CHARACTERIZATION OF LI^{+} ALUMINO-SILICATE ION SOURCE FOR TARGET HEATING EXPERIMENTS*

P. K. Roy†, S. M. Lidia, W. G. Greenway, J. W. Kwan, P. A. Seidl, W. L. Waldron, and D. P. Grote
Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

The Heavy Ion Fusion Sciences (HIFS) program at Lawrence Berkeley National Laboratory will carry out warm dense matter experiments using Li^{+} ion beam with energy 1.2 - 3 MeV to achieve uniform heating up to 0.1 - 1 eV. Experiments will be done using the Neutralized Drift Compression Experiment-II (NDCX-II) facility. The NDCX-II accelerator has been designed to use a large diameter (10.9 cm) Li^{+} doped alumino-silicate source to produce short pulses of 93 mA beam current. Fabrication of a lithium source is complex. It is necessary to apply a high temperature ($\simeq$ 1250° C) for thermionic emission to achieve the required beam current density $\sim$1mA/cm^2 in the space-charge limited regime. The lifetime of this source is roughly 50 hours, when pulsed. Characterization of an operational 10.9 cm diameter lithium alumino-silicate ion source is presented.

INTRODUCTION

To heat targets to electron-volt temperatures for the study of warm dense matter [1] with intense ion beams, low mass ions, such as lithium, have an energy loss peak (dE/dx) at a suitable kinetic energy [2]. The accelerator physics design of Neutralized Drift Compression Experiment (NDCX-II) [3, 4] has a pulse length at the ion source of about 0.5 μs [5, 6]. Thus for producing 50 nC of beam charge, the required beam current is about 100 mA. Focusability requires a normalized (edge) emittance $\leq$2 π-mm-mrad.

Li^{+} ions have been produced by thermionic emission from the alumino-silicates compounds β-Spodumene and β-eucryptite [7, 8, 9]. In an ion gun injector, a thermionic source, may be heated by Ohmic heating, laser radiation, induction heating or other methods. The source surface temperature places a lower bound on the required input power, $P = A\sigma\varepsilon T^4$; where A is the cross sectional area (πr^2) of the emission surface, σ is the Boltzmann constant, ε is the emissivity of material and T is the source surface temperature. This is less than the required input power due to conductive and radiative heat loss from the sides and back of the source assembly. Once operating temperature is achieved, ions are extracted by applying an electric field. The field between the source surface and the extraction electrode controls the extracted current density. The space-charge limited current density of an ion gun is defined by the Child-Langmuir law:

$$J\left(\chi, V, d\right) = \chi \frac{V^{3/2}}{d^2}, \tag{1}$$

where, $\chi = \frac{4\varepsilon_0}{9}\sqrt{\frac{2q}{m}}$, d is the distance between source and extraction electrode, V is the beam extraction voltage, m is the mass of an ion, and q is the ion charge. The space-charge limited beam current, or Child-Langmuir current is

$$I_E = PV^{3/2}, \tag{2}$$

where, $P = \chi\left(\frac{\pi r^2}{d^2}\right)$ is the gun perveance which characterizes the geometry, charge state, and ion mass of the injector. Thus, in the space-charge limited regime, the beam current is determined by the ion mass and the geometry of the ion gun, and is proportional to $V^{3/2}$. A space-charge-limited beam with current densities (J) exceeding 1 mA/cm^2 have been measured [10, 11] from lithium alumino-silicate ion sources at a temperature of $\sim$1275° C. At higher extraction voltages, the source appears to become emission limited with $J \geq 1.5$ mA/cm^2, and J increases weakly with the applied voltage. In order to operate a source with uniform extraction, it is preferable to operate a source with low enough V to obtain space-charge limited extraction. The space-charge limit effectively smoothes out spatial variation in emission.

NDCX-II BEAM INJECTOR AND DIAGNOSTICS

There are several steps to prepare a lithium alumino-silicate source: (1) produce the chemical compound, (2) grind the compound into powder, (3) apply a "green coating", (4) sinter the material to form a hard surface layer. The lithium alumino-silicate source fabrication process, source emission density and lifetime have been characterized in a recent publication [12] by these authors for 0.64 mm diameter sources. Here we demonstrate a 10.9 cm diameter source performance. Figure 1 shows a sketch of NDCX-II injector with 10.9 cm diameter Li^{+} ion source, and a picture of the injector with a diagnostics station. A computer code simulation (WARP) has been used to address geometrical parameters of diagnostics. The diagnostics are-Faraday cup to measure beam current signal, and a gated camera with scintillator to determine beam images. Figure 2 shows simulated beam profile for current densities of (a) J=0.5 mA/cm^2, and (b) J=1 mA/cm^2.

