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STUDY ON NEW METHOD FOR GENERATING HIGHLY CHARGED IONS WITH DOUBLE PULSE LASER ION SOURCE*

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Abstract

In this research, we plan to generate highly charged ions by using a laser that can achieve high repetition. This laser is Ytterbium (Yb) laser that can be driven at high power and high repetition. We validate the two methods. The first method is a high-intensity laser that is focused on the solid, which analyzes the valence of generated ions (Single shot method). The second method is a previously formed pre-plasma using a Q-switched laser followed by reheating the pre-plasma using high-intensity Yb laser (Double shot method). At present, we have developed high power Yb laser and pre-testing of the ion source using the Nd:YAG laser is required to perform the measurement test described above. These analyzes were performed on tantalum and carbon ions with a valence analysis of 'Time of Flight' method in the pre-test. Additionally, development of Yb laser have already achieved a laser energy of 70mJ. The next stage we will develop to generate for highly charged ions to further high power laser. (Maybe change judging on the context of the sentence) The next stage we plan to generate highly charged ions to further the high power laser.

INTRODUCTION

In the past decades, intensity heavy ion acceleration has been drawing intense research interest because of their potential applications in heavy ion radiotherapy, radioisotope, cosmic ray, etc. Laser ion source capable of generating a high intensity ion relatively simple is best for the ion source for these applications. A great deal of effort has been made on particle number as Direst Plasma Injection Scheme (DPIS) [1], which seems to be lacking. However this is producing highly charged ions. Previously, it has been used EBIS (Electron Beam Ion Source), ECRIS (Electron Cyclotron Resonance Ion Source), LIS (Laser Ion Source) for ion source of heavy and highly charged. Of these ion sources, the problem of LIS is too low to generate maximum charge state. As far as we know, there have been few reports about how to produce highly charged ions. Only previous research has reported that high charge state such as Au^{+53} ions are produced by PALS laser [2]. "Nonlinear plasma absorption" mechanism, such as self focusing and was used for this. However, these methods have limitations, for example they cannot have a high repetition rate of the laser. These experiments don't really represent the situation in nonlinear plasma process in detail. The production of multiple charged ions can be achieved by the laser since these are shown, but it is not known for a detailed physical mechanism of the plasma non-linear effects. However, it depends on the laser intensity for most of these nonlinear effects, so it becomes significant when it exceeds 10^{14}W/cm^2. From the above, Laser of high repetition rate can be achieved from laser intensity of 10^{18}W/cm^2 easily if we use the laser method of Chirped Pulse Amplification (CPA). In addition it can be expected that ions of higher valence is generated. In particular, Nd (λ=1064nm, E<1.2J, t~10ns) and Yb laser(λ=1030nm, E<10J, t~500fs) systems is possible to operate at 10 - 50Hz repetition rate. This double pulse laser system, especially Yb laser, with attainable laser intensity up to about 10^{18}[W/cm^2], was used to generate highly charged ions of solid target. First, the Nd laser creates a plasma plume. Next, the Yb laser reheats the plasma plume by a high intensity pulse at a delay of one nanosecond. Nd:YAG laser, which enters first causes ionization one by one by classical absorption mechanism. Plasma plume of this state is the charge state from 20 to 30 valence, ionization cross section of highly charged ions are increased. Accelerated fast electron by the ponderomotive force is incident toward the high density of the plasma and reheating the plasma further more high temperature?. Additionally, when laser enters into a high-density part, it is reflected and plasma reheat is performed by the resonance absorption etc. We have proposed that highly charged ions are generated by these schemes, and the ion acceleration of high energy by combination with a laser ion source are considered.

EXPERIMENTAL SETUP

We were designing the test bench for the laser ion source at the same time as development of Yb laser. It is possible to do measurement valence analysis and beam current amount in the test bench. Furthermore, we constructed a circuit system, which can be irradiated by delay time with control of the two lasers.

Figure 1 shows schematic picture of the experimental system. The generated plasma is separated into each charge state using a time of flight method and it is detected by amplifying the signal at Micro Channel Plate (MCP). Shows the diagram of the system for irradiating with delay-time controlled by double pulse lasers in Fig. 2. Figure 3 shows an example of the control the delay signal is detected by photo-detector.

