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Research Article

Simulation of Some Material when Exposed to Gamma Radiation

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Abstract

Simulation of some metal oxides when exposed to gamma radiation helped in choosing the materials to be used in designing and hence fabrication of a gamma radiation sensor. The choice of a particular detector type for an application depends upon the gamma energy range of interest, the application's efficiency requirements, detector's performance, acceptable reliability under the exposure conditions and, of course price. Metal oxides are famous types of materials used for radiation sensing and dosimetry. In this study, some metal oxides were evaluated for Gamma radiation sensing and dosimetry purposes. The evaluated metal oxides were Titanium dioxide (TiO_2), Zinc oxide (ZnO), Copper oxide (CuO), Aluminum oxide (Al_2O_3), Silicon oxide (SiO), Magnesium oxide (MgO) and Cadmium oxide (CdO). A new program was developed with MATLAB to simulate the metal oxides when exposed to gamma energy range of (1keV–1MeV) through comparing their total mass absorption coefficients and then compared with WinXCom software. The evaluation results showed that CuO had the highest total mass attenuation coefficients from all the previous metal oxides. Also, the total mass absorption coefficients for Aluminum (Al_3), Silicon (Si), Carbon (C), Copper (Cu) were evaluated to be used as substrates, and Copper (Cu) was chosen for it had the highest total mass absorption coefficients of them all. Finally, the results of the simulation showed that the Gamma radiation sensor can be made using CuO thin film on a Copper substrate.

Keywords: *Simulation; MATLAB; Metal Oxides; Gamma Radiation Sensor, Total Mass Attenuation Coefficients, Substrate.*

1. Introduction

Radiation measurement, technique for detecting the intensity and characteristics of ionizing radiation, such as alpha, beta, and gamma rays or neutrons, for the purpose of measurement.[1] Ionizing radiation is represented through subatomic particles and photons whose energy is satisfactory to cause ionization in the matter with that interact. The ionization process involves removing an electron from an initially neutral atom or molecule. For many materials, the minimum energy required for this process is about 10 electron volts (eV), and more common types of ionizing radiation are characterized by particle or quantum energies measured in thousands or millions of electron volts (keV or MeV, respectively). This energy range covers the common types of ionizing radiation encountered in radioactive decay, fission and fusion systems and the medical and industrial applications of radioisotopes. It excludes the regime of high-energy particle physics in which quantum energies can reach billions or trillions of electron volts. [2]

The ionizing radiation types are divided into two major categories: those that carry an electric charge and those that do not. In the first group are the radiations that are normally viewed as individual subatomic charged particles. Such as the alpha particles that are spontaneously emitted in the decay of certain unstable heavy nuclei that carries a positive electrical charge of two units and the beta-minus radiation that is emitted in the decay of some radioactive nuclei. In this case, each nuclear decay produces a fast electron that carries a negative charge of one unit. In contrast, there are other types of ionizing radiation that carry no electrical charge such as gamma rays, that have high-frequency electromagnetic photons, and neutrons, which are classically pictured as subatomic particles carrying no electrical charge. In the discussions below, the term quantum will generally be used to represent a single particle or photon, regardless of its type.[3]

Only charged radiations interact continuously with matter so, they are directly detectable in the detector

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devices. In contrast, uncharged quanta must first undergo a major interaction that transforms all or part of their energy into secondary charged radiations. Properties of the original uncharged radiations can then be inferred through studying the producing charged particles. The previous interactions can be occurred only infrequently, so it is uncommon for an uncharged radiation to travel distances of many centimeters through solid materials before interaction occurs. Instruments that are designed for the efficient sensing of these uncharged quanta consequently tend to have relatively large thicknesses to increase the probability of observing the results of such an interaction within the detector volume [3].

Ionizing radiation also can take the form of electromagnetic rays. When emitted by excited atoms, X rays are produced that have quantum energies that are measured from 1 to 100 keV. But when emitted by excited nuclei, they are called gamma rays, and characteristic energies can be as high as several MeV. In both cases, the radiation takes the form of photons of electromagnetic energy. Meanwhile the photon is uncharged, it does not intermingle through the Coulomb force, so that it can pass through many distances in matter without important interaction. The average distance traveled between interactions is called the mean free path and in solid materials ranges from a few millimeters for X-rays through tens of centimeters for gamma rays. The energy and direction of the photon can be affected by a single interaction or it can disappeare entirely. In interaction, all or part of the photon energy is transferred to one or more electrons in the absorber material. The fact that an original X-ray or gamma ray was present is indicated by information on the energy carried by the incident photons and can be indirect by measuring the energy of these electrons. The three major types of such interactions are Photoelectric absorption, Compton scattering and Pair production [4].

