MODELLING OF ELECTRON AND ION DYNAMICS IN THE ELECTRON CYCLOTRON RESONANCE ION SOURCE BY MEANS OF PIC-SELF CONSISTENT NUMERICAL SIMULATIONS*

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Abstract

The properties of Electron Cyclotron Resonance Ion Sources (ECRIS) plasmas, up to now, have been largely studied on the basis of a global approach. However the design of new generation sources, able to provide high intensity beams of multiply charged ions, requires a more accurate investigation of both electron and ion dynamics.

Recent experiments have demonstrated that even slight frequency's changes (of the order of MHz) considerably influence the output current, and what's more important, even the extracted beam properties (beam shape, brightness and emittance) are affected [1,2].

The paper will briefly describe the approach used to simulate the phenomena observed by referring to some recent papers for further details.

INTRODUCTION

According to the model that has driven the development of ECRIS in the last years, a large variation of the pumping microwave frequency (order of GHz) along with the proportional increase of the magnetic field boosts the extracted current for each charge state because of a larger plasma density.

However the improvement of ECRIS performances, based on the simultaneous increase of the above mentioned parameters, is now close to saturation, limited mainly by the reliability of the magnets and by the costs.

Therefore to overcome such limitations several alternative heating schemes were proposed, by different teams spread over the world. The most successful, named Two Frequency Heating (TFH) [3], consists in the use of two waves at different frequency instead of one, both carrying a total amount of power that is approximately the same of a single wave. Even if a clear improvement has been observed, these experiments have not given an explanation or a methodology to better understand the coupling mechanism between feeding waveguide and cavity filled with plasma and the energy transfer between the electromagnetic field in the source plasma chamber and the plasma therein confined.

From a couple of years, the INFN-LNS ion source group, on the basis of different experiments carried out from 2001 [4,5] has proposed a model [6,7], now accepted from the scientific community, to explain the observed results, based on the hypothesis that standing waves are formed inside the ECRIS plasma chamber.

Such hypothesis has been verified experimentally on different 2nd generation ECRIS by slightly changing the frequency around the operating one [1,8,9]. Remarkable changes in the beam intensity and in its distribution have been observed confirming that a frequency dependent electromagnetic distribution is preserved even in the presence of plasma inside the source (the so called "Frequency Tuning Effect").

In order to investigate how this fine tuning affects the plasma heating, a set-up for the injection of variable microwave frequency into the ECRIS cavity has been prepared. The microwave power was fed by means of a Klystron-based generator [1,8] or a by means of a Travelling Wave Tube amplifier with a broad operating frequency range [9]. The frequency has been systematically changed and the beam output was recorded either in terms of charge state distributions and beam emittance. Since the microwave frequency was the only parameter changed in each measurement, the variation observed in terms of reflection coefficient, extracted current and beam emittance, clearly reveal the role of the electromagnetic distribution inside the plasma chamber cavity which changes with the frequency and affects the final structure of the extracted beam.

In recent experiments we recorded also the bremsstrahlung X-rays emission in order to achieve some insights about the electron energy distribution function (EEDF) [10]. The ECRIS have a broad EEDF, not ideal for the safe operation of the sources, especially when superconducting magnets are used. X-rays measurements reveal a large amount of MeV electrons, that locally heat the cryostat and make the aging of the insulator faster. Conditions for the suppression of high energy particles must be understood in order to fully exploit the ECRIS ability to produce high brightness beams, and the plasma heating modelling permits a better insight.

In order to take into account all the above mentioned phenomena a numerical code has been developed at INFN-LNS with MATLAB in order to follow the electron and ion dynamics by means of a Monte Carlo collisional approach. More details are available in [6,7]. We are able to perform fully 3D collisional simulations of ECRIS plasma, splitting the electron and ion dynamics, and looking separately to their time evolution.

The collision probability is calculated according to a well known Monte Carlo technique, once known the characteristic time of Spitzer collisions. Finally, the Monte Carlo hybrid code solves the relativistic Landau equation for electrons and a non-relativistic equation for ions:

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FUTURE PERSPECTIVES

The above presented model well explains the0results observed as a consequence of the mode structure. The Frequency Tuning Effect helps to improve ECRIS performances without any modification to the hardware of the source, permitting to overcome the limitations of the current. For this reason TWT amplifiers are preferable because of their versatility in changing the output frequency. For third generation sources, which make use of Gyrotrons at 28 GHz, Gyro-TWT should be employed, conjugating the requirements of high frequencies (Gyrotron) devices with the easy tuning ensured by TWT-based amplifiers.

Theoretical investigations aiming to the comprehension of the generation mechanisms of hot electrons will be pursued at LNS. The magnetic field profile, and especially the gradient at the resonance point, is the main parameter affecting the electron energy distribution function (EEDF), and simulations will be improved to determine the time evolution of EEDF at different field profiles.

On this purpose, the theoretical approach will include also self-consistent interactions between electrons and ions in order to correctly determine the inner plasma ambipolar potentials. Some efforts will be finally devoted to the minimization of the computing time.

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