ION PRODUCTION WITH A HIGH-POWER SHORT-PULSE LASER FOR APPLICATION TO CANCER THERAPY

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Abstract

Ion production process with a high-power (~50TW) short-pulse (20fs) laser is to be utilized as a compact injector of the synchrotron for cancer therapy. In the scheme, an RF voltage with the frequency of 160 MHz is applied to the laser produced ion-beam within the energy width of ±5% in order to rotate in the longitudinal phase space to reduce the momentum spread to ±1%, which is further cooled down to ±0.1 % by an electron beam cooling to realize needed characteristics of the beam to be safely accelerated by a pulse synchrotron.

1 INTRODUCTION

Recently number of the patients who loose their lives due to various cancers has increasing rapidly. Radiation therapy has such merits as can keep function and shape of human body and is mild to the patients. These characteristics of radiation therapy have an important role from the point of view of “Quality of Life” of the patients.

Among radiation therapy, charged particle therapy has an additional merit as can localize the radiation dose to the tumor part by the presence of Bragg-peak. Through recent achievements at National Institute of Radiological Sciences (NIRS), carbon beam is found to be especially effective because of its high Radio Biological Effectiveness (RBE).

Conventional carbon therapy facility as HIMAC in NIRS, however, is rather large in its size as shown in Fig. 1. It also needs rather large construction cost and operation human resources.

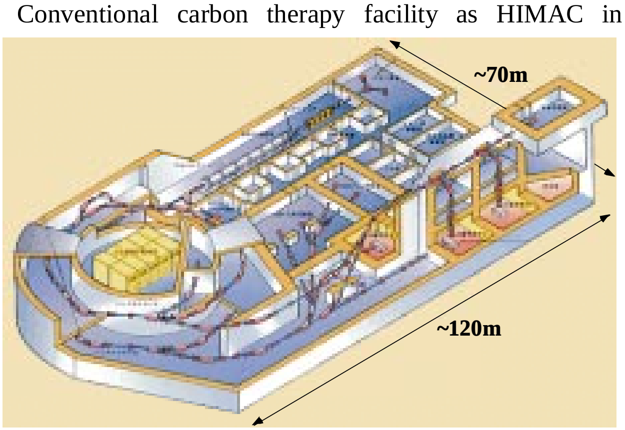


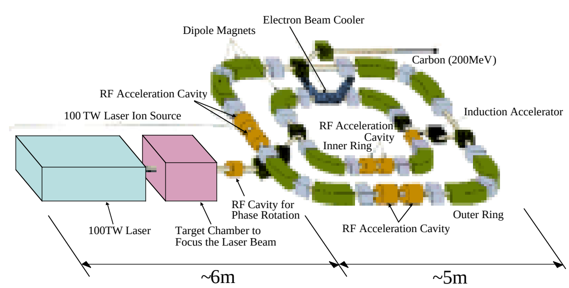
Fig.1 Layout of HIMAC

For the purpose of realizing wide spread use of such charged particle therapy, downsizing of the needed facility is now in R&D phase. In the present paper, a scheme is described to use laser-produced ions to inject into a compact pulse synchrotron with a high peak magnetic field[1].

2 SCHEME OF THE INJECTOR

2.1 General Layout

The total scheme of charged particle therapy with use of laser induced ion is illustrated in Fig. 2. It consists of (1)high-power short-pulse laser and its focusing system on a foil taget, (2)RF system synchronized with the pulse laser, (3) electron beam cooling system to create much colder beam and (4) pulse synchrotron with very high peak magnetic field. Among them, items (2) and (3) are the scope of the present paper.



Compact Heavy-Ion (Carbon Ion) Synchrotron

Fig. 2 Scheme of injector with use of laser produced ions

2.2 Phase Rotation

Recent development of high-power short-pulse laser

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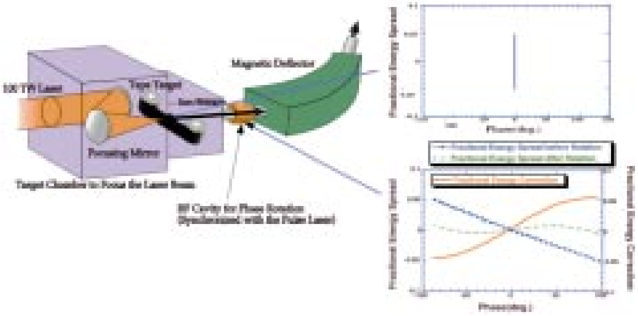

