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STATUS OF ITEP DECABORANE ION SOURCE PROGRAM[*][a)]

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The joint research and development program is continued to develop steady-state ion source of decaborane beam for ion implantation industry. Both Freeman and Bernas ion sources for decaborane ion beam generation were investigated. Decaborane negative ion beam as well as positive ion beam were generated and delivered to the output of mass separator. Experimental results obtained in ITEP are presented.

Introduction

Progressive semiconductor device scaling in each technology node requires the formation of shallower junctions, and thus lower energy implants. The continuing need to reduce implantation energies creates significant challenges for the designers of advanced

implanters. Current density limitation associated with extracting and transporting low energy ion beams result in lower beam currents that in turn adversely affects the process throughput. It has been proposed [1] that by implanting clusters of boron atoms, the implanted dose rate will be larger and the problems associated with low energy beam transport will be less significant. The individual atoms on a singly charged cluster of n identical atoms accelerated with voltage V, have an energy of eV/n. The extracted energy would have to be n times greater to get the same velocity as the monomer. In addition, the dose rate would be n times the electric current. That is why BF_2 is used extensively in the industry – a 10 keV BF_2 implant, for example, is equivalent to a 2 keV boron implant. A much more dramatic example of this energy partitioning is decaborane ($B_{10}H_{14}$) and even octodecoborane ($B_{18}H_{22}$). The boron atoms in an ion beam of molecule decaborane have energy less of approximately 1/11 of the molecule's energy. The implanted dose is ten times the integrated beam current [2].

In ITEP, in the context of an IPP THRUST II grant, a joint (with IHCE, Russia, and BNL, USA) research and development efforts whose ultimate goal is to develop steady state intense ion sources to meet needs of 100's of electron-volt ion implanters has been in progress. The Bernas and Freeman ion sources with directly heated cathodes are the main ion sources for this research. From April 2005 the positive/negative decaborane ion beam generation is the main goal of the experiments with these ion sources. The results obtained since last ICIS are presented.

Test-bench upgrade.

Since last conference ICIS2005 in ITEP we upgraded the test-bench used for decaborane ion sources researches. The new vacuum tank with specially designed low energy beam transport (LEBT) was installed. The new vacuum tank enables installation of ion source at the distance of 200 mm from the input of mass-analyzer. The both kind of ion sources are used the magnetic field perpendicular to the beam extraction axis. The magnetic field bends the extracted ions depending on the mass/charge ratio. To compensate the magnetic field influence and to provide total beam delivering to the mass-analyzer magnet, the new LEBT (see Figure 1) was designed and installed. It includes the electrostatic deflector, two electrostatic lenses with positive potential at the

central electrodes, and two additional electrodes with negative potential to maximize the focusing force of second lens. It is impossible to compensate the influence of magnetic field equally for ions with different charge states accelerated in electrostatic field. Nevertheless it is possible to deliver all ions to input of the mass-analyzer. In Figure 2 the result of beam transportation throughout the new LEBT is shown. Different charge states are shown by different colors. One can see that at the input of mass-analyzer the beam is already separated in horizontal plane, nevertheless all ions enter in mass-analyzer with about same angle and with small difference by transverse coordinate. Therefore the CSD of total generated ion beam can be measured.

The decaborane is fragmentized at the temperature of ~350°C [2]. To provide the discharge chamber temperature less than 300°C, we constructed the water-cooled discharge chamber from copper. From other hand, to prevent the decaborane crystallization at the vapor channel walls, decaborane vapor channel should be kept at high enough temperature. The decaborane vapor tube for this chamber has the length ~40 cm with diameter 4 mm. It was found that the decaborane condensates at the point where the decaborane vapor channel has a "jump" of aperture diameter. In our case it is a point of the valve between oven and ion source. To avoid the condensation, the additional heating up to 60-80°C at the point of the channel diameter jump was provided. During operation the temperature of the cupper discharge chamber riches the temperature of 60 - 80°C for both Freeman and Bernas ion sources. To provide the decaborane vapor pressure needed in the discharge chamber region, the oven was heated up to 60 – 100°C. Therefore the quasi-uniform temperature distribution along all decaborane vapor channel was established.

Decaborane beam generation by ITEP Freeman and Bernas ion sources.

