K^+ Ion Source For The Heavy Ion Induction Linac System Experiment ILSE*

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Abstract

Low emittance singly charged potassium thermionic ion sources are being developed for the ILSE injector. The ILSE, now under study at LBL, will address the physics issues of particle beams in a heavy ion fusion driver scenario. The K^+ ion beam is emitted thermionically into a diode gap from alumino-silicate layers (zeolite) coated uniformly on a porous tungsten cup. The Injector diode design requires a large diameter (4" to 7") source able to deliver high current (~ 800 mA) low emittance ($E_n < .5\ \pi$ mm-mr) beam. The SBTE (Single Beam Test Experiment) 120 keV gun was redesigned and modified with the aid of diode optics calculations using the EGUN code to enable the extraction of high currents of about 90 mA out of a one-inch diameter source. We report on the 1" source fabrication technique and performance, including total current and current density profile measurements using Faraday cups, emittance and phase space profile measurements using the double slit scanning technique, and life time measurements. Furthermore, we shall report on the extension of the fabricating technique to large diameter sources (up to 7"), measured ion emission performance, measured surface temperature uniformity and heating power considerations for large sources.

I. INTRODUCTION

The potassium thermal Ion Source is being developed at LBL for the HIFAR (Heavy Ion Fusion Accelerator Research) 2 MV Injector Program and the ILSE (Induction Linac System Experiments) experiment. The Injector [1] consists of a diode of up to 1 MV followed by electrostatic quadrupoles (ESQ) to simultaneously focus and accelerate the ion beam to 2 MV. A 2 MV Marx pulse generator is used to drive the injector ESQ-diode system. The Injector diode design requires a large diameter (4" to 7") curved source capable of delivering a high current (~ 0.8 A) low emittance ($E_n < .5\ \pi$ mm-mr) singly charged potassium K^+ beam. The size of the source together with the tight injector emittance budget imply that the source emittance must be nearly temperature-limited. Furthermore, as a critical component of the ILSE and driver injector, the source must have sufficient reliability, life time and reproducibility.

Two types of sources have been studied [2], namely plasma sources and a thermal surface sources. The alumino silicate surface thermal source was found to meet the above requirements. The K^+ ion beam is emitted thermionically into a diode gap from alumino-silicate layers (zeolite) coated on a porous tungsten cup. An improved potassium alumino-silicate (Spodumene analog) uniform coating technique was developed leading to a source with a uniform high emission current density and a high depletion charge density. A 1" diameter K source was fabricated and tested in the SBTE injector setup. Initial measurements showed a maximum space charge limited extracted ion beam current of 95 mA, corresponding to a density of 19.5 mA/cm^2. The maximum density achieved thus far is limited by the source diode optics, and not by source emission. The normalized emittance measured was 0.059π mm-mrad, corresponding to a transverse temperature of 0.2 eV. Nondestructive life tests showed that the source can be operated under ILSE continuous operating conditions for more than a month (twenty, eight-hours days with 1 μs long pulses at 1 second repetition rate). D. C. destructive life tests showed that ~ 30% of the total stored K can be ionized and extracted, allowing for years of ILSE operation. Following these encouraging results, larger sources with diameters of 4" and above have been fabricated and tested.

* Work supported by the Director, Office of Energy Research, Office of Fusion Energy, U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

II. SOURCE FABRICATION

The source uses a porous (80%) tungsten cup with a high heating efficiency. The potassium alumino silicate (zeolite) is spread on the porous tungsten cup surface and fired in a vacuum oven to a temperature of 150° C allowing it to melt and soak into the curved surface pores. The source is cooled slowly at a rate of 150° C/hr allowing the crystallization of the alumino-silicate into a uniform thin cristabolite phase layer. The coating is mechanically bonded to the cup surface allowing high current density and charge depletion out of the source. This technique is used to coat the 1" source as well as the large diameter curved surface sources.

III. SOURCE CURRENT MEASUREMENTS

The total ion current was measured using a Faraday cup collector. The current waveform is monitored across a 50 ohm resistor using the Tektronix 2440 oscilloscope. Looking for the source emission and space charge limits the current was measured at various source diode voltages and heating powers. The SBTE injector consists of the source emitter and a series of accelerating planar electrodes. The extracted current depends mostly on the first electrode voltage and distance, to which we shall refer to as Ugap and Dgap. The other electrodes are used mostly for controlling the beam optics.

