COLLECTION AND COOLING SCHEME OF LASER PRODUCED ION BEAM

A. Noda, H. Fadil, Y. Iwashita, A. Morita, S. Nakamura, T. Shirai, H. Tongu
Institute for Chemical Research, Kyoto University, Gokanosho, Uji-city, Kyoto, 611-0011, Japan
K. Noda, S. Yamada, National Institute of Radiological Sciences, Inage-ku, Chiba, 263-8555, Japan
M. Beutelspacher, M. Grieser, Max-Planck-Institut für Kernphysik, Heidelberg, D-69029, Germany
Y. Kato, H. Daido, M. Yamagiwa
APRC, Kansai Research Establishment, JAERI, Kizu, Kyoto, 619-0215, Japan

Abstract

Laser produced ion beam followed by an RF phase rotator and electron beam cooler is investigated as a compact injector for a pulse high magnetic field synchrotron dedicated for cancer therapy. Carbon beam of 2 MeV/u with energy spread of ±5% is to be collected and reduced to ±1% and ±0.1% in fractional energy spread by phase rotation and electron beam cooling, respectively with the rate of 10^9 ions per second.

1 INTRODUCTION

Radiation therapy is, in general, mild for the patients compared with other therapies and can keep the function and shape of the patient's body. So it is recently paid attention from the point of view of "Quality of Life" of the patients. In addition, charged particle therapy has such a merit as can localize the radiation dose to the tumor part avoiding the serious damage to the normal cells due to the presence of "Bragg Peak".

The facility for charged particle therapy, however, so far has been considered to require larger cite and budget compared with the photon therapy. For the purpose of wide spread use of the charged particle therapy, it is inevitable to reduce the needed cost and cite for such a facility.

A compact injector for a pulse high field synchrotron consisting of a laser ion source followed by a small cooler ring is under development for downsizing of the needed cost and cite for charged particle therapy facility. In the present paper, the scheme of the compact injector is described together with our recent experimental results on electron beam cooling of hot ion beam.

2 PULSE SYNCHROTRON AND ITS INJECTOR

For the purpose of such downsizing, a pulse high-field synchrotron is one of the most attractive candidates [1]. As its energy acceptance is rather limited (~±0.1%) because of the high magnetic field, it is needed to match the energy spread of the laser induced ion beam to the acceptance of the synchrotron.

To apply for cancer therapy, the needed number of Carbon ions is ~10^9 per second and we assumed the

