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Effect of Temperature on Luminescence Intensity in a Natural Quartz using a Time-Resolved Pulsing System

Uriri, Akpore Solomon[1]; Unuafe Sunday Edewor[2];
Asano Nelson Omarijivwie[3]; Ese Ebhuoma[4]

[1]Department of Physics, Southern Delta University, Ozoro, Nigeria
[2]Department of Environmental Management and Toxicology, Southern Delta University, Ozoro, Nigeria
[3]Department of Geology, Southern Delta University, Ozoro, Nigeria
[4]Department of Environmental Management, University of Bedfordshire, Luton
Corresponding Author: Uriri, Akpore Solomon[1]

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Abstract: Time-resolved stimulated luminescence is a method that is employ for the study of dosimetric materials including quartz, feldspar, carbon doped aluminium oxide, important materials used in dosimetry. Time-resolved OSL separate in time the stimulation and emission of luminescence. The dependence of luminescence intensity on measurement temperature was investigated using a newly designed LEDs based pulsing system. The intensity of the luminescence obtained decreases as the measurement temperature increases from 20^{0}C to 200^{0}C for quartz annealed at 500^{0}C and irradiated to 85 Gy. The luminescence intensity increases as the temperature was decreased from 200 to 20 ^{0}C. A similar trend was observed in both cases for change in intensity with respect to measurement temperature. The change in intensity against measurement temperature is as result of thermal quenching. The thermal energy of thermal quenching ΔE obtained was 0.62 ± 0.08 eV from 20 ^{0}C to 200 ^{0}C and ΔE = 0.67 ± 0.08 eV from 200^{0}C to 20^{0}C in steps of 20^{0}C.

***Keywords**: Quartz, Luminescence Intensity, Temperature. Pulsing System, Leds, Thermal Activation Energy, Time-Resolved Luminescence.*

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I. INTRODUCTION

Luminescence is a process whereby light of an unknown wavelength is emitted from irradiated materials, such as semiconductors and insulators when exposed to light at a wavelength different from the wavelength of the irradiated material or heated. There are different forms of luminescence including thermoluminescence, optically stimulated luminescence (OSL), photoluminescence, etc. Optical stimulation is the light emitted at a given wavelength from an irradiated materials such as semiconductors or insulators during exposure to light at a wavelength different from the wavelength of the irradiated material. Optical stimulation measurements are performed by stimulating an irradiated material with light in the ultra-violet, infrared, or visible region of the electromagnetic spectrum.

Time-resolved optical stimulation (TR-OSL) is an important technique for measuring OSL whereby light short pulses of same intensity are used to separate the emission and stimulation of luminescence in time (Uriri, 2016). The luminescence measured is stimulated using a short pulse emitting visible, infrared light or ultra-violet at a certain wavelength. A photomultiplier tube was used to detect the emitted luminescence. The signal measured consists of scattered stimulated light and luminescence component increasing linearly. After the brief pulse, the scattered light stimulated and the luminescence are segregated by the use of band pass filters and transmission filter. The luminescence is transmitted using the band pass filters and the intensity of the stimulated scattered is attenuated by using the the transmission filters (Botter-Jensen, 1997; Galloway et al., 1997). The exponential decrease in the measured luminescence intensity

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in time resulted to a decay curve. In time-resolved luminescence, the decay curves can be separated by non-linear regression into three principal components, respectively; the fast, medium and slow component **(**Chithambo and Galloway, 2001; Bailey et al., 1997; Smith and Rhodes, 1994). Time-resolved luminescence technique gives high signal-to-noise ratio over extended measurement times (Galloway et al., 1997). From the spectra obtained from time-resolved luminescence, we can get the details of the process of the radiative recombination relating to the nature of the defects and particular bands where recombination takes place (Bailiff, 2000).