Fig. 3 Principle of Phase Rotation

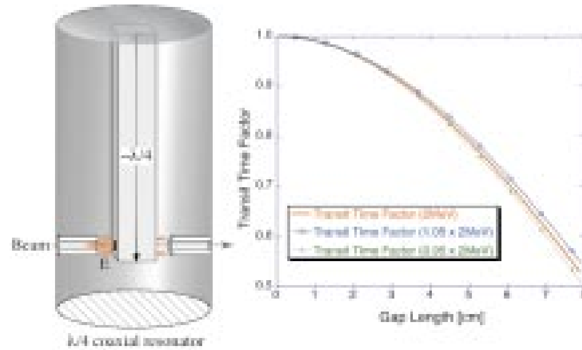

Fig. 4 RF cavity for phase rotation

realized a very high laser power density. By focusing on a solid target such a high power laser as exceeds 10^{18} W/cm^2, high energy ion production is reported from Lawrence Livermore Laboratory[2] and Rutherford Appleton Laboratory[3]. These energy spectra, however, have no peak, but the intensity decreases exponentially according to the increase of the ion energy, which resulted in difficulty in applying these ions for real usage.

So as to remedy this situation and create a peak in energy spectrum, a phase rotating scheme with use of a phase synchronized RF with the pulse laser is proposed [4]. This scheme utilizes the fact that laser produced ions are produced in a very short time interval, although they have a very large energy spread. In Fig. 3, the principle of the phase rotation is illustrated. Ions within the energy width of ±5% are to be selected for usage as indicated in upper graph, which obtains phase difference as indicated in lower graph by dotted line at the target position due the velocity difference. By application of sinusoidal RF as shown by a solid line in the lower graph, energy correction is made and the energy spread becomes less than ±1% as indicated by a dashed line in the lower graph.

For the purpose of phase rotation, a quarter wave length cavity with two gaps as shown in Fig. 4 is considered as a candidate. Its frequency is fixed to twice (around 160 MHz) of the seed laser to realize easy synchronization with the pulse laser. In the figure, relation between transit time factor and gap size is also given.

Table 1: Main Parameters of the Present Scheme

Ion Species	$^{12}C^{6+}$
Central Energy	2 MeV/u
Design Intensity	10^9 / shot
Energy Width	
Laser produced ion	±5%
After phase rotation	±1%
After e-cool	±0.1%

2.2 Electron Beam Cooling System of Hot Ion

The energy acceptance of the high field pulse synchrotron is rather limited as ±0.1% and phase rotated laser produced ion needs one order of magnitude further reduction of its energy spread. For this purpose, an electron beam cooling method is to be utilized. Up to now, the electron beam cooling is considered to be efficient to cool down rather cool beam to much lower temperature and is not suitable for cooling of hot beam [5]. This is due to the fact that if the energy spread of the ion beam is too large, the ion at the tail of the energy distribution has the somewhat different velocity from the one of the electron and it cannot co-propagate so long. Stochastic cooling has been used for cooling of hot beam such as anti-protons, but its cooling time becomes long in proportion to the number of cooled beam.

We propose the scheme of electron beam cooling for hot ion beam by applying induction acceleration as illustrated in Fig. 5. Such scheme has been applied for the laser cooling in the storage ring at TSR [6], but not yet applied for electron beam cooling. This scheme has been experimentally tested at TSR in 2001 and is found to be promising as is described in the next section.

3 EXPERIMENTAL INVESTIGATION

3.1 Phase Rotation of Laser Produced Ions

For the purpose of quantitative experimental studies, we have assumed a 100 TW 20 fs laser at JAERI, Kansai Research Establishment as the high power short pulse laser to produce high density plasma, although it size is not so compact. As this laser needed some time before real focusing on a solid target for ion production with high energy from the regulation related to radiation safely, we tried experiments with use of 12 TW 50 fs laser available at Nuclear Engineering Laboratory, Faculty of Engineering, University of Tokyo, in Tokai, Ibaraki Prefecture.

