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A HIGH CURRENT DENSITY LI⁺ ALUMINO-SILICATE ION SOURCE FOR TARGET HEATING EXPERIMENTS*

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Abstract

The NDCX-II accelerator for target heating experiments has been designed to use a large diameter ($\simeq$ 10.9 cm) Li⁺ doped alumino-silicate source with a pulse duration of 0.5 μs, and beam current of $\simeq$ 93 mA. Characterization of a prototype lithium alumino-silicate sources is presented. Using 6.35 mm diameter prototype emitters (coated on a $\simeq$ 75% porous tungsten substrate), at a temperature of $\simeq$ 1275 ^{0}C, a space-charge limited Li⁺ beam current density of $\simeq$ 1 mA/cm^2 was measured. At higher extraction voltage, the source is emission limited at around $\simeq$ 1.5 mA/cm^2, weakly dependent on the applied voltage. The lifetime of the ion source is $\simeq$ 50 hours while pulsing the extraction voltage at 2 to 3 times per minute. Measurements show that the life time of the ion source does not depend only on beam current extraction, and lithium loss may be dominated by neutral loss or by evaporation. The life time of a source is around $\geq$ 10 hours in a DC mode extraction, and the extracted charge is $\simeq$ 75% of the available Li in the sample. It is inferred that pulsed heating may increase the life time of a source.

INTRODUCTION

To uniformly 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]. A study has been undertaken to create warm dense matter conditions in thin-foils [1] with a Li⁺ with energy 1.2 - 4 MeV to achieve uniform heating up to 0.1 - 1 eV. The required beam charge is about 50 nC. The accelerator physics design require that the pulse length at the ion source should be about 500 ns [3]. Thus for producing 50 nC of beam charge, the required beam current is about 100 mA, and the required emittance is about <2 mm-mrad. For NDCX-II, a high current-density emitter is generally preferred so that the source is reasonably compact.

Li⁺ has been produced by thermionic emission from the alumino-silicates compounds β-Spodumene and β-eucryptite [4, 5, 6], but it requires a higher operating temperature than for heavier alkali ions, such as K⁺, Cs⁺. Table 1 shows Li⁺ current density data presented by several authors, but the dependence of the lifetime on temperature has not been extensively described. A progress on Li⁺ ions source and beam study, towards target heating experiment, is presented in this proceeding.
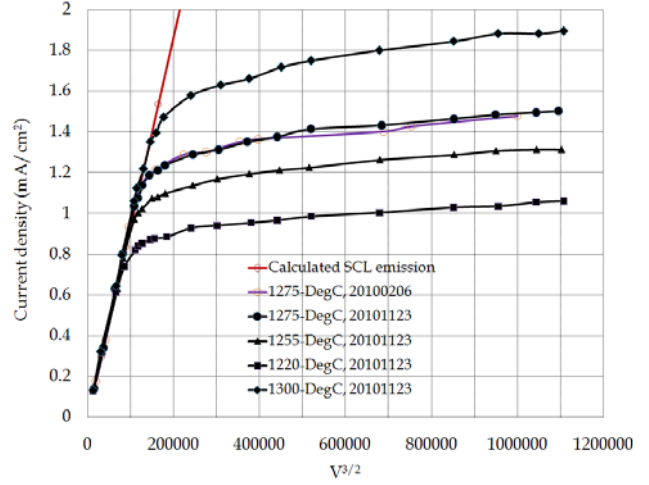
Figure 1: Measured beam current density vs. V$^{3/2}$, measured at 1220 ^{0}C, 1255 ^{0}C, 1275 ^{0}C and 1300 ^{0}C temperatures. The line (blue in color) with hollow circles represents data of a different source operated at 1275 ^{0}C.

Table 1: Li⁺ Beam Current Density.

