ION SOURCES FOR USE IN RESEARCH AND APPLIED HIGH VOLTAGE ACCELERATORS

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Brief description of design and performance of some ion sources, developed at the Efremov Institute for use in different types of accelerators, is given. They are several modifications of duoplasmatron ion source including H^--version; RF-, Penning, Freeman and ECR ion sources for positive ion and cesium sputter source for negative ion production. Extracted current range spans 10^{-4} - 10^{+2} mA.

I. INTRODUCTION

Ion sources (IS) of different types have been developed at the Efremov Research Institute and many of them are in operation during long time in Van de Graaf accelerators, tandems, in linear accelerators' injectors, neutron generators, ion separator installations, ion implantation setups, etc. Hereafter we will outline some of the sources recently improved or developed.

II. DUOPLASMATRON

There are many modifications of duoplasmatron IS have been developed at the Efremov Institute during more than 30 years [1-3]. The basic construction of the source is being used in recent years is shown in Fig.1. One of its design feature is using the silver- or copper-soldered metal-ceramic vacuum sealing connections that provide precision in line assembly of the source electrodes to 0.02 mm and allow to heat them when outgassing. The employing of copper-tungsten and copper-steel thermo-diffusive welding when anode insert and anode itself manufacturing makes it possible to increase permissible discharge power up to 1.2 kW. The directly heated impregnated cathode is used in the source. The life time of such cathodes in hydrogen plasma is more than 1000 hours. The different models of the duoplasmatron are designed to generate H^+_1, N^+_1, He^+, Ar^+ and another ion species beam with current in 1 - 100 mA range in cw and 100 - 1200 mA in pulse mode of operation.

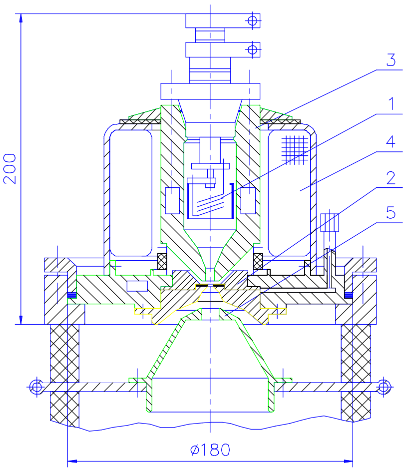

Fig. 1 Duoplasmatron Ion Source
1 - cathode, 2 - anode, 3 - intermediate electrode, 4- magnet coil, 5 - extracting electrode.

The similar source with 1.2 - 1.5 mm displaced emissive hole provides the H^-_1 beam current up to 120 µA. It can be used also for high brightness H^+_1 beam generation with current up to 100 µA and 60% proton component.

The duoplasmatron with hollow tubular discharge developed yields H^-_1 beam current up to 1 mA in cw and up to 20 mA in pulse mode without cesium adding [2].

III. RF ION SOURCE

Some of the Van de Graaf accelerators manufactured at the Efremov Institute are under operation during many years in different scientific centers. The model of RF source developed in particular for upgrading in such machines is shown in Fig. 1. The quartz tube is used as the discharge chamber. The plasma potential is defined by the holders of anode quartz shield. The source flange is completed with changeable insert that allow to use the quartz tubes 30±2 mm in diameter. The four-electrodes initial beam forming system is applied to correlate the beam angular characteristics with the accelerating structure. The newly developed thermo-resistant glue is used for stainless steel electrodes to ceramic insulators vacuum sealing connections. The beam current up to 100 µA for such ion species like H^+_1, N^+_1, He^+, Ar^+ is provided at gas flow rate not more than 10 cm^3/hour at atmospheric pressure.

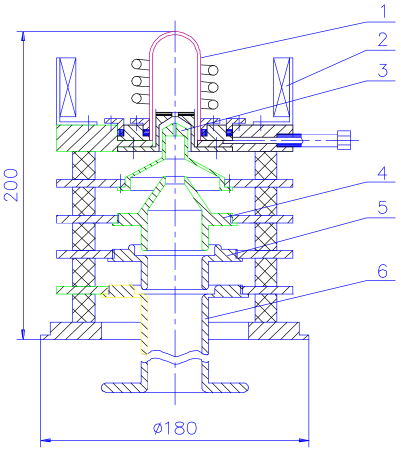

Fig. 2 RF Ion Source.
1 - discharge tube, 2 - permanent magnets (BaFe), 3 - extracting electrode (Al), 4 - accelerating electrode, 5 - focusing electrode, 6 - interface electrode.

