NEW DEVELOPMENTS IN ION SOURCES AT IBA

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Abstract

Due to the increasing need for high performance ion sources, both within IBA and in the commercial market, an Ion Source Development Group has been formed. Miniature negative and positive PIG ion sources have been developed for our programme of "baby cyclotrons" (see papers and posters at this conference). Below a review of their design and their preliminary measured performance is given. Programmes are underway, using both numerical models and experiments to improve the performance, and reduce the cost of our positive and negative multicusp sources. The highly intense and efficient ECR ion source of the electromagnetic isotope separator developed by IRE (Institut national Radio Elements, Belgium) following a conceptual design by IBA is discussed by one of the authors (FB).

PIG Ion Source Development Programme

PIG ion sources are some of the best known ion sources and have been widely used with great success for the production of both heavy and light ions[1]. Our challenge was to design a series of extremely **compact** ion sources which could be installed at a cyclotron centre and could be changed by a relatively unskilled operator in 15 minutes. These were developed for our 3Mev D^+ cyclotron (hereafter "C3D") and our 10Mev H^- / 5Mev D^- cyclotron (hereafter "C10/5").

The most severe design limitation is that of available area. For both of these machines the central region is very small. In the case of the C10/5 with a negative deuteron and hydrogen capability the two sources must fit into a diameter of 12cm. In all cases the height of the ion source cannot be greater than the distance between the cyclotron poles ie 50mm. Because of the complexities in the magnetic field in the central region with axial insertion it was felt that the most certain method was to insert the sources transversely. This places another constraint that the beam must pass between the source cooling pipes and electrical feeds. For the negative ion versions of this design, gas leaks are kept to a minimum in order to reduce the effects of electron stripping.

By designing an ion source with cathodes that are only heated by ionic bombardment and thus do not require additional heating, it is possible to squeeze two ion sources into a space of twelve cm diameter. Figure 1 shows a cross-sectional view of the ion source concept. Cathodes are made of high purity tantalum which with a head thickness of two millimeters which gives an operational lifetime of approximately 500 hours. Cathode lifetime is significantly reduced by heavy ion contamination of the arc chamber which radically increases the sputtering rate. It is thus essential that the source be extremely clean. The small size required makes water cooling of the arc column chimney extremely difficult. The chimney can be operated at a very high temperature by the use of a tungsten/copper composite.

To date the prototype has been running successfully in the C3D for 6 months. The negative version of this source has just been installed in the C10/5 and though successfully ignited the performance has not yet been measured.

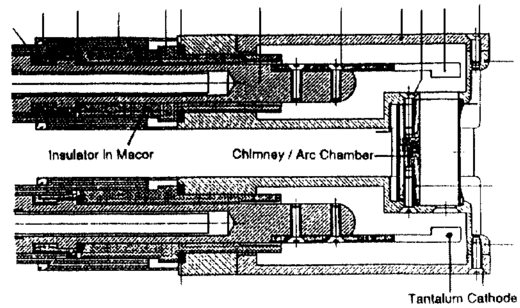

Figure 1 Cross-Sectional View of the Miniature PIG Ion Source

The operational parameters of the C3D source can be summarised in the table below.

Operational parameters of the IBA D+ Miniature PIG Ion Source

Start up voltage	3 kV
Operational voltage/current	600 V / 2 A
Gas Input Rate Deuterium	2 sccm^{-1}
Total Positive Current Output (20kV extr)	8mA

Multicusp Development Programme

After several years of success with both positive and negative ion sources, several new projects are underway: increasing the output of negative ion sources, improvement of the beam optics of positive ion sources at low extraction voltages, redesigning of the source body to improve performance and reduce cost. In order to meet these goals a powerful new test system is in the very final stages of completion, see Figure 2. It comprises of a beam transport line, in which may be placed: an emittance meter (under construction), moveable faraday cups (being designed), a graduated faraday cup(being designed), an Einsell or a glaser lens (here), "kapton camera" [5] (being designed) and analysis magnet (both here).

In order to be able to perform experiments as easily as possible, the system modules are mounted on rails which allow a single person to split the system and rapidly remove or add components. Several modular vacuum chambers have been constructed each of which provide four ports to allow the insertion of beam analysis instruments without breaking the vacuum.

The experimental test system is complemented by the use of modelling software. For the last two months AXCEL INP [6] has been used to model the extraction geometry of positive ion sources. When the test system is completed it should give us the possibility of verifying these results which will allow us to *engineer* the extraction geometry. Figure 3 below presents an example run of the extraction geometry of the source constructed for AGOR.

