THE DEVELOPMENT OF HEAVY ION PIG SOURCES FOR THE NSCL K-500 SUPERCONDUCTING CYCLOTRON*

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Introduction

During the commissioning of the K-500 cyclotron we had available one PIG ion source, axially inserted through the lower center plug, that operated DC at modest power levels. Since that time we have introduced a a number of system enhancements, including completing the mirror image ion source for the upper center plug, implementing pulsed operation for high charge states, and adding back-bombardment feed for the production of ions from solids. In addition, we have exploited an operating mode for nitrogen and carbon beams, in which the normal tantalum cathodes are replaced with hafnium cathodes, with some unusual operating characteristics. This has resulted in a large increase in ion source lifetime, with a significant impact on the operation of the facility. The properties of a heavy-ion PIG source operated with hafnium cathodes are the subject of a separate report at this conference[1]. We have also had to deal with a source activation hazzard that results from heavy ion stripping in the cyclotron.

In this report the general characteristics of our heavy-ion PIG sources will be reviewed, with the emphasis on those new features mentioned above. The steps taken to deal with the radiation problem are also considered, and finally a brief look at upcoming changes in the system will be reviewed.

General Characteristics

The basic K-500 heavy-ion source design has not been altered from that reported previously[2,3] as is shown in Figure 1. The source compatible with the lower center plug was built first and commissioned in the old 50 MeV cyclotron in the fall of 1981.

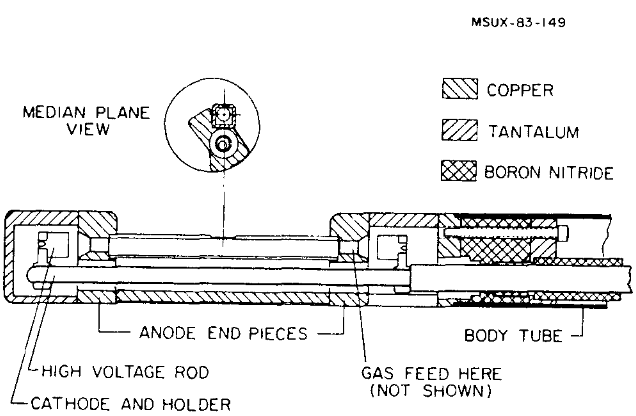

Fig. 1. The K-500 cyclotron heavy-ion PIG source.

In January 1983, the ion source, lock and insertion mechanisms for the upper center were completed, and this then allowed us to operate an ion source from either side of the cyclotron. With two complete ion sources and locks, we have an excellent backup should one system or the other fail. Careful alignment of each source with respect to the dee tips was required to insure that the accelerated beam behaved the same regardless of which source was operated, and this was found to be the case. Then in December 1983 four additional source assemblies and a supply of spare anodes were completed. These can be configured as lower or upper ion sources, and presently for instance, are all assembled as lower sources, with some of these in addition specially configured to do metal ions, as will be discussed below. Table 1. summarizes the performance of the K500 heavy-ion PIG sources to date.

In the operation of K-500 PIG sources, we have encountered a substantial radiation hazzard, where the ion source is often more activated than the beam probe or the deflectors! An example of this difficulty, from a 56 hour run with N^{4+} accelerated to 30 Mev/n, is shown in Figure 2. The analysis of this problem has led to the conclusion that ion stripping in the residual gas, with the subsequent collision of out-of-resonance higher charge states with the copper parts of the central region, including the ion source, is the cause of the activation[4]. To reduce this radiation hazzard, the median plane surfaces of the anode have been wrapped with tantalum shields, that not only show a lower activation than copper, but also can be removed to a shielded area during the source recycling to reduce the incidence of exposure to laboratory personel.

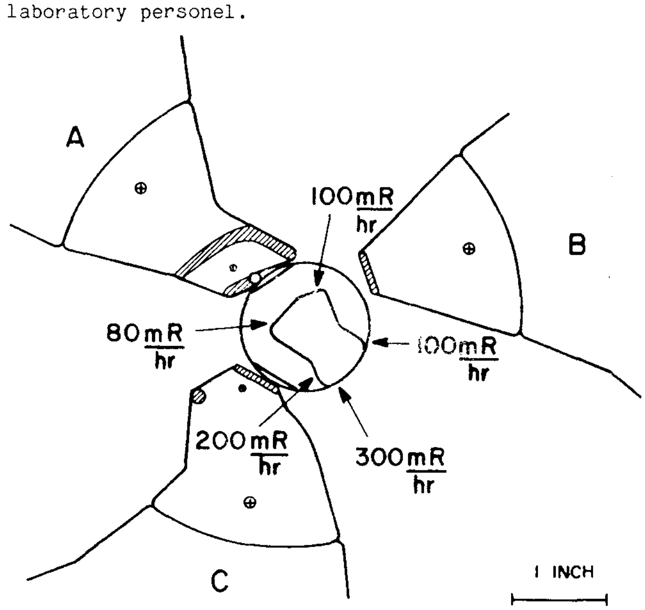

Fig. 2. Activation of the cyclotron central region, after a 56 h lifetime source for N^{4+} at a final beam energy of 30 MeV/n. Stripping to N^{5+}, with a subsequent bombardment of the central region, is thought to cause this activation.

