Application of an Imaging Plate to Radiation Dosimetry

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V. 1. Application of an Imaging Plate to Radiation Dosimetry

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Introduction

In the sensitive layer of an imaging plate (IP) composed of $BaFBr:Eu^{2+}$ phosphors, ionizing radiation creates a large amount of trapped centers, which record information about the deposited energy and its position. The IP has many advantages as a detector of two-dimensional images, and has been utilized in a number of fields[1]. However, there are relatively few reports of applying IPs for quantitative use[2]. The reason for this is that IPs have a large fading effect. That is, some charges stay trapped at localized defects but some recombines with holes after irradiation for a time, depending on the temperature and the activation energy of the traps. This results in a serious problem in developing an IP into an integral-type detector. We have continued our study[3-5] of measuring the fading characteristics and have observed that the fading effect increases as both the temperature and the time following irradiation increase. Considering that thermally released electrons from the F centers are dominant in the fading process, we successfully developed equations as a function of elapsed time (t) and absolute temperature (K) to correct the fading. We have also investigated the dependence of the fading effect of IP on alpha, beta, and gamma radiation and their energies by using three types of IPs: BAS-UR, BAS-TR, and BAS-MS. We found that in all types of IPs the fading effect is independent of the energy of the incident particles of beta and gamma rays. The fading effect was also independent of radiation, except for the first component, which fades out very quickly after irradiation with alpha rays[5]. This result means that the whole amount of radiation dose independent of radiation or energy can be estimated after the first component caused by the alpha rays fades out.

The purpose of this paper is to report on our development of a new method that eliminates the short half-life component by annealing an IP and that estimates the radiation dose with the long half-life component for quantitative measurement. The annealing decreases the effect of fading on the dose estimate, however, it also causes the loss of PSL. Considering an IP as an integral detector for a specific period, the optimum conditions for quantitative measurement with two types of IP (BAS-TR and BAS-MS) have been evaluated by using the fading correction equation.

Methods

BAS-TR and BAS-MS manufactured by Fuji Film Co. are commercially available. BAS-TR has a size of 40.0 cm×20.0 cm and is dyed blue, lacking a protective surface layer to detect low-energy beta rays such as ^{3}H effectively. BAS-MS, which is produced as a highly sensitive and waterproof white IP, has a smaller area of 20.0 cm×25.0 cm with a 9 μm thick protective Mylar film. Both are constructed of a 50μm or 115μm thick photostimulable phosphor ($BaFBr:Eu^{2+}$) individually affixed to a 250μm or 188μm thick plastic backing for support.

Fading correction equations after irradiation with a ^{244}Cm source were obtained as Eq. (1) [4] using BAS-TR scanned by BAS-1000 and Eq. (2) [5] using BAS-MS scanned by BAS-5000:

$$\begin{aligned}(PSL)_{t,k}/(PSL)_{0,k} = {} & 0.461\exp\{-2.19\times10^{8}\cdot t\cdot\exp(-6.14\times10^{3}/K)\} \\ & +0.277\exp\{-1.60\times10^{13}\cdot t\cdot\exp(-1.02\times10^{4}/K)\} \\ & +0.230\exp\{-7.98\times10^{12}\cdot t\cdot\exp(-1.05\times10^{4}/K)\} \\ & +0.030\exp\{-1.99\times10^{12}\cdot t\cdot\exp(-1.05\times10^{4}/K)\} \\ & +0.002\exp\{-4.96\times10^{10}\cdot t\cdot\exp(-1.05\times10^{4}/K)\} \qquad (1)\end{aligned}$$

$$\begin{aligned}(PSL)_{t,k}/(PSL)_{0,k} = {} & 0.373\exp\{-2.08\times10^{12}\cdot t\cdot\exp(-8.92\times10^{3}/K)\} \\ & +0.084\exp\{-9.89\times10^{10}\cdot t\cdot\exp(-8.69\times10^{3}/K)\} \\ & +0.360\exp\{-4.37\times10^{10}\cdot t\cdot\exp(-9.31\times10^{3}/K)\} \\ & +0.144\exp\{-2.41\times10^{10}\cdot t\cdot\exp(-9.54\times10^{3}/K)\} \\ & +0.039\exp\{-2.07\times10^{9}\cdot t\cdot\exp(-9.53\times10^{3}/K)\}\ , \qquad (2)\end{aligned}$$

where $(PSL)_{t,k}$ and $(PSL)_{0,k}$ refer to the PSL of elapsed time t and 0 after irradiation, respectively, and K is the absolute temperature.