The possibility for each of these three interaction mechanisms to happen varies with the gamma-ray energy and the atomic number of the absorber. Photoelectric absorption preponderates at low energies and is critically enhanced in materials with high atomic number. For this reason, elements of high atomic number are mostly chosen for sensors used in gamma-ray energy measurements. Compton scattering is the most common interaction for energies (from a few hundred keV to several MeV). Pair production preponderates for higher energies and is similarly enhanced in materials with high atomic number. In larger sensors, the incident photon causes multiple interactions, such as, several consecutive Compton scatterings or pair production are followed by the interaction of an extinction photon. The little time separates these events, so that, the dumped energies add together to limit the complete size of the output pulse.

Small packets of photographic mixtures are routinely used by workers to monitor radiation exposure. Developed film can be exposed to a determine their radiation dose. In this way, variations that result from differences in film properties or development procedures are canceled out. When it used to monitor exposure to low-energy radiation such as X-rays or gamma rays, emulsions tend to overrespond due to the rapid rise of the photoelectric cross section of film material at these energies. To reduce this deviation, the film is often wrapped in a thin layer to absorb some of the low-energy photons before they reach the emulsion.

Metal oxides are a class of materials that consists of positive metallic and negative oxygen ions. The electrostatic interaction bonds oxygen ions with the metallic together, resulting in a strong ionic bond [2]. A variety of unique properties for partially or fully filled d-shells of metal oxides can be used for all kinds of electronic device applications, that includes thin film transistors, photo catalysts, dosimeters, solar cells, photo-electro-chemical (PEC)cells and sensors.[3] In addition, metal oxides are famous type of materials being used for radiation sensors and dosimetry. It is utilized in a film form. Most of the produced films are prepared by different techniques of deposition such as thermal evaporation and screen printing. The main property that changes with radiation is the electrical conductivity.The influence of radiation depends on both the dose and the parameters of the films including their thickness: the degradation is more severe for the higher dose and the thinner films [4].

There are different researches for using metals oxides as radiation sensors. K. Arshaket al. [5]studiedtheeffects the radiation in metal oxide thin film structures.The properties of the materials undertake changes by the effect of gamma-rays. The grade of these changes could be served as a measure of the received radiation dose.Metal oxides thin films are highly affected by the influence of radiation. The changes caused their electrical or optical properties tobe correlated with radiation dose for dosimetry applications. It was noticed that material mixing as well as thickness variations could be employed to control the sensitivity to radiation and working dose range.K. Arshaketal[6]prepared thick film oxide diode structures for personal dosimetry application. N. Chanthimaet al [7], studiedthe radiation attenuation properties of gamma-ray for cement containing with BaSO4 and PbO through calculatingthe mass attenuation coefficientsof cement by theoretical approach by using WinXCom program at the photon energies of 1 keV to 100 GeV. The mass attenuation coefficients variations were shown graphically for total and partial photon interaction. The results showed that the values of mass attenuation coefficients were changed with energy and concentration of BaSO4 and PbO.The aim of this work is evaluating the effect of gamma radiation sensing properties on different metals oxides and their compounds using a new proposed algorithm with MATLAB. In addition, evaluating the effect of gamma radiation sensing properties for some metals to be used as substrate.

Prior to designing a gamma radiation sensor some materials were chosen for evaluation and according to this evaluation the material with the highest mass attenuation coefficient was chosen to be used in the fabrication of the gamma radiation sensor. This evaluation is based on the simulation of these materials when exposed to gamma radiation.

2. Partial absorption processes

Gamma-ray absorption occurs as illustrated in Fig.1 by four different processes:

Coherent scattering, photoelectric effect, Compton effect, and pair production. For each of these processes, a partial coefficient can be expressed:

$$\mu = \mu_{coh} + \mu_{phot} + \mu_{Comp} + \mu_{pair} \quad (1)$$

where:μ_{phot} and μ_{pair} are absorption processes, whileμ_{coh} is only a scattering process; μ_{Comp} contributes to both the absorption and thescattering terms.