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† PKRoy@lbl.gov

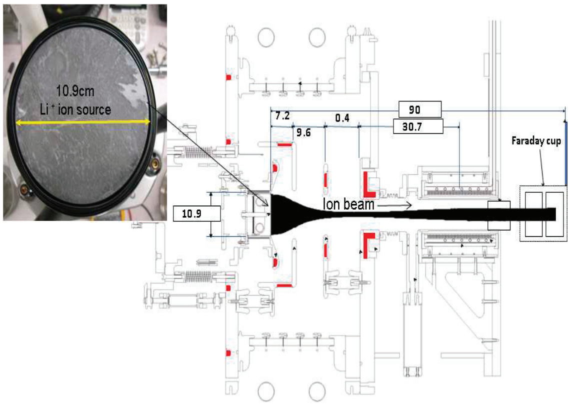

Figure 1: A sketch of NDCX-II injector.

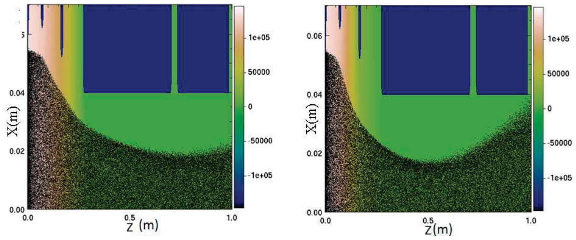

Figure 2: Results of WARP simulation (a) for J=0.5 mA/cm^2, and (b) J=1.0 mA/cm^2.

SOURCE TEMPERATURE AND LITHIUM BEAM CURRENT

Temperature in this study was measured using a disappearing filament-type brightness pyrometer with null balance, lamp-current measuring circuit, made by Leeds and Northrup Co. (8632-C series). The pyrometer is sensitive to the brightness at λ = 0.65 μm. The "brightness temperature" measured using the pyrometer is affected by the emissivity of the alumino-silicate material, and we note that the emissivity of the alumino-silicate at λ= 0.65 μm may not be 1.0. The Faraday cup is temporarily removed from the beam axis, without breaking vacuum, when doing the temperature measurement with the pyrometer . A source surface temperature of 1250 ^{0}C was measured when $\geq$3.5 kW electrical heating power was applied. Figure 3 shows measured heating power vs. measured surface temperature. At the temperature of 1250 ^{0}C, the Faraday cup was placed on the beam axis and beam current was measured with variation of extraction voltage. This is shown in Fig. 4. The beam current waveform was responded according to the applied extraction voltage. A series of measurements were performed by varying source surface temperature within 1100 to 1250 ^{0}C. The beam current increased with source surface temperature and extraction voltage as shown in Fig. 5, and Fig. 6.

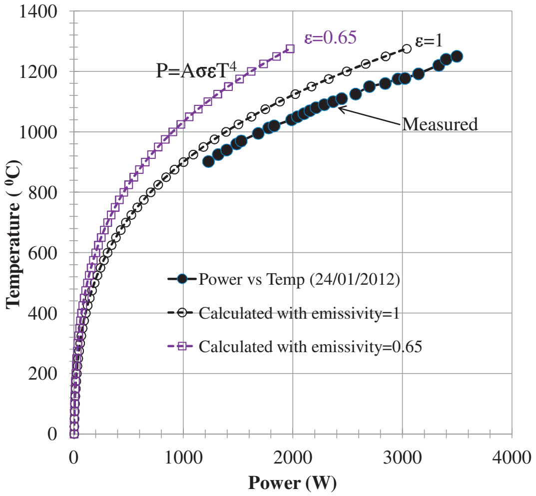

Figure 3: NDCX-II 10.9 cm diameter source heating power vs surface brightness temperature.

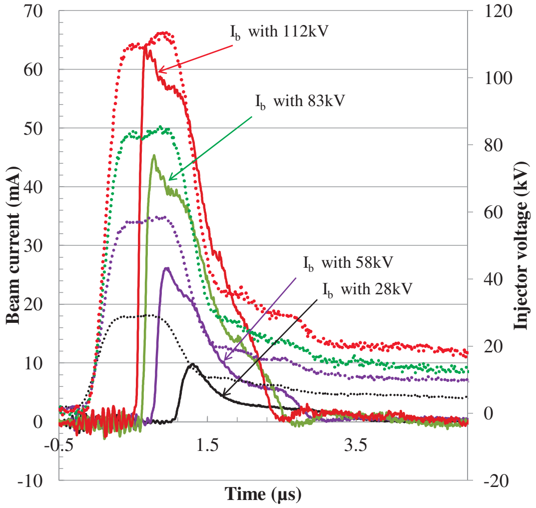

Figure 4: NDCX-II beam extraction voltage and beam current waveforms.

Figure 7 shows measured integrated beam charge within FWHM of a beam pulse for the corresponding voltage. A maximum of $\sim$50 nC charge was measured for $\geq$115 KV with the source surface temperature of $\geq$1250 ^{0}C. The beam optical image was captured using a Roper scientific gated ccd camera. Figure 8 shows evolution to emission-limited flow. These are scintillator images obtained at downstream diagnostic station. A 500 ns camera gate captures most of the lithium beam only. The beam spatial uniformity confirms uniform emission from source. A recent article [13], published elsewhere, describes further about NDCX-II injector initial performance.

