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Changes in the Glow Curve of Thermoluminescent Dosimeter According to Magnetic Field Strength

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The thermoluminescent dosimeter is the most commonly used instrument for measuring radiation dose. Based on the previous study that the glow curve changes in the magnetic field environment of a thermal luminescence dose device, the change of the glow curve according to the change of the magnetic field strength is evaluated. Accordingly, the change in the glow curve was analyzed by irradiating 0.5-2 cGy to the thermoluminescent chips with a radiation generator while changing the magnetic field strength using a permanent magnet. As a result of the evaluation, an average increase of 0.3% was observed at 90~120 °C, an average decrease of -10.6% at 120-160 °C, and an average increase of 3.2% at 160-260 °C. Therefore, when applying the thermoluminescent dosimeter, it is necessary to evaluate the dose considering the error rate according to the magnetic field strength.

Keywords : thermal luminescence dosimeter, glow curve, magnetic field strength, exothermic temperature, dose evaluation

1. Introduction

A thermoluminiscent (TL) dosimeter is an chips-type measuring device used to measure cumulative radiation dose [1]. The TL dosimeter is the most commonly used device not only in the medical field but also in industrial applications when measuring personal exposure dose. It has very good sensitivity because it can measure from a minimum of 2.58×10^{-8} C/kg to a maximum of 258 C/kg [2]. It uses a method of measuring the radiation dose via the TL phenomenon, which means that the electrons present in the device are excited by the phosphor by irradiation and are captured by the activator's energy trap [3]. This process of being in the energy trap is called the conversion to a metastable state, and when heat is applied in the metastable state, electrons recombine with positive holes and emit surplus energy as fluorescence [4]. The probability of occurrence is proportional to the frequency factor, and is proportional to the product of the natural number as a negative constant as much as the energy level depth of the trapping center times the product of the Boltzmann constant and the absolute temperature [5].

While the sensitivity of the TL dosimeter is good, there are some characteristics to be considered [6]. First, the readings of the TL dosimeter cannot be maintained when re-measured since electrons trapped are converted back to the ground state by heating [7]. Therefore, it is very important to record and store the readings. In addition, electrons may be stuck in the energy trap by background radiation such as natural or artificial radiation during storage for a certain period after measurement. The values of trapped electrons in this manner can be summed up when irradiating radiation to measure the radiation dose using a TL chips, acting as a cause of error [9, 10]. Therefore, when using a TL dosimeter, it is necessary to ensure that electrons trapped in the energy trap can be converted to the ground state by heating before irradiation [11, 12]. Moreover, since the dosimeter uses the principle of generating light by heating the chips, the user should prevent recombination by external heat until measurement after irradiation [13]. The period from irradiation to measurement is also very important. Although it is less

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than other general chips, the TL chips also have a degeneration phenomenon [14, 15]. Although it is about 3 to 5 times lower than that of an chips using a film, degeneration occurs about 1 % to 2 % per month [16]. The TL dosimeter also has energy dependence like other chips and it needs to be corrected [17, 18]. For single energy, the correction is relatively simple. However, in the case of energy from the radiation generator, it is difficult to correct because it mainly has a continuous distribution [19], so the effective energy is obtained using a correction method or a non-sensitive method for correction [20-22]. The difference between chips is one of the factors that bring the largest error when measuring radiation using a TL dosimeter, so this should be considered as an important factor. The difference in TL efficiency occurs according to the density of the active material, and this in turn leads to a difference in the radiation dose. Therefore, when using a TL chips, the chips with a difference of less than 5 % in the dose for the same radiation exposure are grouped and evaluated in advance [24, 25]. The measurement process of this TL dosimeter is very important, with heating as an essential factor. An extra heating system is required for heating the chip, which is present in the reader [26, 27]. When heating the chip inside the reader, the heating temperature is gradually increased, rather than applying high heat at once, and the resulting amount of light is emitted by the glow curve [28]. The glow curve is a graph of luminescence intensity according to heating temperature and time. It is used when reading the dose of a TL dosimeter, with the dose evaluated using the average value of the height of the glow peak or the total area [29]. When reading the TL dosimeter, the amount of emitted light is measured while raising the heating temperature according to the glow curve obtained in advance. The irradiated radiation dose is inferred from the amount of light emitted at the temperature to be evaluated [30]. Therefore, the glow curve information of the TL chip used for irradiation should not be changed by the external environment. However, when a strong magnetic field is formed around the free electrons present in the chip when they are captured by an unstable energy trap during irradiation, a change in the formation of the fluorescence center may occur [31]. In this study, we sought to identify the change pattern of the glow curve according to the change in magnetic field strength to provide basic data that can contribute to the improvement of the dose evaluation accuracy using the TL dosimeter.