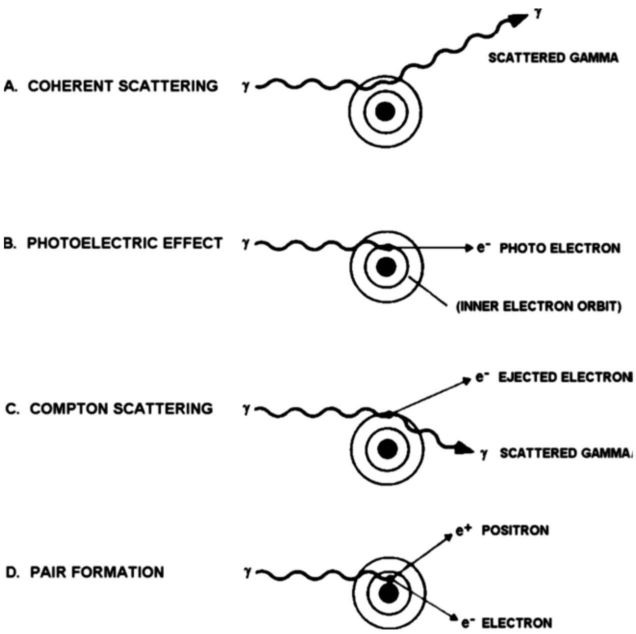

Figure 1. Schematic description of the four main processes accounting for γ-ray interaction andabsorption [book].

2.1. Coherent scattering

In coherent scattering, the γ-ray is absorbed and immediately re-emitted from the atomic nucleus with unchanged energy but in a different direction it is denoted asσ_r. It can give interference patterns, so this process is used for structural analysis of materials as in X-rays. The probability for coherent scattering increases with the square of atomic number of the absorber and decreases with γ-ray energy. [book]

2.2. Photoelectric effect

In the photoelectric effect, the absorption of γ-rays (photons) are absorbed completely through the atom electrons which causes excitation of the atom above the binding energy of some of its orbital electrons then an electron is ejected and an ion pair formed with the energy of the emitted photoelectron is represented in equation (2).

$$E_e = E_\gamma - E_{be} \quad (2)$$

Where: E_e, is the emitted photoelectron energy, $E_\gamma$is the energy of the γ -ray and E_{be}, is the binding energy for that electron in the atom.

If the photoelectron originates from an inner electronic orbital, an electron from a higher orbital moves to fill the vacancy. The difference in binding energy of the higher and the lower energy orbital causes emission of X-rays and of low energy Auger electrons. The process of electron cascade, accompanied by X-ray and Auger electron emission, continues until the atom is reduced to its ground state energy. The photoelectron as wellas the Auger electrons and the X-rays cause extensive secondary ionization by interacting with the surrounding absorber atoms.

The probability for the photoelectric effect decreases with increasing γ-ray energy.It is largest for the most tightly bound electrons and thus the absorption coefficient forthe photoelectric effect increases in the order of electron shells K > L > M >, etc. Gamma-rays of higher energy, rather than interacting with the field of the whole atom as in the photoelectric effect, interact with the field of one electron directly. This mode of interaction is called the Compton effect after its discoverer, A. H. Compton.

2.3. Compton effect

In the Compton effect an electron is ejected from an atom while the γ-ray is deflected witha lower energy. The energy of the scattered γ-ray, E'_γ, is expressed by the equation

$$E'_\gamma = E_\gamma - E_e \quad (3)$$

where E_e is the kinetic energy of the Compton electron. The probability for Compton scattering increases with target Z and decreases with E_γ. Since the Compton interactionoccurs only with the most-weakly bound electrons and high energy γ-rays, the bindingenergy of the electron is negligible compared to E_γ. The Compton electrons andscattered γ-rays have angles and energies which can be calculated from the relationshipsbetween the conservation of energy and momentum, correcting for the relativistic massof the electrons at these kinetic energies. The scattered γ-ray may still have sufficient energy to interact further by the Compton effect, the photoelectric effect or pair production.

Again, emission of X-rays and Auger electrons usually accompanies Compton interaction and extensive secondary ionization follows. Since the Compton electron can have a spread of energies, the scattered γ-rays exhibit a broad spectrum. The Comptonelectrons, as in the case of photoelectrons, are eventually stopped by the processesdescribed for b-particles.

Only the energy of the electron is deposited in the absorber as the scattered γ-ray has a high probability of escape. Thus,Compton electrons contribute to the (energy) absorption coefficient μ_a while the Comptonγ contributes to the total attenuation coefficient μ through the scattering coefficient μ_s.

