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Thermoluminescence of electronic components from mobile phones for determination of accident doses

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HIGHLIGHTS

- Resistors in mobile phones could function as reliable fortuitous dosimeters in case of a large scale radiological accident.
- The dose response of the TL signal is linear up to several Gy.
- Correction factors have been identified that need to be applied to the measured dose for an improvement in accuracy.

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ABSTRACT

The dosimetric properties of resistor substrates extracted from the circuit board of mobile phones were studied in detail using Thermoluminescence for the purpose of dose reconstruction following a radiological accident or attack. Many studies have shown the usefulness of this material using Optically Stimulated Luminescence but TL studies are scarce. The typical glow curve of a set of irradiated resistors has a peak at about 170 °C. Unexposed resistors showed a strong zero dose signal in the higher temperature region, peaking between 300 and 350 °C, which also led to a minor zero dose being detected in the chosen integration window of 100–200 °C. Exposure to white light can significantly increase the zero dose, presumably due to phototransfer of charge carriers from deep traps into the dosimetric trap. The dose response of the TL signal was linear up to several Gy but an irreversible sensitivity change was observed in the first thermal readout. A correction factor was therefore deduced from a number of dose recovery tests. Similar to the OSL signal, the TL signal is not stable but fades with time since irradiation. Overall, a slightly smaller fading rate up to 60 days was observed for the TL signal, as compared to the OSL signal. A protocol is proposed for TL based on the measured properties and validated in irradiation trials.

1. Introduction

Luminescence techniques have been employed to estimate doses to exposed population in contaminated areas using ceramic materials found in the environment. Such materials include bricks, pottery and porcelain items (Bøtter-Jensen, 1997). Recently, there have been investigations on the use of personal objects carried by the general public for the assessment of dose in case of radiological accident. The need for these investigations arises due to the growing concern of the public about accidental radiation exposure as a result of the ageing of the nuclear power industry, illegal dumping of nuclear waste or terrorist attacks with radiological materials (Radiation Dispersion Device (RDD) or Radiological Exposure Device (RED)). Personal objects that have potential for the assessment of dose include chip cards (credit cards, SIM cards, debit cards, health insurance cards, electronic ID cards) and portable electronic devices, such as cellular phones, USB flash drives, portable computers etc. (Woda et al., 2012; Cauwels et al., 2010; Bassinet et al., 2010a; Woda and Spöttl, 2009; Inrig et al., 2008; Göksu, 2003). The dosimetric components are ceramic materials used as substrates in resonators, resistors, capacitors and transistors, mounted onto the electronic circuit board (Beerten et al., 2009) and for mobile phones also the display glass (Bassinet

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et al., 2014a; Mrozik et al., 2014a; Discher and Woda, 2013; Discher et al., 2013; Bassinet et al., 2010b). Other materials such as plastic cards, bills, shoes, coins, nails and buttons (Sholom and Mckeever, 2014; Sholom et al., 2011), salt (Ekendahl and Judas, 2011; Christiansson et al., 2014), dental ceramics (Ekendahl et al., 2013) and dust on personal objects (Della Monaca et al., 2013; Bortolin et al., 2010, 2011) have also been investigated using luminescence methods. While some of the latter materials do show promising dosimetric properties, more work is needed to be able to fully judge their potential as emergency dosimeters.

For electronic components in mobile phones and other electronic devices, optically stimulated luminescence (OSL) has often been the method of choice and several irradiation trials and a first inter-comparison have demonstrated the principal applicability and reliability of this method (Bassinet et al., 2014b; Mrozik et al. 2014b; Ekendahl and Judas, 2012; Beerten et al., 2011; Inrig et al., 2008). In contrast there have been only few studies on the usability of TL on this kind of material (Mesterházy et al., 2012; Beerten et al., 2009; Beerten and Vanhavere, 2008). Many national radiation protection agencies however only possess conventional TL readers, without the possibility to perform optical stimulation.

In principle, TL could offer two potential advantages over OSL for dose assessment. Firstly, as there is no need for an optical stimulation unit, the PM tube can be brought closer to the sample, leading to an increase in solid angle and to a potential increase in sensitivity. Secondly, the TL signal will encompass also the slow OSL components and thus potentially offer a reduced fading rate as compared to OSL (in which essentially the fast components are sampled in the typical integration windows). A disadvantage would be the somewhat longer measuring times (400 s per signal including background correction), whereas for OSL a fast readout with 30 s measuring time has been suggested and tested (Bassinet et al., 2014b). Furthermore, it has been observed by Beerten et al. (2009), that resistors substrates from the investigated Sony flash drive showed a zero dose signal in the higher temperature range (250–400 °C), in contrast to the resonator, and it is not clear how far this signal will influence dose assessment using the lower temperature dosimetric signal.

