150 kV high voltage platform. In this ion source, neutral atoms are created by sputtering and negatively charge by interacting with a cesium atmosphere. Basically any element, from H to Au, can be ionized and extracted by applying this technique. The injector is enclosed in a vane made of thermally insulated walls, in order to keep stable temperature and humidity and avoid discharges of the high voltage platform. Previously, the main supply to the devices installed on the platform was ensured by a system consisting in a motor connected to an alternator through an insulated shaft. Unfortunately, due to mechanical vibrations and the difficult alignment of the system, it suffered of several failures. The devices installed on the platform were controlled by rotating insulated rods connected to potentiometers, in turn connected to the various analog inputs. The above mentioned aspects have been object of a recent upgrade. The motor-alternator system has been substituted by a resin-insulated transformer: to allow its installation as close as possible to the platform, the vane containing the injector has been added with another part made of the same insulating material, as shown in Fig. 1. The interface between the transformer and the injector vanes consists of a metallic grid with a safety locker whose opening is allowed only if the main power to the primary has been cut. More, the high voltage cable used to polarize the platform has been connected to a high voltage relay that, before opening the door to access the vane, grounds the platform to avoid any possible contact with parts having a residual voltage. The previous remote control of the devices has been substituted with an EPICS-based [2] control system: besides setting and reading several source and platform parameters, the new software has very useful features, like the possibility to acquire mass-analyzed spectra at the exit of the ion source or the implementation of a controller to keep stable the evaporation temperature of the cesium, thus allowing a higher beam stability. The negative injector is presently under preparation for the next experimental campaign expected for the second half of 2023.

POSITIVE IONS INJECTOR

Highly charged ions are produced by a 2nd generation Electron Cyclotron Resonance Ion Source (ECRIS [3]) called LEGIS (LE Gnaro ecrIS [4]), installed on a 400 kV high voltage platform. In this ion source, a plasma is created by microwave in the GHz range and confined by a particular magnetic structure (the B-minimum structure), thus allowing the production of high charge states. The extracted beam is injected in the PIAVE-ALPI complex for acceleration up to 10 MeV/A, for ions whose mass-over-charge ratio lies between 4 and 7. The activity carried out recently on the LEGIS source aimed at: (i) increasing the performances for the already available beams; (ii) developing new beams requested by the users.

The performances of ECRISs strongly depend on the distribution of the electromagnetic field set up inside the plasma...
chamber. In fact, ionization are generated by electrons’ impact, that acquire the required energy by absorbing the injected microwave power through the ECR process, on those locations where the microwave frequency equals the electrons’ Larmor frequency. Those locations form usually a closed ellipsoidal-like surface called the resonance surface. The higher is the electric field on the resonance surface, in particular in the points close to the chamber axis, the higher will be the energy acquired by electrons. For this reason, an optimization of the performances of an ECRIS pass through the optimization of the microwave coupling to plasma electrons. Generally, the plasma chambers of the ECR sources are cylindrical: most of the allowed resonant modes (TE and TM) show an electromagnetic field distribution with off-axis maxima; the only exception is represented by the TM_{0,n,0} modes. The LEGIS plasma chamber consists in a cylinder with a radius of 22.0 mm and a length of 128 mm: considering these dimensions, none of the TM_{0,n,0} modes fall within the operating range. Analytical calculation showed that, by reducing the chamber diameter to 18.3 mm, the mode TM_{0,2,0} could be excited at 14.4 GHz. Following this evaluation, the chamber radius reduction was accomplished by inserting an aluminium tube, with external and internal diameters respectively 22 mm and 18.3 mm. The performances of the source after the modification were compared to the conventional ones from the point of view of the beam production, in particular for high charge states of ^{136}\text{Xe}. All the main source parameters were kept constant (microwave power, gas pressure), except for the microwave frequency that was optimized for both cases (considering the different geometries), thus obtaining 14.365 GHz and 14.433 GHz respectively before and after the modification (it is worth noting that the value obtained experimentally after the modification is very close to the one estimated analytically). Figure 2 shows the results obtained for the two configurations: it can be clearly seen how the charge state distribution shifted towards higher charge states, with the maximum going from 24+ to 25+. What is more important from the point of view of the acceleration with the PIAVE-ALPI complex is the improvement on the highest charge states, from 25+ to 28+: the gain in intensity goes from the 10% for the 25+ to a factor of 2 for the 28+, one of the most frequently accelerated at LNL.

