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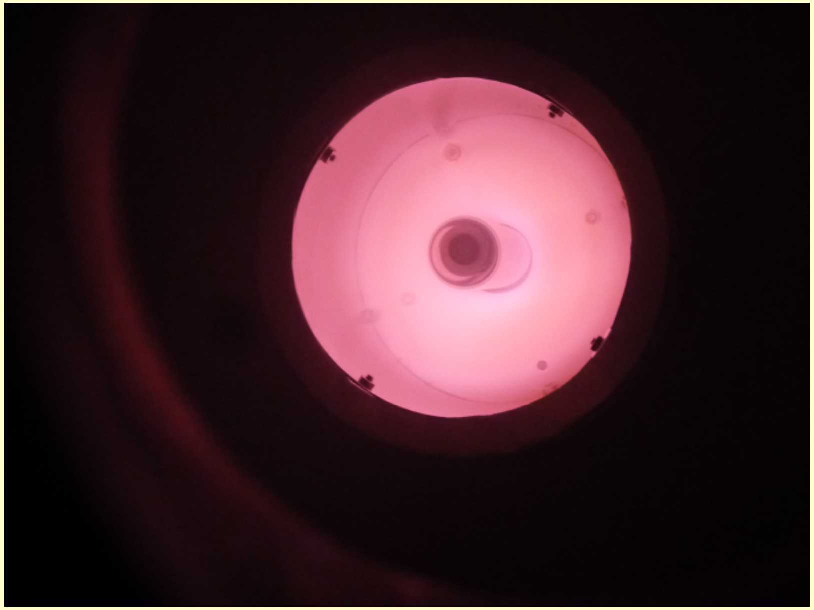
JENION

UHF-ECR-Plasmas, excited with 433 MHz, for Plasma- and Broad Ion Beam Sources



Content:

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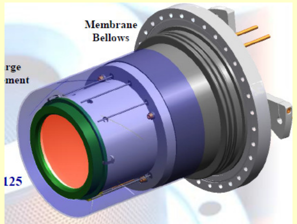
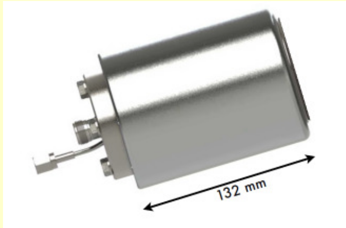
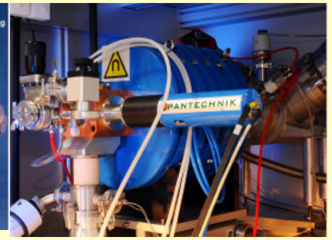
1. ECR ion sources for mono charged and multi charged ions
2. ECR Plasma sources – frequency and magnetic field
3. UHF- Plasma sources (principle, plasma generators, magnetic fields, pulsing)
4. Some results for ECR plasma- and ECR ion sources analyzed with plasma probes
5. Current situation at 433 MHz plasma sources
6. Summary

ECR Ion sources – from mono charged to multi charged ions

Overview of some commercial ECR ion sources







company	IOT Leipzig	Pantechnik	Pantechnik	Pantechnik
frequency	**2.45 GHz**	**2.45 GHz**	**10 GHz**	**14.5 GHz**
power	< 1 kW	30 W	< 200 W	< 600W
weight	Approx. 20 kg	4 kg	11 kg	220 kg
Ion beam	Up to 500 mA, 0.1 to 1 keV	1 mA, 30 keV	Some mA, up to 30 keV	< 200 uA, up to 30 keV
Multi charged ions	no	no	Up to Ar^{4+}	Up to Ar^{8+}

ECR Plasma sources – frequency and magnetic field

Magnetic field for Electron Cyclotron Resonance:

$$B = \frac{2 * \pi * f * me}{e}$$

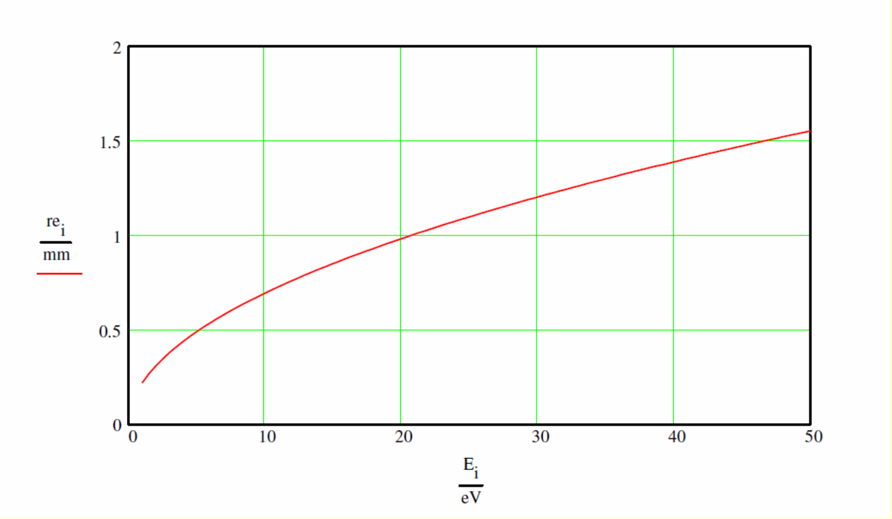
frequency [MHz]	B[mT]
144	5
433	15
915	31
2450	87
5000	170

