OPERATION OF ECR ION SOURCES AT THE FLNR (JINR) CYCLOTRONS.

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Abstract

During the past three years the FLNR cyclotrons U-400M and U-400 were equipped with ECR-type ion sources: DECRIS-14-2 (**D**ubna **E**lectron **C**yclotron **R**esonance **I**on **S**ource) and ECR4M built at GANIL. The basic characteristics of the sources and the beam transport lines are presented. A wide range of ions of gases, such as He, N, O, Ne, Ar, Kr and Xe were delivered by the sources and accelerated in the cyclotrons. For production of metal ions a microoven for evaporation of metal samples was developed. A combination of the microoven with a hot tantalum sheet inside the discharge chamber allowed producing intensive beams of ions of metals, such as Li, Mg and Ca, with a relatively low melting point.

1 INTRODUCTION

Two compact type cyclotrons U-400 and U-400M are at present in operation at the FLNR. The first one, U-400 with K=600, serves for acceleration of heavy ions with energies in the range of (0.5 - 18) MeV/n. The U-400M cyclotron with K=400-550 provides accelerated heavy ion beams with energies of (6 - 100) MeV/n.

With the aim of extending the possibilities for experimental investigations, in the early 80`ies a project was developed for creation of a cyclotron facility including the U-400 cyclotron as an injector and the U-400M cyclotron as a postaccelerator. Using this facility beams of ions ranging from ^{12}C to ^{238}U with energies of 100 - 20 Mev/n and intensities of 5×10^{12} - 10^{11} s^{-1} could be obtained [1].

The substantial progress achieved in developing ion sources made us draw a conclusion that the cyclotron U-400M combined with a modern ECR source can substitute the suggested cyclotron complex, and at present the two cyclotrons are equipped with ECR ion sources at 14 GHz.

At the same time, these two cyclotrons are a good basis for creating a modern ISOLDE-type RIB facility, in which one of the cyclotron will be the production stage and the another - the postaccelerator [2].

2 DECRIS-14-2 ion source

The ECR ion source DECRIS-14-2 [3] was created at the FLNR within 1994.

The magnetic structure of the source is based on the GANIL ECR4 source [4]. The axial mirror ratios for the extraction and injection sides are 1.8 and 2.5, respectively. The sextupole magnet consists of 24 segments in the central part and 12 segments in the end parts arranged in Halbach configuration and produces a magnetic field of about 1.1 T on the plasma chamber wall.

The extraction voltage of maximum 25 kV can be applied to the source. The extraction system of the source consists of a plasma electrode and a remotely movable puller. The microwave power is generated by a 14 GHz klystron amplifier with a maximum output power of 2 kW.

In the beginning of 1995, the DECRIS-14-2 source was installed at the U-400M cyclotron equipped with an axial injection system [5]. The beam line consists of a short solenoid (lens) in the horizontal part, three long solenoids in the axial magnet hole and a bending magnet with a radius of 400 mm, which fulfils two functions: the beam momentum analysis and the beam bending into the vertical channel. The lens focuses the extracted beam at the entrance slit of the magnet. At the exit slit position the ion beam dispersion is 1.6 cm/%. The optical parameters of the elements provide transmission of the beam with the emittance of $\varepsilon = 150\ \pi$ mm mrad.

An electrostatic mirror is used for inflection of ion beam into the median plane of the cyclotron.

To carry out the beam's diagnostics, Faraday cups and diaphragms are installed in the diagnostic boxes located in the focal planes of the bending magnet.

The beamline is pumped by turbopumps and cryopumps with the total pumping speed of about 9000 l/s. The working pressure of 10^{-7} Torr is provided inside the ion pipe guide.

During the operation of the source at the U-400M cyclotron the ion beams from Li^{2+} to Ar^{12+} were delivered for acceleration. The results of the ion yields are summarised in Table1.

For production of ions of metals with relatively low melting points (Li, Mg, Ca) a microoven for evaporating metal samples was developed allowing maximum temperatures of up to 900°C [3]. The oven was placed inside the coaxial guide of the microwave.

