CONF 880955--2

The ATLAS PII-ECR Ion Source Project

R.C. Pardo, P.J. Billquist, and J.E. Dey

CONF-880955--2

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

DE89 000594

Résumé - La source d'ions PII-ECR installée à Argonne est en fonctionnement depuis 10 mois. Le développement des faisceaux a progressé de manière satisfaisante pour les faisceaux produits à partir de gaz ainsi que pour les premiers faisceaux produits à partir de matériaux solides. Le mode d'opération avec haute tension a été réalisé et des faisceaux furent délivrés à un programme de recherche en physique atomique pour une période de quatre mois. Des problèmes avec le transformateur de la haute tension ont limité le temps d'expérience aux tensions élevées. Un test d'échauffement par résonance cyclotron a été effectué, démontrant la possibilité d'augmenter sélectivement la production de certains états de charge dans les distributions du faisceau extrait. Le premier faisceau de la phase I du projet d'injecteur d'ions positifs (PII) est attendu en Février 1989.

Abstract - The Argonne PII-ECR ion source has been operating for ten months. Beam development has proceeded well and has included the first beams from solid materials as well as gases. High voltage operation has been accomplished and beams to an atomic physics program have been provided for a total of four months. Problems with the high voltage transformer has limited run time at high voltage. A test of ion cyclotron resonance heating has occurred, demonstrating the possibility of selectively enhancing certain charge states in the extracted beam distributions. First beam from the Phase I Positive Ion Injector (PII) project is scheduled for February, 1989.

Introduction

In the ten months since first beam was extracted /1/ from the Argonne PII-ECR ion source, the source operation has evolved to a point which is comparable to other large ECR ion sources. A cross section of the PII-ECR ion source is shown in figure 1 and the relevant source parameters are given in Table I. The source problems which were identified when operation began have been solved and a cycle of optimization studies have significantly improved the initial source performance.

During this period the source has been operated with a variety of gases, solid material tests have begun using both oven and solid feed methods, and a total of nearly four months of beam time has been provided to an atomic physics program that makes use of the relatively high beam energies possible from the source which is located on a 350 kV high voltage platform. The demand for high voltage operation by the atomic physics program has revealed the most serious problem in our system to be the reliability of the high voltage transformers which provide power to the source system.

Very preliminary results from experiments of simultaneous ECR and ion cyclotron resonance heating (ICRH) of the plasma will be presented. These tests indicate that ICRH can enhance the production of certain charge states, but the results are not consistent with a simple confinement model.

The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. W-31-109-ENG-38. Accordingly, the U.S. Government retains a nonexclusive, royalty free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

MASTER

Optimization Studies

The early source development focused on redesign of certain components which were found to not work as planned and on a general cycle of optimization of source parameters. For these tests, $^{16}\text{O}^{8+}$ was used as the beam of reference. Later tests, and a slow evolution of understanding the source better, lead us to believe that some of these studies should be repeated for a heavier beam such as ^{84}Kr .

I. Extraction Region

Initial operation revealed that the extraction region insulation design was inadequate during source operation. Pumping holes provided in the extractor electrode appeared to allow an excessive amount of plasma into the region and the insulating sandwich which allowed the use of metal screws and a teflon insulator was inadequate to the task. An excellent solution to the early high voltage breakdown problems was found by replacing the metal screws with a glass reinforced, polyamide plastic screw [2]. The pumping holes in the extraction region were also eliminated.

The initial size of the extraction aperture hole was 8mm diameter. This large hole yielded total extraction currents of 2-4 milliamps under certain conditions and appeared to cause space-charge induced beam blowup. Calculations of the extraction optics indicated that a 6mm diameter extraction hole was the maximum useful size. Tests using 5, 6, and 8 mm diameter extraction holes are consistent with those calculations. This general result appears to be independent of the assumed shape of the meniscus over a rather wide range, but is, instead, controlled by the magnetic field in the extraction region for our iron dominated ion source.

Early source performance was limited also by the einzel lens used as the first focusing element after the source. The lens diameter was too small for the beam and introduced significant aberrations into the downstream optics. Increasing the lens diameter to 10 cm has improved the beam optics, but significant distortions still are apparent and an even larger lens is desirable. This is most obvious when total extracted currents are in excess of 2 milliamps and space charge effects are important. Improvement of the puller electrode alignment has also resulted in improved transmission to targets.

II. First Stage Performance

The cross-sectional view of the Argonne PII-ECR ion source shows a very large first stage. The pumping path for the first stage is provided by the body and the large diameter of 7.5 cm is dictated by pumping speed considerations. Coupling of the RF to the first stage has been very good with small reflections, but the tuning of the source was not very sensitive to the magnetic field in the first stage and ionization of gas inside the quartz inner tube was observed over most of the length of the first stage. The best performance achieved in this configuration was approximately 20 microamps of $^{16}\text{O}^{8+}$.

