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ALUMINO-SILICATE ION SOURCES FOR ACCELERATOR APPLICATIONS*

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Summary

As part of the program of Heavy Ion Fusion Accelerator Research at the Lawrence Berkeley Laboratory, ion sources have been developed using thermionic emitters of singly charged alkali metal ions. These emitters are flat surfaces of alumino-silicate, loaded with the apropriate ion. They have become convenient and reliable sources producing pulsed beams of very low emittance.

Thermionic emission of ions from alumino-silicates has been known for a very long time [1]. Here we focus on the practical application as accelerator ion sources. We discuss the fabrication and heating of large area emitters, uniformity of emission and the maximum ion current density which can be extracted under space charge limited conditions,with zero electric field on the emitter surface.

Results are presented for Na, K and Cs ions showing maximum space charge limited current densities of 25, 40 and 120 $mAcm^{-2}$ respectively. In the case of cesium we have produced a 5 mA beam at a kinetic energy of 200 keV with normalized emittance 1.2×10^{-7} π m rad.

Fabrication Techniques

These emitters operate at temperatures above 1000°C and the alumino-silicate forms a layer on the front surface of a molybdenum can which contains a graphite heater element. The emitter diameter is 1.5 inches and 500 watts of power are required to achieve an emitter temperature of 1100°C. The alumino-silicate layer is about 0.020 inches thick. Figure 1 shows such a heater assembly in the test diode configuration.

Na and K loaded alumino-silicates are available commercially [2], the Na loaded product contains cesium contamination. However, since Cs has a lower ionization potential,a short period of initial operation will draw out the contaminant, producing a pure beam. Figure 2 shows a Na source during initiation. At a diode voltage of 10 kV (decaying with a time constant of 50 μs) the Na has a flight time to the Faraday cup of 0.86 microseconds,the Cs takes 2.1 microseconds. After 30000 such pulses the cesium is gone. Cs alumino-silicate is available contaminated with K, but cannot be cleaned up in this way. Instead we have made use of pure home-made material for the Cs sources. A cesium source, fabricated using the techniques described here, was run in the Single Beam Transport Experiment at LBL [4]. By time of flight over a distance of 12 metres at 120 keV the beam was observed to be more than 95% singly ionized Cs.

Alumino-silicates combine the high work function ionizing surface with the reservoir of ions in a single material. We have tried to maintain this situation, whilst easing the problem of coating the molybdenum heater, by mixing the alumino-silicate with a commercially available alumina cementing compound [3]. This cement also has a high work function. One third alumino-silicate and two thirds cement,mixed with distilled water, produces a paste which can be painted on the heater to form emitters of abitrarily large area. After drying, the heater is fired up and the cement hardens without shrinking, producing a resilient emitter surface which can be filed flat.