Table 1. K500 CYCLOTRON EXTRACTED BEAMS.

ION	ENERGIES (MeV/n)	EXT. CURRENT (enA)	CATH	DUTY	FEED MATERIAL	AVER. TIME (h)	MAX. TIME (h)
2 D 1+	53	800	Ta	100%	O2 + CO2		
4 HE 1+	15,20,25	400	Hf	100%	1% He in N2 + N2	12.9	20.5
4 HE 2+	53	250	Ta	100%	He + CO2		
6 LI 2+	35	200	Hf	80%	6 LiF Pellet + N2	37.3	67.6
7 Li 2+	20,25	200	Hf	80%	LiF pellet + N2	16.0	42.5
12 C 3+	15,20,25	180	Hf	100%	CO + N2	10.6	19.0
12 C 4+	30,35	200	Hf	100%	CO + N2	14.1	31.6
14 N 3+	15,20	300	Hf	100%	N2	15.4	27.8
14 N 4+	20,22,25,30	150	Hf	100%	N2	23.4	55.0
14 N 5+	35	120	Hf	30%	N2	24.9	55.1
	35	100	Ta	100%	N2	6.4	10.6
	35	150	Ta	80%	N2	5.5	7.6
16 O 4+	20	120	HF	15%	O2 + N2	10.8	13.9
20,22 Ne 5+	25	80	Ta	10%	Ne	2.2	4.1
40 Ar 6+	10	80	Ta	10%	Ar	1.8	2.6

Source Development Milestones

Pulsed Source Operation

We have found that useful currents of Ne^{5+} and Ar^{6+} are not accessible DC in the K-500 cyclotron, and we have observed that other laboratories have been successfully operating PIG sources pulsed for many years. As a result we altered the ion source power supply to allow pulsed ion source operation. A summary of pulsed beam characteristics is also made in Table 1.

At a fixed arc current, decreasing the duty factor cools the cathodes and the arc voltage rises. As a result, if only the duty factor is lowered the arc would become unstable. Then at the same time the arc current must be raised well above the DC operating level to maintain the cathode temperature. Thus the peak current from our power supply was raised from 3 Amps (typical DC) to 10 Amps to improve pulsed operation. But clearly at low duty factors, where the beam current increases with the arc current up to this new current limit (and presumably beyond), as indicated in Figure 3 for Ne^{5+} at a 17% duty factor, this increase is still not enough. (As a result we have ordered a new power supply with a peak arc current of 18 Amperes.) One interesting point about low duty factors- the gas required for stable operation is quite low. For the neon beam in Figure 3, the neon flow rate was only 0.4 sccm, as compared to 2-3 sccm for DC operation and this is makes a significant contribution to the increased beam current. The disadvantages of pulsing include a significant reduction in the source lifetime, coming from an increased sputtering rate, and the fact that some experiments can not tolerate the added time structure.

Hafnium Cathodes

Detailed characteristics of source operation with hafnium cathodes are given in a separate report to this conference, as was previously mentioned, but for consistency some general remarks will be made here. In 1978 tests were made with Hafnium cathodes in the

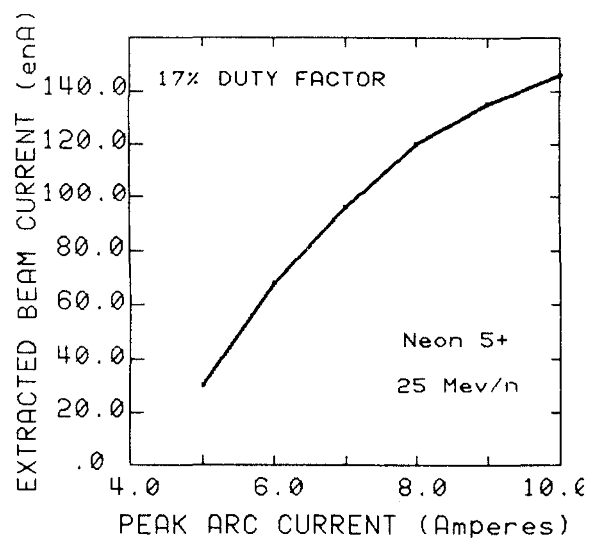

Fig. 3. Dependence of beam current with arc current for Ne^{5+} at a 17% duty factor.

