PRESENT STATUS OF FLNR (JINR) ECR ION SOURCES

S. Bogomolov, A. Efremov, V. Loginov, A. Lebedev, N. Yazvitsky, V. Bekhterev, Yu. Kostukhov, G. Gulbekian, B. Gikal, V. Drobin, V. Seleznev, JINR, Dubna, Russia

Abstract

Six ECR ion sources have been operated in the Flerov Laboratory of Nuclear Reactions (JINR). Two 14 GHz ECR ion sources (ECR4M and DECRIS-2) supply various ion species for the U400 and U400M cyclotrons correspondingly for experiments on the synthesis of heavy and exotic nuclei using ion beams of stable and radioactive isotopes. The 18 GHz DECRIS-SC ion source with superconducting magnet system produces ions from Ar up to W for solid state physics experiments and polymer membrane fabrication at the IC-100 cyclotron. The third 14 GHz ion source DECRIS-4 with "flat" minimum of the axial magnetic field is used as a stand alone machine for test experiments and also for experiments on ion modification of materials. The other two compact ECR ion sources with all permanent magnet configuration have been developed for the production of single charged ions and are used at the DRIBs installation and at the MASHA mass-spectrometer. In this paper, present status of the ion sources, recent developments and plans for modernization are reported.

INTRODUCTION

Main theme of FLNR JINR is super heavy elements research. From 2000 up to 2010 more then 40 isotopes of elements 112, 113, 114, 115, 116, 117, 118 were synthesized in the laboratory.

At present four isochronous cyclotrons: U-400, U-400M, U-200 and IC-100 are under operation at the JINR FLNR. Three of them are equipped with ECR ion sources. In the DRIBs project for production of accelerated exotic nuclides as ^{6}He, ^{8}He etc. the U-400M is used as radioactive beam generator and U-400 is used as a post-accelerator. Layout of FLNR accelerators complex is presented at Figure 1 [1]. Red stars indicate the location of the ECR ion source.

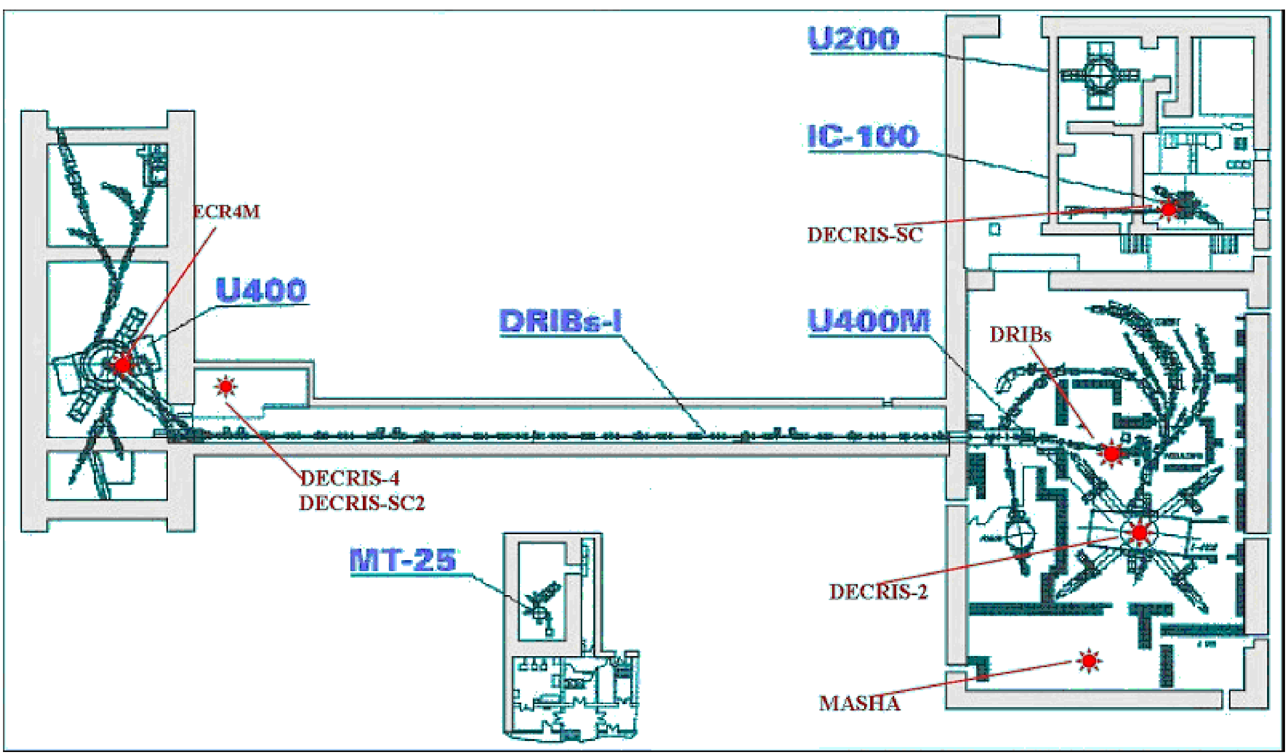

Figure 1: Layout of FLNR JINR accelerator complex. Red stars indicate the location of the ECR ion sources.

