Laser Ablation Production of Molecular Ions

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Abstract

Robust sources of molecular ions are needed for work ranging from quantum chemistry to quantum computing. Here we investigate the use of the technique for laser ablation for the production of molecular ions. $BaCl^+$ ions were created by laser ablating a $BaCl_2$ target using a pulsed Nd:YAG laser. The effect of ablation target preparation on $BaCl^+$ production was investigated by comparing target lifetime, peak ion number, and ion production fluctuation of each target. We found that, based on these characteristics, the 12000 lbs unannealed target would be the best target for further ion production.

Introduction

Laser ablation is a process in which a laser heats up a small area of a target, causing the material at that point to evaporate and form a plume of various atomic and molecular ions and clusters. Ion production through laser ablation is inconsistent and unpredictable, and since "the details of the physics behind laser ablation are quite complicated, and studying ablation is a field unto itself" (Weinstein, 2001, p. 25), knowing how to make improvements is difficult.

We tried improving ion production by comparing ablation targets made in different ways. This idea was based on the presumption that the properties and surface qualities of the target affect ablation. The goal was to develop targets with a long lifetime that produced a large number of molecular ions with few fluctuations.

Besides testing the targets by ablating them, we also measured their thermal conductivity and density to see if there was any correlation between these properties and the quality of the signal the target produced. We chose to look at these properties because the rate at which heat from the laser spreads through the target may affect subsequent ablation pulses and because the number of $BaCl_2$ molecules in the ablated area may affect ion production.

Experimental Setup

Making the Targets

$BaCl_2$ came in the form of a white powder that was then pressed into tablets roughly 13mm in diameter using a hydraulic press. We made two targets each pressed with a maximum force of 6000 lbs, 9000 lbs, 12000 lbs, 15000 lbs, and 18000 lbs.

We then annealed half of the targets at 900°C, which is just below $BaCl_2$ melting point. At this temperature $BaCl_2$ is soft enough to allow all deformities and impurities to move out of the target. Annealing produces a target that is smaller, denser, and harder than an unannealed target.

Thermal Conductivity

To measure the thermal conductivity we built a setup consisting of a heating resistor and two pieces of aluminum (Figure 1). By knowing the power output of the resistor and the temperature gradient, the thermal conductivity of the target could be calculated using the equation:

$$\frac{dQ}{dt} = -kA\frac{\Delta T}{\Delta x}$$

Because of heat loss due to conduction and black body radiation, we were unable to get absolute values for the thermal conductivity and instead got relative values.

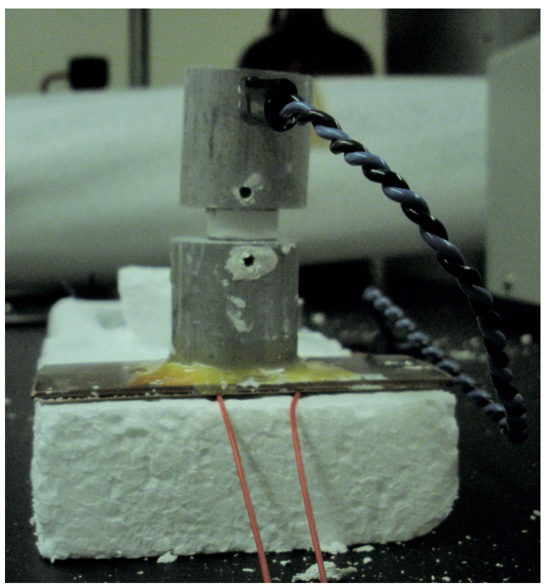


Figure 1: Thermal conductivity measurement

Ion Trap

In order to trap the $BaCl^+$ ions we used an electric field created with four metal rods (Figure 2): two diagonally opposite rods had an RF voltage and the other two rods had a DC voltage. The mass of the particles that can be trapped in the electric field depends on the voltages across the rods; we let $V_{RF} = 100V_{PP}$ and $U_{DC} = -2V$ in order to trap $BaCl^+$ without also trapping Ba^+.

