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Analysis of OSL decay characteristics for beta-irradiated potassium chloride samples

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HIGHLIGHTS

- Optically stimulated luminescence (OSL) of potassium chloride (KCl) was studied.
- Dose response and fading characteristics were determined.
- The occurrence of inverse fading in short time scale was confirmed.
- The influence of thermal treatment of KCl on the OSL signal was investigated.
- OSL decay lifetime components were determined.

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ABSTRACT

Optically stimulated luminescence (OSL) properties of beta irradiated pure potassium chloride (KCl) was studied. The OSL signal was examined depending on the method of sample preparation, absorbed dose, storage time and thermal treatment. Dose-response and fading characteristics were determined. The occurrence of inverse fading in short time scale was confirmed. The analysis of CW-OSL decays was performed. OSL decay curves were deconvolved to show that the annealing at elevated temperatures has significant influence on the shape of OSL decay curves.

1. Introduction

Potassium chloride (KCl) is a simple compound, which exhibits pronounced optically stimulated luminescence (OSL). KCl usually appears together with sodium chloride (e.g. in a table salt, sylvinite ore), which was widely studied due to its potential for retrospective dosimetry (e.g. Bernhardsson et al., 2009; Polymeris et al., 2011; Christiansson et al., 2014; Biernacka et al., 2016). Nonetheless, dosimetric properties of KCl are much less known. The kinetics of radiation-induced luminescence in this simple material is very complex. Investigations of pure KCl showed the occurrence of regeneration effect (Majgier et al., 2016). The regeneration is defined as a self-renewal of the OSL signal during the storage between subsequent OSL readouts. Very strong regeneration, even as high as 2000% for KCl crystals, may suggest high contribution of simultaneous localized and delocalized transitions (Mandowski and Biernacka, 2014; Mandowski, 2005, 2006, 2008).

There are no direct reports on the OSL dosimetric properties of pure potassium chloride. The material was investigated mainly in its doped form, primarily with europium. KCl:Eu was considered as two-dimensional X-ray and UV imaging sensor (Nanto et al., 1993, 1994; Chernov et al., 2001) as well as dosimeter in radiotherapy (Han et al., 2009; Zheng et al., 2010; Li et al., 2013). More attention has been focused previously on thermoluminescence (TL) properties of pure and doped KCl. Investigations of pure KCl showed, e.g. the appearance of TL only below ~550 K, the emission band with maximum at 440 nm for all tested TL peaks (Ausin and Rivas, 1972), fading half-life times from seconds to weeks for various TL peaks (Gunther and Stoebe, 1983) as well as superlinear dose dependence of optical absorption (Mitchell et al., 1961).

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This paper presents various OSL characteristics of beta-irradiated KCl. The OSL signal was examined depending on the method of sample preparation, absorbed dose, storage time and thermal treatment. Using CW-OSL (continuous wave OSL) we determined some basic OSL properties, such as dose-response and fading characteristics. However, the OSL decay is 'featureless' (Chen and Pagonis, 2008). It means that it is difficult to determine significant kinetic parameters without applying a specific kinetic model. The analysis of OSL decays by deconvolution to individual exponential components was applied to show the influence of thermal treatment on the OSL decay shape. It confirms strong changes of the OSL properties in KCl caused by annealing at elevated temperatures (Majgier et al., 2016).

2. Materials and methods

KCl samples were prepared from analytical quality potassium chloride powder (99.5%). Two form of samples were studied: crystals and pellets. The laboratory grown KCl crystals were obtained by dissolution of powder in distillate water and recrystallization. The crystal grains were colorless with white inclusions and grain size of 2–5 mm. The pellets were formed by pressing the KCl powder at 2 ton/cm^2 for 20–30 s at room temperature. The dimensions of pellets were 5 mm in diameter and 1 mm of thickness, the mass was about 50 mg. Irradiation were made using ^{90}Sr/^{90}Y β source.

The OSL measurements were performed using custom-made reader 'Helios-1' (Mandowski et al., 2010). The simulation was carried out by five green LEDs (520–532 nm) with optical lenses. The maximum power of each diode is 5 W, which provides power of about 1 mW cm^{-2} at the sample position for normally used LED's current of 100 mA. Additional stimulation filters (Schott filters GG495 and OG515) were used to cut-off short-wave light component below 500 nm. Detection of the OSL signal in the range 300–380 nm was performed using Schott UG11 filters and the photo counter H7360 (Hamamatsu) with quartz window, counter electronics and computer interface.

