Visualization of Radiation via Radiochromism Induced by Radiation Chemical Reaction

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ABSTRACT

We have succeeded in developing organic radiochromic materials based on dyes and polymers. Among the polymers investigated in this study, PVC was proved to be an excellent host for radiochromic materials.

1 Introduction

Radiation therapy has become an important treatment option for patients with cancer. In radiation therapy, high dose should be delivered to cancer cells while the exposure dose of healthy tissues should be minimized. To enable such dose distribution, intensity-modulated radiation therapy (IMRT) or particle therapy have been developed. Accordingly, dosimetry technique for such complicated dose distribution is required. In particular, characteristics of the energy deposition by the ionizing radiation similar to that of biological tissue are required for dosimeter materials. From this viewpoint, organic dosimeter materials are advantageous.

To achieve the tissue equivalence and practical sensitivity, we have developed radiochromic materials: radiochromism is the coloration upon irradiation. We have used two processes responsible for radiochromism: one is the isomerization of photochromic molecules upon irradiation [1]. The other is the radiation chemical reaction of dyes with radicals [2–4]. In this report, we focus on the latter case.

2 Experiments

We used leuco crystal violet (LCV), Black100, Black305, and Black400 as the dyes and polyvinyl chloride (PVC), poly(methyl methacrylate) (PMMA), polyvinyl butyral (PVB), and polystyrene (PS) as the host polymers. The dyes and host polymers were completely dissolved in tetrahydrofuran. The solvent was evaporated naturally at room temperature in darkness for several days and the films were peeled off, yielding PVC, PVB, PMMA, and PS films containing the dyes.

The absorption spectra of the samples before and after X-ray irradiations were measured to quantitatively evaluate the change in the color. The samples were irradiated with X-rays from an X-ray generator equipped with a Cu-target X-ray tube operated at 40 kV and 40 mA.

3 Results and Discussion

The absorption spectra of PVC films containing 1 wt% LCV before and after X-ray irradiation up to 0.8 kGy are presented in Figure 1. An absorption band appeared after X-ray irradiation, and is attributed to the oxidized form of LCV (CV^+). Among the samples in different polymers, the PVC-based film had the highest sensitivity.

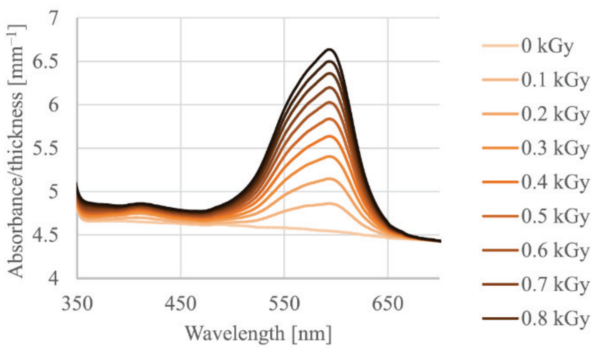

Fig. 1. absorption spectra of PVC films containing 1 wt% LCV before and after X-ray irradiation up to 0.8 kGy. Copyright (2020) The Japan Society of Applied Physics [2].

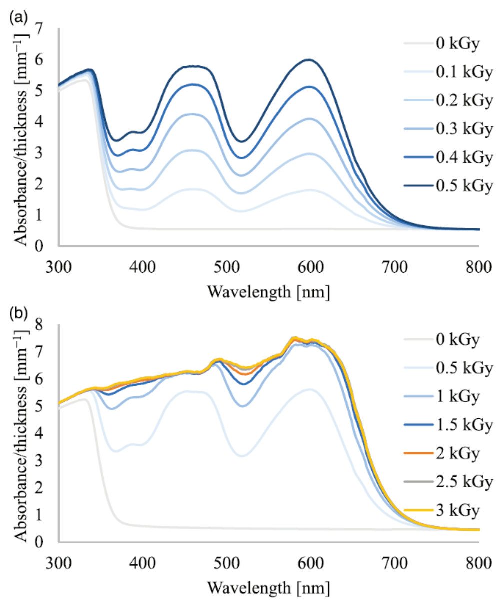

Fig. 2. Absorption spectra of PVC films containing 1 wt%

Black305 before and after X-ray irradiation [(a) 0–0.5 kGy and (b) 0–3 kGy]. We used different samples of the same composition and thickness in (a) and (b). Copyright (2021) The Japan Society of Applied Physics [3].