Density (mA/cm²)	Temp. (^{0}C)	Ref.
$\leq$ 1	$\approx$ 1230	Blewett [4]
$\approx$ 0.02 (spodumene)	$\approx$ 1200	Feeney [6]
$\approx$ 0.5	$\approx$ 1150	Thomas [7]
$\leq$ 1	-	McCormick [8]
$\approx$ 1	$\approx$ 1275	Roy [9]

LITHIUM BEAM CURRENT DENSITY

Several small (0.64 cm diameter) lithium alumino-silicate ion sources have been operated in a pulsed mode, with similar repetition rate and pulse duration as needed for NDCX-II. The source surface temperature was at 1270 $\pm$ 7 ^{0}C. A 5-6 μs long beam pulsed was recorded by a Faraday cup (+300 V on the collector plate and -300 V on the suppressor ring).

Figure 1 shows measured beam current density (J) vs. V$^{3/2}$. A space charge limited current density of $\geq$1 mA/cm^2 was measured with extraction voltage of 2.5 kV at 1275 ^{0}C temperature, after allowing a conditioning (surface cleaning) time of about $\geq$ 12 hours. At the same temperature, the current density was raised to 1.47 mA/cm^2 when the extraction voltage was increased to 10 kV. Beam emission stability with these current density levels was observed for more than 72 hours for a pulse repetition rate of 0.033 Hz. However, the beam current density decreased gradually af-

ter this period. The solid line with hollow circles, at the left, colored in red, represents the space-charge limited current density, calculated using the Child-Langmuir law, $J(\chi, V, d) = \chi \frac{V^{3/2}}{d^2}$, where, $\chi = \frac{4\varepsilon_0}{9}\sqrt{\frac{2q}{m}}$, d=1.48 cm is the distance between source and extraction electrode, V is the beam extraction voltage, m=7 amu is the mass of an ion, and q is the ion charge.

Beam current density at lower extraction voltage follows the space-charge limited (SCL) Child-Langmuir law. At a higher extraction voltage, there are not enough ions, at a given temperature, on the source surface to extract, and thus extracted current fall below the Child-Langmuir law. It is preferable to run an injector system in the space-charge limited extraction mode.

LIFETIME

Lifetime in pulsed beam extraction

Figure 2(a) measured lithium beam current density vs. lifetime emission for two thick ($\approx$ 0.2 mm) coating sources. At $\approx$1275 ^{0}C and with a 10 kV extraction voltage, one of the sources was emitting a current density $\geq$1 mA/cm^2 for more than $\approx$100 hours at a repetition rate of 0.033 Hz. In another test, a current density of $\geq$1 mA/cm^2 was measured for $\approx$ 72 hours with the same beam pulse rate. Other measurements of different 0.64 cm sources show that there is a wide variation in conditioning time (12 to 40 hours) to reach $J \geq$1 mA/cm^2, and in lifetime (40 to 200 hours) when $J \geq$1 mA/cm^2. Fig. 2(b) represents space-charge limited emission with 1.75 kV extraction, demonstrates a uniform beam current extraction for more than 30 hours. These two sources, Fig. 2(b), were relatively thicker than the two other sources as presented in Fig. 2(a).

The lifetime of a lithium source is determined by the loss of lithium from the alumino-silicate material either as ions or as neutral atoms. If the lithium loss is dominated by ions, for high duty factor, then the lifetime will depend on the extracted ion current. On the other hand, if the loss is dominated by neutral atoms (due to the typically low duty factor, even a relatively low neutral evaporation rate can become significant), then the lifetime is simply proportional to the time that the ion source is kept at elevated temperature. Our measurements suggest that for the low duty factor required for NDCX-II, the lifetime of a lithium ion source depends mostly on the duration that the emitter spends at elevated temperature, that is, at $\geq$1250 ^{0}C. That is, lithium loss is due mostly to neutral loss (not charged ion extraction).