Our ion trap also had two endcaps, initially kept at $10V$, that confined the ions axially. 0.15 seconds after the laser pulse, one of the endcaps would drop to $0V$, allowing the ion cloud to move towards the Channeltron, which was kept at $-2500V$.

Since the ablation plume comes off the target at speeds on the order of $10^4\ m/s$ (Mao, 2005), we had a helium buffer gas running through the ion trap to slow down the ions long enough for them to be trapped. The trap was also continuously under vacuum.

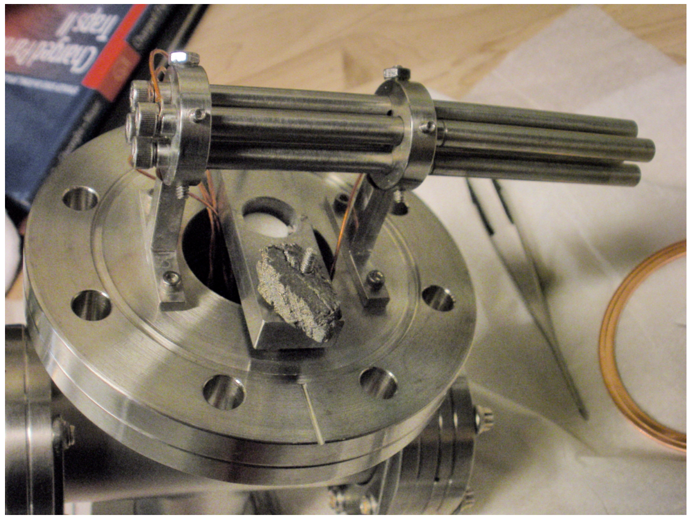


Figure 2: The open ion trap. Also in the picture is the $BaCl_2$ target and a piece of ytterbium, which has the same mass as $BaCl^+$.

Results and Analysis

For each ablation pulse we had a signal proportional to the number of $BaCl^+$ ions created by that pulse (Figure 3).

