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*Target life time of laser ion source for low charge  
state ion production*

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# TARGET LIFE TIME OF LASER ION SOURCE FOR LOW CHARGE STATE ION PRODUCTION

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## Abstract

Laser ion source (LIS) produces ions by irradiating pulsed high power laser shots onto the solid state target. For the low charge state ion production, laser spot diameter on the target can be over several millimeters using a high power laser such as Nd:YAG laser. In this case, a damage to the target surface is small while there is a visible crater in case of the best focused laser shot for high charge state ion production (laser spot diameter can be several tens of micrometers). So the need of target displacement after each laser shot to use fresh surface to stabilize plasma is not required for low charge state ion production. We tested target lifetime using Nd:YAG laser with 5 Hz repetition rate. Also target temperature and vacuum condition were recorded during experiment. The feasibility of a long time operation was verified.

## INTRODUCTION

LIS have been studied to provide high current highly charged state heavy ion beams. For this purpose, the laser light is focused on a target material as much as possible to obtain higher charge states and a big crater is made [1]. However a mild focusing LIS can be used for low charge state ions those are also applicable to many other purposes. For instance, intense singly charged heavy ions might be good seeds for a charge breeding system like electron beam ion source (EBIS). Then, recently, we started basic investigations of the low charge ion beam production using a LIS.

## EXPERIMENTAL SETUP

We used a second harmonics of Nd:YAG laser (0.5 J / 6 ns and 532 nm wave length) as a LIS driver. Laser was running with 5 Hz repetition rate. During experiments, laser power was fixed and laser power density on the target was controlled by adjusting a laser spot size. Figure 1 shows the schematic view of the experimental setup we used. Laser light was transported toward a convex lens located in front of vacuum chamber by three flat mirrors which had dielectric multilayer coating for high power laser irradiation. A convex lens was placed on an optical rail fixed parallel to a laser path which allowed us to change laser spot size easily by defocusing laser during experiment without opening vacuum chamber. In addition, the use of lenses with different focal length also permitted us to control laser spot size. Then laser light went into vacuum through a vacuum

window and a final flat mirror guided laser toward the target with an incident angle of about 6 degrees perpendicular to the target surface. A solid state target plate was fixed to a target holder. We used three different kinds of target which were Fe, Cu and Ta. When Cu target was irradiated, target temperature was recorded. We used a Lake shore DT 670 silicon diode temperature sensor which was controlled by Lake Shore 331. The sensor was pinched between two copper plates which were connected by two screws made of polycarbonate. The laser irradiated onto the target surface just front side of the sensor. Figure 2 shows this copper target and temperature sensor. A residual gas pressure inside of vacuum chamber was kept about  $10^{-4}$  Pa using a 800 L/s turbo molecular pump (OSAKA vacuum: TG800F). Target mass before and after experiment was weighed to estimate how many particles emitted. The crater depth generated by laser irradiation was measured by scanning target surface with a laser displacement sensor (KEYENCE LK-080).

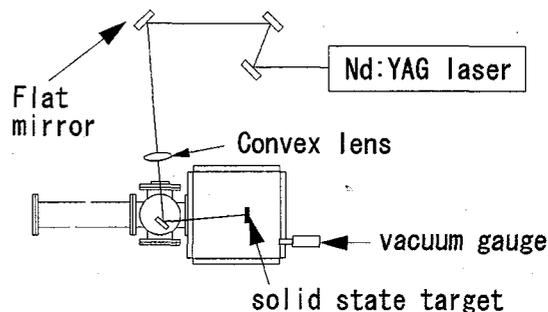


Figure1: Schematic view of the experimental set up

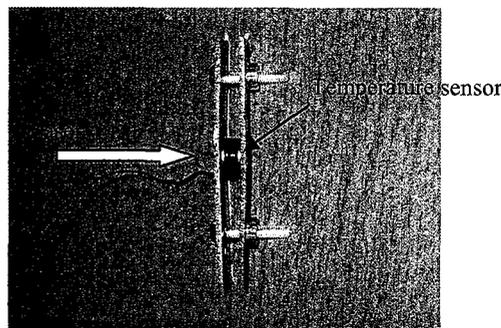


Figure 2: Copper target and temperature sensor

## RESULT AND DISCUSSION

The Cu target was irradiated for about 36 minutes with 5 Hz repetition rate which was corresponding to total of 11000 shots. As mentioned above, target temperature and vacuum pressure was monitored during this experiment. Laser power density was controlled to  $7.6 \times 10^8 \text{ W / cm}^2$  where laser spot size on the target was 4.2 mm. This power density is about threshold of charge state 2+ ion production so below this power density, only singly charged ion was observed. And so this test shows the almost maximum target damage because lower power density creates lower target damage. Figure 3 shows a time dependence of target temperature and target chamber pressure starting from the beginning of laser irradiation. Target temperature gradually increased as time passed. The gradient of temperature growing became lower after 10 minutes and temperature was almost stabilized at about 75 degrees Celsius in 30 minutes. This measurement indicates that an additional target cooling system is not necessary for a 5 Hz operation. About the vacuum, a residual gas pressure immediately became high when laser irradiation was started. The pressure before experiment was  $8.0 \times 10^{-5} \text{ Pa}$ . It immediately became high when laser irradiation was started but dropped to  $3.0 \times 10^{-4} \text{ Pa}$  within a half minute. Then the pressure was gradually decreasing and became almost stable at  $1.5 \times 10^{-4} \text{ Pa}$  in 20 minutes, which is low enough since a vacuum of several  $10^{-4} \text{ Pa}$  is required for a laser ion source. The crater depth on the target measured after experiment was 0.18 mm. This was corresponding to a 0.30 mm per hour.

