**Status of the Superheavy Elements Factory**

***I.V. Kalagin, S.L. Bogomolov, A.G. Popeko***

Production cross sections of superheavy elements (SHE) with Z = 112 ÷ 118 are in the range of a few picobarns (1 pb = 10-36 cm2) or less. To get access to heavier nuclides and carry out a detailed study on their properties, a sufficient increase of the overall sensitivity of experiments is needed. For complete fusion reactions, the direct solution consists in increasing of the beam intensity, development of high loadable targets and separators providing the necessary background suppression. The construction of the Superheavy Element Factory (SHEF) plays a crucial role in the implementation of these research plans. The Factory is based on the high-intensity universal DC-280 cyclotron and is being constructed in a new separate experimental building.

**Ion sources**

For the first stage, a new all-permanent magnet 14 GHz ECR ion source DECRIS-PM has been developed to be used at the high voltage platform above the DC-280 cyclotron magnet yoke. The source has been designed at the FLNR in collaboration with the company “ITT-group” (Moscow, Russia).

The combination of permanent magnet rings and soft iron plates makes the magnetic structure flexible, and provides the possibility of magnetic field correction in the course of assembling. Other specific feature of the source is an additional coil placed at the center of the structure between the hexapole and central PM ring. The coil will be used to tune the Bmin value during the source operation.

Presently the ion source is under tests at the test bench. During the first experiments, the intense beams of Ar8+ (920 eµA), Ar11+ (200 eµA), Ar12+ (100 eµA) and Kr15+ (80 eµA) were produced.

At the second stage of the DC-280 development, a superconducting ECR-ion source will be installed on the second HV platform. The source intended to produce highly charged ions up to U.

**DC280 cyclotron**

The DC-280 cyclotron designed at the Flerov Laboratory of Nuclear Reaction is intended for carrying out fundamental and applied researches using ions from He to U produced by ECR ion sources. The DC-280 is the basic facility of the SHEF that is being constructed at the FLNR. The basic parameters of DC-280 are shown in Table 1.The energy of ions extracted from the cyclotron can be smoothly varied from 4 up to 8 MeV/amu. The expected ion beam intensity is 10 pμA for ions with masses < 60 (see Table 2).

**Table 1.** Design parameters of the DC-280 cyclotron

|  |  |
| --- | --- |
| Ion source  | DECRIS-4 - 14 GHzDECRIS-SC3 - 18 GHz |
| Injecting beam potential | Up to 100 kV |
| A/Z range | 4÷7 |
| Energy | 4÷8 MeV/n |
| Magnetic field level | 0.6÷1.35 T |
| K factor | 280 |
| Gap between plugs | 400 mm |
| Valley/hill gap | 500/208 mm/mm |
| Magnet weight | 1000 t |
| Magnet power | 300 kW |
| Dee voltage | 2x130 kV |
| RF power consumption | 2x30 kW |
| Flat-top dee voltage | 2x14 kV |

**Table 2.**Beam intensity from the ion source, efficiency of capture and acceleration and ion beam intensity

(4÷7 the MeV/nucleon) on targets of physical installations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Ion** | **Ion** **charge** | ***Beam Intensity from 18 GHz ECR*** | **Efficiency of** **capture and** **acceleration** | **Beam intensity of** **(4÷7) MeV/nucl. ions** **on targets,pps** |
| **eμA** | **pps** |
| 20**Ne** | 3 | 150 | 3.1014 | 30% | 1.1014 |
| 40**Ar** | 7 | 300 | 3.1014 | 30% | 1.1014 |
| 48**Са** | 8 | 150 | 1.1014 | 50% | 5.1013 |
| 50**Ti** | 8/9 | 75 | 5.1013 | 50% | 2,5.1013 |
| 54**Cr** | 9 | 125 | 8.1013 | 50% | 4.1013 |
| 58**Fe** | 9/10 | 125 | 8.1013 | 50% | 4.1013 |
| 64**Ni** | 10/11 | 125 | 8.1013 | 50% | 4.1013 |
| 70**Zn** | 11/12 | 100 | 5.1013 | 50% | 2,5.1013 |
| 76**Ge** | 12/13 | 50 | 2.1013 | 50% | 1.1013 |
| 86**Kr** | 14/15 | 150 | 6.1013 | 50% | 3.1013 |
| 96**Zr** | 16 | 10 | 4.1012 | 60% | 2,5.1012 |
| 100**Мо** | 16/17 | 10 | 3.1012 | 60% | 2.1012 |
| 124**Sn** | 20/21 | 10 | 3.1012 | 60% | 2.1012 |
| 136**Хе** | 22/23 | 150 | 4.1013 | 50% | 2.1013 |
| 192**Os** | 32 | 5 | 1.1012 | 60% | 6.1011 |
| 208**Pb** | 34/35 | 15 | 2.1012 | 60% | 1.1012 |
| 209**Bi** | 34/35 | 15 | 2,2.1012 | 60% | 1.1012 |
| 238**U** | 39/40 | 1 | 1,5.1011 | 60% | 1.1011 |

The cyclotron accelerating system consists of two main 40° dees and two flat-top 20°dees. The system is being assembled and adjusted.

