Status Report of the MS-ECRIS Construction*

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Abstract The design of each component of the Multipurpose Superconducting ECR Ion Source (MS-ECRIS) has been completed and some items are ready. The magnets and the cryostat are under construction at ACCEL and the commissioning is scheduled for March 2007. The mechanical have been optimized and their construction is under way; the microwave system is under refurbishment and the 65kV power supply is available and upgraded for afterglow operations. Pumping and extraction system were adapted to the EIS testbench of GSI Darmstadt. The description of each part will be given in the paper along with a schedule of the forthcoming development and experiments.

Key words ECR ion sources, accelerator, ion beams, magnetic field, microwaves

1 Introduction

The expected enhancement of the performances of electron cyclotron resonance ion sources (ECRIS) by one order of magnitude requires the design of a new series of ECRIS and new technologies for the high frequency operation of the source, sophisticated extraction systems for the management of multi-mA beams, high temperature oven for metallic element production, etc. The use of higher frequency (28 to 37GHz) with respect to the previous generation ECRIS (operating between 14 and 18GHz) makes the use of superconducting magnets for the confining trap, B-minimum type, mandatory, as the resonance field B_{ECR} is 1T at 28GHz and according to the ECRIS standard model[1] a radial confinement with values at the chamber wall above 2.2T is ideal, along with an axial confinement mirror with the two maxima respectively above 4T and above 3T. These values can be achieved only by superconducting magnets and even for NbTi superconductors this level of field is close to the technological limits nowadays. The MS-

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ECRIS source[2] is designed to fulfil all these requests; it has been funded by the European Union, in the framework of the EURONS JRA07-ISIBHI initiative. Its B-minimum magnetic trap has the highest design values to date, to get an optimum confinement[1] for 28GHz or higher frequency. Its design is open to be adapted to the major accelerators in Europe; tests will be carried out both in dc mode and in pulsed mode. The main parameters of its design are given in Table 1 and compared to the ones of the SERSE source, which is the parent project. With respect to SERSE it will have the advantage of a LHe-free cryostat (served by two cryocoolers) and of a much more complex plasma chamber, designed for 60kV insulation, for the management of 10kW microwave power and including also a X-ray tantalum shield to prevent the LHe boil-off experienced in previous experiments[3, 4]. As for the case of SERSE, particular care was given to the design of the hexapolar

Table 1. Main features of MS-ECRIS.

F	18GHz	28GHz
B_{radial}	1.55T	2.7T
B_{inj}	2.7T	4.5T
B_{ext}	1.6T	3.2T
Φ_{chamber}	130mm	180mm
L_{chamber}	550mm	650mm
Φ_{cryostat}	1000mm	1100mm
L_{cryostat}	1310mm	1700mm
V_{extr}	20—25kV	40 to 60kV
O^{8+}	~7pμA	~20 to 50pμA
Xe^{20+}	–	~50pμA
Pb^{27+}	–	40pμA

coils, not only in terms of stability versus quench, but also in terms of uniformity for different azimuth, which is important to avoid preferential loss paths for the electrons and to keep the plasma stable. The possibility to get a last closed ECR surface inside the plasma chamber with a value close to 3T may permit even the coupling of higher frequency microwave generators, up to 37GHz, or even 56GHz, with a modest confinement. The design of MS-ECRIS (Fig. 1) has taken benefit of the experience with the SERSE source[3] and the VENUS source[4] and of the know-how from the GyroSERSE project[5] which showed that relevant technological problems are present in 3rd generation ECRIS, as the X-ray heat load on the the cryostat, the watercooling of the plasma chamber, the high voltage insulation and the high power (10kW) microwave injection must be considered. A description of the source design was presented in Ref. [2]; updates will be given in the following.

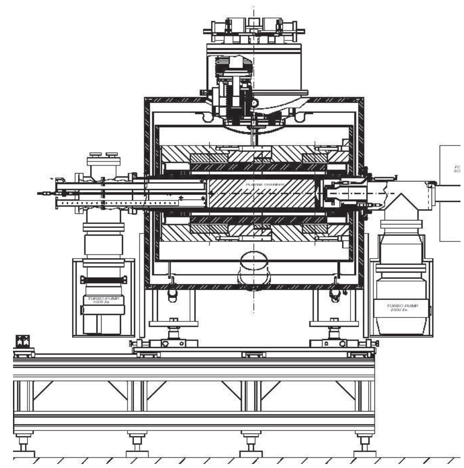

Fig. 1. A layout of the MS-ECRIS source with the cryostat and support.