The first stage was modified by adding a sliding short inside the first stage as shown in figure 1. This immediately doubled the beam from the source and made the source tuning much more sensitive to the magnetic field configuration. Part of the reason may be due to the elimination of RF power in the region of the second ECR condition from the falling fringe magnetic field. This does not explain all of the effect since we now routinely operate with no on-axis ECR condition in the first stage for light ions. Possibly an equally important consideration is the increased RF power density which has resulted from the smaller first stage.

III. Coil Position

The source design included the ability to move the three solenoid coils for optimization of the solenoidal magnetic field profile. This design allowed us to have a simple power supply configuration for the coils but maintain some flexibility in optimizing the source performance.

The optimization was carried out by adjusting the position of the two first stage coils with respect to the extraction region coil which was kept fixed. The optimum position was found to be within 7mm of the original installed position, but that slight change produced a 20% increase in beam current. This method of optimization is most sensitive in selecting the best field configuration for the first stage performance. The change in the second stage mirror ratio was minimal over the range that the tests were conducted.

Present Source Performance

I. Gaseous Material Feed

The source performance, at present, when delivering beams from gases is presented in Table II. These results were obtained using gas mixing with either oxygen or helium as the support gas. Total RF power never exceeded 850 watts for any operation. The consumption of gas varied from a low of 1.2 mg/hr for Krypton to 9 mg/hr for one operating mode with Argon.

A new gas exhausting manifold has been installed so that we may begin to use a variety of noxious gases in the source. Immediate plans include the use of SiH_4 , HI , GeH_4 , and H_2S . The gas manifold for these gases will also be enclosed and vented to the outside.

II. Solid Material Feed

A. Wire feed material

Solid feed material for source operation has also been initiated. The first solid feed tests were done with a 2mm diameter nickel wire fed by a manual linear insertion device. One of the radial access ports was used for material insertion as shown in figure 2.

The first test with the nickel wire used oxygen as a support gas. Performance was very erratic with low charge state distributions and strong ion gettering action causing the second stage gas pressure to drop by a factor of two when the nickel wire was in place. After this unsuccessful trial the source performance for gases was drastically affected. For example, initial currents for $^{16}\text{O}^{6+}$ after this test was only 3 microamps. After sanding the interior and running the source for one week performance of the source returned to the original conditions.

A second test of the nickel wire using helium support gas was tried with significantly improved results. The best performance for this method is shown in Table III and a charge state spectrum for nickel is shown in figure 3. The operation of the source for production runs will require the use of a stepping motor to position the wire on a continuous basis. To maintain source operation the wire feed had to be advanced approximately every five minutes a distance of 0.2 mm. It appears that a stepping motor controlled on time or current as read by the analyzing magnet entrance slits may provide acceptably stable beams. Also test using a different wire trajectory might reduce the sensitivity to position that was observed in these tests. The nickel consumption measured during these tests was 1.1 mg/hour.

A trial with a 2mm diameter copper wire has also been conducted. The results of that short test are also given in Table III. The operation of the source was more stable with copper than with nickel but the beam current achieved in this test was significantly less than observed with nickel.

B. Oven evaporation

A medium temperature (600 C) oven has been constructed for use with materials with the appropriate volatility. This oven design is shown in figure 4. The oven is quite simple and small. It is designed to mount on a water cooled radial port flange which is thermally isolated from the oven by thin-wall stainless steel. The total power consumption for this oven is about 50 watts. Tests have been conducted off-line with cesium and cadmium.

High Voltage Platform Performance

The PII-ECR ion source system includes a high voltage platform designed for operating voltages up to 350 kV. This feature is necessary in order to properly match the velocity of heavy ions from the source to the acceptance of resonators in the PII superconducting linac. The high charge state of ions from the source and the ion energies delivered off the high voltage platform provide a unique set of beams for atomic physics studies and has generated significant interest for use of the system for atomic physics. During the development phase of the source and the construction of the PII linac, a temporary beamline for atomic physics use was installed. A total of about four months of beam time has been provided to the atomic physics program at Argonne since the source began to operate. Of that time about two months of operation at high voltages has occurred.

A variety of measurements /3,4,5/ have been made of energy spread from ECR ion sources which indicate that these sources should be able to provide beams which will compete well with the beam quality from electrostatic accelerator systems. In fact the stability of the preacceleration high voltage will be important in determining the overall beam quality of the preaccelerator. While providing beam to the atomic physics program, the voltage stability of the high voltage platform has been measured when biased to 100 kV. The voltage was found to have a four volt, 60 hertz ripple due to capacitive coupling from the high voltage transformers and a slow (few hertz), less than one volt oscillation from the high voltage power supply. The total voltage stability was found to be less than 5×10^{-5} from all sources. This value is better than our design goal of 1×10^{-4} . The largest component of this stability can be removed with active feedback as is presently accomplished on a similar system used on our tandem electrostatic accelerator. This will be attempted when beam bunching tests begin in November, 1988.