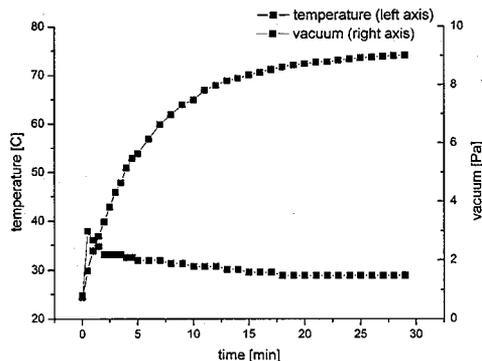


Figure 3: Target temperature and residual gas pressure inside target chamber using Cu target

The next target species was Ta which was irradiated for 30 minutes with 5 Hz repetition rate which was corresponding to 9000 shots in total. Laser power density and spot size was same as Cu target experiment. The result of scanning on the target surface showed that crater depth due to laser irradiation was about 0.16 mm per 30 minutes. Mass of the target was precisely measured

before and after laser irradiation. Loss of mass was 11.05 mg which was corresponding to 1.23  $\mu\text{g}$  per shot. Total number of particles emitted was  $3.7 \times 10^{19}$  calculated based on atomic number and  $4.1 \times 10^{15}$  particles were emitted per shot.

Then we applied lower power density of  $2.4 \times 10^8 \text{ W / cm}^2$  where laser spot size was 7.6 mm. Fe target was used for this experiment. Laser irradiation time and repetition rate was 30 minutes and 5 Hz, respectively. Total of 9000 shots was made to the target. Figure 4 shows the target surface after laser irradiation. The ununiformity of laser profile can be seen on the target. Some part was not deeply damaged. This deformed crater can influence long-term operation and stability. But this can be avoided by rotating target continuously or improving laser profile uniformity since this is purely caused by laser profile itself. Figure 5 shows the result of target surface scan using a laser displacement sensor. The depth of crater was about 0.02 mm per 30 minutes. Total loss of mass was 1.62 mg which was equal to  $3.7 \times 10^{19}$  particles and was corresponding to  $1.9 \times 10^{15}$  particles per shot.

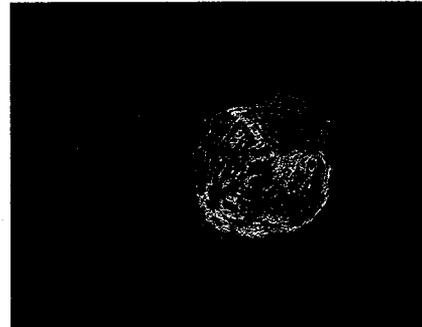


Figure 4: Fe Target surface after 30 minutes laser irradiation with 5 Hz. Laser power density and spot size was  $2.4 \times 10^{-4} \text{ W / cm}^2$  and 7.6 mm, respectively.

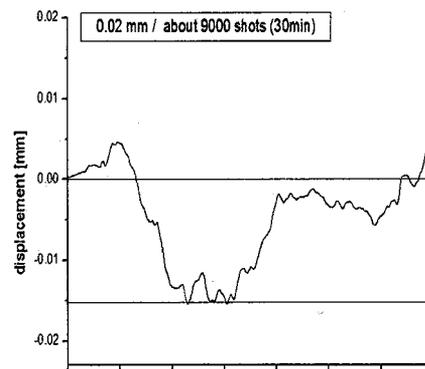


Figure 5: Result of surface scanning on Fe target shown in Fig. 4.

Table 1 shows the summary of these experiments. These results gave us basic information about target damage caused by laser irradiation which can be compensated by simple target displacement system along the beam direction.

### CONCLUSION

The target damage, temperature and vacuum change caused by Nd:YAG laser irradiation (500 mJ / 6 ns) with 5 Hz continuous operation was experimentally tested using Cu, Fe and Ta target. The result shows that the target

temperature and vacuum condition will not pose any difficulties in this operation condition. And target damage was also small enough.

### REFERENCES

- [1] T. Desai, D. Batani, S. Rossetti and G. Lucchini, "Laser-induced ablation and crater formation at high laser flux", Radiation Effects & Defects in Solids 160 (2005) 595.

Table 1 Summary of experiment results

Target species	Power density [W/cm <sup>2</sup> ]	Spot size [mm]	Target loss [g/shot]	Estimated emitted loss [particles/shot]	Crater depth [mm/30min]
Cu	7.60E+08	4.2	-	-	0.15
Ta	7.60E+08	4.2	1.23E-06	4.10E+15	0.16
Fe	2.40E+08	7.6	1.80E-07	1.90E+15	0.02