2. Materials and Methods

A TL dosimeter, a reading device, a radiation irradiation device, and a permanent magnet for forming a magnetic field were applied to evaluate the change in the glow curve of the TL dosimeter according to the strength of the magnetic field. LiF:Mg. Ti chip, the most commonly used chip when measuring individual exposure dose, was used as a TL dosimeter. Harshaw TLD Model 5500 Reader (Thermo Scientific, USA) was used for reading the TL dosimeter. An X-ray exposure device (Doshiba, Japan) was used to irradiate the device. A neodymium magnet (Magland, Korea) was used as a permanent magnet to

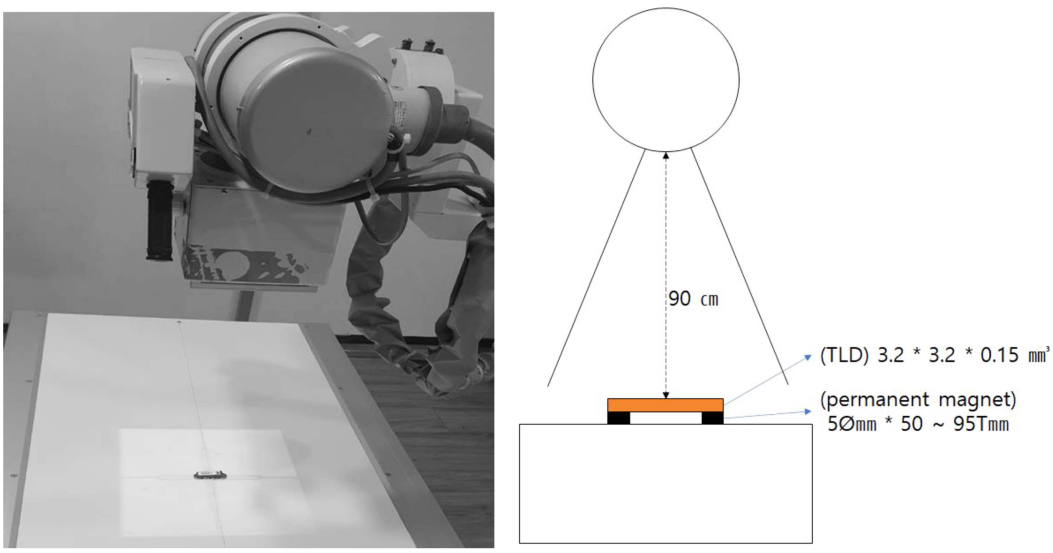

Fig. 1. (Color online) A 3.2 × 3.2 × 0.15 mm TLD chips is attached to a 40 × 15 × 5.0 mm case and directed in the direction of radiation emission. At the bottom, a permanent magnet with a diameter of 5 mm is placed by varying the height from 50 mm to 95 mm.

Fig. 2. The measured TLD device is an image of the process of extracting and comparing the glow curve expressed in the process of evaluating the dose through the TLD reader during the evaluation process.

form a magnetic field. TM-801 (KANETEC, Japan), a Gauss meter, was applied to evaluate the magnetic field strength when using a neodymium magnet.

After preparing four identical model TL chips and placing them on the table as shown in Fig. 1, the permanent magnets are classified into four types according to conditions and placed below. Then, the radiation generator is irradiated toward the TL chip, and a glow curve is extracted and compared using a TL reader as shown in Fig. 2. Detailed conditions and environments are as follows.

