Design and preliminary tests of an Active Plasma Chamber for ECR Ion Sources

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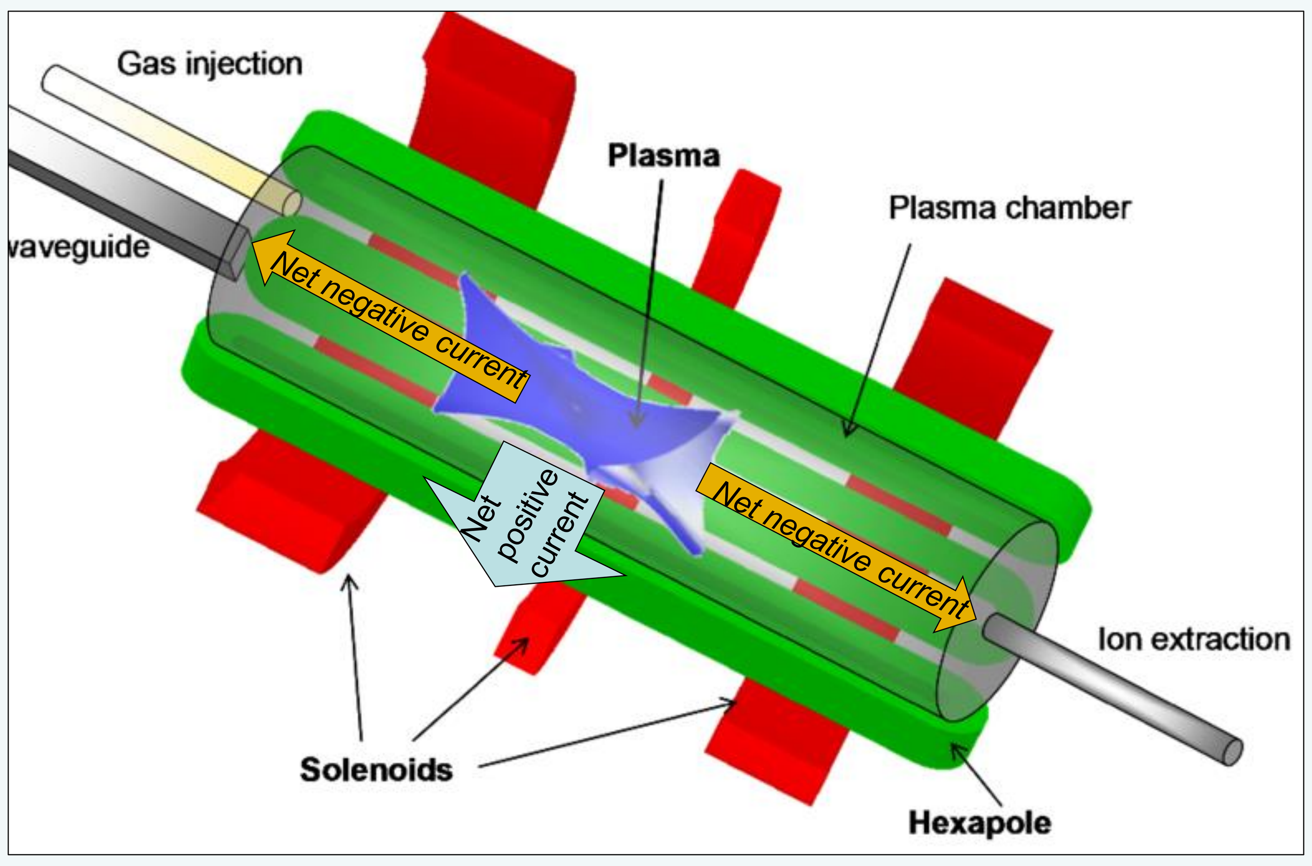
Abstract