UHF

Typical magnetic fields for ECR condition

Electron radius at ECR condition depends on electron energy:

$$re = me * \sqrt{\frac{2 * E}{me}} * \frac{1}{e * B}$$



Typical electron radius for ECR conditions at 433 MHz

Conclusion for 433 MHz:
- Only 15 mT magnetic field necessary (enables large fields with permanent magnets),
- electron radius is some millimeters (small against source dimensions)

ECR Plasma sources with Ultra High Frequencies (UHF)

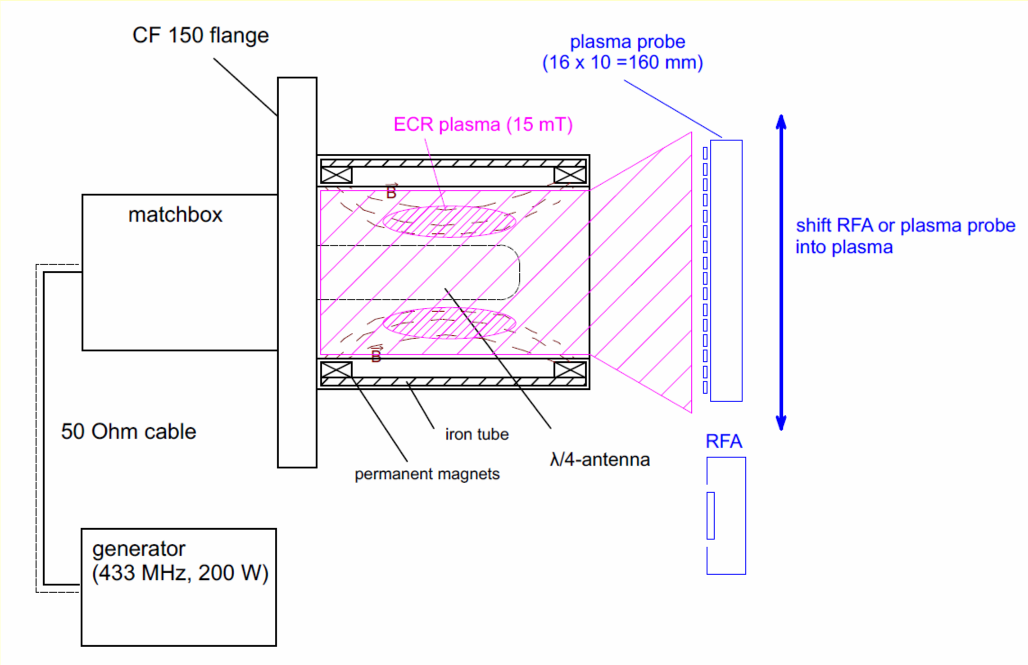
Some more advantages (compared to 2.45 GHz sources):

- lower dielectric losses at isolators, → more materials usable for construction,
- Larger zones with ECR condition constructible with permanent magnets, → larger broad sources,
- For UHF-powers smaller 2 kW no waveguide technique necessary (coaxial cables plus cavity resonators or strip line resonators possible),

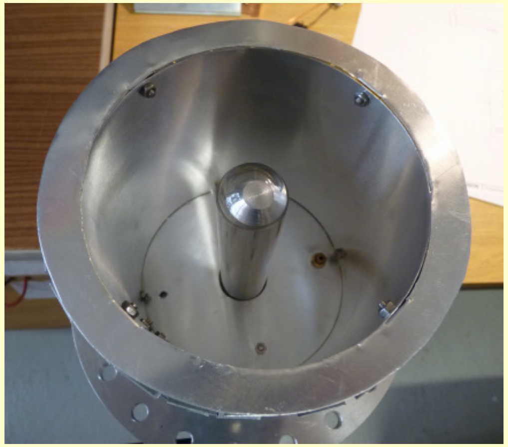
UHF-plasma generator situation:

