

Analysis and Research on Sensitivity and Working Stability of X-ray Detectors

Ting Wei^{1,a,*}

¹Department of Microelectronics, School of Integrated Circuit, Dongguan University of Technology, Guangdong, China

a. 2022455120142@dgut.edu.cn

**corresponding author*

Abstract: The field of photoelectric detectors is expanding in the quickly evolving technology period of today, with applications including industrial non-destructive testing, national security inspection, medical imaging diagnosis, and so on. Undoubtedly, high-performing photo detectors enable more effective exploration of some uncharted territory. The primary focus of this paper is to examine and evaluate X-ray detector sensitivity and stability of operation. Studies have indicated that the performance of these devices is significantly influenced by their sensitivity and operational stability. In order to optimize certain aspects of performance and enhance sensitivity and operational stability, this article analyzes and lists several useful techniques for doing so, including the use of novel perovskite materials and ongoing optimization of the production of perovskite crystals to modify the crystal structure to some extent.

Keywords: X-ray detector, perovskite, sensitivity, working stability.

1. Introduction

With the rapid development of the times and the continuous progress of technology, people's demand for photodetectors is increasing, and the requirements are also becoming higher and higher. Due to the fact that X-rays passing through objects recorded by X-ray detectors leave corresponding images, this can greatly help people analyze the internal structure and characteristics of certain objects that cannot be seen by the naked eye, which is of great help to the future development of humanity [1]. At present, X-ray detectors have been applied in many fields such as medical imaging diagnosis, national security inspection, industrial non-destructive testing, etc. [2]. Because X-ray detectors are a type of tool with significant importance in industry, society, and military, it is necessary to conduct research and analysis on this type of detector. This is a necessary process for developing detectors with better performance and lower cost [3].

This article aims to introduce the important factors that affect the sensitivity and stability of X-ray detectors, as well as how to improve and enhance the performance of X-ray detectors through special methods.

The first chapter of this paper serves as an introduction, introducing the research background and significance of X-ray detectors. Chapter 2 provides important formulas for determining the sensitivity of X-ray detectors and analyzes important factors that affect the sensitivity of X-ray detectors, such as dark current, response photocurrent, etc. In addition, considering the excellent optoelectronic

properties of perovskite, Chapter 2 focuses on analyzing the advantages of using perovskite materials to enhance device sensitivity. Chapter 3 focuses on the research and analysis of the stability of X-ray detectors, pointing out that factors such as radiation hardness, lattice defects, and temperature can affect the stability of the devices. Effective methods to improve stability, such as temperature inversion crystallization and vacuum thermal evaporation technology, are also analyzed. The fourth chapter is the conclusion section, which summarizes and generalizes the entire text.

2. Sensitivity

Photo detectors can effectively convert optical signals into electrical signals, thereby achieving detection of different object structures and properties. There are many photo detectors on the market, such as purple light detectors, blue light detectors, etc., and the X-ray detector studied and analyzed in this article also belongs to a type of photo detector referring to figure 1 [4]. Silicon, molybdenum, and indium are the main materials used to manufacture X-ray detectors. Electrons are concentrated by an electric field and sent to the anode in the form of electron hole pairs, which are generated when X-rays collide with semiconductor materials. This process generates a current signal. This signal can be further processed to provide spatial resolution and energy X-ray images with attributes such as count rate and resolution. It can also be used to check other information, such as the composition, structure, and morphology of the sample [5]. Given its wide range of applications, the research and analysis of the basic parameters of X-ray detectors are particularly important.

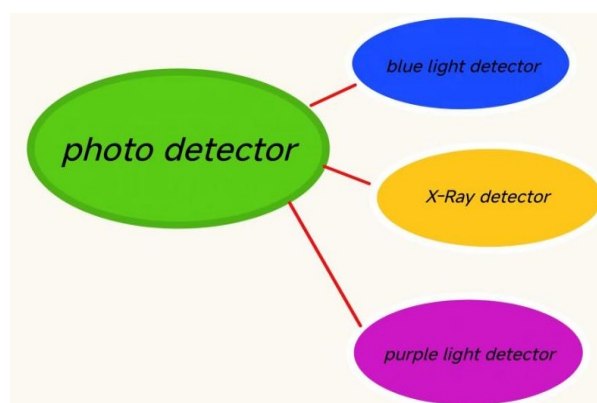


Figure 1: Classification of photodetectors

2.1. Sensitivity of X-ray detector

The least X-ray signal strength that a detector can detect is known as its sensitivity, and it often refers to the detector's response or responsiveness to X-ray signals. The ability of detectors to generate more precise and dependable results at lower X-ray intensities is made possible by their high sensitivity, which is essential for numerous applications including medical imaging, material analysis, and leak detection. For instance, in medical imaging, lower X-ray dosages can significantly lessen the harm done to human cells while simultaneously yielding more precise data feedback, allowing for quicker cause identification and more focused therapy.