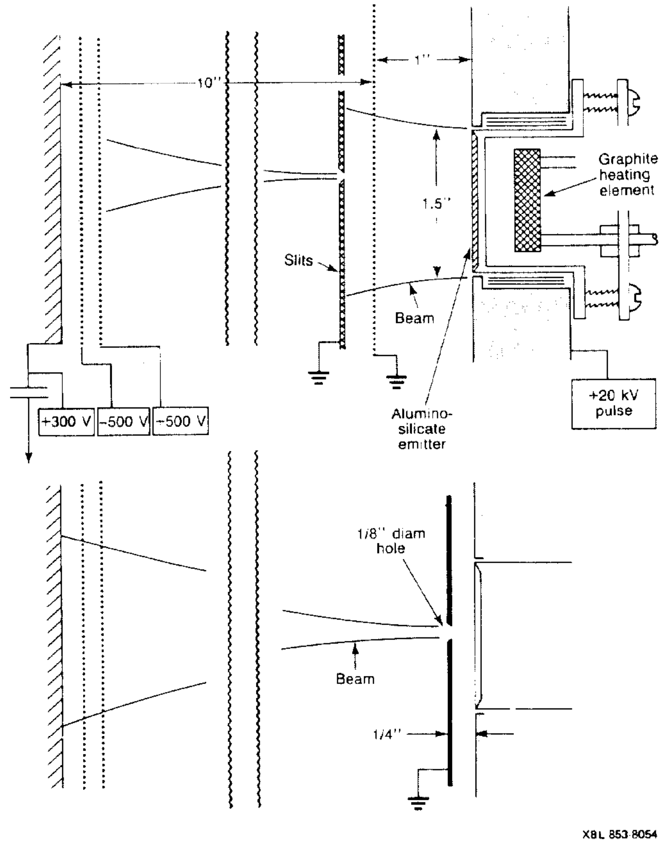

Fig. 1. Diode Configurations

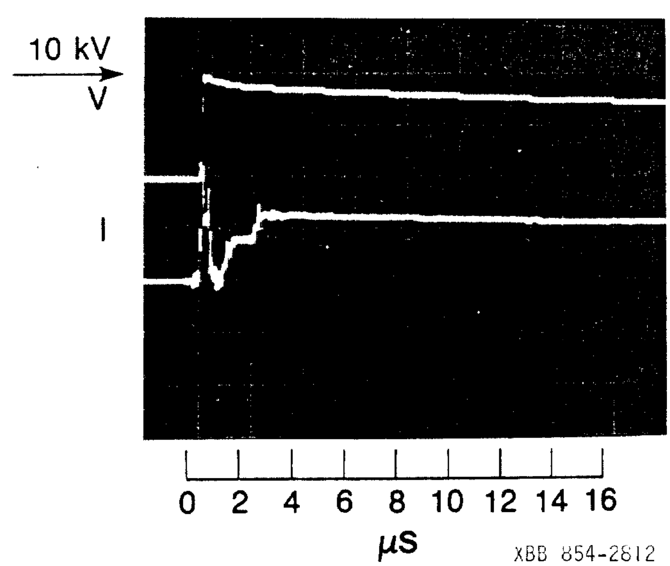

Fig. 2. Voltage and Current Pulse During Initial Operation of a Na^+ Emitter

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Imperfections in the surface are of a size .002 inches or smaller.

Measurement Techniques

Figure 1 shows the two test diode configurations. Uniformity scans are made with the low perveance arrangement in the upper part of the figure. Beams from the diode are scanned with a pair of crossed slits and the ion current passing through the aperture is measured,as a function of x and y, in a gridded Faraday cup ten inches downstream. The biased cup prevents co-moving electrons from entering and retains secondary electrons produced when the ions strike the collector surface. It measures the absolute ion current to an accuracy of better than ten percent.

The lower part of the figure shows a higher perveance configuration used to explore the maximum space charge limited emission. In this case the beam is collimated by a small aperture of known area immediately it leaves the diode to enable the Faraday cup to measure maximum current densities.

Results

Figure 3 shows the uniformity of emission. These measurements are made on a Cs beam that has already begun to spread under the influence of its space charge field. Some of the original non-uniformity may have smoothed out by this time. The emitter diameter is 1.5 inches and the beam has spread to 2 inches diameter at the slits. Typically, the emission current density shows random fluctuations of ± 10% across the emitter surface under space charge limited operation (top two portions of figure 4). As the emission becomes thermally limited (in this case at temperatures below 900°C) the beam size and current decrease but the non-uniformity is at about the same level.

Figure 4 shows the thermal emission limits measured in the high perveance diode in the lower part of Fig. 1. In the case of Cs the diode gap was closed to 0.02 inches to extract thermally limited current densities. Our heaters are capable of temperatures up to 1200°C. This is close to the melting point of the alumino-silicates and a rapid deterioration of the vacuum pressure is observed when sources are operated at these elevated temperatures. The source lifetime against evaporation is rather short under such conditions, no more than 24 hours. At 1000°C these sources can be operational for months.