The glow curve obtained during measurement is compared and evaluated according to the strength of the magnetic field. The size of the TL chip prepared for this experiment is $3.2 \times 3.2 \times 0.15$ mm^3, and the emission spectrum is 3500-6000 Å. The amount of radiation to the chip using the radiation generator is 1.5-2.0 mSv in consideration of the average dose to which radiation workers are exposed, and the irradiation conditions are set at 100 kVp, 20 mAs to match the dose. In the case of permanent magnets, four types of magnetic fields were applied: 5,000 Gauss (5ømm × 50Tmm), 6,500 Gauss (5ømm × 65Tmm), 8,000 Gauss (5ømm × 80Tmm), and 9,500 Gauss (5ømm × 95Tmm). As shown in Fig. 3, the magnitude of the magnetic field is measured using a Gaussian meter after each permanent magnet is set for accurate magnetic field verification.

Fig. 3. Images measured for each condition using a magnetic field measuring tool to evaluate the exact magnetic field strength of the permanent magnet located during the experiment.

3. Results

The results of irradiation with a radiation generator for four TL chips are shown in Fig. 4.

Like the existing glow curve, the peak is low at low temperature and high at high temperature, and the graph consists of a minimum of 497 a.u. and a maximum of 17376 a.u. After placing a permanent magnet corresponding to 5,000 Gauss, the magnetic field strength obtained was 4,769 Gauss. The glow curve according to irradiation is shown in Fig. 5, consisting of a minimum of 496 a.u. and a maximum of 17875 a.u.

In measuring the magnetic field strength after placing a permanent magnet corresponding to 6,500 Gauss, the result obtained was 6,425 Gauss. The glow curve according to irradiation is shown in Fig. 6, consisting of a minimum of 499 a.u. and a maximum of 17834 a.u.

In measuring the magnetic field strength after placing a permanent magnet corresponding to 8,000 Gauss, the result obtained was 7,713 Gauss. The glow curve according to irradiation is shown in Fig. 7, consisting of a minimum of 491 a.u. and a maximum of 17967 a.u.

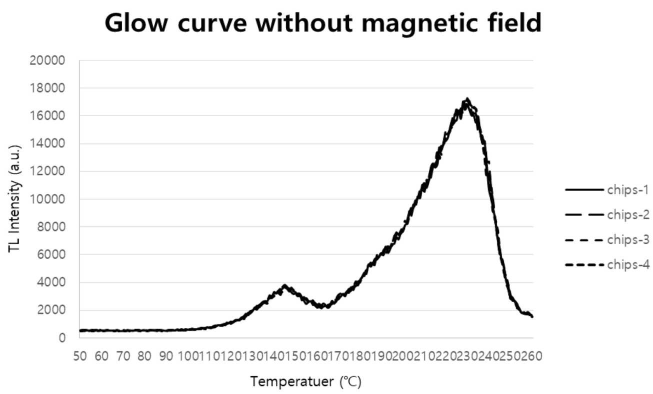

Fig. 4. A graph image obtained by obtaining a glow curve in a state without a permanent magnet and expressing it for each chips.

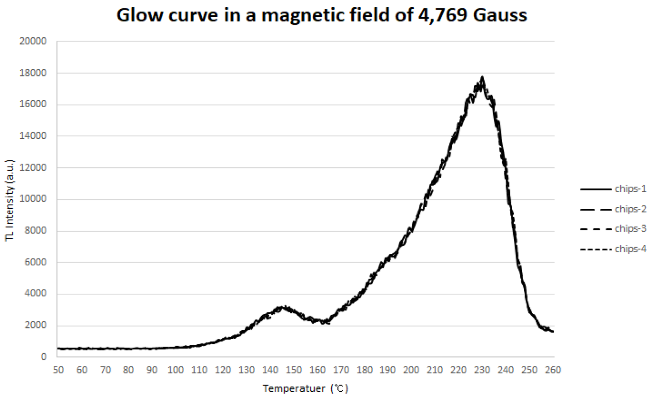

Fig. 5. A graph image of each chip obtained by obtaining a glow curve at 4,769 Gauss with a permanent magnet of 5Tmm.

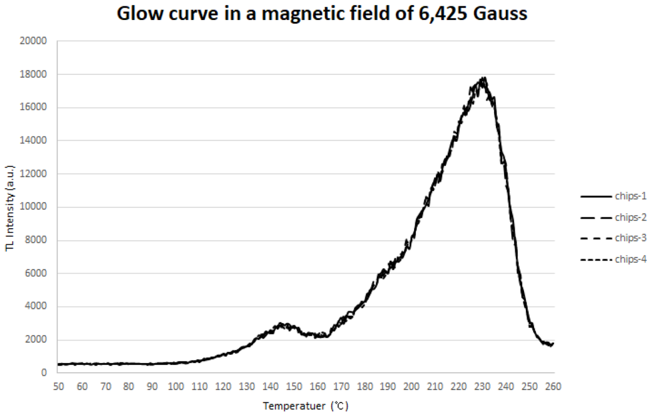

Fig. 6. A graph image of each chip obtained by obtaining a glow curve at 6,425 Gauss with a permanent magnet of 6.5Tmm.

