Thermoluminescence emission spectrometry of glass display in mobile phones and resulting evaluation of the dosimetric properties of a specific type of display glass

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Abstract
Glass displays of mobile phones are sensitive to ionizing radiation and can be used for retrospective dosimetry for the purpose of triage after a radiological accident or attack. In this study the two main types of glass display that are used in modern mobile phones were investigated using thermoluminescence (TL) emission spectrometry. A different TL spectrum was observed for the glass display of category A (lime-aluminosilicate glass) and category B (boron-silicate glass). Based on the spectral measurements an optimized detection window was chosen to re-evaluate the dosimetric properties (dose response, optical and long-term stability) of glass display category B.

Keywords: Retrospective dosimetry; accident dosimetry, glass display of mobile phones; emergency dosimeter; thermoluminescence emission spectrometry

1. Introduction

Glass samples extracted from displays of mobile phones are sensitive to ionizing radiation and can be measured using both electron paramagnetic resonance (EPR) spectrometry (Trompier et al (2011) and thermoluminescence (TL) method (Discher et al. (2013); Discher and Woda (2013); Bassinet (2010). In a study of more than 80 glass displays of mobile phones (different brands and models) a categorization was carried out according to the radiation induced shape of the TL glow curve and the EPR spectrum (Discher and Woda (2013). For a specific type of glass (category A, lime-aluminosilicate glass) the dosimetric properties were studied in detail in Discher and Woda (2013). For a second type of glass (category B, boron-silicate glass) the dosimetric properties had not been investigated due to the comparatively low radiation sensitivity, when measuring in the blue/UV wavelength range (280 – 500 nm). Both types of glass are used in modern mobile phones and could be useful for retrospective dosimetry for the purpose of triage after a radiological accident or attack. The aim of this work was to study the emission spectra of both investigated glass types in order to see whether the used detection modes are appropriate. Based on these results the dosimetric properties for glass category B were investigated in detail using an optimized detection window.

2. Materials and Methods

This study was carried out with glass samples of mobile phones which belong to different categories of display glass, categorized in Discher and Woda (2013): Category A (lime-aluminosilicate glass) and category B (boron-silicate glass). Aliquots of display glass samples were extracted from the mobile phones and if necessary were previously heated in an oven for 10 min at 500 °C to erase the intrinsic background signal (zero dose signal). The dimensions of the samples were approx. 5 x 5 mm², fitting into the measuring cup of the TL readers. For spectral measurements, where higher doses are needed, irradiations were carried out at the Secondary Standard Dosimetry Laboratory of the Helmholtz Zentrum München (SSDL) using a closed Co-60 gamma irradiation chamber with an air kerma dose rate of 11.1 Gy/min. The given dose was 1.0 kGy and the TL measurements were carried out between 30 and 80 min after the end of the irradiation. Samples were sandwiched between two PMMA plates (3 mm thickness) and placed in the center of the chamber. Irradiations for TL measurements were done using the built-in beta source (Sr-90/Y-90) of the TL reader, with a dose rate of ≈28.2 mGy/s, calibrated for display glass using a Cs-137 source of the SSDL. TL spectrometry measurements were performed using an Andor Technology iDus CCD camera DU420A-OE, cooled to -80 °C, together with a Shamrock 163 spectrometer controlled by an automated luminescence measurement unit “Lexsyg”, made by Freiberg Instruments. The wavelength resolved readouts, recorded in a range from 240 to 750 nm, had a temperature resolution of 40 °C and a wavelength resolution of 1.5 nm. Heating rate was set to 2 °C/s with a maximum temperature of 400 °C.

To investigate the dosimetric properties of glass category B (boron-silicate glass), TL measurements were performed using an automated luminescence reader Risø TL-DA-12, equipped with a Thorn-EMI 9235Q bialkali photomultiplier. Due to the results of the TL spectra measurements, which will be discussed later in this paper, a transmission window between 530 – 630 nm was chosen using a combination of a heat absorbing filter (HA03) and a long-pass filter (Schott OG530). Optical bleaching of the TL signals was achieved using the blue LEDs (470±30 nm, approximately 36 mW/cm²

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at the sample position) of a Risø TL/OSL-DA-15 reader. Comparative red enhanced TL measurements in the detection window 530-720 nm were carried out with a Hamamatsu H7421-40 photomultiplier in a Lexsyg reader at Freiberg Instruments. All TL measurements were performed in a nitrogen (N2) atmosphere with a heating rate of 2 °C/s to a maximum temperature of 400 °C. A second TL measurement was carried out for thermal background subtraction. Following Discher and Woda (2013) the TL signal was integrated between 100 – 250 °C for analysis, as a compromise between maximizing signal stability and minimizing the influence of the intrinsic background signal.