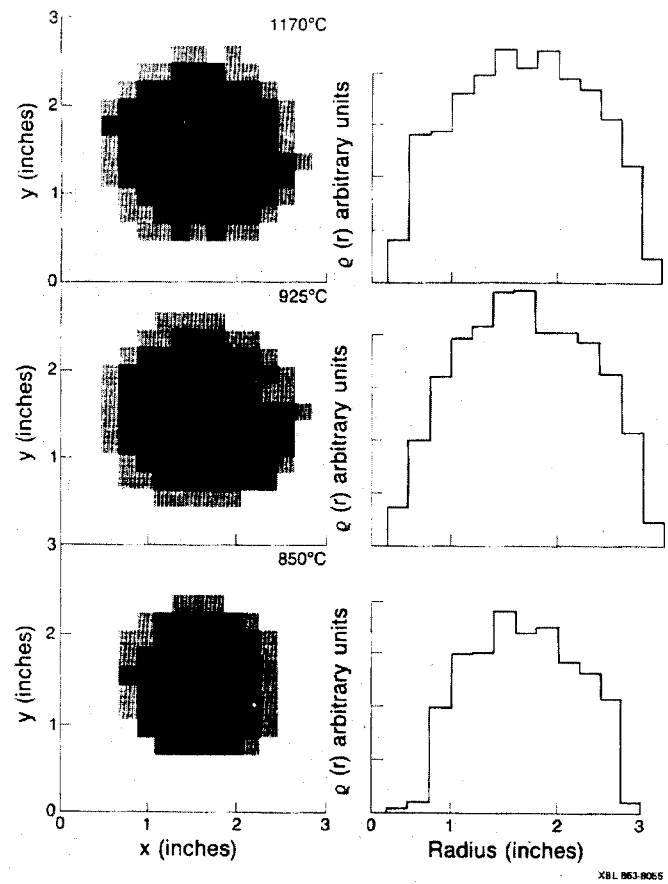

Fig. 3. Cs^+ Emission Uniformity as a Function of Temperature.

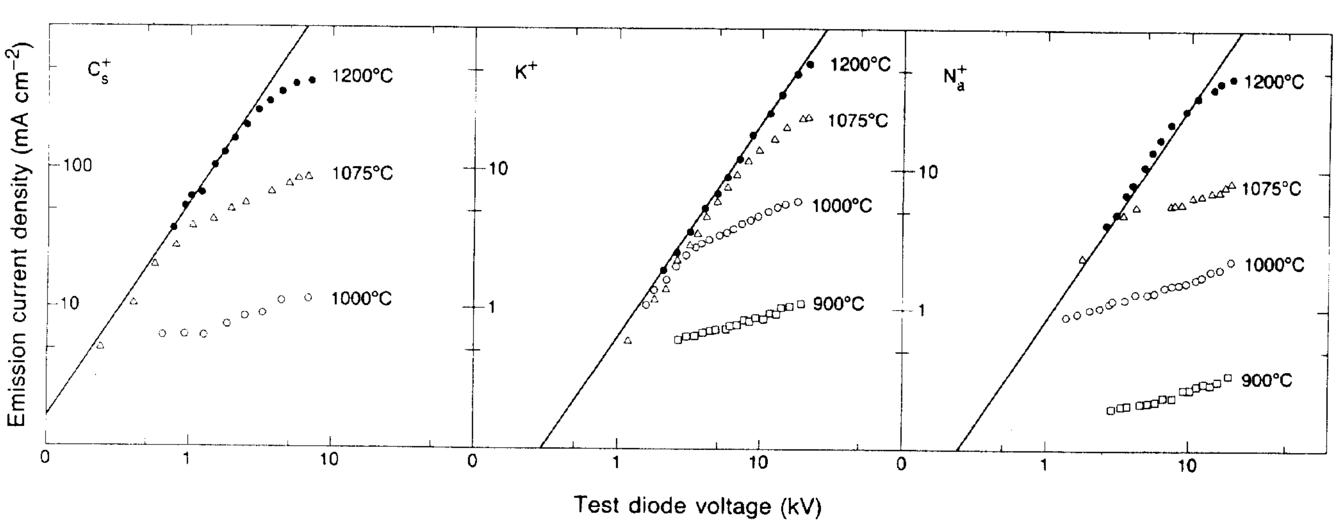

Fig. 4. Thermal Emission Limits for Cs^+, K^+ and Na^+ Emitters

Following the analysis of Pargellis and Seidl [5], ionic work functions have been extracted. The zero field current density is parametrized by

$$J_0 = AT^2\left\{\exp -\phi/kT\right\}$$

where A and ϕ are constants of the material. ϕ is the ionic work function, it is the difference of the ionization potential of the emitted atom and the electron work function of the surface. Crude estimates of ϕ from the data presented here are 2.2, 1.9 and 2.3 eV for Na,K and Cs respectively. The Na and K values are in broad agreement with previous measurements on various alumino-silicates. Our Cs value is higher. This indicates that the home made material provides a surface with lower electron work function, but a more plentiful supply of ions (larger value of A).

The motivation behind this work was to provide four cesium sources of exceptionally low emittance for the MBE-4 experimental induction linac at LBL. The MBE-4 gun design is described elsewhere in these proceedings. This gun produces four beams with currents up to 15 mA each at 200 keV using four 1.5 inch diameter Cs source as described here, operating at 1100°C. The measured r.m.s. emittance in the horizontal or vertical plane, for one 5 mA beam, is

$$\pi\epsilon_n \equiv 4\pi\beta\gamma\left(<x^2><x'^2>-<xx'>^2\right)^{1/2} = 1.2\times10^{-7}\ \pi\ \mathrm{m\ rad}$$

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