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HIGH INTENSITY CALCIUM, CHROMIUM AND TITANIUM ION BEAMS FROM THE PERMANENT MAGNET ECR ION SOURCE DECRIS-PM

D.K. Pugachev†, S.L. Bogomolov, V.E. Mironov, A.A. Efremov, V.N. Loginov, A.N. Lebedev, A.E. Bondarchenko, K.I. Kuzmenkov, K.B. Gikal, A.A. Protasov, Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia

Abstract

The first experiment on synthesis at the Superheavy Elements Factory (SHE) was launched at the end of 2020. The result of the experiment with a calcium ion beam and an Americium target is more than 100 events of the synthesis of Moscovium. Two years of operation have shown good capabilities of the Factory. These results allow to start preparing for the synthesis of SHE with atomic number >118. For these experiments we have to use heavier ion beams, such as titanium and chromium. The article describes the method, technique, and last experimental results on the production of metal ion beams such as ^{48}Ca, ^{48}Ti, ^{52}Cr, and ^{54}Cr ion beams from the DECRIS-PM ion source at the DC-280 cyclotron.

INTRODUCTION

For many years, one of the main scientific directions of the FLNR JINR has been the synthesis and study of the properties of superheavy elements. In recent years, almost all the last discovered elements of the Periodic Table have been synthesized using the ^{48}Ca at the U-400 cyclotron in our laboratory.

Further research into the field of superheavy elements requires a new approach and equipment. For these purposes, SHE was built in the FLNR in 2019. Factory is equipped with cyclotron DC-280 (Fig. 1), the main parameters are shown in the Table 1. The main goals of the SHE Factory are experiments at the extremely low cross sections, such as synthesis of new SHE, new isotopes of SHE and study of decay properties of SHE. In addition, experiments requiring high statistics will be conducted, such as nuclear spectroscopy and the study of the chemical properties of SHE [1].

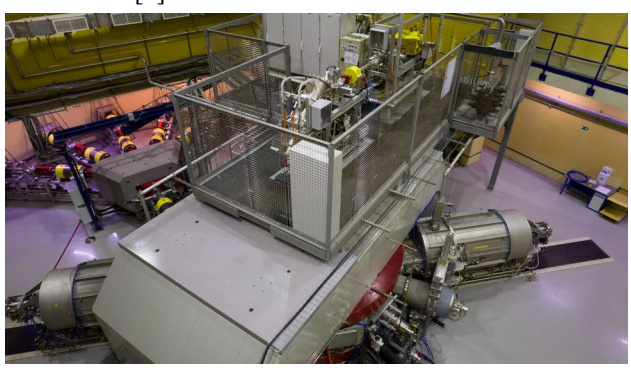

Figure 1: The DC-280 cyclotron.

Table 1: The Main Parameters of DC-280

Ion sources	DECRIS-PM - 14 GHz
Injection energy	Up to 80 keV/Z
A/Z range	4÷7.5
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.3 T
K factor	280
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV
Deflector voltage	Up to 90 kV

The first experiments at the SHE factory will be performed using ^{48}Ca+$^{242,\ 244}$Pu and the ^{48}Ca+^{243}Am reactions. After completion of these experiments, it is planned to start the synthesis of new superheavy elements in reactions of ^{50}Ti and ^{54}Cr ions with ^{248}Cm, ^{249}Bk and $^{249\text{-}251}$Cf isotopes.

DECRIS-PM ION SOURCE

The injector of the cyclotron includes a high-voltage platform to increase the injection energy and thus to reduce the influence of the space charge of the beam. To reduce the power consumption of HV-platform we developed all-permanent magnet ion source DECRIS-PM. The requirements for the ion source are the production of ions with low and medium masses (from He to Kr). The ion source and the high-voltage platform are shown on Fig. 2.

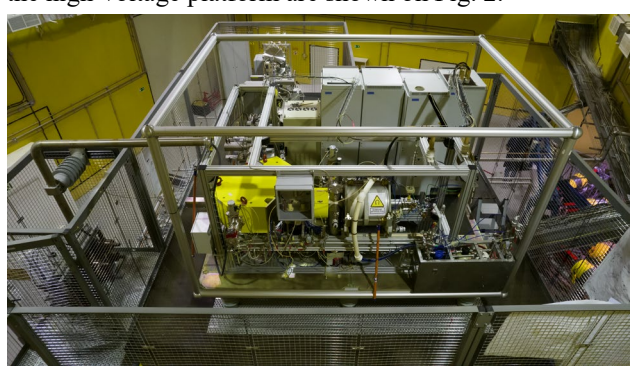

Figure 2: The DECRIS-PM on the high-voltage platform of the DC-280 cyclotron.