Measurement systems for time-resolved luminescence based on LED systems and lasers have been reported (Chithambo and Galloway, 2003; Markey et al., 1995; Chithambo, 2011; Sanderso and Clark, 1994.). Sanderson and Clark (Sanderso and Clark, 1994] make use of a 470 nm blue light from an N2 dye laser to generates optically stimulated luminescence from alkali feldspar with a pulse having a width of 10 ns. In 2003 [Chithambo and Galloway, 2003), Chithambo and Galloway obtained time-resolved lumunecence from quartz and feldspar using a 525 nm green LED system. Markey and his colleagues (Markey et al., 1995) carried-out time-resolved luminescence to investigate properties of luminescence from carbon doped aluminium oxide using an Ar-ion laser as the stimulation source.

II. THE NEW PULSING SYSTEM

A schematic diagram of the newly designed pulsing system is shown in Figure 1. Figure 1(a) shows how the measurement and detection of time-resolved luminescence spectra was obtained. Figure 1(b) shows the diagram of the designed circuit that was implemented to generates the short pulse. The system for detection shown in Figure 1(a) was described by Galloway [Galloway, 2002), Chithambo and Galloway (Chithambo and Galloway, 2003), and Chithambo [Chithambo, 2011). The newly designed pulsing circuit represented in Figure 1(b) is new and described in detail. A monostable multivibrator consisting of a NE555N timer IC was used to produced short pulses of different duration and the output pulses are sent into a MOSFET transistor (2N700 MOSFET transistor). A 16 LEDs set that are placed in a dural holder were used to stimulate the luminescence, with a long-pass filter (Schott GG-420) positioned in front of each LED to stop stimulated scattered light from entering the photomultiplier tube. A transmission filter (Schott BG39), with a peak at 340 nm was positioned in front of the photomultiplier tube to transmit the generated luminescence to the photomultiplier tube. The luminescence obtained from several measurements is combined giving rise to a time-resolved luminescence spectrum. The spectrum is obtained by timing the duration between a STOP and a START signal. The START signal that triggers the LEDs based pulsing system to turn ON the 16 LEDs for stimulation is produced by the multichannel scaler. The photomultiplier tube was used to detect emitted luminescence and the signal fed into the combination of a timing filter amplifierand a constant-fraction discriminator. A valid STOP signal is provided by the first arriving photon signal detected from the sample of quartz stimulated. The luminescence-photon counting rate is recorded by the multichannel scaler until a STOP signal arrives. To stop scattered stimulation light from reaching the photomultiplier tube, a long pass filter was positioned before the 16 LEDs. A transmission filter (Schott BG39) was then positioned before the photomultiplier tube that transmitted the emitted luminescence.

