Abstract. This study investigated the dosimetric properties of various electronic components extracted from a new generation mobile phone using optically stimulated luminescence and thermoluminescence. The studied resistors exhibit high linearity in the dose range of interest, signal repeatability and reproducibility, along with a minimum detectable dose of 16 mGy after preheating.

Key words: OSL, TL, electronic components, retrospective accident dosimetry.

1. INTRODUCTION

In the aftermath of a radiological accident, rapid and accurate absorbed dose evaluation of exposed victims is needed in order to perform an appropriate triage before medical treatment. As the conventional personal dosimeters are not in widespread public use, previous studies have demonstrated the successful usage of personal objects as fortuitous dosimeters. Chip card modules found in mobile phones, bankcards, ID or health insurance cards [1–6] and electronic components, such as resistors, capacitors, inductors, resonators, diodes, and glass displays removed from mobile phones, portable media player, and USB flash drive [6–14] were investigated as emergency dosimeters using luminescence techniques.

In a recent work, the dosimetric properties of an extensive variety of electronic components and chip card modules removed from both old and new generation mobile phones representative for the Romanian residents/market were investigated in detail with regard to OSL signal intensity, signal reproducibility, dose response, sensitivity and homogeneity, fading and minimum detectable dose [6]. While in the case of alumina rich components (resistors, inductors, and
resonators) most studies available in literature used a thermal treatment (10 s preheat at 120°C [7]; 10 s preheat at 100°C [8, 9]) and stimulation at approximately 100°C in the case of this previous study no thermal treatments were applied due to the lack of significant OSL signals to a zero dose administered in the measurement protocol following an irradiation to a high dose and the low sensitivity variations observed for most components. However, the resistors pronounced signal loss during the first day after irradiation noticed previously, indicated that investigations using thermal treatments in conjunction with thermal stability tests would be welcomed especially that it has been shown by other studies [7] that fading of the signal can be observed on short time scale (minutes to hours) even after applying preheat treatments.

Thus, the aim of this work was to conduct a comparative analysis of the dosimetric properties presented by some electronic components removed from a new generation mobile phone with and without using thermal treatments.

2. INSTRUMENTATION

Electronic components extracted from a new generation mobile phone (LG KP502; released in 2009) were analysed in this study. Sample preparation was done by removing the electronic components from the circuit board of the mobile phone, without using any chemical treatments [6]. The components extracted were resistors, capacitors, and integrated circuits. After mechanical extraction, the samples were classified according to their type and size (for capacitors) and placed in stainless steel cups. For each aliquot a variable number of components were used, depending on the size of the components being studied. Electronic components containing an alumina substrate were measured with the radiation sensitive side facing upwards. OSL and TL measurements of the samples were performed with a Risø TL/OSL Luminescence Reader model TL/OSL-DA-20. The heating rate for TL measurements was 5 °C/s. Optical stimulation was performed using 28 blue LEDs, emitting at 470 nm with a total power of 36 mW/cm². The stimulation time was 100 s for both versions of the experimental set-up design: first version involved measuring the OSL signal without preheat and the second one consisted of recording the OSL signals following a preheat (5°C/s) of 10 s at 120°C. The light detection system consists of a bialkali EMI 9235QA photomultiplier tube (PMT), and a UV detection filter (Hoya U-340; 270–370 nm). Irradiations were performed using the built-in 90Sr/90Y beta source calibrated using calibration quartz from Risø. The dose rate was roughly estimated at 0.1 Gy/s considering that others [3] explained that at least in the case of chip card modules using the same dose rate as for coarse calibration quartz is an appropriate approximation. The signals used for calculations were integrated over the first 2 s
of stimulation minus a background evaluated from the last 2 s. A similar integration window was used by others [4] observing that the fast component, responsible for 60% of the OSL signal, is found in the first 2.1 s of the OSL curve.

3. LUMINESCENCE ANALYSIS

3.1. TL SIGNALS

All the samples investigated exhibited bright TL signals consisting of two main peaks, but with some variations (Fig. 1). Also, all the electronic components show a low temperature peak at ~100°C, while the position of the high temperature peak for most of the samples is found in the temperature range between 250 and 300°C. Unlike the other electronic components, the inductor gave only the low temperature peak at ~100°C. The position of resistors high temperature peak was at ~200°C. Similar values for the position of the resistors TL peaks have been presented previously (two peaks at ~100 and ~200°C [7]). Others reported one peak in the temperature range between 150 and 200°C [8, 15] and two peaks at ~180 and ~240°C [15].