The fourth mode of interaction for γ-rays with an absorber involves conversion inthe Coulomb field of the nucleus of a γ-ray into an electron and a positron. This process is termed pair production since a pair of electrons, one positive and one negative, is produced. The process can be considered as the inverse phenomenon of positron annihilation. Since the rest mass of an electron corresponds to 0.51 MeV, theγ-ray must have a minimum value of 1.02 MeV to interact by pair production. As the energy of the γ-ray is increased beyond this value, the probability of pair productionincreases. The excess energy (above the1.02 MeV) appears as the kinetic energy of the electron pair as:

$$E_\gamma = 1.02 + E_{e^-} - E_{e^+} \quad (4)$$

4. Evaluation of some metal oxides and substrates

In this research, gamma-ray effects are used for evaluation of some metal oxides to be used as gamma radiation sensors based on the interaction of the gamma radiation with matter that produces photon. Since, the photons interact with a certain material may be scattered or absorbed. The probability of interaction of this photon per unit of length of a given absorber characterizes is called its linear attenuation coefficient (μ). μ depends on the material physical state and for this reason it is usually substituted by the mass attenuation coefficient (μ_m), which is the μ divided by its density. Fig. 1 [8] refers the intensity of the radiation which strikes the absorber as the incident intensity, I_0, and the intensity of the radiation which gets through the absorber as the transmitted intensity, I.

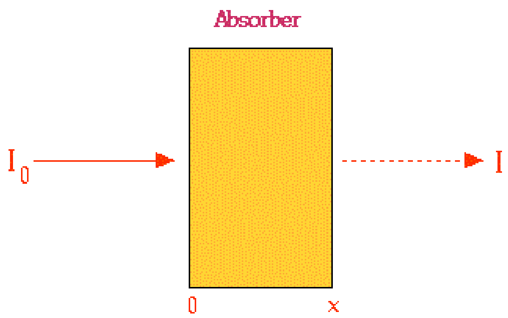

Figure 2 The effects of the intensity of the radiation in material.

The transmitted gamma-rays in the main be those which pass through without any interactions at all. It can be therefore expected to find that the transmitted intensity will be less than the incident intensity, that is:

$$I < I_0 \quad (5)$$

The intensity of the radiation is decreased as a function of thickness of the absorbing material. The mathematical expression for intensity (I) is given by:

$$I = I_o e^{-\mu x} \quad (6)$$

where, I_o is the original intensity of the beam, I is the intensity transmitted through an absorber thickness x and μ is the linear attenuation coefficient for the absorbing material.

The two terms attenuation and absorption coefficients are often used interchangeably even though they differ slightly. Attenuation is the result of both absorption and scattering of the photons in the material [1]. The study of attenuation coefficient of various materials has been an important part of research in Radiation, Chemistry, Physics, agriculture and human health.

Mass attenuation and mass absorption coefficients are two parameters commonly used in the study of gamma rays properties. These parameters mainly depend on various factors including photon energy, nature of absorber and the medium through which radiation passes. The mass attenuation coefficient gives information about the effectiveness of a given material per unit thickness, in promoting photon interactions. [4] So, in this research, the mass attenuation coefficients for different metal oxides are used to evaluated them to be used as gamma radiation sensers as thin films and in addition for different metal to be used as substrates for the thin films.

4.1 Evaluation of the metal oxides

In this research, many famous metal oxides which have been used in many electrical applications such as: Titanium dioxide (TiO_2), Zinc oxide (ZnO), Copper oxide (CuO), Aluminum oxide (Al_2O_3), Silicon oxide (SiO), Magnesium oxide (MgO) and Cadmium oxide (CdO) are evaluated for gamma radiation sensor. The simulation was made by the new proposed algorithm that determines the total mass absorption coefficients which represents the interaction of gamma photons with the previous metal oxides at low energy range of (1 keV–1 MeV) as shown in fig. 3 which showed that CuO had the highest total mass absorption coefficient of previous metal oxides.

