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A HIGHLY EFFICIENT H^- ION SOURCE FOR CYCLOTRONS

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An internal high current H^- ion source for cyclotrons and other accelerators were developed, where some very effective methods of H^- ion production are used. The source is distinguished by high gas efficiency. A plasma-surface method for H^- ion production without using cesium vapour was applied.

1. Introduction

It has been known for some time that high-current H^- ion sources is often used at the charged particles accelerators, which is intended for the solving of the commercial and scientific task [1 - 4]. One of the most important advantage of using H^- ions, for example, in isochronous cyclotrons is the possibility of realization on high efficiency extraction high-currently beam of protons from cyclotron by a simple method of transform a $H^- \rightarrow H^+$ ions into thin foils.

For the accelerator with the external system of injection charge particles the external ion sources are used. However, the transportation of high current beams of H^- ions to accelerator and it acceleration involves large losses of beam intensity. The utilization cesium in the negative H^- ion sources causes the additional difficulties in operation of accelerators as decrease of electrical strength the insulators and reduction to break-down of vacuum distances with different potentials.

2. The principle of ion source action and the design of detachable discharge chamber

For Kiev Isochronous cyclotron U-240 where by standard method (deflector, current channel, magnetic screen) is possible to extract about 10 - 15 μA proton beam, we developed and constructed internal highly-current H^- ion source (Fig. 1, 2) with high gas efficiency which permit to extract more greater proton beam by foil recharge method. In the ion source some very effective methods of H^- ions production are used. A surface-plasma method for H^- ion production without using cesium vapour was realised. In a double-chamber ion source with high-current discharge in the first chamber and low-current low-voltage discharge in the second chamber with supplementary electrode is used, which compound is covered by composite-plate with low work function of electron ($\varphi \leq 1{,}5$eV). A strong current arc discharge was applied for dissociation, ionization and dissociative ionization of H_2 molecules. For changing $H^+ \rightarrow H^-$ a positive hydrogen ions from first discharge chamber, which are extracted toward the ion source slit, is the recharged method on residual gas layer in the second discharge chamber was used.

A single crystal LaB_6 as a good electron emitter is used as a cathode and anticathode [5 - 7]. This material have very good physical properties such as high melting point, chemical inertness, high brightness of emission current, low work function of electrons and resists erosion under ion bombardment. In our case lanthanum hexaboride is used in form of thin plate as an indirectly heated cathode and anticathode. The crystal LaB_6 oriented by crystal face with very small work function of electrons (<001> $\varphi \leq 2{,}3$ eV) in the direction of both chamber discharge.

3. Composite ionizer

In according to the Saha - Langmuir law the probability of evaporation from ionizer surface negative ions (β) is determine by equation:

$$\beta = Ae^{e(s-\varphi)/kT}(Ae^{e(s-\varphi)/kT}+1)^{-1}, \qquad \alpha = Ae^{e(s-\varphi)/kT}, \qquad (1)$$

were α - degree of ionization; s - electron affinity of hydrogen; φ - work function of electrons ionizer material; T - temperature of ionizer.

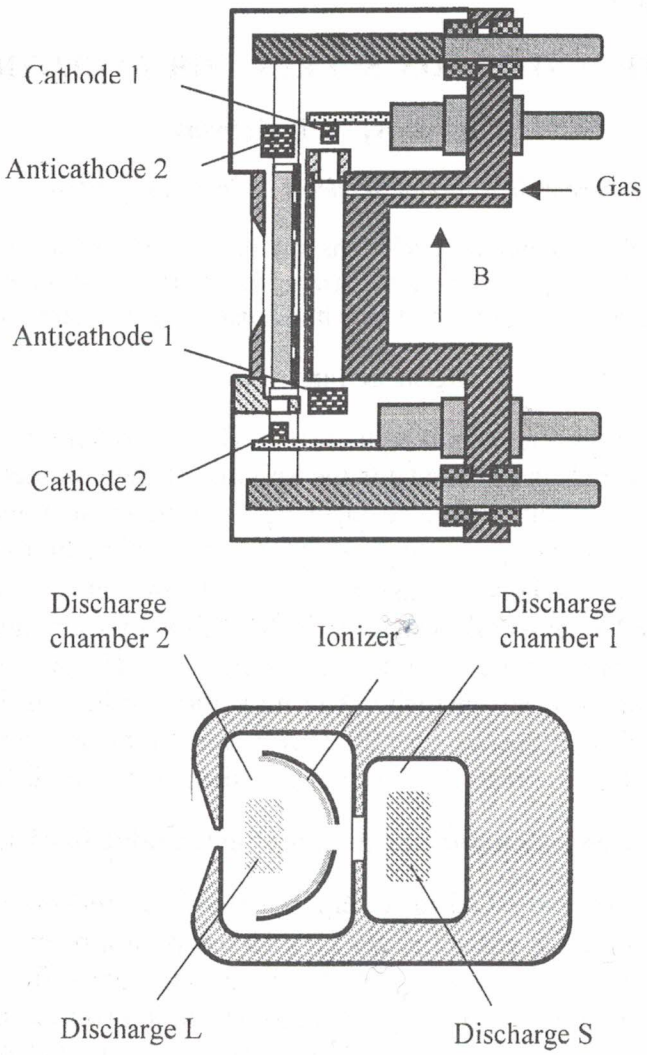

Fig. 1. A schematic construction of the H^- ion source.

In according to this expression it will be a good idea to have ionizer with a very low work function of electrons.