SUMMARY

A 10.9 cm diameter lithium alumino-silicate ion source has been fabricated, operated, and beam current measured. A $\geq$3.5 kW power is required to reach a source surface brightness temperature of $\sim$1250 ^{0}C. At this stage the source has delivered $\sim$60% of the expected beam current with 1 mA/cm^2, and this may be due to partially non-coated

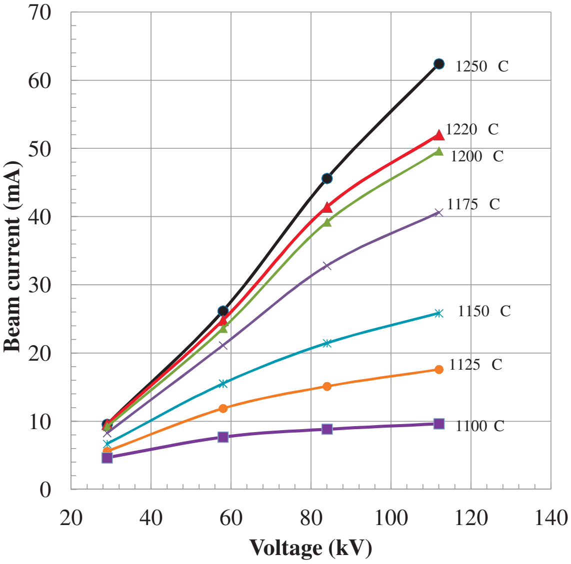

Figure 5: Beam current with source surface temperature and extraction voltage.

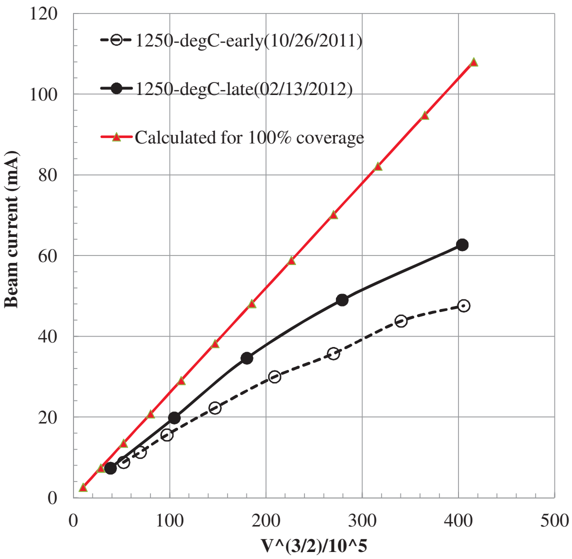

Figure 6: Beam current varies with $V^{3/2}$.The calculated current is with the distance of d=27.24 cm, and mass of the element is of 7 amu.

surface during sintering process. A source lifetime is limited to around $\simeq$50 hours and additional 15 to 20 hours time is required to clean up initial contaminations. More data will be collected to characterize the ion source performance as we progress in commissioning the NDCX-II machine. Beam emittance measurement is also underway, which will provide data for comparison to optical simulations. Present injector is capable to start beam transport with induction acceleration and beam compression experiments.

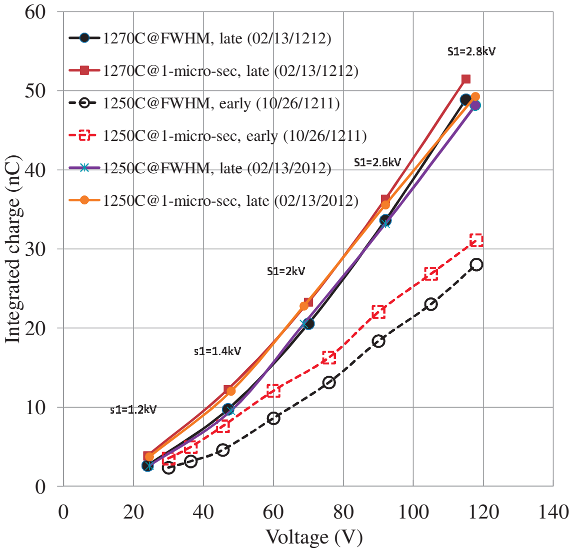

Figure 7: An integrated measured beam charge.

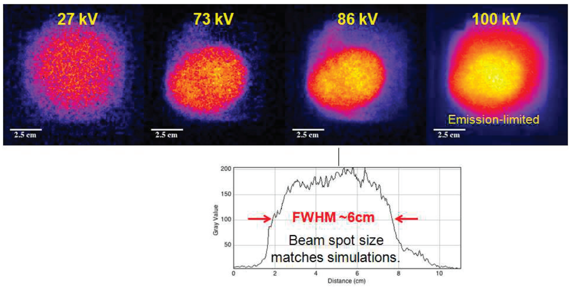

Figure 8: Lithium ion beam optical profile.

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