The yield of the ions of metals was significantly increased by introducing a thermally isolated tantalum sheet inside the discharge chamber. With the microwave power in the range from 200 to 300 W it became possible to provide up to 300 eμA of Li^{2+} .

Table 1. Ion yields (eμA) from the DECRIS-14-2 ion source. Extraction voltage 17 kV, extraction hole 10 mm.

I/Q	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+
^{4}He	2500*	345													
^{7}Li	138	290	50												
^{11}B	20	55	100	50											
^{12}C				110											
^{14}N			465	570	640*	70									
^{16}O			290	340	660*	203	68								
^{20}Ne		342*	130	233	280*	156	108	53*	3,5						
^{40}Ar				120	192	214	300	600*	250	196	70*	45*	4,5		
^{84}Kr								73	88	74	62	22	11,5	9	
^{132}Xe													40*	42	44

* - optimization

For the B ions production the volatile compound $C_2B_{10}H_{12}$ has been used which has a vapor pressure of about 1-2 Torr at room temperature was used. The spectrum of B ions is shown in Fig.1.

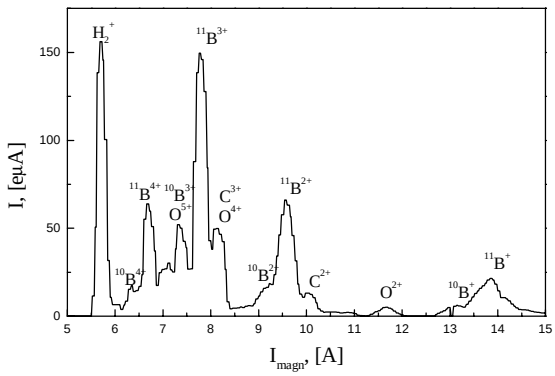

Fig.1 The spectrum of B ions produced from $C_2B_{10}H_{12}$ compound.

3 The ECR4M ion source

The ECR4M [6] ion source was supplied by GANIL at the end of 1995. It is a modified version of the ECR4 ion source. The main purpose of the modification was to upgrade its magnetic system so that it became possible to produce up to 30 eμA of Ca^{14+} with a total efficiency of more than 30%.

Compared with the prototype, the coils and hexapole of the source have been changed. The new coils allow reaching 1.6 T for the axial magnetic field at a coil current of 1250 A. The new hexapole produces a field of 1.25 T on the wall. Under these conditions the minimum B value equal to 0.6 T can be produced, which implies the use of a 18 GHz transmitter.

In the second part of 1996 the ECR4M ion source was installed at the U-400 cyclotron. Fig.2 shows the layout and elevation views of the injection beam line [7]. The horizontal part of the beam line consists of a short solenoid (lens), an analysing magnet and four steering magnets. Charge state selection is provided by a 102° magnet of 350 mm radius, 35.5° entrance and exit angles. For the 20 mm slits the charge state selection is 1 in 40. The vertical part of the beam line consists of a 90° magnet, three long solenoids in the axial magnet hole and a steering magnet at the entrance of the axial hole. The ion beam is transported axially through the upper yoke of the cyclotron's magnet and focused on a spiral inflector in the median plane. The optical parameters of the elements provide transmission of the beam with the emittance of $\varepsilon = 150\ \pi$ mm mrad.

To carry out the beam's diagnostics, Faraday cups and diaphragms are installed in the diagnostic boxes located in the focal planes of the magnets.

The axial injection system is pumped by turbopumps and cryopumps with the total pumping speed of about 7000 l/s, that allows to maintain the working pressure of 10^{-7} Torr. An ion getter pump is used to maintain the vacuum when the system is switched off.

Since the end of 1996 ion beams in the range from Ne to Xe were delivered for acceleration in the U-400 cyclotron. The yields of ions are summarised in Table 2.

For production of ions of solids the same technique as for the DECRIS-14-2 source was used.

The main effort was made to produce a ^{48}Ca ion beam for experiments on synthesizing superheavy elements. Preliminary tests were performed with natural metallic Ca. About 200 eμA of $^{40}Ca^{6+}$ were produced at a material consumption of 0,4 mg/h.