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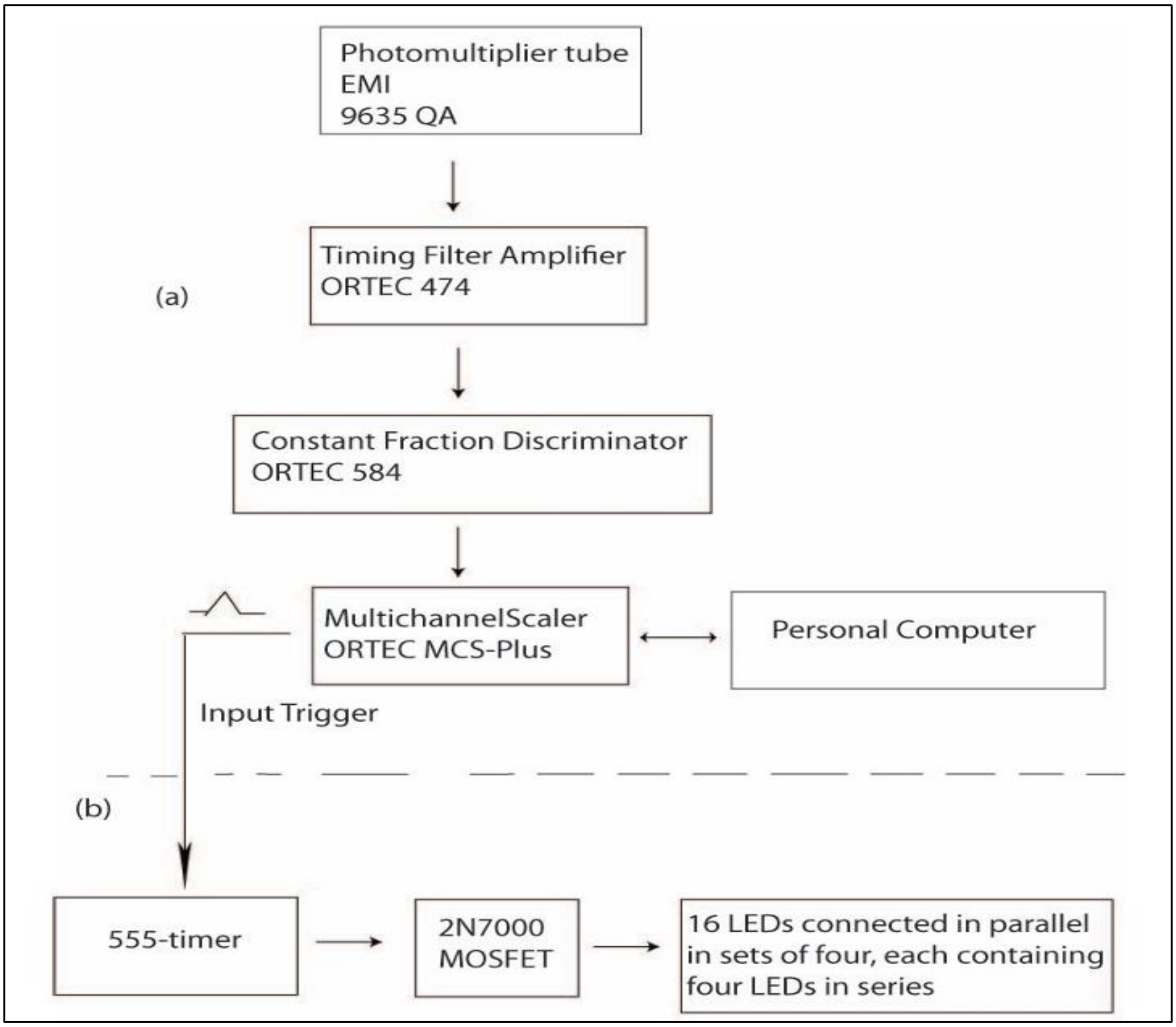

Fig 1: The Arrangement of the Pulsing System that was used for Detection and the Recording of Time-Resolved Luminescence Spectra (a) and the LEDs based Pulsing Circuit (b)

The signal detected by the photomultiplier tube is fed into the combination of a constant-fraction discriminator and a timing filter amplifier. The work of the timing filter amplifier is to optimize the signal-to-noise ratio and shape the pulses for time-based measurements. These are then sent to a constant-fraction discriminator for counting. The multichannel scaler at the same time triggers the pulsing circuitry and records the counting rate of events with respect to time.

III. RESULTS AND DISCUSSION

The influence of measurement temperature on luminescence intensity was studied in a natural quartz annealed at 500 ^{0}C. The measured intensity was realized by summing the TR-OSL spectrum that correspond to each run of measurement temperature from 20 ^{0}C to 200 ^{0}C. The influence of measurement temperature on the luminescence intensity is shown in Figure 2. From 20 ^{0}C to 200 ^{0}C, the luminescence intensity decreased with temperature and increased with temperature from 200 ^{0}C to 20 ^{0}C.

The change in intensity with temperature in both cases is similar. The change in intensity with measurement temperature as shown is due to thermal quenching described using the following equation

$$I(T) = \frac{I_0}{1 + A\exp\left(-\frac{\Delta E}{KT}\right)}, \quad (1)$$

where I_0 represents the value of the initial luminescence intensity, A is a scaling parameter, K is the Boltzmann constant, ΔE thermal activation energy, and T measurement temperature (17, 36). Thermal quenching occurs due to an

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increased probability at elevated temperature of non-radiative transitions.