Lifetime in DC beam extraction

In the interest of enabling a more rapid sequence of experiments, we built an in-situ sintering and beam extraction test stand. Beam was extracted to a negative bias plate, located $\simeq$ 4 mm from the emitting surface. Figure 3 shows the DC extraction beam current (primary vertical axis), and
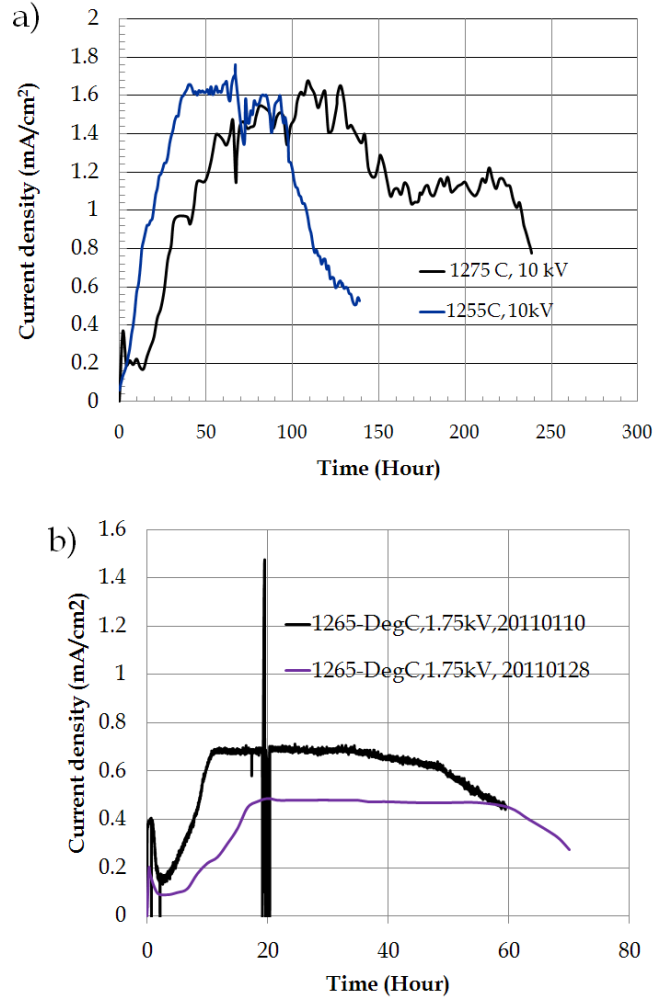
Figure 2: Litetime of Li$^+$ ion sources with (a) 10 kV extraction, and (b) 1.75 kV extraction.

the extracted total beam charge (secondary vertical axis) vs. time of beam emission for several samples of different masses (0.0024 gm, 0.0031 gm, 0.0069 gm, 0.0079 gm). The diameter of the source samples was varied between 2.5 to 3 mm. These data indicate that surface thickness of a source may contribute emission level, and a controlled experiment with maintaining proper surface area is necessary to verify this result further. It was observed that the lifetime of a source is around $\geq$15 hours in a DC mode extraction, and the extracted charge is $\sim$ 75% of the available Li$^+$ in the sample.

It was inferred that pulsed heating, synchronized with the beam pulse, might increase the lifetime of a source. Again, for rapid sequence of experiment, several source samples, mostly prepared in a furnace were tested in the DC test stand. In this case, beam was extracted (120 V) for a certain time (5 minutes) and then after filament temperature was reduced to 800 ^{0}C for a longer period (such as 5, or 10, or 20 minutes for a source) and was maintained the same sequence until deflection of emission was observed by measuring beam current signal. Figure 4 shows data
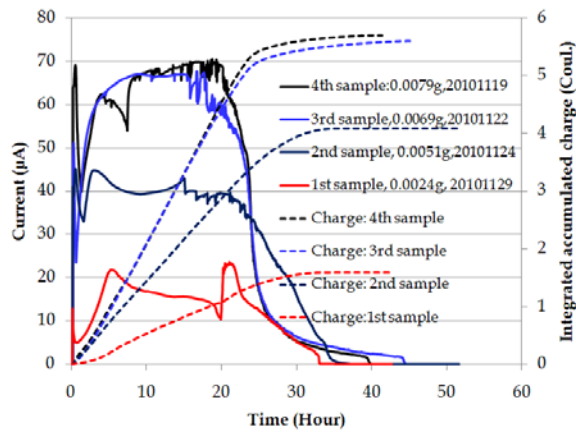
Figure 3: Beam emission and lifetime by varying mass of the samples. Diameter of the source samples was not the same, but was as ≤3 mm.