The use of the system at high voltages by the atomic program has provided us with an early test of our high voltage platform components which have been valuable in the system development. Most of the system design features have been shown to operate at or above their design goals. These include the fiber optics control highway, the deionized (resistivity = 10 megohm-cm) water cooling system, and the high voltage power supply. But operation at high voltage has uncovered a major problem with the high voltage isolation power transformers purchased for the system.

The high voltage isolation power transformers are rated to provide 400 kV isolation and provide a total power of 140 kilowatts. The units provided have failed twice while operating at approximately 280 kV. The second failure occurred after nearly one month of continuous operation at voltages between 250 and 320 kV. The failure mode is a high resistance short between the primary and secondary windings. The units are under warranty and the second repair cycle has included significant design changes. Tests of the repaired units should begin in late September, 1988.

Ion Cyclotron Resonance Heating Tests

In the previous ECR conference, an attempt to modify the charge state distribution of endloss ions from the Constance B Quadrupole Mirror was reported /6/. By selectively heating a particular ion species with ion cyclotron resonance heating (ICRH), the loss rate for that ion was expected to be enhanced and an increase in extracted current for that species might occur. In fact when a resonance heating of $^{16}\text{O}^{4+}$ was attempted, the $^{16}\text{O}^{3+}$ end current increased by 25%.

We have begun a series of measurements with ICRH techniques in our ECR ion source to determine if such a technique can be useful as an ion source tool. Here we report a very preliminary series of measurements using ICR heating of oxygen ions.

A solenoidal coil antenna 20 cm long, 9.2 cm diameter (Nagoya type I) /7/ was installed in the second stage of the PII-ECR ion source centered between the second stage magnetic mirrors. The coil was resonated as part of a tank circuit to maximize the inductive voltage in the plasma region. The resonant frequency was chosen to achieve resonance for a particular ion species at the same magnetic field for which electron resonance occurred. The maximum power which could be applied to the circuit was 100 watts resulting in a maximum peak voltage of 850 volts at a frequency of 1.744 MHz (resonance with $^{16}\text{O}^{5+}$) and 660 volts at a frequency of 1.046 MHz (resonance with $^{16}\text{O}^{3+}$). The charge state distribution from the source was then measured as a function of applied ICRH power. The results of these measurements are shown in figure 5 and 6.

The behavior of the source when operated with ICRH strongly depended on the choice of frequency or heated ion species. When the $5+$ charge state of oxygen was chosen as the resonant ion, the performance of the $1+$, $5+$, and $6+$ ions decreased for all ICRH powers. Charge states 2, 3, and 4 showed resonance-like effects at ICRH powers of 5 watts and 60-70 watts. At high power, the overall source performance decreased by approximately 20%. The stability of the source deteriorated as well, but was still acceptable as a source operating mode. It was possible to retune the source with the ICRH power on at fixed power and approximately restore the original source operation.

On the other hand when the ICRH circuit was tuned for resonance with the $^{16}\text{O}^{3+}$, figure 6 shows that a number of charge states were enhanced. The most significant change occurred for the $5+$ charge state current which increased by 100%. Source stability was excellent during this period and total source drain current increased slightly.

Very small amounts of power were required to produce the observed results. Again this was especially true for the heating of the lower charge state. In general most of the modification of the charge state distribution had been accomplished with no more than 30 watts of continuous RF power.

The source conditions during the tests are shown in Table IV. Oxygen was the only gas supplied to the source. These tests were performed just after our terrible experience in the first nickel tests using oxygen as a support gas and the source performance was drastically depressed.

The electric field distribution on axis is peaked at the ends of the antenna. In this region the magnetic field varies rather rapidly and so more than one charge state is in resonance with the ICRH frequency. In the case of the $3+$ charge state resonance tune, the $2+$ oxygen ions are also in resonance. In the case of the $5+$ charge state tune, the $4+$ and $6+$ ions are in resonance as well.

These results indicate that a rather complicated coupling of charge state, ion temperature, and confinement is involved. The poor operating condition of the source does make the generality of these results uncertain. Other measurements will

be necessary if one is to better understand the implications of these tests. Later this year we plan to continue these measurements. An attempt to measure the ion energy spread with a time-of-flight chopping system is planned during the PII injector bunching tests. A spectrometer has also been installed so that the charge state distribution in the plasma can be studied and compared to the extracted distribution. The spectrometer can view the second stage region through a window in the first stage flange.

