ION SOURCE FOR THE JUELICH SNQ-PROJECT

G. Crecelius and R. Hölzle

Kernforschungsanlage Juelich, SNQ-ABT
POB 1913, D-5170 Juelich, Germany

Abstract

We report on the construction of a hydrogen ion source to provide a proton beam of about 150 mA at an energy of 50 keV. The source is of the magnetic multipole type. The ion density in the extraction plane at a discharge current of 76 A has been determined to be 200 mA/cm^2 from the ion saturation current of a Langmuir-probe. The proton fraction in the plasma is as high as 74 % at this operation condition as measured by a magnetic momentum mass analyser. The proton fraction in the plasma is related to plasma parameters via a scaling equation to give reasonable agreement.

In a spallation source neutrons are produced by bombarding a high-Z-material target with energetic particles, preferentially with protons. In the Juelich project a peak current of 200 mA of protons at a duty factor of 2.5 % is to be accelerated. The current has to be supplied by two ion sources, each delivering about 150 mA dc.

To meet the requirements imposed by the accelerator, we have constructed a magnetic multipole type ion source [1] to be operated with hydrogen. Major disadvantage of the source for our purposes is the nonproton fraction in the extracted beam to be too high for the source to be used without a bending magnet to clean out H_2^+ and H_3^+ species.

We have constructed a cylindrical discharge vessel being double walled for water cooling with an inner diameter of 130 mm and a length of 140 mm. The source contains 3 hairpin shaped tungsten filaments of 1 mm diameter and 8 axially arranged rows of Sm Co permanent magnets on the cylinder wall. The magnets are oriented radially on the rear cover. The magnetic field at the inner chamber wall has been 2 kOe in these experiments and can be increased to about 3 kOe by adding soft iron yokes. The plasma electrode is at cathode potential to serve as reflex electrode. A schematic of the source is shown in fig. 1. The inner chamber wall is made from stainless steel.

The essential advantage of this type of source is that it produces a large volume plasma of homogeneous density. The insert in fig. 1 represents the ion density in the source as a function of the source radius. The ordinate actually is the ion saturation current of a Langmuir-probe [2] measured at a probe potential V_s = - 80 V with respect to anode potential at a discharge current of 34 A. The probe area was 1 mm^2. It will be shown in the following, that the source is reasonably operated at about 75 A discharge current, so that the ion current density is 200 mA/cm^2 in the extraction plane.

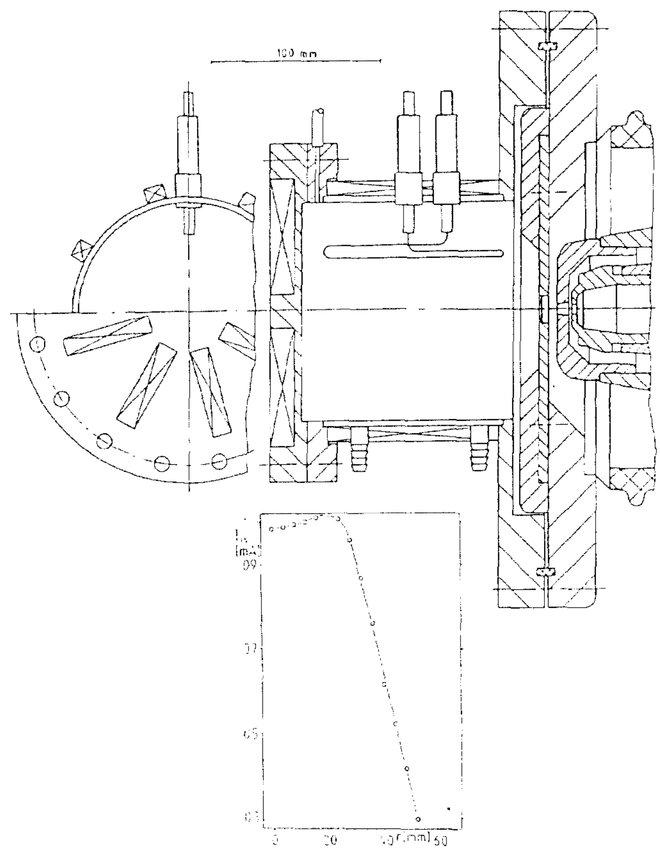

Fig. 1 Cross sectional view of the magnetic multipole ion source. Insert shows the ion density as function of distance from bucket axis.

The ion current density is also estimated by polarizing the accel electrode to minus 100 V with respect to the cathode potential thus using it as a Faraday cup. With an extraction aperture of 1 cm^2 the ion current was 130 mA which is in line with the finding by B. Piosczyk [3] who also observed a ratio of about 1.5 between current densities determined by Langmuir-probe and direct extraction, respectively.