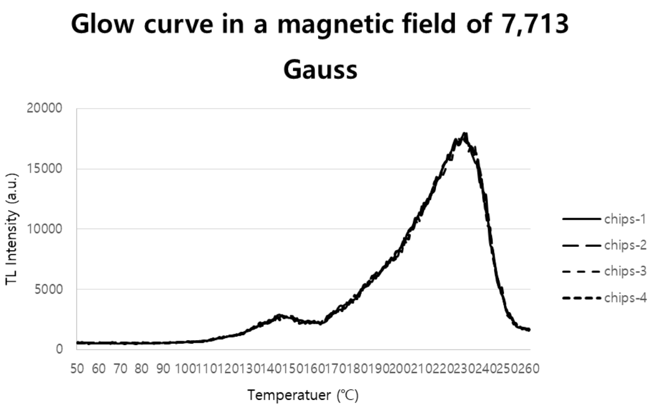

Fig. 7. A graph image of each chip obtained by obtaining a glow curve at 7,713 Gauss with a permanent magnet of 8Tmm.

In measuring the magnetic field strength after placing a permanent magnet corresponding to 9,500 Gauss, the result obtained was 9,384 Gauss. The glow curve

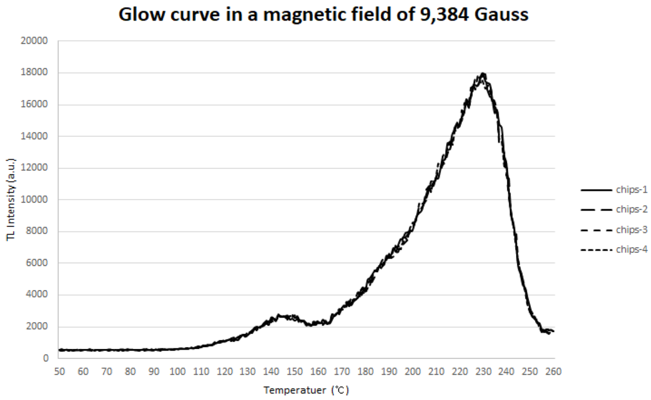

Fig. 8. A graph image of each chip obtained by obtaining a glow curve at 9,384 Gauss with a permanent magnet of 9.5Tmm.

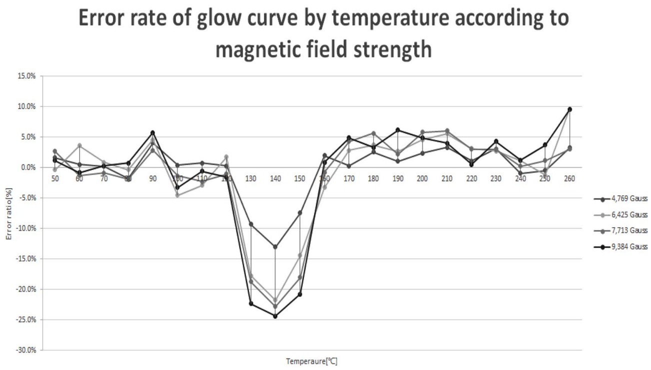

Fig. 9. Error rate graph of the glow curve for each temperature according to the strength of the magnetic field versus the non-magnetic field.

according to irradiation is shown in Fig. 8, consisting of a minimum of 495 a.u. and a maximum of 17998 a.u.

The result of comparing the amount of emitted light by temperature of the glow curve according to the magnetic field strength is shown in Fig. 9, with the increase/decrease pattern of the error rate changed around 120 ℃ and 160 ℃.

The error rate for changing the strength of the magnetic field compared to the case where there is no magnetic field is shown in Table 1. The maximum decrease error rate is -24.3 %, while the maximum increase error rate is 9.6 %.