Freeman ion source

For first experiment the ITEP Bernas was updated to Freeman. The tungsten wire with diameter of 1 mm was connected to cathode and anticathode support and passed throughout the discharge chamber. Therefore this wire was a cathode for the Freeman ion source. The investigation of ion source operation modes was done with Argon. It was found that the extracted beam current rises with the ion source magnetic field till the

some level B_l and then falls down rapidly. B_l depends on the pressure into the disacharge chamber. The higher pressure in the ion source the higher value of B_1. Then the decaborane beam was generated and investigated. The 1 mA total decaborane beam current was extracted under 7 kV from Freeman ion source. The measured mass distribution of decaborane beam from the Freeman ion source is shown in Figure 3. The discharge voltage was the single difference in Freeman IS operation mode for decaborane as against argon. The stable discharge for decaborane beam generation exists when the discharge voltage is 300-350 V, meanwhile for argon the stable discharge exists already at 100 V.

Besrnas ion source with directly heated cathode

As we wrote two years ago [3], first experiments with decaborane beam we carried out at Bernas ion source with indirectly heated cathode (IHC). The extracted beam current was significantly less then 1 mA. To increase the discharge current, it is necessary to increase the temperature of the working surface of indirectly heated cathode. We found that for water-cooled discharge chamber it is impossible. The working surface of IHC is overcooled due to heat transmission to cooled part of discharge chamber. Even if the opposite surface of IHC reaches the temperature of melting point for tungsten the emission current from the working surface is less than 1 mA.

The IHC was taken out and we carried out experiments with Bernas ion source with the filament as a directly heated cathode. Again at the beginning, the ion source operation mode was investigated with argon. It was found that the stable discharge occurs when the pressure in the vacuum tank is significantly larger than for Freeman ion source operation. It is a result of the opening of discharge chamber from the cathode side. Nevertheless, the stable decoborane beam of 1 mA total current under 4 kV was extracted. At the target the decaborane peak current was 60 μA that was limited by the mass-analyzer throughput efficiency. The spectrum is given in Figure 4. Such result is process equivalent to a 0.37 keV, 10 mA (for total current and 600 μA for target) implant, a condition not allowed by the Child–Langmuir law.

Decaborane negative ion generation

The set of experiments for decaborane negative ion generation was carried out. The ITEP Bernas IS with additional e-beam was used [4]. It was found that the highest decaborane negative ions current was extracted when the cathode and anode of discharge chamber are electrically connected (short circuit between them). The experiments with both the convenient polarity and the inversed one at the discharge electrodes resulted the significant decrease of extracted current. It means that the negative decaborane ions production is a result of e-beam electrons termalization in region between cathode and anticathode and capture by decaborane molecules. The typical spectrum of the decaborane negative ions is shown in Figure 5. It is necessary to describe the measurement procedure used. The decaborane negative ions are very sensitive to charge-exchange process all over the way from ion source to beam detector. Therefore at the first experiments it was impossible to detect any signal at the detector at the mass-analyzer output even when we were sure that the negative ion beam was extracted from ion source. To solve the problem, we provided at the detector the electrical field accelerating the secondary electrons emitted by the charge-exchanged (in fact neutral) decaborane beam from the beam detector surface. It is necessary to note, that so good charge-exchange capability of decaborane negative ions is a positive effect from the implantation point of view. Therefore we saw the positive signal from the detector. Nevertheless, the shape of measured signal enables to say that some negative ions reach the detector. The top of the measured signal has the depression – it indicates that some negative ions reach the detector.

In Table 1 the main parameters of ion source for decaborane both positive and negative ions generation with additional electron beam are shown.

At the next step, the set of measurements was done to find the best parameters for decaborane negative ions generation. The three main parameters were taken into account – the decaborane vapor pressure into the discharge chamber, e-beam current and e-beam accelerating voltage. The different regions of electron beam current and voltage providing high current of decaborane beam was detected and named H, DV and D (see Figure 6 – Figure 8). The parameters for these regions are given in Table 2. As one can see, the higher the pressure into discharge chamber, the higher decaborane ion beam

5

current can be generated by the significantly lower e-beam current accelerated by lower voltage.

References

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Figure

Figure 1. LEBT for new test bench. 1 – Electrostatic deflector, 2 – First positive potential electrode, 3 – second positive potential electrode, 4 – "Ground" electrodes, 5 – negative electrodes..

