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AN ALPHA PARTICLE DIAGNOSTIC BEAM LINE SYSTEM TO GENERATE AN INTENSE Li^- BEAM WITH AN ORNL SITEX SOURCE*

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ABSTRACT

The Oak Ridge National Laboratory (ORNL) SITEX (Surface Ionization with Transverse Extraction) negative ion source utilizes a 100-V/20-A reflex arc discharge in a 1300-gauss magnetic field to generate Cs^+ ions and H^+ or D^+ ions, depending on the beam required. A shaped molybdenum plate is placed directly behind the arc column. Cesium coverage on this plate is used to minimize the surface work function, which requires two-thirds of a monolayer coverage. Cesium coverage is adjusted both by cesium flow control into the arc discharge chamber and by temperature control of the converter using gaseous-helium cooling channels in the converter plate. Normal converter operational temperatures are 300° to 500°C. H^-/D^- beams are generated at the biased converter surface (−150 V with respect to the anode) by Cs^+ sputtering of absorbed hydrogen or deuterium and by the reflection-conversion mechanism of H^+/D^+ ions which strike the converter surface at 150 eV. The negative ions are accelerated through the 150-V plasma sheath at the converter surface and are focused by the converter geometry and magnetic field so as to pass through the exit aperture with minimum angular divergence. The ion optics of the SITEX accelerator has been calculated using the ORNL 3-D optics code and results in a divergence perpendicular to the slot of $\theta_{\perp rms} = 0.35°$ and parallel to the slot of $\theta_{\parallel rms} = 0.18°$. This beam divergence should be adequate for injection into a radio frequency quadrupole (RFQ) for further acceleration.

H^- beams of 650 mA, 18 kV, and 9 s, along with similar D^- beams have been accelerated at a 10% duty cycle. Development is under way to permit steady-state operation. The extracted electron to extracted H^-/D^- current ratio of 15%/5% has been achieved. All extracted electrons are recovered on the source with an electron-recovery system at an energy that is 10% of the first acceleration gap potential energy difference. The arc efficiency is 5 kW of ion source power per 1 A of accelerated H^-/D^- beam.

We propose to produce intense Li^- beams for further acceleration and neutralization to be used in a charge-exchange alpha particle diagnostic scheme. Li^- ions would be generated by Cs^+ sputtering of lithium adsorbed on the converter, with Li^- accelerated by a system whose performance is similar to that described above. Beams of fewer than 10 μA have been produced in accelerator sources by mechanisms similar to those we propose. If the Li^- production efficiency is as good as expected, we will be able to produce 100-mA Li^- beams with an emittance suitable for final acceleration by an RFQ accelerator. Arc efficiency, electron control, and optics are projected to be as good as those for H^-/D^- beams already produced. A proof-of-principle experiment will soon be conducted at modest cost by modifying existing SITEX equipment to verify production efficiency of Li^- ions.

INTRODUCTION

Most magnetic-confinement fusion power reactor concepts rely on alpha particle heating to supply a portion of the fusion power to keep the plasma hot. These 3.5 MeV alpha particles are produced by the deuterium-tritium nuclear reaction in the hot plasma. It is critical to determine at the earliest time the physics of the alpha particle slowing-down process to determine whether the alpha particle energy transfer to the plasma is classical or anomalously fast or slow. An anomalously high alpha particle loss rate to the walls would increase the $n\tau_E$, auxiliary heating power, and β required for ignition. Anomalously high ion heating