For this purpose on the ionizer surface a mixture of oxides elements of Ba, Sr and Ca were applied, which have work function of electrons in a range of 1,0 ÷ 1,8 eV, dependent on backing material, density composition, depth of oxide layer, depends from the residual gas pressure. It has been known, that oxides BaO, SrO and CaO have no stability in air, therefore as starting coat materials for formation working layer the carbonates of this matters were used, which after leating by calcination in vacuum is transformed into the oxides. The carbonate $(BaSrCa)CO_3$ was needed as starting materials. Oxide coating on the molybdenum base produced in the process off pre-burn age ion source in vacuum chamber of cyclotron. Work function of electrons on such surface accounts for around 1,4 - 1,6 eV. The lifetime of the ionizer surface ion source by $T \leq 1300$ K account for several days in good vacuum in cyclotron chamber.

The energy of activation of desorbted atoms from ionizer surface depends on temperature, which was not possible more then temperature of melting point of the backing material. The degree of ionization hydrogen atoms desorbtion from ionizer surface by $T \leq T_{melt}$ even with low work function of electrons ($\varphi \leq 1,5$ eV) may be not big ($a \approx 0,06 \cdot 10^{-4}$ at the $T \approx 1200$ K).

In order to amplification H^- ions desorbtion from ionizer surface it is possible by method of ion bombardment of this surface by positive charged hydrogen ions extracted from gas discharge.

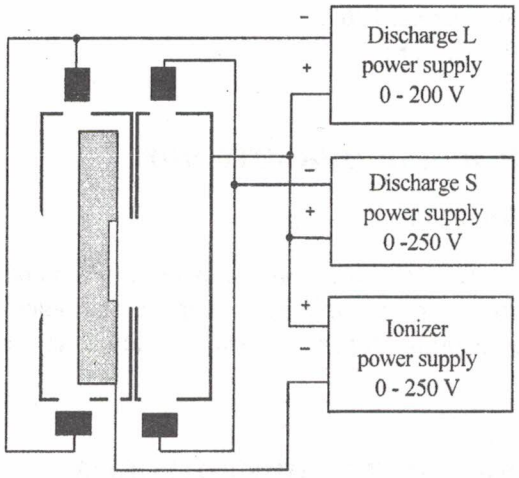

Fig. 2. The electrical block diagram of the operating circuits.

Degree of ionization H^- ions (S_H = 0,75 eV) to oxide ionizer $\alpha_{1,5}$ (φ = 1,5 eV) and lanthanum hexaboride ionizer $\alpha_{2,3}$(φ = 2,3 eV)

T, eV	T, K	$\alpha_{1,5}$	$\alpha_{2,3}$
0,1	1164	$0{,}057\cdot10^{-4}$	$2{,}0\cdot10^{-7}$
0,2	2328	0,024	$4{,}4\cdot10^{-4}$
0,3	3492	0,083	$6{,}0\cdot10^{-3}$
0,4	4656	0,1545	0,02
0,5	5820	0,2244	0,046
1,0	11640	0,4737	0,213
2,0	23300	0,6889	0,462
3,0	34900	0,777	0,6
4,0	46600	0,83	0,68
5,0	58200	0,86	0,734

For this aim an variable negative potential (0÷-250 V) is applied to the ionizer. The energy of proton 1 eV correspond to T = 11640 K. Using the ion bombardment method of ionizer surface it is possible to use instead of oxides a single crystal lanthanum hexaboride (LaB_6), which is oriented to the discharge side by crystal face with low work function of electrons (2,27 – 2,3 eV). A single crystal of LaB_6, mentioned above, is a very hard material and has another unusual physical properties such as high melting point, high resists erosion under ion borbardment. The degree of ionization negative hydrogen ions according to the bombardment energy of proton (H^+) is presented in the table for the oxides and lanthanum hexaboride ionizer.

Ionizer with oxide layer was developed by Kyiv Institute of Material Research.

4. Conclusion

If the beam current of H^+ ions which are extracted from gas discharge in a second discharge chamber to the ionizer electrode about 0,1 A and the coefficient of sputtering ~ 0,1 the flux of H^- ions from the surface of ionizer will correspond to ~ 10mA. H^- ions, produced in low-voltage gas discharge [8] in a second chamber and by charge exchange H^+ ions on the residuel gas anticipate a total current H^- ions ≥ 12 mA. The H^+ ions are extracted by means of electrode ionizer from the strong-current discharge in the first chamber.

Such ion source may be used for production of another negative ions elements, which have large electron affinity, for example, Cl^- (s= 3,61 eV), O^- (s = 1,46 eV).

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ВИСОКОЕФЕКТИВНЕ ДЖЕРЕЛО ІОНІВ H^- ДЛЯ ЦИКЛОТРОНІВ

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Розроблено внутрішнє джерело іонів для циклотронів, яке дає можливість завдяки використанню дуже ефективних методів отримувати високий струм іонів H^-. Джерело має високу газову ефективність. Використовується плазменно-поверхневий метод одержання іонів H^- без застосування пари цезію.

ВЫСОКОЭФФЕКТИВНЫЙ ИСТОЧНИК ИОНОВ H^- ДЛЯ ЦИКЛОТРОНОВ

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Разработан внутренний высокоточный источник ионов H^- для циклотронов в котором используется несколько очень эффективных методов образования ионов H^-. Источник ионов обладает высокой газовой эффективностью. Используется плазменно-поверхностный метод получения ионов H^- без применения пара цезия.

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