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On the use of OSL of chip card modules with molding for retrospective and accident dosimetry

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HIGHLIGHTS

- ► Chip cards with molded encapsulations have potential for retrospective dosimetry.
- ► Extraction of filler material strongly increases sensitivity.
- ► Correction for signal fading has so far not been successful.

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ABSTRACT

The potential of optically stimulated luminescence of wire-bond chip card modules with molded encapsulations for retrospective and accident dosimetry is investigated. Contact-based and contactless modules were studied, the latter finding potential use in electronic documents (e.g. electronic passports, electronic identity cards). Investigations were carried out on intact as well as chemically prepared modules, extracting the filler material. Contact-based modules are characterized according to zero dose signal, correlation between OSL and TL, dose response and long-term signal stability. For prepared modules, the minimum detectable dose immediately after irradiation is 3 mGy and between 20 and 200 mGy for contact-based and contactless modules, respectively. Dose recovery tests on contact-based modules indicate that the developed methodology yields results with sufficient accuracy for measurements promptly after irradiation, whereas a systematic underestimation is observed for longer delay times. The reasons for this behaviour are as yet not fully understood.

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1. Introduction

Previous studies have shown that portable electronic devices and certain type of chip cards have high potential to be used as fortuitous dosimeters using optically stimulated luminescence for rapid assessment of the individual radiation exposure in the case of a radiological accident or attack (Eckendahl and Judas, 2012; Inrig et al., 2010; Beerten and Vanhavere, 2010; Beerten et al., 2009; Woda and Spöttl, 2009; Inrig et al., 2008; Mathur et al., 2007; Göksu, 2003). For chip cards the radiation sensitive component was traced to silica in the epoxy encapsulant, the latter protecting the chip and wiring from the environment and mechanical stress (Barkyoumb and Mathur, 2008; Göksu et al., 2007). Using infrared stimulated luminescence (IRSL) the minimum detectable dose was above 100 mGy, while 10–20 mGy could be achieved for OSL (Woda and Spöttl, 2009; Mathur et al., 2007).

All chip cards studies so far have a translucent encapsulation, which however is less frequently encountered when security relevant chips are used. In this case molding technology is often applied, where a thermosetting plastic composition is injected around the chip with pressure and high temperature, resulting in a black, intransparent encapsulation. This at first seems to preclude the application of any luminescence dosimetry method but the high amount of silica powder used as filler (up to approx. 80%) indicates that there still could be some potential of these kind of chip card modules for emergency dosimetry.

2. Materials and methods

Investigations were carried out on sample tapes of molded encapsulations without or with mechanically broken chips (for

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security reasons). We investigated chip card modules from a single production batch (production year of 2010), directly obtained from the producer (Infineon). Contact-based and contactless modules were studied, the former finding use in credit and debit cards, the latter in electronic documents (e.g. electronic passports, electronic identity cards). Measurements were conducted on intact, on mechanically crushed (in an agate mortar) as well as on chemically dissolved modules using fuming HNO_3. Contactless modules could be dissolved at room temperature within a few minutes, whereas for contact-based modules heating of the HNO_3 to 70–80 °C is necessary. In first experiments this was achieved using a heating plate while taking care to prevent superheating and boiling over. Complete dissolving of the module was then achieved within 6–10 min. For greater control of the actual temperature at the sample, subsequent experiments were carried out using a heatable ultrasonic bath and setting the temperature to 80 °C. After several cycles of dilution and careful decanting, the extracted filler material (silica grains) was washed in acetone and directly pipetted in several steps (20 μl) onto the measuring cup, waiting between each step until all acetone on the cup had evaporated. For dose-recovery tests, intact modules were irradiated with ^{137}Cs at the Secondary Standard Dosimetry Laboratory (SSDL) of the Helmholtz Zentrum München, in a Perspex holder with 6 mm wall thickness. Accounting for the attenuation in the holder, the air kerma was 475 mGy and this was treated as the unknown accident dose. Modules were then prepared under subdued red light conditions (also for testing for zero dose signals). Examples of the different kind of chip card modules, including the previously studied modules with a translucent encapsulation, are given in Fig. 1.

OSL measurements were performed on a Risø TL/OSL-DA-15 automated reader, equipped with blue LEDs (470 ± 30 nm) for stimulation and a Thorn-EMI 9235 bialkali photomultiplier combined with a 7.5 mm U-340 Hoya filter (290–370 nm) for detection. The built-in ^{90}Sr/^{90}Y source is calibrated against a ^{60}Co source of the SSDL for quartz in the grain size fraction of 140–200 μm and has a dose rate of approx. 45.5 mGy s^{-1}. This value should be readily adoptable for the extracted silica but might be somewhat too high for the intact module due to stronger attenuation in the 500 μm thick and 80% silica filled epoxy and the silicon chip. Unless stated otherwise, OSL decay curves were integrated for the first 6 s and for 6–12 s for determination of signal and background, respectively. TL measurements were made on the same reader using a heating rate of 2 °C s^{-1}.

