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HIGH RESOLUTION SPECTROMETER DEVELOPMENT FOR USE IN ECR ION SOURCE*

R. Kronholm†, T. Kalvas, H. Koivisto and O. Tarvainen
University of Jyvaskylä, Jyvaskylä, Finland

Abstract

A high resolution spectrometer setup have been developed for optical emission spectroscopy of ECRIS plasmas. The spectrometer has been used in multiple studies with the JYFL 14 GHz ECRIS yielding new information on the low energy electron population and ion temperatures. This is a overview of the development process and recent studies.

INTRODUCTION

Electron cyclotron resonance ion sources (ECRIS) are under constant development, which motivates understanding the plasma properties. Therefore the ECRIS plasma is continuously studied, theoretically, numerically and experimentally. Experimental studies are usually complicated as the measurement setup easily affects the plasma and skew the results.

Spontaneous de-excitation of electronic states of atoms and molecules, present in Electron Cyclotron Resonance Ion Source (ECRIS) plasmas, enables studying them non-invasively through optical emission spectroscopy (OES). A high resolution spectrometer (10 pm FWHM at 632 nm) with phase-sensitive lock-in data acquisition setup has been developed at JYFL specifically for the diagnostics of weak emission lines characteristic to ECRIS plasmas.

PHYSICS BACKGROUND

In ECRIS plasma heating is based on energy transfer from microwaves to electrons via electron cyclotron resonance. This leads to wide electron energy distribution function, starting from cold electrons with a few eV energies up to hot electrons with energies on the order of 100 keV. Collisions between electrons and ions and neutral atoms results to energy transfer from free electrons to electrons bound to potential of the atomic nucleus. If the bound electron receives enough energy, ions are generated or the charge state of the ions is increased. This reaction is called electron impact ionization. In addition to ionization bound electron can be also excited to higher energy state. This reaction is called electron impact excitation. Excited electronic states can decay via radiative transition from higher energy state to lower energy states by emitting electromagnetic radiation. The wavelength of the emitted photon can be expressed as

$$\lambda = hc/(E_J - E_K), \tag{1}$$

where h is Planck constant, c is speed of light, E_J and E_K are energies of the higher and lower energy states, respectively. The intensity of emission is given by

$$I_\lambda = n_J A_{JK}, \tag{2}$$

where n_J is the electron density in energy state J and A_{JK} is the Einstein coefficient for the JK transition.

The wavelength spectrum of emitted light is a fingerprint of an element and therefore optical emission plasma spectroscopy can be used to identify particle species present in the plasma e.g. the impurity content. As the intensity of the emission depends on the ion density and electron energy distribution, the diagnostic can be used to study cold electron energies and relative ion densities [1]. Optical emission lines never have delta function profile ($\Delta\lambda > 0$). In addition to intensity and wavelength of the emission also the broadening of the emission line gives insight on fundamental plasma physics such as ion temperature, pressure, electric and magnetic fields.

MEASUREMENT SETUP

The optical emission spectroscopy setup has been developed mainly for use with the JYFL 14 GHz ECRIS [2]. Nevertheless, the system can easily be adapted to other ECR ion source. The JYFL 14 GHz ECRIS uses a minimum-B magnetic field configuration generated by two solenoid coils and a sextupole permanent magnet array. This magnetic field configuration and microwave plasma heating enables high charge state ion production. The primary heating frequency of the source is 14.1 GHz. The source allows monitoring optical emission both radially (between the magnetic poles) and axially (through an oven port). More information about the source can be found from Ref. [2].

In the case of heavy ion plasma, the number of emission lines in the visible light range is high, which requires a high resolution monochromator to separate individual radiative transitions. High resolution is also beneficial, if the interest is in emission line broadening. The intensity of the optical transition of interest can be very low and, therefore, a high optical throughput and good high signal-to-noise (SNR) is required. The developed OES setup of three main parts: The optical interface between the ion source and the spectrometer, the spectrometer and the data acquisition and control. The spectroscopy setup is described in Ref. [1] in detail.

CONDUCTED EXPERIMENTS

The development process of the high resolution spectrometer setup has been successful. The spectrometer setup is now free of "infant problems" and can be operated on regular

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† risto.j.kronholm@jyu.fi

basis. The setup has been used for a number of studies. In Ref. [1] the temperature of the cold electron population was studied by measuring multiple emission lines and using the line-ratio method to analyze the cold electron temperature. The cold electron temperature was measured with the extraction voltage off and on under otherwise identical conditions. The temperature was found to change from 20 ± 10 eV to 40 ± 10 eV, respectively. The rate coefficient of neutral to 1+ ionization was found to decrease to 42 % of the original and 1+ to 2+ ionization to 24 % when the 10 kV high voltage was switched off. Furthermore, it was observed that switching the extraction voltage off reduces the emission intensity of Ar^9+ ion by almost two orders of magnitude. This highlights the importance of performing plasma diagnostics studies of ECR ion source with the extraction voltage being applied as only then the results are valid in terms of high charge state production.

In Ref. [3] the optical emission spectroscopy was used to study the intensities of the Ar^9+ and Ar^{13+} optical emission and ion beam current. The relative changes in both the optical emission and the ion beam current were measured in CW and amplitude modulation (AM) operation mode. The results implied that in CW mode the ion currents could be limited by diffusion transport and electrostatic confinement of these high charge state ions rather than beam formation in extraction region and subsequent transport. Recent studies focusing on emission line broadening have revealed that the ion temperatures in ECRIS plasma can be greater than 10 eV i.e. significantly higher than previously thought. These results will be published shortly [4].

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