In addition to a homogeneous ion density in the region of the extraction aperture the ion source should be characterized by a high electrical efficiency, ionization efficiency and proton yield.

0018-9499/85/1000-1785$01.00© 1985 IEEE

The electrical efficiency, defined as the ion-current at the extraction plane per kilowatt dissipated power [4] is (2.10 ± 0.06) A·kW^{-1} for our source independent of arc voltage in the regime 50 V ≤ U_A ≤ 120 V.

The ionisation efficiency η_{eff} is the number of primary electrons necessary to produce an ion [4] .

$$\frac{1}{\eta_{eff}} = \frac{I_e}{I_i} \propto \frac{1}{n_o \cdot \tau_e} \qquad (1)$$

I_e is the electron current emitted by the filaments, I_i designates the measureable part of the ion current, i.e. that which flows through the plasma electrode, n_o is the gas density and τ_e the electron life time.

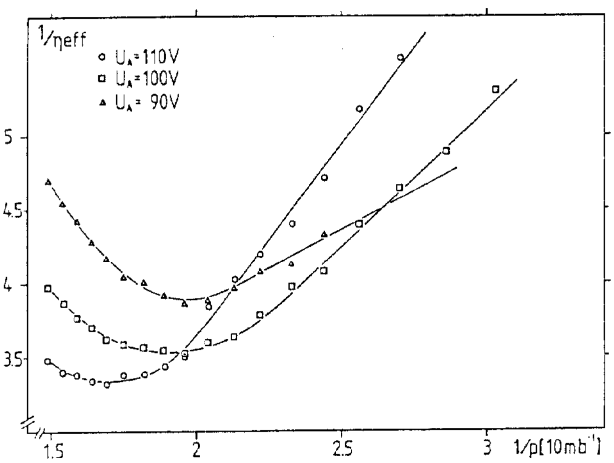

Fig. 2 Reciprocal effective ionisation effidiency $1/\eta_{eff} = I_e/I_i$ as function of reciprocal source pressure 1/p.

Fig. 2 shows $1/\eta_{eff}$ as function of p^{-1} for three values of arc voltage. As expected from equ. (1) $1/\eta_{eff}$ is linear with 1/p for not too high pressure and as the slope is smaller the larger τ_e, the electron lifetime decreases with U_A. The ionisation efficiency of our source is not too good as compared with those reported in the literature [4]. We use three cathodes to increase source lifetime which increases the ion loss area. It will become clear below, that we also do not want to decrease ion loss in the cusp areas too much as this also reduces plasma volume more than proportional.

The proton fraction in the discharge has been measured by a magnetic momentum mass analyser. Fig. 3 shows H_1^+ , H_2^+ and H_3^+ contributions in the extracted beam as function of arc current for arc voltage U_A = 90 V, and hydrogen pressure p = 4.8·10^{-2} mb. Representative spectra are given in fig. 4 for I_A = 22 A, 42 A and 76 A. The proton fraction increases with I_A somewhat slower than linear and for I_A = 76 A is as high as 74 %.
We have also measured the contribution of different ion species to the extracted current as function of arc voltage at constant arc current I_A = 22 A and source pressure p = 5·10^{-2} mb.

Fig. 5 shows ion species in the extracted beam as function of arc voltage. H_3^+ contribution remains about constant at 57 ± 3 %, H_2^+ increases about linear from 3 % at 40 V to 22 % at 120 V, proton content decreases from 42 % at 40 V to 24 % at 120 V.
OKUMURA etal. have derived a scaling equation on the proton - to H_2^+ - ratio as a function of plasma volume V_p and ion loss area L_s [5]

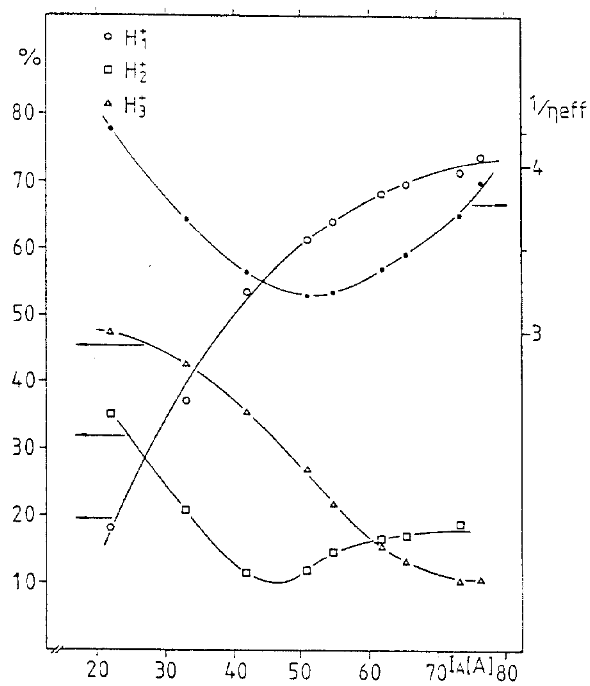

Fig. 3 H_1^+, H_2^+ and H_3^+ contents in the extracted beam as function of arc current I_A at arc voltage U_A = 90 V. Dots represent inverse ionisation efficiency $1/\eta_{eff}$ as function of U_A.