DECRIS-2 ION SOURCE

The ion source DECRIS-2 is in regular operation at the U400M cyclotron since 1995 [2]. Nowadays the main physical setups at the cyclotron U400M are the fragment-separators ACCULINNA and COMBAS. Besides, the accelerator is used for the secondary beam production at the DRIBs facility. Intensive beams of ^{7}Li, ^{11}B, ^{13}C, ^{15}N, ^{18}O ions with energies of 35 -55 MeV/nucleon on the U400M cyclotron provide good possibilities for generation secondary beams of ^{6}He, ^{15}B, ^{9}Li, ^{11}Li, ^{12}Be,

^{14}Be, ^{8}He. The intensity of light ion beams such as ^{7}Li or ^{11}B on the targets is $(3\div5)10^{13}$ pps.

Typical intensities of ion beams, produced by DECRIS-2 source, are listed in Table 1.

Table 1: Typical intensities of ion beams (eμA), produced by DECRIS-2 source

Ion	Li	B	O	Ar	Kr	Xe
2+	300					
3+	70	200				
4+		80				
5+			660			
6+			450			
7+			40			
8+				600		
9+				340	100	
18+						45
20+						40

At present time the cyclotron ensures two acceleration modes:

- acceleration of high-energy ion beams up to 100 MeV/nucleon.
- acceleration of low-energy ion beams (the mode providing the beam energy of 4.5-9 MeV/nucleon was implemented in 2008). This low energy ion beams (such as ^{48}Ca) will be used for synthesis and study of new elements.

ECR4M ION SOURCE

The ECR4M source and the axial injection system were assembled and commissioned in 1996. First accelerated Ar beam was produced in November 1996 [3]. The main goal was to provide the intense beam of ^{48}Ca ions for the experiments on synthesis of super heavy elements at a minimal consumption of this enriched and expensive isotope. First experiment on the synthesis of superheavy elements with the beam of ^{48}Ca was performed in November 1997. Since that total operation time of the U400 amounts more than 70000 hours. About 66% of this time was used for acceleration of $^{48}Ca^{5+,6+}$ ions for research on synthesis and investigation of properties of new elements. The production of the ^{48}Ca ion beam was performed with the use of microoven with the maximal temperature of 900 °C and thin cylindrical Ta sheet placed inside the discharge chamber to prevent the condensation of metal at the chamber wall [4].

The modernization of the U400 axial injection, which included sharp shortening of the injection channel horizontal part, was performed. These changes allow us to increase the $^{48}Ca^{18+}$ ion intensity at the U400 output from 0.9 to 1.4 pμA

According to the plans of the reconstruction of the U400 cyclotron (U400R project) the project of the modernization of the ECR4M source was developed. This modernization include the increase of the plasma chamber diameter from 64 to 74 mm; production of the higher magnetic field in the injection region by insertion an iron plug in the injection side; waveguide UHF injection into plasma chamber. The modified magnetic structure of the ECR4M and the axial magnetic field distribution are shown at Figure 2.

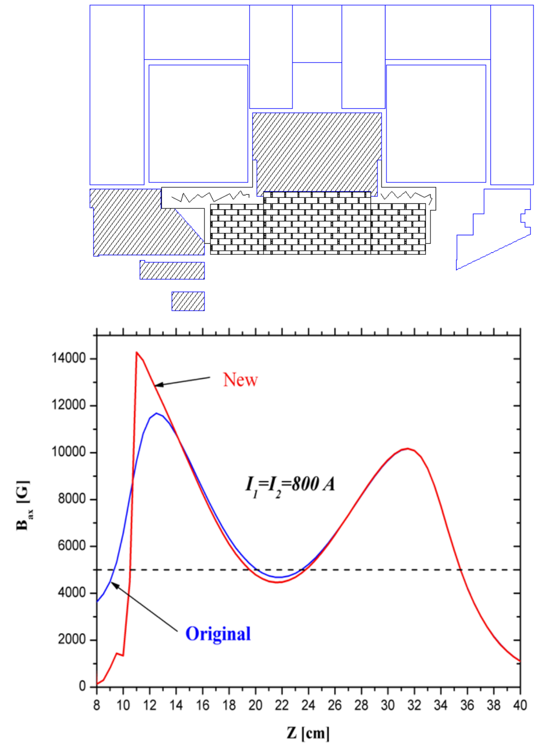

Figure 2: The modified magnetic structure of the ECR4M source (top) and axial magnetic field distribution (bottom)

DECRIS-4 ION SOURCE

The DECRIS-4 ion source [5] was designed for the use as an injector of heavy multiply charged ions for the U-400 cyclotron as well as a “charge breeder” for the second phase of the DRIBs project. The design of the magnetic structure of the source was based on the idea of the so-called “magnetic plateau”. The axial magnetic field is formed by three independent solenoids enclosed in separated iron yokes. Since 2005 the source is in operation at the test bench and is used for the experiments in the solid state physics and for beam development.

