PROGRESS IN RIBOON ION BEAM IMPLANTATION SYSTEMS DEVELOPMENT

***E.S. Masunov*[1]*, S.M. Polozov*[1]*, A.V. Kozlov*[2]*, R.P. Kuibeda*[2]*, T.V. Kulevoy*[2]*, D.N. Seleznev*[2]**
[1]National Research Nuclear University MEPhI, Moscow, Russia;
[2]Institute of Theoretical and Experimental Physics, Moscow, Russia
E-mail: smpolozov@mephi.ru

The ribbon ion sources for ion implantation are under developing in ITEP during last 5 years. The several versions of Bernas ion source are used for ribbon ion beam production. The beam transport for low energy ribbon beam is one of main problems for ion implantation. The progress in ion sources and transport lines development is discussed in this paper. The new results for carboran clusters ion beam driving are presented.

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1. 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. The 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 [3] 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 ($B_{10}H_{14}$). The boron atoms in ion beam of molecule decaborane have energy less of approximately 1/11 of the molecule's energy. The implanted dose is ten times larger for integrated beam current [4]. The carborane ($C_2B_{10}H_{12}$) ion beam is even more attractive material for the ion low-energy implantation thanks the higher thermo stability compare to the decaborane. The joint research activity of ITEP and MEPhI are directed to generation and transportation of low energy cluster beams. The results obtained since last conference are presented

2. BERNAS ION SOURCE

The ITEP IHC Bernas IS was used for the initial experiments (Fig.1). To provide reliable operation, the outer oven was constructed and installed. The fragility of decaborane at high temperature is one of the main problems for decaborane molecular ion beam generation in ion source with hot cathode. Anyway we succeed to generate decaborane ion beam in the ITEP IHC Bernas IS without any upgrade. It was possible at the lowest temperature of tungsten cathode when the electron emission takes place. The following cathode heating results the disintegration of decaborane. To provide higher electron current from the cathode under the lower temperature, the LaB_6 cathode and anticathode were used. During operation with LaB_6 cathode and anticathode the disintegration of decaborane never takes place, but the discharge current never was larger than the 10 mA.

The frangibility of LaB_6 under both electron and especially ion bombardment is the its main disadvantage for using as a material for cathode and anticathode of Bernas IS. The main direction of further investigations was the ion source upgrade, to provide the sufficient cooling of discharge chamber. The upgrade enables the ion source operation with the convenient tungsten cathode and anticathode for decaborane ion beam production. The decaborane is fragmentized at the temperature of ~ 350ºC [3]. To provide the discharge chamber temperature less than 300ºC, we constructed the water-cooled discharge chamber from copper (see Fig.1). From other hand, to prevent the decaborane crystallization at the vapor channel walls, decaborane vapor channel should be kept at high enough temperature to prevent decaborane condensation into the vapor channel. To avoid the condensation, the additional heating up to 60…80°C along vapor channel was provided. During operation the temperature of the cupper discharge chamber reaches the temperature of 60…80ºC. To provide the decaborane vapor pressure needed in the discharge chamber region, the oven was heated up to 60…100ºC. Therefore the quasi-uniform temperature distribution along all decaborane vapor channel was established. It is necessary to note, that to increase the discharge current, it is necessary to increase the temperature of the working surface of indirectly heated cathode. It was found that for water-cooled discharge chamber it is impossible. The working surface of IHC is overcooled due to heat transmission from cathode 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. The stable decoborane beam of 1 mA total current under 4 kV was extracted. At the beginning of operation, when the oven still is under the room temperature (~18ºC) it is possible to initiate the discharge and the measured CSD for extracted beam has the wide peak with maximum at ~230…235 amu (Fig.2). It can be treated as a decaborane dimmer. The oven heating results to changing of CSD measured. The dimmer peak disappears. At the target the decaborane peak current was 60 μA that was limited by the mass-analyzer throughput efficiency. 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.