heavy-ion source of the K50 cyclotron.[5] With CO gas feed a 24 h lifetime was obtained, as compared to 2-3 h with tantalum cathodes, albeit at the expense of lower beam current. The much longer lifetime was unexpected, and attributed to the formation of a layer of HfC on the surface of the cathode. With N_2 or Ne feed and Hf cathodes, the lifetime decreased. We have now re-introduced Hf cathodes in K500 sources, and have as a result enlarged the body of data concerning the lifetime effect. The main characteristics of a source operated with Hf cathodes include:

1. Extended lifetime for N_2, O_2, and CO feed.
2. Very shallow craters form when operated DC.
3. Less sputtered material builds up in the anode bore, resulting in slower beam attenuation with time.
4. Same behavior as tantalum cathodes for Ne or Ar feed-deep craters form in the cathodesand no lifetime improvement.

The dominant cause of these effects is a significantly lower sputtering rate that tantalum cathodes under the same operating circumstances. As can be seen in Table 1., a significant increase in lifetime can result from using hafnium cathodes.

Production of Ions from Solids

The basic source design has been modified to produce ions from solids according to the back-bombardment sputtering process.[6] To accomodate the feed material insert in the chimney back, a flat double-tube high voltage rod is traded for the standard .250 coaxially-cooled arrangement. This allows a tantalum receptacle to be fused to the back of standard tantalum chimneys. With this design we can put .170 inch thick feed material inserts in a standard ion source. These design changes are shown in Figure 4. Presently we are routinely doing $^{6,7}Li^{2+}$ beams with this technique, with the performance summarized in Table 1, where it should be noted that Hf cathodes and N_2 support gas are used for these beams to obtain long source lifetimes.

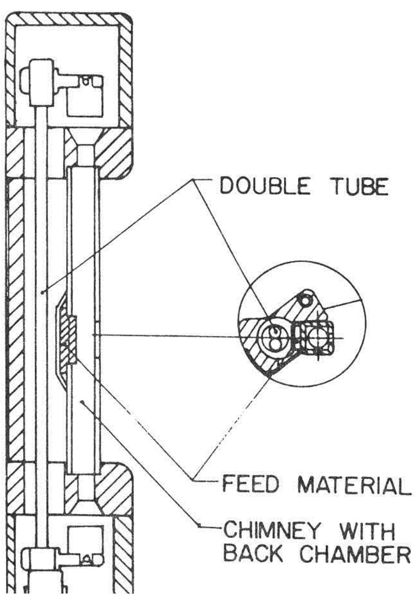

Fig. 4. Modifications to the basic source design to accomodate solid feed via the back-bombardment sputtering process.

Variable Cathode Separation Experiment

The central region of the K500 cyclotron is small,[7] and as a result the ion source must be compact. As we make changes in the source design to accomodate new features, we are always confronted with this difficulty. However, the axial magnetic field of the K500 is quite large, much larger in fact than in previous heavy-ion cyclotrons, and therefore we have looked at exploiting this- moving the cathodes away from the median plane, with its tight clearances, for example. Since this entails a longer PIG arc than is typical, we made a preliminary investigation of the physical properties of long PIG arcs. We wanted to know if such long arcs could be produced and what then would be the distribution of multiply-charged ions for increased cathode separation in the K-500 axial magnetic field. Figure 5 shows the design of this experimental PIG source, that has separated the arc into three parts- an anode that mounts off the lower center plug and two arc chambers, each holding one cathode. The arc chambers are infact located on the ends of the normal upper and lower ion sources, which can be run in and out of the central region along the cyclotron axis via the source insertion/retraction mechanisms. In this way the arc could be struck with the cathodes all the way in and then retracted. Measurement of the effect of increasing the cathode separation on N^{4+} and N^{5+}output was made, as shown in Figure 6. It is clear that the highest beam current is obtained with the cathodes near the cyclotron center.

