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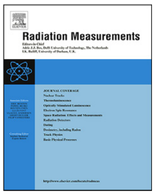

Developments for emergency dosimetry using components of mobile phones

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HIGHLIGHTS

- Modifications of dosimetry techniques with components of smartphones are discussed.
- Fading of OSL signals from SMRs is dose dependent.
- Matrix method is tested for EPR spectra deconvolution for samples of PG.

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ABSTRACT

Several modifications are proposed for emergency dosimetry with different components of mobile phones. Two dosimetric techniques have been exploited, namely optically stimulated luminescence (OSL) from surface mount resistors (SMRs) and integrated circuits (ICs), and electron paramagnetic resonance (EPR) from samples of protective glass (PG). For OSL with SMRs, it was found that fading of the corresponding radiation-induced signal (RIS) is variable among the resistors of different brands and depends also on the value of the administered dose. In the case of ICs, the effect of sample sensitization with an increase in the accumulated dose was compensated by preheating the samples to some selected temperature. An approach based on the matrix spectra deconvolution of EPR spectra was proposed and tested for EPR dosimetry using smartphone protective glasses.

1. Introduction

Among materials that have been proposed and tested as possible emergency dosimeters, mobile phones remain the most popular. They provide several opportunities for researchers to reconstruct emergency doses absorbed by the phone components themselves and to relate these doses to the dose potentially absorbed by the phone's owner. In particular, surface mount resistors (SMRs), capacitors, integrated circuits (ICs) and other electronic components, as well as different glasses from the phone (i.e. display glass and protective glass) have been shown to demonstrate different radiation-induced markers after exposure to ionizing radiation and may be used in dosimetry. These markers can be seen and counted using optically stimulated luminescence (OSL) (Inrig et al., 2008; Bassinet et al., 2010, 2014a; Beerten and Vanhavare, 2010; Ekendahl and Judas, 2012; Pascu et al., 2013; Mrozik et al., 2014a, 2017; Sholom and McKeever, 2016; Lee et al., 2016), thermoluminescence (TL) (Fiedler and Woda, 2011; Bassinet et al., 2014b; Discher and Woda, 2013; Mrozik et al., 2014b; Discher et al., 2016; Woda et al., 2017), phototransferred TL (PTTL) (McKeever et al., 2017), and electron paramagnetic resonance (EPR) (Trompier et al., 2011; Fattibene et al., 2014; Wieser et al., 2017).

To date, the most reliable results for dose reconstruction have been obtained with SMRs and ICs using OSL (Bassinet et al., 2014a; Sholom and McKeever, 2016). Despite the simplicity of the corresponding dose reconstruction protocol, there are some discrepancies in the data reported for these materials. The protocol consists of the measurement of the initial OSL signal from an emergency exposed sample followed by calibration with a known source and conversion of the OSL intensity to units of dose, with final correction due to fading. However, a few different functions have been proposed to describe the fading of OSL from SMRs. Inrig et al. (2008, 2010) used a log-time dependence, which is to be expected if the fading is due to anomalous fading. This dependence was accepted in the last intercomparison with SMRs (Bassinet et al., 2014a). At the same time, Beerten et al. (2011) described the fading

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using a three-exponential decay function while Eakins et al. (2016) used a five-exponential decay function. Most of above studies used a universal fading correction for all samples, and this could be a source of an additional uncertainty because of the possible variability in fading for different SMRs.

Another issue potentially exists for OSL dosimetry with ICs. Dose response curves for this material have been reported to be linear (Lee et al., 2015; Sholom and McKeever, 2016), cubic (Pascu et al., 2013) or second-order polynomial (Sholom and McKeever, 2014). The non-linear dose response was interpreted as being due to a sensitivity change and to overcome this problem Sholom and McKeever (2016) suggested exposing the sample during OSL measurement for at least 600 s. Alternatively, a single-aliquot regeneration protocol (SAR) was used by McKeever et al. (2017) in which the OSL signal from an emergency exposed sample is normalized on the OSL response to a small test dose (i.e., “small” compared to the dose expected from the emergency exposure). The same is done after exposure of the sample to any calibration dose. However, it is likely that this procedure cannot be applied to low sensitivity samples. It was noted by Lee et al. (2015) that many ICs demonstrate weak OSL signals due to low sensitivity. For such ICs, the SAR protocol may be difficult to apply and another approach should be developed and used to account for sensitivity changes. Heating the sample before additional exposure, as was originally proposed by Sholom and McKeever (2014), could be an alternative approach; this option was tested in the present work.

Therefore, one of goals of the current study was to provide more detailed characterization of fading of OSL signals from SMRs, while another goal was to test the influence of preheating on the radiation sensitivity of ICs.

