ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
Journal of Magnetics 17(4), 271-274 (2012) http://dx.doi.org/10.4283/JMAG.2012.17.4.271

Dosimetry Application of Irradiated D-fructose using the Electron Paramagnetic Resonance

Phil Kook Son[1,3], Suk-Won Choi[1,3], Sung Soo Kim[2,3], and Jin Seog Gwag[4]*

[1]*Department of Advanced Materials Engineering for Information & Electronics, Kyung Hee University, Yongin, Gyeonggi-do 446-701, Korea*
[2]*Department of Chemical Engineering, Kyung Hee University, Yongin, Gyeonggi-do 446-701, Korea*
[3]*Regional Innovation Center-Components and Materials for Information Display, Kyung Hee University, Yongin, Gyeonggi-do 446-701, Korea*
[4]*Department of Physics, Yeungnam University, Gyeongsan, Gyeongsang-bukdo 712-749, Korea*

(Received 27 June 2012, Received in final form 9 November 2012, Accepted 9 November 2012)

We examine dosimetry application of irradiated D-fructose materials using electron paramagnetic resonance (EPR). Consequently, we consider that fructose is one of best dosimetry materials. We found that fructose is one of best candidates for dosimetry due to high linearity tilt of EPR signal intensity as a function of dose, irrelevant to photon energy, constant fading value. Also, our results show that fructose materials can be applied as a radiation detector to very weak radiation doses of 0.001 Gray by using EPR at a low temperature (T = 220 K).

Keywords : electron paramagnetic resonance, D-fructose, dosimetry, low temperature, fading value, low radiation

1. Introduction

In the past, the 1986 accident at the Chernobyl nuclear power plants in Ukraine was recorded as one of major nuclear disasters. Recently, Fukushima daiichi nuclear disaster occurred by 2011 earthquake off the pacific coast of Tohoku in the Japan. The radiation caused such as, the death of many persons, severe damage of the environment, tsunami and etc. Although persons have taken an increasing interest in the radiation effects around the plant, the absorbed dose of each exposed inhabitant has not been directly measured. In general, when organic materials is exposed to a radiation accident, free radicals are created, and an electron paramagnetic resonance (EPR) signal can be obtained from the organic material including these free radicals because of the paramagnetic property of free radicals [1, 2].

It was known that as the peak-to-peak amplitude of the first derivative of the EPR absorption curve for sugar was proportional to the free radical concentration of the dose, generally, the intensity of the EPR signal had a linear response for doses up to 10^5 Gy [3] and the EPR signal had a low fading value [4, 5]. Furthermore, organic materials have the singular advantage that it can be found in virtually every household throughout the world. Thus, organic materials may be one of the best dosimetric materials. The typical organic materials are sugar and L-alanine [1, 2]. The change of radiation photo energy of irradiated-organic materials changes quantity of free radicals. However, the dosimetric organic material was used almost at highest doses since it shows poor characteristics at very low does (< 0.5 Gy) as a dosimetry.

In this research, we investigated the linearity of fructose materials bombed as a function of photon energy, fading value, and radiation dose at very weak radiation region. Especially, we found that free radicals of fructose can be produced even when it is irradiated at below 0.05 Gray, by EPR at low temperature (130 K $\leq$ T $\leq$ 300 K). Also, we can demonstrate the dosimetry superiority of fructose material among organic materials (sugar, sucrose, L-alanine, glucose, etc).

2. Experimental

We prepare D-fructose (A-7502, Sigma Chemical Co.) as a granular sample. The granular size of it is about 100

---

*Corresponding author: Tel: +82-53-810-2345
Fax: +82-53-810-4616, e-mail: sweat3000@ynu.ac.kr

μm. The fructose was irradiated with a continuous energy spectrum of X-rays (average energy: 2.2 MeV), (average energy: 10.5 MeV) and γ-ray (with ^{60}Co gamma radiation, average energy: 1.17 and 1.33 MeV), respectively. We used as a radiation source, X-ray equipment with capable of sample irradiation from 0.0001 to 40 Gy was used employed as a radiation source. A quartz tube with a 100-mg sample was put into the cavity of the EPR equipment. We used Bruker EMX-300 system as an EPR spectrometer. The EPR spectrometer was operated with the X-band, which means about a 9.7 GHz microwave frequency for the EPR resonance, with a 100 kHz modulation. The Bruker EMX-300 system was equipped with a low-temperature system (300-130 K).