The activity of beam development was dedicated mainly to verify the feasibility of the production of an Uranium beam. The technique we plan to employ to ionize such element is the sputtering. A rod, with a target of the desired material mounted on the top, is inserted inside the plasma chamber on axis and negatively polarized with respect to it (-1 kV maximum). Ions that naturally leak from the confined plasma are accelerated by the negative voltage and strike on the target, thus producing sputtering. Sputtered neutral atoms, ejected from the target, are captured by the plasma (unfortunately with a low efficiency), ionized and then extracted as a highly charged ion beam. It has been evaluated that an intensity of 500 nA on the charge state 32+ produced by the LEGIS source would be sufficient to schedule several Nuclear Physics experiments at LNL. Unfortunately, Uranium cannot be tested as a conventional beam, due to the safety legislation involved and the necessity of an authorization from the Italian Authorities. For this reason, before starting the necessary bureaucracy, it has been necessary to find a way to demonstrate its feasibility. Uranium beams have been produced by different Laboratories, in particular at GANIL with an ion source similar to the one installed at LNL and with the same technique we plan to apply. The performances reported in [5] show that the intensity obtained at GANIL is comparable to what is needed at LNL: for this reason, we decided to evaluate its feasibility by comparing the performances of the two sources on the production of another element, in particular Tantalum, by employing the same technique. The activity started at the beginning of summer 2022, mounting a target with a conical shape whose surface forms an angle of 60° with the plasma chamber axis: the geometry of the target is shown in Fig. 3.

The target was mounted on the sputtering rod and inserted inside the ion source where an oxygen plasma had been produced previously. Then, the target was moved slowly towards the plasma, checking at the same time the current on a Faraday Cup downstream a selection dipole. The position giving the best yield was found to be at around 5 cm from the plasma, by applying -700 V to the sputtering rod: Fig. 4 shows the charge state distribution obtained in this conditions. By comparing the performances with those reported in [6], it can be seen that the results are absolutely comparable or even better for the LEGIS source. The beam stability has been verified by acquiring the intensity produced on the charge state 29+: Fig. 5 shows a long term acquisition (about 20 h). The intensity has been kept constant within few percent with rare operators interventions. By weighting the target before and after the experiment we estimated a consumption rate of 65 mg/d: Fig. 6 shows the status of the target after the experimental campaign.
The results described above convinced us to start the procedure for the authorization to employ Uranium. In the meantime, further experiments will be carried out in 2023 to further validate the results and to test slightly different target geometries. To help in choosing the optimum one, a numerical code has been developed to calculate the impact angle of plasma ions on the surface of the sputtering target, being the sputtering yield strongly dependent on this parameter. Electrostatic calculations carried out with Comsol Multiphysics© generate matrices of the three components of the electric field produced by the target, imported in Matlab© where the equation of motion of plasma ions is integrated including also the magnetostatic confining field. The calculation applied to the target shown in Fig. 3 revealed the distribution of impact angles shown in Fig. 7: it is interesting to note that most of the ions arrive at the target with an angle of 60° ± 5°. Calculations of the sputtering yield of tantalum by an oxygen beam carried out with SRIM [7] revealed that it is higher than 1 in the above mentioned range. The maximum yield, equal to 1.4, is expected for an impact angle of 70°: this will be the angle of the new target, similar to the one shown in Fig. 3, foreseen to be tested in 2023.

ACKNOWLEDGEMENTS

This work has received funding from the European Union’s Horizon Europe Research and Innovation programme under Grant Agreement No 101057511. The support of the LNL mechanical workshop is greatly acknowledged.
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