Spectroscopic Investigation of Nitrogen loaded ECR Plasma

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Abstract

Energy dispersive X-ray spectroscopy on ions in the plasma and magnetic q/A-analysis of the extracted ions were used to determine the plasma properties of nitrogen loaded ECR plasmas. A comparison between the ion charge state distributions shows significant differences. The use of a pin-hole camera allows to analyse the particle distribution inside the source chamber and gives a clear picture of electron loss currents inside the source. Furthermore, the influence of different source operating regimes and of an additional electron injection into the plasma were investigated, whereby the later one leads to a considerable higher output of highly charged ions.

Introduction

Traditionally, the CSD is obtained by q/A-analysis of the extracted ion beam using a magnetic analyzer, that leads to the following problems:

- The extracted ion beam expands from a limited plasma edge and the extraction process disturbs the plasma properties in this region; the beam composition does not anymore correspond to the bulk plasma composition.
- The ion transport from the plasma edge to the detection device is charge state sensitive, what can falsify the result additionally.
- Ion currents are only extracted from the plasma edge, there is no information on the ion distribution in the plasma centre.

A different diagnosis method will be introduced here: the modelling of energy dispersive X-ray spectra and fitting them to measured spectra.

Numerical Modelling

The balance equations for the ion density and the electron energy are solved numerically considering the main atomic processes. Multiple elements can be included in the calculation. The differential equations are solved stationary when the particle densities are time independent. In most cases some easy to use empirical formulas for the following cross sections were used:

- single electron impact ionization [1]
- double electron impact ionization [2]
- single and double charge exchange processes [3]
- radiative recombination processes [4]
- electron impact excitation processes [5] for modelling X-ray spectra
- cascading processes due to inner shell ionization and shake off processes are calculated numerically [6, 7]

- bremsstrahlung for modelling X-ray spectra

The ionization potentials are calculated using a multiconfigurational Dirac Fock Code [8, 9, 10] and radiative transition rates necessary for modelling X-ray spectra are calculated within the adiabatic model [11]. Additional details can be found in [12, 13].

The electron density can be calculated by considering plasma neutrality $n_e = \sum_{i=1}^{Z} i \cdot n_i$. The necessary radial distribution of the neutral gas is calculated by solving the equation $\dot{n}_0 + \nabla j_0 = 0$ assuming a cylindrical plasma. Ion loss from the plasma is assumed to be independent of the charge state (the confinement time is constant): $\dot{n}_i = n_i / = \; n_i \tilde{n}_0 \;_0$, the factor $0 < \; < 1$ cannot be calculated easily but must be empirically adjusted until the numeric result matches the measurements.

An additional electron current I can be injected into the plasma volume V with an electron gun to enhance the density of electrons and ions. It is assumed that the electrons are trapped in the magnetic mirror system and do not only transmit straight through the plasma. The influence on the electron energy distribution is neglected.

The model for simulating the electron energy distribution includes the assumption that the electron impact ionization is the most dominant process for the electron and that every electron ion collision produces two electrons with the half energy of the projectile electron. That model results in the differential equation (P is the microwave power)

$$f^0(E) = -f(E)\;(E) + f(2E)\;(2E); \; (E) = \frac{n_e V}{P} \sum_{i=0}^{Z-1} n_i \;_i(E); \qquad (1)$$

which can only be solved numerically.

The calculation of X-ray spectra includes both characteristic lines and bremsstrahlung and can include both solid state detectors or crystal diffraction spectrometers. The efficiency of the detection system is taken into consideration.

Diagnostic from shifted Energy Peaks

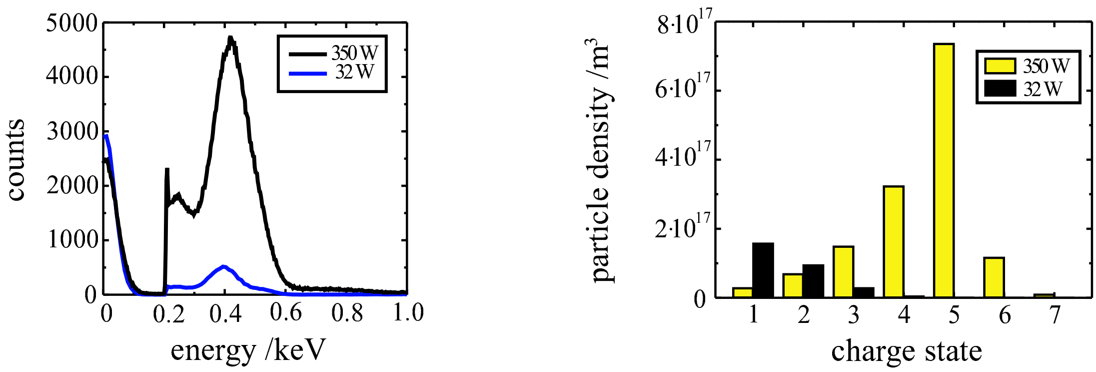

Figure 1: Shifted nitrogen X-ray peak and calculated ion charge state distribution at different microwave powers.

The measured lines are an ensemble of X-ray satellite lines from ions of different charge states averaged over a small plasma cone. The energy shifts of the satellite lines are of such an order of magnitude that the measured integral shifts of superimposed X-rays allows to analyze the ion CSD by following the strategy [14]:

- Spectra of characteristic X-rays from ions inside the plasma are measured (Fig. 1 left).
- The balance equation for the ECR plasma is solved (Fig. 1 right).

