Luminescence Instrument : A Brief Overview

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ABSTRACT

Luminescence signal is normally used in radiation dosimetry and geological chronometry. This article gives an introduction to the instrumentation used for stimulation based luminescence studies. Detail description of the system cannot be explained sensibly in one short review. Instead here the focus is to introduce the main unit of the luminescence reader to a non-expert user. This paper covers the main idea of luminescence and three main units of luminescence system i.e. stimulation unit, detection unit and irradiation unit.

Keyword : - *Luminescence Instrument, Detection Unit, Stimulation Unit, Irradiation Unit*

1. INTRODUCTION

Luminescence is a phenomenon of emission of light on the application of the internal or external stimulation. It is common among insulators like naturally occurring minerals (e.g. quartz, feldspar etc). The mechanism of luminescence can be understood by the band theory of solids.

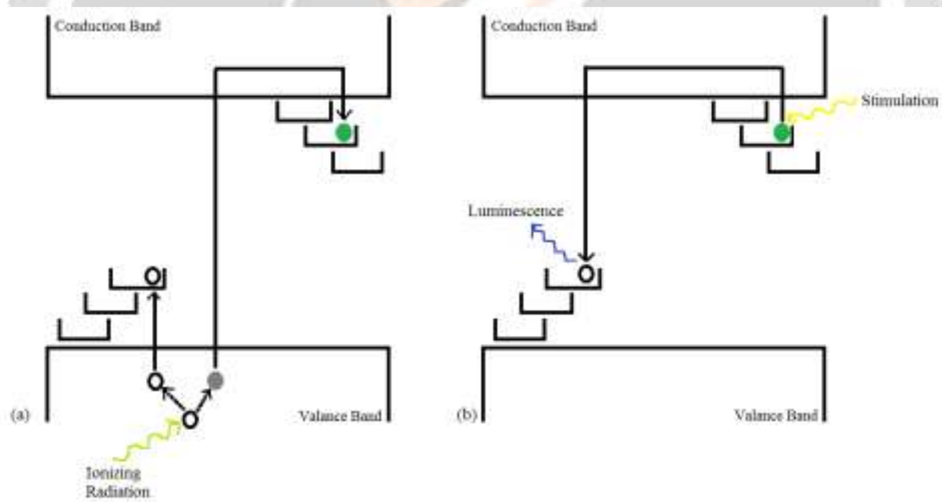

Fig. 1. (a) Ionization and charge trapping, (b) Charge detrapping and recombination

In pure crystal forbidden gap do not have any allowed energy states. However no crystal is pure in nature. It contains imperfections in their crystalline structure. Some of these imperfections provide localised metastable energy states within the forbidden gap of the material. In insulator, valance band is full of electrons and conduction band is usually empty. As shown in Fig. 1(a) charges are created in crystal when they are exposed to ionizing radiation. Most of the electrons will recombine soon but some get trapped storing the energy of the radiation in the form of trapped charges in the defects. The residence time (also called the lifetime) of the charges in the traps depends on the depth of the traps (that is energy required to free an electron from them) and can vary from less than a second to several million years. When stimulation is applied on the electrons in metastable states (Fig. 1(b)), they are released and some of them recombined and emit light. Recombination can happen at trapped electron or hole sites, or at new traps called luminescent center sites.

The light emitted is called luminescence and plays an important role in dating ancient materials and in the measurement of the absorbed dose delivered by ionizing radiation. Depending on the nature of stimulation, luminescence is known by different names like thermoluminescence (TL - stimulation by heat) , optically stimulated luminescence (OSL - stimulation by light) etc. Among these methods OSL is widely used technique and has been trending among researchers for many years. The light emitted is detected by highly sensitive light detectors and the output can be obtained in form of graphs or two dimensional images.

To obtain accurate results in measurement related studies, instrumentation plays an important role. Here in our discussion also, to estimate the final dose obtained from sample, a well developed instrumentation is needed which is characterised by its sensitivity, reproducibility and reliability. The basic arrangement of the luminescence instrument for both TL and OSL based stimulation is shown in Fig. 2. The irradiation unit is placed aside of stimulation unit. This discussion introduces the main units of the system : thermally stimulation unit, optically stimulation unit and the reference irradiation unit. The chapter discusses developments around Risø TL OSL reader which is very popular in luminescence studies.

