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***Calcium and lithium ion production for
laser ion source***

**M. Okamura^{1,2}, K. Palm³, C. Stifler⁴, D. Steski¹,
S. Ikeda^{2,5}, M. Kumaki^{2,6}, T. Kaneshue¹**

¹Brookhaven National Laboratory, Upton, NY 11973 USA

²RIKEN, Saitama, 351-0198 Japan

³Cornell University, Ithaca, NY 14853 USA

⁴Providence College, Providence, RI 02918 USA

⁵Tokyo Institute of Technology, Yokohama, Kanagawa 226-8502 Japan

⁶Waseda University, Tokyo 169-8555 Japan

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Calcium and Lithium Ion Production for Laser Ion Source^{a)}

M. Okamura^{1,2,b)}, K. Palm³, C. Stifler⁴, D. Steski¹, S. Ikeda^{2,5}, M. Kumaki^{2,6}, and T. Kanesue¹

¹Collider-Accelerator Department, Brookhaven National Laboratory, NY, USA

²Nishina center for Accelerator-Based Science, RIKEN, Saitama, Japan

³Department of Physics, Cornell University, Ithaca, NY, USA

⁴Engineering Physics Systems Department⁴Providence College, Providence, RI, USA

⁵Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, Kanagawa, Japan

⁶Research Institute for Science and Engineering, Waseda University, Tokyo, Japan

Calcium and lithium ion beams are required by NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory (BNL) to simulate the effects of cosmic radiation. To find out difficulties to provide such high reactive material as laser targets, the both species were experimentally tested. Plate shaped lithium and calcium targets were fabricated to create ablation plasmas with a 6ns 1064nm Nd:YAG laser. We found significant oxygen contamination in both the Ca and Li high charge state beams due to the rapid oxidation of the surfaces. A large spot size, low power density laser was then used to analyze the low charge state beams without scanning the targets. The low charge state Ca beam did not have any apparent oxygen contamination, showing the potential to clean the target entirely with a low power beam once in the chamber. The Li target was clearly still oxidizing in the chamber after each low power shot. To measure the rate of oxidation, we shot the low power laser at the target repeatedly at 10sec, 30sec, 60sec, and 120sec interval lengths, showing a linear relation between the interval time and the amount of oxygen in the beam.

I. INTRODUCTION

A laser ion source (LIS) is an effective and simple method for creating a wide variety of ions. A plasma plume is created by a pulsed power laser focused on the target surface. Ions are extracted from the expanded plasma and subsequently are collimated into a beam. By replacing target materials, ion species can be easily changed. This method has not yet been extensively tested on Li and Ca targets due to their high reactivity. Those beams are requested by NASA space radiation laboratory (NSRL) in Brookhaven National Laboratory (BNL) for cosmic rays simulation [1]. Li ion beams also have a potential use for neutron beam creation [2]. Because a LIS can be used with direct plasma injection scheme (DPIS)[3,4] to accelerate intense fully stripped Li ions onto a hydrogen rich target. In this work the plasma properties of Li and Ca for the LIS were investigated.

II. EXPERIMENTAL SETUP

The targets were irradiated with a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser operating at a wavelength of 1064 nm and 6 ns of pulse length. The laser was focused on the target with a plano-convex focusing lens with a focal length of 100 mm. The distance of the lens from the target was adjustable from outside of the target vacuum chamber, allowing for the beam to be

focused and defocused. The incident angle between the laser path and the beam line was 20°. The target chamber and subsequent beamline were held below 1.8×10^{-4} Pa for the duration of the experiment. Both Li and Ca oxidize rapidly when exposed to the oxygen in the atmosphere. To limit the exposure of the targets, special precautions were taken in the making of the targets. The metals were polished, rolled to the proper thickness using a rolling mill, and immediately stored in a portable vacuum chamber. When the targets were installed, argon gas flow was used to reduce the exposure to oxygen. Then the target chamber was immediately pumped down to vacuum. Figure 1 is a sketch of the Li target holder which was specially designed to stabilize the very soft metal without cutting through it. The rigidity of the Ca target allowed for using a regular mounting fixture. Each target had a thickness of 1 mm. A Faraday Cup (FC) with $\phi = 10$ mm aperture was placed at 2.4 m away from the targets to measure the beam current.

