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Violet stimulated luminescence signal from electronic components for radiation accident dosimetry

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HIGHLIGHTS

- Resistors and inductors extracted from mobile phones are potential dosimeters.
- They exhibit a strong violet stimulated luminescence (VSL) signal.
- Dosimetric properties of this VSL signal were investigated.
- These preliminary results appear to be promising for retrospective dosimetry.

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ABSTRACT

Due to recent technological advances, new optical stimulation sources with higher energies became commercially available. In the present work, laser diodes emitting in the violet (~405 nm) were used to investigate dosimetric characteristics of the violet stimulated luminescence (VSL) signal from electronic components (resistors and inductors) extracted from mobile phones. All component types exhibit higher sensitivity using violet stimulation than using blue one. The sensitization was negligible after 10 cycles of irradiation and measurement. The dose response was linear from 0.6 Gy to 30 Gy. Additionally, signal fading of one type of inductors was studied. Results were similar for blue stimulated luminescence (BSL) and VSL signals. Fading measurements performed at 40 °C after a preheat (125 °C hold for 10 s) or at 125 °C indicated low fading rates (~95% of signal remaining 1 h after irradiation). These preliminary results appear to be promising for retrospective dosimetry.

1. Introduction

When radiation accidents occur, the dose absorbed by the victims has to be assessed rapidly and accurately in order to select an appropriate medical treatment. If data from conventional personal dosimetry does not exist, objects found on the victims may be used as fortuitous retrospective dosimeters. Mobile phones are carried by a considerably large part of the population. They seem to be good candidates for this application and non-invasive retrospective dosimetry methods might be based on the materials from which they are made. With this aim in view, in the recent past dosimetric characteristics of alumina rich electronic components (resistors and inductors) extracted from mobile phone circuit boards have been widely investigated with optically stimulated luminescence (OSL) and thermally stimulated luminescence (TL) techniques (e.g., Inrig et al., 2008; Bassinet et al., 2010; Woda et al., 2010; Fiedler and Woda, 2011; Ekendahl and Judas, 2012; Pascu et al., 2013; Lee et al., 2015, 2016). Reported results appear to be promising. In particular, two measurement protocols using blue stimulated luminescence (BSL) of resistors were developed in the framework of the EU-FP7 MULTIBIODOSE project and successfully validated by an interlaboratory comparison (Bassinet et al., 2014).

However, in new generation mobile phones, the number of resistors and inductors is sometimes low or their size is reduced. As a result, the amount of material available to perform an accurate dose assessment using these types of electronic components decreases. The aim of this study was to investigate another luminescence signal that may present higher sensitivity in order to still enable the estimation of low radiation doses using resistors and inductors. New optical stimulation sources with higher energies have become commercially available due to recent technological advances. In

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particular, laser diodes emitting in the violet (~405 nm) are now available and, e.g., used for stimulating deep traps in quartz (Jain, 2009; Ankjaergaard et al., 2013; Hernandez and Mercier, 2015) and this method has been applied for luminescence dating of old Quaternary sediments (Ankjærgaard et al., 2016). In the present work, these new diodes were used to stimulate alumina rich resistors and inductors and the induced violet stimulated luminescence (VSL) signal was studied and compared with the BSL signal.

2. Materials and methods

Resistors (R402) and inductors (I402) (cf. Fig. 1) from different models of mobile phones (brands: NOKIA, SAMSUNG) were investigated. The components were removed from the circuit boards using a dissecting needle. Investigated resistors showed a black front layer and a white back side. Two types of inductors were studied. Some of them showed a green and black face and others a white and black (or white and grey) face. In order to simplify, hereafter they will be called “green/black inductors” and “white/black inductors”, respectively. The opposite side is green for green/black inductors and white for white/black inductors. For all measurements, the back side was investigated and thus faced the detection head of the analysis instruments.

In the literature, these electronic components are described as alumina rich substrates. A JEOL JMS 6460 LV Scanning Electron Microscope (SEM) operating at a 20 kV accelerating voltage and equipped with an Oxford X-Max 20 EDS Silicon Drift Detector (SDD) was used to determine and verify the major elemental composition of the samples. For this purpose, the components were placed onto a carbon tape. In total 29 components were scanned (namely 12 resistors extracted from 5 mobile phones, 8 green/black inductors extracted from 4 mobile phones and 9 white/black inductors extracted from 4 mobile phones).

