ELSEVIER
Nuclear Instruments and Methods in Physics Research A 441 (2000) 489–493
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.nl/locate/nima

Deterioration of imaging plate by proton irradiation and an evidence of its recovery

A. Nohtomi[a,b,*], T. Sakae[b,c], T. Terunuma[b], R. Kohno[a], Y. Takada[a,b], Y. Hayakawa[b,d,1], A. Maruhashi[b,c], K. Yasuoka[b,d]

[a] *Institute of Applied Physics, University of Tsukuba, Tsukuba 305, Japan*
[b] *Proton Medical Research Center (PMRC), KEK, University of Tsukuba, Oho 1-1, Tsukuba 305-0801, Japan*
[c] *Institute of Clinical Medicine, University of Tsukuba, Tsukuba 305, Japan*
[d] *Institute of Basic Medical Science, University of Tsukuba, Tsukuba 305, Japan*

Received 29 June 1999; received in revised form 30 August 1999; accepted 16 September 1999

Abstract

An imaging plate (IP) was excessively irradiated by 250 MeV proton beam up to 4.3×10^{13} protons/cm^2 in order to examine the resultant radiation damage. As a function of proton fluence, variations in photo-stimulated luminescence (PSL) signals were evaluated by comparing with the region without previous extensive proton irradiation on the same IP. Notable deterioration of PSL signal was found for the fluence more than 5×10^{12} protons/cm^2. Furthermore, partial recovery of the deterioration was evidently observed, which was promoted by keeping the IP at 50–70°C. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Clinical proton beam; Upper limit of repeatable use; Imaging plate (IP); Radiation damage; Deterioration of photo-stimulated luminescence (PSL) signals; Recovery of IP

1. Introduction

The imaging plate (IP) technique is widely used to measure the two-dimensional distribution of incident radiations since it has a high sensitivity, a wide dynamic range and a high position resolution [1–12]. An IP sheet can be used repeatedly by erasing the previous latent images with a fluorescent eraser; this is another advantage to employ this technique, especially in daily routine tasks.

We have applied IP to dose-distribution measurement of clinical proton beams [6,12]. In such application, a practical upper limit of repeatable use of IP should be known. While Kobayashi et al. studied radiation effects of 1 and 2 MeV He^+ ion irradiation by comparing with that caused by fission neutrons and ^{137}Cs and ^{60}Co gamma rays [13], radiation effects of IP caused by protons have not been examined yet. It is practically important to reveal the tolerance of IP to radiation damage

* Correspondence address. Proton Medical Research Center (PMRC), KEK, University of Tsukuba, Oho 1-1, Tsukuba 305-0801, Japan. Fax: + 81-0298-64-2575.
E-mail address: nohtomi@medaxp.kek.jp (A. Nohtomi)
[1] Present address: Dept. Biomedical Department, Toin University of Yokohama, Kurogane-machi, Aoba-ku, Yokohama 225-8502, Japan.

PII: S0168-9002(99)01000-1

due to proton irradiation. In the present study, an IP was excessively irradiated by 250 MeV protons. After latent images were adequately erased, low-dose protons were irradiated to the IP and the variation of photo-stimulated luminescence (PSL) signals was evaluated as a function of the proton fluence which had been previously irradiated in excess.

2. Experimental

The experiment was carried out at the horizontal beam line of Proton Medical Research Center (PMRC), University of Tsukuba. For the excess irradiation, an unused IP (BAS III, Fuji film Co. Ltd.) was placed on the surface of 10 μm-thick stainless-steel foil vacuum window on which 250 MeV proton beam was bombarded, as shown in Fig. 1. The beam profile (i.e. relative distribution of proton fluence) was measured at this position. It had a two-dimensional Gaussian shape; the standard deviation in the vertical direction (σ_V) was 13.1 mm and that in the horizontal direction (σ_H) 6.9 mm. The total number of irradiated protons was determined by a current transformer (CT) monitor which was placed in the vacuum pipe near the IP. With this information, it is possible to obtain the fluence distribution of protons as a function of the position on IP.

