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Recent Development in Compound Semiconductor Based Medical Radiation Detector

Biswajit Nath

Junior Physicist, Department of Radiology, Silchar Medical College & Hospital

Abstract

Conventional semiconductor detectors using Silicon and Germanium are used for medical radiation detection for long. The compound semiconductor can be presented with some advantages over the conventional semiconductor in various radiation detection applications, including X-ray, gamma-ray, and infrared detection. These materials are valued for their high resistivity, good energy resolution, and the ability to operate at room temperature. The purpose of this paper is to do a comprehensive literature review on the recent development on compound semiconductors as medical radiation detector. Our method of bibliographic search and systematic review made use of Google Scholar, Scopus and Science Direct search engines for the major clinical relevant articles and Medical Physics and JACMP for specific physics articles. Using proper key words, the temporal range 2010–2024 was imposed as a constraint. We also extended our search to include the main guidelines and reports available from IAEA, ASTRO, AAPM and ESTRO.

Keywords: Semiconductor detector, compound semiconductor, radiation sensors.

Introduction

In the medical field, ionizing radiation has become an inescapable tool used for the diagnosis and treatment of a variety of medical conditions. The radiation exposure poses a potential risk to both patients and healthcare professional. Radiation protection aims to reduce unnecessary radiation exposure with a goal to minimize the harmful effects of ionizing radiation. Dosimeters are devices that measure radiation exposure. Detailed knowledge of the dosimeters' characteristics is a prerequisite for obtaining accurate measurements. The most important physical properties of a dosimeter are: a) accuracy and precision, b) signal response with dose, c) dose and dose rate dependence, d) energy response, e) directional dependence, f) spatial resolution, g) dynamic range, h) the impact of the influence quantities, and i) the stability of its calibration factor. The most commonly used detectors for radiation dosimetry are ionization chambers, TLDs, diodes and MOSFETs, each having advantages and disadvantages that determine their specific application. A semiconductor detector is a device that uses a semiconductor (usually silicon or germanium) to measure the effect of incident charged particles or photons. The conventional semiconductor radiation detectors made of silicon (Si) and germanium (Ge) have been reported with shortcomings (Cherry, Sorenson and Phelps, 2012; Girolamo & Nessi, 2014). Compound semiconductors are created by combining two or more semiconductor elements from different groups on the periodic table. Compound s are formed from group III–V, group IV, and group

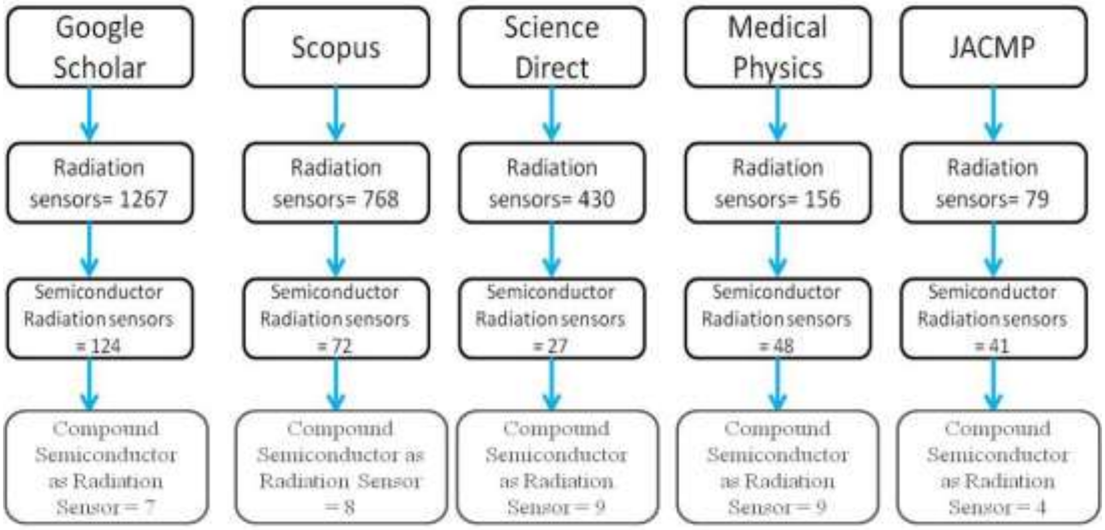
II–VI. Their advantages over conventional semiconductor include wide band gaps, higher electron mobility, and suitability for optoelectronic applications.

Materials and Methods

Various science literatures through Google Scholar, Scopus, Science Direct, Medical Physics, and JACMP databases using the terms “semiconductor detector” and “compound semiconductor as radiation sensor” were searched. The search covered published articles from 2010 through August, 2024. Bibliographies of relevant articles were searched as well. Inclusion criteria were articles written in English language that investigated a form of correlation between semiconductor detector and compound semiconductor as radiation detector or application of the compound semiconductor based radiation detectors in diagnostic radiology dosimetry.

