DOSIMETRIC PROPERTIES OF Al_2O_3:C, Mg EXPOSED TO EXTERNAL COBALT-60 GAMMA IRRADIATION

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I specially dedicate this work

To my parents,

Saharin bin Kassim & Surianti Juhri

To my siblings

Hanaffee,Naqquiddin,Shafiq,Hafiz

To my specials

Mohd Rizuan bin Mat Amin

To my supervisors, friends

And Everybody that have contributed

Thank you for always with me along to complete this journey,

I am very appreciates with your support and help.

Thank you for all the memories.

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ABSTRACT

This study concerns on the thermoluminescence properties of Al_2O_3:C, Mg exposed to cobalt-60 gamma rays. The thermoluminescence properties investigated were thermoluminescence glow curve, linearity, sensitivity, fading, reproducibility, minimum detactable dose, energy response and thermoluminescence parameters. The samples were supplied by Testbourne Ltd, England in the form of sputtering target and the samples were crushed into powder form with grain size of 75 µm to 200 µm. The crystalline phase of the samples was identified using X-ray diffraction analysis. The results indicated that the powder samples are in polycrystalline state. Thermoluminescence properties were investigated by irradiating the samples to cobalt-60 gamma ray with doses from 5 Gy to 70 Gy. The glow curves were analyzed to determine various thermoluminescence properties of the samples. The results clearly show that Al_2O_3:C (0.2%), Mg (0.2%) has better thermoluminescence properties in terms of sensitivity, linearity, reproducibility and fading compared to other samples. Z_{eff} of the samples were calculated as 10.83 ± 0.01 and the results are close to Z_{eff} of bone. The total mass absorption coefficients of Al_2O_3:C (0.2%) and Al_2O_3:C (0.2%), Mg (0.2%) were calculated using WinXCom software in order to calculate the photon energy response of the samples. By using the trumpet graph, the values of R ($D_{measured}$ / $D_{delivered}$) for Al_2O_3:C (0.2%), Mg (0.2%) sample were within the acceptable limit recommended by ICRP. The average activation energy of Al_2O_3:C (0.2%) and Al_2O_3:C (0.2%), Mg (0.2%) were calculated as 2.03 eV and 1.49 eV, respectively. The frequency factor calculated from TL glow curves of Al_2O_3:C (0.2%) and Al_2O_3:C (0.2%), Mg (0.2%) were 2.61×10^{25} s^{-1} and 7.51×10^{17} s^{-1}, respectively.

ABSTRAK

Kajian ini tertumpu kepada sifat termoluminesens Al_2O_3:C, Mg yang didedahkan kepada sinar gama cobalt-60. Sifat termoluminesens yang dikaji ialah lengkung berbara, kelinearan, kepekaan, kelunturan, kebolehgunaan semula, dos pengesanan minimum, sambutan tenaga dan parameter termoluminesens. Sampel dibekalkan oleh Testbourne Ltd, England dalam bentuk sasaran percikan dan sampel dihancurkan dalam bentuk serbuk dengan saiz 75 µm hingga 200 µm. Fasa hablur dikenalpasti menggunakan analisis pembelauan sinar-X. Hasil kajian menunjukkan bahawa sampel serbuk tersebut adalah polihablur. Sifat termoluminesens ditentukan dengan menyinarkan sampel kepada sinar gama cobalt-60 pada julat dos daripada 5 Gy hingga 70 Gy. Lengkung berbara dianalisis untuk menunjukkan pelbagai sifat termoluminesens sampel tersebut. Hasil kajian jelas menunjukkan Al_2O_3:C (0.2%), Mg (0.2%) mempunyai sifat termoluminesens yang lebih baik seperti kepekaan, kelinearan, kebolehgunaan semula dan kelunturan berbanding dengan sampel yang lain. Z_{eff} sampel dihitung sebagai 10.83 ± 0.01 dan hasilnya menghampiri Z_{eff} tulang. Jumlah pekali penyerapan jisim Al_2O_3:C (0.2%) dan Al_2O_3:C (0.2%), Mg (0.2%) dihitung menggunakan perisian WinXcom bagi menghitung sambutan tenaga foton sampel tersebut. Dengan menggunakan graf trumpet, nilai R ($D_{measured}$ / $D_{delivered}$) bagi sampel Al_2O_3:C (0.2%), Mg (0.2%) adalah dalam had dibenar yang dicadangkan oleh ICRP. Purata tenaga keaktifan Al_2O_3:C (0.2%) dan Al_2O_3:C (0.2%), Mg (0.2%) yang dikira masing-masing bernilai 2.03 eV dan 1.49 eV. Faktor frekuensi yang dihitung daripada lengkung berbara Al_2O_3:C (0.2%) dan Al_2O_3:C (0.2%), Mg (0.2%) masing-masing ialah 2.61×10^{25} s^{-1} dan 7.51×10^{17} s^{-1}.

