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ALL-PERMANENT MAGNET ECR ION SOURCE DECRIS-PM

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Abstract

Super-heavy-element factory is under construction at the Flerov Laboratory for Nuclear Reactions, JINR, Dubna. The factory will include DC-280 cyclotron, which will be equipped with two 100 kV high voltage platforms. A high charge state all-permanent magnet 14 GHz ECRIS – DECRIS-PM has been designed and fabricated to provide intense multiple charge state ion beams. The request for the source is a production of medium mass ions with A/q=4÷7.5 such as 48Ca8+. The conceptual design of DECRIS-PM is presented. During the first tests at the ECR test bench, the source shows a good enough performance for the production of medium charge state ions (such as 900 eμA Ar8+, 550 eμA Ar9+, 200 eμA Ar11+, 160 eμA Kr15+, etc.).

INTRODUCTION

One of the basic scientific programs, which are carried out at the FLNR, is a synthesis of new elements requiring intense beams of heavy ions. To enhance the efficiency of experiments for next few years, it is necessary to obtain accelerated ion beams with the parameters listed in Table 1. These parameters have formed the base for the new cyclotron DC-280 [1]. Some required beam currents are collected in Table 2

Table 1**:** Required Beam Parameters

Ion energy	4÷8 MeV/n
Ion masses	10÷238
Beam intensity (A≤50)	up to10 pμA
Beam emittance	≤ 30 π mm×mrad
Total efficiency	> 50%.

Table 2: Required Beam Intensities

Ion	^{48}**Ar**$^{7+}$	^{48}**Ca**$^{8+}$	^{58}**Fe**^{10}
Intensity from ion source μA	300	150	125
Intensity on phys. target pps	3×10^{14}	5×10^{13}	4×10^{13}

The axial injection system of the DC-280 cyclotron will include two high voltage platforms, which will allow for efficient injection of ions from helium to uranium with M/Q ratio in the range of 4÷7. Each HV-platform will be equipped with the low power consuming ECR ion source.

For production of ions with the low and medium masses (from He to Kr) the all-permanent-magnet (PM) ECR ion source will be used. Many good performance all-permanent magnet ECRISs have been built around the world. Most of them are compact versions of ECRIS. Parameters of some PM ECRIS are listed in Table 3.

Table 3: Parameters of PM ECRIS

Ion source	**Nanogan 14 GHz**	**Super Nanogan**	**LAP ECR2**
Frequency	14.5	14.5	14.5
Plasma Chamber Ø	28	45	67
Weight	90	200	~500
Ar^{8+}	60	200	460
Ar^{9+}	20	90	455

Nanogan and Supernanogan ion sources are available for purchase from Pantechnik [2]. However, it is obvious that the compact versions of the sources do not provide the required ion beam intensities for our project. The only previously created "full-size" ion source which practically reproduces the structure and ion yields of CAPRICE-type ECRIS is LAPECR2 [3]. For this reason, the following design parameters of DECRIS-PM were selected:

- Microwave frequency – 14 ÷ 14.5 GHz
- B_{inj} - ≥ 1.3 T
- B_{min} - 0.4 T
- B_{extr} - 1 ÷ 1.1 T
- Plasma chamber Ø - 70 mm

SOURCE DESIGN

The main advantages of the all permanent magnet ECRIS are low power consumption, low pressure in the cooling water system, simplified operation, etc. However, there are few significant drawbacks of all permanent magnet ECRIS. First, the magnetic field is fixed and comparatively low. Thus, the designed magnetic configuration should be optimized from the very beginning. Another drawback is strong mechanical force acting on the individual parts of the system. As a result the correction of the magnetic field after the assembly of the magnetic system is practically impossible without demagnetization.

Deviations from the required field distribution can occur for many reasons. The variation in properties of permanent magnets (about of 5%) and the variation of easy axis direc-

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tion for magnets with angular magnetization lead to a difference between the calculated and the actual distribution of the magnetic field.

The magnetic structure and the source assembly are shown in Fig. 1. The magnetic structure consists of five 36-segmented axial magnetic rings with the corresponding axial or radial magnetization. Magnets with angular magnetization were not used. Permanent magnet (PM) rings at the extraction and at the injection sides are inserted into the soft iron rings, which help to slightly increase the magnetic field at maxima and strongly suppress the stray field around the source.

The soft iron plates around the PM rings with the axial magnetization play an important role in the final magnetic field distribution. By changing their thickness, it is possible to tune the minimum field if necessary (magnetic field correction).