2 Magnets and cryostat

The minimum B magnetic trap of MS-ECRIS is generated by three coaxial solenoidal coils and of a radial field generated by hexapolar coils, coaxial with the mirror coils. The front ends of the magnet cryostat are made of soft iron. The field of the central coil will be opposite to that of the two outer mirror coils. The magnetic field maxima will be 4.5T for the injection side, 3.2T for the extraction, with a minimum axial field variable between 0.3 and 0.9T. The maximum value of radial field is expected to be above 2.7T. The cryostat includes six high temperature superconductor (HTS) current leads and two 1.5W cryocoolers, in order to be able to operate in stand-alone mode, as proposed for the GyroSERSE project and used in other ECRIS[4, 5]. Its warm bore has an inner diameter of 202mm, able to host a 180mm plasma chamber. The choice of small section wires (simple for the solenoid, ribbon-linked for the hexapole) permits to keep the current low for all the magnets (320A for the hexapole and 130A for the solenoids). The ribbon-linked wire is made of 5 wires of NbTi (1.20mm times 0.75mm) with a critical current above

600A at 7T, 4.2K. The solenoids are made by single wires, 0.80mm diameter, with a critical current of 330A. Then the maximum operating current will be about 50% for the hexapole and 40% for the solenoids. The inductance of the coils is quite high, ranging from 4.7H of the hexapole to 114H of the solenoid on the injection side and the voltage of the power supplies is 5V for the hexapole and 10V for the solenoids. Ramp rate will be about 60 to 100mA/s. The winding technique was chosen to avoid excessive magnetic forces and fields in the conductor, particularly at the coil heads; a $\cos(3\theta)$-shape solution was adopted to minimize the field inside the conductor. An additional heat load of 500mW was added to the thermal balance to take into account the X-rays from the plasma and a total cooling capacity of 3.0W was considered. The quench detection system (QDS) will switch off the magnets in case of a quench, without any damage to the magnets. Cold diodes will permit to avoid the use of high sensitivity-fast QDS by keeping a high level of safety. In Fig. 1 the layout of the cryostat assembled with the other components of the source is presented. The characteristics of the cryostat and magnets are described in Refs. [2, 6].

3 RF system and mechanical design

The 28GHz microwave system that will be used for the MS-ECRIS source will follow exactly the same design as the one used for the experiment described in Ref. [3]. The gyrotron will be followed by an arc detector, a bi-directional coupler and a mode filter before the TE_{02} to TE_{01} converter; then a 90° corrugated bend follows which avoids higher order mode excitation and also acts as an additional mode damper; a straight waveguide and a mechanical compensator takes close to the source where a dc break designed for 60kV insulation is placed, then a water-cooled window separates the part in air from the part under vacuum. The injector flange is shown in Fig. 2. Most of the power coupled into ECRIS heats the plasma electrons, but some is lost on chamber walls or reflected. Numerical calculation have been undertaken to define the optimum location of the waveguide in the injection flange to minimize the losses. The geometry of the chamber define the possible operating modes for a given frequency while the location of the waveguide is important for the excitation of the desired modes[7]; an optimum position around 0.5 times the radius has been found. The biased disk is located on the axis and the oven is placed on the lower part that is not much affected by electrons coming from the plasma. Room for plasma diagnostics is left on the right side, away from the plasma leakage path.

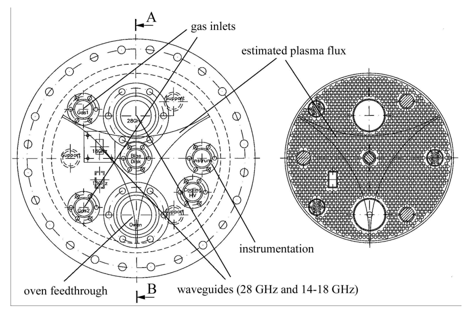

Fig. 2. The injection flange.

The gyrotron-based generator is now under refurbishment and it will be installed at GSI in the beginning of 2007; with respect to the experiment in Ref. [3] many changes are under way. The main power supply will be replaced by a brand new one (30kV—1.3A) with similar characteristics except for the rise and fall time that is too long (about 10ms) to permit ideal operations in pulsed mode. Reflected power is limited to 10% for safety reasons. The output waveguide is a circular one, 1.284” diameter. The power supplies may be operated at any distance within 15m from the gyrotron itself. RS232 and local control are provided.

The source layout is shown in Fig. 1. The beam axis is placed at a height of 1700mm. The box at the injection side contains all the services for the biased disk, for the oven and for microwaves and gas input. It is pumped by means of a 1000l/s turbomolecular pump. The box at the extraction side contains all the services for the movable extractor, either for motion, for water cooling and for high voltage connections. It is pumped by means of a 2000l/s turbomolecular pump. Vacuum gauges are located on both sides and at the two gas input pipes. The cryostat will be movable over rails to get full accessibility to the inner parts and to permit to keep safe the cryocooler services and the cabling from the power supplies to the current leads.

The plasma chamber is the heart of each ECRIS and it suffers of all the constraints. The design of the MS-ECRIS chamber is the result of compromises that finally permit to fulfill the requirements of RF power dissipation, of the X-rays shielding and of electrical insulation with respect to the grounded wall of the cryostat warm bore. The chamber tube has a length of 1150mm and it is made of AISI 316L stainless steel; inner diameter is 180mm and thickness of 1.7mm. The watercooling is obtained by means of a series of channels machined in the external wall of the tube with a depth of 2.4mm and then closed with another tube of inner diameter of 188.2mm and outer diameter of 194mm coaxial before at the two ends to get the water circulation between the two walls. A dig of 2.6mm is made at the position of maximum X-ray emission to contain a 1.5mm thick tantalum tube. Finally a 4mm thick PEEK tube will be mounted between the plasma chamber and the warm bore.

