Ain Shams University
Faculty of Science
Physics Department

Effect of different nanoparticle dopants on Al_2O_3 as a radiation dosimeter

A Thesis

"Submitted for the degree of Master of Science as partial fulfillment for requirement of the master of Science"

By

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Thanks to My Allah

The Merciful,

For my Success in completing this work

Dedication

For All My Loving Family;

My Father of the deceased and My Mother,

My Husband

My Sisters and My Brothers.

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Abstract

Radiation dosimetry is fundamental in the application of the radiation and radioisotopes, especially in medical physics. Ionizing radiations mostly used in radiodiagnosis, radiotherapy are X-rays, gamma rays and beta particles. Dosimetry in medical physics involves the patients and phantom dosimetry as well as that for the occupationally exposed personnel and the environmental monitoring in hospitals.

This type of measurements are carried out more conveniently by using thermoluminescent dosimeters (TLD), based on thermoluminescence phenomena which can be observed when the insulator or semiconductor solid is thermally stimulated. Thermoluminescent dosimeters depend on the type of thermoluminescent materials. There are two types of thermoluminescent material; Natural such as (quartz, zircon and feldspar) and Artificial such as (LiF, $CaSO_4$, CaF_2 and Al_2O_3 which was prepared)

A novel series of Cr_2O_3-Al_2O_3 nanoparticles containing various molar compositions of Cr_2O_3 (0-5wt %) were prepared by sol-gel method. An octadecylamine was used as nano-assembling template to prepare novel dosimeter nanoparticles. The crystalline features, morphology, sample composition and the nanostructure of the prepared samples were investigated by X-ray diffraction [XRD], Scanning electron microscope [SEM], Energy dispersive X-ray [EDX] and High resolution transmission electron microscope [HRTEM]. The XRD and HRTEM results reflect the existence of nanoparticles with rod-like structure. It is obvious to notice from The XRD pattern the

disappearance of the majority of diffraction peaks that assigned to Cr_2O_3 revealed the dispersion of chromium oxide as amorphous layers between alumina nanoparticles.

It was found that Al_2O_3 nanoparticles with compositions of 1.5% Cr_2O_3 exhibited the highest response for gamma rays than all different compositions. This composition displayed a linear gamma dose response in the range from 3.5mGy up to 350mGy.Sensitivity of this composition is higher than LiF (standard dosimeter) about 7 times at low dose and about 1.3 times at high dose. This composition is good reproducibility. Fading of this composition reduced to 63% after 2days.

Chapter (1)

Theoretical Aspects

Theoretical Aspects

There are different types of Luminescence such as fluorescence, phosphorescence, and bioluminescence are generated from chemical reactions, electrical energy and reactions in crystals, or excitation of an atomic system. The topic goes on to have a major technological role of humanity in the form of applications such as light emitters organic and inorganic for flat screens and flexible display such as plasma, Liquid Crystal Display "LCD", Organic Light Emitting Diodes "OLED" screens. Luminescent Materials and Applications makes a wide range of materials and applications of interest to the present, including the organic material light-emitting devices, light and non-organic materials emitting diode devices, nanomaterials, powder and thin-film materials electrically phosphors and devices. Thermoluminescence dosimetry (TLD) is generally renowned as a most versatile technique for the quantitative measurement of X, gamma and beta radiations, especially in personnel monitoring. Developments in this field of radiation protection dosimetry are continued.

1.1.Luminescence:

Luminescence is the property specially some of material which is absorbed energy from any ionizing radiation then occurring emission of energy as light. When the material absorbed energy, the electron moved from its ground energy level to a larger energy (excited level). The light emitted, when the electron moves from excited energy level to its ground energy level, can be categorized according to a characteristic time, T, between the energy absorption and light emission. If this time is less than 10^{-8} sec, the phenomena is called fluorescence. If the characteristic time is larger than 10^{-4} sec, this phenomenon is called phosphorescence. Phosphorescence is illustrated with the existence of a metastable level, between the fundamental and excited levels, which acts as a trap for the electron. If the difference of energy E, between the excited and metastable levels, is much greater than KT, the electron has a high possibility to stay trapped for a very long time. On the assumption Maxwell and distribution of the energy, the possibility of escaping from the trap is given by:

$$P = s \exp(-E/KT) \quad (1.1)$$

As a result, the time between the excitation and the transition back to the ground state is delayed due to electron spends time in the metastable energy state. In equation (1.1), the probability p is function of the stimulation procedure, which can be thermal or optical and different form, depend on the type of stimulation.