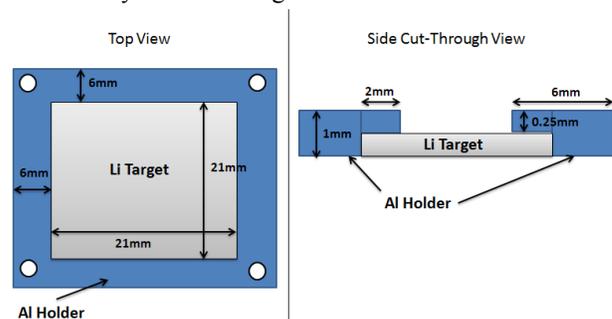


FIG. 1. Sketch of Li Target holder

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^{b)}Author to whom correspondence: okamura@bnl.gov

The suppressor voltage of FC was set to -3.5 kV. The plasma was analyzed by an electrostatic ion analyzer (EIA). The selected ions were detected by a secondary electron multiplier (SEM). The total distance between the detector and target was 3.7 m. Ion species and charge states were determined by time of flight information in the SEM signal and the applied voltage to the EIA. In the experiment we detected H, Li, O and Ca ions. Unfortunately this apparatus cannot distinguish ions those are different species but have a same mass to charge ratio. Therefore some detected signals may be contributed by different species as summarized in Table I. The entire view of the experimental setup was explained in our previous publication[5].

m/q	Ion	m/q	Ion
1	H^{1+}	3.636	Ca^{11+}
2	${}^6Li^{3+}, O^{8+}, Ca^{20+}$	4	O^{4+}, Ca^{10+}
2.105	Ca^{19+}	4.444	Ca^{9+}
2.222	Ca^{18+}	5	Ca^{8+}
2.286	O^{7+}	5.333	O^{3+}
2.333	${}^7Li^{3+}$	5.714	Ca^{7+}
2.353	Ca^{17+}	6	${}^6Li^{1+}$
2.5	Ca^{16+}	6.667	Ca^{6+}
2.667	O^{6+}, Ca^{15+}	7	${}^7Li^{1+}$
2.857	Ca^{14+}	8	O^{2+}, Ca^{5+}
3	${}^6Li^{2+}$	10	Ca^{4+}
3.077	Ca^{13+}	13.33	Ca^{3+}
3.2	O^{5+}	16	O^{1+}
3.333	Ca^{12+}	20	Ca^{2+}

TABLE I. Mass to charge ratio of ions.

III. EXPERIMENT

It was clear from the initial tests that an appreciable amount of oxide formed on the surfaces of the targets, despite the careful mounting procedure. The analysis showed significant amounts of both the 7Li and 6Li isotopes in the Li experiments, while only ${}^{40}Ca$ was observed in the Ca experiments with no other notable isotopes. We assumed that the SEM has a constant sensitivity for different materials, charge states, and particle velocities. All beam current data was normalized to a 1 m distance from the source and a beam area of 1 cm^2 using the relation $I \propto L^{-3}S$, where I , L , and S are the current, distance from target, and beam area respectively.

A. High charge state ion production

A focused **XX mJ** laser beam with power density on the order of 10^{12} W/cm^2 was used to create high charge state Li and Ca beams. A fresh laser spot was always supplied by the motorized stage for every laser shot. For the Li beam, the analysis showed oxygen charge states ranging from O^{1+} to O^{8+} as well as ${}^7Li^{3+}$, ${}^7Li^{2+}$, ${}^7Li^{1+}$, and ${}^6Li^{3+}$. The beam composition data can be seen in Fig. 2. Similar oxygen contamination was found in the Ca high charge state beam. Many O and Ca peaks were indistinguishable due to same mass to charge ratios. The

histogram showing the abundance of the ions (Fig. 3) shows a charge state distribution in the Ca ion data. On the contrary, low charge state oxygen were not observed, although even charge state oxygen might be hidden in the Ca peaks. Fig. 5 shows time structure oxygen in the Ca plasma. The oxygen was not detected after $3.6\ \mu\text{s}$. The

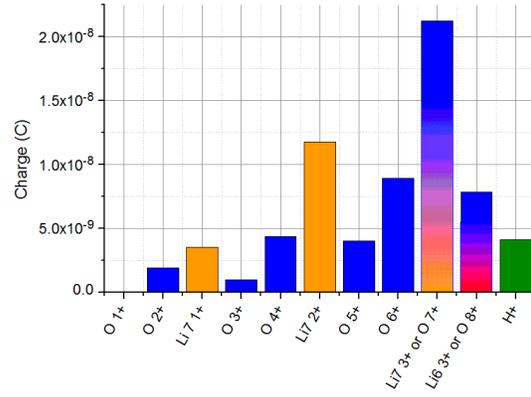


FIG. 2. Sketch of Li Target holder

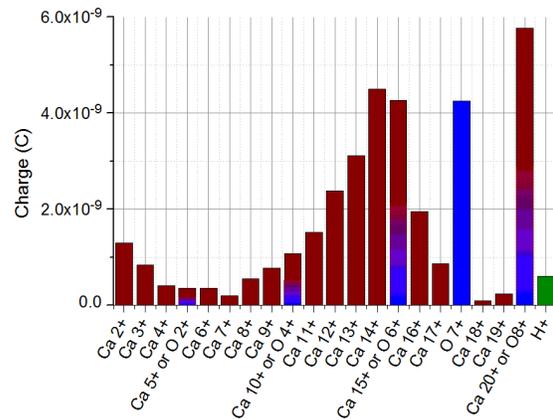


FIG. 3. Charge state and ion distribution from Li target.