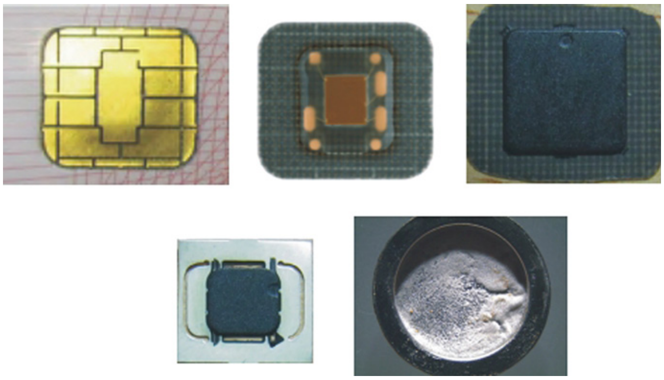

Fig. 1. Examples of chip card technologies. From top left to bottom right: typical front side of a contact-based chip card module found on credit and debit cards. Back side of the same module revealing a UV-cured translucent encapsulation. Back side of the same type of module but with molded encapsulation. Contactless module with molding, potentially found in electronic documents. Measuring cup with chemically extracted filler material (silica) of a contact-based molded encapsulation.

3. Results and discussion

3.1. Zero dose signal

Similar to UV-cured translucent encapsulations, a zero-dose signal is observed in TL, peaking around 175 °C but roughly corresponding to a dose of only 1 Gy at the higher temperature side, as compared to more than 40 Gy for UV-cured encapsulations (Fig. 2a and Woda and Spöttl, 2009). This difference might be attributable to the exposure of the epoxy to higher temperature during hardening for the molding technology as compared to the hardening at room temperature for the UV-cured encapsulations. A subsequent irradiation with 1 Gy produces a broad signal structure with peaks around 80 °C and 140 °C. A zero dose signal is not observed in OSL for the intact and chemically dissolved module (Fig. 2b), but a short-lived signal is observed for the mechanically crushed sample (not shown), roughly corresponding to 200 mGy. For this reason, the latter technique was not further pursued. Extracting the silica increases the sensitivity by a factor of 40–100, as compared to the intact module. It also results in an increase of the fast component of the OSL decay curve, presumably due to a reduced attenuation of stimulating and emitted light as compared to the intact module (Fig. 2b).

3.2. Correlation between TL and OSL

Fig. 3a demonstrates that the defects responsible for the TL emissions are also photo-active in the temperature region up to approx. 250 °C, with a possible faster depletion on the lower temperature side, leading to an overall shift in peak temperature with optical stimulation time towards higher temperatures. Similar results were observed for the 190 °C TL peak in alumina rich electronic components from portable electronic devices (Woda et al., 2010). Defects responsible for the higher temperature emission above 250 °C seem to be comparatively insensitive to blue photon stimulation. On the other hand the defects responsible for the OSL emissions are thermally sensitive in a very similar region (50–250 °C) in which the optically active TL signals occur (Fig. 3b). Thus it might be that the same defects are involved in TL up to approx. 250 °C and OSL.

This is investigated further in Fig. 3b–d. The OSL pulse anneal curve can be well interpolated using a fourth order polynomial regression. There is almost no difference in the fit if higher polynomial orders are used (Fig. 3b). By differentiating the polynomial expression(s), a numerical derivative of the OSL pulse anneal curve is obtained. As the area under the OSL decay curve is proportional to the number of trapped electrons n, the derivative will be proportional to dn/dt and thus this will give a TL-like representation of the thermal stability of the OSL traps. Comparison with the actual glow curve in Fig. 3c shows that, as expected, the OSL “glow curve” lies in the same region as the main TL signal but that is peaks at a higher temperature, around 200 °C, as compared to the TL glow curve, which shows two peaks around 80 °C and 150 °C. There are two possible explanations for this discrepancy: Firstly, the shape of the TL glow curve is most likely to be the result of a distribution of traps, as is often encountered in glass (Sakurai et al., 2001). Then the OSL signal, if integrated within the limits given in Section 2, might have less contribution from the more shallow, thermally less stable traps in the temperature region between 50 and 100 °C and a higher contribution from deeper, thermally more stable traps around 200 °C than the TL glow curve indicates. Secondly, the TL glow curve might be affected by thermal quenching, as is the case e.g. crystalline quartz (Wintle, 1975; Veronese et al., 2004), which would overemphasize the lower temperature part of the TL curve in comparison to the higher temperature part. The “TL curve” generated from

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