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Dose re-estimation using thermoluminescence of chip inductors and resistors following the dose estimation by using optically stimulated luminescence readout for retrospective accident dosimetry

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HIGHLIGHTS

- Dose re-estimation using TL of inductor and resistors after dose estimation using OSL was studied.
- TL signals after OSL measurements were still remained in inductors and resistors.
- The dose re-estimation was possible by using the residual TL in retrospective dosimetry.

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ABSTRACT

In the recent years, intensive research on the application of optically stimulated luminescence (OSL) from alumina rich electronic components, such as resistors and inductors of electronic gadgets, is being carried out for retrospective dosimetry in the event of radiological accidents or terroristic attacks. It was noted that in inductors of mobile phones, the OSL readout did not significantly affect the thermoluminescence (TL) signal of glow peaks above 200 °C which exhibited negligible fading. This effect was exploited to re-estimate the doses by using TL signal ("residual TL") of the inductors and the resistors which were already subjected to OSL readout for the estimation of the given doses. The dose response of the residual TL signal was also found to be linear up to about 4 Gy for both the inductors and resistors. The estimation of doses by using OSL and the re-estimation by using residual TL was carried out for the nominal doses of 300 mGy, 1700 mGy and 3300 mGy. The estimated doses and the re-estimated doses were in the range of about 80%–97% of the nominal doses for the inductors and in the range of about 76%–111% for the resistors. It was concluded that the residual TL could be used for the re-estimation of doses in some cases of radiological accidents.

1. Introduction

In view of the growing apprehensions of radiological accidents and terroristic attacks, measurement of radiation doses in unforeseen situations is needed to give reliable information on the doses incurred by the affected persons for triage. This is also needed for tracking the radiation sources and the culprits in the case of theft and terrorist acts including the use of radiological dispersal device (RDD). Such situations cannot be covered by planned radiation dosimeters such as personal dosimeters or area monitors installed at some strategic locations. Dosimetry of nuclear accidents such as Chernobyl had been possible by using thermoluminescence (TL) and optically stimulated luminescence (OSL) techniques by processing common material such as bricks, tiles etc (Hütt et al., 1993; Bøtter-Jensen, 2000). The procurement of such materials and processing is often a very time consuming. In cases of the unforeseen situations of radiological accidents, the evaluation of doses is needed to be carried out in shortest possible time because the delay in communicating the information on risk enhances the disruption of normal life. It became important to be able to measure doses by using defined ubiquitous objects as quickly as possible to help in overcoming the panic and to start the needed medical care. This enhanced the search of radiation sensitive components in the most commonly used objects which are carried by most persons all the

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time. Intensive research efforts have been made to demonstrate that OSL and TL of electronic components in personal devices such as chip-cards, mobile phones, mp3 players and USB drives can be used as emergency dosimeters (Göksu, 2003; Inrig et al., 2008; Woda et al., 2010; Bassinet et al., 2010; Fiedler and Woda, 2011; Woda et al., 2012; Pascu et al., 2013; Bassinet et al., 2014; Lee et al., 2015). Among the electronic components of personal devices tested previously, resistors of electronic components were noted (Pradhan et al., 2014) to exhibit higher OSL sensitivity, smaller sample to sample variation and higher reproducibility than any other component and hence, resistors were concluded to be more suitable for retrospective accident dosimetry. However, we recently (Lee et al., 2015) demonstrated that in some cases (new generation mobile phone, smart phone) inductors (with Al_2O_3 substrate) exhibit OSL sensitivity higher than that of the resistors and are also suitable for the purpose.

Further, for the use of inductors from mobile phones, Fiedler and Woda (2011) showed that inductors exhibit two main TL glow peaks at 170 °C and 270 °C which are suitable for retrospective accident dosimetry. The stable 270 °C TL peak (fading of only 14% one week after irradiation) of inductors appeared to be very attractive for accident dosimetry, because anomalous fading of OSL signals of electric components of portable devices was generally considered to be the main hindrance for their use in retrospective accident dosimetry (Pradhan et al., 2014). Also, it was noted that in some cases, optical bleaching could erase TL only partially (Inrig et al., 2008, in resistors and Woda et al., 2010, in resonators). From these results, it was conceived that significant/measurable TL should persist after OSL readout of electronic components which exhibit radiation induced TL and OSL. During our previous study (Lee et al., 2015), we also noted that the OSL readout of inductors did not significantly affect the TL signal of the glow curves above 200 °C. In view of these observations, an effort was made to re-estimate the doses by using TL readout "residual TL" of inductors and resistors which were irradiated and already subjected to OSL readout for the study of estimation of doses for retrospective accident dosimetry.