- Solid state generators are now better and better available because:
  - Driven by telecommunication market (typical OEM module 200 W),
  - Driven by industrial food heating (915 MHz, 200 to 1000 W),
- 433 MHz only small ISM band (with some restrictions),
- 915 MHz broad ISM band,

Principle of UHF- ECR Plasma sources



Principle of the 433 MHz ECR plasma source together with plasma analysis

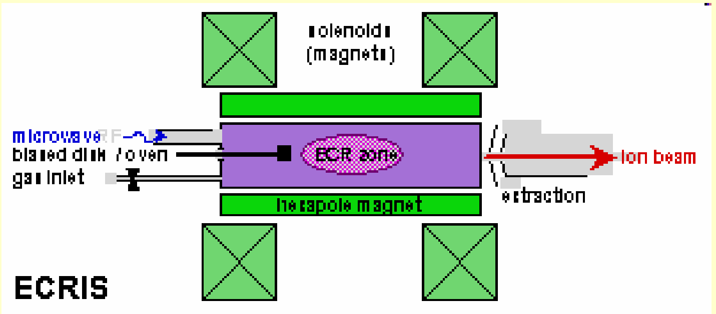


150 mm diameter ECR Plasma source

Components:
- solid state generator, 433 MHz, 200 W with circulator,
- coaxial cable 50 Ohm, N-connector,
- Matchbox (pi-filter or L-type matchbox, cavity resonance box with two capacitors (manual or step motor controlled),
- flange mounted source (CF 150),
- permanent magnet system (CoSm magnets, iron joke as tube),
- for ion source two grid extraction grid (40 mm diameter, graphite)

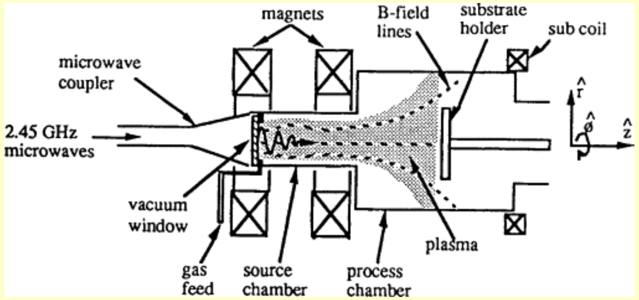
Different magnetic fields for UHF- ECR Plasma sources

Classic ECR source for near axis ion beams



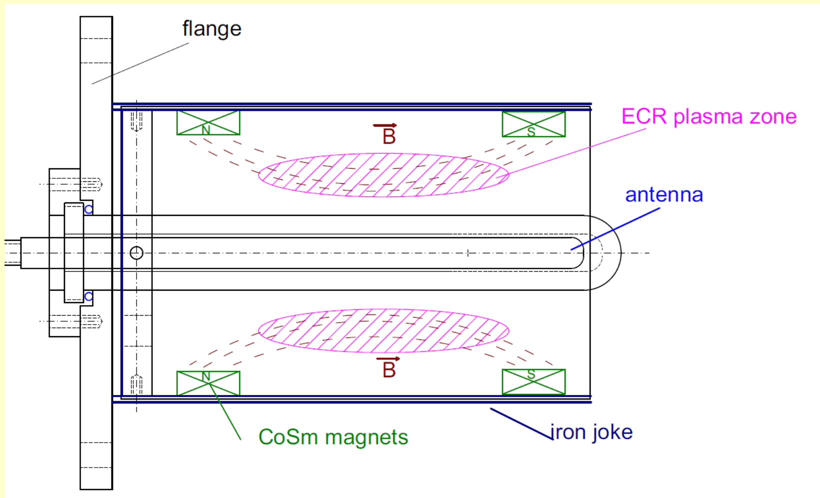
M.M.Abdelrahman, Science and Technology 2012, 2(4): 98-108

