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An affordable optically stimulated luminescent dosimeter reader utilizing multiple excitation wavelengths

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HIGHLIGHTS

- Inexpensive flexible reader for optically stimulated luminescent readout was built.
- High power light emitting diodes with multiple wavelengths used for stimulation.
- Optical light table enabled easy assembly and adjustment
- Digital acquisition board with easy programmability simplified project.

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ABSTRACT

A lower-cost optically stimulated luminescence (OSL) reader with increased flexibility for pursuing laboratory research into OSL theory and application was designed and constructed. This was achieved by using off-the-shelf optical components and higher-power light emitting diodes. The resulting reader includes more wavelengths of excitation light than current commercial readers, as well as the ability to swap out filters and other components during an experiment.

1. Introduction

During the past few decades, optically stimulated luminescence (OSL) dosimetry using aluminum oxide doped with carbon (Al_2O_3:C) has become a widely-used and effective medium for personnel dosimetry applications. The OSL mechanism relies upon the illumination of an irradiated sample with light to produce the stimulated emission of light proportional to the radiation dose that previously caused trapping of electrons in the material (Bøtter-Jensen et al., 2003a, 2003b). Of course, not all materials exhibit the phenomenon and different materials behave quite differently with respect to the extent to which they exhibit these properties. A great deal of research has been done to identify materials and formulations which produce a strong and stable OSL signal when stimulated with light of convenient wavelengths (Pradhan and Ayyangar, 1977; Henniger et al., 1982; Allen and McKeever, 1990; Miller and Endres, 1990; Kristianpoller and Oster, 1995; Jaek et al., 2002).

In addition to the personnel dosimetry application of OSL, the phenomenon has also been harnessed for the purpose of geological dating of soil samples (Banerjee et al., 2000; Bøtter-Jensen et al., 1993; Huett and Jaek, 2001; Stokes and Fattahi, 2003). By analyzing the total absorbed dose of an excavated sample of a natural OSL material such as quartz or feldspar, one can determine how long the material has been buried. This is possible because, conveniently, these minerals' OSL signal is “bleached” or reset by prolonged exposure to sunlight (Banerjee et al., 2000; Singarayer and Bailey 2004). As such, the OSL signal’s intensity can be correlated directly to the burial time of the sample. This methodology has also been applied to accident dosimetry scenarios using various building structural materials that exhibit the OSL property (Bøtter-Jensen, 2000; Inrig et al., 2008; Bailiff, 1995; Hashimoto et al., 2002).

The benefits of OSL dosimeters over thermoluminescent dosimeters (TLDs) for dosimetry applications include faster readout, greater dose sensitivity, relative insensitivity to heat and humidity,

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and the ability to perform multiple read-outs from a single sample (Bøtter-Jensen et al., 2003a). This makes OSL an attractive candidate for further research. However, to date the only OSL readers that can be purchased are either specifically intended for reading one company's Al_2O_3:C dosimetric badges (InLight® OSL Readers, Landauer, Inc., 2 Science Road, Glenwood, Illinois, 60425-1586, USA, custserv@landauer.com, +1 800 323 8830, www.landauer.com) or are designed specifically for geologic dating applications and research (Risø Laboratories Model DA-15C/D TL/OSL Reader and Daybreak Model 2200 OSL Reader). As such, these systems' components are optimized for particular materials and read-out protocols. A research laboratory interested in starting an OSL research program could modify an existing system to allow more flexibility in terms of excitation sources (e.g., allowing a variety of wavelengths, intensities, or timing), detection systems (e.g., different types of photo-detectors optimized for different emission wavelengths and intensities), electronics, software, and physical configuration. The most established commercial reader, hereafter called the Risø reader (Model DA-15C/D TL/OSL Reader, Risø National Laboratory, Frederiksborgvej 399, P.O. Box. 49, 4000 Roskilde, Denmark, risoe@risoe.dtu.dk, +45 4677 4677, www.risoe.dtu.dk), utilizes blue and infrared LEDs in its standard configuration and has a 48-sample automated changer (Markey et al., 1996, 1997; Bøtter-Jensen et al., 2003b). Limited to two wavelengths, the ability to fully study new materials is somewhat restrictive (Kearfott et al., 2015). In addition, its price, as of this writing, exceeds US$100,000. This cost does not include the additional expenses that would be required for modifications. Other readers are also available commercially with several excitation options available (Bortolot, 2000). Finally, bench-top and portable OSL readers exist specifically for dosimetry applications (Gaza and McKeever, 2006), but these devices are closed, specialized designs not intended for general laboratory research. For many research laboratories, the expense or the technical limitations of a commercial reader are prohibitive and therefore construction of a lower-cost and/or more customizable lab-built rig becomes necessary. Custom-built OSL readers have been used by various research groups for specific experimental purposes. For example, Gaza and McKeever built a custom laser-based OSL system for a fiber optic dosimetry system (Gaza and McKeever, 2006) Schilles et. al. built an early LED-based system for dating of geologic samples (Schilles et al., 1999) and Smetana et. al. built a compact LED-based system for UV dosimetry (Smetana et al., 2008). The design presented for this paper uses, to the extent possible, off-the-shelf mechanical and optical components, as well as an open table-top design appropriate for a research team desiring to have complete control and upgradeability of reader geometry and subsystems.

