OPERATING EXPERIENCE WITH THE ARGONNE PIIECR ION SOURCE SYSTEM

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Abstract

The Argonne PIIECR ion source is the first ECR ion source system to operate on a high voltage (350 kV) platform. The system is the injector into a new superconducting linac which will eventually provide beams over the entire periodic table, including uranium. The experience we have had with the system to date will be discussed. Emphasis will be placed on the source performance with solid materials and the initial performance of the system as an injector to the superconducting linac. The bunching system which is part of the overall source system allows a determination of the system longitudinal emittance. Results of these initial measurements will be presented.

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Introduction

The Argonne PIIECR ion source is a two stage, 10.25 GHz ECR ion source mounted on a high voltage platform which can be biased to 350 kV. This system is designed to provide bunched, high charge-state heavy ions with a velocity of approximately 0.01c for further acceleration in a superconducting linear accelerator.¹ The source injector system and a new 12 MV superconducting linac will replace the present tandem injector to the ATLAS linac. This upgrade will provide ATLAS with the capability of accelerating all ion species through uranium for the heavy-ion research program at Argonne.

The source design is typical of contemporary high charge state ECR sources. Emphasis was placed on minimizing the power consumed by the solenoid coils and beam transport system and on the production of ion species from solid feed materials. The details of the source design have been reported in previous publications.^{2,3}

Solid Material Development

The use of solids as feed materials is important for our applications because our user community demands beams from throughout the periodic table. We have used three different techniques for solids - externally heated ovens, plasma heated crucibles, and plasma evaporation of wires. All of these techniques make use of radial access ports into the source second stage. These ports were made possible by using high residual field NdFeB permanent magnets for the second stage hexapole. Table I summarizes the source operation for a variety of beams from elemental solids which have been tested.

A plasma-heated enclosed tantalum boat approximately 4 cm long by 6 mm diameter has been used successfully for beams of calcium and selenium. The boat is suspended from a linear motion feedthrough using a thin tantalum wire to provide thermal isolation. The technique has proven to be simple, reliable, and

reproducible for materials whose volatility is such that temperatures of less than approximately 1400 C is sufficient for adequate beam currents. A calcium run of over two days required no adjustment of the boat during that period.

The maximum temperature of 1400 C was measured with an optical pyrometer during a calcium run. The observed maximum temperature is generally consistent with estimates based on the balance between the total energy density in the plasma, estimates of how that energy is distributed, and the thermal radiation from the boat. Although these are very crude estimates, they do point to the fact that this technique runs into a variety of limitations for refractory materials. These observations were also confirmed when a test of the boat technique was tried for aluminum and only nanoamps of aluminum were produced.

For materials requiring temperatures less than approximately 500 C, a low-temperature externally heated oven has been used. The results for cesium using this oven are shown in Table I.

A higher temperature oven is now undergoing preliminary tests. Temperatures of approximately 800 C are expected with this device. Initial off-line tests of the oven have achieved 750 C. Design of externally heated ovens is complicated because of the small size of the radial access port (0.7 cm x 6.4 cm).

An additional "technique" for materials which are solids in their elemental form is to use a compound which is gaseous or can be treated as gaseous for the source material. This approach has been used for beams of boron, silicon, and uranium. For uranium, UF_6 was used as the feed material. The UF_6 was fed into the second stage of the source to minimize consumption. The consumption rate was not directly measured but based on operating pressures and estimated pumping speeds, the consumption rate was in the vicinity of 2-4 mgm/hr. A spectrum optimized for charge state 22 is shown in figure 1. You may notice that the beam current for charge states 13 and 14 increases rather than continuing to

decrease. This effect persisted throughout the test and did not seem to be due to trivial issues such as beam tuning. Instead it may indicate two distinct populations of uranium species in the plasma.

The source was operated in a low uranium charge state mode for an atomic physics experiment using charge state 6 for a total of seven days. It was difficult to reduce the charge state distribution to this value, possibly because the fluorine from the UF_6 tends to force the uranium charge state distribution toward higher values.

The usage rate of these solid materials has varied depending on a variety of parameters, including the goals of the specific measurement. Generally, usage rates are approximately 1 mg/hr for most tests. The lowest usage rate obtained has been 0.1 mg/hr for a calcium run.

The tendency of a particular species to remain as part of the source output after the last addition of fresh feed material - source memory - has been encouraging. Generally, after removal of the solid feed material, the ratio of beam currents of specific charge states from the old material to the new material is less than 1%, and often the old material cannot be identified in the spectrum after 2-3 hours. This has been especially true for higher volatility materials such as calcium and selenium.

Accelerator Injection and Longitudinal Emittance

The first tests in which the ECR source injected beam into the first cryostat of the new injector linac occurred in February, 1989. During those tests, a one microamp beam of $^{40}\text{Ar}^{12+}$ was analyzed, bunched, delivered to the new injector, and accelerated to approximately 200 MeV. A demonstration experiment was conducted at the Argonne gamma-ray facility with the beam.

