LASER ION PRODUCTION AS THE INJECTOR FOR CANCER THERAPY SYNCHROTRON

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Abstract

Ion production by focusing high-power short-pulse laser is investigated as an injector for pulse synchrotron dedicated for cancer therapy. Combination of phase rotation and electron beam cooling is proposed as the scheme to reduce the energy spread and make acceptance matching with the synchrotron. Threshold power per pulse to realize target normal sheath acceleration and conversion efficiency of laser-power to ion energy need still further experimental investigation with precise control of pre-pulse

1 INTRODUCTION

Cancer therapy with use of charged particle beam has been found to be effective because of the merit of possible dose localization by the presence of so-called Bragg peak. It is also paid attention from the point of view of “Quality of Life” of the patients because of the fact that it can keep the function and shape of the human body. Clinical trials at HIMAC and other facilities demonstrated the effectiveness of charged particle therapy especially to cancers at such organs as liver and lung.

The number of patients who can receive such a benefit, however, is rather limited. For example, HIMAC can treat only ~200 patients per year, which is extremely limited compared with the total number of patients who suffer from various cancers every year.

For the purpose of its wide use, downsizing of the facility for charged particle therapy is now under development, combining a laser-ion source[1] and a very short pulse synchrotron[2]. As illustrated in Fig.1, the size of the facility is expected to be reduced more than one order compared with HIMAC. In the present paper, the scheme of the laser-ion source, which aims at replacement of the injector linac for the synchrotron, is described together with the present status of recent experimental approach.

2 SCHEME OF LASER-ION SOURCE

2.1 Ion Production from High Power Density Plasma

It is reported that the high power laser with short pulse length produces high energy (several tens MeV) ion beams when focused to a small spot and laser power density exceeds 10^{18}W/cm^2 [3,4]. The laser power per pulse, which can induce target normal sheath acceleration (TNSA) has been reported to be reduced down to 30 Joule[5] starting from Petawatt laser with pulse energy of several hundreds watt. In this case, the normalized emittance of produced ion beam is reported to be as small as 0.06 π mm·mrad [6], which is better than the one attained by the conventional ion source. Lasers utilized for such experiments, however, are oriented for laser fusion and their repetition rates are rather limited as fewer than every twenty minutes, which is not enough for real application purpose. In order to increase the repetition rate to the level higher than 1 Hz, it is needed to reduce the laser power per pulse.

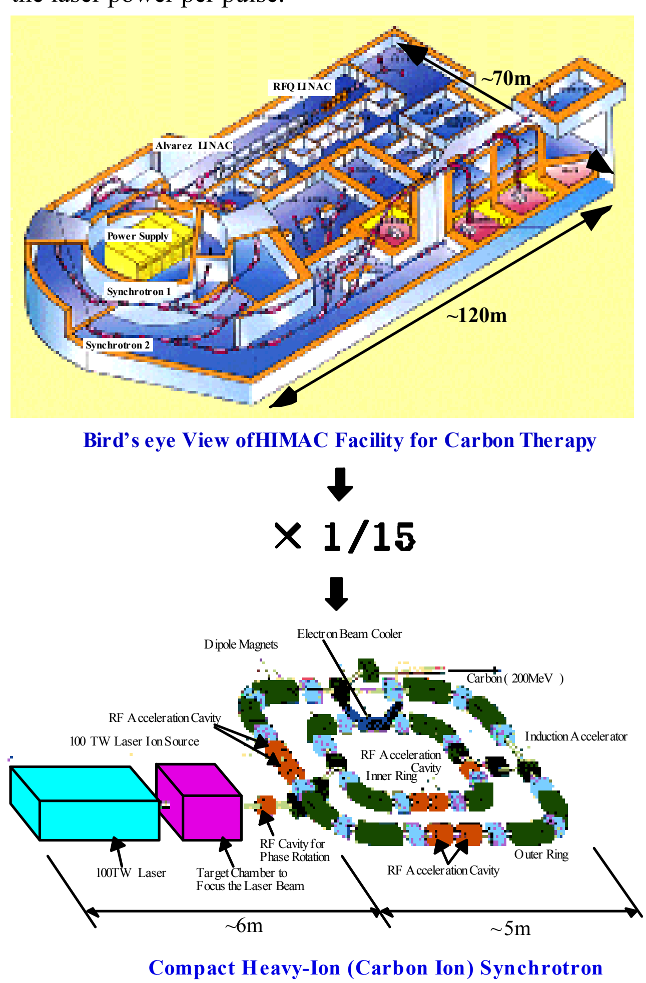

Fig.1 Comparison in size between conventional HIMAC and new compact accelerator scheme.