The electron temperature in our source at 76 A arc current has been determined to be about 5.4 eV by extrapolation of Langmuir-probe measurements. Using parameters of our source their equ. (13) reads

$$\Gamma \approx \frac{1}{1 + \frac{L_s}{0.19\ V_p}}$$

With an estimate of V_p/S_L = 10 cm we arrive at a proton fraction of 65.4 % which is in reasonable agreement with experiment if we realize, that V_p/S_L cannot be determined very accurately, and reaction rate coefficients may vary with electron temperature, too.

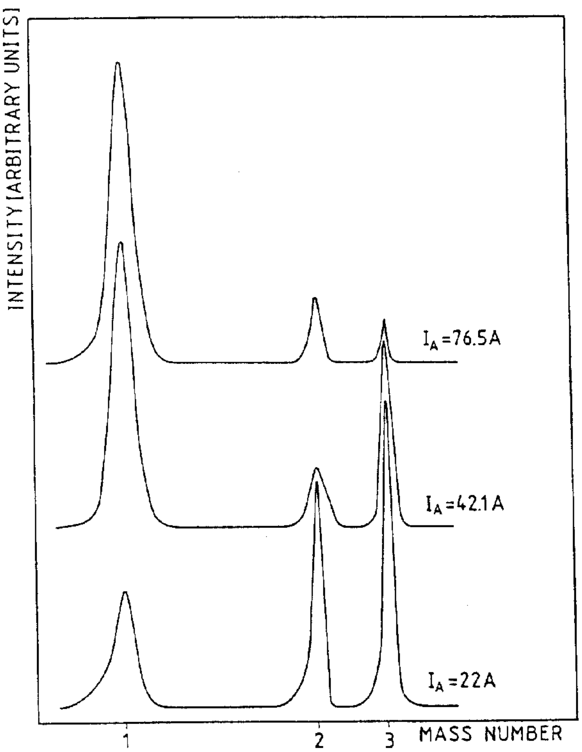

Fig. 4 Mass spectra of the extracted beam at I_A = 22A, 42 A and 76 A showing relative contributions of H_1^+, H_2^+ and H_3^+ at U_A = 90 V.

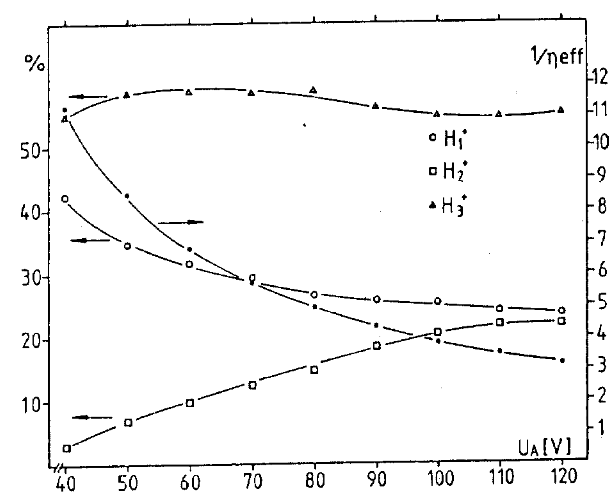

Fig.5 H_1^+, H_2^+ and H_3^+ contents in the extracted beam as function of arc voltage U_A at arc current I_A = 22 A. Dots represent inverse ionisation efficiency $1/\eta_{eff}$ as function of U_A.

We gratefully acknowledge experimental assistence and aid in preparing the manuskript by Frau B. Kurth, H. Schell, G. Müllejans, N. Wolters, [illegible]. Eggenweiler and A. Beuel.

References

[1] R. Limpaecher and K.R. McKenzie, Rev. Sci. Instr. 44, 726 (1973)

[2] See for example L. Schott in: Plasma Diagnostics, W. Lochte-Holtgreven, ed., North Holland, Amsterdam 1968

[3] B. Piosczyk, Realisierungsstudie zur Spallations-Neutronenquelle, G. Bauer, S. Sebening, J.-E. Vetter, H. Willax, ed., Juelich & Karlsruhe 1981, Vol. III A1, p. 12, 20.

[4] T.S. Green in: Low Energy Ion Beams, I.H. Wilson and K.G. Stephens, ed., The Institute of Physics, Bristol and London 1980, p. 271

[5] Y.Okumura, H. Horiike, and K. Mizuhashi, Rev. Sci. Instr. 55, 1 (1984)