Summary

The PII-ECR ion source has now met all of its general design goals. The most important problem yet to be resolved is the reliability of the high voltage transformers for the high voltage platform. The immediate developmental plans for the system are the continued development of solid material operation and the installation and testing of the injection bunching system required for the PII superconducting linac. The injection beamline to the superconducting linac will be ready for beam tests near the end of 1988 and the first cryostat of the linac will be ready for initial beam tests in early 1989.

Acknowledgement

This research was supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38.

REFERENCES

- /1/ R.C. Pardo and B.J. Billquist, The Argonne PII-ECR Ion Source Project Status, "International Conference on ECR Ion Sources and Their Applications", NSCL Report #MSUCP-47, 279 (1988).
- /2/ Craftech Industries, Box 1021 Mill-North 2nd. St., Hudson, NY. 12534.
- /3/ H. Köhler, M. Frank, B.A. Huber, and K. Wiesemann, "Energy Distribution of Ion Extracted from a 5 GHz ECR-Ion Source" Contributed Papers of the 7th Workshop on ECR Ion Sources, JUL-CONF-57, 215 (1986).
- /4/ F. Meyer, "Operation of the ORNL ECR Source", Contributed Papers of the 7th Workshop on ECR Ion Sources, JUL-CONF-57, 11 (1986).
- /5/ D.J. Clark, "Emittance Measurements on the LBL ECR Source", NSCL Report #MSUCP-47, 433 (1988).
- /6/ C.C. Petty, D.K. Smith, D.L. Smatlak, and D.L. Goodman, "Studies of High Charge-State Ions in the Constance B Quadrupole Mirror", NSCL Report #MSUCP-47, 151 (1988).
- /7/ T. Watari, et al., Phys. Fluids, 21, 2076 (1978).

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Table I

Argonne PII-ECR Ion Source Parameters as Built

Magnetic Field

Peak on Axis Field	4.75 kG
Solenoid Magnetic Power	35 kW
Maximum Solenoid Current	500 Amp
Typical Solenoid Current	390 Amp
Mirror Ratio	1.60
Length of Second Stage Mirror	47 cm.
Hexapole Material	Nd-Fe-B
Number of Poles	12
Hexapole field at chamber	3.5 kG

RF System

Frequency	10.25 GHz
RF Power	2.5 kW
Independent Control	Both stages

Dimensions

Solenoid Inner Diameter	21.6 cm.
Solenoid Outer Diameter	64.8 cm.
Hexapole Inner Diameter	12.0 cm.
Hexapole Length	49.5 cm.
Vacuum Chamber Inner Diameter	10.8 cm.
Extraction Aperture	6 mm.
Puller Aperture	13 mm.
First Stage Aperture	1.2 cm.

Table IIPIL-ECR Ion Source Beam Currents for Gases
(electrical micro-amps)

Q	^{16}O	^{20}Ne	^{40}Ar	^{58}Ni	^{84}Kr	^{129}Xe
4	-	23				
5	60	-				
6	60	18				
7	4	6	40	30		
8	-	5	60	30		
9		0.1	30	20		
10			-	10		
11			2.5	4	10	
12			1	0.5	-	
13					12	
14					-	5
15					8	4
16					-	-
17					4	2.5
18					-	1.5
19					2	-
20					0.8	1.0
21					-	0.4
22					-	-
23					0.2	0.3
24						-
25						0.2
26				-		0.2

Table III

PII-ECR Ion Source Beam Currents for Solids
(electrical micro-amps)

Q	^{58}Ni	^{63}Cu
7	30	
8	30	
9	20	
10	10	2.5
11	4	3.3
12	0.5	-
13		1.2

Table IV

Operating Parameters of PII-ECR During ICRH Tests

Resonant Ion	$^{16}\text{O}^{3+}$	$^{16}\text{O}^{5+}$
RF Power (watts)	313	439
Extraction Voltage(kV)	10	10
First Stage Vacuum (Torr)	5.4E-6	4.5E-6
Second Stage Vacuum (Torr)	8.6E-7	7.1E-7
First Stage Mirror	1.55	1.62
Second Stage Mirror	1.48	1.42

Figure Captions

- Figure 1. A cross-sectional view of the PII-ECR ion source.
- Figure 2. Solid wire feed assembly for the PII-ECR ion source mounted on a second stage radial access port.
- Figure 3. First spectrum of natural abundance nickel produced from the PII-ECR using the solid wire feed assembly.
- Figure 4. Medium temperature oven mounted on a second stage radial access port for evaporation of high volatility solid materials into the PII-ECR.
- Figure 5. Charge state distribution as a function of ICRH power.
- Figure 6. Charge state distribution as a function of ICRH power.

ARGONNE POSITIVE ION INJECTOR

ECR ION SOURCE

PII-ECR CHARGE STATE SPECTRUM

Fig. 4.

ION CYCLOTRON RESONANCE HEATING TEST