Figure 2. Simulation of multi charge state ion beam delivering to the mass analyzer by new LEBT. Black – protons, Red – decoborane (m=124), other colors – fragments of decoborane.

Figure 3 Mass spectrum from ITEP Freeman ion source.

Figure 4. Mass spectrum from ITEP Bernas ion source

Figure 5. Typical spectra of decaborane minus ion beam

Figure 6. Beam current amplitude v.s. initial electron beam current and energy for vacuum 8×10^{-5} Torr

Figure 7. Beam current amplitude v.s. initial electron beam current and energy for vacuum 1.2×10^{-4} Torr

Figure 8. Beam current amplitude v.s. initial electron beam current and energy for vacuum 2.6×10^{-4} Torr

Tables.

Table 1 Ion source parameters for decaborane positive and negative ions generation with additional electron beam

Table 2 Regions of electron beam current and voltage providing high current beam of negative decaborane ions

4   3   4   2   1   4

Beam

5

100
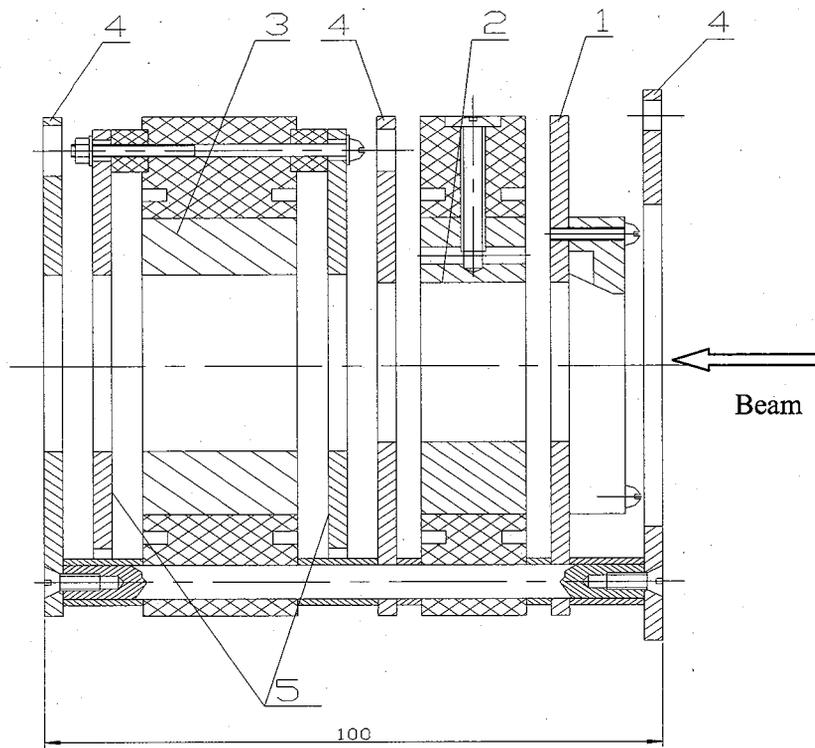
KOBRA3-INP   magnetic flux density

'E -2   y [m]   z comp.   in   xy   plane   at z=   .0985   meter   color table   [T]
20.   dz: .0985   <->   .1005   .1205

