27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 1689 -1692*

EXPERIMENTAL STUDIES OF ELECTRON CYCLOTRON RESONANCE PRODUCTION IN A MULTI MAGNETIC MIRROR MACHINE

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1. INTRODUCTION-Magnetic confinement with mirror type fields have been used to investigate basic fusion and space plasma phenomena for several years [1,2]. Plasma heating with electron cyclotron resonance is today a successful method used in most of the controlled thermonuclear fusion experiments [3]. Basic plasma theoretical and experimental developments were also made in order to clear some basic plasma processes aspects such as the kinetic instabilities generated by the mirror loss cone distribution function. Electron and ion diffusion to the mirror cusps fields are strongly dependent on kinetic and collision processes. One of the main process is connected with the electron cyclotron plasma waves trapped in the mirror throats during the resonant electron heating. In this work an experimental evidence is found showing that electron cyclotron waves are responsible for particle acceleration due to momentum and energy transfer from waves to particles [4].

Recently numerous materials surface treatments with improvements on the methods of film deposition, ion implantation and plasma etching were made by using different types of electron cyclotron resonance in plasmas [5]. Semiconductor components development by using ion sputtering and etching have grown up extensively in the past twenty years. Plasma materials processing require large volume, low ion temperature, high density and uniform plasma in order to keep the ion flux to the substrate constant [4]. Lifetime limitations on the operation of ion sources based on electron emission by thermionic effect is also a reason to use plasma production with electron cyclotron resonance sources. This is specially relevant for several schemes of electrostatic propulsion based on ECR plasma sources [6].

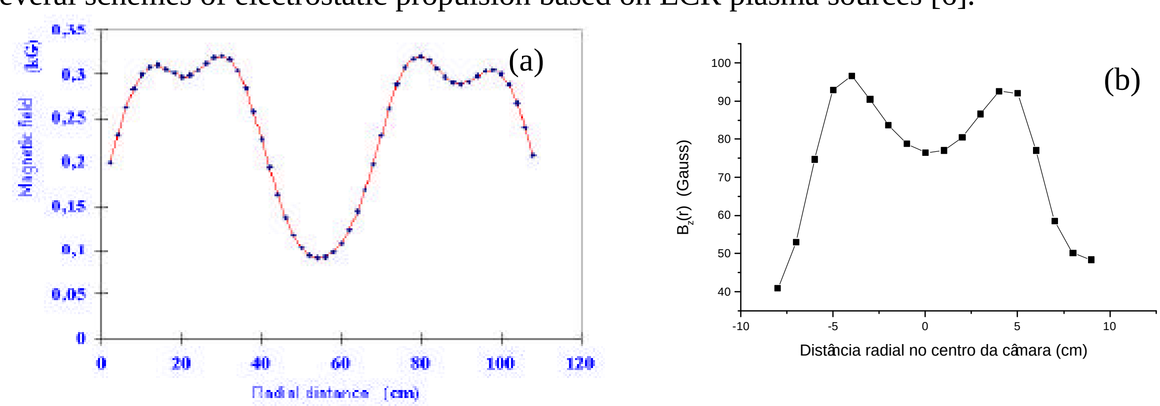

Fig. 01 (a) *Axial space profile of the magnetic field* (b) *Radial space profile of the magnetic field. (Measured by Hall probes)*

This work will describe a mirror machine designed to generate plasmas using thermionic discharge, in the pre-ionization phase, and a radio frequency plasma source in the UHF range. Electron heating, density increase and wave particle processes are studied in the

ECR frequency . Special attention will be given for the electron density and temperature diagnostics with Langmuir probes and the magnetic field space profiles made with magnetic Hall probes. Ion and electron flow to the cusps fields are also measured with an end mirror particle collector.