4. Discussion

The TL dosimeter is the most commonly used instrument in evaluating individual radiation exposure dose and environmental dose. It also has the widest range of applications. However, since the radiation dose information accumulated in the chip is evaluated using

Table 1. Table expression of the glow curve expression value of the thermofluorescence dosing device for each temperature according to the change in the strength of the magnetic field.

Deviation / Temp.	4,769 Gauss	6,425 Gauss	7,713 Gauss	9,384 Gauss
50 ℃	1.70%	-0.30%	2.70%	1.20%
60 ℃	0.60%	3.60%	-1.30%	-0.80%
70 ℃	0.20%	0.90%	-0.80%	0.30%
80 ℃	-1.70%	-0.40%	-1.90%	0.80%
90 ℃	4.10%	4.60%	2.80%	5.80%
100 ℃	0.40%	-4.50%	-1.30%	-3.30%
110 ℃	0.70%	-2.90%	-2.30%	-0.60%
120 ℃	0.30%	1.70%	-1.00%	-1.60%
130 ℃	-9.30%	-17.70%	-18.70%	-22.30%
140 ℃	-13.00%	-21.70%	-22.80%	-24.30%
150 ℃	-7.40%	-14.40%	-18.00%	-20.80%
160 ℃	2.00%	-3.20%	-0.70%	0.90%
170 ℃	0.30%	2.90%	4.30%	4.90%
180 ℃	2.60%	3.70%	5.70%	3.40%
190 ℃	1.10%	2.70%	2.20%	6.20%
200 ℃	2.40%	4.60%	5.90%	4.90%
210 ℃	3.30%	5.60%	6.10%	4.00%
220 ℃	1.10%	3.20%	3.00%	0.50%
230 ℃	3.10%	2.80%	3.00%	4.30%
240 ℃	-0.90%	1.20%	0.20%	1.20%
250 ℃	-0.40%	-1.20%	1.20%	3.70%
260 ℃	3.30%	9.60%	3.00%	9.50%

the measurement system, it may be affected by various environmental factors. Therefore, many previous studies have evaluated the dose characteristics of TL chips according to environmental factors. There have been many studies on changes due to external factors such as irradiation direction, heating rate, frequency change, and application of various radiation [32-36]. In particular, it has recently been reported that the glow curve changes according to the magnetic field environment in the process of estimating the dose of the TL chip. In this way, in this study, a permanent magnet was used to confirm the change trend of the glow curve according to the strength of the magnetic field. In previous studies, the change in the glow curve according to the change in the magnetic field was judged only by the presence or absence of the magnetic field, but in this study, the change in the strength of the magnetic field and the resultant change in the glow curve were evaluated by leveling to secure more reliability. As such, a permanent magnet was used in this study to check the change trend in the glow curve according to the strength of the magnetic field. In the case of 50 °C to 120 °C, the increase/decrease in the amount of light emission as the magnetic field strength increased was within 5 %, and the amount of light emission decreased sharply at 120 °C. The decrease intensified at 120 °C to 160 °C, with an average change of -5.5 % for 4,769 Gauss, -11.1 % for 6,425 Gauss, -12.3 % for 7,713 Gauss, and -13.6 % for 9,384 Gauss. The maximum decrease was observed at 140 °C, while an increase was observed after 160 °C. However, the increase in the error rate after 160 °C was 3.2 % on average, which was lower than the decrease in the error rate. This is attributed to the affinity of the captured electrons depending on the increase in the magnetic field, and additional research is required to verify it. Recently, as radiation therapy and diagnostic devices used in parallel with magnetic resonance imaging devices have been developed, this tendency depending on the magnetic field strength should be identified when using a TL dosimeter to measure radiation dose. In particular, the glow curve at 5,000 Gauss to 30,000 Gauss, which is widely used in clinical practice, should be considered when measuring the dose.

5. Conclusion

As shown in the results of this study, a very large error rate reduction occurs at 120 °C to 160 °C, so it is better to apply the second peak with a large amount of light emission rather than using the first peak of the glow curve. In terms of radiation protection, it would be useful to measure the amount of light emission at 220 °C to 230 °C with little or very little increase in the error rate from a conservative point of view. Therefore, if there is a magnetic field effect when using a TL dosimeter in the future, the analysis should be made as follows: (1) the second peak with high luminescence should be used for the measurement; and (2) dose evaluation should be made from a conservative point of view.

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