Sensitivity is a crucial X-ray detector metric that describes how well the detector reacts to different radiation levels. High sensitivity is directly correlated with high-quality imaging since it shows that X-rays may produce a sizable photo current at a specific irradiation dose rate. In general, the charge collected per unit area under irradiation determines sensitivity (S), and the following formula is used to calculate it:

$$S = \frac{I_p - I_d}{D \times A} \quad (1)$$

A is the detector's effective detection area, D is the X-ray dosage rate, and I_p and I_d are the response photo current and dark current, respectively [1]. The current that passes through a detector when there is no X-ray radiation is referred to as dark current. Greater noise from a higher dark current may overpower part or all of the electrical signals produced by X-rays. Thus, the detection limit may be raised and sensitivity may be decreased. The allowable dark current for detectors used in medical imaging should not be greater than 0.1 nA cm^{-2} [6].

2.2. Methods to improve the sensitivity of X-ray detectors

Creating X-ray detectors with metal halide perovskite as the material. Because of their distinct crystal structure as shown in Figure 2, metal halide perovskite materials have a wide range of good optoelectronic properties and hence hold significant potential for use in optoelectronic detecting applications [7].

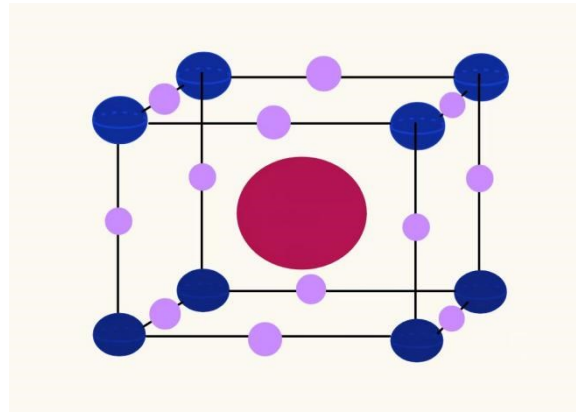


Figure 2: Crystal structure of metal halide perovskite [7]

This substance is a semiconductor with a direct bandgap. Electrons can move from the valence band to the conduction band without the aid of phonons once they have absorbed photon energy. It can thus absorb light very well, with a light absorption value of roughly 10^5 cm^{-1} . The great light absorption capacity allows the absorption layer thickness of perovskite-based detectors to be less than one micron, which is advantageous to the collection of charge carriers by vertical structure detectors and reduces the dark current generated.

The electrical resistance of this substance is high. An essential factor in determining a material's conductivity is its electrical resistance. Higher resistivity has the potential to significantly lower a photodetector's dark current [7]. Therefore, high resistive semiconductors should be taken into consideration in order to suppress dark currents. The resistivity of lead halide-based perovskite is normally between $10^7 \Omega \text{ cm}$ and $10^{10} \Omega \text{ cm}$. $\text{Cs}_2\text{AgBiBr}_6$ and $\text{Cs}_3\text{Bi}_2\text{I}_9$ single crystals (SC) have resistivity values of up to 1.6×10^{11} and $1.24 \times 10^{12} \Omega \text{ cm}$, respectively [4]. This indicates that metal halide perovskite materials have a usually high resistance.

(3) This content has the potential to increase charge collection efficiency. The assessment of X-ray detectors' charge collection efficiency (CCE) is crucial since it has an impact on the detectors' sensitivity. Because carriers are caught and recombined at the interface, electron hole (E-H) recombination typically takes place there. By generating photocurrent (I_R) and theoretical photocurrent (I_p), the detector's CCE can be computed using the formula below:

$$CCE = \frac{I_R}{I_P} \quad (2)$$

Typically, there are two ways to raise CCE. The first is to use a high bias voltage to prevent charge capture and lengthen the drift length of charge carriers. Reducing trap density is the second step towards improving the material's quality. Generally speaking, as dosage rates rise, carriers place themselves in shallower traps, yielding lesser gains, which causes CCE to decline. It has been established that CCE can reach over 95% for lead halide-based perovskite materials, such as CsPbBr₃ based solar cells, which is greater than a-Se and comparable to CdZnTe [4].

In addition to employing perovskite materials, further advancements based on perovskite should be made to improve sensitivity. For example, metal semiconductor metal structure X-ray detectors can be prepared using bromine-based perovskite CH₃NH₃PbBr₃ single crystals rather than thin sheets. Thin single crystal devices have been shown to have a sensitivity that is 1163 times greater than that of thin film devices [8]. Device sensitivity can be greatly increased by switching to a single crystal structure rather than a thin film structure.

