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PORTABLE DOSIMETERS FOR ENVIRONMENTAL MONITORING*

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ABSTRACT

With the increasing use of nuclear energy, particularly for power production, there is need for radiation detection and dose assessment. There is every need for the development of portable dosimeters for personal and environmental monitoring in the fields like medicine, nuclear engineering, space exploration, etc. Attempts are being made to develop portable solid state dosimeters for in-situ measurements by utilising the techniques like thermoluminescence, thermally stimulated currents and optically stimulated luminescence. Some of the salient features of the above techniques for various types of dosimeters are described and discussed in this paper.

Key words: Thermoluminescence, Portable dosimeter, Environmental monitoring

INTRODUCTION

Since the creation of life on this planet, man has always been exposed to various radiations from space and from naturally occurring radioactive materials present in the earth, sea, air and even his own body. From the last century onwards, mankind is aware of all these radiations. These radiations are highly dangerous, since they are not sensed by any of the five sensors of human body. With increase in the usage of ionizing radiations and radioactive materials in medicine, industry and research, it has become necessary to develop techniques for assessing or measuring these radiation exposures on individual workers and on public at large. There is every need for portable dosimeters for personal and environmental monitoring in the fields like medicine (UV, x-rays), nuclear engineering (γ-ray, neutrons) and space exploration (cosmic rays). There is a fast growth in the development of radiation detectors and devices in the past few decades and these are being routinely used for environmental monitoring. Thermoluminescence (TL), radiophotoluminescence (RPL), optically stimulated luminescence (OSL), thermally stimulated currents (TSC), thermally stimulated exo-electron emission (TSEE) are some of the solid state methods in addition to ionisation chamber, Geiger counter, scintillation counter etc. Of these methods, TL is the best so far in the field of environmental monitoring because of its durability, stability, simplicity and accuracy. Recently attempts are being made to design a miniature TL dosimeter [1-3] to be used for in-situ measurements.

The direct association of TL with radiation was reported in the early days of this century [4,5]. The application of TL to radiation dosimetry really started with the investigations of 1950 [6]. Till 1960, TL dosimetry (TLD) was fruitfully used mainly in the field of medical and personnel dosimetry. Efforts were then made on the phenomenon of TL, development of instrumentation and technical procedures. The usage of TLDs was extended to environmental monitoring in mid-1960s in different ways, for example, the roof tiles from Hiroshima (Japan) were used to determine the doses from the atom bomb (Little Boy) [7,8], distribution of TLDs in the form of lockets to be worn around the neck or waist to individuals in the high radiation background monazite zones spread over coastal Kerala and Tamilnadu [9] and in Brazil [10] to assess the population doses over 3-6 month intervals, TLD measurements were made over 4 and 7 weeks at various locations and depths in the Columbia river to determine the doses resulting from the cooling water effluents discharged from nuclear reactor near Hanford and consequent radiation exposure to river organisms [11]; TLDs were also used in space programs for measuring radiation doses during manned spacecrafts [12-15] and so on [16]. The development and usage of OSLDs and TSCDs, when compared with rapid growth of TLDs, have not obtained much encouragement in the past. Recent findings [17-20] reveal that these methods too could be more advantageous in many aspects with TLDs and other solid state dosimetry systems. The present paper deals with the phenomenon of stimulation process, phosphor materials, design and fabrication of miniature dosimeters based on TL, TSC and OSL methods.