The extraction system consists of the plasma electrode, fixed to the chamber and cooled by contact with the wall, and of the movable system made by the puller and ground electrode that may be shifted over 80mm, to optimize the puller position even for a 45mm shift of the plasma electrode. The puller is watercooled with demineralised water. The distance between the puller and the ground electrode is fixed to 5mm. The electrodes can be replaced after source venting. The extraction hole diameter will be smaller during the commissioning phase (8mm) for safety reasons after that the optimum diameter (12mm) will be used. The two turbomolecular pumps below the injection and extraction boxes will be adequately shielded for stray magnetic fields by means of a series of 30 bars made of soft iron and of a 30mm panel attached to the lower part of the cryostat, that decrease the field from 70mT to 5mT.

4 Metal ion beam production

The production of metal ion beams plays an important role in the ISIBHI project. For metal ion beam production the GSI standard oven and HTO (High Temperature Oven[8]) will be modified and developed for the operation with MS-ECRIS. New resistively heated and inductively heated ovens are being developed. In the case of resistively heated oven the current up to 70A (500W) is conducted through the 25μm Ta foil. The crucible is heated by the radiation emitted from the foil. In the experiments temperatures around 2000℃ have been measured in the crucible for days[9]. Valuable development of inductively heated ovens has been carried out at MSU-NSCL, with a maximum temperature over 2300℃[10]. This technology may be applied to MS-ECRIS and a home-made resonant circuit was designed[9]. Temperatures above 2000℃ have been reached with this simple assembly, but the durability of the resonant circuit is not high and a commercial frequency generator can be used. The same feedthrough can be used for all ovens with the aid of a centering ring (see Fig. 3). The oven can be changed and loaded without venting of the ion source. In addition, the MIVOC method can be used to produce metal ion beams (as Fe and Ni). The contamination, which degrades the performance, can be minimized with a proper use of mixing gas; oxygen is the best mixing due to its reactions with carbon atoms. Anyway the use of liner is still highly recommended[9].

5 Testbench and installation issues

The ECR injector test setup (EIS) at GSI[11] will be used as testbench for MS-ECRIS. The presently installed CAPRICE will be replaced by the MS-ECRIS with its ancillary equipment while the beamline will be used in its present configuration but upgraded to handle the increased beam power. The transport through the beamline has been studied with different computer codes to investigate the influence of space charge and its compensation[2]. The maximum beam magnetic rigidity allowed by the beamline is 0.088Tm, suitable for full characterization of any beam at a voltage of 40kV or lower. The beamline consists of a solenoid located at 350mm from the source, followed by a quadrupole and two 67.5° bending magnets for the analysis of the beam. Some of the existing beam diagnostics will be used for the experiments with MS-ECRIS, as the watercooled Faraday cups; the presently used grid profile monitors are not suitable and will be replaced by Ta foil and optical viewing targets. To get information about the anisotropic emittance, pepperpot devices will be used instead of commonly used slit-grid devices. Simple pepperpot devices available at GSI can be installed at different positions along the beamline[12]. In addition another versatile emittance meter also based on the pepperpot principle is under construction[13]. A 5mm Pb shield is provided around the testbench to decrease the radiation level. Additional shielding will be provided after the source commissioning according to the safety regulations.

The preparation of the test stand has been started. The support for cryostat, injection box and extraction box, which will enable a longitudinal movement of the source along the axis for 1.2m, is under construction at GSI. The procurement of mechanical material, vacuum equipment, and ancillary cryogenic equipment has been started. The installation of the MS-ECRIS source will begin in April 2007 and its commissioning will be done in about four months. After this phase, the experimental part will start and it will last about 15 months, six of which will be devoted to the full characterization of the source behaviour, including the study of the effects of microwave power increase, of magnetic field changes and of high voltage increase. Different gases will be used in this phase, while in the following period the oven will be installed for the commissioning of metal ion beams, which is a relevant part of the experimental programme. Finally pulsed mode and afterglow mode will be optimized, according to the requirement of different EU laboratories involved in the project.

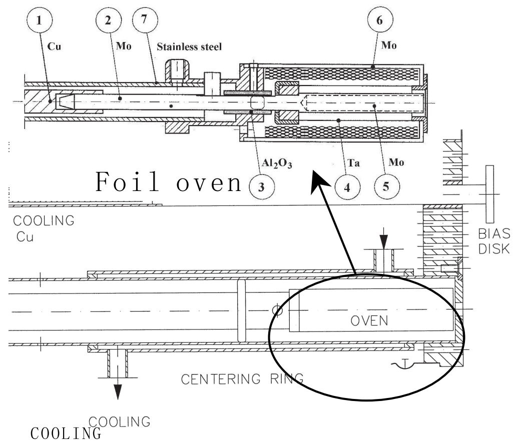

Fig. 3. The oven assembly in the injection side.

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