3. Work Stability

X-ray detector sensitivity and operational stability are closely related and crucial components to consider when assessing the device's functionality. This article will concentrate on researching and evaluating the stability of X-ray detectors that utilize perovskite as the primary material because of the great optoelectronic capabilities of perovskite materials and the fact that most X-ray detectors now use them as the base material.

3.1. Working stability of X-ray detector

The level of stability an X-ray detector exhibits during an extended period of uninterrupted testing with a constant electric field and X-ray radiation dosage is known as its operational stability. The quality of the subsequent graphic imaging is highly dependent on the stability of detector operation, and systems with high stability tend to yield final images that are clearer [9]. Therefore, it is imperative to investigate and assess the stability of X-ray detectors. Several factors affect how stable an X-ray detector operates.

(1) Hardness of radiation. A material's durability or repairability following exposure to high doses or continuous radiation is referred to as its radiation hardness. In general, materials that exhibit high radiation hardness tend to possess a greater radiation damage limit or the ability to self-repair following radiation exposure [4]. Accordingly, the internal structure and optoelectronic characteristics of the device, such as the rate at which carriers migrate or the rate at which electron hole pairs are generated, will not significantly change during a prolonged period of high-dose radiation.

(2) Lattice flaws. Ion migration-induced hysteresis and device instability are brought on by the many imperfections seen on the surface or grain boundaries of polycrystalline perovskite films [8].

(3) Deliquescence reaction[6]. When perovskite comes into contact with oxygen or moisture in the air, it will react chemically, losing stability. Using MAPbI₃ as an example, the combination of MAPbI₃ and H₂O yields an intermediate product MA₄PbI₆·2H₂O that, if exposed to a humid environment for an extended period of time, will degrade into PbI₂ and MAI. H₂O molecules can readily cross grain boundaries in MAPbI₃ polycrystalline films, causing the film's air stability to be compromised [8].

(4) The degree of heat. High temperatures can hasten the dissolution of perovskite at the surface or grain boundaries because of contaminants stored in voids or grain boundaries, for example.

Temperature can also cause phase transitions and changes in the optoelectronic properties of perovskite. therefore, having an impact on the device's thermal stability [8].

3.2. Methods to improve the stability of device operation

At present, with limited material and technological capabilities, most methods to improve the stability of device operation are through innovative and unique manufacturing methods to generate new perovskite crystals with special and stable structures.

Generate Cs_4PbI_6 crystals through reverse temperature crystallization method [6]. The deliquescence of common organic-inorganic perovskites in air significantly restricts their uses. Good air stability is required for X-ray detectors that are sold commercially. But studies have demonstrated that Cs_4PbI_6 this kind of pure inorganic perovskite does not deliquesce in the presence of air for extended periods, and that exposure to air does not appreciably alter its sensitivity, suggesting that the material has exceptional operating stability [9].

utilizing thick film deposition technology to create MAPbBr_3 thick film X-ray detectors that have a thickness of more than 100 μm and outstanding performance. Studies have demonstrated that the device's response current remains relatively constant when subjected to varying applied bias voltages and environmental factors, indicating the MAPbBr_3 thick film device's strong repeatability and stability in air [10].

Using vacuum thermal evaporation to produce MAGeI_3 single crystal X-ray detectors. For a while, MAGeI_3 single crystal can continue to exhibit strong stability. With a dosage rate of $16.7 \mu\text{G yair s}^{-1}$, MAGeI_3 single crystal X-ray detectors can operate steadily for almost two hours under dark current and continuously for over an hour under strong electric fields, all the while preserving a steady X-ray response [5].

4. Conclusion

This article mainly analyzes and studies the sensitivity and working stability of X-ray detectors to a certain extent, emphasizing the importance of sensitivity and working stability in the evaluation of X-ray detectors. Sensitivity determines whether an X-ray detector can respond very quickly to a light source while maintaining high phase clarity, while operational stability reflects the device's ability to maintain operating intensity and sensitivity under certain environmental influences such as extreme temperature and radiation intensity. In addition, this article proposes some current methods to improve device sensitivity and operational stability, namely using perovskite materials as the basic material to fabricate X-ray detectors, and continuously optimizing the crystal structure on the basis of the original perovskite structure through different fabrication methods such as inverse temperature crystallization, thick film deposition technology, and vacuum thermal evaporation technology to fabricate new perovskite crystals, such as using single crystal structure instead of thin film structure. The focus of this article is mainly on the sensitivity and operational stability of X-ray detectors, ignoring other important factors such as signal-to-noise ratio, minimum detection limit, and other aspects that affect the performance and operational capability of the device. At the same time, considering that the types of perovskite crystals are not yet fully comprehensive at present, in the future, the author of this article will conduct further research and analysis on silver bismuth iodine materials based on perovskite, namely AgBiI_4 .

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