APPLICATION OF DPIS TO IH LINAC

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Abstract

We are now designing a Laser Ion Source (LIS), which will be operated with an Inter-digital H (IH) structure linac using Direct Plasma Injection Scheme (DPIS). The DPIS has been applied to RFQ linacs and has successfully achieved very high current with simple structure. The IH structure linac was designed to accept 40 keV proton beam which could be produced by the DPIS. The combination of the DPIS and IH structure linac will realize quite compact accelerator complex with intense proton beam. To provide proton beam from the DPIS, a new plasma production scheme was proposed. A detailed design of a plasma production chamber with a cryogenic cooler is investigated.

INTRODUCTION

The DPIS has been studied as effective method of heavy ion generation. It produces and accelerates very intense carbon ions and the maximum peak current was successfully reached more than 60mA which was much higher than capable currents produced by conventional ion sources.

The DPIS is a method for inducing plasma by irradiating high purity solids with a pulsed laser and taking the plasma into an RFQ linac. The ions contained by the plasma can be efficiently injected with thermal expansion velocity of the plasma suppressing coulomb repulsion. Ion sources in general use gases which will be ionized by radio frequency or discharge. On the other hand, the DPIS generates plasma from solids. So in principle the DPIS has an advantage to utilize very high ion density. Also, adopting high purity carbon as the laser target enables us to generate highly charged carbon ion with good purity.

An IH linac which has the substantial advantages of small transverse dimensions and high shunt impedances especially at a low velocity region has been studied and it was proved that the IH structure can accommodate very low energy beam without pre-accelerator like RFQs and can accelerate up to several-tens times of injection energy in a short single-cavity. If a chain of the injector linacs can be replaced by the combination of the DPIS and IH linac, it will realize quite compact accelerator complex with intense proton beam.

In DPIS, normally the target of a laser must be solid. In fact material which is gas at room temperature has not been able to be used. Therefore to generate proton beam with the DPIS, we started to investigate how to change hydrogen gas to solid with a cryocooler which can be used as the laser target. We needed to shift the target mechanically in response to the every laser pulse to provide a fresh surface. However, the method of changing gas to a solid will not need the shift described above. If the area of laser irradiation is larger than the area of hydrogen condensation, all the solid hydrogen will be evaporated and then be condensed again at the same spot. We believe this scheme can be possible by considering the thermal loading from laser beam carefully.

MATERIALS AND METHODS

We place the cryocooler cold head inside the vacuum chamber. The cold head cools up to 40 K at the first stage and 4 K at the second stage. Hydrogen gas is supposed to be sprayed to the surface of the cold head and change from gas to solid. By irradiating laser to the solid hydrogen, we can generate high intensity plasma. The target vacuum chamber is shown in Fig. 1.

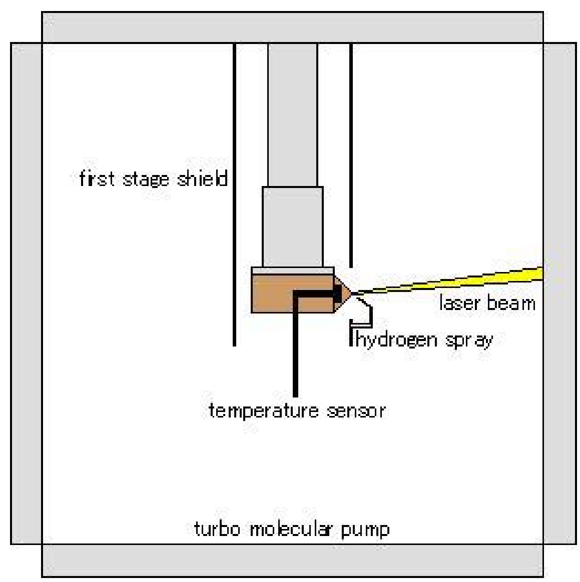

Figure 1: The target vacuum chamber.