- The corresponding X-ray spectrum is approximated with atomic data (transition energies, emission rates).
- The approximation result is then compared with the measured spectra, the simulation parameters are adjusted and this process is continued iteratively while both spectra do not correspondent.

Spectroscopic measurements are done with a LN_2 cooled Si(Li) solid state detector ($\Delta E = 144$ eV at 6 keV) directly mounted to the UHV flange of a collimator channel.

Q/A-Analysis vs. X-Ray Diagnostics

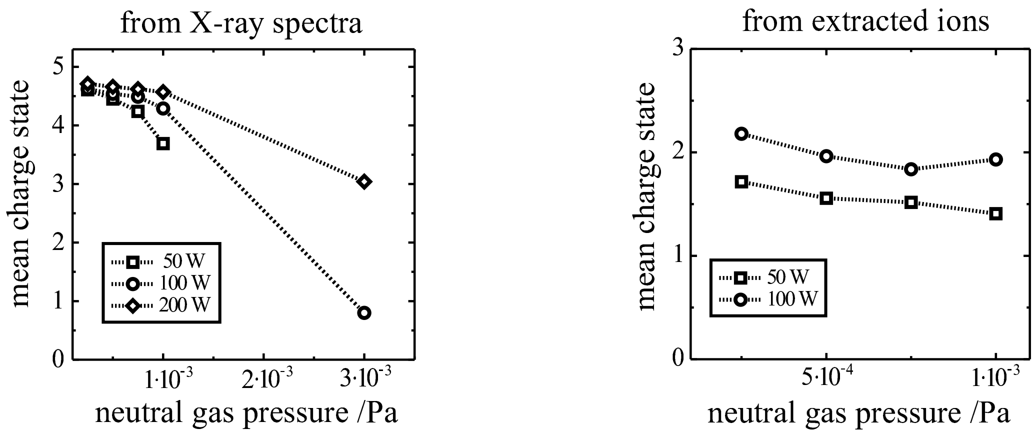

Figure 2: Dependence of the mean ion charge state on the neutral gas pressure.

Information on the ion CSD inside the source are obtained by extracting an ion beam from the plasma and using a magnetic analyzer. That is compared with results of plasma modelling and X-Ray spectroscopy (Fig. 2).

Additional Electron Injection

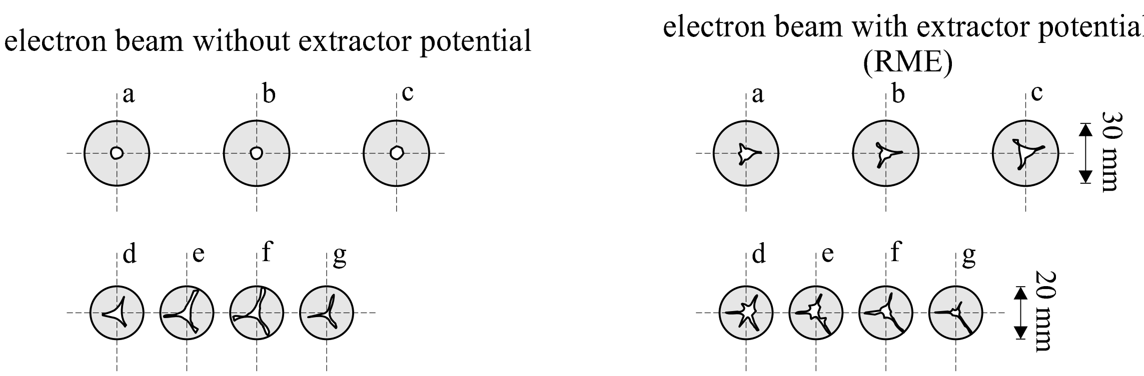

Figure 3: Aluminium foils for determination of the trajectories of the electron beam (a. . . c are located between the gun and the plasma region, d. . . g are located inside the plasma region).

An electron gun is installed in axial direction, so that the electron beam is injected opposite to the extraction aperture. It uses a cathode with a long lifetime and resistiveness providing high emission current densities with electron currents up to 50 mA and acceleration voltages up to 4 kV.

A sequence of aluminium foils is used to investigate the trajectories of the electrons in the magnetic field (Fig. 3) for the case of the extraction potential is switched off (left figure) and switched on (right figure) using the reflecting mode electron beam (RME, [15]). The electrons that travel from the cathode in a strong axial field meet the extractor potential, are reflected and go back to the cathode and so on. The electrons reflect until the anode aperture is fullfilled and they are collected there.

Additionally X-ray pin hole pictures contribute to an understanding of the electron movement (Fig. 4).

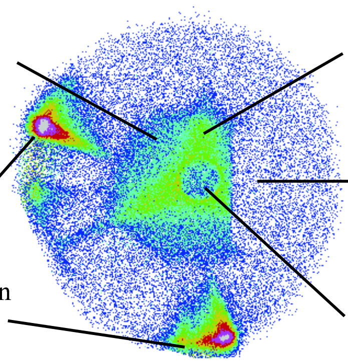

Figure 4: Pinhole picture of emitted X-rays.

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