Classic ECR plasma source

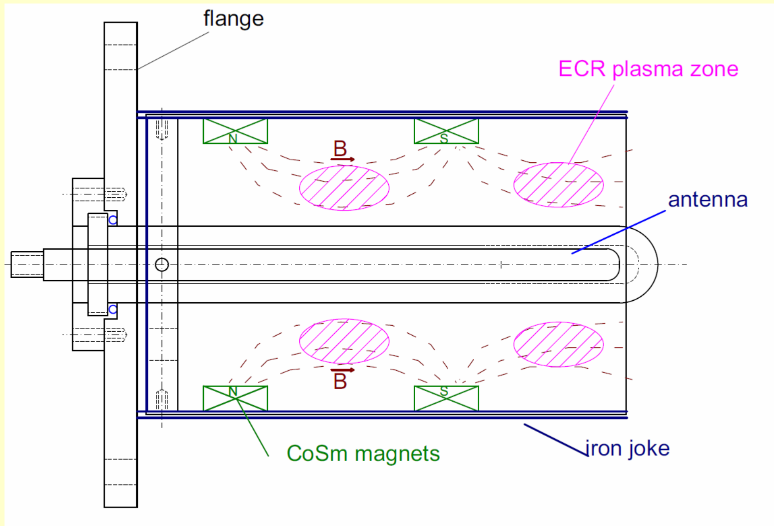


James E. Stevens, **in "High Density Plasma Sources Design, Physics and Performance" Book • 1996**

"convergent" ECR plasma source 433 MHz



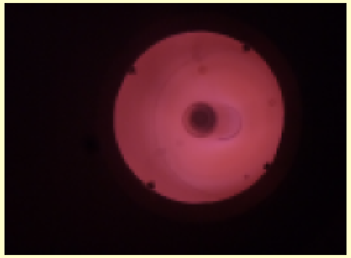
"divergent" ECR plasma source 433 MHz



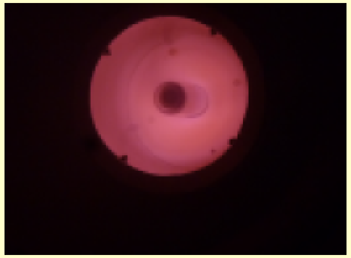
Some results for convergent ECR source

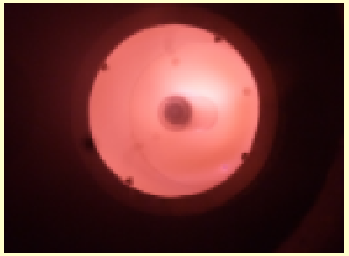
Operating range (pressure, power) and ECR zones demonstrated with nitrogen plasma

25W



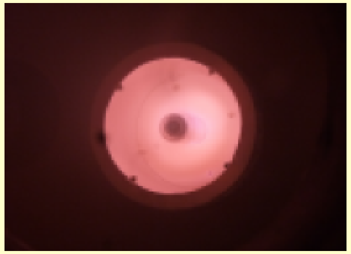
50W





$2x10^{-4}$mbar *10^{-3}mbar* *$5x10^{-3}$mbar*

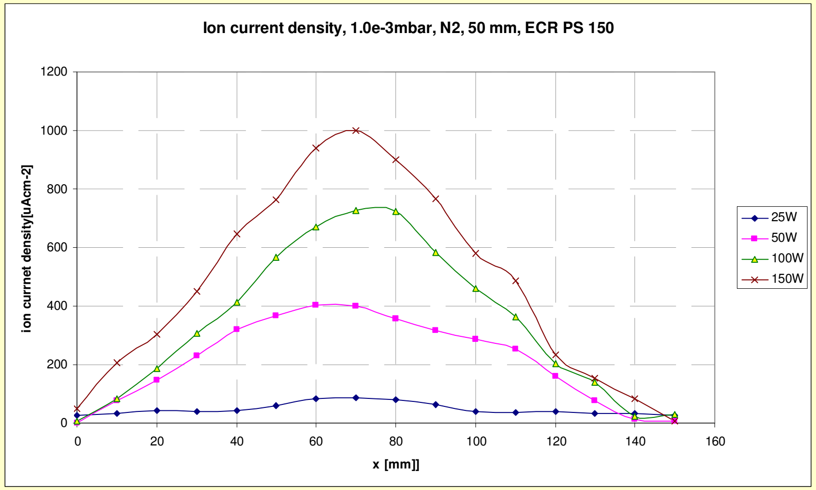
150W



Remarks:
- wide working pressure range from 10^{-4} mbar to 10^{-2} mbar,
- plasma power density is still low (< 100 mW cm^{-2})

Some results for convergent ECR source

Ion currents and ion energy analysis with Plasma probes and Retarding Field Analyzer (PlasmaMon)



