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Emergency OSL dosimetry with commonplace materials

S. Sholom*, S.W.S. McKeever

Department of Physics, Oklahoma State University, Stillwater, OK 74078, USA

HIGHLIGHTS

- Money, plastic cards, clothing and shoes were studied as emergency OSL dosimeters.
- Values of the minimum measurable doses were below 2 Gy for most tested samples.
- Tested materials could be used as emergency OSL dosimeters in triage applications.

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ABSTRACT

Several commonplace materials were studied as possible emergency optically stimulated luminescence (OSL) dosimeters. The materials included: paper currency (banknotes) and coins of different denomination and from different countries; plastic cards of different types (credit and debit cards, driver's license cards, membership cards, etc.), parts and details of clothing and shoes as well as samples of different fabrics.

The samples displayed significant variability in their OSL properties. They differed in the intensity of the initial 'native' signal; the bleaching time of the OSL signal; the sensitivity to light of different wavelengths; the fading rate of OSL signals, etc. Procedures of OSL analysis were proposed to account for this variety.

Values of the minimum measurable dose (MMD) were below 2 Gy for most tested samples if OSL measurements were conducted within one week of exposure and the samples were kept in dark since exposure (except samples of shoes that were kept under environmental light).

The OSL signals in banknotes appear to originate from compounds containing aluminum, silicon, calcium and titanium – these elements were detected using X-ray microanalysis. For coins, the source of the OSL signals is speculated to be small particles of quartz, which were detected on the coins' surfaces. The X-ray microanalysis spectra from fabrics and shoes revealed sodium, aluminum, titanium, iron and nickel as elements that appeared to be responsible for the radiation sensitivity of those samples.

It was concluded that, under certain constrained circumstances, paper and metallic money, personal plastic cards, clothing and shoes could be used as emergency OSL dosimeters in triage applications.

1. Introduction

In our previous studies (Sholom et al., 2011a,b) several materials were tested as possible emergency individual OSL dosimeters for triage applications. It was demonstrated that doses below 2 Gy (the dose level which is important in after-exposure triage, see Grace et al., 2011; Rea et al., 2010) could be recovered in many cases using radiation-induced OSL signals from teeth, nails, plastic buttons or business cards. In these previous studies some limitations on the practical use of the above materials in emergency triage were also revealed. For teeth, the limitations include the requirement to conduct OSL measurements within 24 h after emergency exposure and the necessity to use several teeth from an individual to be able to detect doses below 2 Gy. For nails, the difficulty is in finding samples that have not been in contact with environmental light during the time since emergency exposure. For plastic buttons and business cards, the main limitation is the low occurrence of samples with acceptable OSL sensitivity to ionizing radiation.

Other materials have been tested as potential emergency OSL dosimeters by other researchers. Woda et al. (2012) studied chip card modules; Discher et al. tested glass displays from mobile phones (Discher et al., 2013; Discher and Woda, 2013); electronic components of personal devices were examined by Pascu et al. (2013) while Ekendahl et al. (2013) explored the properties of glass ceramics used for dental restorations. All mentioned materials were found to be suitable, within certain limitations, for emergency dose reconstruction.

* Corresponding author.
E-mail address: sergey_sholom@yahoo.com (S. Sholom).

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In the current paper, we have continued to test materials that people may commonly have close to their bodies for use as potential individual OSL dosimeters. This time the list of materials that were selected for testing included money (both coins and banknotes), personal plastic cards, clothing and shoes.

Such choice of materials for possible dosimetric application looks at the first sight unusual because OSL dosimetry is normally associated with well-structured materials such as synthesized crystals and minerals (Yukihara and McKeever, 2011). Closer consideration, however, reveals that most of selected materials are manufactured from or contain polymers which are structured to some extent and may emit OSL signals after exposure to ionizing radiation. For example, polyvinyl chloride (PVC), which continues to be the most popular material in the plastic card industry (Barnhart, 2005), contains approximately 10% crystallinity (Gilbert, 1994); polyester (most commonly polyethylene terephthalate, or PET), which has become a very popular material used in clothes (many shirts, pants and jackets as well as garment care labels are made from this material), also demonstrates crystallinity (Hindeleh and Johnson, 1978). There are many other synthetic fabrics used in the clothes industry, but even natural fabrics like cotton contain a polymer (cellulose), see e.g. MacGregor (2002), and this polymer also displays crystallinity (Thygesen et al., 2005).

Cotton is also a dominant component of many paper banknotes. For example, according to the US Bureau of Engraving and Printing (see http://www.bep.treas.gov/uscurrency/theproductionprocess.html), US dollar banknotes use paper that consists of 75% cotton and 25% linen while paper for euro banknotes consists of pure cotton (see European Central Bank website, http://www.ecb.int/euro/pdf/material/Quick_Guide_EN_Specimen.pdf).