An innovative plasma chamber for Electron Cyclotron Resonance Ion Sources (ECRIS) has been developed at INFN and will soon be installed and tested with the AISHa (Advanced Ion Source for Hadrontherapy) ion source. It consists in inserting a particular liner into the existing chamber, which allows an electrical segmentation of the internal walls of the chamber.
The purpose of this system is to reduce the ion losses induced by the anisotropic diffusion mechanism, to improve the plasma confinement and thus to increase the overall performance of the ion source. In fact, in ECRIS plasmas, electrons mostly diffuse along magnetic field lines while ions mostly leak across the same lines. In particular, the inner walls of the plasma chamber are covered with 30 tiles, each one polarized to a proper positive voltage.
The tiles are made of Al-6082 and anodized except for the surface directly facing the plasma. The anodizing process makes each tile electrically insulated from the others and from the plasma chamber while preserving the correct operation of the cooling system. The tiles are wrapped by 2 half-cylinders made of Al-6082 acting as shells. Some tiles are equipped of a temperature sensor and machined to allow the wiring of the entire system.
In this work the results of the preliminary tests of the thermal and electrical behavior of the active chamber and the future perspectives are presented.

Confinement in ECRIS plasma

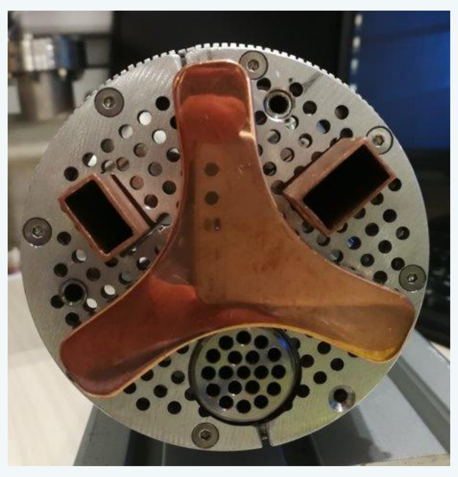
Confinement in ECRIS plasmas is guaranteed by the superposition of three mechanisms:

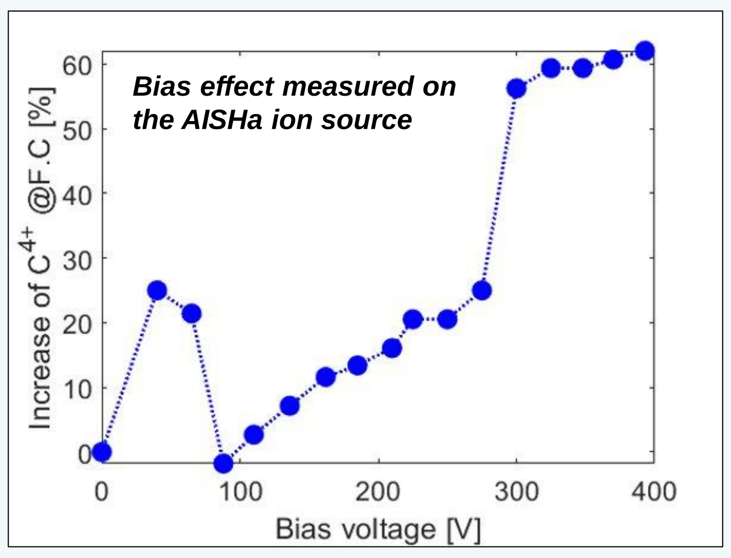
- **Magnetic confinement:** B-minimum magnetic configuration guarantees the confinement of particles by means of a magnetic force proportional to the magnetic field gradient. Roughly, $\tau_{conf} \propto ln\left(\frac{B_{max}}{B_{min}}\right)$.
- **Electrostatic confinement:** A double layer, generated on the ECR surface, increases ion confinement. Closed ECR surface are required to have high confinement time.
- **Diffusion confinement:** Simon diffusion is the typical diffusion mechanism in ECRIS. Strongly magnetized electrons diffuse along magnetic field lines, unmagnetized ions diffuse isotropically. Then, a net negative current is lost axially, a net positive current is lost radially.