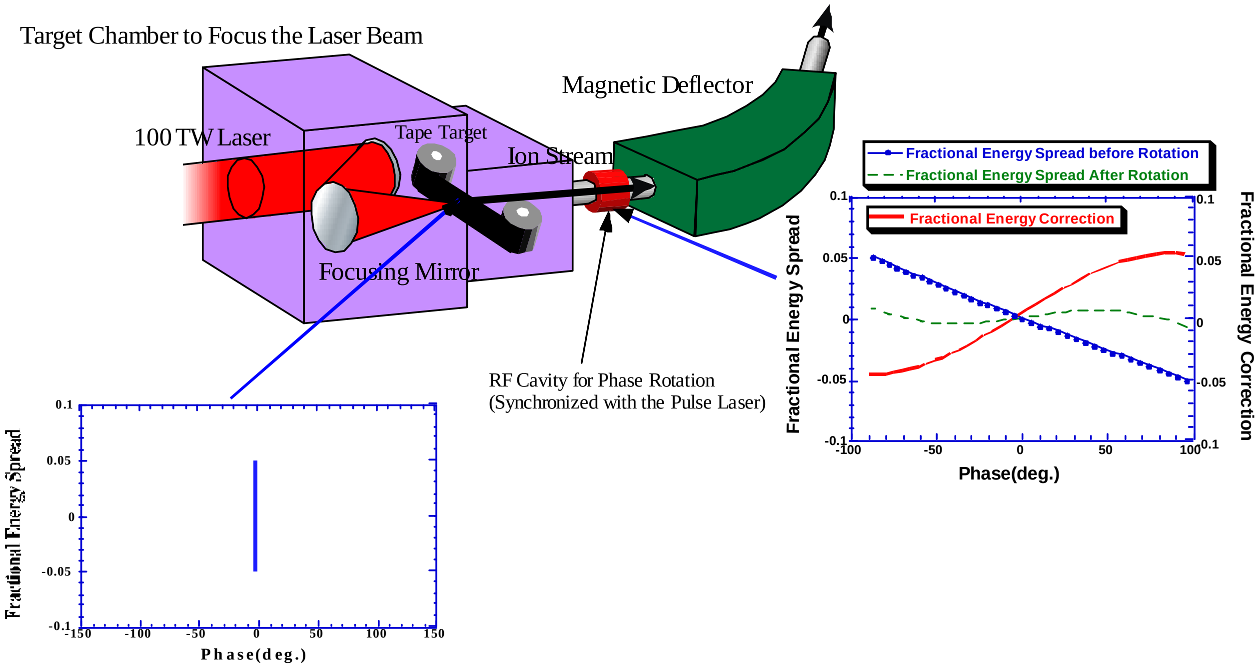

Fig.1 Laser induced ion beam and its phase rotation scheme.

specifications listed up in Table 1 as the tentative design goal.

Table 1 Tentative Design Goal of Collection and Phase Rotation of Laser Produced Ions

Ion Species	$^{12}C^{6+}$
Central Energy	2MeV/u
Design Intensity	$2x10^8$ per shot
Energy Acceptance	±5%
Distance between Target and RF Cavity	2m

3 COLLECTION OF LASER PRODUCED IONS AND THEIR PHASE ROTATION

Recent development of high power short pulse laser has realized such a high power density as 10^{19} W/cm^2 or higher, which results in the generation of high energy (several tens MeV) ion beam [2,3]. The energy spectrum of the produced ions, however, has no peak but decays exponentially according to the increase of the energy, which has serious limitation for real application. In order to improve this situation, phase rotation by an RF electric field synchronized to the pulse laser has been proposed [4]. In Fig.1, the scheme of the high energy ion production by a high-power short-pulse laser is illustrated together with the typical distribution of the produced ions in a longitudinal phase space at both the target and RF cavity positions. There RF frequency of 100 MHz was assumed for phase rotation, which might be modified to 158.66 MHz from the requirement of the synchronization system between the pulse laser and the RF, resulting the shorter distance of ~1.2 m between the target and the RF cavity. As is known from the figure, the energy spread is reduced to ~±1% after phase rotation.

4 ELECTRON BEAM COOLING OF HOT ION BEAM

In order to match the energy acceptance of the pulse synchrotron, the laser induced and phase rotated ion beam is further cooled down by an electron beam cooling. Electron beam cooling has so far been considered to be suitable for cooling of fairly cold beam to much lower temperature because of its rather limited efficient cooling region [5]. If the ion beam velocity is too much different from that of the electron beam, the ion does not co-propagate with the electron not so long. In reality, the effective cooling region is found to be ~±0.1% of the electron velocity [6].

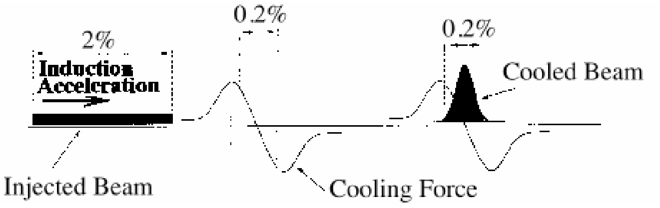

Fig. 2. Electron beam cooling scheme of hot ion beam.

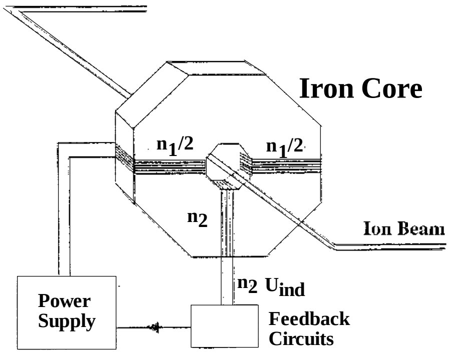

Fig.3 Principle of the induction accelerator.