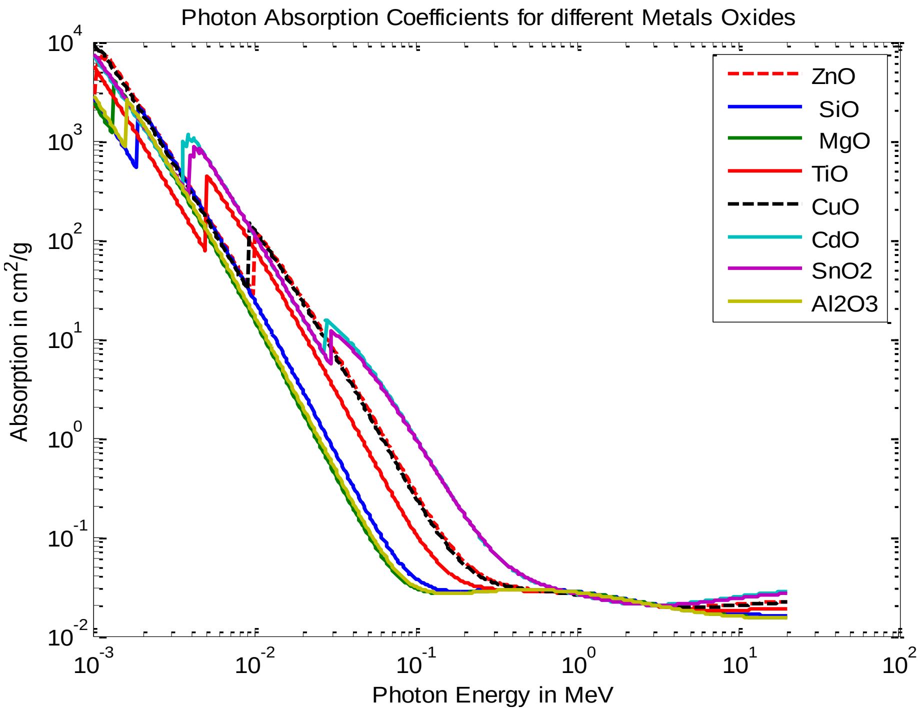

Figure 3. The total mass absorption coefficients for the evaluated metal oxides

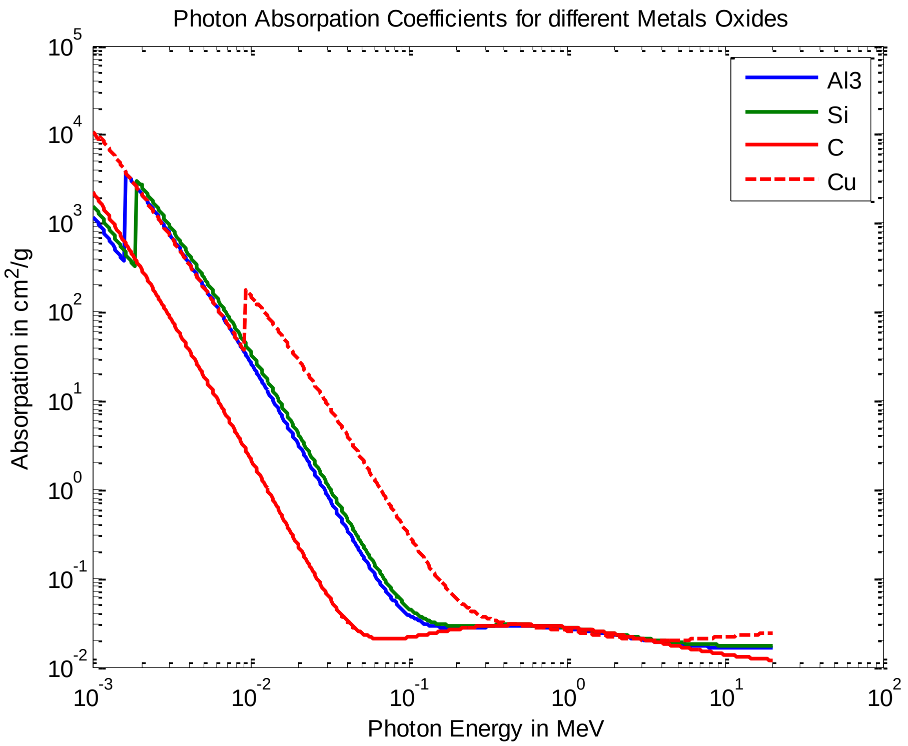

Figure 4 Total mass attenuation coefficients for the evaluated metals.

4.2 Evaluation of Al_3, Si, C, Cu to be used as substrates

The total mass attenuation coefficients for different metals such as Aluminum (Al_3), Silicon (Si), Carbon (C) and Copper (Cu) were evaluated to be used as substrates as shown in fig.4 that showed Copper (Cu) has the highest total mass attenuation coefficients so it can be used as substrate for the CuO thin film.

Conclusion

Metal oxides are famous types of materials used for radiation sensing and dosimetry. From the results of the two evaluations, it was observed that Copper oxide (CuO) and zinc oxide (ZnO) had the highest total mass attenuation, thus the properties of radiation sensors can be increased by a composed compound of them with different ratios. The ratio 90%:10% of CuO/ZnOhad the best efficiency and consumed in cost than CuO alone. Also, from evolution of different metals Aluminum (Al_3), Silicon (Si), Carbon (C) and Copper (Cu) as substrate by comparing their total mass attenuation coefficients Copper had the highest. Thus, a thin film of CuO/ZnO with ratio 90%/10% on a Cu substrate would be a very good choice for fabricating of a thin film gamma radiation sensor.

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