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LIST OF SYMBOLS

$\left(\frac{\mu}{\rho}\right)_i$	Mass Attenuation Coefficien
$\overline{B}$	Mean thermoluminescence background signal
$\eta = \sum_i \eta_i$	Total Number of Atoms Present In Molecule
σ_B	Standard Deviation of the Mean Background
$\left(\frac{\mu_{en}}{\rho}\right)_{ref}$	Mass energy absorption coefficient of references medium or material
$\left(\frac{\mu}{\rho}\right)_i$	Mass attenuation coefficient
$\left(\frac{\mu_{en}}{\rho}\right)_m$	Mass energy absorption coefficient of the material
μ_g	Symmetry Factor
μ_m	Mass Attenuation Coefficient
Al_2O_3	Aluminium Oxide
Al_2O_3:C	Aluminium Oxide Doped with Carbon
b	Order of Kinetics
D_0	Minimum Detectable Dose
E	Trap Depth
E_α	Thermal Energy
E_{av}	Activation Energy
F	TL System Calibration Factors
H_1	Conventional true dose
H_o	Lowest dose that need to be measured
Lif:Mg,Ti	Litium Floride doped Magnesium and Titanium
R^2	Regression Coefficient
s	Frequency Factors

T^2_m	Maximum temperature
T_m	Maximum Temperature
W_i	Weight fraction of element
Z	Atomic Number
Z_{eff}	Effective Atomic Number
Z_i and A_i	Atomic Number and the Atomic Mass of the Each Element Present In a Molecule

LIST OF ABBREVIATIONS

ANSI	American National Standard
CB	Covalence Band
CC	Charge Carriers
EBM	Electronic Band Model
ED	Energy Dependence
EDAX	Energy Dispersive Analysis X-ray
FB	Forbidden Band
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units
RC	Recombination Centre
RER	Relative Energy Response
RTL	Radiothermoluminescence
TL	Thermoluminesence
TLD	Thermoluminesence Dosimeter
TTP	Time Temperature Profile
VB	Valence Band
XRD	X-Ray Diffraction Analysis

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Radiation is a general term to describe the emission and transmission of energy through space in form of waves, including charged and uncharged particles as well as electromagnetic radiation. Depending on its ability to ionize matter, radiation is categorized in two main types, non-ionizing and ionizing radiation. Ionizing radiation is a radiation that has the ability to cause ionization upon interaction with matter whereas non-ionizing radiation does not. People have benefited from the use of radiation either in medicine and industry application ever since it was discovered.

Ionizing radiation is very dangerous to humans; therefore, a precaution step needs to be taken in order to avoid any effect that occurs while exposed to ionizing radiation. Dosimeter is one of the techniques that are commonly used to detect the amount of absorbed dose in the body. One of the common personal dosimeter is thermoluminescence dosimetry (TLD). TLD is the well-established technique to measure absorbed dose. Over the last decade, the investigation of thermoluminescence (TL) properties has expanded enormously and it has been used in radiation therapy and diagnostics, in environmental radiation monitoring and in industrial applications such as food irradiations and sterilization of health care products (Onder et al 2012). Studies on radiation induced defects in insulating materials have been interesting over the last few decades. Thermoluminescence is one such radiation induced defect related process in crystalline materials.

In TL, while heating the irradiated material, energy stored in the crystal is released with the emission of light and the intensity of the emitted light as function of temperature forms glow curve. The important of thermoluminescence for radiation dosimetry is due to the fact that the amount of light emitted is proportional to the absorbed dose by the irradiated material, which provide sensitive detection and accurate measurements of ionizing radiation.

One of the materials of being studied for possible used as dosimeter was aluminium oxide (Al_2O_3). The properties of Al_2O_3 such as linearity in wide dose range, easy handling and mechanical resistance shows the advantages of this compound to be used as TLD (Margit,1980). However, the study on this material discontinued for a long time because of its low sensitivity performance as compared with that of LiF:Mg,Ti (TLD - 100). Studies of this compound become interest when Al_2O_3 with different dopants have been introduced by several researchers for nearly 50 years. As an example, α-Al_2O_3:C crystal, which was first introduced by Akselrod et al. (1990) has been widely used as a material for TLD. Since aluminium oxide shows an effective number close to that human tissue (Z_{eff} = 11.28), it becomes the better choice to be used in medical and environmental dosimetry (Bos ,2001). Grown α - Al_2O_3:C crystal shows excellent TL properties that it possesses a high (TL) sensitivity to α, β and γ radiations. It has sensitivity approximately 40 - 60 times greater than TLD-100 at heating rate 4 °C s^{-1}, has a single glow peak at 460 K, low background and low detectable threshold limit (0.1 μGy with nitrogen flow), low fading during storage in the dark and linear dose response up to 10 Gy (Yang et al, 2008).