MODERN SOLID STATE DOSIMETERS

Thermoluminescence Dosimetry (TLD)

Some materials emit light when heated after exposure to radiation (ionising as well as particles). This phenomenon is known as thermoluminescence, and the technique used in the measurement of radiation is known as 'TL dosimetry' (TLD). TL involves two steps. In the first step, the solid is exposed to the exciting radiation such as electromagnetic radiation or particles at a fixed temperature (say, room temperature). In the second step, the sample is heated at a certain rate of heating, and while heating the sample emits light. During exposure to radiation, a fraction of the energy is stored or trapped in the trapping centres (luminescent). The trapped energy is released in the form of visible light while heating. The luminescence intensity as a function of temperature, which exhibits several maxima is called TL glow curve. There are certain factors to be considered for an efficient TLD like linear energy transfer (LET) or storability, fading, tissue equivalent, stability, reproducibility, emission, durability, etc. [27]. Many materials [22] are developed and are being developed in various laboratories to satisfy the above factors. But a few materials like LiF, CaF_2, $Li_2B_4O_7$, BeO and $CaSO_4$ are commercialised under various trade names. After the successful use of this technique (TL) in radiation dosimetry, its applications developed towards automation. Because of the simplicity and suitability for automation, much R & D work has been carried out on this type of dosimeters, and many automatic TL readers have appeared in the commercial market.

Optically Stimulated Luminescence Dosimetry (OSLD)

OSL phenomenonn is related to the emitted light (visible) after stimulation (IR) of previously irradiated (ionising/particle) phosphor material. This 'cold method' is very similar to TL evaluation; the essential difference is transfer of activation energy i.e. optical instead of thermal energy. The emission (detrapping) depends on the stored (trapped) energy and the nature

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of stimulation. Selection of a suitable material for an OSLD of a specific purpose particularly in environmental monitoring, is a major task. Till today, MgS:RE [23], CaF_2:Mn, BeO and $CaSO_4$:Dy [24-25] have been investigated. Further experimentation is needed to standardise the method, to be used as an efficient dosimeter. With respect to TL, this technique has more advantages like non-heating, fast reading and non-destructive.

Thermally Stimulated Current Dosimetry (TSCD)

As mentioned in TL, the trapped energy could be released while heating, after irradiation in the form of transient electrical conductivity. This is called thermal current (TC) effect. It can also be called "Radiation Induced Thermally Activated Currents (RITAC)" or TSC. Until half decade ago, TC was not seriously proposed for a sensitive dosimetry. Recent discoveries on high purity dielectrics (like Al_2O_3) reveal that TC ,ensitivities are fully competitive or better than TL sensitivity. No doubt it has an excellent future. The main advantages are: simple read-out, more direct, easy device fabrication and no optical components and PM tube. It is an absolute measurement.

EXPERIMENTAL

Brief description of material preparation of alkaline earth sulphides like BaS and MgS are given since these materials are used in development of above dosimeters [26,27]. It was also observed that mixed systems like (Ba, Ca)S phosphors are more efficient than simple sulphides [28]. BaS, MgS and mixed systems have been prepared by firing the mixture of respective sulphates, spec pure carbon, NaCl flux [29] and dopants [30] in the form of sulphates or chlorides at 800-1000°C for 1 to 2 h in a tubular furnace; the details of material preparation and characterisation were described in earlier papers [31,32].

In TL and TSC experiments, phosphor samples of average grain sizes [33] packed in a small brass well, are exposed to various radiations. After excitation, the samples are transferred to a vacuum chamber of TL/TSC set-up [34,35]. The TL and TSC are recorded by heating the sample under vacuum (10^{-2} torr) at the rate of 30°/min. To study the LET and fading, the samples are exposed in dark to different doses and stored in dark for different durations of time.

In case of OSL, after excitation the samples are stimulated with IR from a YAG:Nd laser. While firing the sample with a fine beam of laser, the emission was displayed on a storage oscilloscope. By measuring the total area/height of the emission peak, the energy stored in the material could be determined. The experimental details are given elsewhere [36].

