Heavy Ion Microbeam Project in RIKEN Ring Cyclotron -2

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Abstract

The RIKEN Accelerator Research Facility has made several studies to realize a heavy-ion microbeam which is a new powerful tool in radiation biology. The new method to produce a high-energy heavy-ion microbeam is reported in this paper as well as the results of test experiments.

1 Introduction

A heavy-ion beam causes a great biological effect on a living body because of its high linear-energy-transfer (LET) radiation. Biologists have made good use of this point for their researches, to investigate the mechanism of mutations on a cell and so on. The RIKEN Research Facility (RARF) supplied beams for bioscience about 400 hours in 1998. In these experiments, a biological target is irradiated uniformly by heavy ions. It is suited to investigate the total effect on the target, but we can not recognize individual effects, complex transduction between cells or groups of cells (bio-crosstalk). A heavy-ion beam whose spot size on a target is in a range of micrometer is considered as an effective probe to studies of bio-crosstalk phenomena [1].

Heavy-ion microbeams have already realized in several institutes. For example, JAERI Takasaki has constructed the single ion hit system installed in its heavy-ion microbeam systems [2]. However, the maximum beam energy is limited less than few MeV/nucleon in status. Compared with them, the RIKEN Ring Cyclotron (RRC) is capable of accelerating light-mass ions up to more than 100 MeV/nucleon. This high-energy feature enable us new types of experiments because the range of heavy ions in a target is long. In other words, we can irradiate a deeper cell in a living body directly.

When we started the project, we employed the beam collimation method which was widely used in producing low-energy heavy-ion microbeams. At the first step, we tried to produce a microbeam whose diameter was 50 μm. The 10 mm-thick Bi collimator was installed just in front of a target. The target was a nuclear track detector, CR-39. What we found in the experiment was that particle tracks extended in wider regions than the hole of collimator. One of the reasons might be an effect of ions scattered from the collimator. In addition, it is very difficult to make a fine collimator (10 μm-ϕ, for example) with the thickness of 10 mm mechanically.

Thus, we introduce a new method which is suitable for production of a high-energy microbeam.

2 Method and Experiments with using an energy degrader

2.1 New method for production of a high-energy microbeam

In order to decrease an effect of scattered ions on a target, we should select a small fraction of beam at a position far from the target. To this end, we inserted an energy degrader with a very fine hole in the upper stream of a beam line. Most ions loose their energies by passing through the degrader, but a few ions pass through the hole without losing their energies. The energy-lowered ions can be separated by using the slits inserted on the dispersive focal point of the beam course. On the contrary, ions which pass through the hole are collected on the target finally. As the energy degrader is inserted in the upper stream of the beam line, the scattered ions give little influence on the target. The size of the beam is determined by the size of hole and the magnification factor of the beam transport system.

2.2 Results of test experiments

The test experiments were performed to verify the effectiveness of this method. At the beginning of this, a 80 μm-thick Cu foil was selected as an energy degrader. The

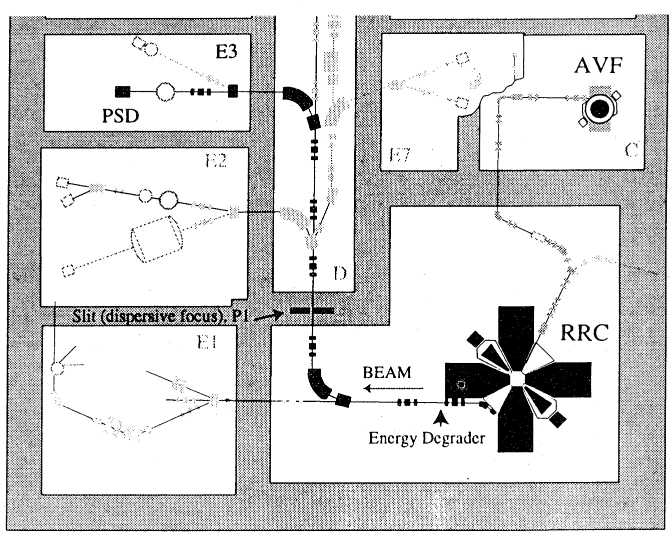

Fig.1 The beam line used for the production of a heavy-ion microbeam.

