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HIGH CURRENT ION SOURCE FOR RFQ EXPERIMENTS*

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ABSTRACT

A source capable of producing high ion currents at low beam energies has been constructed for RFQ applications. The plasma generated by a Duoplasmatron is compressed by a solenoidal field to produce a high density plasma column of 1 mm diameter and 200 mm length. Extraction is done from a single aperture by a high voltage ratio accel/decel system. The beam leaves the plasma boundary divergently and is made parallel by the focussing action of the decel electrode. The small extraction aperture and the low beam energy result in a high normalized brilliance of that source. Ion currents up to 20 mA have been extracted at beam energies of only 1 keV. At higher energies the current may be raised up to 100 mA and more.

INTRODUCTION

To study the physical limitations of RFQ accelerators high current proton beams with a low energy (1-20 keV) and a low emittance are required. The ion current which can be extracted from a single aperture of a plasma source by a conventional accel/decel extraction system is limited by space charge and follows a $U^{3/2}$-law [1]. The maximum perveance which can be obtainded for protons is in the region of $2*10^{-8} A/V^{3/2}$. This limitation is valid for all ion sources wich use plasma extraction and higher currents can only be obtained by the use of multiaperture extraction systems. Multiaperture extracion, however, results in a larger emittance and an inhomogeneous distribution in phase space, wich complicates the study of beam dynamics in the RFQ.

Another limitation of most high current ion sources is a low proton fraction in the beam, so not all the extracted current can be utilized for acceleration.

Thus a new concept for an ion source with a high perveance extraction system and a high proton fraction was investigated at our institute.

THE PLASMA GENERATOR

The plasma generator (fig. 1) consists of a GSI-Duoplasmatron source followed by a second discharge chamber which can be evacuated by a turbo-pump at source potential. The plasma produced by the Duo-