RESULTS

For an efficient dosimeter, storability or linear energy transfer (LET) and fading (loss of stored energy with duration of time) are the two important features. Some of the results on LET and fading of alkaline earth sulphide phosphors are presented here. Fig. 1 shows the TL glow curves of (Ba, Ca)S:Cu excited by x-rays of different durations where dosimetric peak at 180°C increases with dose and attains a saturation at a certain value. TL glow curves of (Ba, Ca)S:Cu recorded after storing at different durations of time are presented in fig. 2, which shows the fading behaviour. The excitation (ionising) emission (visible) and stimulation (IR) spectra of MgS:RE phosphors are given elsewhere [37]. These spectra are essential to understand the OSL phenomenon of a particular phosphor to be used in OSLD. It was observed that stimulation maximum of MgS:Eu, Sm was around 1.07 μm which is very close to the emission of YAG:Nd laser (1.06 μm). Fig. 3 shows the stimulation of MgS:Eu, Sm with YAG:Nd laser.

Thermally stimulated current (TSC) curves of BaS:Cu, Bi are shown in Fig. 4 which are recorded after excitation with x-rays. It was observed that the low temperature peak is destroyed with 30 min storage and the fading of high temperature peak is 20% with 3 h. storage. Fig. 5 gives the fading behaviour of BaS:Cu, Bi phosphors. The above results are of preliminary nature and needs further investigations.

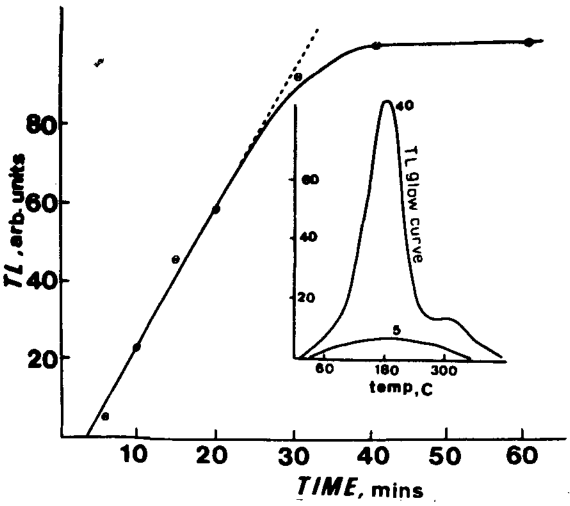

Fig. 1 TL glow curves of (Ba, Ca) S: Cu; Dose Response

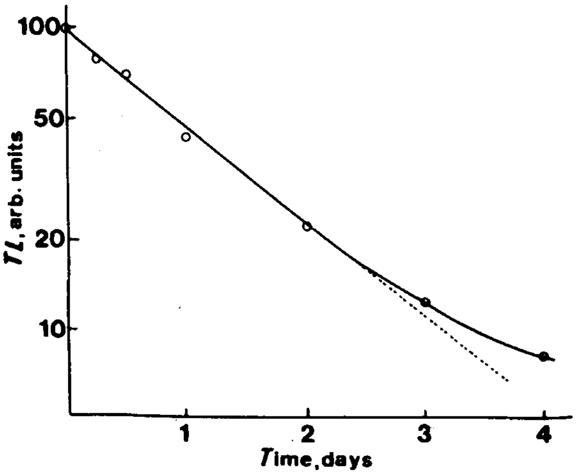

Fig. 2 TL glow curves of (Ba, Ca) S: Cu; Fading

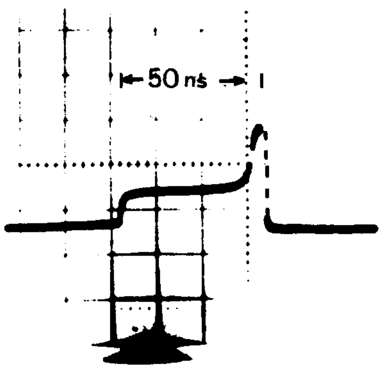

Fig. 3 YAG: Nd Stimulation of irradiated MgS: Eu, Sm

DESIGN OF MINIATURE DOSIMETERS

The mini-dosimeters function on Si, PIN diodes, PMOS transistors and small ionization chambers are used in enviornmental monitoring for a specified dose. But their sensitivity is limited and get damaged permanently beyond certain radiation levels. Hence it is proposed to develop mini-dosimeters functioning on TL/TSC/OSL.