Before the present test system has been completed a tentative series of tests is being undertaken in an attempt to increase the efficiency of the negative multicusp sources. Attempts have been made to duplicate the results of Leung *et al* [2] where the efficiency of a negative ion multicusp source was greatly improved (a factor of two) by reducing the distance between the extraction hole and the

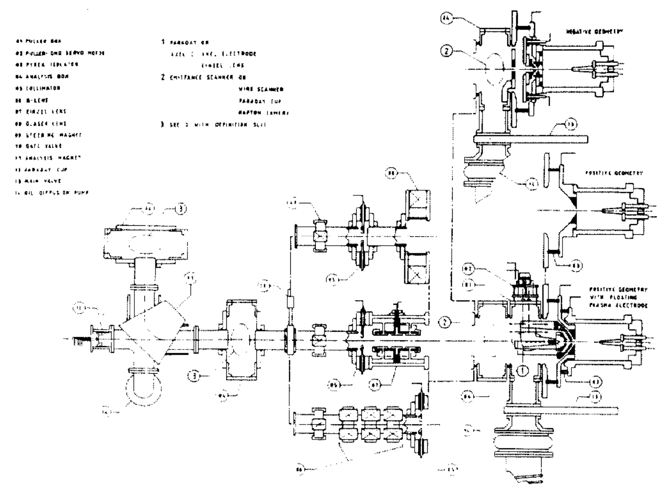

Figure 2 Modular Ion Source Test System
This shows the possibilities of mounting multicusp ion sources in several different configurations. Several different lenses are available to be inserted. In each of the four analysis boxes instruments can be placed.

magnetic filter. Also to duplicate the results by adding xenon to the source of Walter et al [3]. In our case the results were either neutral or deleterious. As these are only preliminary results it is hoped that this difference of comportment between our and their sources will be soon understood.

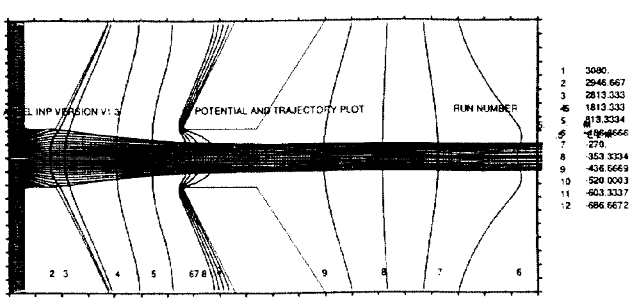

Figure 3 Extraction Geometry Simulation.
The ion source is at 3kV, the puller at -500V, the source is assumed to give 800 microamps of current, with "standard" plasma parameters used.

E.C.R. high intensity high efficiency ion source for E.M.I.S.

A new kind of ECR source producing high intensity beams of singly-charged heavy ions has been developed by IRE following a conceptual design by IBA. The source was initially built for EMIS to separate xenon but may also be used for others isotopes and has applications in ion implantators.

Current densities between 4 and 5 mAcm^{-2} in singly-charged xenon can be produced with an acceleration of 35 kV. The source runs at a comparative high pressure (10^{-3} mbar) for an ECR source and has an efficiency greater than 55%. The percentage of multiply-charged ions is less than 15%.

The coupling wave-plasma is very efficient (>90%) and the input power low (150 W). The extraction electrodes are adjustable to ensure that the emittance does not exceed 125 π mm mrad.

The reliability of operations and the easy tuning of the source parameters, means that the complete source including the vacuum system, the power supplies and the klystron amplifier can be remotely controlled. The source can run for several weeks without intervention.

Introduction: The important factors for ion sources for use in an electro-magnetic isotope separator (or ion implantator) are filament lifetime, reliability and the ability to produce high currents of singly-charged ions with high brightness.

In most ion sources, the sputtering and erosion of the filament are major drawbacks. In an ECR ion source, the plasma is heated by microwaves injected via a window from a waveguide thus insulator coating is the only factor limiting the operational lifetime. Three easily adjustable parameters control the operation of the source: The microwave power injected, the gas input whish establishes the pressure inside the plasma chamber and the magnetic confinement.