2. DESCRIPTION OF THE MACHINE AND ITS DIAGNOSTICS- The vacuum system contains two cylindrical Pyrex (Diam. = 0.15 m, Length = 1.2 m) glass tube connected by a stainless steel flanged tube, which also allow the system connection with an Edwards vacuum cryogenic system (CR130). The machine centered metal chamber is assembled with three radial access windows which provides vacuum measurements, gas injection and filament electrical supply . The Argon gas flux into the mirror machine can be varied by a leaking needle valve allowing a precise pressure. The plasma is produced by thermionic discharge with hot tungsten wire cathode with barium oxide layer. The loop 7.0 cm filament is positioned in the center of the chamber to produce an symmetric uniform plasma. Two end metal flanges are equipped with vaccum feedthrew to allow metal shafts positioning inside the mirror machine. Langmuir probes, electrostatic energy analysers and single particle collectors are assembled on them.

The mirror machine used in this experiment has a new scheme as shown in fig1.The main magnetic field, with controllable mirror ratio is produced by four magnetic coils symmetrically located around the metal chamber. Fig. 2a shows the axial space profile of the main magnetic field. Produced by two end coils (912 turns of 3.5 mm diameter cupper wire) and two center 730 turns coils with 24 cm averaged radius. Inside the central metal chamber there is a multidipole magnetic field made by permanent ceramic magnets to produce surface plasma confinement. The averaged surface 100 Gauss field (fig. 2b) act on the plasma boundary and it is responsible for a significant improvement of the total particle confinement. It decreases the plasma losses due to particle diffusion perpendicular to the axial magnetic mirror field in the central part of the chamber

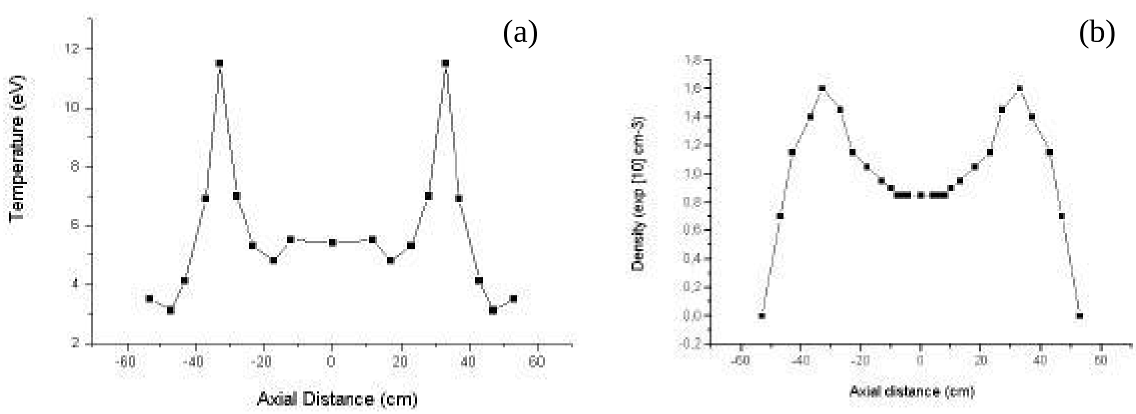

Fig 02 Axial electron plasma temperature(a) *and density* (b) *space profile.*

3. EXPERIMENTAL RESULTS-The electron cyclotron plasma production and heating data were taken within 10 -4 torr of argon pressure, magnetic field from 120 to 200 Gauss with coil current from 20 to 35 Amps. A DC thermionic discharge produce preionization with typical plasma parameters of electron temperature and density given by Te=2.0eV and Ne=1x 10^9 part./cm . Maximum density and temperature (T_e=3.0 eV, N_e=3 x 10^9 part/cm^3) are found on the mirror cusps as expected for a magnetically confined quiescent plasma.