For production of ^{48}Ca beams two methods were employed. According to the first one, reduction of calcium from calcium oxide was performed directly in the vacuum volume of the ECR source [8]. A mixture of CaO and Al with a weight ratio of 3:1.2 was heated in the microoven. Up to 100 eμA of $^{48}Ca^{5+}$ were produced at a Ca consumption of about 0,6 mg/h. This method requires the temperature in the microoven close to the thermal limit of the heater. Therefore, in the subsequent experiments the metallic ^{48}Ca was used which was reduced from calcium oxide in a separate vacuum volume with the use of the oven with higher temperature.

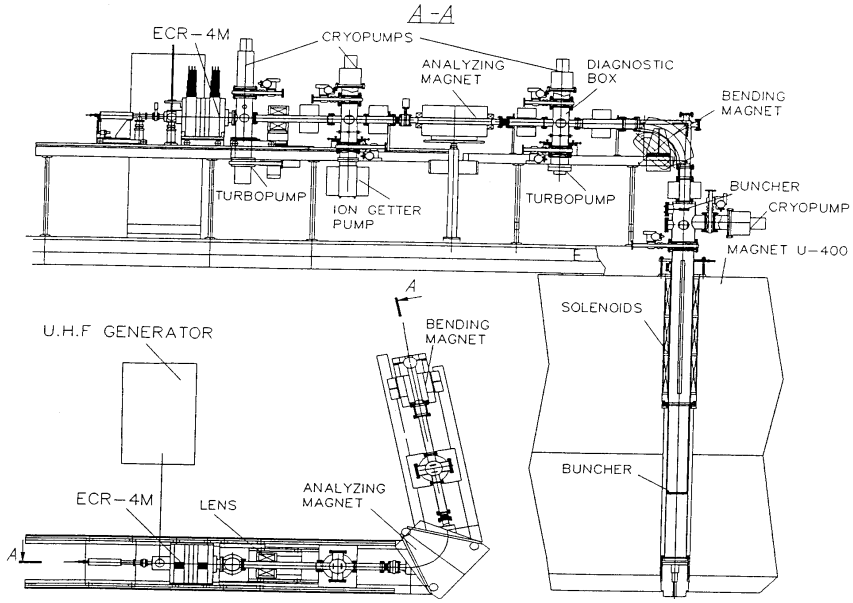

Fig.2 The layout and elevation views of the axial injection system of the U-400 cyclotron

Table 2. Ion yields (eμA) from the ECR4M ion source. Extraction voltage 13,5 kV, extraction hole 8 mm.

I/Q	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+
^{4}He	1096*	390													
^{12}C	200	330		80											
^{16}O		460	430	410	205	90									
^{20}Ne		175	225	240	120	40	10								
^{24}Mg		80	259	175	140	65	17								
^{40}Ar			303*	240	304*	320*	370*	500*	210	75	20				
^{40}Ca			132	315	245	200*	165	125	80	52	14				
^{84}Kr							108	160	185	176	142	125*	72	80*	
^{136}Xe										72		108	80	65	40

* - optimization

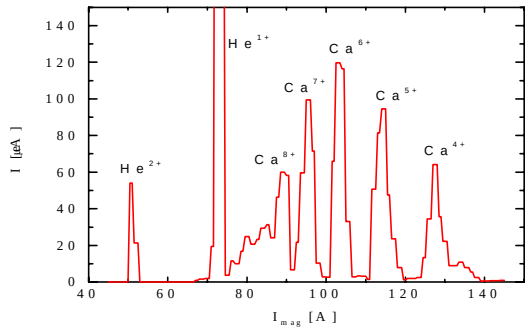

Fig.3 The spectrum of ^{48}Ca ions optimised for production of ^{48}Ca $^{5+}$.

The spectrum of ^{48}Ca beam optimised for production of ^{48}Ca^{5+} is shown in Fig.3. In a long-term operation an average consumption of calcium was about 0,4 mg/h. The ratio between the physical target current and the quantity of calcium fed into the source (with a single gap buncher in the axial injection system) constitutes 17×10^{-3} .

ACKNOWLEDGEMENT

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