electrons are mainly lost **axially**	$I_\parallel^e > I_\parallel^i$
ions are mainly lost **radially**	$I_\perp^i > I_\perp^e$

A Bias disk (see the three-pointed star in the picture) is typically used to improve the overall ion lifetime by reducing electron losses on the axial direction





Quasi-neutrality condition
The sum of the loss currents is zero
$$I_\perp^i + I_\perp^e + I_\parallel^e + I_\parallel^i + I_{drain} = 0$$

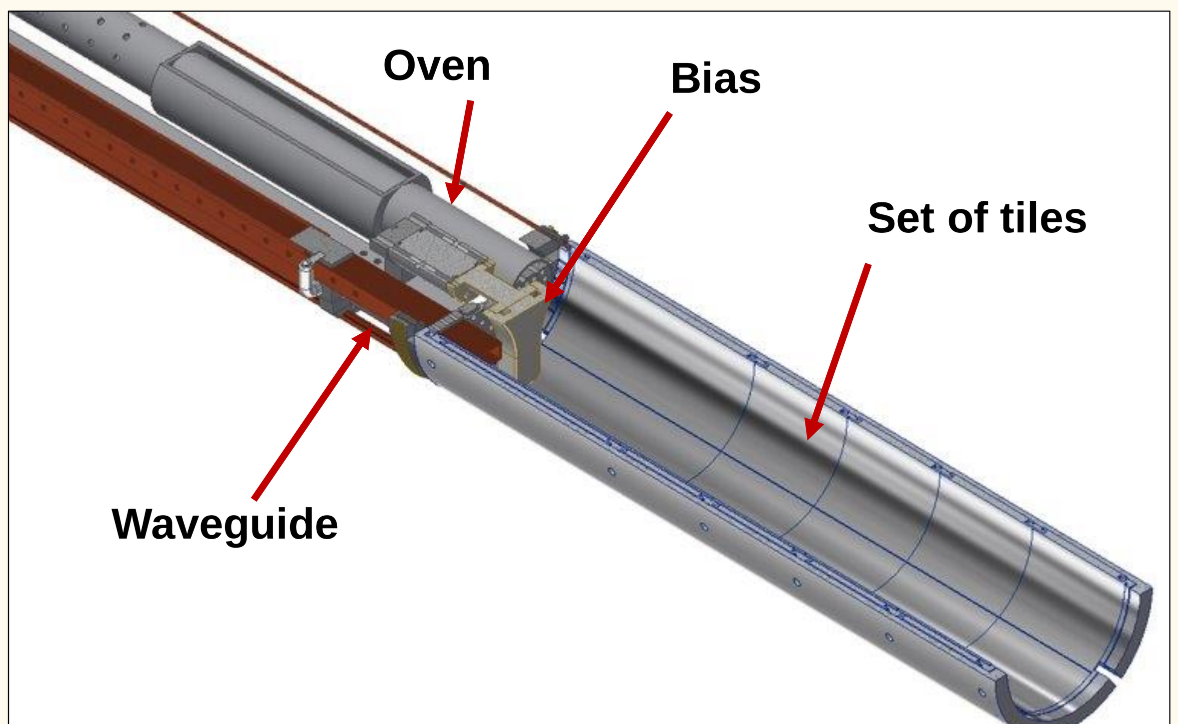
If loss currents of positive (negative) charges are reduced, loss currents of negative (positive) charges reduce to maintain quasi-neutrality → **Increase of ion lifetime** → **Increase of average charge state**