The magnetic field of the source is a superposition of an axial magnetic field and a radial magnetic field formed by

† pugachev@jinr.ru

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the 24-segment hexapole with a Halbach structure, which provides the creation of a radial magnetic field of 1.05 T on the inner surface of the plasma chamber. In the central part of the source the coil is installed for correction of B_{min} value in the range of ±0.075 T [2]. The magnetic structure and axial magnetic field distribution are shown in Fig. 3.

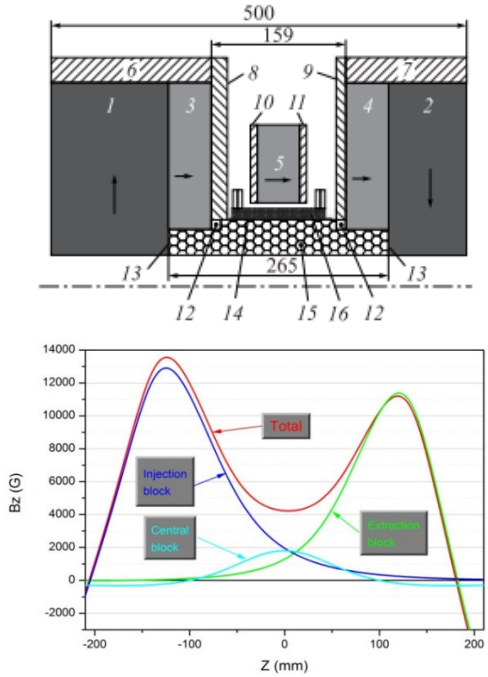

Figure 3: (Top) Magnetic structure of DECRIS-PM 1÷5 – PM rings; 6, 7 – soft iron rings; 8÷11 – soft iron plates, 12÷14 - auxiliary elements, 15 - hexapole, 16 – coil. (Bottom) Axial magnetic field.

PRODUCTION OF ^{48}CA BEAM

The production of calcium beam is described in details in the paper [3]. Therefore, we will present a brief technical description of the equipment.

For stable and long term operation with calcium beam, we use micro-ovens developed in FLNR. Their length is 50 mm, the outer diameter is 6 mm (Fig. 4). A crucible with the working substance is placed inside. The length of the crucible is 30 mm, the inner diameter is 2 mm (Fig. 5). The internal volume is sufficient to load about 100 mg of calcium, which corresponds to several days of continuous work with high beam intensity.

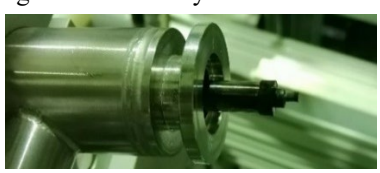

Figure 4: Oven.

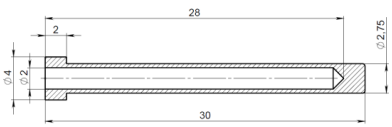

Figure 5: Crucible.

A significant part of the metal vapor evaporated from the oven condenses on the walls of the source chamber and only a small part leaves the source as an ion beam [4]. To prevent deposition of atoms on the water-cooled walls of the chamber, we use a hot tantalum screen (Fig. 6).

Figure 6: DECRIS-PM vacuum chamber, a hot tantalum screen is red.

During the source operation, the screen is heated by the plasma electrons and microwaves that leads to re-evaporation of the atoms condensed on the screen surface. The injected microwave power of 500 W provides the screen temperature of 550 °C, which is quite enough for the evaporation of calcium from the screen surface. [5] The ^{48}Ca ion spectrum, optimized for Ca^{10+} is shown in Fig. 7.

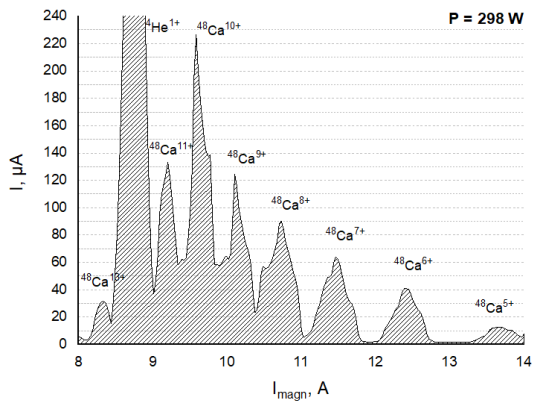

Figure 7: The ^{48}Ca ion spectrum, optimized for Ca^{10+}.

The total operational time with the calcium beam is currently ~ 4500 hours; the average consumption for the entire operation time is 0.67 mg/h excluding regeneration with the average intensity of 8 pμA for Ca^{10+} from the source. The global efficiency of the Ca ion production is 16%, the efficiency of Ca^{10+} production is about of 5%. The dependence of consumption on the ion beam intensity of Ca^{10+} is almost linear (Fig. 8).

