ION SOURCE RELATED RESEARCH WORK AT JYFL*

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Abstract

In this article the work of the JYFL ion source group will be presented. New bremsstrahlung measurements were carried out in order to compare the results with different electron heating models. Especially attention was paid to study the effect of different heating parameters on the evolution of bremsstrahlung energy. A project to obtain new information about the ion temperatures and their time evolution has been initiated. The study will be performed using spectroscopic techniques measuring the ion temperature from the Doppler broadening of emission lines. The objective is to obtain accurate information about the evolution and the behaviour of highly charged ions in the ECRIS plasma. The work of the JYFL ion source team also includes frequency tuning experiments, beam quality experiments and tests with a so-called collar structure mounted on the plasma electrode. The beneficial effect of collar was first tested and noticed with the ECR ion sources by the KVI ion source group and has been shortly confirmed at JYFL. The JYFL ion source group is also developing a low power electron gun for the needs of spacecraft applications. The results of the development work can possibly be applied also with the ion sources in order to increase the density of cold electrons.

INTRODUCTION

The JYFL ion source group has studied the plasma physics of ECR ion sources. This includes for example the studies of plasma potential and evolution of electron energies via bremsstrahlung diagnostics. The intention is to extend the studies to cover the most of the energy range of the photon emission. In addition to the plasma studies, the ion source group also carries out the active research and development work for developing ion sources and their beams.

EXPERIMENTAL WORK AT JYFL

Electron Heating Limits of JYFL 6.4 GHz ECRIS

The high-energy bremsstrahlung emission generates an extra heat load to the cryostat of superconducting ECR ion sources [1]. An efficient shielding is very difficult to realize because of the limited space inside the ion source. In order to understand the parameters affecting the heating limits the experimental results were compared to the stochastic heating theory presented in ref. [2]. According to the theory the heating limit depends on the gradient of the magnetic field and the amplitude of the electric field E on the electron cyclotron resonance surface. The theory can be expressed as

$$W_s = 0.2\left[m_e L\left(1+\frac{l^2}{L^2}\right)\right]^{1/4} l\omega^{1/2}(eE)^{3/4} \qquad (1)$$

where $\omega = 2\pi f$ (f is the microwave frequency), m_e the mass of the electron, e is the unit charge, L is a parameter, which can be calculated from the axial magnetic field profile ($B = B_{min}(1+z^2/L^2)$), where the resonances are at z = ± l. Here B_{min} is the minimum magnetic field and z the axial distance from this minimum. Adiabatic heating limit is defined to be $W_a = 5W_s$. The objective of the work was to found out if the end point energy of bremsstrahlung follows the behaviour of adiabatic heating limits.

Figure 1 shows the effect of magnetic field gradient on the bremsstrahlung spectrum extracted from the JYFL 6.4 GHz ECRIS. Both the end point energy and the yield of the emission increase. Using the values shown in Figure 1 and Table 1 it can be seen that Eq. (1) fails in predicting the behaviour of high-energy photon emission (compare $W_{end\text{-}point}$ and W_a in Table 1). A possible explanation is that the theory does not take into account the relativistic effect, which tends to move the resonance point towards higher magnetic field values. This is illustrated in Figure 2, which shows that the length l is longer for the relativistic electrons. The maximum length l for the relativistic electrons equals the distance between the B_{min} and extraction aperture and is independent on the magnetic field gradient. Table 1 shows the energy of electron when the resonance takes place at the extraction aperture of the ion source. According to the experiment it is possible that the energy of the electron is limited by the magnetic field configuration (for details see ref. [3]).

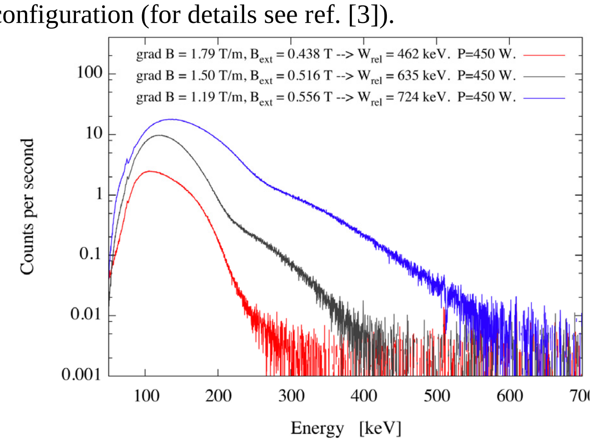

Figure 1: Effect of magnetic field settings on the bremsstrahlung energy and count rate.