IV. PENNING ION SOURCE

The Cold Cathode Penning IS with axial extraction to be used in Van de Graaf accelerators have been developed too [4]. It is intended first of all to produce inactive gaseous ion beams. As to hydrogen ions, the H^+_1 component content in extracted beam is less than 15% when discharge current is in the milliamps range. The general view of the source attached to initial beam forming system is shown in Fig. 2. The discharge system consists of two magnetic steel flanges with cathode and anticathode mounted in, stainless steel anode and ceramic rings connected together through Al vacuum seals. The magnetic field of about 0.12 T is produced by permanent magnets. To decrease discharge voltage and thus to increase source life time we employ LaB_6 as a cathode and anticathode material. The source provides the beam current of 70 µA for inactive gaseous ions at the 10 mA discharge current. The gas flow rate is not more than 12 cm^3/hour at atmospheric pressure when the ∅4 mm x 28 mm channel in extracting electrode is applied.

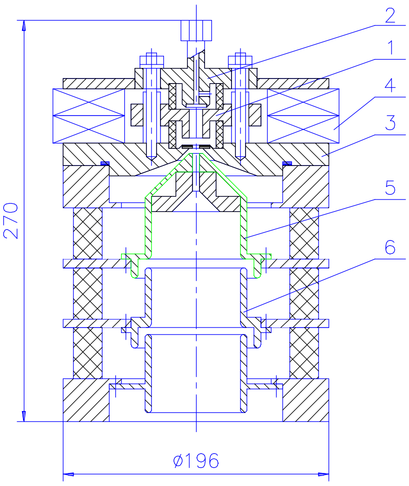

Fig. 3 Penning Ion Source
1 - anode, 2 - top flange with LaB_6 cathode, 3 - bottom flange with LaB_6 anticathode, 4 - permanent magnets, 5 - extracting electrode, 6 - focusing electrode.

V. CESIUM SPUTTER ION SOURCE

A broad spectrum of negative ions can be obtained from the cesium sputter ion source shown in Fig. 4. It is intended for using in tandem accelerators [5]. The negative ions are produced as the result of secondary ion-ion emission when the cone target is bombarded by 1 - 3 keV Cs^+ ions. The Mo or Re tube ionizer with outlet focusing cone is used for Cs^+ ions production. The cesium vapor is led to ionizer from the furnace, filled with Cs_2Cr_4 pills. The tube ionizer efficiency is about 70% for 0.5 - 2.0 mA Cs^+ current.

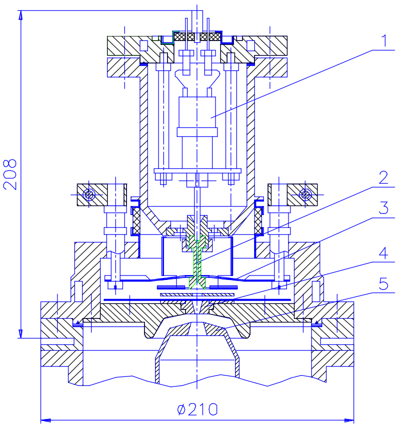

Fig. 4 Negative Sputter Ion Source
1 - Cesium container with heater, 2 - ionizer, 3 - ionizer heater, 4 - sputter cone insert, 5 - extracting electrode.

The extracted beam current is in the range of 0.1 - 50 µA for various negative ions. The version with several cone sputtering targets placed on the disk and changed under vacuum without ion source disconnection have been designed too.

VI. FREEMAN ION SOURCE

The variant of Freeman type positive heavy ion source has been designed for use in ion implanters and ion separators (Fig. 5). The directly heated tungsten cathode is displaced relative to discharge chamber axis to extracting sleet for increasing plasma density in extraction region. The magnetic field is about 0.015 T in value along the discharge chamber is produced by permanent magnets. The ion source is supplied by internal and external furnaces to provide the evaporation of solid and liquid feed materials. Ions are extracted through 50 x 2 mm sleet in anode. One of the source feature is the design of the three electrodes accel/decel system employing of special thermoresistant glue to provide metal-ceramic vacuum sealing.