3. Results and Discussion

3.1 TL emission spectra

The TL emission spectra of two different display glass types are shown in Fig. 1. For the glass sample of category A (Blackberry Curve 3G 9300) the TL spectrum shows two emission peaks around 380 and 465 nm at a temperature between 200 and 300 °C. A shoulder for longer wavelengths can be seen, extending down to maximum recorded wavelength of 750 nm, with a possible peak between 590 – 600 nm. In contrast the TL spectrum of the glass sample of category B (Samsung M3510) shows a prominent emission peak around 605 nm at a temperature of approximately 150 °C, with two minor emission bands at 380 and 465 nm. The similarities in recorded peak wavelengths for both types of glasses indicate that the same defects might be involved in the recombination process in both materials but with different relative intensities of the corresponding emission bands.

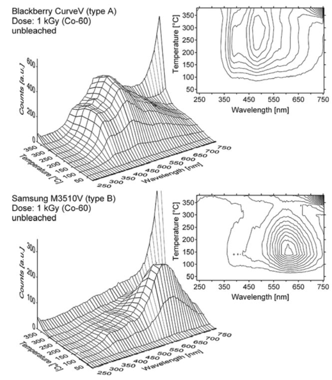

Fig. 1.: TL spectrum of a glass sample category A (lime-aluminosilicate glass) irradiated with 1 kGy (top). Two emission peaks around 380 and 465 nm can be identified. TL spectrum of a glass sample category B (boron-silicate glass) (bottom). A prominent emission peak is observed around 605 nm at a temperature of approximately 150 °C.

Pre-bleached TL spectra of two different glass types

The measurement protocol developed in Discher and Woda (2013) implements an optical bleaching before TL, in order to remove that part of the glow curve which is affected by daylight and the illumination from the LEDs of the display itself. To investigate how this pre-treatment affects the emission spectrum both types of display glasses (category A and B) were given the same dose as before, but bleached after the irradiation with blue LEDs of the luminescence reader for 30 and 500 s, respectively (see Fig. 2).

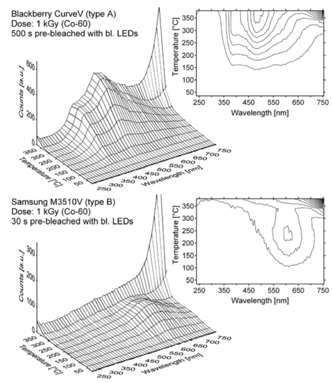

Fig. 2.: TL spectra of a glass sample category A (lime-aluminosilicate glass, top) and glass sample category B (boron-silicate glass, bottom), after pre-bleaching with blue LEDs. Changes in peak temperature and intensity of the lower temperature part of the TL signal are observed but not in the respective peak wavelengths.

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For both types of glasses the TL spectra show a shift to higher temperatures of the peak maxima and a reduction in TL intensity in the lower temperature region, which is in agreement with conventional TL measurements on glasses of category A (Discher and Woda, 2013). The relative intensities of the emission bands however do not change nor do new emissions appear.

TL spectrum of an unirradiated glass sample

The TL spectrum of an unexposed glass sample is measured as the sum of four aliquots of the same display glass category A and B. The thermal background was determined with a second measurement and subtracted from each TL spectrum measurement. Fig. 3 (category A) shows an intrinsic background TL signal at temperatures above 300 °C which peaks at similar wavelengths as the spectrum of an irradiated sample. The same observation was found for glass category B. Therefore, it is impossible to separate the radiation induced signal from the intrinsic background TL signal by means of optical filters.