Other polymers can be found in shoes. Two of the most popular are ethylene vinyl acetate (EVA) and polyurethane (PU), see e.g. Subotnick et al. (2010) and Martin-Martinez (2011). These polymers are typically used in the soles of shoes and they too may demonstrate crystallinity (Verdejo and Mills, 2002).

Radiation-induced OSL signals have already been observed in polymer-based materials. In particular, such OSL signals were detected in some samples of paper business cards and plastic buttons (Sholom et al., 2011a).

An important requirement for any potential emergency dosimetry material is widespread occurrence. Money and plastic cards satisfy this requirement because they can usually be found in pockets, purses or wallets on many people. Clothing and shoes may be different for different countries and also depends on weather conditions.

Although plastic cards are associated mainly with different credit/debit cards, they are also found in many other applications. For example, today's market of plastic cards includes, credit/debit cards, driver's license cards, identity cards, membership cards, business cards, loyalty cards, gift cards, key access cards (including hotel key cards), ministry cards, discount cards, fund-raising cards, promotional cards, phone cards, integrated circuit/smart cards and many others. The scale of plastic cards occurrence could be imagined from the following numbers. According to the International Card Manufacturers Association (see website icma.com), more than 30 billion cards were manufactured globally in 2011. Among them, there were about 2 billion Visa cards issued by Visa Inc. (see website Corporate.Visa.com), 439 million Visa cards issued by Visa Europe (Visa Europe Annual Report 2011 on visaeurope.com), over 1.7 billion Mastercard cards (Mastercard 2011 Annual Report on Mastercard.com) and about 97.4 million AmericanExpress cards (2011 Annual Report on AmericanExpress.com). Worldwide statistics are not available for many of the other applications, but there are some national-scale numbers which illustrate the popular occurrence of such cards. For example, according to the US Federal Highway Administration (see website fhwa.dot.gov), there were over 210 million driver's licenses in the US in 2010. Another example is membership cards issued by American Automobile Association (AAA). According to aaa.com website, AAA had 53 million members in the United States and Canada (in August 2012).

So, it is possible to state that plastic cards have become an essential attribute of the modern life. In the wallet/purse of a typical inhabitant of a developed country could be found several plastic cards; as a minimum, a driver license and one/two credit/debit cards. Because they are usually kept in places protected from exposure to environmental light, they could be used, in principle and if sensitive enough to ionizing radiation, as emergency OSL dosimeters.

Most of plastic cards are manufactured from PVC; other materials used for plastic card production are acrylonitrile butadiene styrene or ABS (Shelfer and Procaccino, 2002), polycarbonate and polyester (Liersch, 2008). ABS plastic is a main component of many SIM cards, while the latter two materials are mainly used for manufacturing of identity cards, which are required to be resistant to mechanical deformation and weather exposure. Many vendors of plastic cards also use a combination of two materials (PVC–polyester, polycarbonate–polyester, etc.).

Many different technologies are utilized for plastic card manufacturing. For example, finishes for cards can be clear, frosted, gloss, matte, and/or UV coated; cards may be laminated for personalization. Also many options can be added to cards like barcoding, embossing, foiling, magnetic stripe, etc. All these features are reflected in the visual variety of plastic cards and may result in variability of their OSL properties.

The goal of the present work was a comprehensive study of above-mentioned materials as possible emergency OSL dosimeters. OSL signals in samples were tested with stimulation light of different wavelengths. Sensitivity to ionizing radiation was compared for different samples and for different aliquots of the same sample. Stability of the OSL signals was studied for different time intervals up to 7 days after radiation exposure.

2. Materials and methods

Thirty four banknotes (bills) from 6 countries as well as 103 coins mainly from the USA were tested in this study. Banknotes included US dollars; Ukrainian hryvnias; yuans and jiaos of the People's Republic of China; Romanian lei; Brazilian reais and European Union euros. Coins included US pennies, nickels, dimes and quarters (i.e. US cents in denominations of 1, 5, 10 and 25 cents, respectively); and Ukrainian kopiykas in denominations of 1 and 10 kopiykas.

91 Plastic cards collected from 8 vendors (sampler cards) as well as from individuals (private expired/used cards) were also tested. Additionally, 10 samples of driver's license cards were kindly provided by the Oklahoma Public Safety Department. Most cards have the same size: 85.6 mm × 53.98 mm × 0.76 mm, which corresponds to the ID-1 format, according to the ISO/IEC 7810:2003 standard. The ID-1 format is used for credit/debit cards and for driver licenses cards in many countries as well as for many other different cards. Some cards, mainly samples of plastic business cards, were thinner.

There was no information about a type of plastic used in those cards obtained from individuals, but probably most of them were manufactured from PVC. Most of sampler cards were from PVC, and some were from a combination of PVC and polyester; others had no information about composition.

The fabrics consisted of 110 samples of known composition (fabric samplers) collected from 3 vendors. Samplers included different types of cotton, silk, linen, hemp, nylon, rayon, lycra, fleece