16.   .1039

12.   .0861

8.   .0689

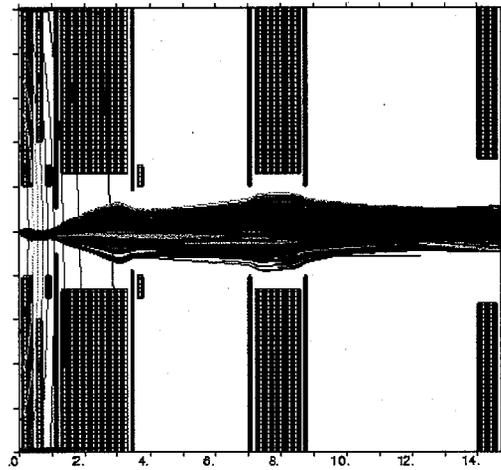   .0516

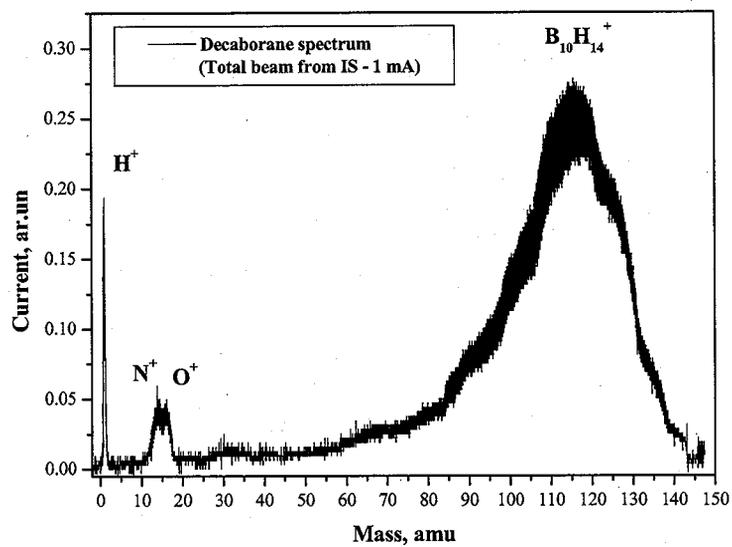4.   .0344

                                                                                                           .0172

.0   .0

   .0'   2.'   4.'   6.'   8.'   10.'   12.'   14.'   'E -1   x [m]
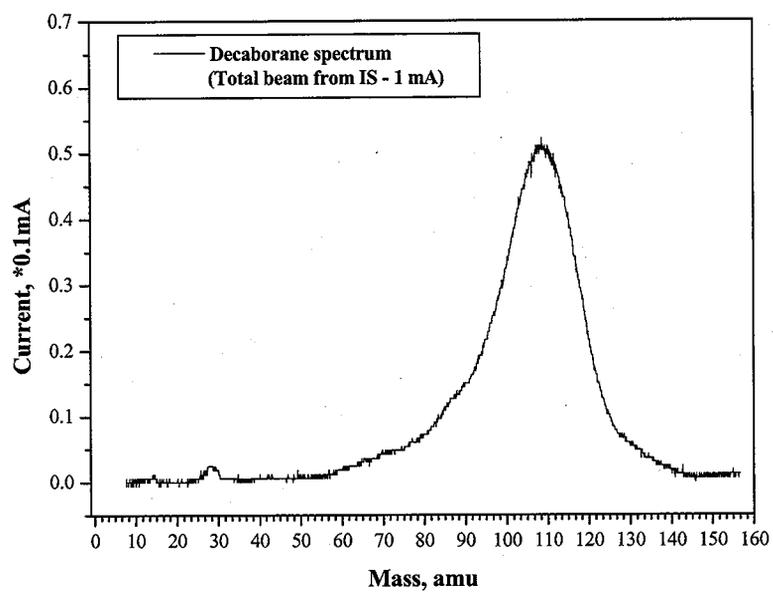
Amplitude of $B_{10}H_{14}^{-}$ beam current in µA
v.s. e-beam parameters, vacuume 8e-5 Torr