Two models expressing fading curves during the elapse of t days (one model is t = 1 and another is t = 30) after irradiation and a decreasing curve after annealing at K°C are shown in Fig. 1. All values of PSL were normalized with the value of PSL one day after irradiation. A model of the accumulating radiation dose each day is also shown. T_1 and T_{30} are the values of PSL after t days have elapsed when t = 1 and t = 30, each without annealing. $T_{1,K}$ and $T_{30.K}$ are the values after annealing with T_1 and T_{30} at K°C for 24 hours. It is clear that the difference between the two points, T_1 - T_{30} and $T_{1,K}$ - $T_{30.K}$, becomes smaller after annealing, and the effect of fading on PSL is decreased. However, the process also causes a loss of sensitivity.

Results

A comparison of the effects of an integral period on the value of PSL without annealing, and with annealing at 60, 70, and 80°C were evaluated, considering IP as an integral detector for 2, 7, 15, and 30 days. Figure 2 shows the results: (a)for BAS-TR and (b) for BAS-MS. All values of PSL were normalized with the value of PSL left at 20°C for one day after irradiation, indicated as PSL_1. For BAS-TR, the ratio of PSL_t to PSL_1 shows a large difference (0.78 and 0.07) between 2 and 30 days without annealing. The difference becomes very small (< 5%) when the IP is annealed at 60°C. In contrast, for BAS-MS, the difference of the ratio of PSL_t to PSL_1 between 2 and 30 days is not as large as BAS-TR (0.94 and 0.53) without annealing. The difference does not get smaller when the IP is annealed at 60°C, but does decrease by about 15% when the IP is annealed at 80°C.

In addition, the loss of PSL was investigated after 2, 7, 15, and 30 days had elapsed after irradiation. Figs. 3(a) and 3(b) show the decrease of PSL without annealing, and with annealing at 60, 70, and 80°C each for BAS-TR and BAS-MS. Just as for Figs. 2(a) and (b), all values of PSL were normalized with the value of PSL left at 20°C for one day after irradiation, again indicated as PSL_1. For BAS-TR, even without annealing, the ratio of PSL_t to PSL_1 is 7% 30 days after irradiation. After annealing at 80°C, it goes to 0.4%. For BAS-MS, no drastic decrease of PSL was observed. The ratio remains above 13% after annealing at 80°C 30 days after irradiation. This level is considered sufficient for practical use as a month-long integral detector.

Therefore, the optimum condition for quantitative measurement appears to be to anneal BAS-MS at 80°C for 24 hours after irradiation for a month-long detector. This can decrease the effect of the elapsed time, retaining sufficient sensitivity. The results demonstrate new possibilities of radiation dosimetry offered by IP.

Discussion

In this work, two types of IPs were investigated. The effect of annealing is clearly demonstrated by the difference in the decrease of PSL. That is, annealing even at a relatively low temperature (60°C) causes a large amount of emission of luminescence for BAS-TR, but causes less for BAS-MS (see Figs. 3(a) and (b)). This result could be explained by the difference of the activation energies and the component amplitudes between the two IPs. We showed that the activation energy increases as the components proceed[4]. This result satisfies the idea that fading occurs in the order of the component having the lower activation energy. The activation energies of each component in Eq. (1) for BAS-TR are 0.53, 0.88, 0.90, 0.90, and 0.90 eV. For each component in Eq. (2) for BAS-MS, the values are 0.76, 0.75, 0.80, 0.82, and 0.82 eV[5]. The amplitude of the first component for BAS-TR is larger than that for BAS-MS: 0.461 in Eq. (1) and 0.373 in Eq. (2). Annealing accelerates advance of fading. Emission of the first component of BAS-TR should be drastically affected by annealing. In contrast, each component for BAS-MS has a relatively high activation energy, so it can retain sufficient sensitivity after annealing.

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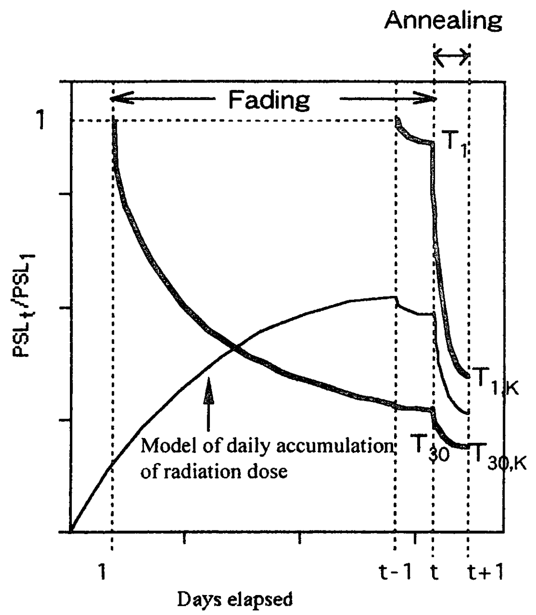

Fig. 1. Scematic model of fading and annealing curves during the elapse of t days after irradiation.