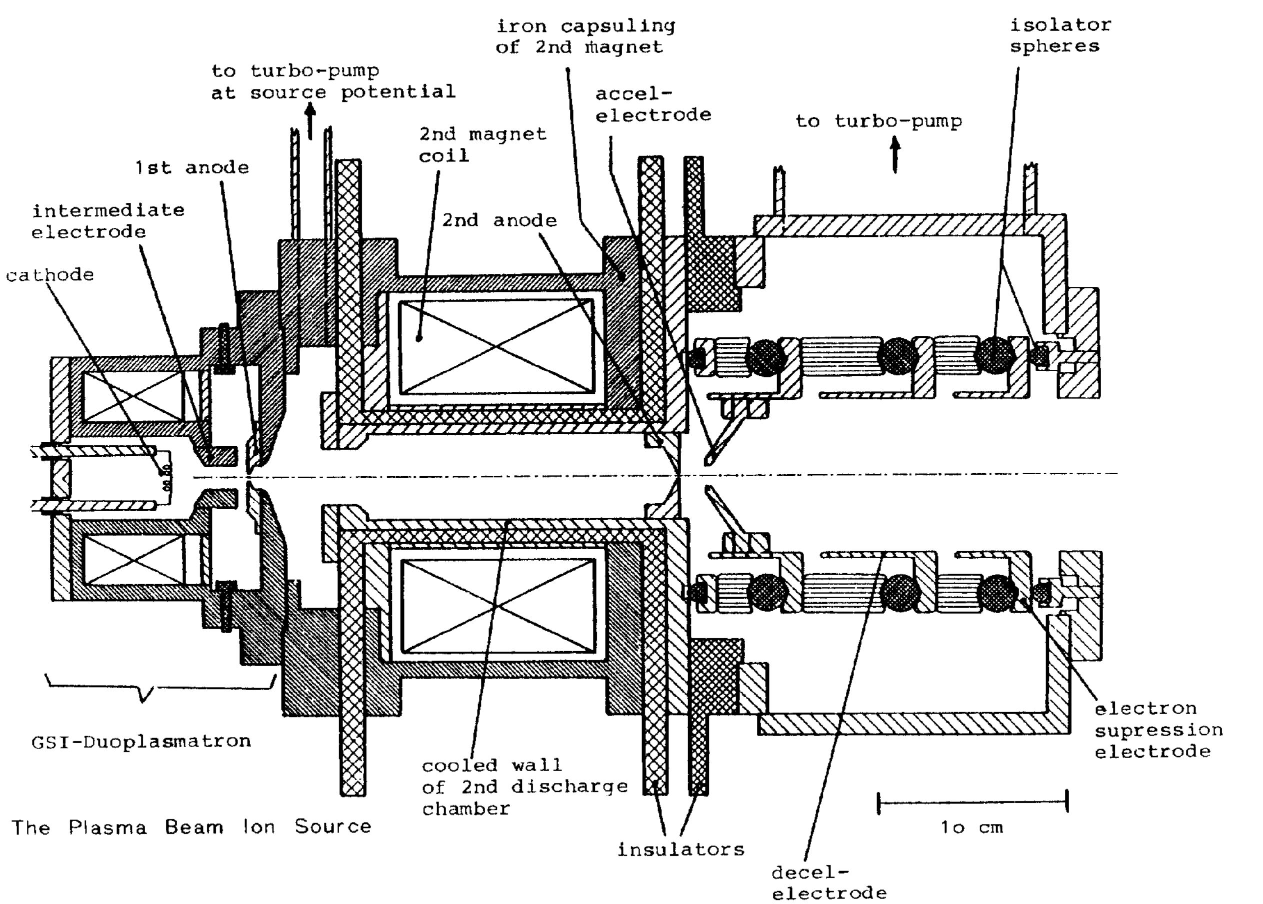

Fig. 1 The Plasma Beam Ion Source

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plasmatron is injected through an aperture of 2 mm into the second chamber, where it is further compressed by an inhomogeneous solenoidal field. This results in a high density plasma column of aproximately 1 mm diameter and 200 mm length.

The second anode can be either positive or negative with respect to the anode of the Duoplasmatron (1st anode). At a potential of +100 V the discharge current amounts to 10 A or more with a subsequent current density of 1000 A/cm. In this mode of operation the highest ion current densities can be obtained at the outlet aperture.

At negative potentials (up to -200V) with respect to the first anode a high intensity discharge can still be maintained, even though the current meassured in the second discharge circuit is nearly zero. Electrons are reflected by the 2nd anode and perform a pendular motion in the second discharge chamber. In this mode the ion current density that can be extracted is about 40% lower than in the case of a positive potential on the 2nd anode. The proton fraction however is increased dramatically.

THE EXRTRACTIONSYSTEM

In conventional accel/decel extraction systems the ions are extracted with a low voltage ratio U_{ex} / U_b (U_{ex} = extraction voltage, U_b = beam energgy/e) from a slightly concave plasma meniscus and are made parallel by the defocussing effect of the extraction electrode. The negative potential of the extraction electrode with respect to ground potential serves merely to supress secondary electrons from the beamline. The lens effect of the final deceleration is negligable for the commonly used voltage ratio of 1.2 . The perveance of this type of system is limited to about $2*10^{-8}$ for protons.

The perveance with respect to the final beam energy (U_b/e) can be increased however if the beam is extracted with a high extraction voltage U_{ex} and then decelerated to the desired low energy. As Greens [2] has shown, such a high voltage ratio (U_{ex}/U_b > 3) has a net focussing effect, i.e. the beam is accelerated from a convex meniscus in this case and is made parallel by the focussing effect of the deceleration. This type of extraction requires a high plasma density and a small outlet aperture as it exists in the source described above.

Fig. 2 shows a simulation of the extraction system employed for RFQ injection. The beam is extracted divergently from an aperture of 1 mm with a low aspect ratio r/d = 0.1 (r = outlet aperture radius, d = distance of extraction electrode). This gives a relatively low perveance with respect to U_{ex}. After a drift a few centimeters deceleration takes place, which results in a parallel beam with a large diameter (3-4 cm). The perveance P_b depends on the extraction voltage and can be increased to $60 * 10^{-8}$ A/V $^{3/2}$ by this method.

THE INJECTION LINE

Fig. 3 shows a schematic diagram of the complete injection system for RFQ experiments. It consists of the ion source, the extraction system and a magnetic lens. The emittance of the beam can be meassured with a slit and profile wire assembly directly before the entrance of the RFQ. The ion beam leaves the extraction system parallel or with a slight divergence. The divergence angle can be adjusted by applying a negative or positive high voltage to the middle electrode of the extraction system. In the latter case the last electrode has to carry a negative potential to supress secondary electrons from the beamline. Although the beam perveance is high, the space charge in the beam is low due to its large diameter.