We install the mass flow controller to see amount of hydrogen gas into the vacuum chamber. The thickness of the solid hydrogen will be measured with a laser distance sensor passing through the glass window installed in the vacuum chamber. The region where hydrogen gas change to a solid will be optimized changing the condensation area and nozzle for the hydrogen gas flow. We must keep the degree of vacuum under about 10E-4 Pa to prevent the recombination of the ions and electrons. Time dependence of vacuum will be measured changing the mass flow of hydrogen gas and the opening time of valve.

The target will be irradiated with the Q-Switched Nd:YAG laser and the spot size will be adjusted by changing the focal length of a laser focusing lens. The size of the target will be set smaller than the spot size. The part on which the solid hydrogen is sprayed is made of copper to have a good thermal conductivity. Time dependence of the temperature is measured with a pair of diode temperature sensors, one is installed inside of the copper and the other is attached with the hydrogen gas spray tube.

Before injecting the beam into the IH structure linac, the contents of the ablated plasma will be examined. The plasma measurement instrument consists of the target vacuum chamber which was mentioned above, a faraday cup and an electrostatic deflector. The experimental set up is shown in Fig. 2. The plasma produced in the target vacuum chamber adiabatically expands and the current density will be measured with the faraday cup installed in the place where the density of plasma is thought to be decreased enough. Also we will measure the time of flight using the laser pulse trigger and investigate the kinetic energy distribution.

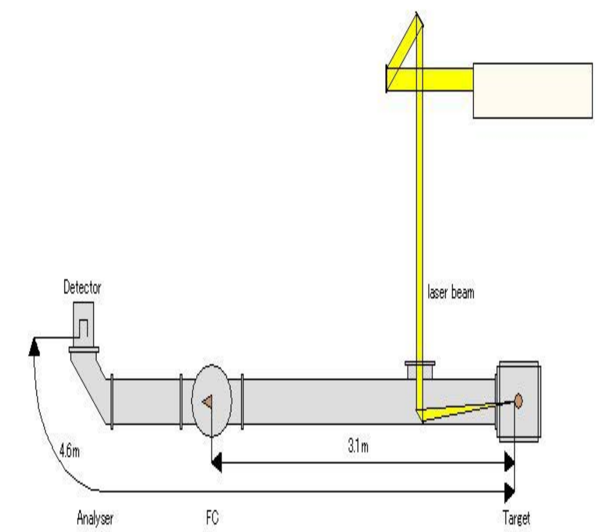

Figure 2: The experimental set up for the plasma measurement.

Considering the injection of the ions into the IH structure linac, the plasma have to be induced at high voltage potential. We need to configure the insulation system satisfying the cooling enough for the heat from the laser emission. The IH structure linac was designed to accept 40 keV proton beam. Therefore we have to apply suited voltage to the part on which the solid hydrogen is condensed.

Other infrastructures for the acceleration test including the linac, an RF amplifier and a cooling water system have been already installed in TIT. Figure 3 shows the acceleration test system using IH structure linac.

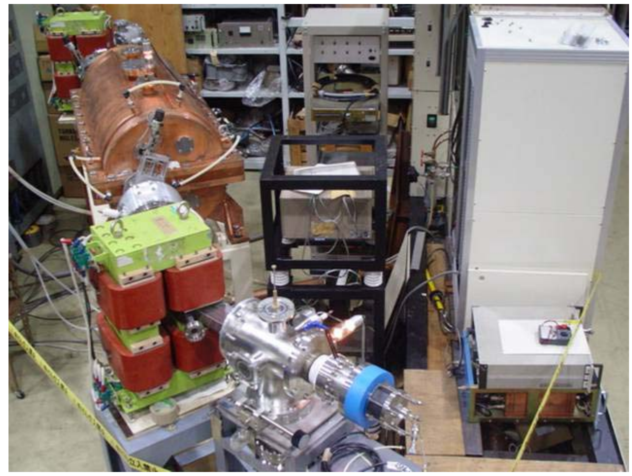

Figure 3: Acceleration test system using IH structure linac**.**

PLASMA CHAMBER FOR CONDENSATION

We fabricated the target vacuum chamber and optimized the structure inside of the chamber which corresponds to the cubic box shown in Fig 4 to confirm the possibility of solid hydrogen condensation.