Two separate spots on an IP were successively irradiated with different numbers of protons on the same IP: 1.1×10^{14} protons in Spot-1 and 2.4×10^{14} protons in Spot-2 (see Fig. 1). The average beam current was about 20 nA. When each irradiation was terminated, a slight dark-blue discoloration was noticed at the irradiated region on the IP. In a few minutes, the discoloration disappeared. Considerable radio-activation was observed at the same region. The activity distribution was measured by another normal IP, which was placed on the irradiated IP, and found to be well proportional to the fluence distribution of irradiated protons.

Ten days later, the activity decreased to less than 0.1% of that just after the irradiation. After 30 min of erasing the latent images, the self-generated PSL signal due to the activation became negligible for the following evaluation of the PSL signal. Then, the IP was exposed to low-dose proton beam (about 0.01 Gy as “proton dose to water”) with nearly uniform lateral distribution. The stored image was readout by BAS2000-II (Fuji Film Co., Ltd.) with fixed scanning parameters: “Latitude” = 4, “Sensitivity” = 400 and “Resolution” = 200 μm.

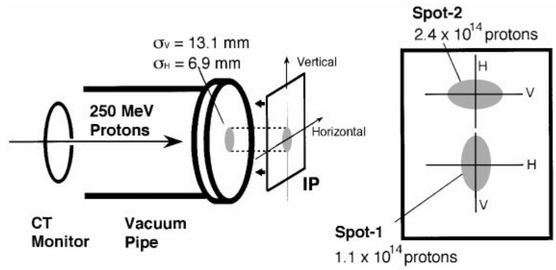

Fig. 1. Experimental setup for the extensive proton irradiation. When Spot-2 was irradiated, the IP arrangement was rotated by 90° to avoid an overlap between both spots.

3. Results and discussion

3.1. Deterioration of PSL signals

“Relative PSL intensity” is defined as the ratio of the readout PSL signal to that expected for non-irradiated IP which is deduced from an interpolation based on the response of the region without previous extensive proton irradiation. The validity of such deduction was directly confirmed by the low-dose exposure for non-irradiated IP. An example of this analysis is shown in Fig. 2. The distribution of PSL intensity and that of relative PSL intensity of Spot-2 along the vertical direction are shown together with the proton fluence distribution. The same analyses were also carried out for the vertical and the horizontal directions of Spot-1 and the horizontal one of Spot-2. As indicated in Fig. 2, the PSL signals of the irradiated region have apparently deteriorated compared with those of the region without previous extensive irradiation. The deterioration seems to be almost proportional to the fluence of irradiated protons though there is slight saturation just around the maximum fluence position.

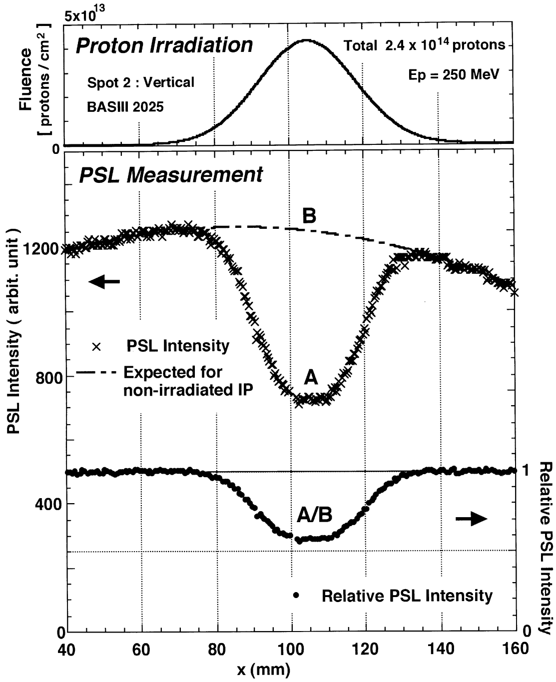

Fig. 2. Evaluation procedure of “relative PSL intensity”.