1.2 Problem Statement

Aluminium oxide attracted scientific interest because of its high optical, chemical and thermal stability under ionizing irradiation exposures. The challenge was to make it more sensitive to ionizing radiations (Akselrod et al 1993). Pure α - Al_2O_3 does not exhibit TL properties but addition of Carbon impurity (100 – 500 ppm) enhanced the sensitivity to ionizing radiation (Akselrod et al., 1990). The study on this material becomes more interesting due to the development of anion defective Al_2O_3:C single crystals, which provide sensitivity more than TLD-100. However, sample preparation of Al_2O_3:C single crystal requires a sophisticated laboratory infrastructure of high temperature using a highly reducing atmospheres and these facilities are normally not available in common laboratory. In this work the study was concerned on carbon doped aluminium oxide (Al_2O_3:C) and aluminium oxide doped with carbon and magnesium (Al_2O_3:C, Mg) in form of powder subjected to cobalt-60 gamma irradiation. The samples were supplied by Testbourne Ltd, England with different concentrations of carbon and magnesium. There are very few works have been done on the thermoluminescence properties of Al_2O_3 powder especially at high dose range.

1.3 Objectives of the research

The objectives of the research are as follows:

a) To characterize the sample virtuosity as well as determination of doped and co-doped concentrations of the samples by using X-Ray diffraction (XRD) and energy dispersive analysis X-Ray (EDAX).

b) To study the fundamental thermoluminescence properties of various concentrations of carbon and magnesium of Al_2O_3:C, Mg sample subjected to cobalt-60 gamma radiation in terms of glow curve, linearity, sensitivity, fading characteristic, reproducibility and minimum detectable limit.

c) To compare the TL properties of different concentrations of doped and co-doped Al_2O_3 samples subjected to cobalt-60 gamma.

d) To determine the activation energy and frequency factors of Al_2O_3:C, Mg samples subjected to cobalt-60 gamma radiation.

1.4 Scope of the research

In this work aluminum oxide samples with different dopant and co-dopant concentrations were investigated as shown in Table 1.1.

Table 1.1: Doped and co-doped aluminum oxide samples investigated in this work.

No	Name of sample	Dopant concentration (%mole)	
		Carbon	Magnesium
1	Al_2O_3: 0.1C	0.1	-
2	Al_2O_3: 0.2C	0.2	-
3	Al_2O_3: 0.2C:0.1 Mg	0.2	0.1
4	Al_2O_3: 0.2C:0.2 Mg	0.2	0.2

TL properties of different concentrations of doped and co-doped aluminum oxide samples in form of powder after being irradiated by Cobalt-60 gamma were investigated. The following steps were carried out throughout the study:

a) Determination of amorphous and crystalline state of the samples by using X - ray Diffraction (XRD) Analysis.
b) Determination of dopant and co-dopant concentration of the samples using Energy Dispersive X - ray Analysis (EDAX) in order to calculate effective atomic number of the samples.
c) Irradiation of the samples using Cobalt-60 gamma ray at various doses up to 70 Gy.
d) Measurement of TL response of irradiated samples using TLD Reader.
e) Analysis of TL data to investigate the TL properties of the samples in term of glow curve characteristics, linearity, sensitivity, reproducibility, minimum detectable limit, fading and TL parameters.
f) To study the performance of TL response by using poly-crystalline sample

1.5 Significant of the study

The fundamental thermoluminescence properties of Al_2O_3:C and Al_2O_3:C, Mg in powder form subjected to Cobalt-60 gamma radiation were investigated as a TL dosimeter. The comparison has been made in term of TL properties of various dopant and co-dopant concentrations of Al_2O_3 samples. The concentration of carbon doped and magnesium co-doped of Al_2O_3 sample that one producing the best TL properties will be identified. This work provided information of the capability of aluminum oxide to be introduced as thermoluminescence dosimeter particularly in environmental dosimeter applications.

1.6 Report outline

Chapter 1 covers an introduction on thermoluminescence studies included the objective, scope and the significance of the study. **Chapter 2** discussed a literature review about thermoluminescence theory, as well as the presentation of previous studies of the capabilities of aluminum oxide as TLD. The importance of TL properties such as annealing procedure, glow curves parameters and dose rate were discussed. **Chapter 3** describes the methodology of the measurements that are carried out in this work. **Chapter 4** discussed the results obtained in this study. Last but not least, **Chapter 5** summarized the findings of the study and the suggestions of the possible future works to be carried out in this field.

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