COMPACT ION ACCUMULATION AND COOLER RING IN COMBINATION WITH LASER

A. Noda[1], H. Fadil, Y. Iwashita, A. Morita, S. Nakamura, T. Shirai, H. Tongu,
ICR, Kyoto University, Kyoto, Japan
M. Grieser, M. Beutelspacher, MPI für Kernphysik, Heidelberg, Germany
S. Yamada, K. Noda, NIRS, Chiba, Japan
H. Daido, M. Yamagiwa, APRC, Kansai Reseach Establishment, JAERI, Kizu, Kyoto, Japan
M. Uesaka, NERL, Graduate School of Engineering, University of Tokyo, Tokai, Ibaraki, Japan

Abstract

A compact ion accumulation and cooler ring is under construction. Its circumference and maximum magnetic rigidity are 18 m and 1T·m, respectively. Its research scope consists of verification of electron beam cooling scheme of rather hot ion beam produced from laser induced plasma and 3-dimensional laser cooling.

1 INTRODUCTION

At Nuclear Science Research Facility (NSRF) of ICR, Kyoto University, construction of a compact accumulation and cooler ring for ion beam has been just started to be installed in the accelerator hall as shown in Fig.1. The research scopes to be covered with this ring are (1) research and development of laser ion source as an injector for a compact synchrotron dedicated for cancer therapy and (2) beam physics research such as 3-dimensional laser cooling of rapidly circulating ion beam.

Recently high-energy ion production with a high power short pulse laser has been reported [1,2]. The result, however, has no peak in its energy spectrum, which decays exponentially as the energy increases. The beam acceleration with use of very strong electromagnetic field associated with the high power laser has been investigated and it has achieved fairly high acceleration gradient for electron [3], but the beam intensity was not enough for real application due to above mentioned spectrum.

For the purpose of real application of such laser acceleration mechanism, a scheme to collect enough intensity of beam has been proposed, which combines the phase rotation in a longitudinal phase space by using an RF electric field synchronized with the pulse laser and beam cooling technique in a cooler ring [4]. This scheme aims at the realization of heavy ion (Carbon) injector of a compact size of the synchrotron dedicated for cancer therapy. The cooler ring can be also utilized as the playground of beam physics and we are investigating the

