# LASER PRODUCED IONS AS AN INJECTION BEAM FOR CANCER THERAPY FACILITY*

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*Abstract*

Ion production from a solid target by a high-power short-pulse laser has been proposed to replace the injector linac for the synchrotron dedicated for cancer therapy in order to reduce the size of the facility. For the reduction of the energy spread of the laser-produced ions up to ±5 %, a scheme of phase rotation is to be utilized. A quarter wave length resonator with the resonant frequency of 79.3~82.7 MHz and its power amplifier of the maximum power of 30 kW are designed and fabricated. Ion production from the solid target has also been studied and experimental results suggest the ion production from under dense plasma for the case with the presence of pre-pulse.

## INTRODUCTION

High energy ion production from the solid target by a high-power laser has recently been reported [1, 2]. In such a process, target normal sheet acceleration is expected [3]. The lasers utilized for such purpose had been high power lasers mainly oriented for laser fusion and their repetition rates are, in general, very low and less than once per twenty minutes, which does not match the real application for medical use and so on. For the purpose of demonstrating the feasibility of utilization of the laser-produced ion-beam as the injection beam for cancer dedicated synchrotron, possibility of inducing target normal sheet acceleration of ion beam from the solid target with the pulse laser of much shorter pulse width and higher repetition rate as 10 Hz has been investigated. By focusing the laser to the size ~10μm in diameter, ion production up to 1 MeV has been observed even for the rather limited laser power density of ~$10^{18}$ W/cm$^2$. The intensity of the laser-produced ions, however, decreases exponentially according to the increase of the ion energy. In order to remedy this situation, a scheme of phase rotation with use of the laser-synchronized RF electric field has been proposed [4], which has been developed assuming the experiments utilizing 100 TW, 20 fs, 10 Hz laser at JAERI, Kansai Research Establishment.

In the present paper, the preliminary results of experimental research on laser ion production is presented together with the design and fabrication of the quarter wave length RF cavity for phase rotation.

## PRELIMINARY TEST OF LASER ION PRODUCTION

Ion production by the laser with the power ~10 TW and short pulse width (50 fs) has been performed as the preparatory work for ion production and its phase rotation with use of 100 TW, 20 fs laser, because the available time of the latter laser is rather limited.

Wth use of a 30TW, 50 fs laser at Nuclear Engineering Research Laboratory, Graduate School of Engineering, University of Tokyo, ion production from various solids targets such as polyethylene, Ti, Ta and so on, has been performed. Among these targets, Ta target, 5 μm in thickness was most preferable. In Fig. 2, comparison of energy distribution among the metal targets is shown together with the data taken using the 10 TW, 50 fs laser

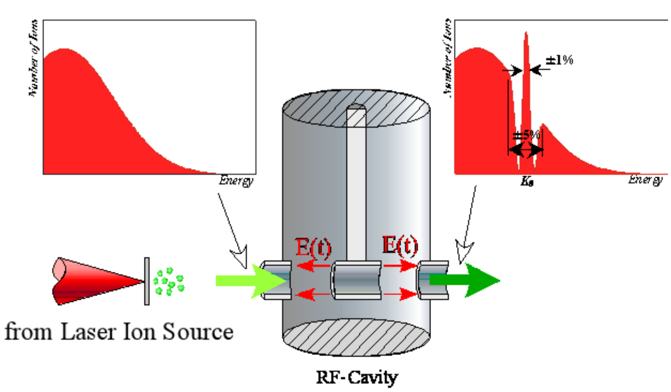


Figure 1: Schematic illustration of phase rotation of laser produced ions by a laser-synchronized laser.

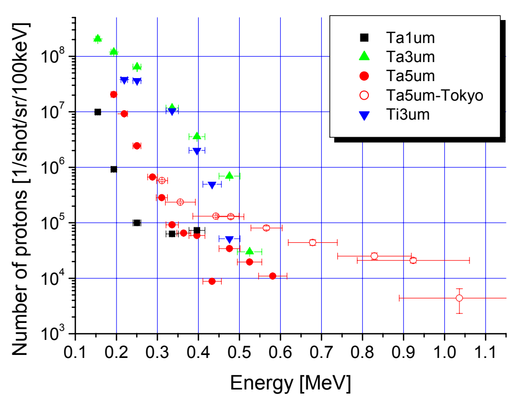


Figure 2: Comparison of energy distributions of laserproduced proton from various metal targets.

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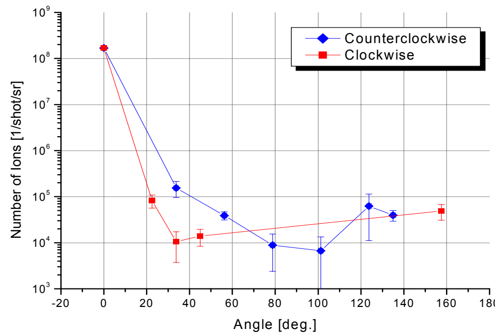



Figure 3: Angular distribution of laser produced protons.

available at JAERI, Kansai. In Fig. 3, the angular distribution of produced proton is shown, which indicates that most of laser produced protons are emitted in the direction less than 20 degree from the direction of the laser, while the solid target is set perpendicular to the laser direction.