While OSL with SMRs and ICs are the most recognized techniques for dosimetry with mobile phones, they both require disassembling the device. At the same time, many modern smartphones have a protective glass (PG) cover (the most well-known being Corning's Gorilla® glass), which can be removed from the phones without destroying them. Both radiation-induced TL and EPR centers have been detected in PGs after exposure to ionizing radiation doses (McKeever et al., 2017; Wieser et al., 2017). For TL signals, strong sensitivity to environmental light has also been observed, which may be overcome by using phototransferred TL, in which the deep traps within the glass are exploited (see for details McKeever et al., 2017).

For EPR signals, the main problem is the variability of both the background (native) and radiation-induced signals, which complicates the procedure of spectral decomposition and the correct estimation of the RIS intensity. Wieser et al. (2017) identified seven model signals in the EPR spectra of Gorilla® glass, and it is assumed that the spectra of any emergency-exposed sample can be fitted by a combination of these model signals. This approach has still to be verified on the PGs from different phones. In the present study, we propose use of the matrix method of spectral deconvolution (Sholom and Chumak, 2003) to fit the EPR spectra of irradiated PGs and, in this way, determine the intensity of the corresponding RIS. This method requires knowledge of two reference signals for each type of PG: the native signal reference and the radiation-induced signal reference (NS_{Ref} and RIS_{Ref}, respectively); both can be obtained experimentally. Once NS_{Ref} and RIS_{Ref} are obtained for each glass type, they can be used for dose reconstruction for the corresponding phones.

2. Materials and methods

Surface mount resistors of the same size ($0.5 \times 1.0 \times 0.4\ mm^3$) from eight different manufacturers were tested. One “sample” for OSL measurements consisted of twenty SMRs placed on a Risø stainless steel cup covered by a thin layer of silicone spray; ten to twenty such samples were prepared from resistors of each brand.

ICs (few tens from 4 different smartphones) and samples of PGs (from five different smartphones and one online vendor) were collected from inoperative and new smartphones purchased from local stores. To get the IC samples, circuit boards were roughly cut with metal snips around the IC locations and the ICs were separated from the remains of the circuit boards with a low-speed, diamond saw. The outer surfaces of the ICs were used for experiments because these surfaces do not require any additional treatment. Samples of protective glasses were separated from their layers of plastic film with a sharp knife and a blade and then washed thoroughly in ethanol. The samples were then cut into pieces of about $5 \times 5\ mm^2$ using a water-cooled, diamond saw.

A Risø DA-15 OSL/TL reader with a Hoya U-340 filter pack mounted at the front of the photomultiplier tube was used to conduct the OSL measurements.

A Bruker EMX spectrometer equipped with a Bruker 4119 cavity was used for EPR tests of PGs. Samples were measured with a Wilmad Suprasil 8-mm-diameter EPR tube.

The signals from the samples were measured according to the following protocols. For SMRs, we measured the OSL with and without a preheat (similar to the “full-mode” and “short-mode” protocols, respectively, described by Bassinet et al., 2014a). In experiments with a preheat, the samples were preheated to 120 °C for 10 s and the OSL signals were subsequently recorded at a measurement temperature of 100 °C. The OSL signal was collected for 300 s of stimulation time; the radiation-induced signal (RIS) was calculated as the subtraction of two OSL signals: one integrated over the first 5 s of the OSL decay curve and the second integrated over the last 5 s of the same curve (corresponding to the background signal). In fading studies, the signals measured at different times after exposure were normalized on the signal measured as soon as possible after exposure. The minimum time between exposure and OSL readout was about 25 s for the short-mode protocol and about 3 min for the full-mode. In case of the full-mode protocol, the minimum time consisted of time required to rotate a tray with samples to the “irradiation position” and back to the “measurement position” plus time of sample irradiation plus time of a preheat. The mentioned 3 min included a pause of variable time, which was necessary to account for the fading occurring during sample exposure and was dependent on the exposure duration (i.e. variable exposure time for different doses). We note that this was tested only with the full-mode. Thus, the maximum tested dose (8.5 Gy) required a radiation exposure of 100 s. In this case we assumed an effective fading time of $100s/2 = 50$ s. No additional pause was added in this case. For the minimum tested dose (0.17 Gy) an exposure time of 2 s was needed, for which the effective fading time is taken to be 1 s. Therefore, we added an additional pause of 49 s to make a total effective fading time of 50 s, as before. Intermediate values of the pause time were used for the other doses used, between 0.17 and 8.5 Gy.

For ICs, OSL signals were collected for 150 s of stimulation time; RIS were obtained in the same way as in the case of SMRs, but with a longer signal integration period (10 s). In some experiments, samples were preheated to different temperatures before irradiation in order to determine the optimal preheat temperature. The OSL responses were normalized to the OSL response of the sample before heating.

EPR spectra of PGs were recorded with the following parameters: central magnetic field 351 mT, sweep width 20 mT, microwave power 25 mW, conversion time 20.5 ms, time constant 41 ms, resolution 1024 points, number of scans 4. The matrix method of spectral deconvolution (Sholom and Chumak, 2003) was used to fit the spectra. NS_{Ref} were obtained from unexposed samples while

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