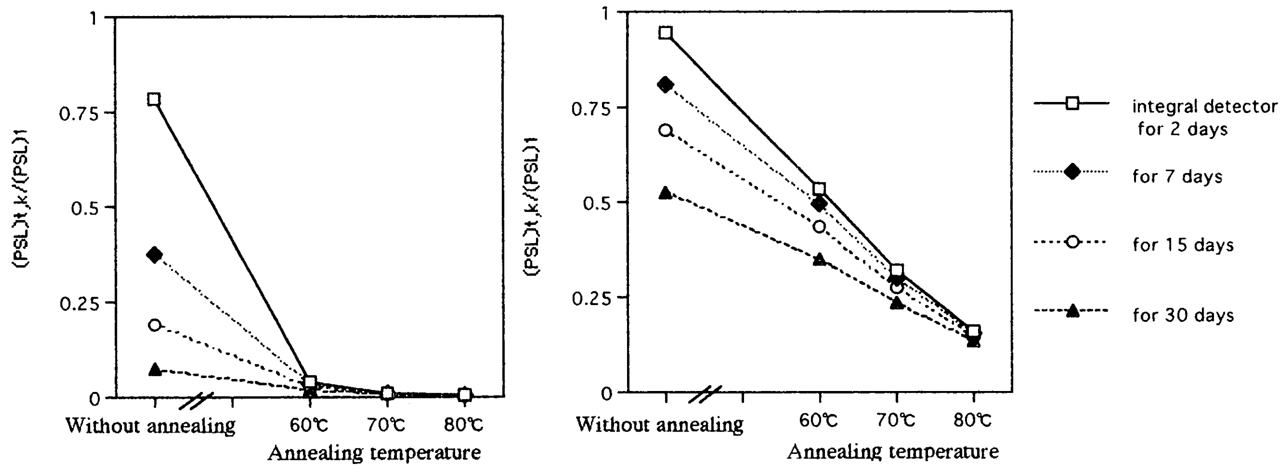

Fig.2(a) Fig.2(b)

Fig. 2. Comparison of the effects of an integral period on the value of PSL without annealing, and with annealing at 60, 70, and 80°C.

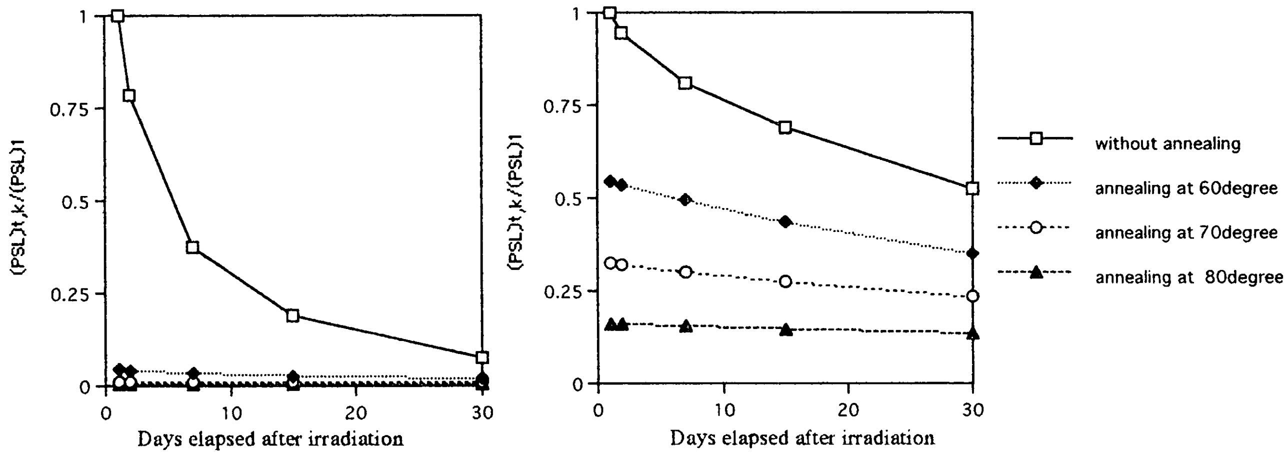

Fig.3(a) Fig.3(b)

Fig. 3. Loss of PSL after irradiation. without annealing, and with annealing at 60, 70, and 80°C.