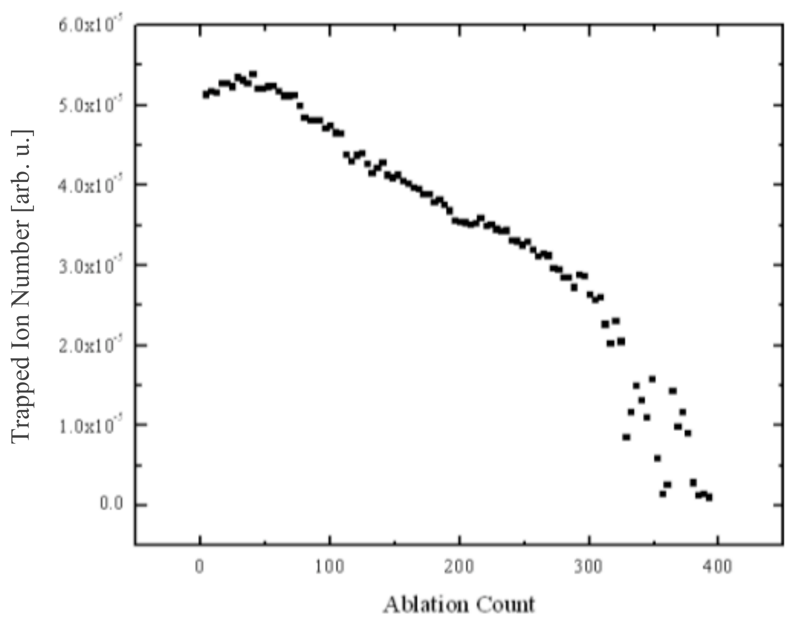
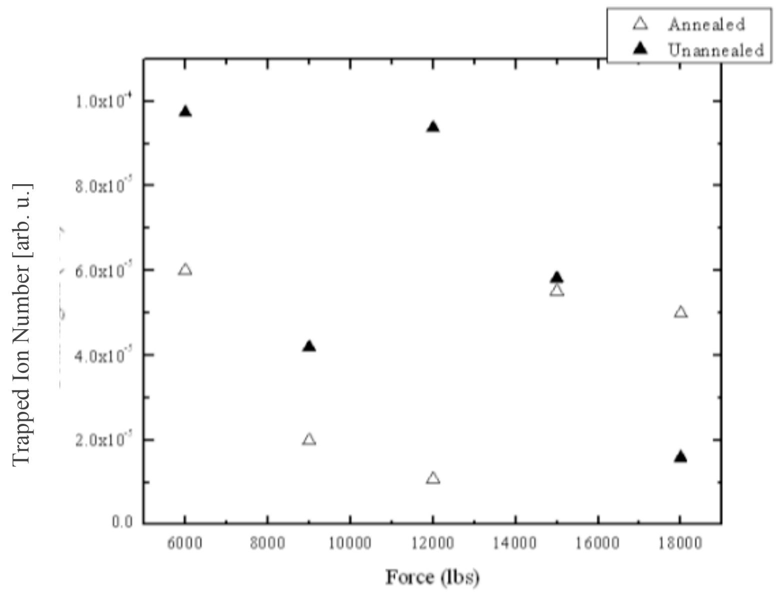
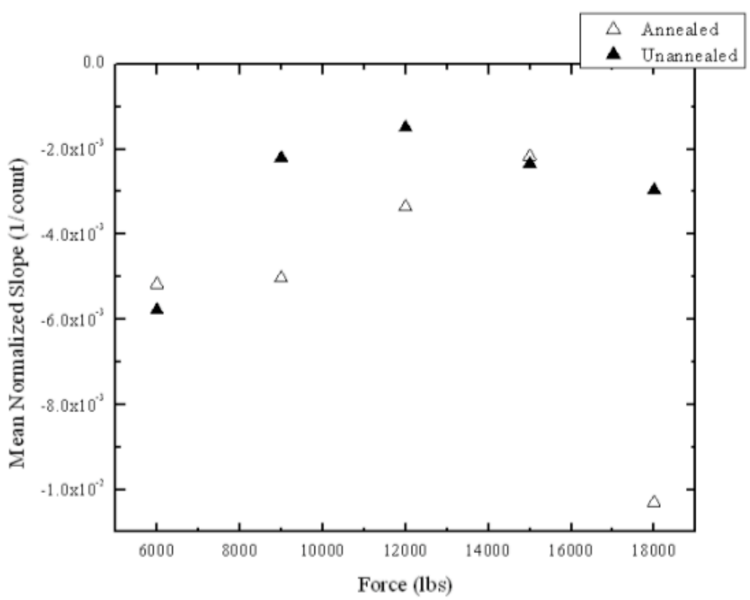