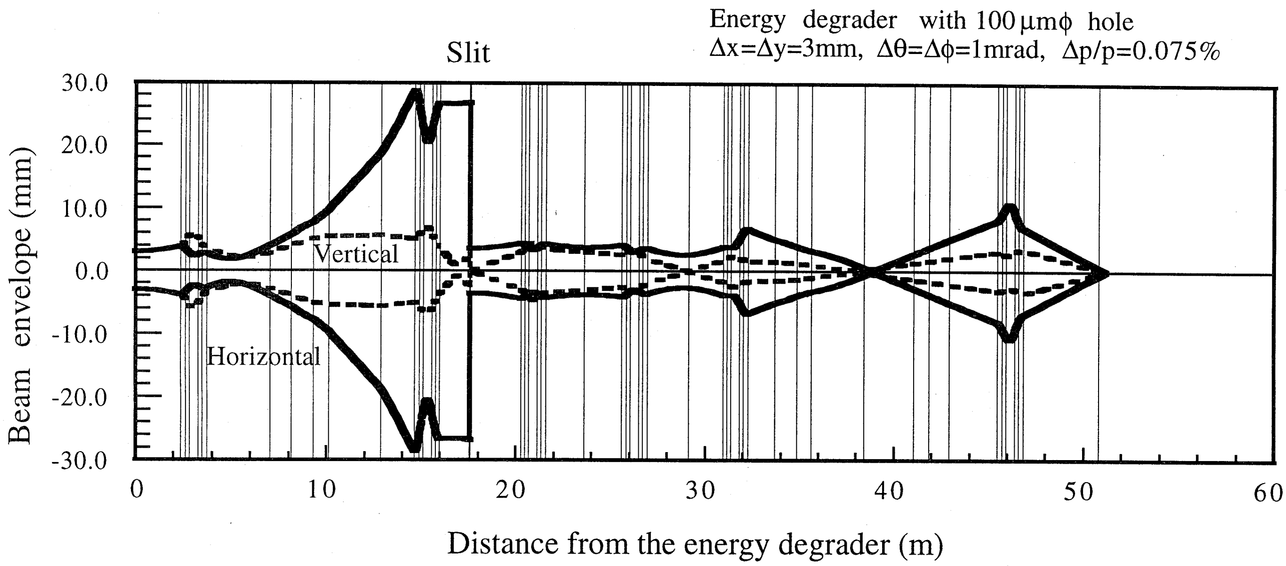

Fig.2 The optics of beam transport system to the E3A course.

energy degrader had many holes on it whose diameter and pitch was 100 μm and 300 μm, respectively (shown in fig.3). The energy loss at the degrader is 1 % for a 135 MeV/nucleon $^{20}Ne^{10+}$ beam. The beam separation at the dispersive focal point (P1 in fig.1) is 26 mm in this case, which is much larger than the beam extent. The magnification factor of the beam line is 0.63 for the horizontal direction and 1.26 for the vertical direction in the present experiments.

As shown in fig.1, the beam line to the E3 experimental hall, was selected as a microbeam line. The optics of beam transport system to the E3A course is shown in fig.2. The energy degrader was inserted just behind the exit of RRC. To detect the beam size at the target position, a two-dimensional position sensitive Si detector (PSD, S2044 HAMAMATSU) was set in the target chamber. The position of an injected ion was determined based on the charge division method. The sensitive area of this detector was 4.7mm*4.7mm. The performance of the detector was examined by using 5.48 MeV/nucleon α-particles emitted from a ^{241}Am source. The result showed that the position linearity was good enough even if the hit position was near the edge of the detector. We also found the position resolution was sufficient for the present experiment.

Figure 3 shows the result of the experiment performed on June 4th in 1998. The beam used in the experiment was a 135 MeV/nucleon $^{20}Ne^{10+}$ beam. The spatial distribution of ions on the target was shown in fig.3. Each peak corresponds to a hole of the energy degrader. The size of the peak is estimated to be 70 μm (horizontal) * 300 μm (vertical). The result shows that the new method works well, basically. However, the beam size in the vertical direction is much larger than the ideal value (126 μm). In addition, the image of holes was rotated by nearly 45 degrees. It means that the optical system for ions and/or its tuning is poor.