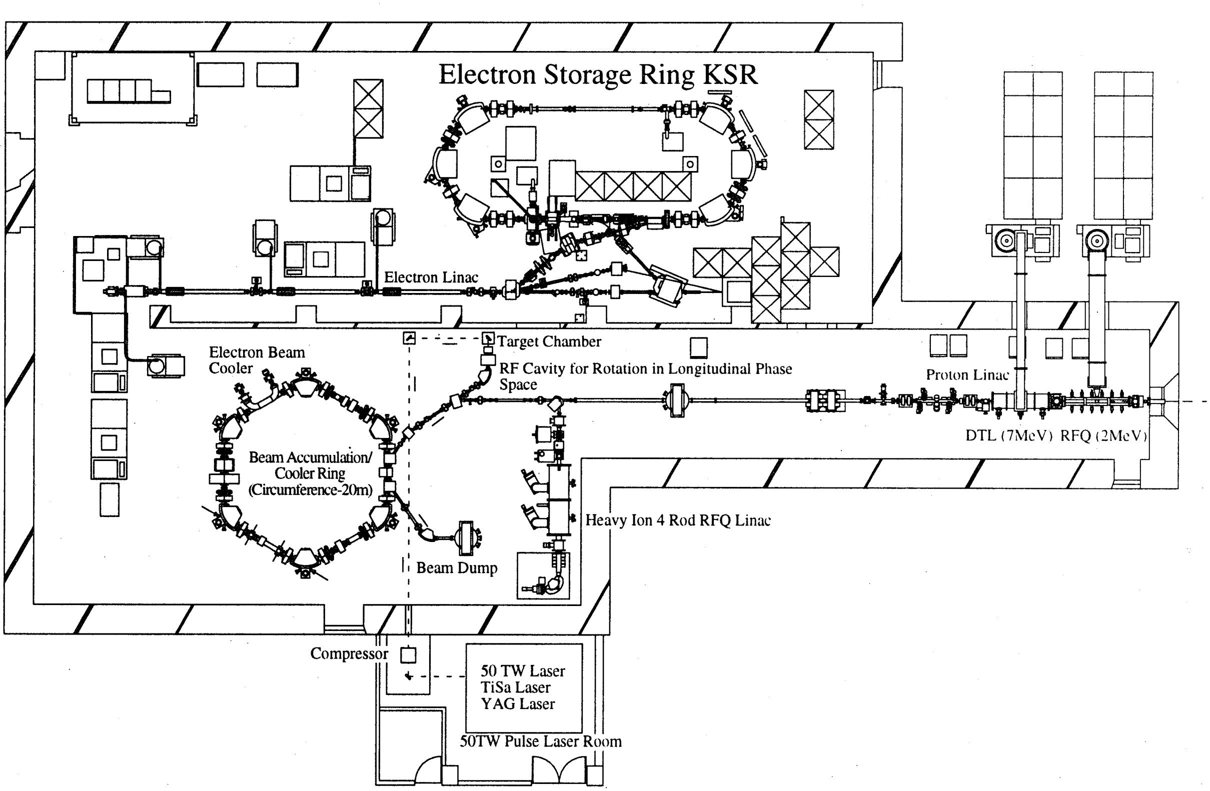


Fig. 1 Layout of the compact accumulation and cooler ring to be installed in the accelerator hall of NSRF of ICR.

[1] e-mail address: noda@kyticr.kuicr.kyoto-u.ac.jp

possibility of applying 3-dimensional laser cooling in order to investigate the feasibility of "crystallization" of the rapidly circulating ion beam.

In the present paper, the brief outline of the laser ion production system is described in connection with the compact accumulation and cooler ring. The possible usage of the ring for beam physics is also described.

2 PHASE ROTATION OF LASER PRODUCED IONS

2.1 General Specification of Laser Ion Source

The high power pulse laser will produce high-energy ion when it is focused on a solid target with the power density higher than 10^{19} W/cm^2. The maximum energy reaches several tens MeV, which is considered to be enough high to be injected into the synchrotron for cancer therapy at 2 MeV/u. For the purpose of cancer therapy, however, the required beam intensity is about 10^9 particles per second. As the high power short pulse laser, we assume the one with 100 TW and 20 fsec with 10 Hz repetition at APRC, Kansai Research Establishment of JAERI. So it is required to provide ~10^8 particles per shot.

The ion acceleration is considered to occur by the Coulomb interaction of the ion with the high-energy electron emitted to the forward direction by the high power laser. For production of high energy Carbon beam, it is considered to be very important to suppress the contamination in the carbon target, otherwise most energy provided by the laser through the high energy electrons are taken away by lighter ions as hydrogen. For the purpose of evaluation of such ion production rate, we are planning the experiments utilizing 12 TW laser at Nuclear Energy Research Laboratory at Tokai of University of Tokyo. In the experiments, the angular dependence of the produced ions will be studied changing the target material and thickness and laser power.

2.2 Phase Rotation with Synchronized RF Field

As the main accelerator, we assume a short pulse high magnetic field synchrotron [5], the momentum acceptance of which is rather limited to the order of ±0.1%. As already mentioned, the ion beam is produced in a wide range of energy by a high-power laser and it is required to match the energy spread with the energy acceptance of this synchrotron. For this purpose we restrict the energy spread of the generated ion beam to be accepted up to ±5% as shown in Fig.3 (a). After passage to the RF cavity position, the ion beam becomes to have the phase spread as shown in Fig.3 (b) by a dotted line because of the velocity difference. If we apply such an RF correction as indicated in the figure by a solid line, then the fractional energy spread becomes as is shown by a dash-dotted line, which is well below ±1%. In the present case, we assume 2 m distance from the target to the RF cavity and 100 MHz RF frequency. In the calculation the Coulomb repulsion is not taken into account. Numerical calculation indicates that if the carbon ions with the intensity of 10^8 is focused in a size of 10 μmϕ and 0.4 μm in length (corresponds to 20fs time duration), then the beam will suddenly diverge without the presence of space charge neutralization by low energy electrons around the target plasma. Evaluation of such space charge neutralization is also our subject to be studied by the preparatory experiment at NERL.