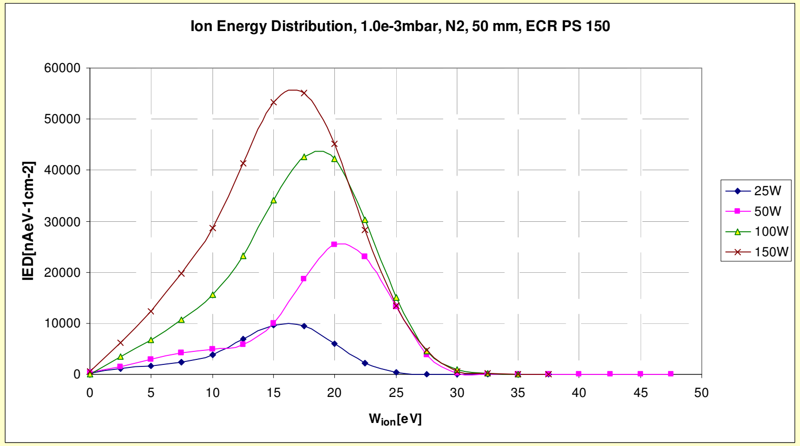
Ion saturation current density profile at 50 mm distance

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 at 50 mm distance

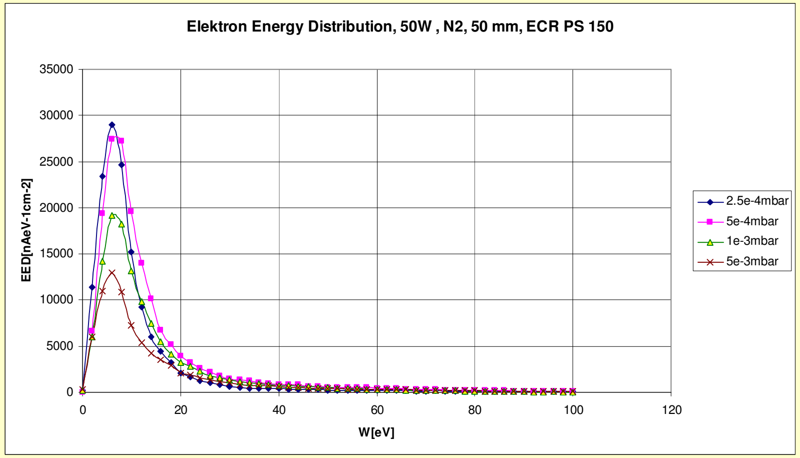
Ion energy distribution:

• 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.

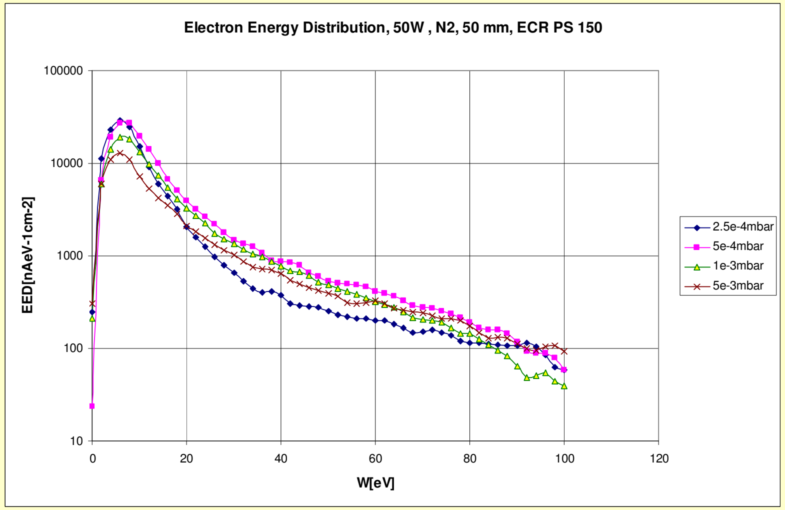
• A mean ion energy between 15 and 20 eV was measured.

Some results for convergent ECR source

Electron Energy analysis with Retarding Field Analyzer (PlasmaMon)



Electron energy distribution at 50 mm distance



Electron energy distribution at 50 mm distance (logarithmic scale)

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.

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

Some results for divergent ECR source

Plasma probe analysis at the vacuum chamber wall (400 mm diameter)