of this kind of experiment. It shows that lifetime of a Li alumino-silicate source may be enhanced by pulsed heating. A technique of pulse heating of this kind of source is recently investigated for a small size source [10]. A study on a larger source heating technique is necessary.
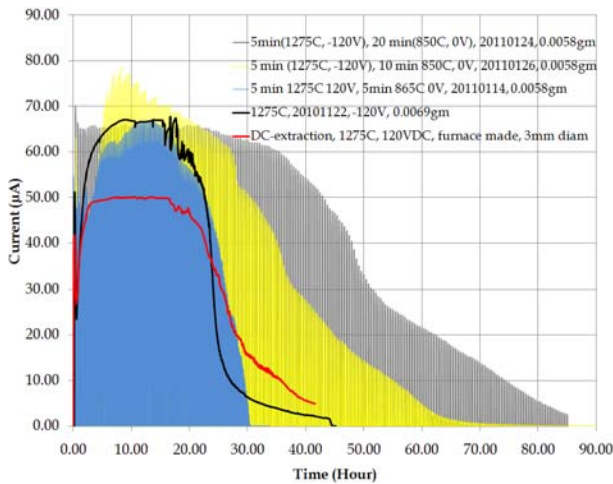

Figure 4: Litetime of several source samples for duty factors: DC, $1, 0.5, 0.25$, operated at $\approx 1265\ ^0$C.

NDCX-II-INJECTOR

The NDCX-II design seeks to operate the ion source at the maximum current density without running into heat management and lifetime problems. In preparation to fabricate a larger, 10.9 cm in diameter, source for the NDCX-II experiment, recently a 7.6 cm diameter source was fabricated as shown in Fig. 5. The method of fabrication of this larger source was similar to that of fabrication of a 6.3 mm diameter source except a longer heat cycle time was used due to mass difference (for geometrical sizes). The larger source surface, Fig. 5(b), was mostly glassy type and coated material uniformely distributed. Fabrication of

a larger size diameter source was made our confidence to fabricate a larger source for NDCX-II. Figure 6 shows a computer code simulation (WARP) of a (a) $J=0.5$ mA/cm^2, and (b) $J=1$ mA/cm^2 Li$^+$ ion beam profiles for NDCX-II. By this time we are preparing diagnostics to characterize the beam first time of its kind. Also, NDCX-II injector construction is being underway [11].
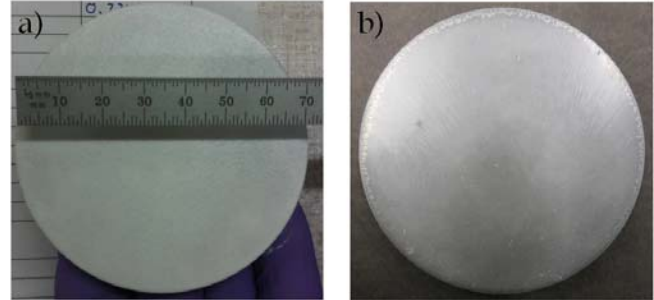

Figure 5: A 7.6 cm diameter source preparation (a) sample coated and dried , and (b) a glassy look source surface, aftering sinterinrg at 1400 ^{0}C.
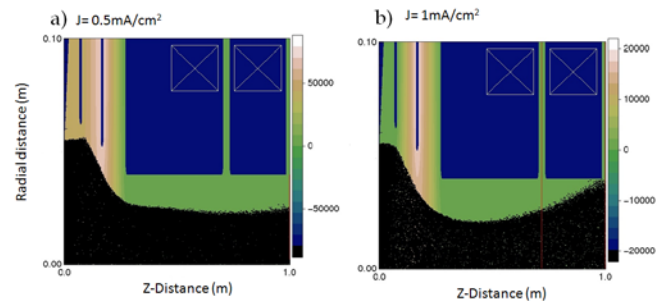

Figure 6: NDCX-II beam profile, using WARP code, for a beam current density of (a) 0.5 mA/cm^2 , and (b) 1 mA/cm^2 when the transport solenoid magnet is off.

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