This paper reports the design, construction, and initial setup of a novel OSL reader that is designed to allow the maximum amount of experimental flexibility in the research of OSL material properties and physical principles. In addition, some recommendations regarding modifications that could be made to this design to allow various other specific types of experimentation in the field will be included.

2. OSL reader design and construction

2.1. General design principles

The design process began with experience using two other commercially available readers, the Risø. Though the Risø reader is very well-engineered and well-built for its intended purpose of geological dating, a number of limitations for basic OSL research were identified, including the limited number of excitation wavelengths available and the single available light detection subsystem, consisting of a bialkali photomultiplier tube (PMT) behind two high-pass filters. However, it was decided that the basic components of this design, which is very effective at reading Al_2O_3:C, would serve as a very good starting point for the design process and also allow for the performance of comparative testing on the reader once finished to validate its proper operation.

One major design priority for this reader was to allow for equipment modularity. That is, the ability to add or change excitation light sources, emission light detection systems, and associated filtration quickly and easily was considered highly desirable. This would allow us to swap out various components during a single experiment should that be required and also to change configurations depending on the particular material being studied. To obtain this flexibility, it was decided to build the reader hardware on a standard laboratory optical breadboard (Model 07OBK007, CVI Melles Griot, 200 Dorado Place SE, Albuquerque, NM 87123, USA, optics@cvimellesgriot.com, +1 505 296 9541, www.cvimellesgriot.com) and to use optical components and fittings to the degree possible. This approach allows the use of the extensive range of positioning hardware available for optical components and also provides a very simple horizontally-oriented experimental setup to allow easy component access as well as the option of incorporating large laser light sources. There were two significant challenges to this approach. First of all, a horizontal setup requires a vertical sample mounting system, unless complicated optics were utilized, which is more difficult to implement than a horizontal mounting system which uses gravity to hold the sample in a sample chamber. Secondly, using a modular layout versus a custom-machined case means that the optical efficiency of the design is somewhat lower than it would be otherwise. The former issue was addressed by designing a vertical sample holder that uses a simple vacuum pump designed for home acquarium systems to hold the sample in place. The latter issue was addressed by minimizing the light source-to-sample-to-light detector distance to the extent possible and by simply using somewhat higher experimental radiation doses to samples to create a stronger OSL signal. A photograph of the device, showing its basic layout, is included as Fig. 1.

Once the basic structure of the OSL reader was decided, the initial components to comprise the excitation and detection systems were determined. On the excitation side, LEDs were employed, instead of lasers or broadband bulbs with filters or monochromators. These light sources were selected because of (1) price, (2) speed, (3) complexity, (4) size, and (5) wavelength availability. LEDs are notoriously inexpensive, have very fast turn-

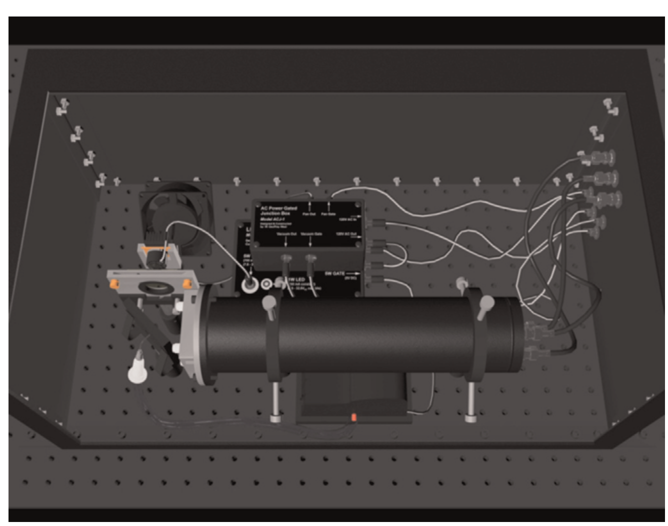

Fig. 1. Basic layout of the optically stimulated luminescence (OSL) reader.