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by alpha particles could lead to a reduction in ignition requirements.[1] Post et al.[2] have reviewed the possible techniques for measuring the alpha particle velocity distribution $f_\alpha(\vec{V}, \vec{r}, t)$. Many of the diagnostic techniques reviewed give only partial information on the alpha particle distribution. The use of a high-energy lithium doping beam offers a diagnostic from which most of the distribution information can be obtained.[1] The lithium beam would undergo single or double charge-exchange events with fast alpha particles. One can then observe either the fast He^0 escaping from the plasma after acquiring two electrons through double charge exchange with the beam or the doppler shifted de-excitation radiation from the decay of excited He^+ states populated by single charge exchange. The charge-exchange cross sections are maximum near a beam energy of 880 keV/amu or ~6 MeV for Li^7 propose to use a SITEX negative ion source to create intense low-emittance Li^- beams at 100 keV which are then injected directly into an RFQ for an energy boost up to ~6 MeV. A gas neutralizer and charged particle beam dump would result in about ≤50% of the beam being available as 6-MeV Li^0. This paper will concentrate on the characteristics and advantages of a Li^0 beam as generated by a SITEX-source-based beam line.

ION SOURCE

The SITEX[3-14] source has been modified slightly to produce Li^- beams.[15-16] Figure 1 shows the basic reflex discharge plasma generator. A hot tantalum filament is used to supply electrons to the discharge at 100–150 eV. The discharge will be aided by use of an inert support gas such as helium which produces negligible negative ions. The primary electrons oscillate between the filament and the reflecting (electrically floating) electrode through the anode chamber. Cesium will be admitted to the anode chamber through a motor-controlled heated valve and from a temperature-controlled oven. Cesium flow rate is adjusted by valve position and oven temperature to maintain cesium cover on the converter at approximately two-thirds of a monolayer, where the work function should be minimized.

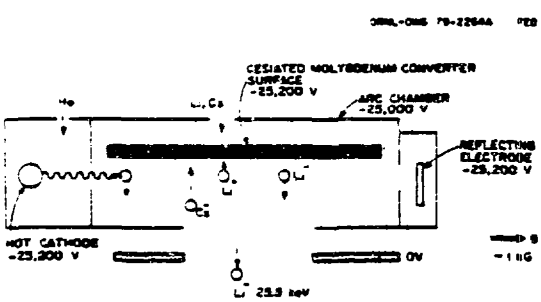

Fig. 1. Basic SITEX reflex discharge concept.

The converter temperature can also be varied between 200° and 700°C to aid in keeping the proper converter coverage of two-thirds of a monolayer. Figure 2 shows how the converter is biased at a nominal −150 V(dc) with respect the the anode chamber. Since the source runs in a ~1300-gauss magnetic field, the converter voltage is fixed by optical considerations to transport the beam through the ion exit slit. A nominal 100-V(dc), 120-A arc will be used. Li^0 is then admitted to the anode chamber and directed at the converter front from a heated valve and temperature-controlled oven. Li^0 coverage of the converter will then be adjusted to give maximum Li^- output. Li^- is expected to be produced by Cs^+ sputtering at the converter surface.[17] Hiskes has estimated that the conversion efficiency of Cs^+ bombardment to Li^- ion release may be as high as 2%.[18] Alton has estimated from results on his accelerator sputtering source that the conversion efficiency may be as high as 10%.[17] We can attain converter currents of 500 mA/cm^2 [at 150 V(dc), this corresponds to 75 W/cm^2]. With a conversion efficiency of 2%, this would produce a converter Li^- current density of 10 mA/cm^2. We estimate that we can transport and inject 100 mA of useful beam into an RFQ at 100 keV using the 2% conversion. Figure 3 shows one 3-D optics plot of the beam which would be suitable for injection into an RFQ calculated using the ORNL optics 3-D code.[19-24] The 3-D code will be used to maximize the useful current injected into the RFQ. The emittance requirements of the RFQ are small enough for all beam from the RFQ to

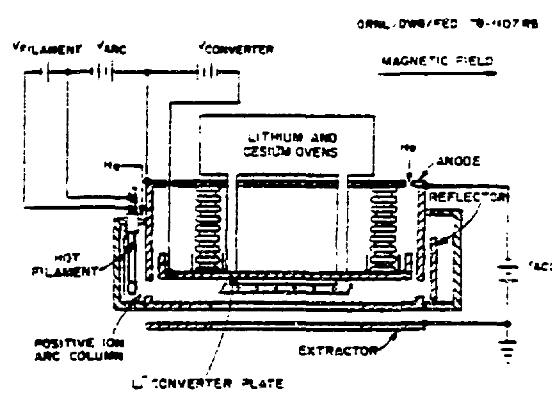

Fig. 2. Top view of the SITEX source with power supply connections.

