Heavy-ion irradiation test of radiochromic films

T. Kambara,[*1] A. Yoshida,[*1] Y. Hayashi,[*1] K. Ishii,[*1] and T. Abe[*1]

The heavy-ion irradiation of biological or industrial samples requires the dose-distribution measurement of a beam spot 5–10 cm in diameter. A radiochromic film changes its color according to the absorbed dose of ionizing radiation and enables two-dimensional high-resolution dose-distribution measurements. It is easy to handle and portable, and a personal computer can capture its image with an inexpensive and common image scanner and convert the numerical data of the image to optical density (OD) as a function of the absorbed dose.[1] Radiochromic films are widely used in radiotherapy for dosimetry of high-energy photons.

In order to assess the usefulness of radiochromic films in our high-energy heavy-ion irradiation, we tested two types of films, GAFCHROMIC^{TM} HD-V2 for a higher dose and EBT-3 for a lower dose,[2] using heavy ions with a wide range of linear energy transfer (LET). The irradiation targets were 4 cm × 5 cm rectangular segments of vendor-supplied 25 cm × 20 cm sheets of the films. The HV-D2 targets were irradiated by C ions with LETs of 22.5 and 179 keV/μm, Ar ions with LETs of 184 and 673 keV/μm, and Fe ions with LETs of 637 and 1061 keV/μm with dose ranging from 1 to 400 Gy, and the EBT-3 targets were irradiated by C ions with LET of 22.5 keV/μm, Ar ions with LET of 184 keV/μm, and Fe ions with LET of 637 keV/μm with dose ranging from 0.2 to 10 Gy.

The targets were irradiated at the E5B beamline of the RIKEN Ring Cyclotron where the LET was adjusted by Al-plate degraders.[3] The beam was collimated by a 20-mm-diameter aperture on a 10-mm-thick brass plate about 153 mm upstream of the target.

Before and after the irradiation, the target was scanned by an image scanner and converted to a 24-bit 75-dpi bitmap file. The numerical values of the three primary colors (RGB) of each pixel were converted to OD values following the procedure described in Ref. 1). Although each of the RBG colors can yield OD distributions, we show in the following the results for green, which is the most sensitive.

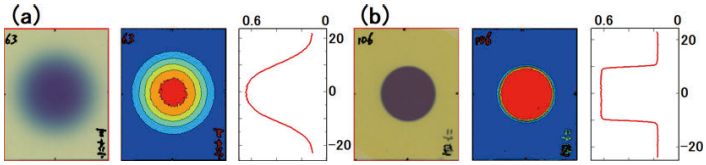

Fig. 1. Images, the corresponding OD distributions and one-dimensional vertical distributions through the center of films irradiated by (a) C ions after an 18.6-mm-thick degrader and (b) Ar ions without a degrader.

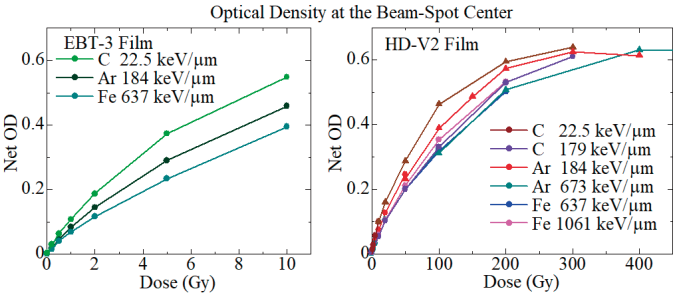

Fig. 2. OD of the films irradiated by heavy ions with different LETs as functions of the absorbed dose.

Figure 1 shows examples of images of the irradiated targets, the corresponding two-dimensional OD distributions, and its one-dimensional distribution along a vertical line through the center: (a) an HD-V2 film irradiated by 200 Gy of 179-keV/μm C ions and (b) an EBT-3 film irradiated by 10 Gy of 184-keV/μm Ar ions. The image in (a) is blurred since the C ions passed through an 18.6-mm-thick degrader before the target. The image in (b) is clear; its OD distribution is flat in the beam spot and drops sharply within about 1 mm at the edge since the Ar ions did not pass through a degrader.

We obtained the net OD distribution of a target as the difference between the distributions before and after the irradiation, and we took the OD value at the center of the beam spot. Figure 2 compares the dose dependence of the net OD value for different irradiation conditions and films.

The dose dependence of OD has a common feature: it first increases linearly and finally saturates above 200 Gy for HD-V2, but it does not saturate up to 10 Gy for EBT-3. It is higher for lighter ions and lower LETs but does not strongly depend on the ion and LET, remaining within ±30% overall, although the atomic number of the ions is different by more than 4 and the LET is different by nearly 50.

As a whole, the radiochromic films can be useful for various heavy ions with a wide range of LETs to evaluate doses between 0.2 and 200 Gy and to measure the two-dimensional dose distribution with a spatial resolution of about 1 mm. The films may also be useful for the comparison of irradiation dose between distant irradiation facilities since they are easily transported and treated.

References

1) T. Agematsu, H. Hanaya, T. Kojima, Radioisotopes **57**, 87 (2008) (Japanese).
2) `http://www.gafchromic.com/`.
3) H. Ryuto, T. Abe, N. Fukunishi, M. Kase, Y. Yano, J. Biomed, Nanotechnol. **2**, 1 (2006).

*1 RIKEN Nishina Center