1.2. Types of Luminescence:

Photoluminescence is caused through moving electrons to higher levels by absorbing the photons. It's occurred in semiconductors by photons of energy larger than the band gap to radiate recombination channels then create band gap light. It can be classified into:

a) **Fluorescence** is often utilized only for luminescence caused by ultraviolet. Fluorescence has many practical applications, such as mineralogy, gemology, fluorescence spectroscopy, fluorescent labeling, dyes, biological detectors, cosmic-ray detection, and, most commonly, fluorescent lamps.

b) **Phosphorescence** is delayed luminescence or "afterglow". When an electron is absorbed energy that moves to a high-energy state, it may get trapped there for some time. In some cases, the electrons escape the trap in time. Many glow in the dark products, specially toys for children, include materials that absorb energy from light, and emit the energy again as light later.

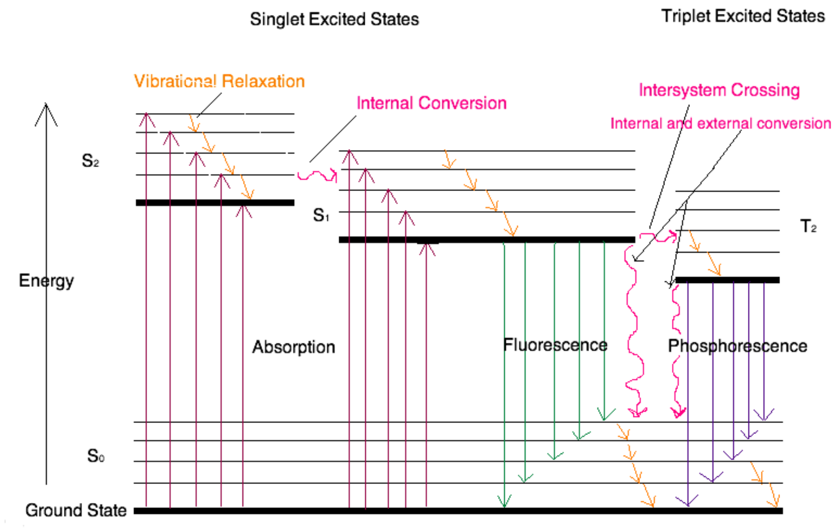

Figure (1.1): different types of luminescence phenomena

Bioluminescence is created by a living organism. Excitation of the light producing molecules by a chemical reaction; resulting bioluminescence is associated to chemiluminescence.

Chemiluminescence (or chemoluminescence) generated from chemical or electrochemical reactions. The energy required gets from the enthalpy of reaction. Some new molecule that can have its electrons in an excited state is produced by the reaction. Return to a ground state then produce visible light or photons.

Crystalloluminescence is generally resulted during crystallization. It's another kind of chemiluminescence because the energy comes essentially from bonding between atoms.

Electroluminescence is produced by an electric current passing through some of the materials. Electroluminescence generates when occurring recombination between electrons and holes; usually in semiconductors. It is fundamental for light-emitting diode (LED’s) and semiconductor Lasers and it is very important in the sequence of light sources. Recently electroluminescence is also used for recognizing solar cell.

Cathodoluminescence occurs when the influence electron beam on a luminescent material such as a "phosphor". Nearly 100 years, cathodoluminescence has been utilized for traditional cathode ray tube or TV tube that was recently exchanged flat screen displays such liquid crystal display (LCD's). Also cathodoluminescence is still used for electron microscope (TEM and SEM type) screens.

Mechanoluminescence, producing from mechanical action on a solid material, can be classified into:

a) **Triboluminescence** take a cluster of sugar, go to a dark room, wait for some time until your eyes adapt in dark room, and then sharply crushed sugar between your teeth (keeping your lips open, so you can see your teeth and the sugar in a mirror). It will create blue flashes of light; Triboluminescence is not just seen at daylight because it is usually weak. It occurs when bonds in the material are broken because of scratching, crushing, or rubbing.

b) **Fractoluminescence,** pretty much the same thing as triboluminescence. It generated when bonds in certain crystals are broken by fractures.

c) **Piezoluminescence**, is created by pressure on, well, piezoelectric materials. It differs about fractoluminescence because bonds do not break but just some elastic deformation.