![Image](image.png)

Fig. 1 – TL glow-curves (recorded to 400°C, heating rate of 5°C/s) for each electronic component (a–integrated circuits; b–capacitors1; c–resistors; d–inductor; e–capacitors2) following an irradiation with a dose of 8 Gy (*90*Sr-*90*Y). The five graphs (a-e) plotted for each sample show the immediate TL output without preheating. Capacitors type “1” are small size (code 1, 1×0.8 mm), while type “2” represent intermediate size (code 2, 2×1 mm).
3.2. OSL SIGNALS AND REPEATABILITY

Continuous wave optically stimulated luminescence (CW-OSL) was recorded without using thermal treatments. Most of the investigated electronic components gave a considerable OSL signal after irradiation with 1.2 Gy with values between a minimum of \(~90\) cts in 0.4s/Gy in the case of the inductor and a maximum of \(~12,500\) cts in 0.4s/Gy for the resistors (Fig. 2). As previously reported [7], the resistors OSL curve showed a relatively slow decay (Fig. 2c) and the OSL response to a given a dose (8 Gy–82,000 cts/s) was brighter than the TL response (8 Gy–200 cts/s).

Fig. 2 – OSL decay curves for each electronic component (a–integrated circuits; b–capacitors1; c–resistors; d–inductor; e–capacitors2). The OSL signal of unexposed sample (native signal) is compared to that obtained following beta-irradiation with 1.2 Gy. The five graphs (a-e) plotted for each sample show the immediate OSL output without preheating.

In order to check the possible presence of sensitivity variations caused by irradiation, after constructing the growth curves up to 8 Gy the first four samples were subjected to eight repeated irradiation-readout cycles using a constant dose of 2 Gy and no delay time between irradiations and read-out. The signal in each measurement cycle was then normalized to the initial response, which was obtained when constructing the growth curve. The results indicated small sensitivity changes for the resistors (less than 10%), feature also observed in other studies [7, 18], while the other components were characterized by significant sensitivity variations (Fig. 3).
Fig. 3 – Sensitivity variations of the first four electronic components (a–integrated circuits; b–capacitors1; c–resistors; d–inductor) following repeated irradiation – readout cycles using a constant dose of 2 Gy. Reported values represent normalized data to the first measurement during the construction of the dose-response curve. The dashed lines (eye guide) indicate a 10% deviation from unity.

4. FURTHER INVESTIGATIONS ON DOSIMETRIC PROPERTIES OF RESISTORS

Among the electronic components investigated so far, alumina rich resistors seem particularly suitable for retrospective and accident dosimetry using OSL. In contrast to integrated circuits, inductors and capacitors they exhibit intense OSL signal and remarkably small change in sensitivity over multiple cycles of irradiation and optical stimulation. Thus, our next investigations focused on determining the resistors dosimetric properties with and without using thermal treatments.

4.1. DOSE RESPONSE RELATIONSHIP

In order to construct the dose response curve, a modified single-aliquot regenerative-dose (SAR) protocol was used [16, 17]. For each sample six doses were applied using the integrated beta source, namely 0.3 Gy, 0.6 Gy, 1.2 Gy, 2
Gy, 4 Gy and 8 Gy, followed by the measurement of the signal for a nil dose (0 Gy) and two repeat doses (0.6 Gy and 4 Gy). When a thermal treatment was applied, the recording of the OSL dose-response was performed following a preheat (5°C/s) of 10 s at 120°C and a readout temperature of 100°C, thus ensuring that the thermally unstable trap (TL peak at about 100°C) was kept empty, minimizing the possibility of charge transfer between the two traps during stimulation. It was found that the resistors exhibit a linear dose response in the studied dose range (0–38 Gy) in both cases (with and without preheating; Fig. 4) as reported by others [7, 15, 18].

The zero dose signal measured after constructing the dose response growth is used to evaluate the recuperation of the signal following multiple irradiation-readout cycles. The resistors showed an OSL recuperation signal under 10% (6.2% without preheating; 7.4% after preheating) in comparison with the signal measured following a 1.2 Gy irradiation.