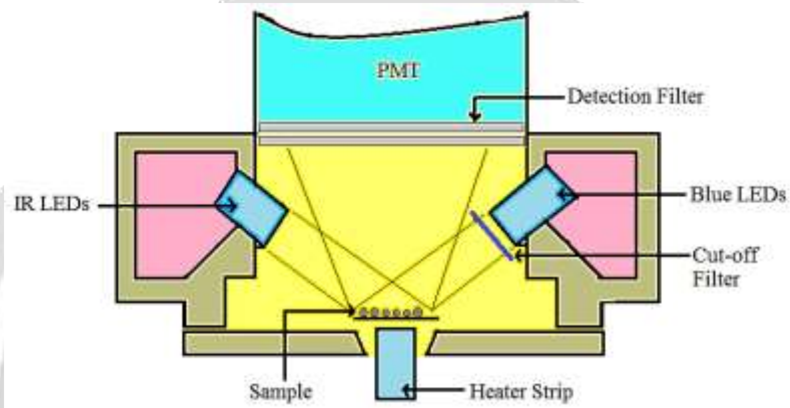

Fig. 2 : Basic Schematic Diagram of combined IR and Blue LED OSL unit[1].

2. THERMALLY STIMULATION UNIT

Heating the sample at the fixed rate from room temperature to higher temperatures between 450 ℃ and 700 ℃ releases the trapped charges and the signal generated is called thermoluminescence (TL). Another purpose of this unit is for preheating. Before OSL measurement the sample is heated so the unstable electrons from the shallow traps are emptied and we can get the signal from the deeper traps which we are interested in. This heating is called preheat. Thus, TL unit should be able to perform the preheat and heating of the samples at different and constant rates. High resistive alloys (e.g. Nichrome and Kanthal) are used to make a heater strip. To apply the heat in controlled manner a feedback mechanism is employed using thermocouple which is welded beneath the heater strip. High frequency AC heating (20-40 kHz) allows the use of small size ferrite pot core transformers to transfer the required power (~100 VA) to the heating element[2].

3. OPTICALLY STIMULATION UNIT

The main idea in the OSL studies is to stimulate the irradiated sample with light source by applying selective wavelengths. The intensity of the light can be constant or variable with the help of continuous or discrete pulses of frequency. Depending on that it is also termed as Continuous Wave OSL (CW-OSL, i.e. constant intensity) and Linearly Modulated (LM-OSL, i.e. changing intensity with the help of feedback) etc. Huntley et al. first proposed the application of OSL in dating, by measuring blue/violet light from quartz using Argon laser (~514.5nm) [3]. Filter lamp system was also used before LEDs (Light Emitting Diodes) become available[4][5]. In contrast to lamp and laser, LEDs have advantages like compactness, well defined wavelengths, cheapness and one has better control on their intensity by modulating the current. Currently there are two main techniques used in OSL, one is an array of IR (Infrared) LEDs and second is an array of blue LEDs. As shown in Fig. 2 the clusters of these LEDs are arranged in the ring shaped holder. An array of IR (Infrared) LEDs (～880nm) is normally used to stimulate the feldspar which emits light beyond the visible spectrum. But infrared stimulated luminescence (IRSL) is only measured from feldspar not from quartz[6]. This fact can be used to check the purity of the quartz. Another alternative is blue LEDs (～470nm) which generates OSL from both quartz and feldspar. To minimize the scattering of blue light a long pass filter (e.g. GG-420) is fitted in front of every cluster of blue LEDs.

4. DETECTION UNIT

In OSL as the stimulation source is light, the major challenge is to distinguish between the signal emitted and other detectable light of the source. Luminescence generated from the sample is normally weak and invisible to naked eye. Intensity ratio between stimulation light and emitted light is of huge order (equivalent to $10^{10} - 10^{15}$). So sensitivity of the detector is very important. The two most commonly used detector types are photo-multiplier tube (PMT) or solid state detectors (like PIN diodes, avalanche photodiodes (APDs), charge coupled device (CCD) etc).

