Estimation method of microbeam divergence from glass capillaries for biological use

R.J. Bereczky,[*1] T. Ikeda,[*1] T. Kobayashi,[*2] M. Utsugi,[*3,*1] T. Hirano,[*4,*1] Y. Sakai,[*3] and T. Abe[*1]

Ion microbeams can be used in various fields such as basic research, or for many different technical applications such as in radiobiology. When an ion beam with energy on the order of megaelectron volts is transmitted through a tapered glass microcapillary, the extracted beam can be used as a ion microbeam for cell irradiation. Moreover, the ions can be directly guided to the cell using a capillary with a thin-end window. At RIKEN, we have developed a unique technology for mutation breeding using high-energy heavy-ion beams. Heavy-ion beams at relatively low doses induce mutations at a high rate without severely inhibiting growth. Densely ionizing radiation produces clusters of DNA damage that cannot be repaired by the cell, leading to cell death, or can only be repaired incompletely by the cell, which induces mutations. The effects of heavy-ion beams on both the lethality and effectiveness of mutation induction should be investigated in more detail in future studies. An ion microbeam is a useful tool for DNA damage or repair process research. The regions relevant to mutations in a living cell are not distributed uniformly, but concentrated into a small region. A well-defined microbeam is required to irradiate these small regions.

The purpose of our work is the development of microbeam irradiation for human cells, in which it is easy to observe DNA damages. Through these investigations, we provide an estimation method to define the beam divergence in a tapered glass capillary. Our studies have been performed both experimentally and theoretically. In the case of thinner capillaries, i.e., on the order of 1 micron, the divergence of the transmitted beam has been investigated, and similar experiments with a 200 μm diameter capillary without a thin end-window were also reported[1]. No study has yet reported on capillaries with outlet diameters in the 10 μm range and with thin end-windows, a size at which the application for cell irradiation is not obvious anymore.

The result of our first SRIM simulations[2] showed discrepancy from the experimental ones (see procedure below). When we changed the divergence of the beam inside the capillary from 0 to a nonzero value, i.e, 2.5°, the results of the simulation and the experiment were in good agreement (Fig. 1).

We measured the beam distribution extracted in air as a function of the distance between the exit of the capillary and a piece of CR-39, using He ions with the energy of 4.5 MeV produced by the RIKEN pelletron accelerator.

*1 RIKEN Nishina Center
*2 Atomic Physics Laboratory, RIKEN
*3 Toho University, Department of Physics
*4 University of Miyazaki, Faculty of Agriculture

The ions were transmitted through a tapered glass capillary (pulled from injection needle), set at the end of the beam line.
The inlet diameter of the capillary was 800 μm, the outlet diameter was 4 μm, and it had a thin end-window made of plastic with a thickness of 8 μm[3]. The length of the capillary was ~ 65 mm. The profile of the extracted beam was measured with CR-39 (Fig. 2). The average rate of the ions was 14 counts/s during the measurement. To avoid the overlap of the ion tracks on the CR-39 surface, the number of transmitted ions was chosen once as 200, and as 600 in the other cases.

Further systematic studies will be performed in the near future that will contribute to the development of microbeam irradiation of human cells.

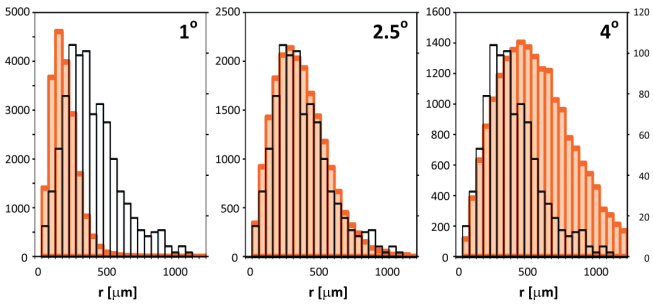

Fig.1. Comparison of the beam profile of the experiments (black) and SRIM simulations (orange). The horizontal axis shows the distance of the ion tracks from the center of the beam. The values of the beam divergence inside the capillary are shown in each figures. The distance between the exit of the capillary and the CR-39 was 6 mm.

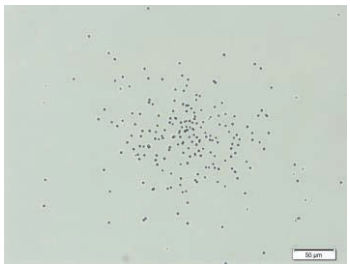

Fig.2. Profile of the extracted beam, when the distance between the exit of the capillary and the CR-39 was 2 mm. The scale corresponds to 50 μm.

References
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