Plasma diagnostic with plasma probes and a Retarding Field Analyzer on ECR plasma sources, excited with 433 MHz

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Motivation

• ECR Plasma- and ion beam sources are developed since more than 40 years developed.
• Mostly they are used to generate multi charged ions for ion beams at ion beam accelerators, ion implanters and other beamline applications.

• The basic plasma effect enabling high ionization degree at very low pressures is the **E**lectron **C**yclotron **R**esonance **(ECR)** excitation at a plasma with a magnetic field B and an excitation frequency f (equ. (1).

$$B = \frac{2*\pi*f*me}{e} \qquad (1)$$

• Typical ECR plasmas use 2.45 GHz with 87 mT magnetic field strength, and generate the magnetic field by electromagnets (Helmholtz coils) at plasma chamber diameters smaller than 100 mm (or 5 MHz with 177 mT) to produce multi charged ions.

• To generate only single charged ions, but at larger plasma dimensions, a lower excitation frequency like 866 MHz (30 mT) or 433 MHz (15 mT) is a successful way, because therefore the magnetic field can be generated by systems of permanent magnets.

• Moreover today solid state plasma generators for this frequencies become available as a byproduct of telecommunication or industrial food heating.

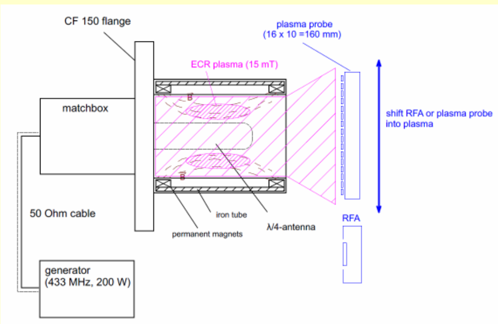
• This work presents a ECR plasma source with 150 mm diameter, excited at 433 MHz with a λ/4 – antenna.

• The plasma at the output of the plasma source is analyzed by 16 plasma probes or a Retarding Field Analyzer (PlasmaMon from Jenion [1]).

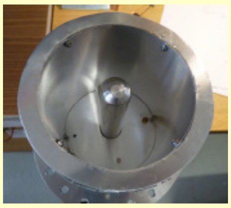
150 mm ECR plasma source

• The ECR plasma source was mounted on a CF 150 flange with a simple match box direct mounted at atmospheric side of the flange.
• An UHF-generator (433 MHz, 200W) was connected via a 50 Ohm cable.
• A coaxial λ/4 – antenna surrounded by a isolator of quartz glass excites the plasma.
• Two rings of permanent magnets, mounted on an iron tube, generate the magnetic field like shown at the principle figure below.

• Nitrogen was introduced into the plasma,
• The plasma ignites already at very low UHF-power (>= 10W).
• Lowest operation pressure was 10^{-4}mbar, at pressure higher than $5x10^{-3}$mbar the ECR effect distinguishes and a simple UHF-plasma was generated.



Principle of the ECR plasma source together with plasma analysis

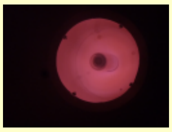


150 mm diameter ECR Plasma source

RFA at ECR Plasma

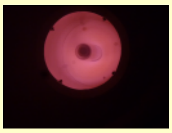
• Like shown at the figure above the permanent magnet system generates a non uniform field inside the ECR plasma source.
• There are regions with higher magnetic field near the magnets and regions with lower magnetic field outside the source, the region with 15 mT for Electron Cyclotron Resonance should be near the antenna.
• The photos below demonstrate the different plasma excitation at the ECR zone and at the surrounding regions in dependence from UHF-power and pressure for nitrogen.