In this study, the occurrence of a zero-dose signal for a variety of samples is investigated, along with the dosimetric properties such as dose response, dose recovery, optical stability and fading. Based on these observations a suitable protocol is developed and evaluated in irradiation trials.

2. Materials and methods

Resistors were extracted from electronic circuit boards of different brands of mobile phones, the majority produced between 2009 and 2010. The resistors are made of white alumina porcelain substrates. Sample preparation was carried out in normal white light and in dark room conditions. The resistors were cleaned in an ultrasonic bath with acetone for about 20 min to remove the adhesive used to secure the components to the circuit board during the process of manufacturing. For the measurements, ten resistors were placed with the ceramic side facing upwards on a stainless steel cup sprayed lightly with silicon. This was to ensure that the resistors are secured on the cup and do not remove or fall off in the process of movement.

TL measurements were performed using automated luminescence reader (Risø TL-DA-12), detecting the emission through a heat-absorbing filter HA-3 together with a blue (300–530 nm) transmitting Schott BG12 glass filter and using a heating rate of 2 °C/s. All TL measurements were done under a nitrogen atmosphere. Samples were preheated at 120 °C for 10 s (same heating rate as for the main TL run) in order to remove the lower temperature TL peak at ~ 80 °C (Woda et al., 2010; Beerten et al., 2009). The TL glow curves were integrated from 100 °C to 200 °C for the determination of the signal values, unless otherwise stated. Fading experiment was performed using resistors manufactured by AGL Technology GmbH for development, research and laboratory applications (referred to in this study as resistors from kit). To compare the fading rates of TL with OSL, OSL measurements were done on a Risø TL/OSL-DA-15 automated luminescence reader. Optical stimulation was achieved using blue LEDs (470 ± 30 nm), giving approx. 35 mW cm^{-2} at the sample position and emission were detected through a 7.5 mm Hoya U-340 filter (290–370 nm), using a Thorn-EMI 9235 bialkali photomultiplier. Samples were irradiated with a beta-irradiator holding a calibrated Sr-90/Y-90 source. The OSL was measured at 100 °C following a preheat of 10 s at 120 °C (Bassinet et al., 2014b; Woda et al., 2010). The OSL measurement times were 300 s and 150 s, for trial irradiations and fading tests, respectively. For the trial irradiations a single aliquot was used for several cycles of irradiation and OSL measurement. In this case it was important that the OSL signal is sufficiently reduced each time so as not to have a cumulative effect of carrying information from one measurement cycle to another. The fading experiment was a multi-aliquot experiment and each aliquot was only irradiated and measured one more time after the first readout, for the purpose of inter-aliquot normalization. In this case the shorter readout time was sufficient. The values for the signal and background of the OSL decay curves were determined from the integration of the first 5 s and the next 37–56 s of the decay curve, respectively.

For trial irradiation, intact mobile phones were affixed onto the ISO water slab phantom and irradiated with doses of 200 mGy and 500 mGy (air kerma value) using a Cs-137 source of the Secondary Standard Dosimetry Laboratory (SSDL) of the Helmholtz Zentrum München. The distance of the circuit board within the mobile phones to the source was 1 m, with the front side of the phone (display glass) facing the source. This set-up does not strictly correspond to irradiations in kerma reference conditions and thus a slight difference between (set) air kerma value and actual absorbed dose in air (in absence of the phone) is possible due to backscatter from the phantom. The set-up was used to simulate an accident scenario where the phone is expected to be close to the body and dose values in air might be available from environmental measurements for comparison. The same set-up was used in Discher and Woda (2013) for irradiation of the display glass in a mobile phone and in that study comparative irradiations in air kerma reference conditions yielded dose values that agreed within error limits.

After irradiation, the mobile phones were disassembled in the laboratory (under dark room conditions), electronic components extracted, cleaned, dried and placed onto the measuring cup. Two cups per phone were prepared with resistors for measurements using both TL and OSL.

3. Results and discussion

3.1. TL response and zero dose signal

The TL response of resistors of different mobile phones extracted in laboratory white light (R_L) and those extracted in the dark (R_D) are shown in Figs. 1a and 2a, respectively. A pronounced zero dose signal for R_L is seen in the higher temperature range above 320 °C for five out of seven samples, but also a signal in the temperature range of the dosimetric signal (100°C-200 °C) for all samples. As a result, zero doses up to several hundreds of mGy's were measured. If resistors were extracted under subdued red light conditions (Fig. 2a), the pronounced zero dose signal at higher temperatures is