2. Experiments and samples

Inductors and resistors were collected from sample reels produced by Samsung Electro Mechanics Corporation. The inductors and resistors were SMD 1005 type of 4.7 nH and SMD 1005 type of 510 Ohm, respectively, which are used in the circuits of new generation mobile phones. A set of 10 inductors in a cup or a set of 20 resistors in a cup were used for OSL and TL readouts. It was noted that, generally, about ten inductors and more than twenty resistors can be extracted from each mobile phone. The TL and OSL measurements were made by using a Risoe TL/OSL-DA-20 Reader with blue LEDs (470 nm) for optical stimulation and a bialkali EMI 9235QA photomultiplier tube (PMT) with Hoya U-340 and Schott BG-39 optical filters in front of the PMT (to ensure minimal interference from the stimulating light during OSL readout, Lee et al., 2012) for the detection of OSL and TL signals. For operational convenience, as the OSL and TL readouts were taken in tandem in the same reader, the optical filters (meant for OSL readout) in the Risoe reader remained the same (unchanged) during TL readouts. Irradiations were carried out by using a built-in 150 MBq $^{90}Sr/^{90}Y$ reference source in the reader (dose rate of 8.7 mGy/s as ^{137}Cs gamma equivalent dose rate at the sample position). Continuous-wave (CW) 470 nm stimulation was carried out for 100 s (250 channels) for each OSL readout. For dose measurement, OSL signal was integrated for 50 channels (20 s). TL signal was recorded by using a heating rate of 5 °C/s. For each experimental point, readouts of a minimum of 3 cups were used.

3. Results and discussion

Fig. 1 and Fig. 2 show typical TL glow curves of inductors and resistors, respectively. The glow curves were recorded from room temperature to 400 °C for an irradiation of 870 mGy. The solid line and the dotted line represent TL glow curve measured before OSL readout and after OSL readout (residual TL), respectively. Apparently, there are four peaks in the TL glow curve of inductors (80 °C, 180 °C, 280 °C and 360 °C) and three peaks in the TL glow curve of resistors (80 °C, 180 °C and 345 °C). The TL glow curve shape of inductors is very similar to that reported by Fiedler and Woda (2011). It can be seen that after the OSL readout of the inductors, there is almost no change in the intensity of the TL glow curve above 200 °C while the lower temperature peaks decreased significantly (180 °C peak almost erased). In the case of resistors, after the OSL readout, the intensity of the TL glow peaks at 80 °C decreased remarkably (by about a factor of 10). The intensity of glow peak at 180 °C also decreased considerably (by about a factor of 2.25).

For the study of dose response of the residual TL signal of inductors and resistors, fresh samples (three sample cups each for inductors and resistors) were taken. The sequence of the readout for the dose response study was as follows; 1) OSL readout, 2) residual TL measurement 3) irradiation to a given dose, 4) OSL readout, 5) TL measurement, 6) irradiation to a test-dose (437 mGy), 7) OSL readout, and 8) residual TL measurement for the sensitivity change correction by using SAR protocol (Murray and Wintle, 2003). The sequence 1 to 8 was repeated for different doses from 437 mGy to 10 Gy. The residual TL signal for the inductors was integrated in the temperature range from 200 °C to 400 °C, whereas for the resistors it was integrated from 120 °C to 400 °C. It may be noted (Figs. 1 and 2) that unlike the inductors there is not enough signal in peaks above 250 °C of the resistors, however, the reduced 180 °C peak is still available after the OSL readout. Figs. 3 and 4 show the dose response curves of the residual TL signals of inductors and resistors, respectively. The corrected dose responses are linear up to about 4 Gy and sub-linear at higher doses. Based on three times the standard deviation of un-irradiated samples, the minimum measurable dose using residual TL was found to be 67 mGy for the inductors and 45 mGy for the resistors.

For fading studies, fresh samples (three cups each of inductors and resistors) were irradiated to 870 mGy and stored in dark before

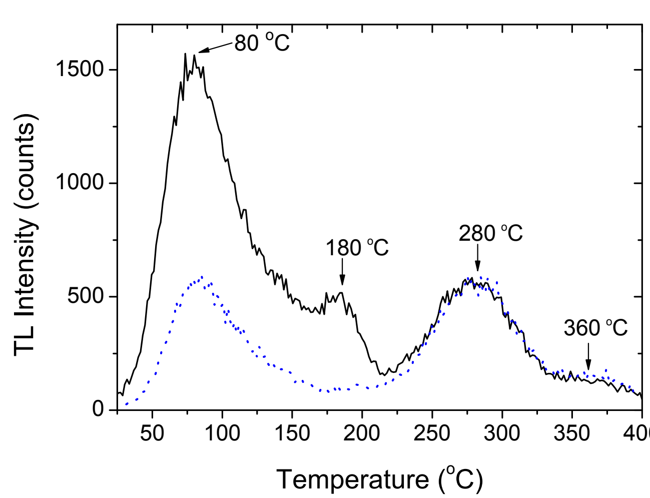

Fig. 1. Typical TL glow curves from inductor sample irradiated to 870 mGy (solid line without subjecting to OSL readout and the dotted line for residual TL after the OSL readout) recorded on Risoe TL/OSL_DA-20 reader by using a heating rate of 5 °C/s.