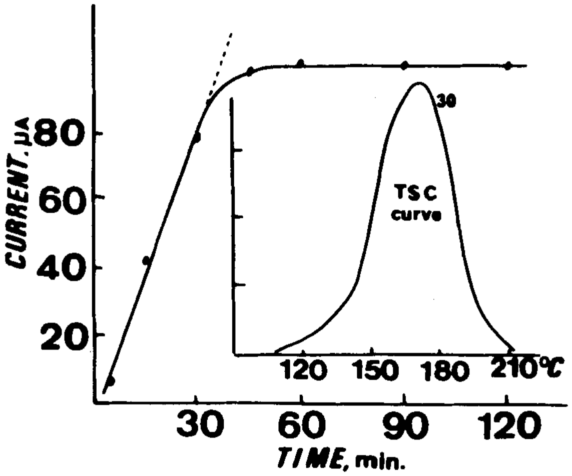

Fig. 4 TSC curves of BaS: Cu,Bi; Dose response

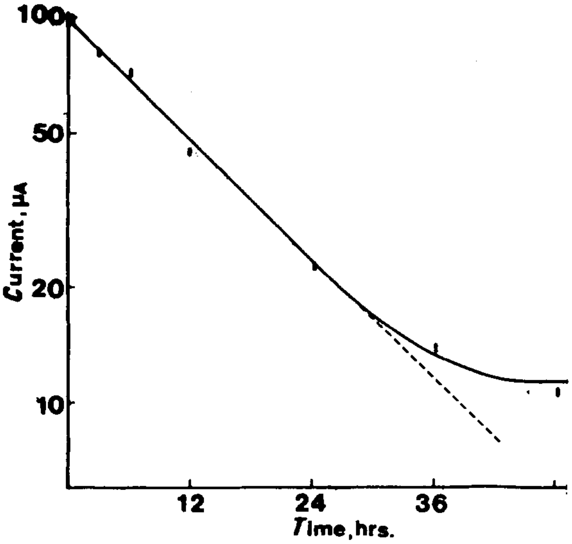

Fig. 5 TSC curves of BaS: Cu,Bi; Fading

The most important advantage here is that the phosphor material could be changed according to the dose specifications in the range 10^{-6} to 10^{6} R. The workers [39] in Central Research Institute for Physics of the Hungarian Academy of Sciences have designed and fabricated mini-TLD and successfully used it to measure the cosmic radiation doses during space flight of cosmonauts. The TLD readers have also been used for environmental monitoring where TLD reader is built into a cross-country car; so the dose measurements are carried out in the field (the measured dose values can immediately be reported back by radio—an important aspect in an emergency situation). This NA-206E based on $CaSO_4$: Dy TLD is operated by a 12 V car battery, with its built-in automatic range switch covering 7 orders of magnitude (10^{-4} to 10^{3} R). It is still possible to develop further and the possibilities are described below.

Main features

(a) Conventional thermal heating could be replaced with laser heating in TLD technique. Laster heating is very accurate, fast and simple to operate. Since the laster technology is so advanced, it is very easy to select a laser of smaller size with less voltage.

(b) It is also possible to replace PM tube and its accessories like HV source, amplifiers etc. by a photodiode or a phototube of high efficiency with ICs. The integrated and amplified signal from the diode is fed to a display meter (LDC) or an x-y recorder and to a memory from where the stored information could be analysed through a computer for further studies.

(c) All complicated problems with optical components and alignments could be minimised by using TSC instead of TL technique. The details of design and fabrication of this type of dosimeter are given in previous paper [39].

Finally, these mini-dosimeters can be used fruitfully not only in environmental monitoring but also in personnel, accidental, and other immediate measurements. These dosimeters can also be used in spececrafts and minimise weight and space problems. With these systems, the crew could measure the radiations in space and send the information frequently to the ground station for further study and necessary action, instead of reading the TLD badges after the completion of the mission.

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