When Radio frequency is injected on the plasma density and temperature parameters are improved, plasma density and temperature space profiles(Fig. 2) now have are higher values (ne = 10 cm Te = 12 eV) for the electron cyclotron resonance frequency (345 Mhz). The electron saturation current as function of the injected frequency is shown on fig. 3a. To achieve these conditions a wave generator HP 8648A (100 kHz to 1 GHz) connected with an RF amplifier model 1000M7 AR (40 db) with maximum output power of 50 W will be used to excite the lower ECR frequencies in a system of two loop antennas located at the magnetic mirror cusps around the cylindrical glass tube vessels. A model for the mode coupling mechanism of RF waves to the plasma using N type loop antennas [7] were also on development. The higher RF frequencies will resonate with the electrons of the main mirror field in the end cusps of the machine, and the lower frequencies with the electrons in the multidipole magnetic fields of the central metal chamber.

The effect of electron cyclotron waves on electron diffusion was measured with a particle collector made by a single positively polarized electrode positioned near by the mirror cusp fields. A maximum of electron loss cone flown at the 345 Mhz resonance frequency is also shown on fig. 3b indicating a strong effect of anomalous electron diffusion due to turbulent wave particle interaction processes. (D_B = 7,2 m^2/s D_{exp} = 13,6 m^2/s). Based on experimental results within similar conditions (8), electron cyclotron waves must be playing an important role on the electron acceleration to the mirror throats.

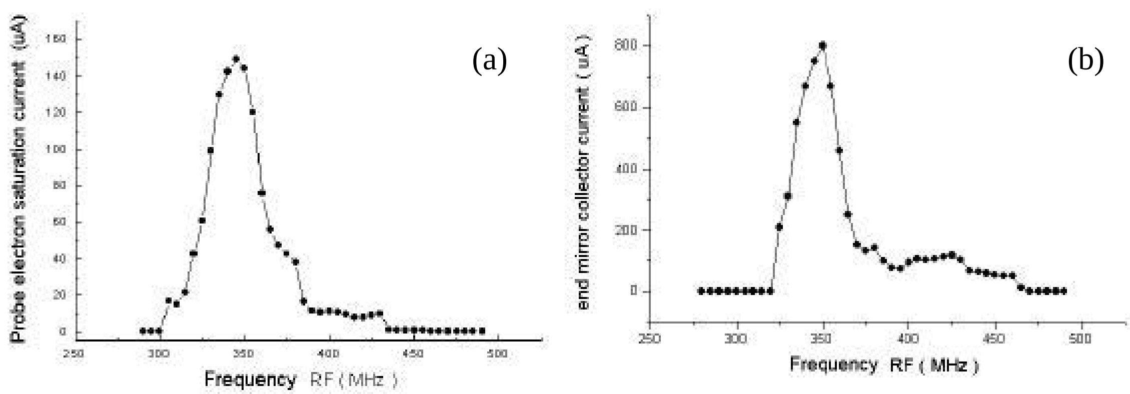

Fig. 03. (a) *Electron saturation current versus RF frequency detected by aLangmuir probe.*
(b) *Electron axial flow collected by a disk positively bias probe versus RF frequency.*

3. CONCLUSION-A magnetic mirror machine was constructed at the plasma laboratory of UnB. Magnetic field measurements are in good agreement with the designed characteristics of the magnetic coils. Density and temperature measurements in the pre-ionization phase with Langmuir probe in the thermionic discharge are also in the expected range for a quiescent low density and cold plasma. A significant increase of electron density and temperature were measured during RF injection in the electron cyclotron resonance frequencies. The wide range of magnetic field variations on the machine are responsible for the observed broad resonance peak . A strong localized ECR plasma heating process in the end cusps is responsible for the observed particle anomalous transport. Additional plasma diagnostics using RF probes, spectrum analysers and spectroscopic techniques are planned to be made in the near future to measured localized kinetic instabilities caused by non linear electron cyclotron waves.

4. ACKNOWLEDGMENTS-The authors are grateful for financial support from Fundação de Apoio a Pesquisa FAP- DF , CNPq and CAPES.

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