Divergent ECR source 2.5e-3mbar, 100W

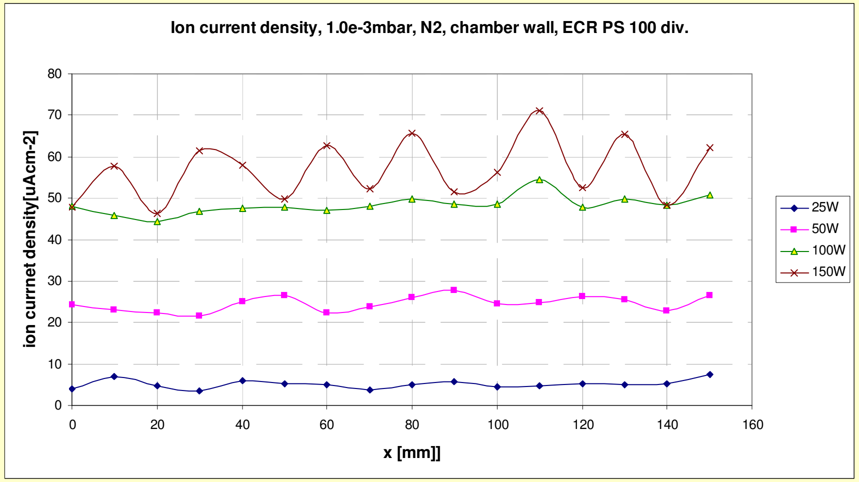
16 Plasma probes over 160 mm

2.5e-3mbar N2, 150 W

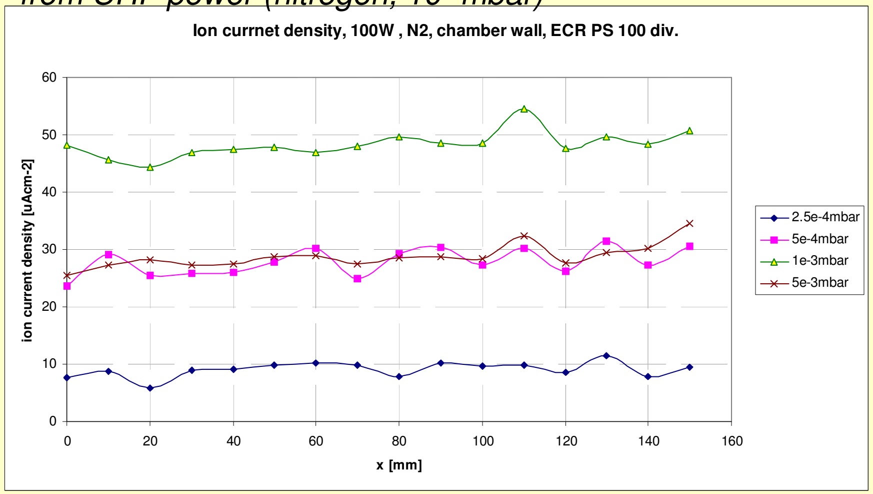
Divergent ECR source:
- only 100 mm diameter,
- good magnetic extraction for electrons,
- delivers the electrons, ionizing the gas at the full vacuum chamber in a second step,

Vacuum chamber plasma:
- Fulfills the complete vacuum chamber with nearly the same plasma density,
- 16 plasma probes over a distance of 160 mm show a nearly constant plasma density,

Some results for divergent ECR source



Ion current density at the chamber wall in dependence from UHF power (nitrogen, 10^{-3}mbar)



Ion current density at the chamber wall in dependence from the pressure (nitrogen, 100 W)

Ion current density at the chamber wall:

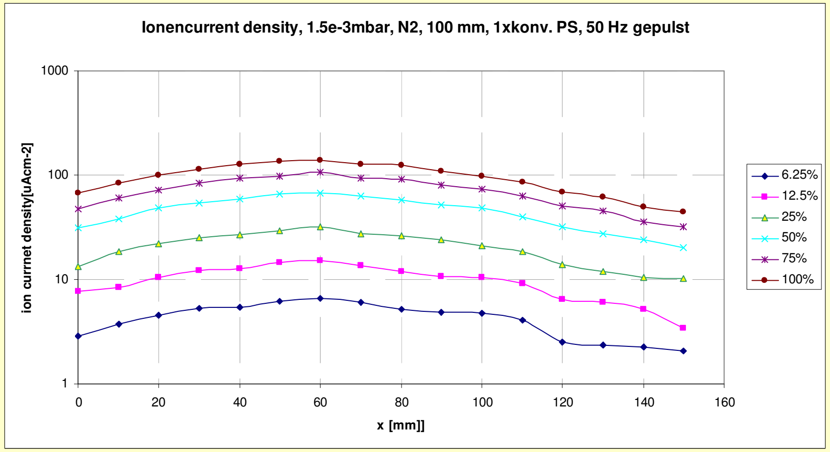
- increases with UHF power,
- maximum at $5x10^{-3}$ mbar,

Estimation of total wall ion current (100W 5x10-3mbar):