Figure 3: An example of trapped ion number vs. ablation pulse count graph

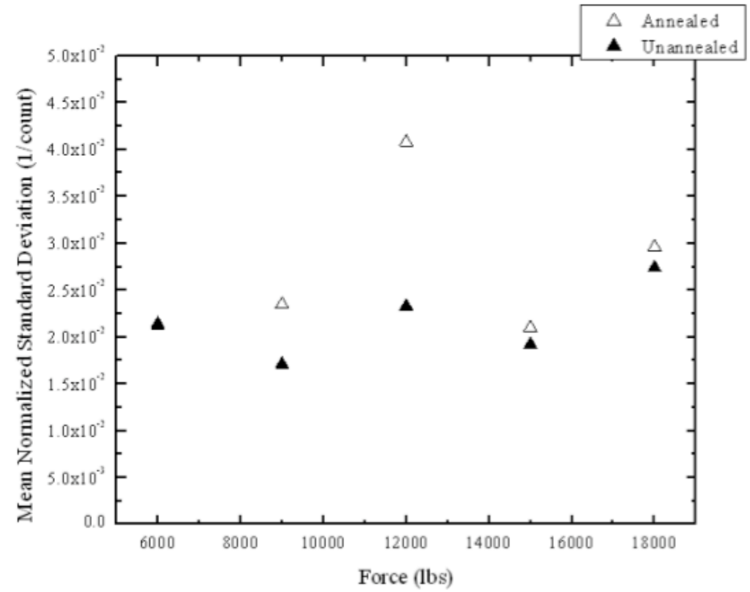
The mean numerical derivative gave us the lifetime of the run, and the standard deviation of the numerical derivative gave us the fluctuation of the signal. We normalized the mean and standard deviation by the peak signal in order to be able to compare different ablation spots and targets. The results of the analysis are shown below as a function of the force used to press each of the targets.



Graph 1: Peak Signal vs. Pressing Force



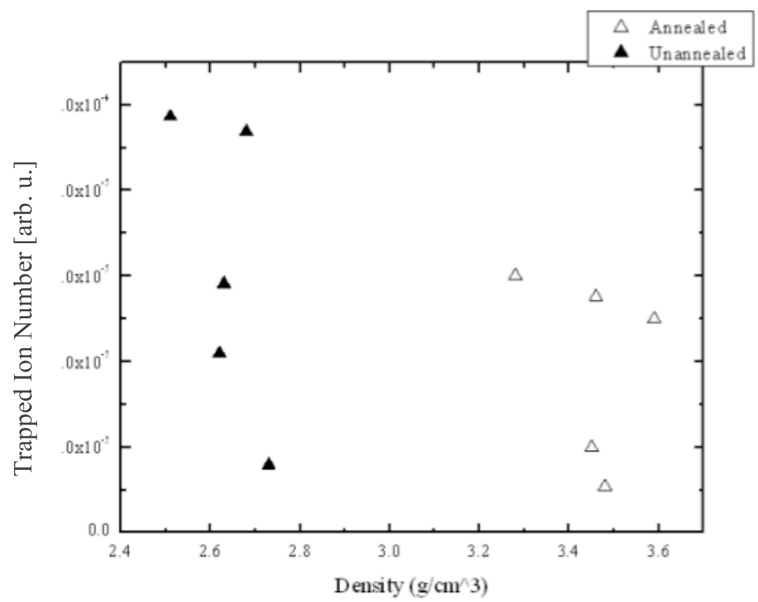
Graph 2: Target Lifetime vs. Pressing Force



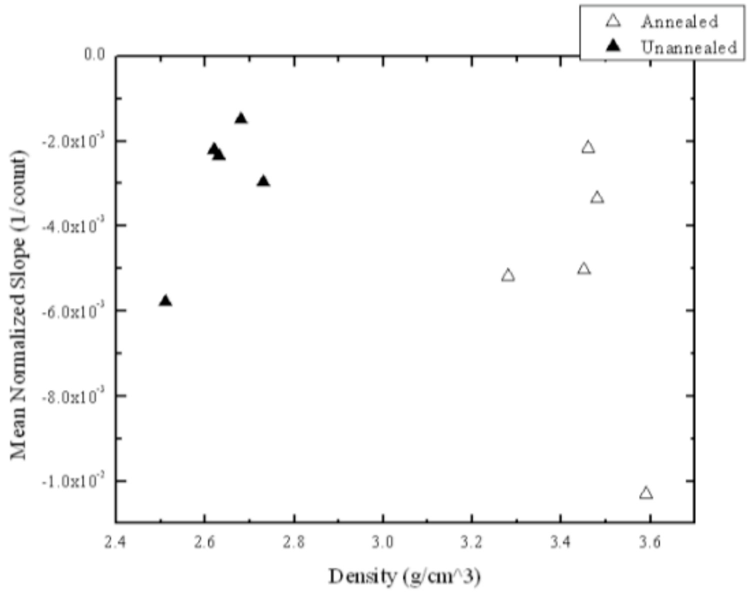
Graph 3: Signal Fluctuation vs. Pressing Force

The amounts of ion production fluctuation for all the targets except the 12000 lbs annealed target were similarly low. After also taking into account the peak ion number and the target lifetime, the 12000 lbs unannealed target was the best ion source.