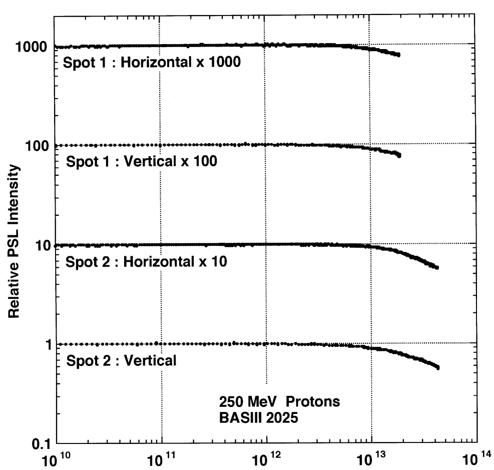

Fig. 3. Relative PSL intensity as a function of proton fluence.

In Fig. 3, the relative PSL intensities are plotted as a function of proton fluence. From this figure, it can be seen that the four curves show a consistent dependence on the fluence. Up to 5×10^{12} protons/cm^2, there is no notable deterioration of PSL signals. Higher than this fluence, the PSL intensities start to decrease with increase of fluence. The minimum relative PSL intensity obtained in Spot-1 is 0.78 at 1.9×10^{13} protons/cm^2; and that in Spot-2 is 0.58 at 4.3×10^{13} protons/cm^2.

3.2. Recovery of the deterioration

Eight months after the excess irradiation of protons, PSL signals were measured again by the same procedure described in the previous section; during the 8 months, the IP had been kept in a desiccator at room temperature. We noticed that the deterioration had been partially recovered. The minimum relative PSL intensities had changed from 0.78 to 0.86 for Spot-1 and from 0.58 to 0.76 for Spot-2. Then, the IP was put in a thermocontrol unit and kept there for 10 days at 50°C. After that, the relative PSL intensities were evaluated and some additional recovery was observed in both Spot-1 and Spot-2. As shown in Fig. 4, however, the recovery seemed to be saturated up to these values, even for 70°C heating.

In order to confirm the recovery of deterioration due to some thermal contributions, another unused IP was irradiated by 2.1×10^{14} protons in the same

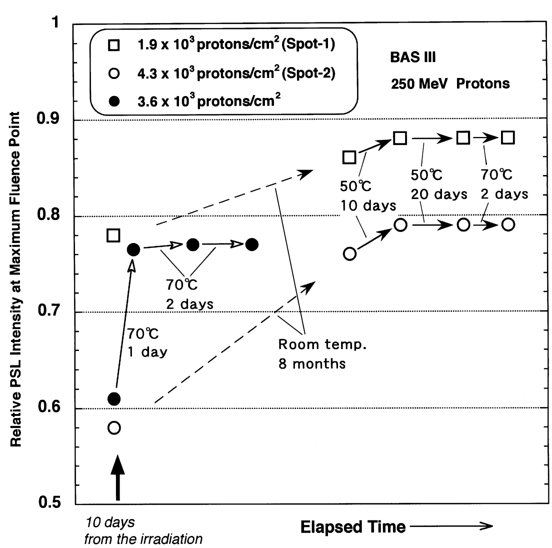

Fig. 4. Recovery of the relative PSL intensity at maximum fluence points under different temperature conditions.

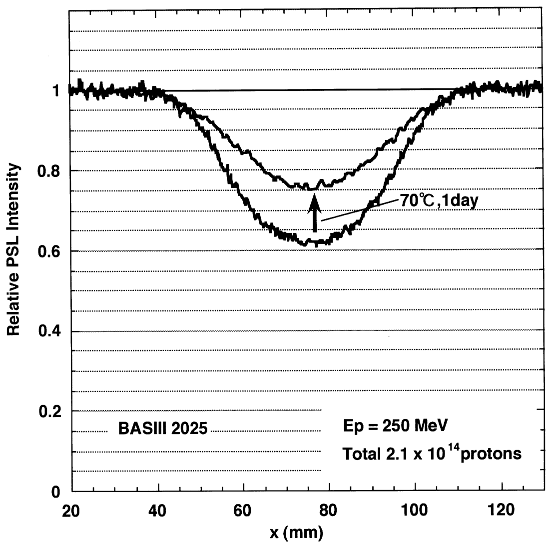

Fig. 5. Recovery of the relative PSL intensity (in 1 d) which was efficiently promoted by keeping the IP at 70°C.

manner. When PSL signals were measured 10 days after the irradiation, the minimum relative PSL intensity was found to be 0.61 at the maximum fluence point of 3.6×10^{13} protons/cm^2. Following this, the IP was kept at 70°C for 1 day, which induced an evident recovery of PSL signals as indicated in Fig. 5; the minimum relative PSL intensity increased to 0.76. The results are also plotted in Fig. 4. Keeping the temperature at 70°C for another 2 days brought the slight additional recovery up to 0.77. No further detectable recovery was observed by keeping the IP at this temperature.