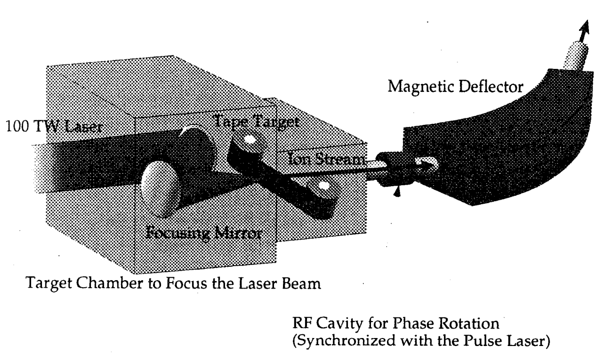
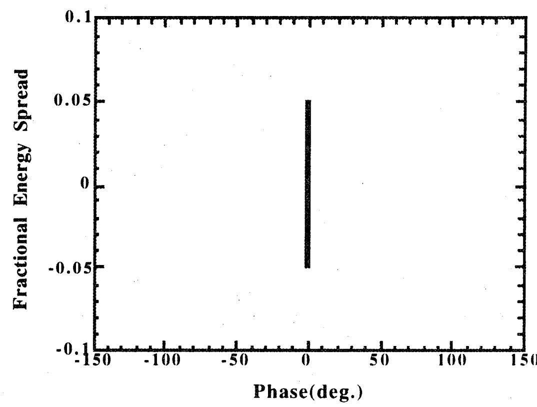
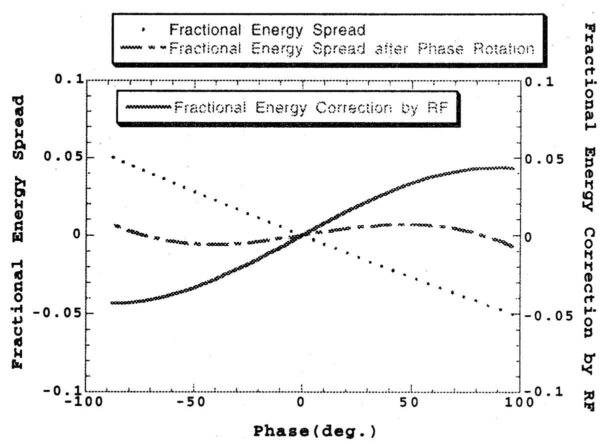


Fig.2 Laser ion source and its phase rotation scheme.



(a) at the position of the target



(b) at the position of RF cavity

Fig. 3 Fractional energy spread before and after Phase Rotation.

3 ELECTRON BEAM COOLING OF RATHER HOT ION BEAM

The energy spread of the phase rotated carbon beam will be further reduced by an electron beam cooling. Electron beam cooling has so far been considered to be suitable to further cool down the rather cold beam [6]. In the present case, however, the transverse beam size is expected to be small if space charge neutralization works well as we expect and beam blow up is not so serious. In this case, the transverse beam size is well expected to be smaller than the electron beam size (~5cmφ) and transverse cooling is not necessary. The longitudinal cooling works only for rather limited relative energy difference of the order of ±0.1 % and it is difficult to directly cool down the hot beam with energy spread ±1%. If we sweep the energy of the ion beam through the friction force region with use of an induction accelerator as utilized for laser cooling [7] as shown in Fig.4, then such hot beam is also expected to be cooled down by an electron-beam cooling. We have estimated that the possible repetition of such electron cooling can go up to 5 Hz for the present condition [4]. In order to investigate this possibility experimentally, we have made an experiment at TSR and promising results are obtained [8].

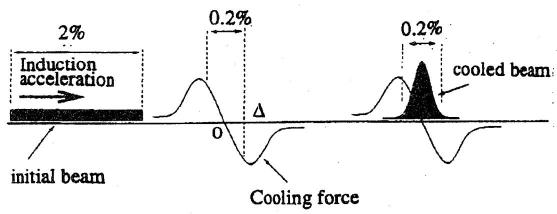


Fig. 4 Scheme of hot ion cooling with e-cool method.

4 THREE DIMENSIONAL LASER COOLING FOR ULTRA-COLD BEAM

Recently experimental indication of phase transition of ion beam circulating with relativistic velocity has been reported [9,10]. These results show sudden decrease of momentum spread of electron-cooled highly charged ions when number of ions has decreased less than a certain level, which suggests the ordering of the circulating ion beam. Possibility of beam crystallization with use of strong cooling force by laser cooling has been proposed for TARN II ring with six fold symmetry and satisfying maintenance condition [11]. So as to enable three dimensional laser cooling, the synchro-betatron resonance is to be utilized, which requires the condition as $\nu_s - \nu_H = \text{integer}$, where ν_s and ν_H are synchrotron tune and betatron tune in horizontal direction respectively. As ν_H is required to be somewhat(~0.1) different from the integer value in order to be free from the integer resonance, ν_s should be as large as ~0.1. To realize such a synchrotron tune with rather low (~100 V) RF voltage which does not affect laser cooling, the ion-beam energy should necessarily be lower. At the moment, $^{24}Mg^+$ or $^{9}Be^+$ with kinetic energy of 50keV/u is the candidate of the ion to be 3-dimensionally laser cooled. We have started construction of a compact accumulation and cooler ring as shown in Fig.1. The ring is designed to have six-fold symmetry and further requirement for the ring to realize "beam crystallization" is to be clarified through the computer simulation from now on.

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