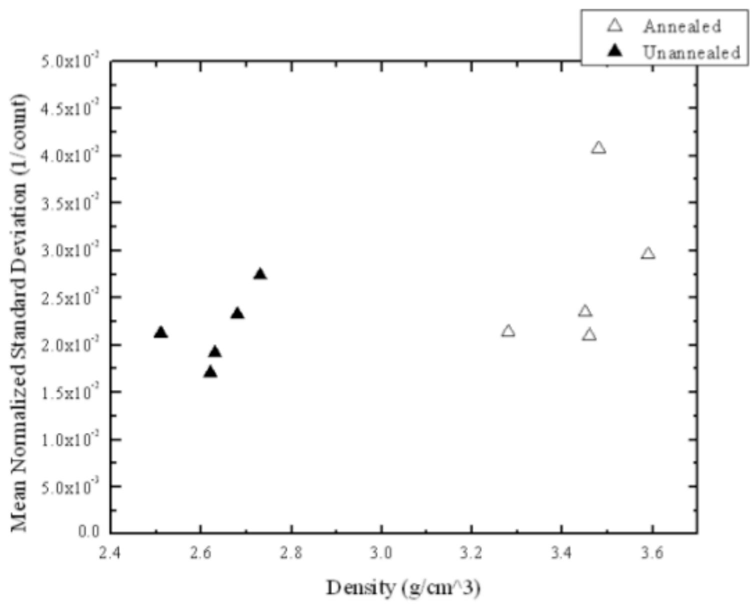
After measuring each target's density, we compared this value to the peak ion number, the target lifetime, and the ion production fluctuation to see if the density affected any of these values.



Graph 4: Peak Signal vs. Target Density



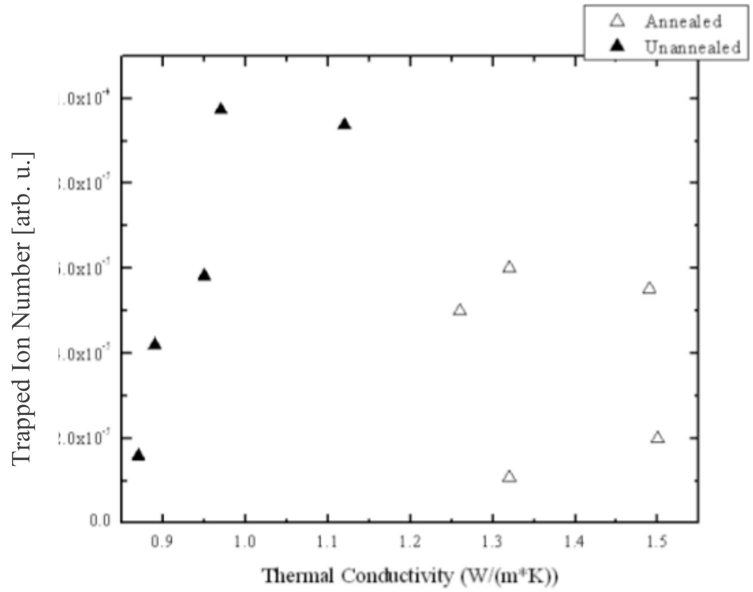
Graph 5: Target Lifetime vs. Target Density