25W

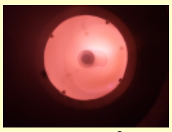


50W

2x10⁻⁴mbar

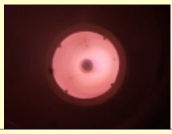


10⁻³mbar

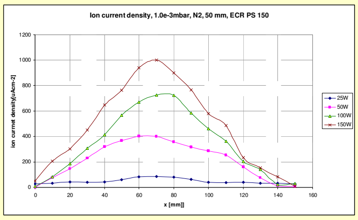


5x10⁻³mbar

150W



Plasma Analysis of nitrogen plasma

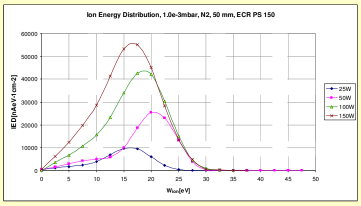


Ion current density profiles in dependence on power

Ion current density profile:
• The ion current saturation density was measured at a probe voltage of -25 V at 50 mm distance from the ECR source.

• The profiles show a near gaussian profile with maximum at the center of the source.

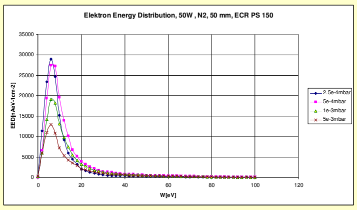
• The ion current density is between 0.1 and 0.5 $mAcm^{-2}$.



Ion Energy Distribution in dependence on power

Ion energy distribution:
• The ion energy distribution was measured at 50 mm distance from the ECR source at the center of the source with a Retarding Field Analyzer.

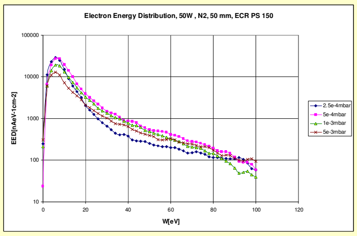
• A mean ion energy between 15 and 20 eV was measured.



Electron Energy Distribution in dependence on pressure

Electron energy distribution:
• The electron energy distribution was measured at 50 mm distance from the ECR source at the center of the source with a Retarding Field Analyzer.

• A mean electron energy in the range of 5 to 10 eV was measured.



Electron Energy Distribution in dependence on pressure on logarithmic scale

• If the Electron Energy distribution is plotted on logarithmic scale, the wide electron energy range up to more than 100 eV can be shown.

Summary

Technique of ECR plasma sources @433 MHz:
• Typical arrangement of magnetic field from permanent magnets around a λ/4 antenna,
• solid state generator for 433 MHz/200W,
• matchbox direct mounted on flange of the source.
• Operated with nitrogen at $1x10^{-4}$mbar up to $5x10^{-3}$mbar for ECR mode and from $5x10^{-3}$mbar up to 0.1 mbar in "UHF – plasma mode"

Analysis of ECR Plasma:
• A "PlasmaMon" from Jenion was used to characterize the ECR plasma.
• Results for a 150 mm ECR source operated at 50 W, 50 mm after the output are:
  • ion current density: 0.5 $mAcm^{-2}$,
  • mean ion energy: 15-20 eV,
  • mean electron energy: 3 – 5 eV (with an electron energy distribution up to over 100 eV).
• It could be shown, that ECR plasma sources excited with 433 MHz do generate plasma for broad ion- or plasma beams at a wide pressure and power range.

Conclusions

• **U**ltra **H**igh **F**requency (**UHF**) ECR Plasma sources could become an interesting alternative to other existing broad beam plasma- and ion sources.

• The therefore usable frequencies are 433 MHz (70 cm) and 866 MHz (35 cm), where no waveguide technique must be used for UHF power transmission.

• Compared to microwave ECR plasma sources @ 2.45 GHz they have some advantages enabling broad sources up to 400 mm diameter.

• Future applications of UHF ECR plasma- and ion sources could be:
  • broad ECR plasma sources operating at the 10^{-4} mbar pressure range,
  • broad ECR ion beam sources,
  • compact neutralizer for broad beam ion sources.

[1] PlasmaMon see: www.jenion.de

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