The Active plasma chamber

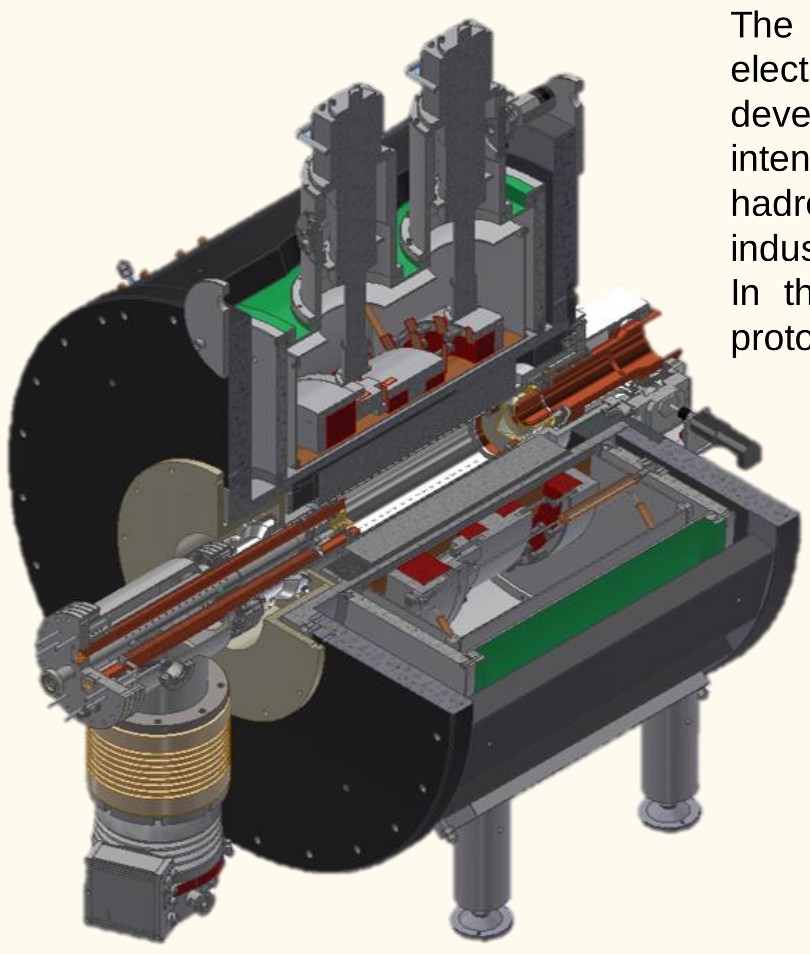
The so-called active plasma chamber is an innovative plasma chamber designed to **reduce the ion losses** induced by the anisotropic diffusion mechanism, and thus to improve the plasma confinement, and finally to increase the overall performance of the ion source. **30 anodized** Al-6082 **electrodes** will cover the chamber to allow biasing in the range **0-100 V**.

Technical aspects

- *30 anodized Al-6082 electrodes (5 axial x 6 radial) called «tiles»*
- *2 half cylinders as shells*
- *8 anodized half rings to keep the tiles in position*
- *Temperature measurements*
- *Electric insulation between tiles*
- *Positive voltage bias (0-100 V) independent on each tile*
- *Cooling performances*



Internal view of the AISHa plasma chamber after installation of the active plasma chamber



The Advanced Ion Source for Hadrontherapy (AISHA)

The Advanced Ion Source for Hadrontherapy (AISHa) is an electron cyclotron resonance ion source operating at 18 GHz, developed at the INFN-LNS, with the aim of producing high intensity and low emittance highly charged ion beams for hadrontherapy purposes, but also to be a suitable choice for industrial and scientific applications.
In the framework of the IONS projects, AISHa will host the prototype of active plasma chamber and first experimental tests.

Radial field (max)	1.3
Axial field (max)	2.6/0.4/1.7
Operating frequency (GHz)/power (kW)	17.3–18.3/1.5
Cryostat length/diameter (mm)	620/5650
Extraction voltage (kV)	20–40
Plasma chamber ø (mm)	92 mm
Extraction hole ø (mm)	7.2
Distance between maxima of the axial field (mm)	370
Distance between microwave port and B_{min} (mm)	203
Length of the resonance zone (mm)	<10
Distance between the plasma electrode and B_{min} (mm)	167

Electrical Insulation

- Each tile **anodized** except for the surface directly facing the plasma.
- **Electrically insulated** each other and from the plasma chamber. Half rings are anodized too
- **No need of ceramic parts!**

View of the 30 anodized tiles ready for installation in the active plasma chamber.