Results

A total of 37 relevant articles that met the inclusion criteria were found (Flowchart 1). These articles covered 2 main aspects: the application of compound semiconductor as electromagnetic radiation detector; the fabrication and development of compound semiconductor based radiation detectors.



Flowchart1: Systematic Review of Literature and Adopted Key words

Use of compound semiconductors as medical radiation detector

Compound semiconductors, including GaAs, CdTe, CdZnTe, and ZnO, are pivotal in the development of advanced radiation detectors. Technological advancements in material quality, detector design, and electronic correction methods have enhanced their performance in various applications, from medical imaging to industrial inspection. Unfortunately, these applications are still very limited and the companies producing compound semiconductors do not provide any information on their devices’ detection properties. This knowledge is crucial to open new application fields.

Cadmium Sulfide (CdS), ZnO, HgTe shows excellent optoelectronic properties, both in thin film and nanostructured forms (Bindu Krishnan et al., 2019) making it suitable for applications in thin-film photovoltaics, nanophotodetectors, and lasers. Denys Ihorovych Kurbatov, et al.(2012) made extensive studies contributing to a comprehensive understanding of the localized states in group II-VI semiconductor films. The study by Edrine Damulira, (2022) demonstrates that compound semiconductors exhibit high sensitivity to ionizing radiation, making them suitable for precise dosimetry in medical applications. Silicon based Light-emitting diodes (LEDs) shows a potential dosimetry candidate because they are radiation hard, spectrally selective, direct band gap, and low-cost devices (Edrine Damulira et al., 2021). Zinc Oxide has emerged as an efficient material for ionizing radiation detection due to its radiation-induced ultrafast scintillation properties (R. M. Sahani et al. 2022). The zinc-oxide (ZnO) materials are promising for deep-ultraviolet (DUV) light-emitting devices (LEDs) due to their wide bandgap and large exciton binding energy (Ying-Jie Lu, 2017). These properties make them suitable for high-performance applications in the DUV region. ZnO thin films, although not commonly used as X-ray photon sensors, show promising results for medical diagnostic applications (Claudia Patricia Varela Valenca et al. 2022). The compound semiconductors, such as $Hg_{1-x}Cd_xTe$ and ZnO, are crucial for various applications, including infrared detection and X-ray detection (Steve M. et al. 2015). For more than four decades, CdTe has been known as a good candidate material for radiation detection. The CdMnTe compound is a relatively novel material for radiation detection. Recently, A^{II}(TM= Mn, Fe, Co, etc)B^{VI} based semimagnetic semiconductors (SMSC) compounds has attracted increasing interest since they considered a promising material for the fabrication of high-performance room temperature γ- and x-ray detectors. $Cd_{1-x}Mn_xTe$ thin films are sensitive to γ-ray irradiation, making them promising materials for γ-ray detectors (M. A. Mehrabova et al., 2023).

Recently, application of Diamond-like Carbon Coating films for compound semiconductor based radiation detector improvement has been achieved (R. Savkina, et al. 2020). Various ways have been studied to adjust the properties of carbon-based materials to create an optical or protective coatings and applied a-C:H:N film as a passivation coating of IR and gamma radiation detectors based on these materials. Novel nanocomposites based on reduced graphene oxide (RGO)-functionalized ZnO nanorods have demonstrated exceptional promise for UV photodetection. These sandwich-like structures, with ZnO nanorods coated in RGO and embedded between two RGO layers, exhibited a lower band gap energy than pure ZnO and unique photoluminescence spectra. The resulting photodetector showed exceptional photoresponse with higher photocurrent under UV illumination, which could potentially be adapted for ionizing radiation detection (Boukhoubza et al., 2023).

Conclusion

The use of compound semiconductor as radiation detectors presents several advantages over traditional methods, primarily due to their unique material properties and performance characteristics. These benefits include enhanced sensitivity, faster response times, and improved durability, making compound semiconductor a promising alternative in radiation detection applications.

These semiconductor exhibits an ultrafast decay time, making it suitable for high-speed imaging and radiation detection, outperforming conventional scintillators (Jingkun Chen, 2024). ZnO thin films show superior physical resistance and radiation hardness compared to traditional ionization chambers and semiconductor devices, which often suffer from damage due to ionizing radiation (Claudia Patricia Varela Varenka, 2022). Compound semiconductor can be utilized in various forms, including nanostructures and thin films, allowing for tailored applications in detecting different types of radiation, such as X-rays and gamma rays (R.M.Sahani, 2022).

While literatures do not explicitly discuss compound semiconductors as X-ray radiation detectors, the material's unique properties and the ability to tune its characteristics through various fabrication techniques suggest that compound semiconductor-based detectors could be promising candidates for this application. Further research would be needed to explore the specific mechanisms and effectiveness of compound semiconductor in detecting X-ray radiation.

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