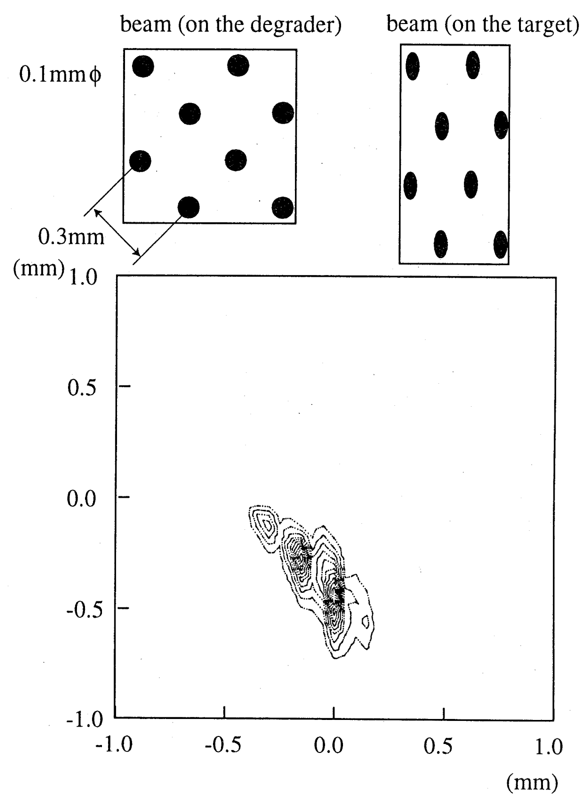

Fig. 3 The spatial distribution of ions on the target. A 135 MeV/nucleon $^{20}Ne^{10+}$ beam was used. The size of the bottom peak is estimated to be 70 μm (horizontal) * 300 μm (vertical).

To improve the situation, we inserted two ZnS foils into

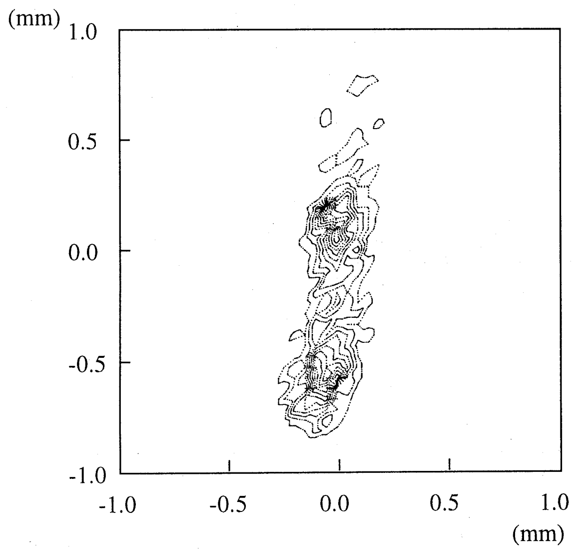

Fig.4 The spatial distribution of ions on the target. A 135 MeV/nucleon $^{12}C^{6+}$ beam was used. The size of the upper peak is estimated 194 μm (horizontal) * 320 μm (vertical).

the beam line to monitor the beam position. These were very useful for beam-axis tuning. The next experiment was performed on December 9th in 1998 with a 135 MeV/nucleon $^{12}C^{6+}$ beam. The spatial distribution of the beam was shown in fig.4. The upper peak shows the ions passing through the hole whose diameter is 300 μm. The size of the peak is estimated 194 μm (horizontal) * 320 μm (vertical). The lower peak appeared gradually during the measurement. This moving of the beam position was considered as the effect of the changing of magnetic field of the RRC main coil. In this experiment, the beam tuning of the RRC was not perfect because of the instability of the magnetic field. In fig.4, the beam position suddenly changed from the upper peak to the lower one. This implies the stability of the beam is essential.

3 Summary

The skill of beam control was improved every experiment. As a result, we can get reasonable width of a microbeam in the case of using the energy degrader with the hole whose diameter is 300 μm. Challenging to the next step, for example to produce a microbeam whose diameter is 100 μm, more precise technique of beam operation is required. We should consider the point that the position of a microbeam spot on the target is affected sensitively by the change of magnetic field of the RRC. In addition, we found a little up and down of the beam line by the level measurement performed in this spring. The fact must be also considered for the next beam tuning and the detection of the beam spot on the target.

Orbit calculations including the effect of misalignment of the magnets shows that the aberration is roughly 50 μm . It means that it is possible to minimize a microbeam up to 50 μm in diameter by using the present set up. We continue further investigation.

References

[1] N.Fukunishi et al., Proc. 11th Int. Conf. on Cyclotrons and their Applications., (1997) 270
[2] T.Sakai et al., Nucl.Instr.and Meth. B130 (1997) 498