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EGUN calculations were used to design the source configuration including gap voltages, gap distances and different Pierce electrode geometries to maximize current extraction from the source and transport through the series of electrodes into the Faraday cup.

The results presented in Figure 1 represent a set of current measurements taken using a Dgap of 2.05 - 2.25 cm Pierce electrode with focusing angle of 55° - 67.5°. Ugap is set to .3 - .4 of the full MARX voltage. The heater power varied from 50 - 150 W (980°). There is a grid in the exit ground electrode. A total current of 95 mA was measured leading to a current density of 19.5 mA/cm^2. The source emission limit was not reached. A further increase in the source current may be possible with additional modifications to optimize the beam optics. A source perveance k of 5.48 nPerves was obtained from the measurements which obeyed the Child-Langmuir Law. The EGUN calculated k was 5.72 nPerves.

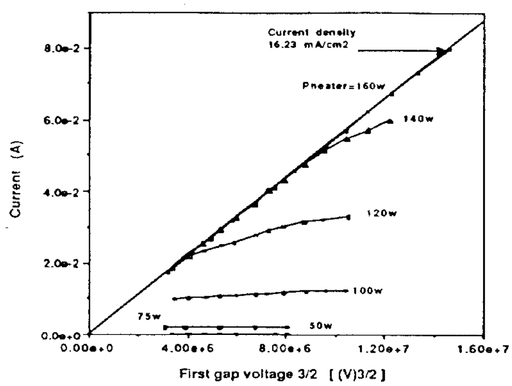

Figure 1. SBTE source current vs. diode voltage to the 3/2 showing the source emission limit for given heater powers (surface temperature)

The beam transverse current density profile was measured using a varying diameter aperture across the beam (Figure 2). The measurement was taken at a MARX voltage of 120 kV gap voltage of 31 kV, total current of 20 mA, Dgap = 3 cm, and a Pierce electrode angle of 67.5°. One can see that the beam has a uniform current density profile in agreement with EGUN simulations.

Recently we ran emission tests on a newly fabricated four inch diameter source. A curved graphite extraction electrode was designed and placed to obtain a planar diode configuration with a 6 mm gap. Ten parallel 20x2 mm slits were cut in the extraction electrode to allow current density measurements using a Faraday cup and temperature measurements using a hot wire pyrometer. The extraction voltage pulse up to about +15 kV is supplied to the source, allowing the extraction electrode to be at ground potential. Figure 3 shows the source surface temperature and current density profiles found to be uniform. The measured source perveance was found to be 24.7 nPerves; the calculated source perveance for a 6 mm gap planar diode is 22.5 nPerves. The difference of 6% between the measured and calculated perveance could be because of uncertainty in the diode gap distance.

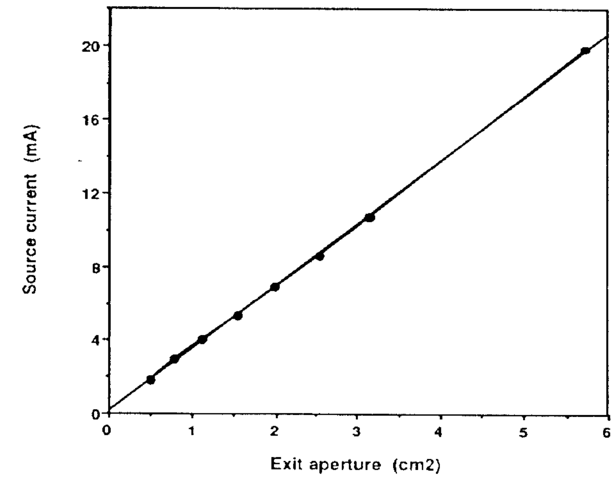

Figure 2. SBTE diode current vs. beam aperture area, showing a uniform current density profile.