As the RFQ requires a beam with a convergence angle of 15 - 20°, the final focussing into the RFQ is done with a lens which is positioned very closely to the entrance of the accelerator. In our case an iron capsulated soledoid lens is used. The pole tips of this lens have been specially shaped and a system of two field gaps is usded to reduce spherical aberrations [3].

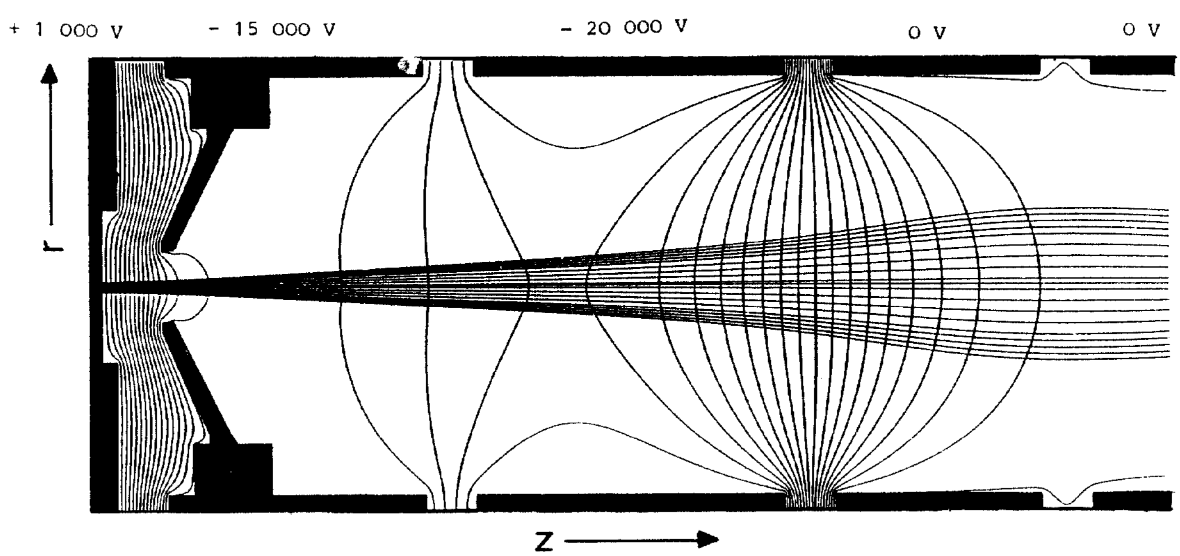

Fig. 2 Computer simulation of the extraction system

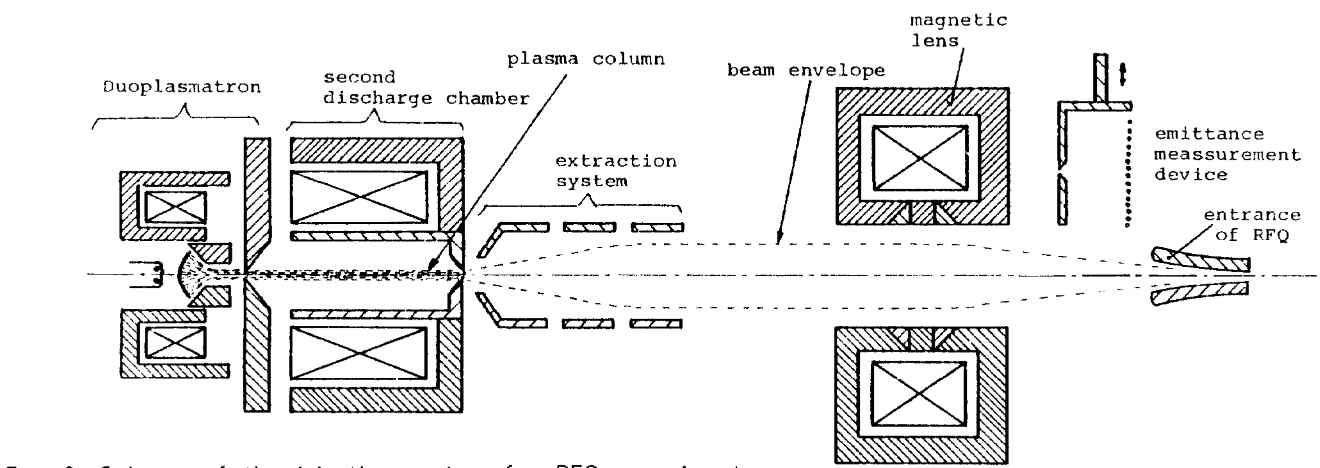

Fig. 3 Scheme of the injection system for RFQ experiments

RESULTS

Fig. 4. shows the percentage of the different ion species in the extracted beam versus the maximum of the magnetic field in the second discharge chamber. The proton fraction can be raised from 20% at low magnetic fields to 90% at a field of 0.5 T. The ion composition does, however not only depend on the strength of the field maximum, but also on the magnetic field at the first anode. The field distribution in this region can be varied through a balance of the currents in the two coils. By this variation and through an adjustment of the pressure and the discharge voltages any charge state in the extracted beam can be optimized. I.e. also 90% H_2 or 80% $H_3{}^+$ can be obtained. Similar effects have been observed with other gases (N_2, Ar, Kr) With Argon operation also higher charge states up to Ar^{4+} were observed. Further investigations in this direction have jet to be made.