For a long period the ECR source was used for the production of multiply-charged heavy ions [7]. In 1985, Bechtold (*et al.*) introduced a new kind of ECR source with a high efficiency for the production of heavy ions in EMIS [8] and production of radioactive ions beam [8] [9] [10]. The source we describe here reaches an intensity of 3.5 mA in singly-charged ions with gas efficiency of above 55%, and the emittance less than 125 π mm.mrad.

Source Design. ECR ion sources are normally used for the production of multiply-charged ions by a high confinement, low pressure and high plasma density. Our aim was to maintain the plasma density and the good efficiency but decrease the percentage of multiply-charged ions.

We chose a frequency of 6 GHz, i.e. λ = 47 mm. In order to have multi-mode operation, we chose a cavity diameter of 110 mm with a length of 300 mm. The radial confinement is produced by an hexapole created by 12 Sm-Co rods [10]. The axial magnetic field has a mirror ratio of 1.2.

The microwave power is injected axially via waveguide and a quartz window at the rear of the source. The gas inlet is calibrated so as to regulate the gas flow into the chamber. A gauge measures the pressure. The source is pumped via the 10 mm diameter extraction hole. An adjustable three-electrode extraction system gives a good emittance and good beam neutralisation.

Source Parameters.

Current density:	4.5 mAcm^{-2} (Xe 1+)
Current efficiency:	n=80-90%singly-charged
Ionisation efficiency:	E= 55% in Xe
Total current:	It= 3.5 mA (Xe)
Input power:	P_{HF}< 150 W
Gas inlet	q = 1.2 10^{-3} mlsec^{-1}.
Source pressure:	P_{source}= 1.5 10^{-3} mbar
Extraction hole:	d = 10 mm
Acceleration voltage:	V_{acc} = 35-40 kV
Puller voltage:	Vp = -1 to -1.8 kV
Emittance:	E = 125 π mm mrad
Ion density:	$n_0 = 2\ 10^{11}$ cm^{-3}
Cut off density:	$n_{cut\ off} = 4.5\ 10$ cm^{-3}
Perveance:	π = 0.09
A extr./ A total :	1.5 10^3

Results. The magnetic confinement is low for an ECR source. The mirror ratio is 1.2 and the magnetic bottle is more open at the extraction side than at the rear.

The gas injection rate is very high (1.2 mbar.l/sec.) and give a pressure of 1.5 10^{-3} mbar. The wave plasma coupling is better than 90% and the RF power is about 150 W. The proportion of the multiply-charged ions is very sensitive to neutral pressure. For a pressure of 1.5 10^{-3} mbar, it is less than 15%. In these conditions, the total current is 3.5 mA, the current of singly-charged xenon is 3 mA.

The current density is 4.5 mAcm^{-2}. We can reasonably assume that the ion temperature T_i < 5 eV, because of the low confining and the low power, wish gives a plasma density of 2 10^{11} cm^{-3}, half as the $n_{cut\text{-}off}$.(Bohm formula). The efficiency is better than 55%. The emittance is lower than 125 π mm mrad. The poissance is less than 0.09.

The complete system including vacuum, klystron amplifier and power supply are fully automated. The operation is so reliable that we can obtain 65% of maximum beam current 5 min after a complete shutdown and maximum beam current after 15 min. High reliability and easy tuning enable this ECR ion source to run for several weeks without any operator intervention.

Acknowledgements

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References

[1] I.G. Brown, in "The Physics and Technology of Ion Sources", Wiley-Interscience, 1989. ISBN 0-471-85708-4.

[2] K.N. Leung, C.A. Hauck, W.B. Kunkel and S.R. Walther, Rev. Sci. Instrum. 60, (4), (April 1989).

[3] S.R. Walther, K.N. Leung and W.B. Kunkel, J. Appl. Phys. 64(7), (Oct 1985.)

[4] "New Developments in Ion Sources at IBA", Steve Laycock, Frédéric Baeten, Marco Bonetti, Edouard Paraf, Emile Conard, Catherine Dom and Yves Jongen. Poster presented at this conference.

[5] Tim Antaya, MSU, private communication.

[6] Peter Spädtke, GSI, private communication

[7] I.J. Brown & Y. Jongen : Taxonomy of ions sources (1989) 207

[8] Bechtold *et al.* Proc. of the accelerated radioactive ion beam workshop (Triumph) (1985)

[9] M. Arnould, F. Baeten *et al.* Journal de physique, 50(1989) C1-813

[10] M. Arnould, F. Baeten *et al.* Nucl. Instr. & Meth. B40/41 498 (1989)