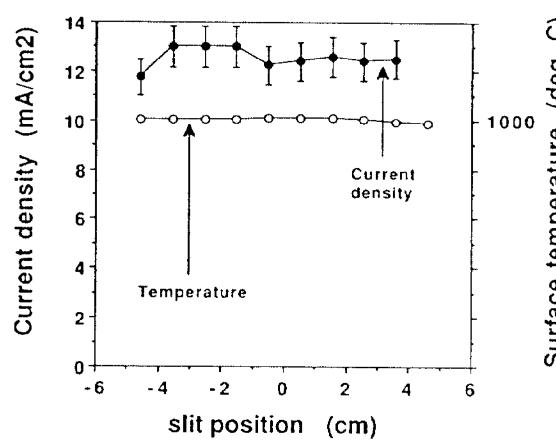

Figure 3. Four inch source current density and surface temperature profiles.

IV. TRANSVERSE EMITTANCE AND TEMPERATURE

The beam transverse rms unnormalized emittance was measured using the double slit scanner. We have used the usual SBTE setup, as in the current density measurements. The measured unnormalized emittance is 6π mm-mrad, leading to a normalized emittance E_n of 0.059π mm-mrad.

The source intrinsic temperature kT in eV can be calculated [3] knowing the measured normalized emittance (Figure 4):

$$kT = En^2(C/2R)^2 mi/q = 0.2 \text{ eV}$$

where C is the light velocity (3e+8 m/sec), R is the beam radius (1.25e-2 m), and mi/q for the potassium ion is 4.08e-7 The measured source surface temperature is about 980°C, i.e., 0.13 eV within 60% of the evaluated 0.2 eV.

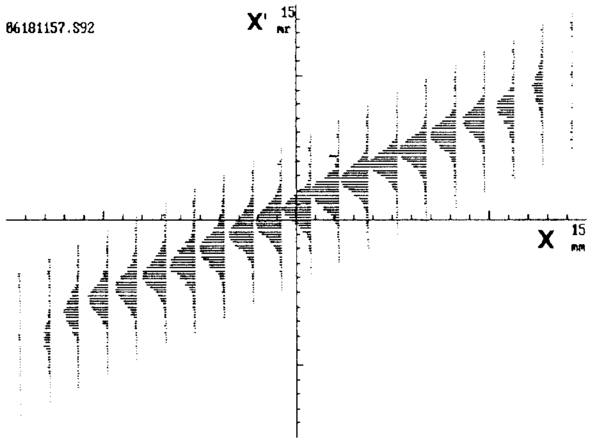

Figure 4. Beam phase space profile in x (radius) and x' (angle).

V. LIFE TESTS

The objective of the test was to show the source performance during experiments that are the equivalent of a one-month of continuous ILSE operation, i.e., twenty eight-hour days with 1 μs long pulses at a one second repetition rate. The source was fired about 50,000 times with extended pulse duration of 7 to 40 microseconds with repetition rates from one in 12 seconds to one per second, extracting a total charge of over 3.7 mCb/cm^2 above the required 2.4 mC/cm^2. The source was kept at a temperature 980°C for over 160 hours. We have not observed any depletion or evaporating effects during and after the test.

A D. C. depletion destructive life experiment was performed on small 1/4" sources. A total depleted charge (25 micro Amp. 12 hour) of 1.6 Cb/cm^2 was extracted, more than is needed by ILSE over years of operation.

VI. CONCLUSIONS

Alumino silicate K^+ sources were evaluated for applications in the ILSE injector and in a possible driver in an Heavy Ion Fusion (HIF) scenario. The measured source transverse emittance and current density were found to meet ILSE requirements. Beam transverse emittance and temperature were found to be consistent with the source intrinsic temperature and emittance within a factor of two. Our new Zeolite coating technology was successfully extended to the coating of large diameter, up to 17 cm, curved surface sources. This technique allows a uniform coating with lasting mechanical bond to the source surface. Life test showed that the source can be operated under ILSE conditions for more than one year and for about one month in a fusion scenario driver. Destructive deletion tests showed that more than 30% of the K atoms estimated to be stored in the alumino silicate coating can be extracted as K ions. One can see that the alumino silicate K zeolite sources can meet the special requirements given by the ILSE experiments. The fabrication of a new ILSE source, the design of which is presented above, is to be tested soon in a diode configuration.

VII. REFERENCES

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