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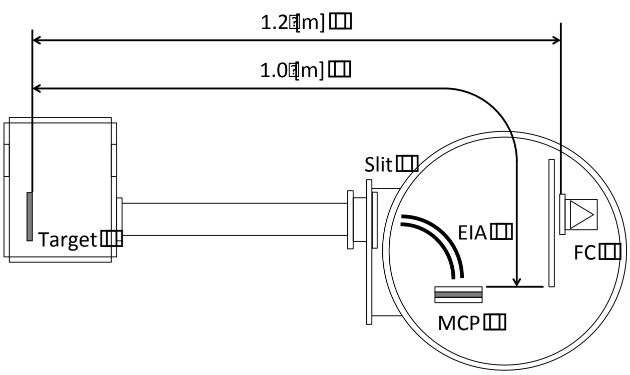

Figure 1: Schematic picture of the experimental.

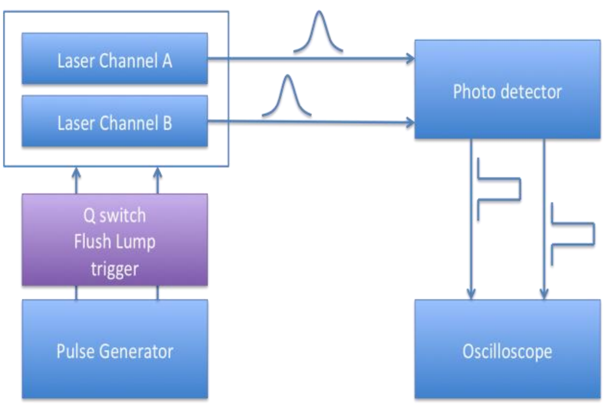

Figure 2: Diagram of delay time control.

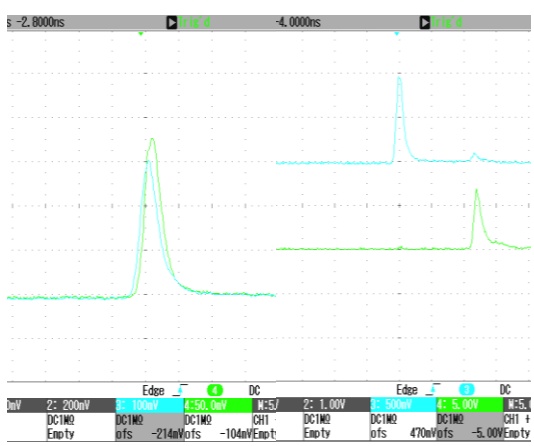

Figure 3: Example of delay time control signal.

DEVELOPMENT OF LASER

Laser repetition of several Hz is required for accelerator ion source. PALS Iodine laser has low repetition rate such as 5shot / hour, it is not suitable for accelerator applications. Therefore, the laser of the candidate is limited to CO_2 laser, Nd:YAG laser, Ti:Sapphire laser, etc. CO_2 laser of CERN laser ion source has been reported to generate Pb^{32+} in the ion source using these commercial lasers [3]. The charge state is the maximum state in the realistic laser ion source. In order to exceed this charge state, it is necessary to use higher intensity laser.

In summary ion production can't be done by these things due to a low repetition rate of the laser or low charge state. Recently, these problems have been solved with the advent of the Yb laser [4]. There is some reason for example Since the difference between the oscillation wavelength and the excitation wavelength is 9 %, the quantum efficiency of Yb is very high as a result good thermal property. Yb laser can be directly pumped by laser diodes (LD) because Yb lifetime is about 951μsec at the excited state. LD which directly convert electricity into light can be high efficiency. Yb can be doped in YAG crystal with high concentration of 100 % because it is almost the same between the radius of Yb and Y. this fact enables thin disk lasers. Also, the large surface to volume ratio of the thin disk enables efficient heat removal from the laser material and decreases the wavefront distortion due to the thermal lens effect.

We have been developing high power Yb laser for these reasons. Recently, we have modify Yb laser system that shown in reference [4]. A schematic drawing of Yb laser system is shown in Fig. 4.

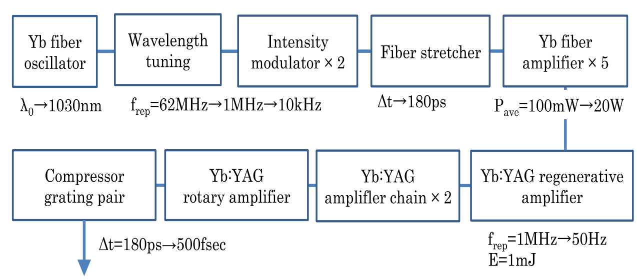

Figure 4: Schematic layout of Yb laser system.