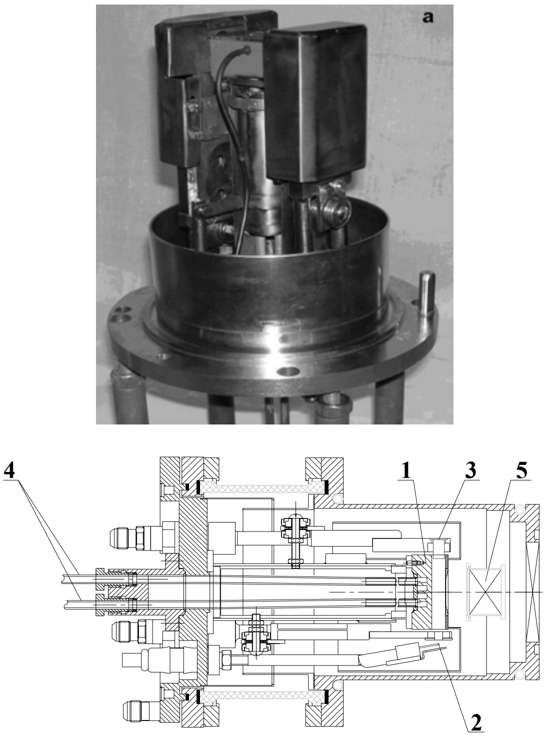

Fig.1. The general view and construction ITEP Bernas IS with cooling discharge chamber. 1 – discharge chamber, 2 – filament, 3 – anticathode, 4 – water cooling channel, 5 – extraction system

The promising material which can be used instead of deca- and octadecaborane is carborane $C_2B_{10}H_{12}$. It has significantly better thermal stability. The three isomers of carborane exist – o-, m-, p-. Below 400°C 1,2-$C_2B_{10}H_{12}$ (o-carborane) is unaffected by heat, but at 400°C to 500°C in a inert atmosphere (static conditions) or 600…620°C (continuous flow system) it rearranges quantitatively to the 1,7-isomer (m-carborane). The latter compound decomposes near 620°C (static conditions) or 750…790°C (continuous flow system) with formation of 1,12-$C_2B_{10}H_{12}$ (p-carborane). The cheapest one – o-carborane – has molecular weight 144.23 amu, melting point – 294,5…295,5°C and density 0,97 g/cm^2 [4].

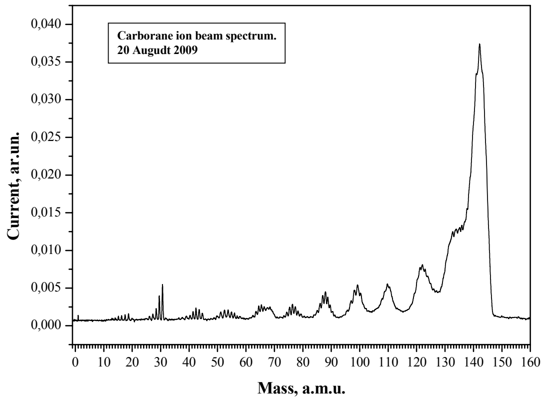

Fig.2. Carborane spectrum from ITEP Bernas IS

The first spectrum of carborane beam generated by ITEP Bernas is shown in Fig.2. The ion source parameters are shown in Table 1.

Table 1

Parameters of ITEP Bernas IS for carborane ion beam

Discharge voltage	110 V
Discharge current	50…60 mA
Discharge chamber emperature	30ºC
Oven temperature	40…55ºC
Vapor channel temperature	60…70ºC
Extraction voltage	4…18 kV
Beam current	0.5…0.8 mA

3. BEAM TRANSPORT

The carborane $(B_{10}C_2H_{12})^+$ cluster ion ribbon beam transport parameters was studied. The longitudinal flat electrostatic undulator based system was simulated [5]. The study was provided for beam energy 4, 6 and 10 keV (beam velocity $\beta=2.5\cdot10^{-4}$, $\beta=3.1\cdot10^{-4}$ and $\beta=4.0\cdot10^{-4}$ respectively), beam current 1 mA and ribbon beam cross-section size $2l\times2t=3.0\times0.3$ см.

The beam dynamics simulation was done for noted above parameters. The especial code BEAMDULAC-Tr was used for simulation. The main results of investigation are represented in Table 2. It is clear that the beam can be effective transported for energies noted above. The necessary value of electrostatic potential is not very large.

Table 2

The beam dynamics simulation results

Ion charge	1		
Atomic weight	136		
Beam current I, mA	1.0		
Transport length L, m	1.02		
Injection energy W_{in}, keV	4	6	10
Injection velocity, β_{in}	$2.5\cdot10^{-4}$	$3.1\cdot10^{-4}$	$4.0\cdot10^{-4}$
Electrostatic field on axe E_0, kV/cm	3.5	5	6
Electrostatic potential, kV	±3.2	±4.5	±5.4
Field period *D*, cm	4	4	4
Channel aperture, cm	6.0×1.4	6.0×1.4	6.0×1.4
Current transmission coefficient, %	99.9	100	100

Some results of beam dynamics simulation for 4 keV beam are illustrated in Fig.3. There are shown: the transverse beam cross-section (a), phase-energy distribution for beam particles (b), the transverse beam emittance (x, β_x) (c) and (y, β_y) (d), the particle distribution along x (e) and y (f) axes and the transverse velocity spectrum for β_x (g) and β_y (h). The initial parameters are shown by gray color, the output – by black one. It is clear that the beam transport is effective, the beam losses are low, the beam halo is not producing and the beam distribution in cross-section is not varying.