3. Results and Discussion

Figure 1 shows the first derivative of the EPR absorption curve of the fructose according to radiation doses at room temperature. On the other hand, the peak-to-peak amplitude of the first derivative of the EPR absorption curve of fructose increased with increasing radiation dose. The spectrum of fructose was complex because the free radicals interacted with a couple of neighboring protons [6]. In general, an unpaired electron can be created at a free radical in carbon-bound hydrogen by the irradiation in carbohydrate material. Electron-nuclear double resonance (ENDOR) spectroscopy provided information about protons in the vicinity of the trapped electron [7-9]. ENDOR spectroscopy shows that the unpaired electron of free radicals was located at carbon-bound hydrogen [10, 11]. Therefore, we can understand that free radical is created at carbon-bound hydrogen. The sensitivity (the ratio of the relative first derivative of the EPR signal intensity to the absorbed dose) of the dosimetric material for radiation is one of the most important properties for an emergency dosimeter. Figure 2 shows the EPR signal intensity of fructose, sugar, sucrose, glucose and L-alanine irradiated at room temperature with respect to the absorbed dose. As the signal intensities of all organics are representative of the radical population, they are proportional linearly to the absorbed dose (up to 40 Gy). Additionally, irradiated fructose had high linearity tilt of EPR intensity as a function of dose rather than the other organic materials. The free radical of fructose was created much more than those of the other organics for the same dose. Therefore, we expect that radiation dose can be predicted more exactly by fructose.

Another important dosimetric parameter is “fading value”

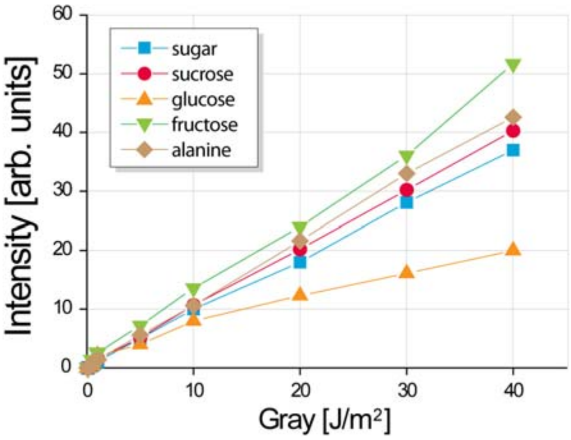

Fig. 2. (Color online) EPR signal intensities of fructose, sugar, sucrose, glucose and L-alanine irradiated at room temperature with respect to the absorbed dose.

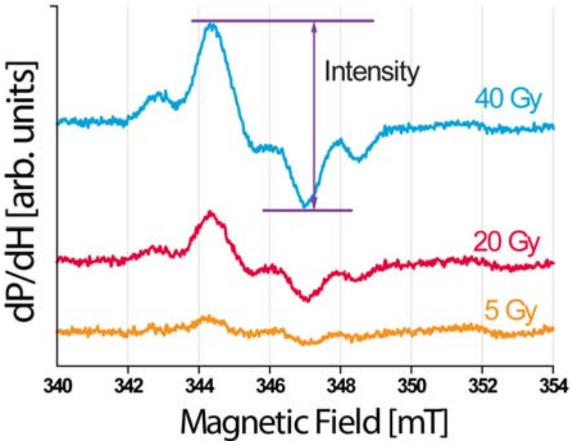

Fig. 1. (Color online) the first derivative of the EPR absorption curve at room temperature of three fructose irradiated by three different radiation doses.