As stated in Ref. [13], the flaw centers generated by incident radiations may act as competitive trap centers to the intrinsic F centers in the PSL material. Therefore, it is likely that the deterioration of PSL signals can be caused by a loss of electrons trapped in the F centers via adjacent flaw centers. If so, the present observation suggests that 40–50% of such flaw centers generated by protons are thermally rather unstable because the recovery of deteriorated PSL signals is efficiently promoted by keeping the IP at 50–70°C. Needless to say, the above explanation is only one of the many possibilities. Further discussion on the observed phenomenon is difficult here.

4. Conclusion

Radiation effects on an IP (BASIII, Fuji film Co. Ltd.) caused by 250 MeV protons have been investigated. Up to 5×10^{12} protons/cm^2, there was no notable deterioration of PSL signals. This fluence corresponds to about 3000 Gy as proton dose to water. Consequently, it has turned out that deterioration of the IP is practically negligible for daily use in our facility because the dose deposition to IP is at most 0.1 Gy for each usual measurement. Notable deterioration of PSL signal was found for fluence more than 5×10^{12} protons/cm^2. Furthermore, partial recovery of the deterioration was evidently observed, which was promoted by keeping the IP at 50–70°C. This recovery may be an interesting phenomenon to consider the mechanism of the deterioration of PSL signals. From this view point, photo-spectroscopic measurements are now being planned.

Acknowledgements

This work was partly supported by a grant-in-aid for scientific research from the Ministry of Education, Science and Culture, Japan.

References

[1] Y. Amemiya, T. Matsushita, A. Nakagawa, Y. Satow, J. Miyahara, J. Chikawa, Nucl. Instr. and Meth. A 266 (1988) 645.
[2] C. Mori, A. Matsumura, Nucl. Instr. and Meth. A 312 (1992) 39.
[3] C. Mori, A. Matsumura, T. Suzuki, H. Miyahara, T. Aoyama, K. Nishizawa, Nucl. Instr. and Meth. A 339 (1994) 278.
[4] N. Niimura, Y. Karasawa, I. Tanaka, J. Miyahara, K. Takahashi, H. Saito, S. Koizumi, M. Hidaka, Nucl. Instr. and Meth. A 349 (1994) 521.
[5] T. Oikawa, D. Shindo, K. Hiraga, J. Electron Microsc. 43 (1994) 402.
[6] Y. Hayakawa, Y. Amemiya, J. Tada, K. Hosono, T. Arimoto, Nucl. Instr. and Meth. A 378 (1996) 627.
[7] F. Cipriani, J.-C. Castagna, L. Claustre, C. Wilkinson, M.S. Lehmann, Nucl. Instr. and Meth. A 392 (1997) 471.
[8] L. Weissman, M. Hass, V. Popov, Nucl. Instr. and Meth. A 400 (1997) 409.

[9] M. Doyama, J. Takano, M. Inoue, T. Yoshiie, Y. Hayashi, M. Kiritani, T. Oikawa, Nucl. Instr. and Meth. A 394 (1997) 146.

[10] M. Yamamoto, T. Kumasaka, T. Uruga, N. Kamiya, H. Iwasaki, T. Ueki, Nucl. Instr. and Meth. A 416 (1998) 314.

[11] S. Taniguchi, A. Yamadera, T. Nakamura, A. Fukumura, Nucl. Instr. and Meth. A 413 (1998) 119.

[12] A. Nohtomi, T. Terunuma, R. Kohno, Y. Takada, Y. Hayakawa, A. Maruhashi, T. Sakae, Nucl. Instr. and Meth. A 424 (1999) 569.

[13] H. Kobayashi et al., Nucl. Instr. and Meth. B 135 (1998) 229.