Luminescence measurements were performed with a Freiberg Instruments lexsyg research system (Richter et al., 2013), equipped with an internal ^{90}Sr/^{90}Y β-source delivering ca. 3.6 Gy/s (calibrated for natural quartz, Risø calibration quartz, Batch 90). Violet and blue stimulations were carried out by 5 violet laser diodes (405 Δ 5 nm) and 5 blue LEDs (458 Δ 3 nm) respectively. In order to compare the violet and blue stimulated signal responses the stimulation power was adjusted for a similar photon flux, resulting in a power density of 80 mW/cm^2 (violet) and 70 mW/cm^2 (blue). Luminescence signals were detected using a UV sensitive Hamamatsu H7360-02 photomultiplier tube (PMT) through a set of filters composed of one Hoya U-340 (3 mm) large band glass filter and one AHF-BL HC340/26 (5 mm) interference filter. The choice of these detection filters was constrained by technical limitations, aiming at shorter detection wavelengths sufficiently enough separated from the stimulation window. This filter combination defined an approximately rectangular-shaped transmission window between 325 nm and 355 nm (cf. supplementary data Fig. S1). 10 resistors, or 4 or 5 inductors were placed onto stainless steel cups previously sprayed with silicon oil (without preliminary treatment). If not stated otherwise, each experiment was preceded by an initial VSL measurement (residual cleanout). VSL and BSL measurements were performed at 40 °C without preheat. Stimulation time was set to 100 s. Integrals used to estimate BSL and VSL signals were set to 0–2 s and a late light background (80–100 s) was subtracted from the signal. This approach was later modified for constructing the VSL dose response curves and determining the minimum detection limit (MDL). During this experiment every VSL signal curve was followed by VSL cleanout curve to determine the remaining background level and ensure a sufficient signal resetting. For these measurements the mean and the standard deviation of the sum of the initial signal in the interval 0–2 s of the succeeding VSL cleanout curves (see supplementary data Fig. S2 and below for further details) were used. Additionally, to investigate signal fading of white/black inductors, VSL and BSL measurements were both done at 40 °C with and without a preheat (125 °C hold for 10 s) or at 125 °C without preheat respectively. Chosen preheat and measurement temperatures were justified by the found dominant TL peaks (see results below). For TL measurements a heating rate of 2 °C/s was chosen.

Data analysis was performed using the statistical programming environment R (R Development Core Team, 2016) and the R package ‘Luminescence’ (Kreutzer et al., 2012, 2016).

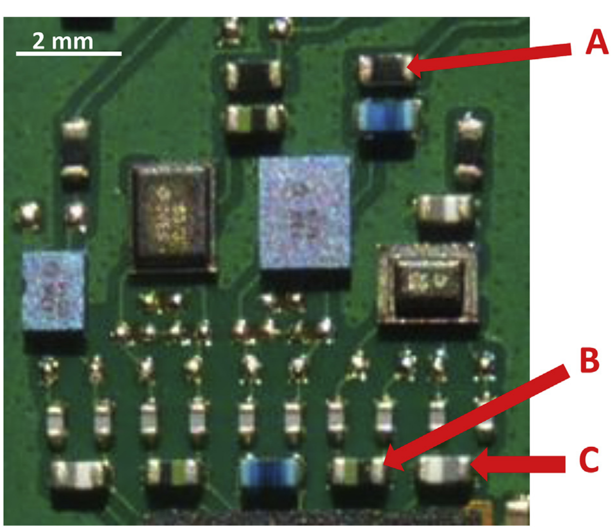

Fig. 1. Examples of electronic components investigated in this study: (A) resistor R402, (B) green/black inductor I402, (C) white/black inductor I402. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results and discussion

3.1. Composition of the electronic components

SEM analyses results are shown in Fig. 2. For each type of electronic component, the composition of the main elements was found to be similar for the investigated mobile phone models. Apart from O, all investigated electronic components contain mainly Al and Si, but the atomic percentage of Al is higher for resistors than for inductors. Inductors contain more Si than resistors (mean log-ratio Si/Al ~ 1.3 for green/black inductors and ~0.2 for white/black inductors). Ba is present in the composition of green/black inductors and was not detectable in the other electronic components with the chosen method.

3.2. VSL signal intensity

VSL and BSL signals of an aliquot with 10 resistors (NOKIA 2730c), an aliquot with 5 green/black inductors (NOKIA 3109c) and an aliquot with 5 white/black inductors (NOKIA 2730c) are shown in Fig. 3. The administered dose was ~1 Gy. For each type of electronic component the VSL signal intensity is higher than the BSL one. The signal bleaches faster for VSL than for BSL. Ratios are: net VSL/net BSL ~1.8 for resistors, ~2.5 for green/black inductors and ~3.6 for white/black inductors.

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