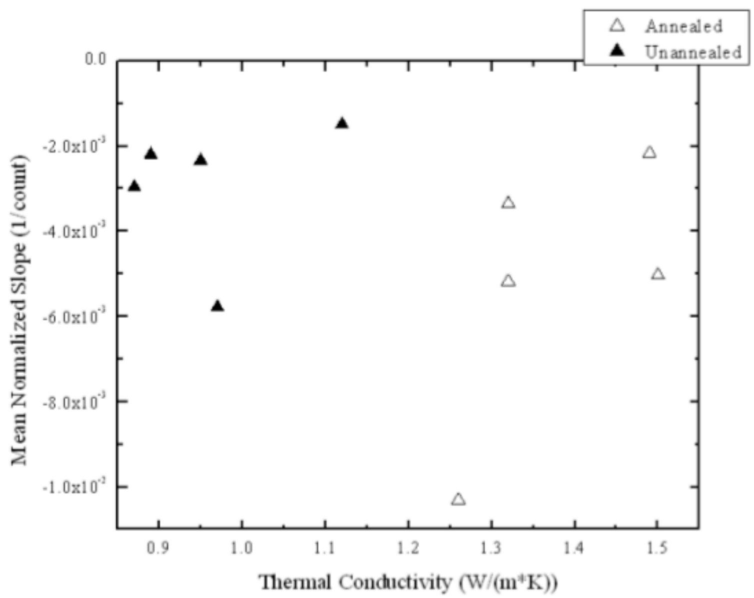
Graph 6: Signal Fluctuation vs. Target Density

From these graphs, it is apparent that there is no correlation between the performance of the target and its density.

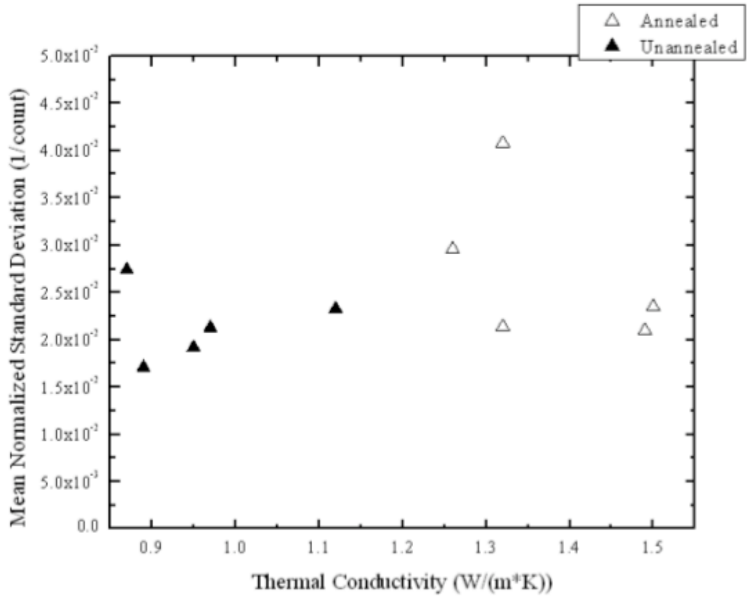
We then tried to find if there was any relationship between the thermal conductivity of a target and its peak ion number, target lifetime, and the ion production fluctuation.