In these experiments, there existed a rather large pre-

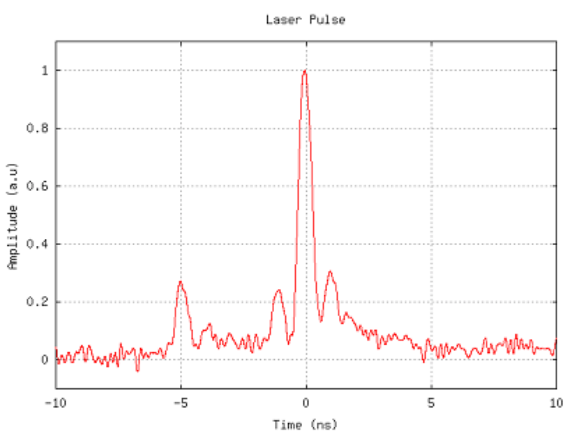



Figure 4: Temporal structure of the pulse laser.

pulse as indicated in Fig.4, which resulted in a rather promising results of producing higher energy protons as is expected by ion production from under-dense plasma compared with the case of production from over-dense plasma as shown in Fig. 5 [5]

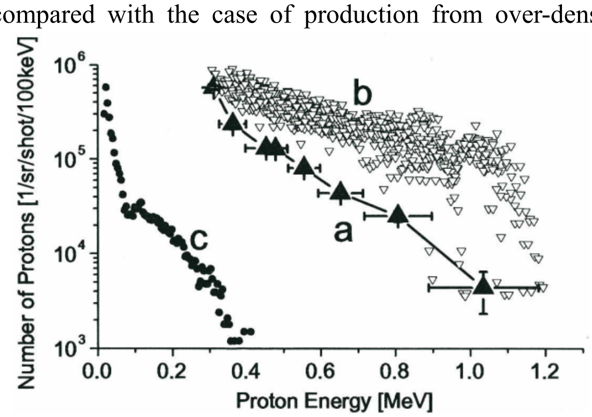



Figure 5: Energy distribution of laser produced proton in the direction of laser propagation. (a)experimental results, (b)simulation by under-dense plasma model, (c)simulation by over-dense plasma model [5].

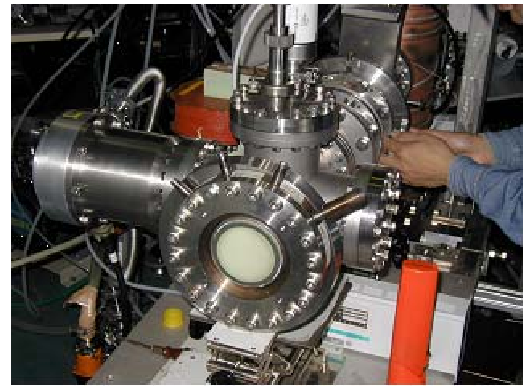


Figure 6(a): Micro-channel plate to observe the Thomson parabola of laser produced ions.

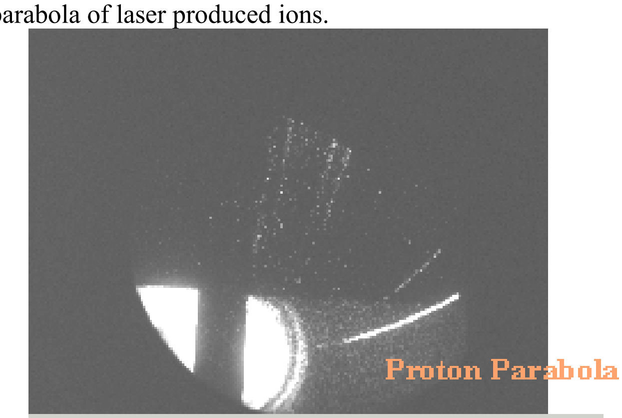



Figure 6(b): Observed Thomson parabola of produced ions by the T6 laser.

Ion production from a mylar target, 2.5 μm in thickness, has also been studied with use of T6 (Table-top Ten TW Ten-Hz Tunable Ti:sapphire) laser at Osaka University. With use of the micro-chanel plate as shown in Fig. 6(a), the Thomson parabola is observed for proton together with carbons of various charge states (Fig. 6(b)).

In the case of T6 laser, the suppression of the pre-pulse is considered to be very good. In such a situation, ion production to target normal direction is considered to be very sharply oriented from the experimental fact that the Thomson parabola can be observed with good reproducibility only with the target already irradiated by the laser. In the case of irradiation on the new surface of the target, usually the Thomson parabola cannot be observed. We defined the direction of ions which come into the apparatus for Thomson parabola observation with use of two collimators set at the front side. Our adjustment of the target to the collimation direction of the laser produced ion is considered not precise enough and the Thomson parabola cannot be observed for the new surface, while the target surface becomes somewhat deformed after irradiation of the laser and the "effective" target normal direction somewhat spreads. This speculation indicates the possibility that the angular distribution of the laser produced ions is much more sharp compared with Fig.3 if the pre-pulse of the irradiated pulse laser is well suppressed, which is the scope of our future experimental research.