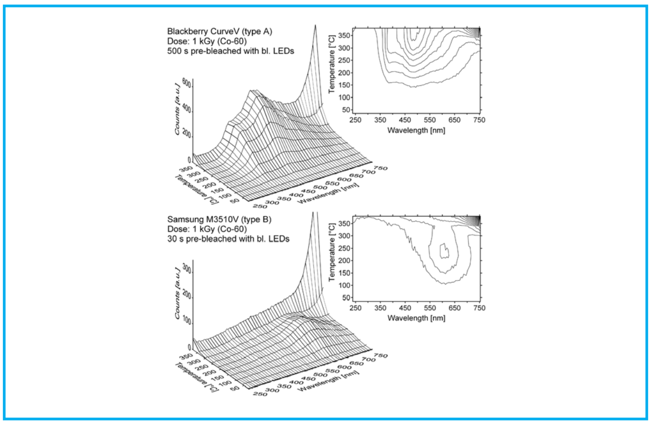

Fig. 3.: TL spectrum of an unexposed glass sample (category A). The intrinsic background TL signal peaks at similar wavelengths as the spectrum of an irradiated sample for temperatures >300 °C. This means that it is impossible to find a detection window which only detects the radiation induced signal and blocks the intrinsic background TL signal.

3.2 Dosimetric properties of boron-silicate glass (category B)

TL glow curves and dose response

A typical TL glow of a display glass category B in the detection window of 530 – 630 nm is shown in Fig. 4a. In comparison to measurements in the UV detection window (see dotted line in Fig.4a), a shift in peak temperature from approximately 80 °C to 150 °C is observed along with a broader peak shape. The pre-bleached TL glow curve (500s with blue LEDs) is shown additionally in Fig. 4a. The dose response in Fig. 4b displays a linear behaviour between 100 mGy and 10 Gy for the integrated signals (100 – 250 °C). The measurements were carried out with different protocols: Unbleached (R^2=0.99972) and pre-bleached (R^2=0.99925).

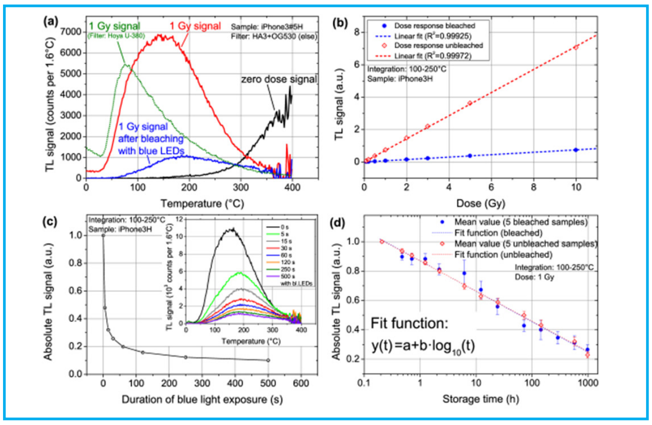

Fig. 4.: Investigations of the dosimetric properties of glass category B in the 530-630 nm detection window: (a) TL glow curves of the intrinsic zero dose signal, radiation induced dose signal of 1 Gy (unbleached and pre-bleached) and representatively 1 Gy signal, measured with measured in the UV detection window (Hoya U-380), (b) dose response of the TL signal with different measuring protocols (unbleached and pre-bleached), (c) optical stability of the TL signal using the blue LEDs of the reader, (d) long-term stability of the TL signal using different measuring protocols (unbleached and pre-bleached).

Optical and long-term stability

The optical stability of the TL signal is shown in Fig. 4c. The decay of the integrated TL signal with increasing light exposure time is much faster (about a factor of 2 at 500 s exposure time) than the decay of the TL signal of display glass category A (Discher and Woda (2013). It is important to mention that the time delay between end of the irradiation and TL readout was the same for measurements with and without optical bleaching to exclude the effect of signal fading. In the inset of Fig. 4c the TL glow curves show that there is a slightly stronger reduction in intensity in the lower temperature part by the first optical stimulation of 5 s than in the higher temperature part. It leads to a shift in the overall peak temperature from 150 °C for the unbleached sample to approximately 190 °C. With increasing bleaching times (>5 s) a uniform decrease of the TL glow curve is observed. In Fig 4d the long-term stability of the TL signal is shown for unbleached and pre-bleached samples. The mean values of five glass samples extracted from different mobile phones were calculated for the fading curve. A fading of the TL signal with increasing storage time (few minutes up to 42 days) is observed when storing irradiated samples in the dark and at ambient temperature, with almost equal fading rates for pre-bleached and unbleached samples. This result is quite different compared to the observations of long-term stability of display glass category A (Discher and Woda (2013), where pre-bleaching was found to significantly reduce the fading rate (about a factor of 2 at 1000 h storage time). Signal fading functions of glass category B can be fitted by a logarithmic function with two parameters a and b: $y(t)=a+b \cdot \log_{10}(t)$, given in Table 1.