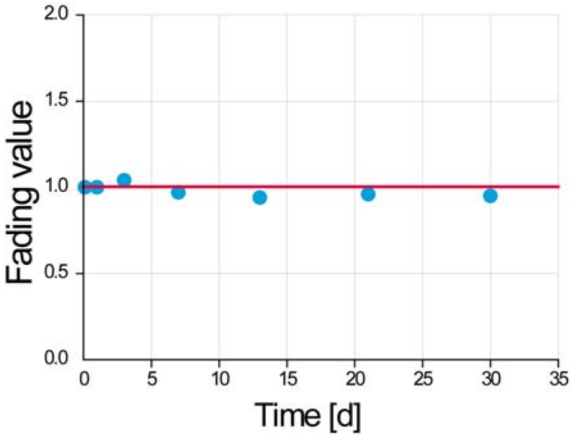

Fig. 3. (Color online) Fading of the EPR signal intensity measured at room temperature according to time of 5 Gy-irradiated-fructose.

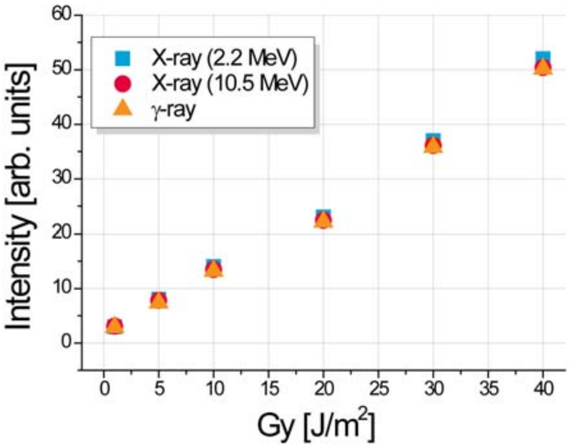

Fig. 4. (Color online) EPR signal intensities of fructose irradiated at room temperature with respect to the absorbed dose with a continuous energy spectrum of X-rays (energy: 2.2 MeV and 10.5 MeV), and γ-ray (energy: 1.17 and 1.33 MeV), respectively.

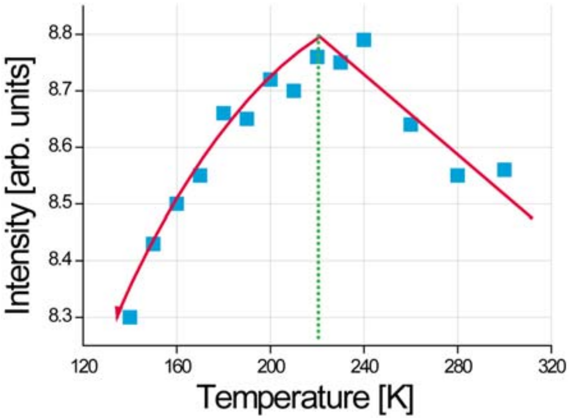

Fig. 5. (Color online) EPR signal intensities according to temperature of the 0.001 Gy-irradiated-fructose.

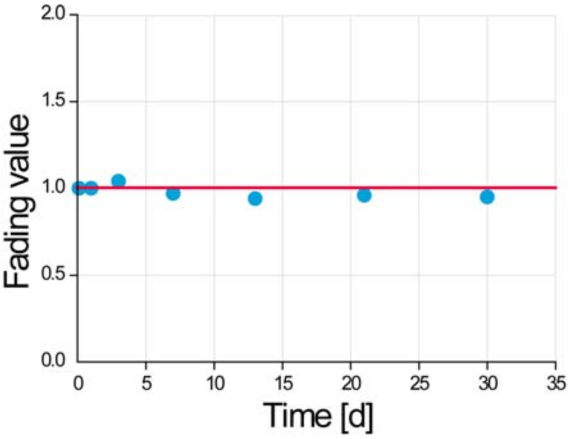

Fig. 6. (Color online) Fading of the EPR signal intensity measured at temperature 220 K according to time of 0.001 Gy-irradiated-fructose at various levels of photon energy (1.17 ~ 10.5 MeV).

because the radiation dose of the exposed organic material was estimated in some days after the accident. In general, the fading value = I/I_o, where I_o is the intensity measured immediately following exposure to radiation and I is the intensity measured after a certain period of time. Figure 3 shows the fading of the EPR signal intensity measured at room temperature from 5 Gy-irradiated fructose. We found that 5 Gy-irradiated-fructose decreased slightly, about average 1%, for 1 month.