PMT is widely used light detector in luminescence instruments since decades. The basic principle of PMT is that an impinging photon produces a pulse of electrons in the detector. Basically it is a vacuum tube consisting of photosensitive cathode, number of electron multiplying dynodes and anode held at the high voltage (+1000 volts relative to cathode). It detects light at the cathode, which emits electrons by the photoelectric effect. These photoelectrons are accelerated and focused on the electron multiplier dynodes who in turn generates secondary electrons. With the help of these subsequent dynodes thousands of electrons are produced and reach at the anode. Thus, a photon reaching the photo-cathode is converted to an electrical pulse at the anode.

To minimize the scattering and reflection of stimulation light and to increase the photon count rate different combinations of optical filters are used. The main function of the filter is to allow emitted light band from the sample and to reject scattered light from the stimulation source. To achieve good signal-to-noise ratio geometrical arrangement is also important. The characteristics of light detectors are its quantum efficiency (percent of photons detected out of the total reached at the detector), gain, pulse width, dark counts (counts generated in the absence of the light).

5. IRRADIATION UNIT

A set of laboratory measurements is done to calibrate the luminescence response of each sample to derive the dose received in nature. Most frequently used measurement approach is to measure the signal from an naturally dosed sample and then apply the known reference doses in laboratory and measure these regenerated luminescence signals. Thus by generating characteristic growth curve of luminescence signal with respect to laboratory doses, and then interpolating the natural luminescence signal on that curve, one can estimate the irradiation dose received in nature.

Normally $^{90}Sr/^{90}Y$ beta source is used to give reference doses to the sample. It emits beta particles with a maximum energy of 2.27 MeV. It can produce a dose rate in quartz of approximately 0.1 Gy/s (1.48 GBq source) at the sample position. The advantage of using radio isotopes as irradiation source is that they have longer stability (half life is about 30 years). But on the other hand shielding of beta source is difficult and distribution of it in the outside world can create problems. The irradiation unit may also contains alpha irradiator ^{214}Am (10.7 MBq) foil source, which is a mixed alpha/gamma emitter. The energy ratings are about 5.49 MeV and 59 keV for alpha and gamma particles respectively. It can produce a dose rate of approximately 45 mGy/S for quartz at sample position.

As an alternative of radio isotope irradiator a mini X-ray generators have been investigated[7]. X-ray generators have several advantages like user variable and high dose rates, excellent linearity between tube current and dose rate, highly uniform irradiation of the sample area etc. One example of X-ray generator used in TL/OSL reader is Varian VF-50J X-ray tube (50kV, 1mA, 50W) with dynamic range of 2-30 mGy/s at 10kV and 10-2000 mGy/s at 50kV.

6. REFERENCES

[1] Guide to "The Risø TL/OSL Reader", DTU Nutech, Denmark. August 2015

[2] L. Bøtter-Jensen, E. Bulur, G.A.T. Duller, A.S. Murray, "Advances in luminescence instrument systems", Rad. Meas. 32 (2000) 523-528.

[3] Huntley D. J., Godfrey-Smith D. I. and Thewalt M. L. W., "Optical dating of sediments". Nature 313,105-107. (1985)

[4] Hutt G. and Jaek I., "Infrared photoluminescence (PL) dating of sediments modification of physical model equipment and some dating results in long and short range limits in luminescence dating", Occasional Publication No 9, Research Laboratory for Archaeology and the History of Art, pp 21-25. (1989a)

[5] Hutt G. and Jaek I., "Infrared stimulated photoluminescence dating of sediments". Ancient TL 7, 48-51. (1989b)

[6] Spooner N. A. and Questiaux D. G., “Optical dating– Achenheim beyond the Eemian using green infrared stimulation”. In Synopses from a Workshop on Long and Short Range Limits in Luminescence Dating, Oxford, April 1989. [RLAHA Occasional Publication No. 9, pp. 97-I03]

[7] C.E. Andersen, L. Bøtter-Jensen, A.S. Murray, “A mini x-ray generator as an alternative to a $^{90}Sr/^{90}Y$ beta source in luminescence dating”, Rad. Meas. 37 (2003) 557-561