Test experiments on production of Ti ion beam were performed. The best results were obtained using MIVOC method with $(CH_3)_5C_5Ti(CH_3)_3$ compound, first used by Jyvaskyla group [6]. More than 60 μA of $^{48}Ti^{5+}$ were produced in stable mode, but there is a problem in synthesizing such a compound from a small quantity of enriched ^{50}Ti. Also the titanium isopropoxide was tested with MIVOC method, but the results were very pure, not more than 1 μA of $^{48}Ti^{5+}$ were produced.

Also TiF_4 was tested using the microoven. The compound was loaded into the crucible with thin capillary, and microoven was moved further from the plasma chamber. About 10÷20 μA of $^{48}Ti^{5+}$ were obtained in stable mode of operation, the further increase of intensity leads to instability of source regime due to overheating of crucible by plasma.

DECRIS-SC ION SOURCE

DECRIS-SC is a hybrid type electron cyclotron resonance ion source using permanent magnet hexapole, providing the radial magnetic field at the plasma chamber wall of 1.3 T, and a set of four superconducting solenoids to make min-|B| structure suitable for operation up to 28 GHz [7]. The compact refrigerator of Gifford-McMahon type is used to cool the solenoid coils. At present the operating frequency of the source is 18 GHz.

Since May 2004 the source is in regular operation at the IC-100 cyclotron for production of polymer membranes and solid state physics. Accelerated beam currents are listed in Table 2.

Table 2: Typical intensities of ion beams (eμA), accelerated at the IC-100 cyclotron

Ion	A/Z	Current, μA
$^{22}Ne^{4+}$	5.5	0.7
$^{40}Ar^{7+}$	5.714	2.5
$^{56}Fe^{10+}$	5.6	0.5
$^{86}Kr^{15+}$	5.733	2
$^{127}I^{22+}$	5.773	0.25
$^{132}Xe^{23+}$	5.739	1.2
$^{184}W^{31+}$	5.9355	0.035

DECRIS-SC2 ION SOURCE

Using the experience obtained during construction and operation of the DECRIS-SC source the new source DECRIS-SC2 was developed [8]. The source is planned to be used at the U-400M cyclotron to replace the conventional ECR ion source DECRIS-2. For ECR plasma heating the existing microwave system (14 GHz) will be used.

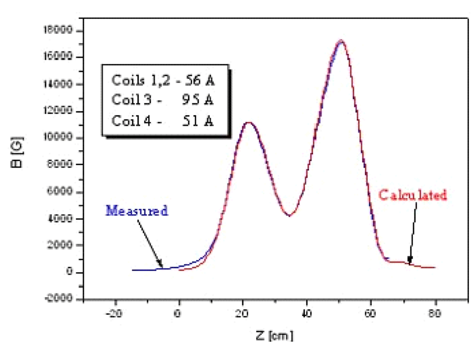

Figure 3: Axial magnetic field distribution of the DECRIS-SC2 source

The design of the superconducting magnet system of the new source differs essentially from the previous one. To decrease the weight and dimensions of the system it was decided to produce the vacuum vessel from chromium plated soft steel, so it will simultaneously serves also as a magnetic yoke. The superconducting magnet system passed the full test. The axial magnetic field distribution is shown at Figure 3. The source is completely assembled and installed at the test bench for beam tests.

ECR ION SOURCES FOR RADIOACTIVE ION BEAMS

The DRIBs (Dubna RIB) project has been running since 2002 [9]. The primary ion beams (^{7}Li or ^{11}B) from U400M are used for production nuclides as ^{6}He, ^{8}He at the target (Be or C). The produced radio-nuclides transported from hot catcher by diffusion into ECR ion source [10] where are ionized. The 2.45 GHz ion source is dedicated for production of singly charged radioactive ion beams. The magnetic configuration of the source is made with three radially magnetised permanent magnet rings. That allows to create pseudo-closed resonance surface. For the primary beam (^{7}Li) intensity of 3 pμA the intensity of accelerated ^{6}He beam reaches of 5 10^{7} pps.

The similar type of the ECR source is used at the MASHA (Mass Analyser of Super Heavy Atoms). The magnetic configuration of this source is made with two permanent magnet rings. The easy axis of the each magnet ring is directed along the axis of the magnetic system.

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