So as to enable efficient electron beam cooling for the hot beam with momentum spread of ±1%, we propose energy sweeping of ion beam by an induction accelerator. In Fig.2, the electron cooling scheme with energy sweeping with use of induction accelerator is illustrated. The principle of the induction accelerator is shown in Fig. 3 [7].

The above scheme is experimentally tested at TSR of MPI, Heidelberg in July this year [8]. The injector of TSR is MP Tandem and the momentum spread of the injected beam is very small. So as to simulate the hot beam with large momentum spread, we used the following procedure,

(1) inject the beam at the center of the TSR acceptance which corresponds to the central electron energy for electron cooling (point A in Fig. 4),

(2) after injection, the energy of the electron is shifted to the lower energy side indicated as B in Fig. 4 by changing the high voltage of the electron gun,

(3) the electron energy is shifted back to the position A by the change of high voltage at electron gun and start the measurement of cooling time of the beam with 1% momentum difference.

In Fig. 5, the measured cooling times for various induction voltages with the electron current of 90 mA are shown. It is known that the necessary time to shift the $^{12}C^{6+}$ beam of 73.3 MeV from –1% to the center

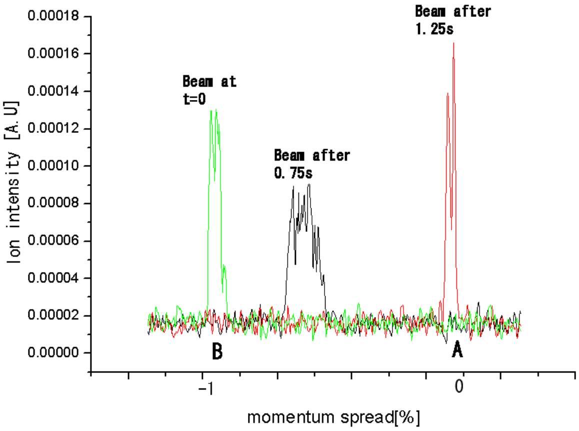

Fig. 4 Measured Schottky spectra with the electron current (I_e) and induction voltage (U_{ind}) of 90 mA and 0.1 V, respectively.

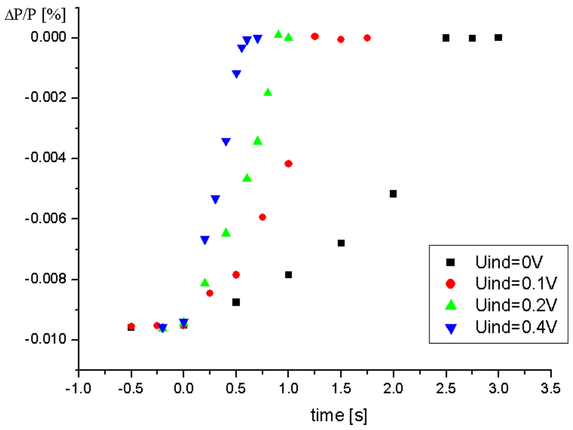

Fig. 5 Momentum change according to time during electron cooling for various induction voltages.

energy is ~0.6 sec. For the TSR with the circumference of 55m. Taking the difference of beam energy and circumference (compact ring assumes $^{12}C^{6+}$ of 2 MeV/u to cool down in the ring with 18 m circumference) into account, we expect the cooling time of 0.1 sec. for the induction accelerator voltage of 0.6V, which is well in the attainable region of real fabrication.

5 PLAN FOR FEASIBILITY STUDY

For the purpose of demonstrating the feasibility of the total scheme of laser ion production, an RF phase rotation and an electron beam cooling, we have started construction of a facility for the feasibility study consisting of a 50TW short pulse (~20fs) laser, an RF cavity for phase rotation and a compact cooler ring with the circumference of 18 m in our existing accelerator hall at ICR, Kyoto University as shown in Fig. 6. Total scheme described in the present paper will be experimentally evaluated in five years from now.

REFERENCES

[1] K. Endo et al., “Table top synchrotron ring for medical applications”, Proc. of EPAC2000, Vienna (2000) pp2515-2517.