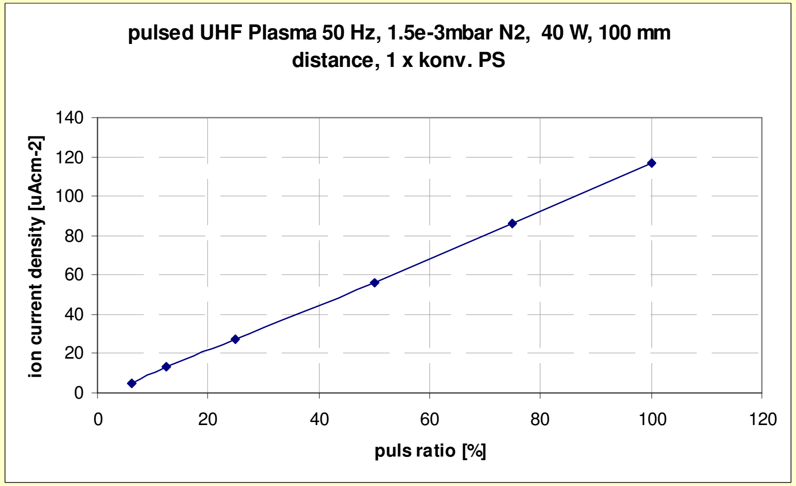
- Chamber dimensions: 400 mm diameter, 600 mm height,
- → chamber wall area approx. 1 m^2,
- ion cuurent density 25 – 50 $uAcm^{-2}$,

- → total wall ion current 250 – 500 mA (@ 100W UHF power)

Pulsed UHF ECR-plasmas



Ion current density profile (at logarithmic scale) 50 mm from the ECR plasma source, (1.5x10-3mbar nitrogen, 40W)



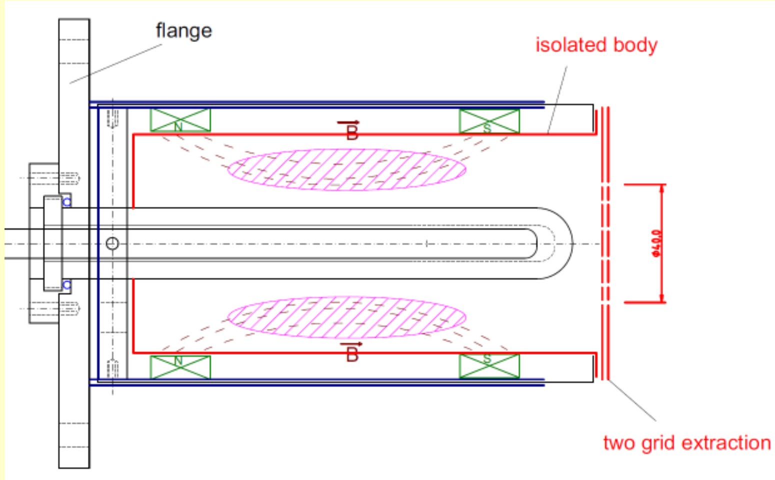
Maximum ion current density at 50 mm from the ECR plasma source, (1.5x10-3mbar nitrogen, 40W)

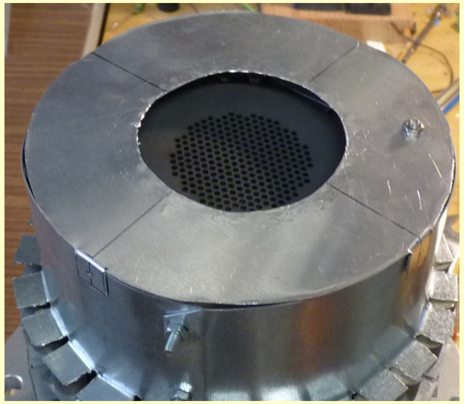
Pulsed UHF plasma:
- pulsing so that plasma is off at duty cycle,
- → low pulse frequency: 50 Hz,
- on time from 5% to 100% precise regulated,
- plasma ignites precise (1.5x10^{-3} mbar nitrogen),

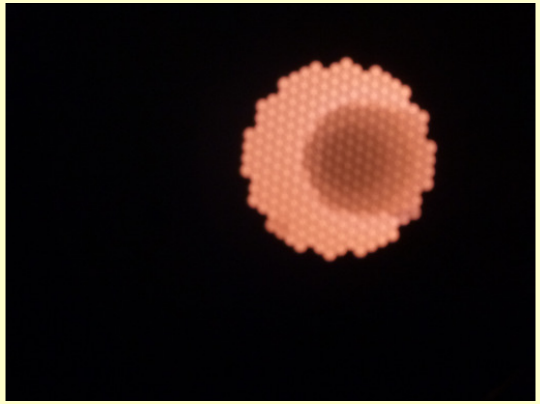
Ion current density profile at 50 mm distance from the source:
- convergent plasma source with 100 mm diameter,
- plasma probes measure the mean value of pulsed ion currents by integration over time,
- the shape of the profile (week gaussian profile) is independent from the pulse ratio,