The luminescence spectra of Figure 2 were fitted to Equation 3. From the fit, ΔE = 0.62± 0.08 eV; A = 7 x 10^7 for measurements from 20 ^{0}C to 200 ^{0}C and ΔE = 0.67 ± 0.08 eV; A = 7 x 10^7 for measurements from 200 ^{0}C to 20 ^{0}C. The values of ΔE obtained agree with those presented in the literature (Galloway, 2002; Chithambo and Galloway, 2001; Murray and Wintle, 1998). For example, Galloway (Galloway, 2002) reported 0.72 ± 0.08 eV for ΔE for a sample of a natural quartz without preheating annealed at 500 ^{0}C. Chithambo and Galloway (Chithambo & Galloway, 2001) presented 0.68 ±0.11 eV for ΔE for temperature from 20 ^{0}C to 200 ^{0}C and 0.57 ± 0.08 eV for temperature from 200 ^{0}C to 20 ^{0}C for natural quartz.

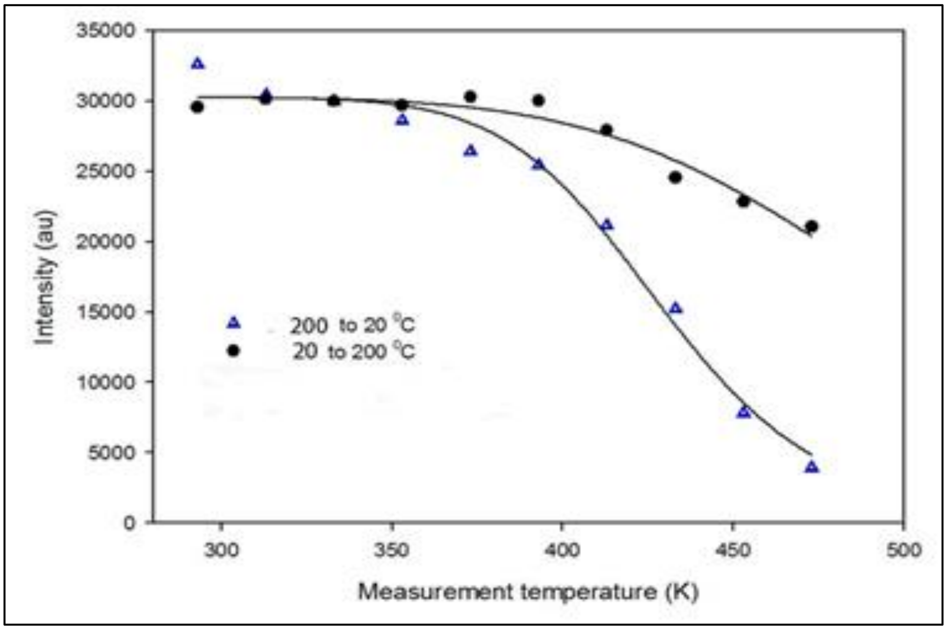

Fig 2: A plot showing the Influence of Temperature on Luminescence Intensity in a Natural Quartz Irradiated to 85 Gy and Annealed at 500 ^{0}C. Measurements were Made from 20 ^{0}C to 200 ^{0}C and from 200 ^{0}C to 20 ^{0}C, in 20 ^{0}C Steps, Respectively

IV. CONCLUSION

A new LEDs pulsing system for measurement of TR-OSL is developed. The pulsing system was used to study the dependence luminescence intensity on measurement temperature. Results obtained using the pulsing system to measure the dependence of luminescence intensity on temperature were presented and discussed. The LEDs in the system are pulsed at various time duration by a 555-timer IC working as a monostable multivibrator. The output signal from the pulsing system was detected by a photomultiplier tube and send to a computer screen for recording.

The time-resolved optical stimulation spectra from quartz are obtained to show the performance of the system. The measured luminescence intensity increased for measurement temperature between 200^{0}C and 20^{0}C and increase between 20^{0}C and 200^{0}C in steps of 200C in a natural quartz annealed at 500^{0}C and irradiated to 85 Gy. The decrease intensity as the temperature increases was as a result of thermal quenching. For measurements from 20 to 200 ^{0}C, ΔE of 0.62± 0.08 eV was obtained for the quartz. For temperature from 200 ^{0}C to 20 ^{0}C, we obtained ΔE of 0.67 ± 0.08 eV.

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