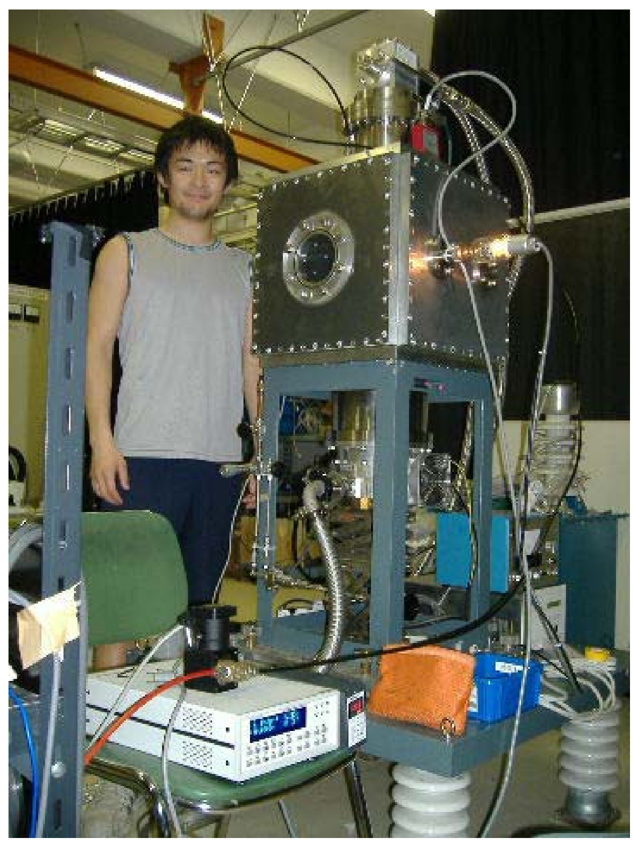

Figure 4: Conversion from gas hydrogen into a solid**.**

The equipment we can see in the upper side of the chamber is the cryocooler cold head connected to a compressor unit. The function of the compressor unit is to supply high pressure helium gas to the cold head and re-compress the returned helium gas from the cold head. The temperature of the copper attached to the second stage of the cold head cooled down up to 5 K without the first stage shield and it took about 90 minutes after switching on the cryocooler units. The temperature measured from this method is always oscillating and this oscillation is the slave synchronization of the cryocooler units. The hydrogen gas tube inside of the chamber is rolled around the first stage copper shield so that hydrogen gas can be cooled down up to 40 K before being sprayed. Also this copper shield has a function of preventing temperature radiation from directly conducting from the chamber flange to the second stage.

CONDENSATION EXPERIMENT

Hydrogen gas, 99.995 % of purity, was sprayed onto the copper surface which was cooled down to below 5 K. The flow rate of the gas was controlled. Meanwhile the pressure of the vacuum chamber was kept under 10E-5 Pa. We could observe some ice growing on the copper shown in fig 5. The white object in the center of fig 5 is the ice. The ice was getting increased gradually and became enough size for us to check with our eyes.

Figure 5: Inside of the chamber.

After switching off the cryocooler units and stopped the flow of gas, we visually observed the ice with increasing temperature. The ice started to disappear at 40 K and the amount of the ice reduced by half at 44 K and dropped at 44.5 K. The temperature sensor is mounted on back side of the copper block respect to the condensation area.

More detailed optimization is in progress. The solid hydrogen is observed changing the mass flow of hydrogen gas and optimal values of various parameters are being searched.

After finishing this process, we are going to measure the ion density in the ablated hydrogen plasma to survey optimal condition for the DPIS.

CONCLUSION

We selected the DPIS and the high gradient IH linac from the recently established accelerator technologies and combined them to realize the efficient single system. This scheme must be effective for miniaturization, power saving, simplification and cost reduction of the system.

As the new ion source development approach, the gas condensation technique was proposed. If we succeed in using hydrogen gas as the laser target, almost all other kinds of gases can become the targets in the same way except helium which has very low melting point. The DPIS will have an advantage of generating high intensity beam from almost all the materials.

We plan to have first plasma experiment in a few months and expect to have proton beam from the IH linac at end of this fiscal year.

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