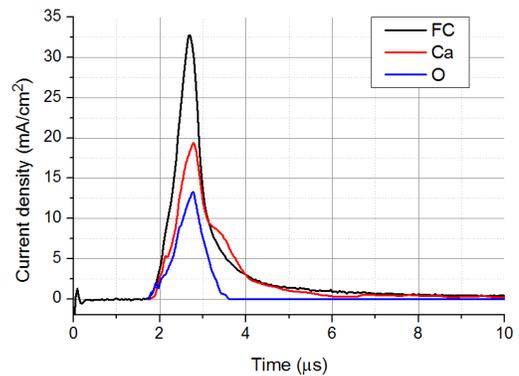


FIG. 4. Current time profile of Ca beam.

oxide were formed only at the surface of the target and did not contribute to slow expanding low charge state production. Surface roughness data was recorded after the

chamber had been opened and it was found that it had a variation of ± 0.25 mm, which is outside of our tolerance of ± 0.1 mm. This could effect on the broad charge state distribution. For industrial application, control of surface roughness may need to be developed.

B. Low charge state ion production

An experiment was run to test the effect of the oxide layer with low charge state production mode. The target was not scanned. A power density of 5.0×10^8 W/cm² was used with a 0.28 cm² spot size with XXmJ laser energy. At this power density, the only ions to appear were ⁷Li¹⁺, ⁶Li¹⁺, and O¹⁺ from the lithium plasma. It was found that repeatedly firing the laser at a single spot did reduce the height of the O¹⁺, however if the target was allowed to sit without being fired upon for longer than a few seconds and then fired upon again, the oxygen peak would increase. This implies that even under a vacuum of 10^{-4} Pa, the Li target was still being rapidly oxidized. An experiment was run to determine how much oxygen is present in the beam at constant interval irradiation of the target. Data was taken for interval lengths of 10 sec, 30 sec, 60 sec, and 120 sec. Before the data was recorded, the laser was shot at the interval length being tested until the ion output stabilized. Approximately 50 laser shots were required to stabilize the beam for each experiment. The results can be seen in Fig. 5. The amount of ⁶Li compared to ⁷Li was found to be approximately 9% for each interval length, which is fairly consistent with its reported natural abundance of 7.5% [6]. The amount of O¹⁺ in the beam and the interval time showed a clear linear relationship. In the LION source in BNL, the vacuum pressure is kept about 3.0×10^{-6} Pa and the interval of the laser shot for NSRL is 5 second. The contamination caused by oxygen is expected to be negligible comparing the obtained linear function.

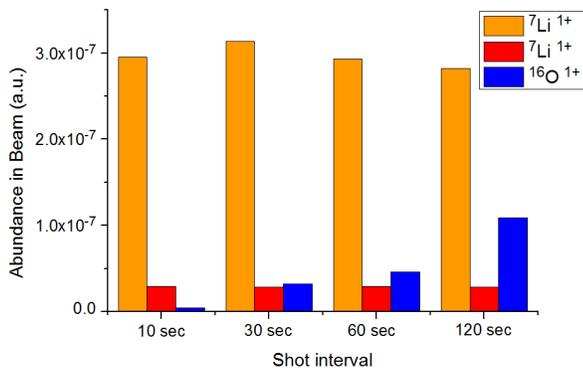


FIG. 5. Laser shot interval and ion yields with Li target.

A low power experiment was run on the Ca target with a power density of 1.7×10^8 W/cm² and spot size 0.52 cm². With these conditions, only Ca¹⁺ and Ca²⁺ were observed with no oxygen. This result shows that after the initial

oxide is cleaned off of the surface, no subsequent oxide is formed on the target surface while it is under vacuum.

XI. CONCLUSION

The LIS can create high charge state ions from both Li and Ca target. There was an apparent oxygen contamination in both beams. We found that the oxidization of Ca target was negligible in the good vacuum condition. The Li target was clearly oxidizing in the vacuum chamber held below 1.8×10^{-4} Pa. A linear relationship between oxygen amount and interval shot time for a low power density, large spot size laser on the Li target shows the potential to regulate the amount of oxide on the surface while the target is inside the chamber.

XII. ACKNOWLEDGEMENT

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