Electron beam current, mA

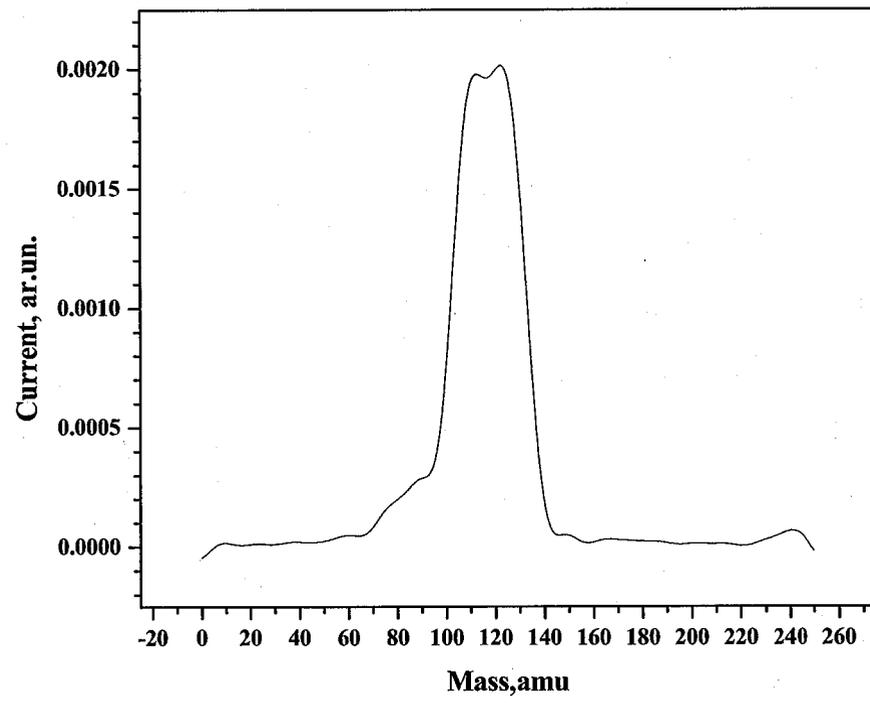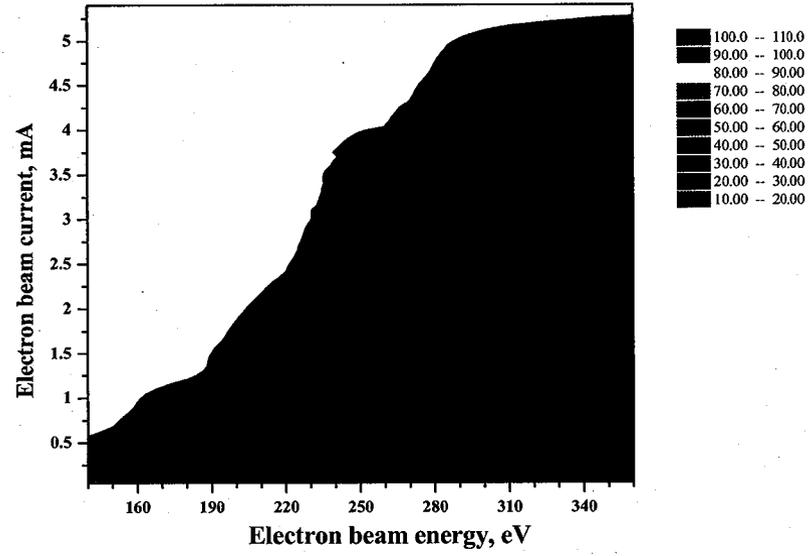Electron beam energy, eV

100.0 -- 110.0
90.00 -- 100.0
80.00 -- 90.00
70.00 -- 80.00
60.00 -- 70.00
50.00 -- 60.00
40.00 -- 50.00
30.00 -- 40.00
20.00 -- 30.00
10.00 -- 20.00

Amplitude of B$_{10}$H$_{14}^{-}$ beam current in μA
v.s. e-beam parameters, vacuume 1,2e-4 Torr

Electron beam current, mA (y-axis): 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5