3. Results

3.1. Dose-response characteristic

Dose response characteristics were studied in the range from 25 mGy to 1 Gy for a series of KCl crystals without signal resetting and for single KCl crystals using various method of signal zeroing (thermal and optical bleaching). In the case of measurements realized without the signal resetting, the samples were not previously irradiated (with the exception of negligible dose of natural radiation) and thereby were not reset before irradiation (the signal from unirradiated samples was at the background level). In the case of a single sample, specific dose was administrated and then the CW-OSL readout was carried out. Subsequent measurements were preceded by the removal of the residual signal using optical or thermal zeroing after each measurement. The results are shown in Fig. 1. As can be seen dose response curves obtained for KCl show linearity below 1 Gy. OSL signal was integrated in the range [0, $t_{0.1}$], where $t_{0.1}$ is the time when the signal has decreased to 0.1 intensity of its initial value. For low doses (below 0.6 Gy) the OSL intensity is also low and the main OSL signal (more than 90%) is recorded during first 1.8 s ($t_{0.1}$) of the readout. Above this time the OSL signal returns to the background level and additional counts have nearly constant value. The integration in total range 0–60 s does not influence the linearity and the slope coefficient, except the value of b coefficient in the $y = ax + b$ linear response. The integration in shorter range allows fitting with the simpler function $y = ax$.

The slope coefficient a for thermal zeroing of the OSL signal is very close to the measurements performed on a series of fresh samples (i.e. without signal zeroing). However, heating to 300 °C may cause the sensitivity changes of the material. De-sensitization of OSL after thermal treatment was observed in NaCl (Polymeris et al., 2011) and it also occurs in the studied KCl crystals. The slope coefficient is much more higher for the measurements performed with optical bleaching. It indicates an increase of the OSL signal with subsequent measurements similarly as in the case of NaCl (Biernacka and Mandowski, 2013; Biernacka et al., 2016).

Measurements for wider dose range, up to 500 Gy were performed on a set of KCl pellets (Fig. 2). The pellets were chosen due to a better reproducibility of the measurements (standard deviation below 5%) and the ease of manufacturing large amounts of similar samples. The OSL signal was integrated from 0 to 60 s (total OSL), which allows the use of $y=ax$ fitting functions for doses higher than 0.6 Gy. Linear dose response was observed at least up to 20 Gy, followed by saturation for doses above 300 Gy.

3.2. The OSL response of KCl versus the time after exposure

The OSL response of potassium chloride was investigated up to 17 h after irradiation. The samples were irradiated and then stored for some time in the dark. After storage, the OSL readouts were performed. Fig. 3 shows the relative OSL response versus time after exposure for a series of KCl pellets and crystals. The first reference value is the average of the OSL signal from three samples (pellets or crystals, respectively) which were measured directly after irradiation (storage time equal to 1 min). The relative OSL for other data points is the average of the OSL signals in relation to this reference value (each data point is the average of three samples). Significant fading can be observed after 100 min of storage time. The OSL signal decreases by about 80% after 17 h. Nonetheless, for lower storage times an inverse fading appears. The effect is more pronounced for crystals (up to 30%) than for pellets (up to 15%). Similar behavior was observed also for other measurements performed on a single sample using signal zeroing between subsequent OSL readouts for successive storage times. This 'inverse fading' effect was noticed also for sodium chloride (Christiansson et al., 2014; Biernacka et al., 2016).

3.3. The effect of thermal zeroing on the OSL signal

To investigate an influence of the preheating and annealing temperature on the OSL signal two experiments were carried out. In the first experiment a set of pellets was irradiated with a dose of 0.63 Gy, then preheated at a given temperature (50, 100, 150, 200, 250, 300 °C) and after that OSL measurements during 60 s were performed. The dependence of OSL (relative to the OSL obtained without preheating) on the preheating temperature is shown in Fig. 4. First data point (the reference) is the average of OSL signal from three samples which were not preheated. The next points are the averages of OSL signals from three samples which were preheated at a given temperature. It can be noticed, that the signal is significantly reduced when samples were heated to 150 °C and almost completely removed when samples were heated above 200 °C.

In the second experiment the series of pellets was irradiated with a dose of 0.63 Gy. After irradiation a short test OSL_{test} signal (100 ms) was read. The OSL_{test} was measured in order to verify the correct dose delivery and eventual rejection of outlier samples. Then, the samples were heated at a given temperature (50, 100, 150, 200, 250, 300, 400, 500, 600 °C) for 5 min to check which temperature is sufficient to remove the residual OSL signal and does not cause drastic changes in the sensitivity of the sample. Next, the

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