The DC280 will be an isochronous cyclotron with the compact main magnet and four pairs of focusing sectors. The main magnet has been assembled at the beginning of 2017 and today it is ready for magnetic field measurements.

The ion beam extraction system will consist from an electrostatic deflector and a passive focusing magnetic channel.

To transport accelerated ion beams to experimental setups five beam lines will be in use. All beam lines will have common switching magnet. The switching magnet is installed in the cyclotron hall.

The experimental hall is divided into three separated radiation shielded cabins.

In accordance with the plans, the cyclotron assembling should be completed and its commissioning should start by the end of 2017.

**Targets**

The design of high power radioactive targets becomes a key problem. The isotopes from 232Th to 251Cf, which are used at FLNR in experiments on the synthesis of SHE in fusion reaction are produced at Oak Ridge National Laboratory (USA).

Special care in preparation and handling of targets and the minimization of amount of expensive materials are required. This is a crucial point because of a limited availability and high specific activity of transuranium isotopes.

The heating of targets by intense heavy ion beams is the main process limiting the receivable beam intensity. The overheating (e.g. the melting temperature of Ti is 1933°C, whereas it is 2860°C for UO2) – destroys the target in a few milliseconds. At the beam intensity of 1 pµA (6×1012 cm-1) and spot diameter of 10 mm (0.78 cm2) the specific power makes at a stationary target 21.5 W/cm2 (1 μm Ti backing, 0.5 mg/cm2 UO2-layer). The temperature will reach 1660K; this is a limit for stationary targets in vacuum.

A significant increase in the acceptable beam intensity provides the application of rotating target wheels. The measured gain in the acceptable beam power was ≈ 15for the rotating target wheel of 310 mm diameter and 375 r. p. m. A generally rectangular beam cross-section having a uniform particle distribution can be provided by the use of multipole (octupole) magnetic fields.

The cooling gas (H2, He, or their mixture) is necessary present in gas-filled electromagnetic separators of reaction products. It has been found that the cooling gas provides the gain of ≈ 18 for stationary targets but only a factor of ≈ 2 for rotating ones compared to vacuum.

A new target block for the gas-filled separator is designed to accept the beam currents up to 8 – 10 pμA.

Other destructive processes – the formation of defects, sputtering, and modification of the chemical composition of the target are relatively slow and have cumulative effect on its lifetime. Unfortunately, there are no models, describing satisfactory these processes in materials exposed to heavy ion beams. Therefore, the design of thermal and radiation stable targets is difficult and requires serious efforts.

Special attention should be paid to beam diagnostic: ion energy, beam current and profile.

**Separators**

The use of beams with the intensity up to 6×1013 s-1 (10 pμA) requires effective separators providing high suppression of unwanted reaction products. The desired products must be separated from the undesired ones, which have higher yields up to 1015.

We need to suppress: unreacted full-energy primary beam particles and projectile-like reaction products; elastically knocked-out target atoms and target-like reaction products; scattered beam particles; neutrons and γ-quanta; products of reactions of a beam with secondary components of targets (N, O, S), target backings (Be, Al, Ti, Zr), target holders, supporting grids, cowering layers, collimators, etc.; high-energy protons and α-particles originating due to scattering of primary beam on a filling gas.

Three different separators are underway to address the unique needs of experiments planned at the SHE Factory. We have chosen:

* a gas-filled separator for experiments on the synthesis and study of superheavy elements. It will be installed at the beam line #3 of the cyclotron DC-280 in October 2017;
* a velocity filter as the most suitable device for studying the spectroscopic properties of heavy nuclei and for investigating the reaction mechanisms leading to the formation of the heaviest and exotic isotopes; this separator called “SHELS” is installed and running at the beam of the cyclotron U-400.
* a simplified version of a gas-filled separator that will serve as a preseparator for primary beam suppression and can be used to study the chemical properties of the heaviest elements and precise mass measurements. The construction of the preseparator is under discussion.

**Detectors**

The detector systems of the separators will be based on “big”128×128 Double-sided Si Strip Detectors (DSSD) with 128+128 analog amplification channels. The DSSD will be surrounded by a box of SSD. In addition, 128 channels are needed for backward detectors. In the first tests, the DSSSD showed excellent energy resolution of about 17 keV without cooling. The digital electronic system for the pulse shape analysis is now under development. For spectroscopic studies the DSSSD can be surrounded by 5 germanium detectors in order

to register γ- and X-rays from the decays of implanted ERs.

Alternatively, for detection of fission fragments in coincidence with prompt neutrons, an SSD-detector box placed inside a 3He-based neutron multiplicity counter can be installed at the focal plane of the separator.