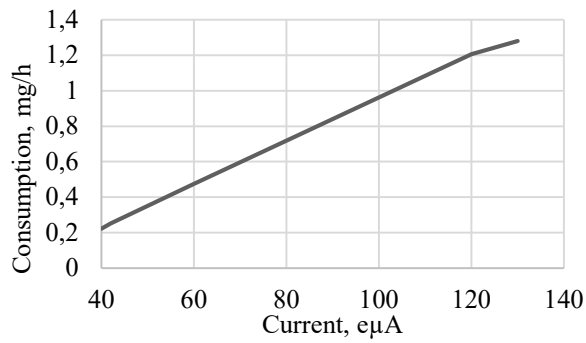

Figure 8: Calcium consumption as a function of Ca^{10+} intensity.

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PRODUCTION OF ^{48}TI AND $^{52-54}$CR BEAMS

The working pressure of calcium vapors is achieved at relatively low temperatures, in contrast to the Ti and Cr. Our micro-ovens don't allow us to use the evaporation technique to produce Titanium and Chromium beams.

Up today we have only one solution for production of high-intensity beams of these metals, it is MIVOC method. This method is based on use of organometallic compounds that have a relatively high vapor pressure (~10^{-3} Torr) at the room temperature [6]. Such vapor pressure is sufficient to operate the source providing the high conductivity of the vapor feed channel. We tried to work with different systems of the gas feeding. The best results were achieved with the gas-regulating valve EVR 116 [7]; it has a smooth adjustment of the gas flow and sufficient conductivity, which eliminates clogging of the valve openings by the deposited compound.

To avoid oxidation, the synthesized substance is placed in a vacuum tight container (Fig. 9). All operations are performed in an argon glove box. The excessive pressure of argon prevents the ingress of air and keeps the substance in working condition for a long time. Before feeding the working substance to the ECR, the substance and the feed channel are pre-pumped with argon filling for several times.

Figure 9: Containers with: left - $(CH_3)_5C_5Ti(CH_3)_3$ and right – $C_{10}H_{10}Cr$.

The operational time with the titanium beam at the DC-280 cyclotron currently corresponds to ~720 hours. The global efficiency of ion source for ^{48}Ti is 15 %, the efficiency for the Ti^{10+} is 1.5%. During short experiments it was determined that the vapor of the titanium compound react with aluminum. The compound sticks to the surface without the possibility of re-evaporation from the surface. Replacing the elements with stainless steel made it possible to increase the intensity by factor 2. Anyway, we haven't reached the project values for the intensity of the titanium ion beam. The ^{48}Ti ion spectrum, optimized for Ti^{10+} is shown in Fig. 10.

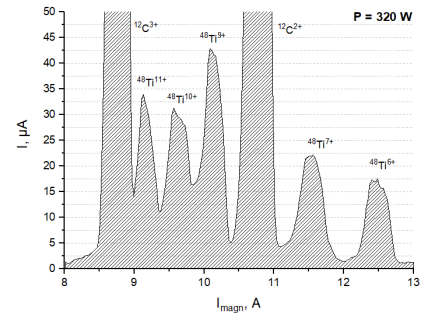

Figure 10: The ^{48}Ti ion spectrum, optimized for Ti^{10+}.

The operational time with the chromium beam at the DC-280 cyclotron currently corresponds to ~1100 hours. The global efficiency of ion source for ^{52}Cr is 10 %, the efficiency for Cr^{10+} is 2%. Chromocene is a very sensitive substance to air, so before starting work, the substance feed channel is pumped out with argon filling more than 5 times. This procedure allows one to get a beam in the shortest possible time. The ^{52}Cr and ^{54}Cr ion spectra, optimized for Cr^{10+} is shown in Fig. 11.

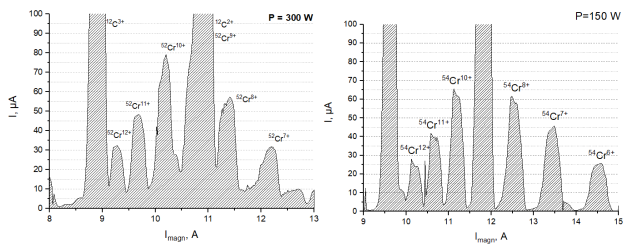

Figure 11: The ^{52}Cr (left) and ^{54}Cr (right) ion spectra, optimized for Cr^{10+}.

CONCLUSION

During the experiments the beams of ^{48}Ca, ^{48}Ti, ^{52}Cr and ^{54}Cr were produced. Calcium ion beam was accelerated with the average transmission from the ion source to output from the cyclotron about of 50%. The average consumption of the Calcium-48 is 0.67 mg/h, for Titanium-48 and Cromium-52-54 the consumption is 0.55-0.65 mg/h.

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