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Table 1 : Main Requirement for Laser Ion Source

Ion Species	$^{12}C^{6+}$
Central Energy of Ion	2MeV/u
Desired Intensity	10^9/ sec
Fractional Energy Spread	
Output of Laser Ion Production	±5%
After Phase Rotation	±1%
After Electron Beam Cooling	±0.1%

On the other hand, it is reported that the conversion efficiency of the laser power to ion beam energy is reduced according to the decrease of the laser power per pulse [5] and it is anticipated that TNSA will not occur at lower power level per pulse. So it is important to find out the threshold laser power per pulse to realize TNSA [7]. We intend to investigate the conversion efficiency of laser power to ion energy and the possibility of TNSA utilizing the high power pulse laser at JAERI Kansai Research Establishment with the laser power of 2 Joule per pulse, which has a repetition rate as high as 10Hz for 100 TW peak power with 20 fsec pulse duration. In Table 1, the main requirements for laser ion source for injector of cancer therapy machine are listed up.

2.2 Phase Rotation by Synchronized RF Electric Field

The energy spectrum of the ions produced from laser induced plasma, however, has no peak but the intensity decreases exponentially according to increase of ion energy, which imposes limitation in real application. In order to improve this situation, we have proposed the phase rotation scheme in the longitudinal phase space as shown in Fig. 2 [8]. Its principle is to accelerate and decelerate according to phase difference produced by

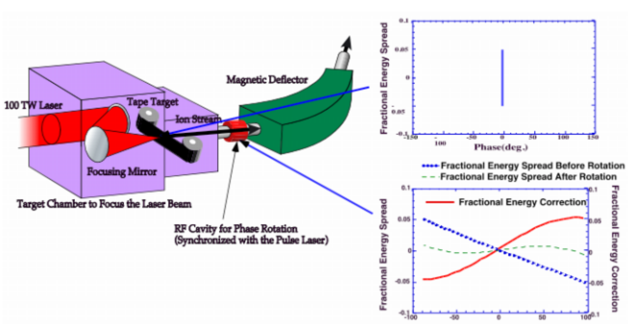

Fig.2 Energy-spread reduction by phase rotation.

flight-time difference in the RF electric field synchronized to the pulse laser as shown in Fig. 3.

2.3 Further Reduction of Energy Spread by Electron Beam Cooling

Phase rotated ion beam will still have the energy spread of ±1% even if we select the ion beam within ±5% energy spread just after production at solid target by the focused laser. In order to match this beam with the energy acceptance of the pulse synchrotron, it is injected in a compact cooler ring and is further reduced in energy

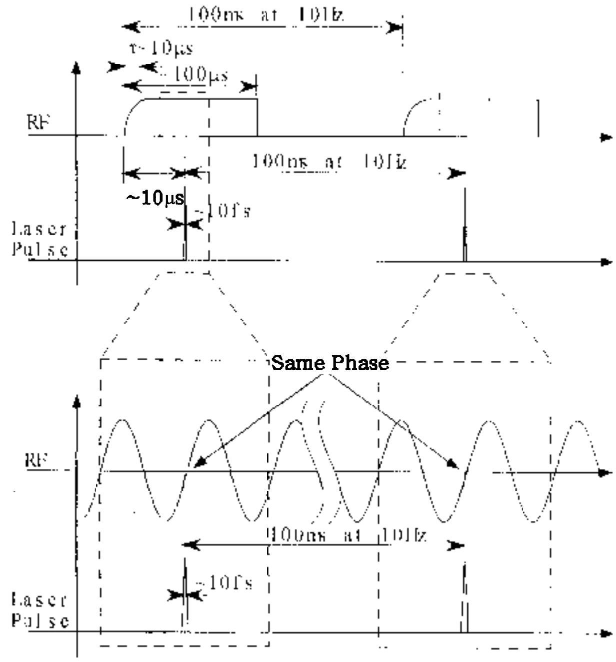

Fig. 3 Scheme for Synchronization between the Pulse Laser and the RF Electric Field.

spread one order of magnitude [9], which is not described in detail here.

3 PRELIMINARY EXPERIMENTS OF LASER ION PRODUCTION

As the high power laser of 100 TW peak-power and 20 fsec pulse-duration at JAERI Kansai needs some time before obtaining permission for focusing its size into small enough one to produce ion beams, because it must be treated as a radiation producing device. Mean while, we have started experiments with use of an already operating laser at University of Tokyo with smaller peak power of 12 TW in order to be well acquainted with handling of foil targets, ion detectors such as Thomson parabola and CR39, which tolerate a very high event rate in a short burst.

In Fig. 4, the focusing scheme at the foil target is shown, which realized the laser power density of 2~3x10^{18}W/cm^2

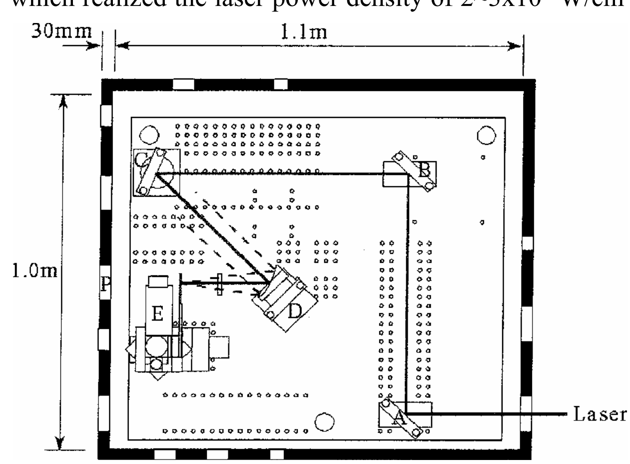

Fig. 4 Optics of the final focusing at the foil target in the vacuum chamber.