## PHASE ROTATION FOR CREATION OF ENERGY PEAK

The laser produced ions, in general, have no energy peak as shown in Fig. 2 and Fig. 5. In order to improve this situation, the phase rotation cavity has been designed and fabricated. The signal from the source laser is utilized to trigger the RF electric field on the quarter wave length resonant cavity and relative phase between the RF electric field and the pulse laser can be adjusted with use of a phase shifter.

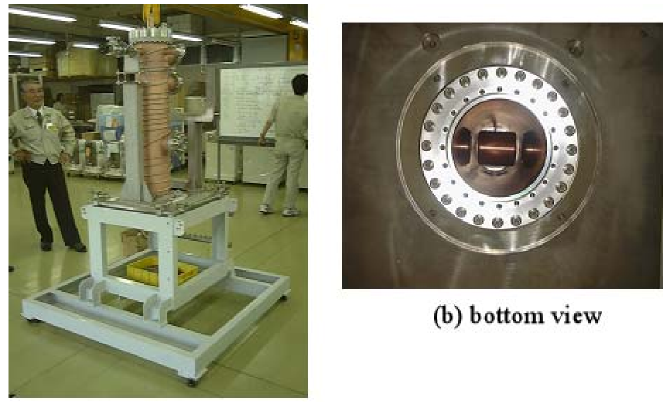
The frequency of the source laser is 82.7 MHz and 79.3 MHz for 100 TW and 10 TW lasers, respectively and the resonant frequency of the phase rotation cavity is designed to be tuned for both frequencies with use of a fixed tuner in addition to the adjustable tuner. The phase rotation cavity, which has double gap, are designed with a quarter wave length type and fabricated as shown in Fig. 7.

A power amplifier to excite this resonator with the maximum power of 30 kW has also been completed. It is expected that the acceleration voltage up to 200 kV with the two gap can be applied. With this voltage, correction of the energy up to ±5 % of carbon ion with the kinetic energy of 2 MeV/u, which is assumed as the injection beam for the synchrotron dedicated for cancer therapy, can be realized.

## PRESENT STATUS

The phase rotation experiment with use of 100 TW, 20 fs laser is scheduled in coming October. The phase rotation cavity and its power amplifier have been set at the down stream of the target chamber and fine tuning of the timing system between the pulse laser and the RF electric field has been started.

As the laser produced ion needs further reduction of energy spread after phase rotation to be utilized for cancer therapy machine [4], overall test of the phase rotation and further beam cooling of laser produced ions are planned at S-LSR, which is now under construction at ICR, Kyoto University. Utilizing the T6 laser to be moved to the laser building constructed next to the accelerator hall, the laser is guided as indicated in Fig. 8 and the phase rotation and electron beam cooling will be applied to the "real" laser produced ions.



(a) overall view (b) bottom view

Figure 7: Fabricated phase rotation cavity.

## ACKNOWLEDGEMENTS

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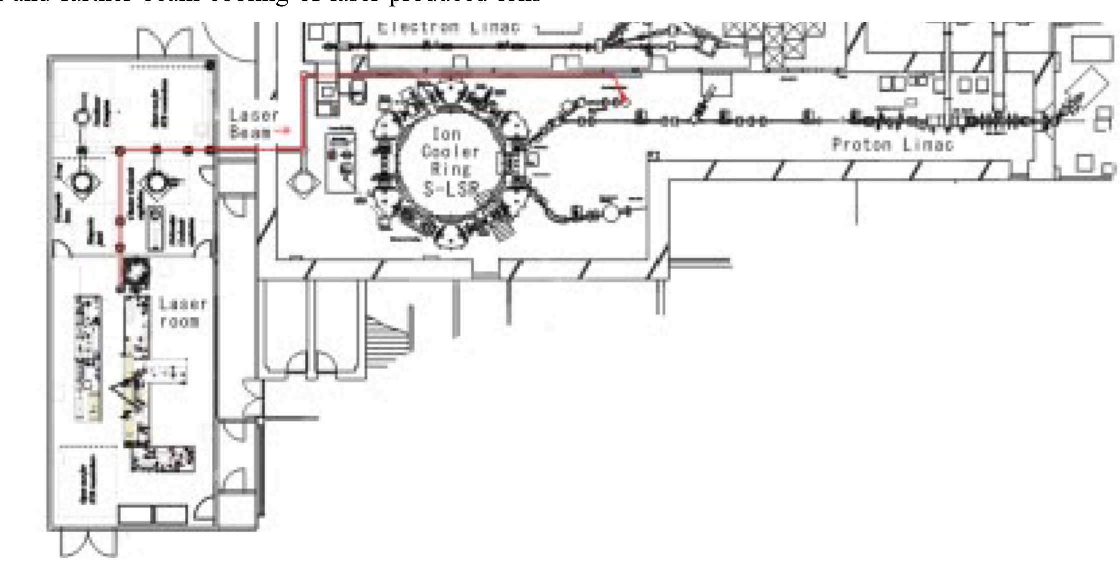


Figure 8: Layout of the combined facility of the accelerator and high power short pulse laser.