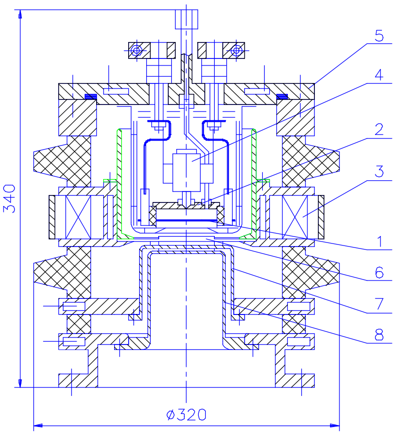

Fig. 5 Freeman Ion Source
1 - cathode, 2 - anode, 3 - permanent magnet, 4 - furnace, 5 - top flange, 6-8 - accel/decel electrodes.

VII. ECR ION SOURCE

Research into microwave source has been performed at the Efremov Institute for several years [6]. One of the ECR-source version, designed for application to intense neutron generators and oxygen ion implanters, is shown in Fig. 6.

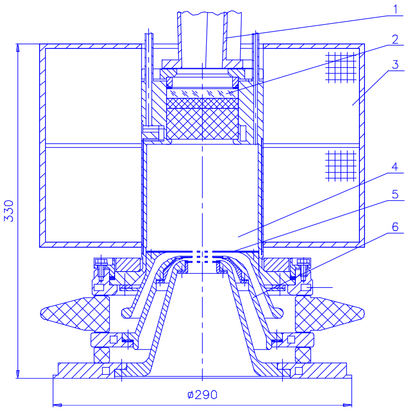

Fig. 6 ECR Ion Source
1 - rectangular waveguide, 2 - triple-layer window, 3 - magnet coils, 4 - discharge chamber, 5 - diaphragm, 6-accel/decel electrodes.

We employ a 600 W, 2.45 GHz magnetron as a microwave power

Table 1. Ion Sources performances

No	Ion Source (IS)	Ion Species	Beam Current, ma	Power Consump., kW	Lifetime, hr.	Notes
1	Radio Frequency IS	H^+_1, D^+_1	0.07	0.2	300	f=80 MHz.
		He^+, N^+_1, O^+_1, Ar^+	0.03	0.2	100	
2	Penning IS /cold cathode/	H^+_1, D^+_1	0.01	0.015	700	Cathode material - LaB_6
		He^+, Ar^+	0.05	0.015	300	
3	Duoplasmatron	H^+_1, D^+_1	5 - 100	0.7 - 1.2	300	
		He^+, N^+_1, Ar^+	1 -30	0.7 - 1.2	150	
		H^-_1, D^-_1	1.0/20*	0.7	200	hollow tubular discharge, *-cw/pulse
		H^-_1, D^-_1, He^+, Ar^+	0,07	0.5	500	Displaced emission hole
4	Negative Sputter IS	O^-	0.008	0.25	80	Negative ions of most elements in the Periodic table are obtainable
		Al^-_2	0.003	0.25	120	
		Cu^-	0.03	0.25	120	
5	Magnetron IS /Freeman type/	B^+, P^+, As^+, Sb^+	1 -10	1.5 - 2.2	40 -80	Gas, liquid and solid feed material are possible to use
		Ti^+	5	2.0	40	
6	ECR IS	H^+_1, D^+_1	10-100	2.5	500	f=2.45 GHz, one or multiple aperture extracting system is used
		N^+_1, O^+_1	5-50	2.5	300	
		Ti^+	1 - 5	2.5	50	

generator. The microwave circuitry includes a three-stub tuner and a block of directional couplers. A circulator with dummy load can be added optionally. The TE_{11} oscillation mode is employed to provide more uniform radial distribution of the plasma density. The microwave power is input into the discharge chamber through a quartz window. A disk of silicon nitride (Si_3N_4) is added to protect the window from accelerated electrons. Finely, an intermediate alumina (Al_2O_3) disk is placed to reduce the reflection of microwave power. A longitudinal magnetic field is induced by two structurally united solenoid coils. The optimal magnitude of the magnetic field and its axial distribution are provided by way of separate current control in the coils and their movement along the source axis. A movable diaphragm, dictating the active length of the discharge chamber is placed in front of the emission electrode. An ion beam is extracted through one, four or seven holes 3 - 6 mm in diameter, depending on a particular application. Such a version is realized in the high voltage accelerator for powerful neutron generator and provides production of accelerated ion beams ($^1H_1^+$ and D_1^+) with current at the Ti-T target up to 60 mA. The atomic ions' content in the extracted beam is about 70% [7].

The ion sources performances are tabulated in Table 1.

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