Radioluminescence is created when some of the materials are exposed to ionizing radiation such as alpha and beta particles or gamma rays. Radioluminescence is also utilized for detecting ionizing radiation, especially gamma rays.

Sonoluminescence is produced by sound when the emission of short burst of light from collapsed bubbles in a liquid when provoked by sound.

Thermoluminscence: Light emission from certain heated substances after exposure to high-energy radiation. The radiation causes movement of electrons within the crystal lattice of material. Upon heating, the trapped electrons return to lower-energy positions, emitting energy in the process. The longer the substance is exposed to radiation, the greater is the energy emitted. By measuring the amount of light released, the duration of exposure to radiation can be defined; thus, thermoluminescence.

1.3. Basic concepts of thermoluminescence:

(TL) is the emission of light from an insulator or semiconductor, after absorption of energy from ionizing radiation [such as γ-rays, X-rays, β-particles, α-particles, neutrons and energetic ions]. There are three conditions for the creation TL. Firstly, the material should be a semiconductor or an insulator metals. Secondly, the material must have absorbed energy during exposure to ionizing radiation at some time. Thirdly, the emission of luminescence is occurred by heating the material as in Mckeever (1985).

A thermoluminescent material is a material absorbs energy which is stored that during exposure to ionizing radiation. When the material is heated, the stored energy is emitted in the form of visible light. Notice that TL does not indicate to thermal excitation, but stimulation of luminescence in a material which was excited. This means that a TL material cannot emit light again by simply cooling the sample and reheating it another time. It should first be re-exposed to ionizing radiation before it emitters light again. The storage capacity of a TL material makes it in principle for dosimetric applications.

1.3.1. The one trap-one centre model:

TL model can be acquired according to the energy band theory of solids. In an ideal crystalline semiconductor or insulator, most of the electrons stay in the valence band. The conduction band is the next highest band that the electrons can occupy. The gap between the valence band and the conduction band is called forbidden band gap. The difference of energy between the de-localised bands is E_g. However, whenever defects occur in a crystal, or whether there are impurities within the lattice, there is a probability for electrons to have energies which are not allowed in the perfect crystal. In TL model simply two levels are supposed, one existing below the bottom of the conduction band and the other existing above the top of the valence band (as in Figure 1.2). The highest level symbolized by T is existed above the equilibrium Fermi level (E_f) and thus empty in the equilibrium state, i.e. before the exposure to ionizing radiation and the production of electrons and holes.

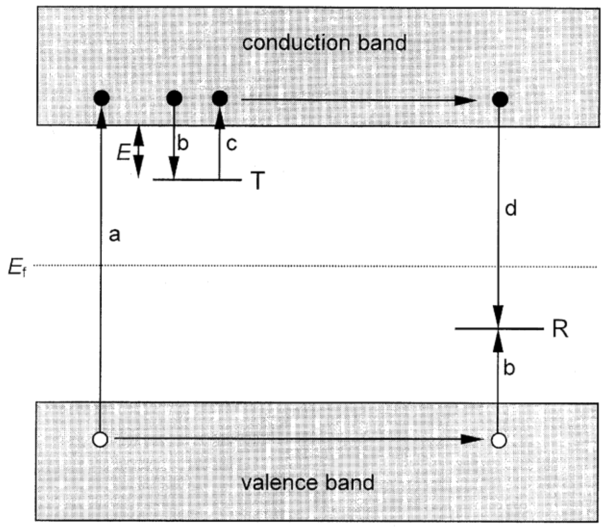

Figure (1.2): Energy band model observing the electronic transitions in a TL material according to a simple two-level model: a) production of electrons and holes; b) electron and hole trapping; c) electron release due to thermal stimulation; d) recombination. Solid circles are electrons, open circles are holes. Level T is an electron trap, level R is a recombination centre, and E_f is Fermi level.

Thus level T is an electron trap. The other level R is a hole trap and can serve as a recombination centre or luminescence centre. The