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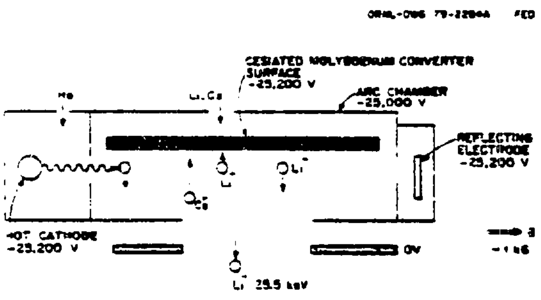

Fig. 1. Basic SITEX reflex discharge concept.

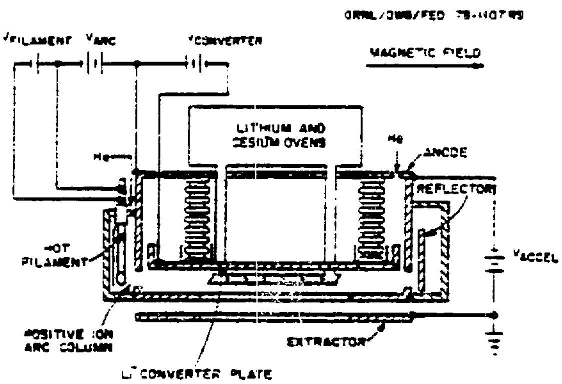

Fig. 2. Top view of the SITEX source with power supply connections.

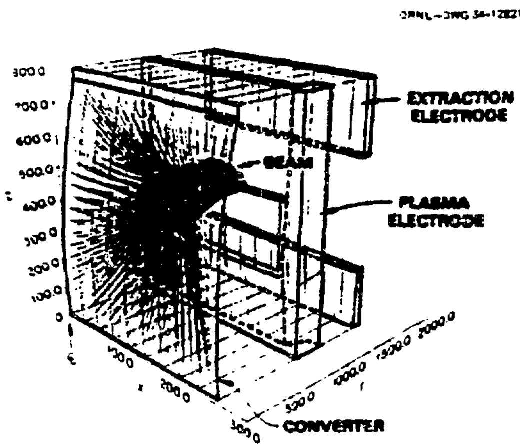

Fig. 3. 3-D optics calculation for injection into an RFQ.

be useful. The normalized beam emittance should be <0.02 π·cm·mrad.

The extracted electron current at the source plasma grid is expected to be about 3% of the Li⁻ current and will be recovered by the standard SITEX electron-recovery system on the source (Fig. 4). Since the electron-recovery voltage will be less than 10 kV, the fraction of ion accelerator power going into electrons will be less than 0.3% for an accelerating voltage of 100 keV. *No electrons are accelerated with the beam.* As such, the few electrons we expect to have will be no problem from either sparking or power loading.

A Li⁻ ion-source isotope separation series was performed at ORNL using a reflex discharge like the SITEX but without the converter. They accumulated ~24,000 h of beam experience at 35 keV with an average run life of 40 h (dc beam). We expect similar reliability. Our original proof-of-principle experiment will be performed at 20 keV (power supply limit). The highest Li⁻ currents produced to date are <10 μA on accelerator sources,[17] so that we are making a large scale-up.