Graph 7: Peak Signal vs. Target Thermal Conductivity



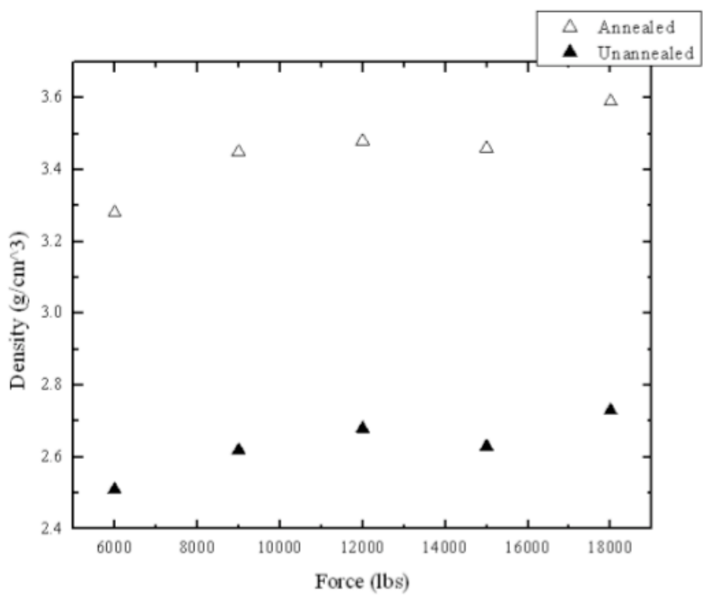
Graph 8: Target Lifetime vs. Target Thermal Conductivity



Graph 9: Signal Fluctuation vs. Target Thermal Conductivity

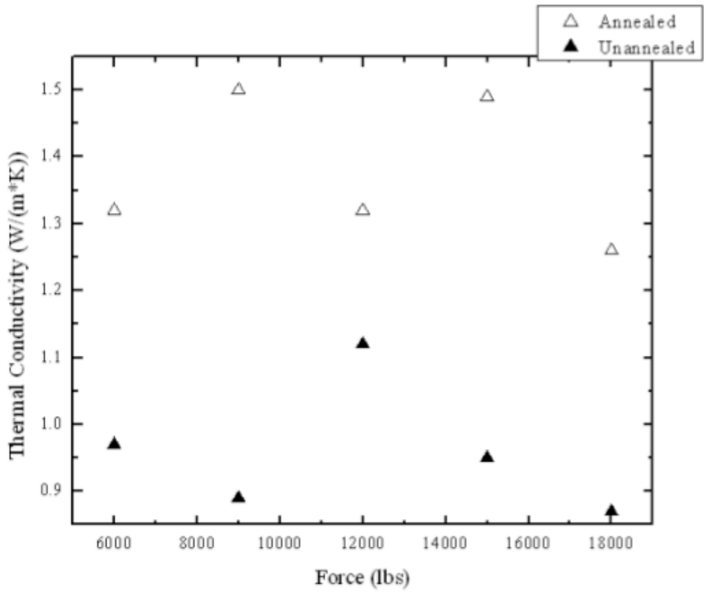
These graphs show that the thermal conductivity of the target does not affect the peak ion number, the target lifetime, nor the ion production fluctuation.

In case the target density and thermal conductivity did affect the quality of ion production from that target, we wanted to know if these two values were related to the way the target was made.



Graph 10: Target Density vs. Pressing Force

The density of the target seemed to increase as the force applied increased. When measuring the density, we assumed that the targets had a perfectly cylindrical shape. If a small piece of a target had chipped off, we didn't take that into account when measuring the density, which is why the two 15000 lbs targets had a lower density than what would be expected.



Graph 11: Target Thermal Conductivity vs. Pressing Force

The thermal conductivity does not seem to be related to the force with which the target was pressed, making it difficult to purposefully make a target with a specific thermal conductivity.

Future Work

Another possibility for making targets would be to grow $BaCl_2$ crystals, since a target with a regular internal structure may produce a better signal. We are currently trying to grow crystals by evaporation and by slow cooling of melted $BaCl_2$; however, we do not have any results for either of these methods yet.

Conclusion

If we are to continue making targets by pressing $BaCl_2$ into tablets, the 12000 lbs unannealed target would be the best target to use. However, it is worthwhile to study different ways of making targets as they may produce better ablation targets.

References

Weinstein, J. D. *Magnetic Trapping of Atomic Chromium and Molecular Calcium Monohydride*. Ph.D. Thesis. Harvard University, Cambridge, 2001.

Mao, Samuel S. "Laser Ablation – Fundamentals and Applications". 2005. <http://www.jlab.org/FEL/LPC/05lpc-mao.pdf"