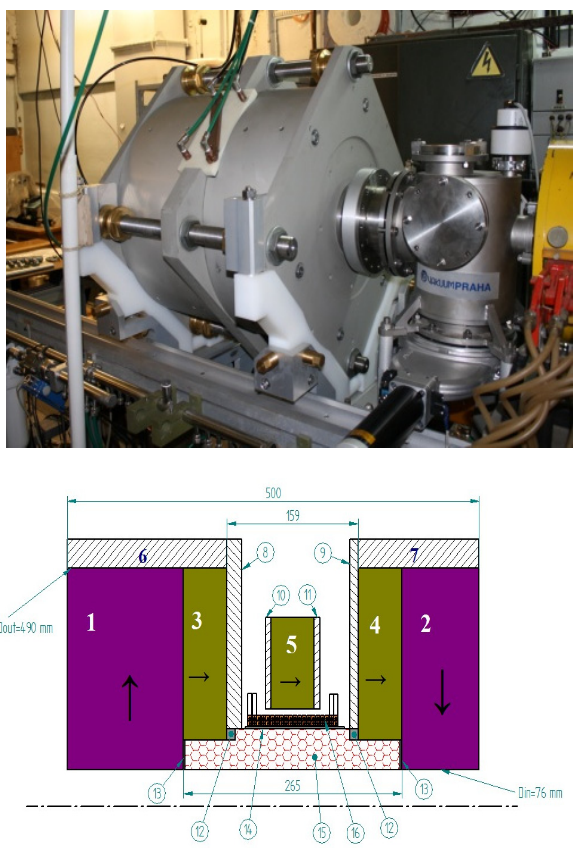

Figure 1: (top) DECRIS-PM at the ECR test bench; (bottom) Magnetic structure of DERIS-PM as follows: numerals 1÷5 – PM rings, 6 and 7 are soft iron rings; 8÷11 are soft iron plates, 12÷14 are auxiliary elements, 15 corresponds to the hexapole, and 16 the coil.

Other specific feature of the source is an additional coil placed at the centre of the structure between the hexapole and central PM ring. The coil is be used to tune the B_{min} value during the source operation. According to [4], the optimal value of B_{min} depends on the level of the injected microwave power and it should be changed on- line for an optimization of the source performance. The coil consumes less than 1.5 kW of electric power and shares the cooling system with the plasma chamber. When the coil is excited to maximum current, the B_{min} value is shifted by ±0.075 T depending on the current polarity.

The magnetic field of DECRIS-PM is the superposition of axial and hexapole fields similar to conventional ECRIS. The hexapole is a 24-segmented Halbach structure magnet, which provides a radial field of 1.05 T at the inner wall of the plasma chamber. The weight of the permanent magnets is around 525 kg and total weight of the system is about 1000 kg.

Calculated and measured axial magnetic field of DECRIS-PM are shown in Fig. 2.

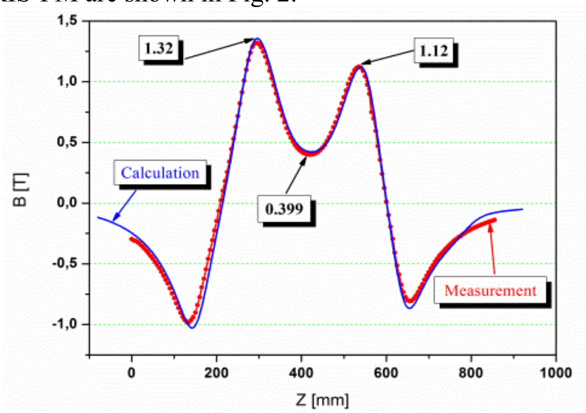

Figure 2: Axial magnetic field distribution of DECRIS-PM (extreme values are indicated at the plot).

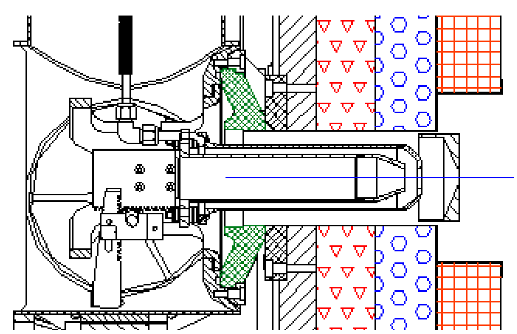

Figure 3: Extraction system.