As the target, Al foils, 5 and 10 μm, in thickness, $(C_3H_6)_n$ foils, 4 and 15 μm in thickness, (CH2)n foil, 100 μm in thickness , Ti foil, 20 μm in thickness and Ta foil 100 μm in thickness are utilized. Up to now, observed

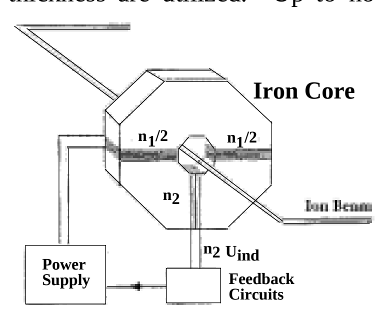

Fig. 5 Scheme of the induction acceleration

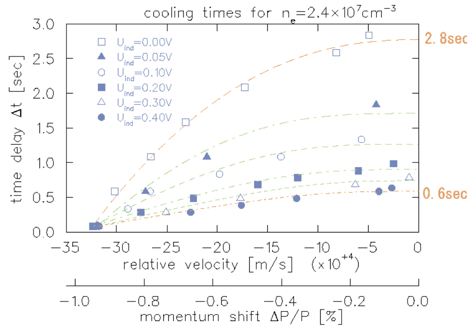

Fig. 6 Cooling time for various conditions of induction acceleration measured at TSR.

energy of produced ion (mostly considered to be proton) is less than 500 keV, which is considered mainly due to the presence of a rather big pre-pulse. Correlation between ion production and the status of the pre-pulse is one of the most important issues to be studied both by experiments and simulation.

3.2 Cooling Experiment of Hot Ion Beam

Experimental evaluation of the scheme presented in 2.2 has been performed at TSR last July. As the injector of TSR is Tandem Van de Graaf and the energy resolution of the injected beam is much smaller than 1 %, cooling time of hot ion beam with momentum spread of 1 % is simulated by measuring the needed time to shift the momentum from –1 % to the central one (Fig. 6). It is known that needed time to shift the $^{12}C^{6+}$ beam from –1% to the center is reduced to 0.6 sec by application of induction voltage of 0.4 V from 2.8 sec without induction acceleration.

Comparison of the above method with the scheme of electron energy sweep is planned also utilizing TSR just after this conference, which will clarify the limit of cooling speed of hot ion beam.

4 TOTAL TEST FACILITY

In order to experimentally show the feasibility of utilization of laser produced ion beam for injection to cancer therapy synchrotron, a demonstrating facility consisting of 50 TW pulse laser and an ion cooler ring LSR is now under construction with the time schedule in 4 years from now at Nuclear Science Research Facility, Institute for Chemical Research, Kyoto University in order to evaluate the total process from laser ion production, phase rotation and electron beam cooling.

5 ACKNOWLEDGEMENTS

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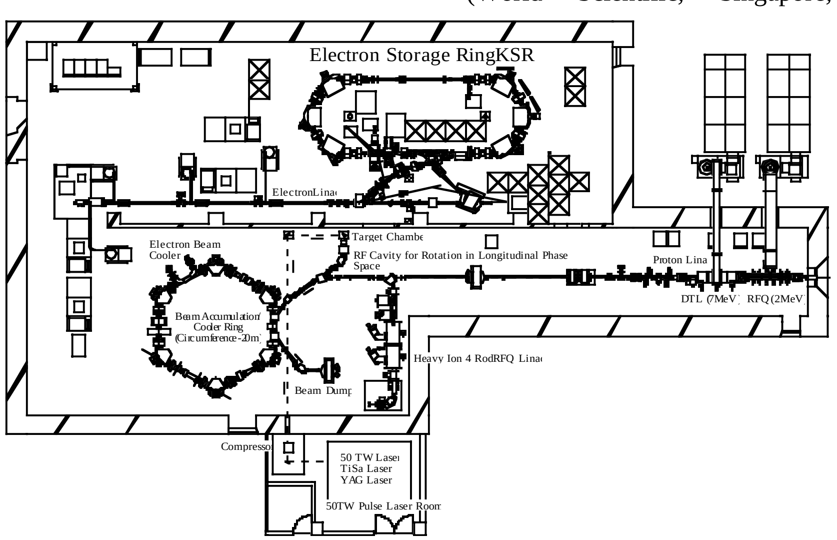

Fig.7 Total test facility of laser ion production as the injector for synchrotron for cancer therapy