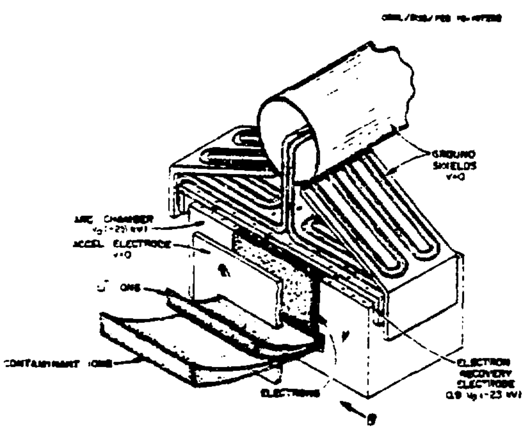

Fig. 4. SITEX electron recovery system and momentum dispersion which purifies the accelerated beam.

DIAGNOSTIC BEAM LINE

Figure 5 shows a concept for an alpha particle diagnostic beam line based on the SITEX direct-extraction source. Due to features of the source, the beam (1) has no impurities, since the estimated 1% extracted impurities are analyzed out by the source magnetic field; (2) has no high-energy electrons, since they are all separated out and recovered by the source-electron recovery system; (3) has short-pulse to direct-current capabilities due to low-power density loading on all source structures; and (4) has superior low-emittance optics for injection into an RFQ accelerator. The RFQ would be followed by a deflection magnet (to help decouple the RFQ from the gas loading of the gas neutralizer), a gas neutralizer (producing ~50% neutrals),[1] a deflection magnet to remove and dump the ion component (~50%), and an entrance duct to the fusion reactor. Note that Fig. 5 beam line is considerably less complicated up to the RFQ [than in Fig. 6 of Ref. 1, which used a Li⁺ beam and a double charge-exchange mechanism to generate Li⁻.

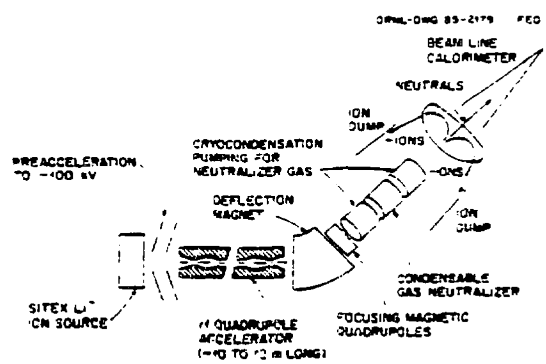

Fig. 5. Alpha particle diagnostic beam-line concept.

Table 1 gives parameters for H^-/D^-, which we have reported previously, and the extrapolations we have made to a near-term, 20-keV Li^- proof-of-principle beam[15] and to the ultimate alpha particle diagnostic beam line.[16] The only critical issue is the Li^- production per incident Cs^+ ion on the converter. We expect to have results on the proof-of-principle experiment before the end of September 1985.

SUMMARY

The high-energy Li^0 doping beam is expected to give the most complete information on the alpha particle distribution. However, it also is the most complicated and expensive diagnostic for this purpose. The use of a direct-extraction SITEX Li^- source would greatly simplify the beam line over one using double charge exchange and, hence, would lower the cost. SITEX offers a low-emittance beam for direct injection into the RFQ and demonstrated long-pulse performance. The beam can also be modulated[9] so that modulation-detection techniques can be used to enhance the charge-exchange signal-to-noise ratio.

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Table 1. H^-/D^- performance status and Li projection for SITEX source

	Achieved		Projected		
Parameter	H^-	D^-	Proof of principle		Beam line Li^-
I_{accel}[a] (mA)	650	260	25		100
$J_{extraction}$ (mA/cm^2)	130	100	10		10
V_{accel} (kV)	18	10	18		100
Pulse length (s)	≤10	≤5		0.001-dc	
Source discharge pressure (mtorr)	4	4		4	
Extracted e/Li^- (%)	<15	<5		15	
Electron recovery at 10% V_{accel}	yes	yes		yes	
Arc efficiency (kW/A of beam)	5	5		25	
Beam divergence (°)	2[b]			$\theta_{\perp rms} = 0.35°$ $\theta_{\parallel rms} = 0.18°$	

[a] Contains no electrons.
[b] Unoptimized accelerator.

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