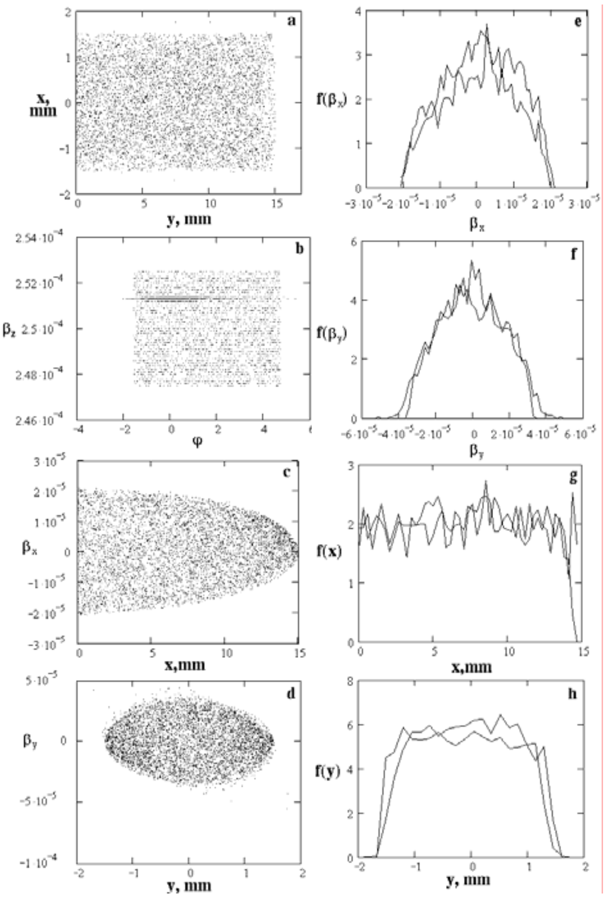

Fig.3. The beam dynamics simulation results for *W_{in}=4 keV* $(B_{10}C_2H_{12})^+$ *cluster ions*

CONCLUSIONS

The new results of the design of ribbon cluster ion beams sources are presented. The spectrum of carborane ion beam produced by ITEP Bernas ion source was represented. Some problems of ribbon beam transport were discussed.

The R&D activities of ribbon ion beam implantation systems are in progress.

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НОВЫЕ РЕЗУЛЬТАТЫ В РАЗРАБОТКЕ ЛЕНТОЧНЫХ ИОННЫХ ПУЧКОВ ДЛЯ ИМПЛАНТЕРОВ

Э.С. Масунов, С.М. Полозов, А.В. Козлов, Р.П. Куйбеда, Т.В. Кулевой, Д.Н. Селезнев

Последние пять лет в ИТЭФ разрабатываются источники ленточных ионных пучков для нужд ионной имплантации. Для генерации ленточного ионного пучка используются источники типа «Бернас». Одной из самых существенных проблем при создании таких систем является разработка каналов транспортировки пучка. В данной статье рассматриваются новые результаты, полученные при разработке источников и каналов транспортировки, приведены данные по генерации пучков многоатомных молекул карборана.

НОВІ РЕЗУЛЬТАТИ В РОЗРОБЦІ СТРІЧКОВИХ ІОННИХ ПУЧКІВ ДЛЯ ІМПЛАНТЕРІВ

Е.С. Масунов, С.М. Полозов, А.В. Козлов, Р.П. Куйбіда, Т.В. Кулєвой, Д.Н. Селезньов

Останні п'ять років в ІТЕФ розробляються джерела стрічкових іонних пучків для потреб іонної імплантації. Для генерації стрічкового іонного пучка використовуються джерела типу «Бернас». Однією з найбільш істотних проблем при створенні таких систем є розробка каналів транспортування пучка. У даній статті розглядаються нові результати, отримані при розробці джерел і каналів транспортування, наведено дані по генерації пучків багатоатомних молекул карборана.