Figure 2 presents the absorption spectra of the PVC film containing 1 wt% Black305 after X-ray irradiations at different doses. The appeared absorption bands at 460 and 600 nm are attributed to oxidized form of Black305. The change in the absorbance per unit dose was the highest for PVC-based films possibly owing to a high yield of radical generation induced by ionizing radiation in PVC.

The absorption spectra of the PVC film containing 1 wt% Black100 before and after X-ray irradiation (0–0.5 kGy) are presented in Figure 3. The increase in the absorbance 450 and 590 nm was observed with the dose, and these absorption bands are attributed to the oxidized forms of Black100. The absorption spectra of the PVC film containing 1 wt% Black400 before and after X-ray irradiation (0–0.5 kGy) are presented in Figure 4. The increase in the absorbance at 460 and 590 nm was observed with the dose, and these absorption bands are attributed to the oxidized forms of Black400.

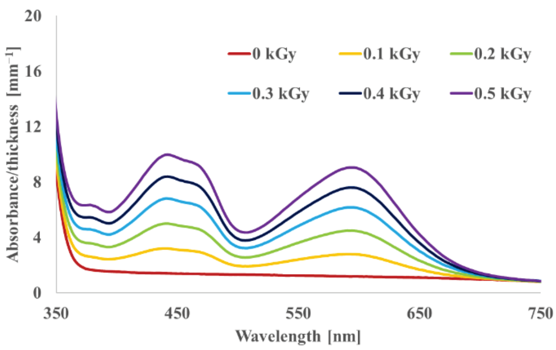

Fig. 3. Absorption spectra of PVC film containing 1 wt% Black100 before and after X-ray irradiation (0–0.5 kGy).

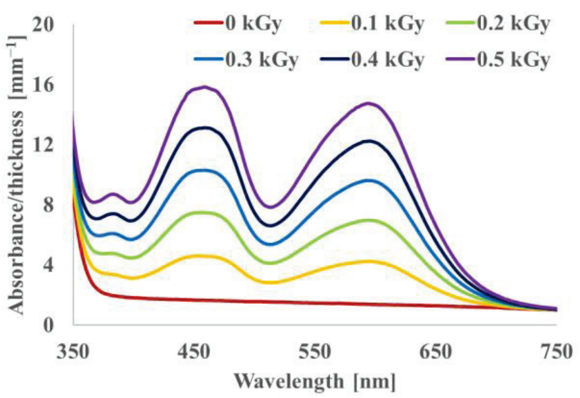

Fig. 4. Absorption spectra of PVC film containing 1 wt% Black400 before and after X-ray irradiation (0–0.5 kGy).

The sensitivity of the polymer films containing dyes are summarized in Table 1. The sensitivity was defined as the change in the absorbance in unit dose in the film of unit thickness. Among the materials, we have achieved the highest sensitivity with PVC containing Black 400 at 1 wt%.

Sample polymer/dye/co-added cmpound	Absorption peak wavelength [nm]	Sensitivity [$mm^{-1}\cdot kGy^{-1}$]
PVC/Black100 1 wt%/-	442	17
PVC/Black400 1 wt%/-	456	28
PVC/Black305 1 wt%/-	600	11
PVC/LCV 1 wt%/TCA 1 wt%	600	2.5
PVB/LMG 5 wt%/CH 35 wt%	629	0.55
PVB/LCV 1 wt%/-	594	0.6
PVB/PR-CN 2.5 wt%/-	550	0.4

4 Conclusions

We have succeeded in developing organic radiochromic materials based on dyes and polymers. Among the polymers investigated in this study, PVC was proved to be an excellent host for radiochromic materials.

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