A proton beam with a current of 20 mA could be extracted at a beam energy of only 1 keV which corresponds to a perveance $P_b = 63 * 10^{-8}$ A/V $^{3/2}$ The extraction voltage was 27 kV and the extraction perveance $P_{ex} = 0.45 * 10^{-8}$ in this case.

The plasma density can be increased to supply ion currents up to 100 mA from an aperture of 2 mm diameter with a positive 2nd anode. This is equivalent to an ion current density of 3.2 A/cm ^{2} at the outlet aperture. Here the beam energy has to be increased however and the proton percentage is only 60%. With an increase in beam energy the beam perveance has to be decreased, as the high voltage ratio of 28 can not be maintained due to sparking in the extraction gap.

Fig. 5 shows an emittance diagramm meassured at the entrance of the RFQ. The beam was focussed onto the slit of the emittance meassurement device, which is indicated by the upright orientation of the emittance diagramm. The divergent part of the beam consists of neutralized particles and is not focussed by the lens. The unnormalized 90% emittance is 50 mm*mrad; with an energgy of 1 keV and a current of 18 mA this results in a normalized brilliance of 3,2 A / mm ^{2} * mmrad ^{2}.

The injection system will be tested in the near future with the split coaxial four rod RFQ [4] which was developed at our institute.

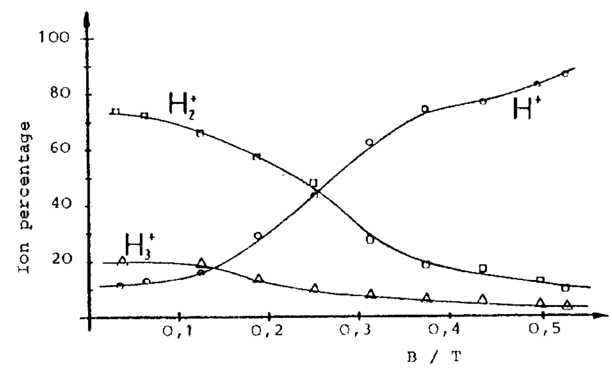

Fig. 4 Ion composition versus magnetic field in the second discharge chamber

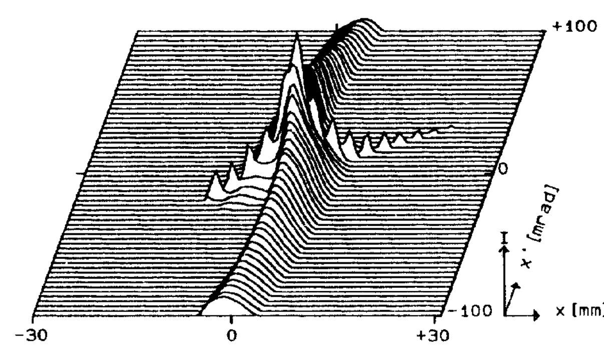

Fig. 5 Emittance meassurement at entrance of RFQ

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