Linearity:
- precise control of the mean ion current density by the pulse ratio

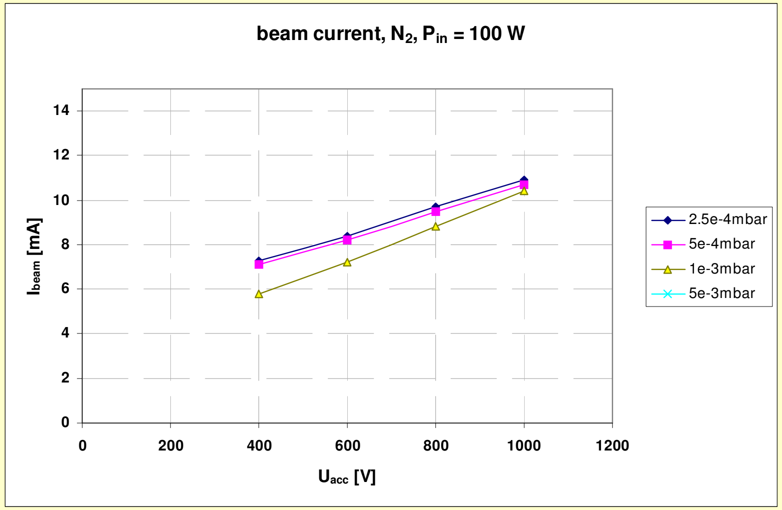
First test UHF ECR ion source







Principle of the test arrangement for ion source operation



Beam current in dependence from the extraction voltage

150 mm ECR plasma source (convergent magnetic field) was used as test arrangement with:

• inner plasma housing (body) made from stainless steel (0.5 mm thick, isolated from ground by ceramics),

• a two grid extraction system (graphite grids with 40 mm diameter beam extraction) had been adapted on front,

First results:

• ECR plasma ignites well (magnetic cponfinement is a little bit reduced by the body),

• ECR plasma works independent from beam voltage up to 1200 V,

• working pressure range is good (constant ion beam between 2x10-4 mbar and 5x10^{-3}mbar),

• ion beam current is considerable poor (max. 15 mA@1500 V extraction voltage),

Current situation for 433 MHz ECR plasma sources

a) 433 MHz UHF generator situation (solid state generators):

- only small ISM frequency range (future ?),
- no synergy with industrial food heating market (food heating at 915 MHz),
- Coaxial cables, matching networks good usable,
- Low dielectric losses at isolators at 433 MHz,

b) UHF coupling by antennas:

- lambda/4 = 17,5 cm is considerable long for smaller plasma sources (100 to 200 mm diameter) good for > 300 mm diameter,

c) ECR plasma generation:

- Because of the long wavelength (70 cm) deep operating pressures < 10^{-4} mbar can be achieved at large sources,
- also larger ECR plasma sources can be made with permanent magnet systems (up to 500 mm diameter),
- It seems so that the “skin depth” of 433 MHz plasma is approx. 75 to 100 mm (at an electron density of 10^{10} to 10^{11} cm^{-3}), → reduced UHF power adsorption at smaller plasma sources.

→ Question: Future of UHF ECR plasmas at 915 MHz ?

Summary

UHF Plasma generation:

- Solid state UHF-plasma generators become more and more available as a byproduct of telecommunication and industrial food heating,
- For UHF powers below 2 kW coaxial cables together with matchboxes basing on cavity- or strip line resonators can be used for power transformation.

UHF ECR-Plasmas:

- UHF ECR plasmas are predestinated for generation of single charged ions over larger dimensions (broad plasma and ion sources)
- For Electron Cyclotron resonance magnetic fields between 15 mT (433MHz) and 31 mT (915 MHz) are required, they can be generated by permanent magnet systems also over larger dimensions,
- The simplest plasma excitation method is by lambda/4 antennas, other methods (input window, area antenna's) also do exist,
- UHF ECR plasmas are excellent pulsable to control their plasma output (from <5% to 100% at 50 Hz with good linearity)

UHF ECR plasma sources:

- Sources with convergent magnetic field (high magnetic confinement) operate well at low pressures (10^{-4} mbar range and lower),
- Sources with divergent magnetic field (with magnetic field extraction of electrons from the source into the vacuum chamber) generate a secondarily plasma inside large chambers,

UHF ECR ion sources:

- Operate very well in the 10^{-4} mbar range,
- Generate already at UHF powers smaller than 100 W ion current densities of 1 mAcm-2 and more

For all that first results had been shown (as 433 MHz study) !

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Thank You!