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Table 1: Table shows the data corresponding to Figure 1.

$gradB_{res}$ [T/m]	B_{min} [T]	B_{ext} [T]	l [mm]	$W_{end\text{-}point}$ [keV]	W_a [keV]	$W_{rel,max}$ [keV]
1.19	0.199	0.556	52.4	620	322	724
1.50	0.178	0.516	68.9	420	431	635
1.79	0.146	0.438	94.6	310	619	462

The energies $W_{end\text{-}point}$ are estimated from spectra shown in Figure 1, W_a is the adiabatic heating limit and $W_{rel,max}$ is the energy corresponding to resonance at B_{ext}.

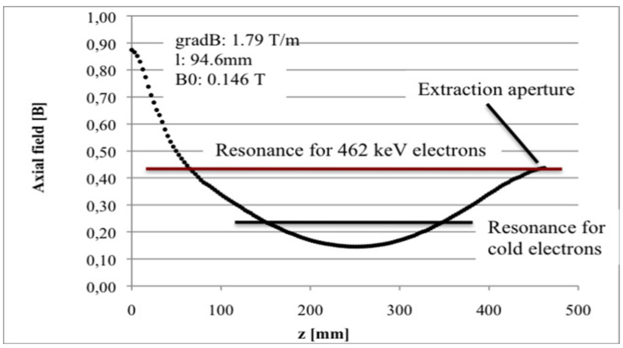

Figure 2: Resonance for cold and 462 keV electrons.

Spectrometer for Ion Source Plasma Diagnostics

A 1000 mm Fastie-Ebert type spectrometer has been built for ion source plasma diagnostic purposes. The spectrometer consists of a spherical mirror, stepper motor controlled 1800 lines/mm grating, interchangeable entrance and exit slits and an ET Enterprises 9406B photomultiplier tube. The device is vacuum compatible and can be used at a wavelength range of 200-600 nm. The control and readout of the spectrometer is computer controlled. The schematic of the monochromator can be seen in figure 3.

The instrument has tested by measuring spectra of He and Hg-Cd discharges. A detailed view of the helium spectrum can be seen in figure 4. The resolution of the device is sufficient for measuring the Doppler broadening of emission lines of light ions with ion temperatures around 1 eV. Other planned applications for the instrument are measurement of time development of ionization in an ECR plasma with different species and study of the effect of gas mixing on ion temperatures.

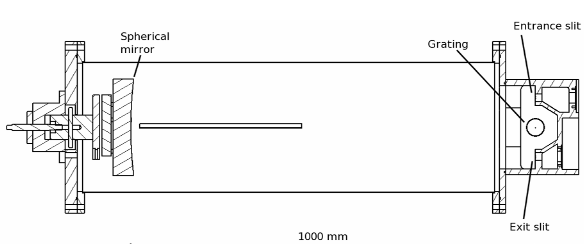

Figure 3. Schematic view of the monochromator.

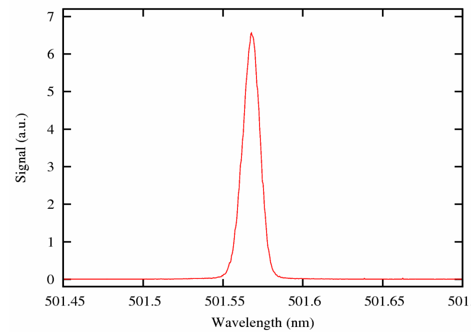

Figure 4. A preliminary helium spectrum of He discharge. The instrumental resolution of monochromator is 17 pm FWHM at 501.57 nm.

Time Evolution of Plasma Potential

ECR ion sources exhibit fast transient peaks of extracted ion beam currents at the leading and trailing edges of the applied microwave pulse [1,2]. The fundamental difference between these transients, called preglow and afterglow, is the charge state distribution (CSD) of extracted ion beams - low charge ions exhibit preglow while the afterglow boosts the beam currents of highly charged ions. Studies of the preglow are driven by the aim of creating a short-pulsed multi-charged ion source with high ionization efficiency. The afterglow mode is utilized e.g. for injection into circular accelerators as it offers intensive beams of highly charged ions. In order to gain understanding on the plasma processes associated with these transients the time evolution of plasma potential during the microwave pulse was measured with the JYFL 6.4 and 14 GHz ECR ion sources. The plasma potential was observed to increase 10-50 % during the preglow and 10-30 % during the afterglow compared to steady state. For detailed description of the experiment see reference 3. Plasma potential peaking during the preglow and afterglow implies that any application, relying on running an ECRIS in pulsed mode and utilizing either one of these transients, must take into account the increased energy spread of the ion beam causing the bending and focusing properties of the ion beam differ from those of a cw beam.