Figure 4 shows the EPR signal intensity of fructose irradiated at room temperature with respect to the absorbed dose with a continuous energy spectrum of X-rays (average energy 2.2 MeV and 10.5 MeV) and γ-ray (with ^{60}Co gamma radiation, average energy: 1.17 and 1.33 MeV), respectively. As the signal intensity of fructose is representative of the radical population, the intensity is increased according to the absorbed dose (up to 40 Gy) and is independent from radiation photon energy. Consequently, the creation of the free radical in irradiated fructose is not determined by photon energy but amount of radiation as a function of dose. This linearity helps us to estimate more accurate radiation does. EPR signal was not observed from samples irradiated below 0.001 Gy.

To examine whether EPR signal of the fructose bombed by very small radiation does (< 0.001 Gy) is observed at low temperature or not, we measure the free radicals of irradiated-fructose using EPR at a low-temperature region ($130 \text{ K} \leq T \leq 300 \text{ K}$). Figure 5 shows the EPR spectra of the 0.001 Gy-irradiated-fructose a function of temperature. We could observe very weak EPR signal of the fructose at room temperature (310 K). However, very weak EPR signal was detected from the sample at 300 K. At 220 K, EPR intensity of the samples exhibited strong resonance. However, intermediate temperature ranging from 130 K to 220 K, EPR intensity of irradiated fructose decreased with decreasing temperature. Here the line-width of the signal and the g-factoe are indicative of 2.8 mT and 2.001, respectively.

Figure 6 shows the fading value of the EPR signal intensity measured at temperature 220 K from 0.001 Gy-irradiated-fructose at various photon energies (1.17-10.5 MeV). We found that 0.001 Gy-irradiated-fructose decreased slightly, about average 1.4%, for 1 month following irradiation at temperature 220 K, irrespectively of radiation photon energy. We also measured the fading value in various temperatures ($180 \text{ K} \leq T \leq 250 \text{ K}$). The fading value of the irradiated-fructose EPR signal intensity almost was kept for 1 month. This indicates that the fructose is one of best materials as a dosimetry application.

4. Conclusion

We presented dosimetry application of irradiated fructose materials using EPR equipment. We found that fructose was adequate for desimetry among organic materials due to high linearity tilt of EPR signal intensity as a function of dose, irrespective of photon energy and had constant fading value. Also, our results show that fructose materials can be applied as a radiation detector to very weak radiation doses of 0.001 Gray by using EPR at a low temperature (T = 220 K). Therefore, we think that fructose is a good candidate for use as an emergency dosimeter.

Acknowledgement

The Human Resources Development Program (R&D Workforce Cultivation Track for Solar Cell Materials and Processes) of Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant (No. 20104010100580) funded by the Korea government Ministry of Knowledge Economy.

References

[1] P. K. Son, C. I. Ok, and J. W. Kim, J. Korean Phys. Soc. **38**, 315 (2001).
[2] P. K. Son, K. C. Heo, C. I. Ok, and J. W. Kim, J. Korean Phys. Soc. **39**, 233 (2001).
[3] Francisco Americo, Marcelino Silveira, and Oswaldo Baffa, Appl. Radiat. Isot. **46**, 827 (1995).
[4] Toshiyuki Nakajima, Health Physics **55**, 951 (1988).
[5] Toshiyuki Nakajima, Appl. Radiat. Isot. **46**, 819 (1995).
[6] I. K. Oommen, K. S. V. Nambi, S. Sengupta, T. K. Gundu Rao, and M. Ravikumar, Appl. Radiat. Isot. **40**, 879 (1989).
[7] H. C. Box, E. E. Budzinski, and H. G. Freund, J. Chem. Phys. **93**, 55 (1990).
[8] E. E. Budzinski, W. R. Potter, G. Potienko, and H. C. Box, J. Chem. Phys. **70**, 5040 (1979).
[9] E. Sagstuen, A. Lund, O. Awaldelkarim, M. Lindgren, and J. Westerling, J. Phys. Chem. **90**, 5584 (1986).
[10] H. C. Box, E. E. Budzinski, and H. G. Freund, Radiat. Res. **121**, 262 (1990).
[11] G. Vanhaelewyn, J. Sadlo, F. Callens, W. Mondelaers, D. De Frenne, and P. Matthys, Appl. Radiat. Isot. **52**, 1221 (2000).