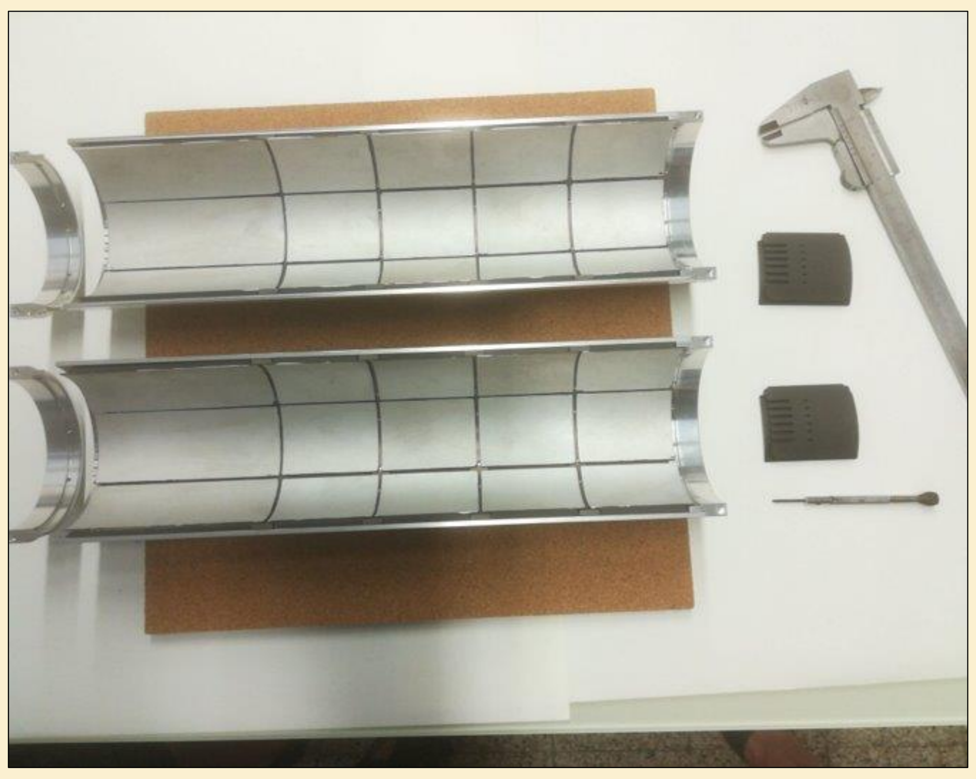
Wiring

- The two half-shells and the back side of each tile are machined to allow the wiring of the entire system, from the injection to the extraction side of the plasma chamber and to be equipped with a **k-type thermocouple.**
- Wires are in Cu/Ni with a thin ceramic insulation that allows a **continuous operation up to 500 °C**

Wiring channels machined on the two half-shells.

Cooling

- The shells will work at the same voltage of the plasma chamber and will be assembled using 4 springs (2 for each end side) to keep them apart after the mounting operation.
- Such spacing of the shells improves their contact with the cooled walls of the plasma chamber, in order to obtain a **good heat transfer (conduction).**



View of shells of the active plasma chamber.

Perspectives

Q3 2023
- Pre-assembling tests (in progress)
- Vacuum test (in progress)
- Electrical insulation test (in progress)
- Thermal conduction test (in progress)

Q2 2024
- Assembling in AISHa @ INFN-LNS
- Thermal measurements

Q3 2024
- Active plasma chamber commissioning

Dummy plasma chamber for tests at INFN-Bologna.