Table 1: Table shows the relative change of plasma potential in preglow and afterglow peaks.

Ion Source	Preglow/ cw plasma potential	Afterglow/ cw plasma potential
JYFL 6.4 GHz	1.06 – 1.12	1.09 – 1.14
JYFL 14 GHz	1.13 – 1.47	1.17 – 1.28

Frequency Tuning at JYFL 14 GHz ECRIS

Microwave frequency fine- tuning [7] of ECR ion sources has successfully been studied and developed by the INFN-LNS ion source group in Catania. This method, where the microwave frequency fed into the plasma chamber is varied in a narrow frequency range around the normal operation point to achieved improved source performance, has been tested also at JYFL in collaboration with the LNS ion source group [8]. The latest results of the work have been presented in ref. [9] and in this proceeding [10]. Some frequency tuning experiments have been performed also in collaboration with the LBNL ion source group (please see. Ref. [12]).

Collar Experiments at JYFL 14 GHz ECRIS

The first very promising collar experiments with the JYFL 14 GHz ECRIS have been carried out. The collar structure developed and tested [11] by the KVI ion source group and shown in Figure 5 was used. In the preliminary tests the improvement of several tens of per cent was seen in the beam currents of high charge states of oxygen. At the same time the intensity of low charge states decreased. Further studies will be performed to optimize the collar geometry and to get more information about the physics related to its positive effect.

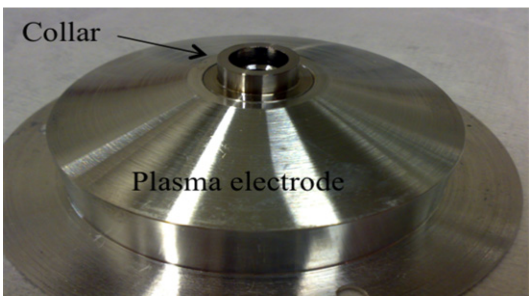

Figure 5: The collar structure used in the experiments at JYFL.

Low Power Electron Gun

The JYFL ion source group is participating in an E-sail project [12], which relates to a propellantless space travelling method using the momentum of solar wind flux. In the method so-called tethers (thin wires, some tens of µm in thickness, length several km) are biased to positive voltage in order to use the momentum of positive charges of solar wind to produce spacecraft propulsion. The positive charge of the tethers is maintained by an on-board electron gun.

The JYFL ion source group will test the durability of the tethers by bombarding them by electrons and ions. The group is also developing a low power electron gun for the test mission which main purpose is to observe and measure the E-sail effect in the ionosphere for the first time. The maximum power available during the test mission is about 1.5 W. The beam intensity of 2 mA is required at the electron energy of 500 eV. The power level available is not sufficient to use a thermionic cathode due to the high radiation losses. Consequently, a cold cathode electron gun is being developed at JYFL. This approach is based on electron field emission from a nanographite or a nanocellulose coated cathode. The gap between the cathode and anode has to be about 100 µm in order to make the field emission at the voltage of 500 V possible. The short gap between the electrodes sets very high requirements also for the anode structure. According to the tests the most viable configuration includes a silicon nitride anode with the mesh size of about 100 µm. The size of the cathode and anode is about 14 mm x 9 mm being capable of producing current of about 0.7 mA through the anode. This requires the emitted current of about 1.2 mA. Consequently three modules are needed to meet the current requirement of 2 mA, which at the moment slightly exceeds the power limit set by the mission.

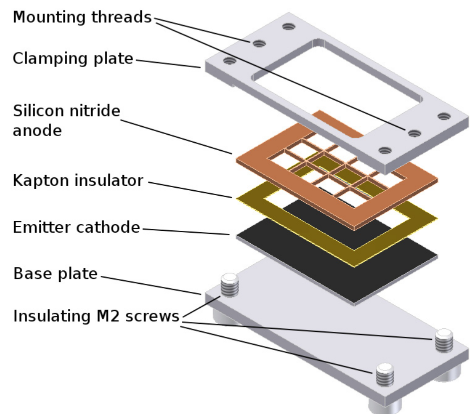

Figure 6: The drawing of the low power (1.5 W) field emitter electron gun developed at JYFL.

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