Fricke nanocomposite gel dosimeter for heavy ion beam irradiation

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In advanced radiotherapy with energetic heavy ions such as pencil beam scanning treatment, a very complex dose distribution is applied to a desired target volume. A real 3D verification dosimeter is needed. Gel dosimetry has been proposed as a possible method for the 3D verification dosimeter in radiotherapy. One drawback of gel dosimetry is the decrease in radiation detection sensitivity with the increase in linear energy transfer (LET), which hinders absolute dose determination when used for ion beams. Thus, we have started developing new nanocomposite gel dosimeters based on the liquid radiation chemical dosimeter and diffusion suppression technique using adsorption properties of nano-clay. In our previous report, we presented the nanocomposite dichromate gel dosimeter with radiation-induced reduction reactions, which showed sensitivity degradation with increase in LET. [1)] On the other hand, nanocomposite Fricke gel (NC-FG) with radiation-induced oxidation reactions exhibited the response almost independent of LET. These observations indicated a different LET dependence from that of the liquid radiation chemistry study, and therefore, more detail investigations were required. In this study, detailed radiological properties of NC-FG under various preparation conditions were investigated under argon and carbon beam irradiation covering an LET range from 10 to 3000 eV/nm. Details of the chemical compositions of gel dosimeters are summarized in Table 1. Irradiations were performed with 290 MeV/nucleon $^{12}C^{6+}$ or 500 MeV/nucleon $^{40}Ar^{18+}$ ion beams accelerated by the HIMAC. Measurements of the relaxation rates ($R_1 = 1/T_1$) were performed using a 1.5-T MRI (Philips).

Figures 1(a) and 1(b) show the R_1 ($1/T_1$) distributions measured for the normal NC-FG sample (composition was 1 wt% Laponite, 3 wt% gelatin, 1 mM ammonium iron (II) sulfate, and 50 mM perchloric acid, as shown in our previous report [2)]) irradiated with 290 MeV/nucleon carbon ion beams and 500 MeV/nucleon argon ion beams, respectively. The dose dependence of R_1 near the entrance surface (square symbol, 5 mm depth) and near the Bragg Peak (circle symbol, 79 mm for carbon beam, 105 mm for argon beam) was shown in Figs. 1(c) and 1(d). Although the peak positions of each irradiated sample was adjusted within 1 pixel of the MRI resolution (0.78 mm) to ensure overlapping, a good linearity was confirmed at every position. The rate of R_1 incensement per unit of entrance surface dose was calculated and is plotted in Figs. 1(e) and 1(f) to compare it with the dose distribution obtained by the ionization chamber (right vertical axis in Fig. 1). The δR_1 distribution of NC-FG faithfully reproduces the dose distribution including the peak of argon ion beam. Surprisingly, the radiation sensitivity of NC-FG does not change even at very high LET (3000 eV/nm) at the Bragg peak region of argon ion beam. This is a unique property because all gel and solid type dosimeters such as film, scintillation, and semiconductor dosimeters have LET dependence.

By varying the concentration of the nano-clay, Fe^{2+} and perchloric acid from the standard composition described in our previous report, we have obtained the following features.

1. NC-FG works not only in an acidic, but also in a neutral condition.
2. The concentration of ferrous ions affects radiation sensitivity.
3. Radiation sensitivity is lost at nano-clay concentration below 0.1 wt%.

The first two features were completely different from those of conventional Fricke gel dosimeters. The third feature suggested that nano-clay in NC-FG is essential for radiation induced reactions, and that ferrous ions oxidize by a new mechanism that completely different from the previous one.

Table 1 Chemical composition.

Gelatin	Laponite	$HClO_4$	Fe^{2+}	Degassing
3 wt%	0.1 – 1 wt%	0 - 150 mM	0.2 - 5 mM	Ar

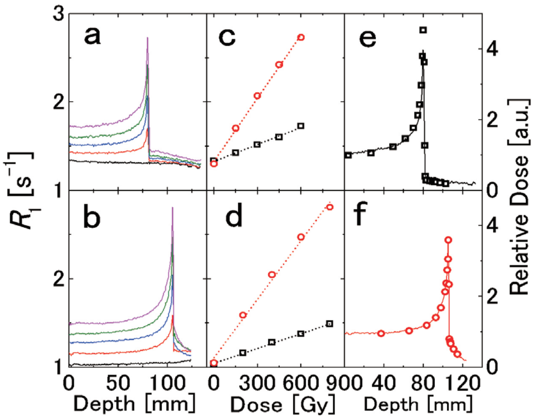

Fig. 1. Dose dependence of R_1 distribution with different ion beam irradiation.

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References
1) T. Maeyama et al.: J. Phys. Conf. Ser. 444, 012033 (2013).
2) T. Maeyama et al.: Radiat. Phys. Chem. 96, p.92 (2014).