The DC beam from the source must be prepared for injection into the linac by beginning a bunching process which results in pulses of approximately 200

picoseconds width being injected into the accelerator. Figure 2 shows schematically relationships of the various components. This occurs in three stages. The first stage of bunching occurs on the high voltage platform immediately after the first 90 degree analyzing magnet. Here a four-harmonic gridded buncher impresses a sawtooth voltage distribution in time to the ions with a period of 12 MHz. The unbunched components are then removed by a sinewave chopper and by the first bending magnet's momentum slits. The remaining beam is then bunched a second time with a 24 MHz resonator immediately ahead of the PII linac.

A measurement of the time spread with a detector shortly after the second resonator, with and without the second buncher operating, is sufficient to determine the longitudinal phase space of the beam from the source injector if nonlinear effects are ignored. The 90% contour measured longitudinal emittance of the beam from the platform for $^{40}\text{Ar}^{12+}$ was 3.74π keV-ns during the tests. These measurements were conducted using only a small fraction (0.001-0.05) of the beam from the source.

The percentage of the beam transmitted through the chopper, 50%, can be used to estimate the fraction of the total beam period which contributes to the measured emittance. With this assumption we can estimate the energy spread from the source system to be 181 eV or 15 V peak-to-peak. This energy spread is a result of a number of instabilities: source, extraction voltage, platform voltage, and buncher instabilities.

Two new timing detectors are under development⁴ which allow all or a substantial fraction of the source beam current to be analyzed. Using these new detectors, we have observed source operation modes in which the longitudinal emittance has increased by a factor of 4 or more over the value cited above. These modes of poor beam timing appear to be correlated with voltage variations induced in the source extraction voltage. Two distinct types of voltage variation have been observed.

One type of extraction voltage variation is an oscillation with a period of about 40 ms and is related to the puller electrode bias. The effect can be initiated and stopped by adjustment of the extraction puller electrode bias supply. Reducing the puller bias voltage to zero initiates the oscillation. Increasing the voltage to a value of approximately 1 kV causes the oscillation to cease. The peak to peak voltage of these oscillations is approximately 50 volts and therefore dominates the longitudinal emittance from the source during these cases.

Other high voltage instabilities are due to variations in the power-supply load caused by plasma fluctuations. With the source running, voltage variations observed are approximately 15 volts rms, with random periods in the regime of 1-10 kHz. These higher frequency components can be damped to about 1 volt rms with a 0.06 mFd capacitor.

After the addition of the capacitors, an additional slow ripple component remains with a period in the regime of 10-20 hertz. These oscillations are strongly dependent on small details in source tuning. For example, fluctuations of 20 volts peak-to-peak were reduced to less than 5 volts peak-to-peak by changes in the solenoid coil currents of less than 2%. Observation of these voltage fluctuations have led us into a project aimed at maintaining the source high voltage stable to a part in 10^4 by means of active feedback in the power-supply regulation.

Conclusion .

The PIIECR ion source has now operated routinely for over one year. It has proven to be a rugged and reliable device. The charge state performance is as expected and the development of techniques for solid material ion species production has proven the general initial design choices. The first tests using the source to inject the new low-velocity positive ion linac demonstrated the

overall performance of the system has met the design requirements, but the source extraction voltage stability must be further improved.

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References

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Table I

PII-ECR Ion Source Beam Currents for Solids

(electrical micro-amps)

Q	¹¹ B	²⁸ Si	⁴⁰ Ca	⁵⁸ Ni	⁶³ Cu	⁸⁰ Se	⁹⁸ Mo	¹³³ Cs	²³⁸ U
3	6								
4	5								
5	0.2	15				2.1			
6		15				2.5			
7		15	10	30		2.6		12	
8		10	15	30		5.8		14	
9		5	30	20		7.0		15	
10		-	-	10	2.5	-	0.2	10	
11		0.8	35	4	3.3	8.2	0.3	10	
12			18	0.5	-	6.8		10	
13			5		1.2	3.0	1.0	10	1.2
14			2			-		10	1.1
15						-	1.4	10	-
16						-		6	0.8
17						-		6	-
18						0.5	0.4	5	1.4
19								-	1.9
20								3	-
21								2	2.6
22								1.3	3.0
23								0.7	2.4
24								.25	2.0
25								.15	-
26									0.5
28									0.2
30								.025	
31									
32									0.07
Method	gas	gas	boat	wire	wire	boat	wire	oven	gas
Material	BF ₃	SiH ₄	Ca	Ni	Cu	Se	Mo	Cs	UF ₆
ZIsotopic	80	92	97	68	69	50	24	100	99

Figure Captions

Figure 1. Charge state spectrum of uranium from UF_6 with N_2 support gas.

Figure 2. Schematic drawing of the Argonne Positive-Ion Injector. Note the relative positions of the two bunchers used in the system.

Fig. 1

POSITIVE-ION INJECTOR

Fig. 2