Electron beam energy, eV (x-axis): 160, 190, 220, 250, 280, 310, 340

Legend:
- 100.0 -- 110.0
- 90.00 -- 100.0
- 80.00 -- 90.00
- 70.00 -- 80.00
- 60.00 -- 70.00
- 50.00 -- 60.00
- 40.00 -- 50.00
- 30.00 -- 40.00
- 20.00 -- 30.00
- 10.00 -- 20.00
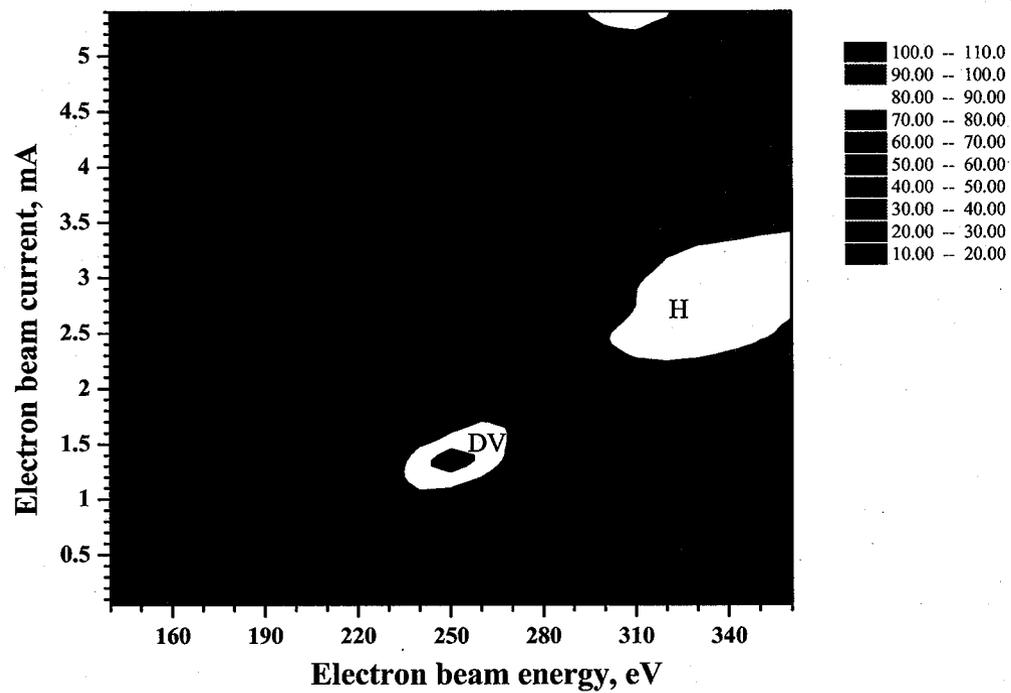
Amplitude of $B_{10}H_{14}^-$ beam current in μA
v.s. e-beam parameters, vacuume 2,6e-4 Torr
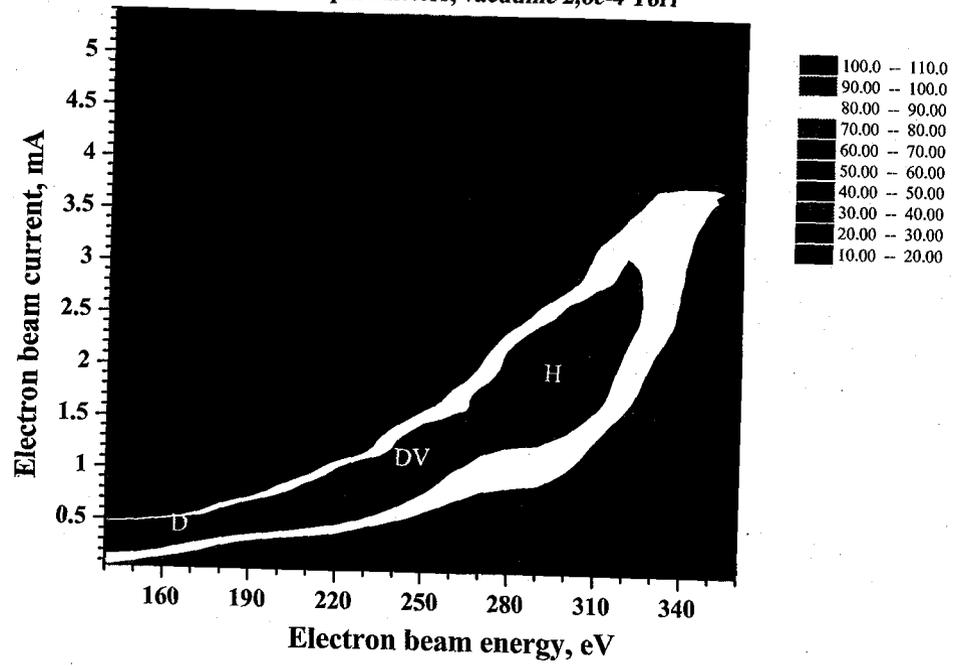
	$B_{10}H_{14}^{+}$	$B_{10}H_{14}^{-}$
Initial electron energy, eV	140-520	140-320
Initial electron beam current, mA	4-8	0.3-2.3
Electron beam diameter, mm	2.5	2.5
Cathode-anode voltage, V	300-400	0
Vacuum in discharge chamber, Torr	$0.8 \div 5 \times 10^{-4}$	$0.8 \div 5 \times 10^{-4}$
Magnet field, Tl	0.1	0.1
Extraction potential, kV	10	10

	D	DV	H
e-beam energy, eV	80-160	230-250	280-340
e-beam current, mA	0,3-0,5	0,8-1,1	1,6-2,3
Heat power, W	7-11	30-42	50-64
Minimal pressure, Torr	$2,15 \times 10^{-4}$	$1,2 \times 10^{-4}$	8×10^{-5}