4.2. SIGNAL REPRODUCIBILITY

In order to verify the signal reproducibility, the resistors dose response was constructed using decreasing doses from 8 to 0.3 Gy, followed by the measurement of the signal for a nil dose (0 Gy) and two repeat doses (0.6 and 4 Gy). The results indicate the same linear dose-response relationship as for increasing irradiations (which are illustrated in Fig. 4), characteristic observed both before and after preheating, with $R^2 > 0.99$. Moreover, the resistors sensitivity (no preheat:~8600 cts in 2s/Gy; with preheat: ~ 2800 cts in 2s/Gy), which corresponds to the slope of the dose response, as it was found that they follow a linear growth for the dose interval
of interest, is similar within error limits to the sensitivity obtained by applying increasing doses (no preheat: ~10000 cts in 2s/Gy; with preheat: ~3000 cts in 2s/Gy).

4.3. FADING

Laboratory fading measurements were performed for the resistors after a thermal pre-treatment at 120°C for 10 s and a readout temperature of 100°C. The samples were irradiated with a dose of 2 Gy and stored in the darkroom to avoid any light induced signal loss. The optical stimulation was performed both instantaneous and after varying delay times following irradiation (2, 4, 8, 24, 48, 96 and 168 hours, respectively). In addition, sensitivity variations caused by irradiation and measurement were monitored using three repeated measurements after prompt irradiations of 2 Gy in each case (Fig. 5).

![Resistors sensitivity variations recorded using prompt irradiations of 2 Gy delivered after each delayed readout process. Each data point represents the average values of 2 or 3 instantaneous signals. The solid line (eye guide) indicate the resistors overall average sensitivity obtained for the values of the instantaneous signals recorded after each delayed readout process.](image)

The fading results indicate a pronounced signal loss occurring in the first two hours following irradiation as the signal drops to 77% of the initial value. Similar fading effects were observed in other studies where no thermal treatments were applied ([6]–30% and 26% loss; [18]–40% loss) suggesting that preheating the resistors at 120°C for 10 s had an insignificant effect on the fading rate. The same linear relationship between the OSL intensity and the logged fading time was reported in previous studies [7, 13] where similar preheating treatments were applied. This implies that the loss of signal might be cause by tunneling (anomalous fading) rather than by the thermal instability of the OSL trap accessed.
4.4. MINIMUM DETECTABLE DOSE

The resistors minimum detectable dose was estimated as the dose for which the signal is three times the standard deviation of the background that corresponds to the last two seconds of stimulation [2, 13]. When no preheating was used a value of 4 mGy was obtained for immediate read-outs in comparison with only 16 mGy estimated after applying a thermal pre-treatment. The difference between the two values emphasizes that the preheating treatment depleted the OSL signal, causing a reduction in the minimum detectable dose as previously observed [7]. However, the reported value after preheating is in accordance with the minimum detectable dose of 10 mGy estimated in [7] and much lower than the values (30 mGy and 80 mGy) obtained for the different sized resistors investigated in [13].

5. CONCLUSIONS

Luminescence properties of various electronic components removed from a new generation mobile phone have been investigated with regard to their usefulness as ubiquitous retrospective dosimeters. All samples exhibited a low temperature TL peak at about 100°C and most of them displayed a high temperature peak in the temperature range between 200 and 300°C. Also, the samples gave bright OSL signals, with a maximum of ~12,500 cts in 0.4s/Gy for the resistors, which were also characterized by small sensitivity variations over multiple cycles of irradiation and optical stimulation. Taking into account the resistors promising features, this type of electronic components were further investigated before and after using thermal treatments. By applying a modified single-aliquot regenerative-dose (SAR) protocol it was observed that the resistors
Electronic components as luminescence retrospective accident dosimeters exhibit a linear dose response in the studied dose range (0.3–8 Gy) in both cases (with and without preheating for 10 s at 120°C and a stimulation temperature of 100°C) and good signal reproducibility. Moreover, very encouraging values for the resistors minimum detectable dose have been estimated (4 mGy when no thermal pre-treatment was used and 16 mGy after preheating, considering prompt measurements). Signal loss occurring in the first two hours following irradiation was observed for these samples and this signal loss proved impossible to be circumvented by applying thermal treatments. While further investigations on the applicability of a universal fading correction factor remain to be done, it can be concluded that this type of electronic components are suitable as fortuitous dosimeters in the event of a radiological accident.

REFERENCES