	unbleached samples	pre-bleached samples
a	0.86940±0.00510	0.87041±0.01423
b	-0.20556±0.00327	-0.20762±0.00865
R2	0.99722	0.97956

Table 1: Parameter of the logarithm function y(t)=a+b•log10(t) to calculate signal fading of glass category B with a given storage time t:

Distribution of the intrinsic background dose

The intrinsic background dose was calculated from the zero dose signal using the calibration curve of the pre-bleached TL signal response. In Fig. 5 the intrinsic background dose is shown for 13 glass samples (etched and unetched) of different mobile phone brands and models, determined using the standard PMT Thorn-EMI 9235Q (detection window between 530-630 nm). For six glass samples the TL measurements were carried out with a red enhanced PMT (Hamamatsu H7421-40 with a 530-720 nm detection window) for comparison. Similar glow curves are observed but with much higher TL intensities. 11 out of 13 unetched samples measured in the 530 – 630 nm detection window have an intrinsic background dose of less than 600 mGy but two samples show a relatively high background dose. Similar to Discher et al. 2013, etching of the glass samples with concentrated HF for four minutes significantly reduces the intrinsic background signal, while not affecting the dose information. With the approach described in Discher and Woda 2013, preliminary estimates of the minimum detectable dose were calculated as 1370 and 210 mGy, for unetched and etched samples, respectively. More measurements on a larger set of display glasses are necessary for a reliable estimation of the minimum detectable dose.

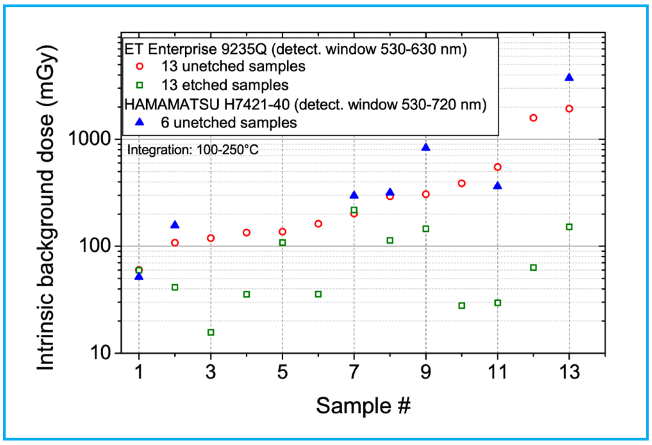

Fig. 5.: Investigations of the intrinsic background dose signal of glass category B (unetched and etched). Comparative TL measurements were carried out with a red enhanced photomultiplier tube.

4. Summary and conclusions

In this study two types of glass displays were investigated using TL emission spectroscopy. Similar peaks can be identified in the spectrum of both glass types but with significantly different relative intensities. Whereas for glass sample of category A (lime-aluminosilicate glass) the emission peaks around 380 and 465 nm are most pronounced, the spectrum of glass sample of category B (boron-silicate glass) is dominated by the emission peak around 605 nm. Pre-bleaching of the TL spectra shows a shift to higher temperatures of the peak maxima and a reduction of the TL intensity in the lower temperature region but no change in the peak wavelengths. Unirradiated glass samples of category A emit in the same wavelength region upon thermal stimulation as do irradiated samples. Therefore the separation of the radiation induced signal from the intrinsic background TL signal by means of optical detection filter is not possible.

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Using an optimized detection window dosimetric properties of category B were re-evaluated which are similar to category A: Linear dose response (0.1 - 10 Gy), optical bleachable TL signal, fading of the TL signal and distribution of the intrinsic background dose. This implies that etched samples of category B, when measured in the optimized detection window, seem to have adequate dosimetric properties for application as emergency dosimeters. This assumptions needs to be strengthened by analysis of the intrinsic background dose distribution on a larger data set and appropriate irradiation trials.

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