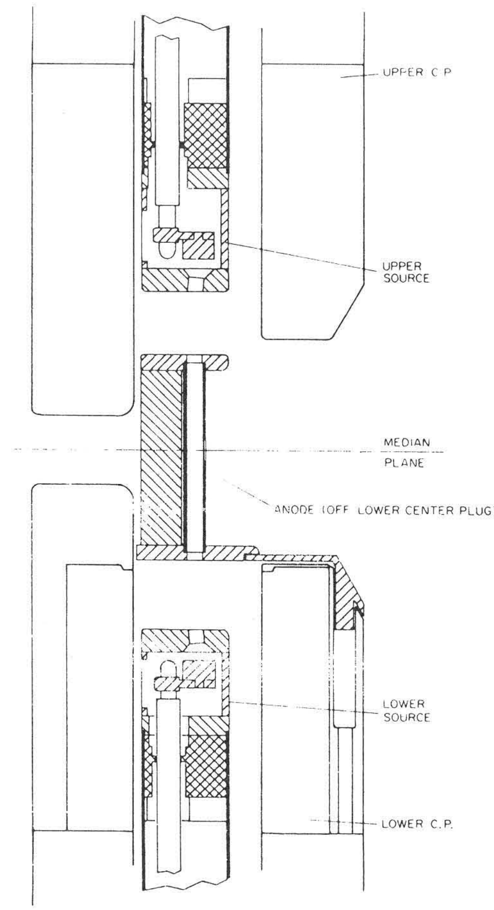

Fig. 5. Experimental source configuration used to study ion production as a function of cathode separation (see text).

Future Projects

We are currently in the middle of an upgrade project which includes a number of items. The four spare sources completed in December 1983, which allow operation of a total of six complete assemblies as lower or upper sources or some combination of both, was part of the upgrade. New gas flow control circuits based on Veeco piezoelectric valves are being added to reduce the source response time to gas flow changes. Characteristics of our first piezovalve gas controller are given in Figure 7. At the same time

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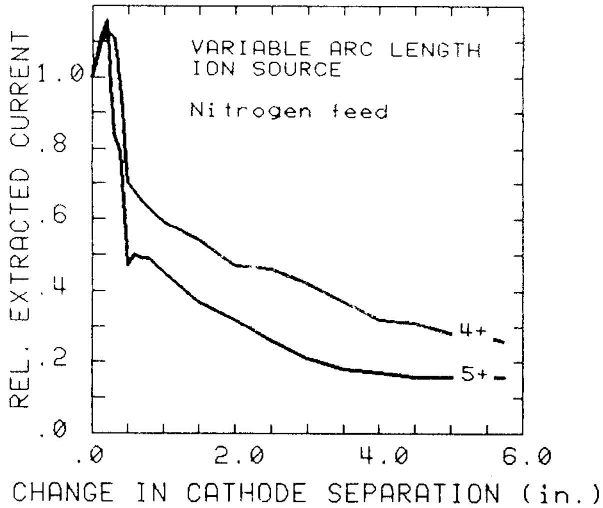

Fig. 6. Variation of N^{4+} and N^{5+} currents from the variable arc length PIG source, with the change in cathode separation from an initial separation of 4 in.

fabrication of an automatic insertion/retraction mechanism for the lower source is nearing completion. With this device we will be able to insert and retract lower sources remotely. We also await the delivery of a new ion source power supply, with higher peak current and provision for pulsed operation included. These projects are expected to add to our reliability and performance of internal ion sources in the coming years.

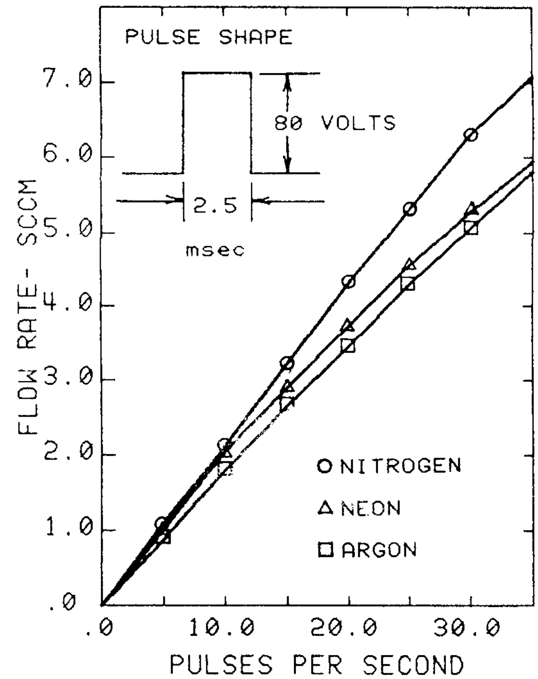

Fig. 7. Performance of a Vecco piezodectric leak valve for selected gases, when drive by a variable pulse rate, square wave voltage signal as given, at an inlet gas pressure of 1 psi above atmosphere.

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