[2] E.L. Clark et al., “Energetic heavy-ion and proton generation from ultra intense laser-plasma interactions with solids”, Phys. Rev. Lett. **85** (2000) pp1654-1657.

[3] P. Stephen et al., “Electron, photon and ion beams from the relativistic interaction of Petawatt laser pulses with solid targets”, Physics of Plasma **7** (2000) pp2076-2082.

[4] A. Noda et al., “Collection and Cooling Scheme of Heavy Ions Produced by a High Power Pulse Laser”, Beam Science and Technology **6** (2001) pp21-23.

[5] D. Möhl. “A comparison between electron cooling and stochastic cooling”, Proc. of ECOOL84, Karlsruhe, Germany (1984)pp293-301.

[6] M. Beutelspacher, PHD Thesis, “Systematische Untersuchungen zur Elektronrnkülung am Heidelberger Schwerionenspeicherring TSR”, Max-Planck-Institut für Kernphysik Heidelberg, Publication, MPI H-V18-2000.

[7] Ch. Elert et al., “An induction accelerator for the Heidelberg Test Storage Ring TSR”, Nucl. Instr. And Meth. **A314** (1992) pp399-407.

[8] H. Fadil et al., “Electron Cooling of Ion Beams with Wide Momentum Spread”, Proc. of the 13th Symp. on Accelerator Science and Technology, Osaka (2001) to be published.

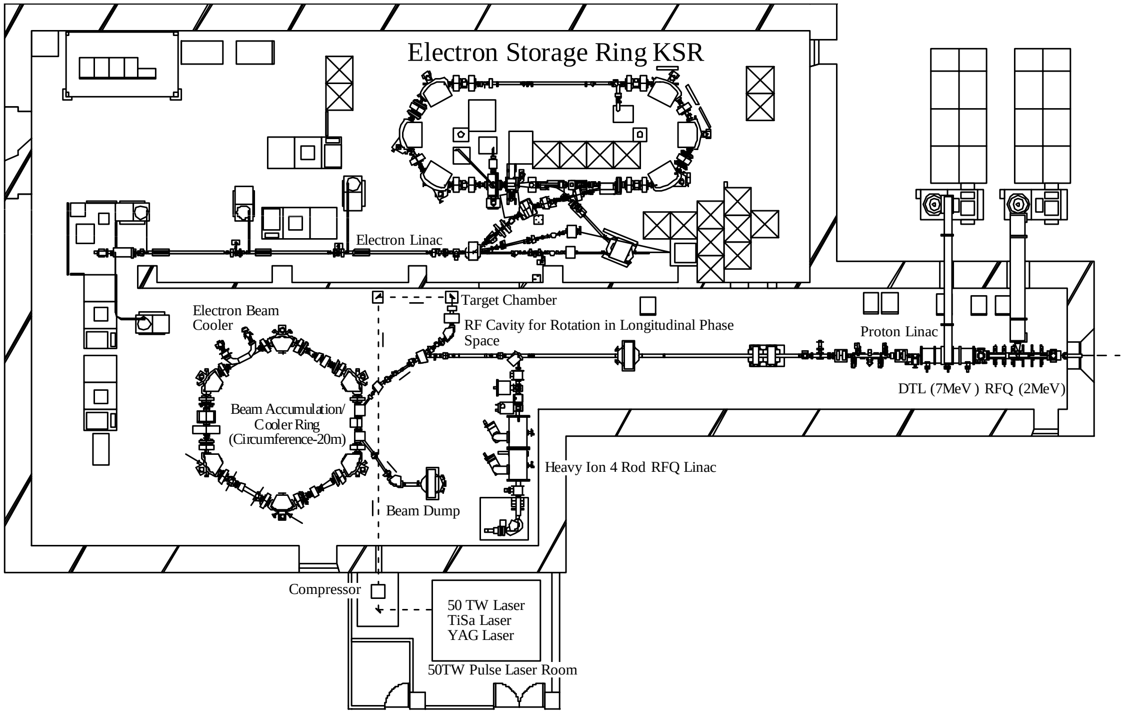

Fig.6 Layout of the Feasibility study facility at NSRF, ICR, Kyoto University.