Presently, we have achieved 70mJ in Yb:YAG amplifier chain and aim to further more output energy. Next step, we will develop Yb:YAG rotary amplifier and compressor in order to perform CPA. Details are shown Table.1 about a present characteristic parameter and desired value.

Table 1: Present and Goal Laser Parameters

	Yb Fiber	Yb:YAG	Goal
Pulse energy	13 μJ	70 mJ	10 J
Repetition rate	1 MHz	3 Hz	50 Hz
Average power	20.9 W	210 mW	500 W
Pulse duration	180 psec	90 psec	500 fsec
Wavelength	1032 nm	1030 nm	1030 nm

PRE-EXPERIMENTS

We fabricated each measurement device in this study. The properties of highly charged ions were investigated mainly on the base of time-of-flight method and current

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measurements. The experiments were conducted using a carbon and tantalum in the target material. Figure 5 shows Time of fight spectrum for carbon and tantalum ions and Fig. 6 shows Ion pulses for Ta^{1+} to Ta^{6+}. However, Ta^{7+} and Ta^{8+} was a weak signal and we don't get the velocity distribution.

We have confirmed that the test bench is working successfully from these results. Also, we confirmed that the same ion ionization state is able to reproduce the same laser intensity from research reports in the past [5]. This is the same problem that we found from the pre-test. First, we found a carbon spectrum that included some signal derive from contamination. If we improve this one, it must use higher purity and low contamination target on this surface. Also, we must improve that we can control the amount of particle number flexibly because it is different to generate the amount of plasma depending on the elements.

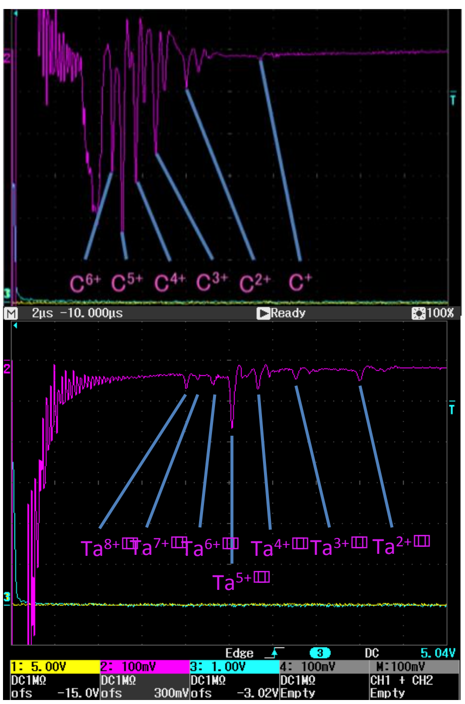

Figure 5: Time of fight spectrum for carbon and tantalum ions.

Originally, laser-produced plasma is formed with a deformed Maxwell-Boltzmann distribution in consideration of the initial velocity. There is a need to improve the resolution since the pulse waveform is steep velocity distribution of tantalum. Taking a longer time for Time of flight (Taking longer length plasma drift) in order to solve this problem is required.

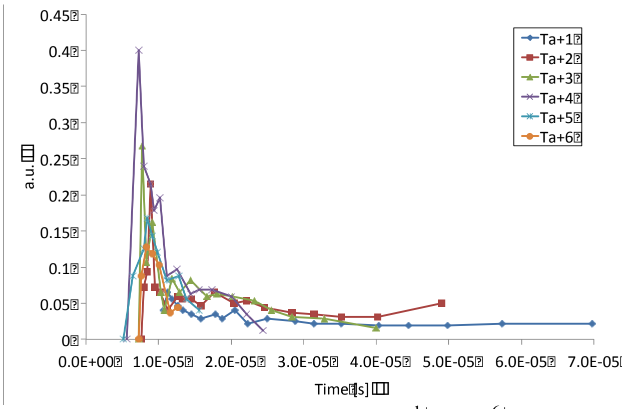

Figure 6: Ion pulses for Ta^{1+} to Ta^{6+}.

RESULTS

In this research, we reported on the pre-test for generating highly charged ions and the progress of laser development. We will go to the next stage of development with a laser with increased power. Finally, we are planning to build the best way of accelerating the method for highly charged ions and DPIS in near future.

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