The three electrode extraction system will be used for beam extraction. Puller electrode is negatively biased and water-cooled (See Fig. 3). Microwave power feeds into the plasma chamber directly through a water cooled rectangular waveguide. Since we are using a TWT rf generator, optimum coupling of the rf power to the plasma by tuning the microwave frequency can be realized.

RESULTS OF THE PRELIMINARY TESTS

The new ion source was tested at the ECR test bench few months ago. During these tests the single gap extraction system was used. The new extraction block could not be installed at the test bench because of its design features.

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Table 4: Comparison of Ion Yields of Ar and Xe From Some ECR Ion Sources

Ion	DECRIS-PM	LAPECR2	SuperNanogan	DECRIS-3	ECR-4M
Ar^{8+}	920	460	200	720	600
Ar^{9+}	500	355	90		450
Ar^{11+}	210	166	35	156	200
Ar^{12+}	150	62	12	68	100
Xe^{20+}	75	85		84	
Xe^{26+}	50	40	7 (Xe^{25+})	23	25 (Xe^{25+})

Table 5: Ion Yields of Solids

Q^+	5+	7+	8+	9+	10+	11+	12+
^{24}Mg	450	140	40	15			
^{40}Ca				220		158	58
^{50}Ti				90	72	60	23
^{56}Fe				85	80	55	

The Central coil was not used because of the remote control for its power supply was not ready. Normally, the extraction voltage was between 17 kV and 20 kV.

First of all the new ion source was tested by producing argon, krypton and xenon ion beams to investigate the source capacity. The best obtained results were compared to the corresponding results obtained with the all permanent magnet ion sources such as Supernanogan [2], LAPECR2 [3], and CAPRICE-type room temperature ion sources DECRIS-3 [5] and ECR4m [6]. This comparison is presented in Table 4.

It is obvious that the typical performances of DECRIS-PM are equivalent to those of some typical room temperature ECR ion sources of the same frequency in the world, which demonstrates that design of this source is successful.

In recent years, the reactions of ^{48}Ca with different targets have been used to synthesize new superheavy elements with Z = 114– 116 and 118. The heaviest target for experiments on synthesis of superheavy elements in heavy ion reactions is ^{249}Cf, so further progress in the synthesis of elements with Z > 118 requires the production of intense beams of accelerated neutron enriched isotopes, such as ^{50}Ti, ^{58}Fe, ^{64}Ni, etc. The use of new isotopes for the production of accelerated beams calls for searching of ways for optimization of the ECR source operation mode and the development of a material feeding technique. For this reason, the new source was also tested by producing Ca, Mg, Ti and Fe ions.

The selection of the best method to feed solids into ECR ion sources strongly depends on specific properties of materials. For producing of Mg and Ca ion beam the traditional method with combination of micro oven and hot screen was applied. The MIVOC method was employed for the production of Ti ($(CH_3)_5C_5Ti(CH3)_3$ compound) and Fe ($Fe(C_5H_5)_2$ compound) ion beams. Table 5 summarizes the results of the Mg, Ca, Ti and Fe ion beam production with DECRIS-PM ion source using the MIVOC method and oven technique

CONCLUSION AND PLANS

Preliminary tests of the source have shown that it is capable of producing intense beams of multi charged ions with intensities comparable or higher than those for tunable Room Temperature ECR sources. DECRIS-PM has already installed at the HV platform of the DC-280 cyclotron. We hope to improve the source performance at the high voltage platform due to the following:

- 3-electrode extraction system (single gap extraction at the test bench);
- effect of the additional coil;
- the larger the gap between poles of the analysing magnet (70 mm at the test bench and 110 mm at the HV platform)

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REFERENCES

[1] G. Gulbekyan *et. al.*, “Development of FLNR JINR heavy ion accelerator complex in the next 7 years. New DC-280 cyclotron project”, in *Proc. 2nd Int. Particle Accelerator Conf. (IPAC’11)*, San Sebastian, Spain, Sep. 2011, WEPB2082, pp. 2700-2702.

[2] http://www.pantechnik.com/#!sources/vstc2=supernanogan

[3] L. T. Sun, *et. al.,* Nuclear Instruments and Methods in Physics Research B 263 (2007) pp. 503–512

[4] T. Nakagawa, *et. al.,* Rev. Sci. Instrum. 77, 03A304 (2006).

[5] A. Efremov, *et. al.,* AIP Conference Proceedings 2011, 040017 (2018); doi: 10.1063/1.

[6] P. Sortais, Nuclear Physics News, (1996) 6:4, 6-8, DOI: 10.1080/10506899609