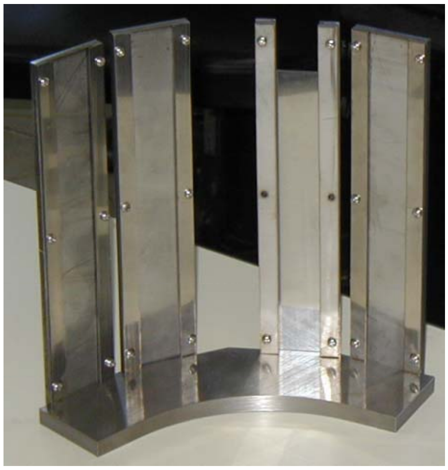

Fig. 5 CR39 holders to measure angular distribution of ion production.

by focusing the laser spot to 15µm in diameter. As the target, Ti, Al, Ta and CH with various thickness between 5 µm and 100 µm are utilized. As the foil target is destroyed even by a single shot at the irradiated position, the foil target is shifted in its position after every shot of the pulse laser with use of the stepping motors set in the vacuum.

The angular distributions of the production rate of ions are studied by CR39 set around the foil target with use of holders as shown in Fig. 5. Typical obtained results are shown in Fig. 6 for the case of Ti and CH targets. As is known from the figure, the angular distributions do not have forward peaks, which means that TNSA does not realized with this condition where the laser power per pulse is estimated to be about 0.2 Joule. In the measurement, the laser is accompanied with a rather large pre-pulse 5nsec before the main pulse as indicated in Fig. 7, which is measured just before the final compression. There exists the possibility such pre-pulse has already blow away the target plasma when the main pulse has arrived, which should be clarified experimentally with precise control of the pre-pulse in coming fall.

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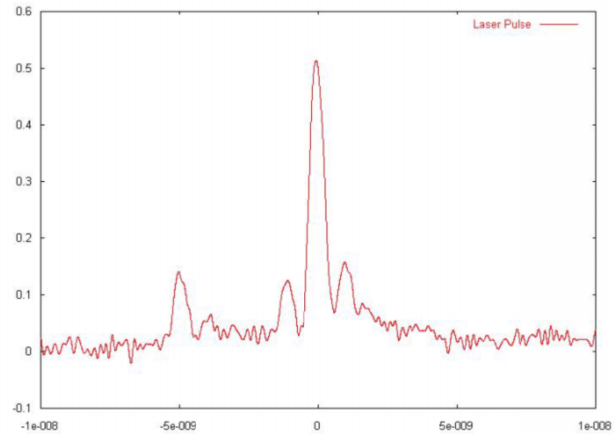

Fig.7 Time structure of the irradiated pulse laser.

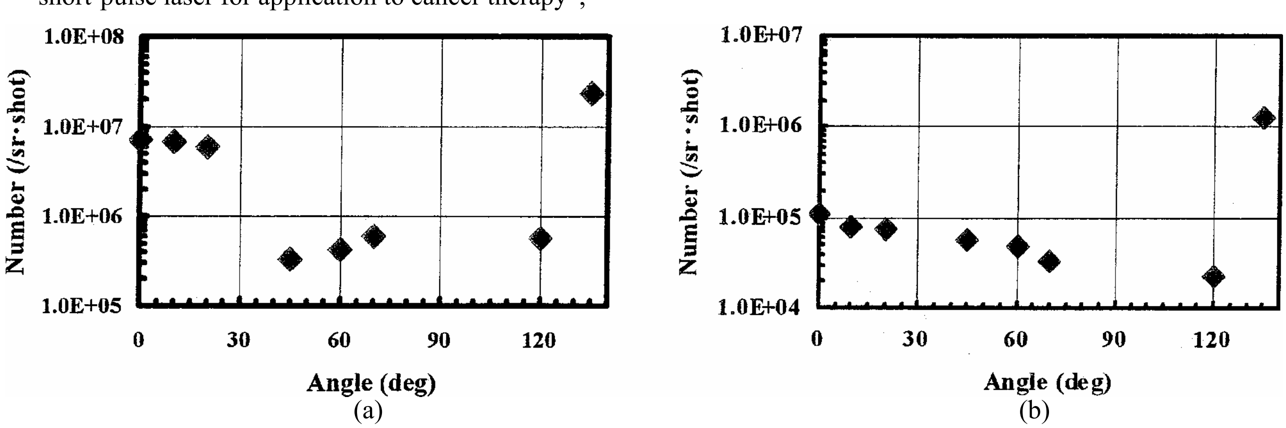

Fig. 6 Measured angular dependence of produced ions.with (a) Ti target and (b) CH target