Reliability Assessment of UWBG Materials Based Optoelectronic Devices

MS ELECTRICAL ENGINEERING

BY

Syed Muhammad Arqum Ejaz Shah

Roll No: MSEE-F21-008

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Supervisor

Dr. Saif Ur Rehman,

DEPARTMENT OF ELECTRICAL ENGINEERING

SUPERIOR UNIVERSITY

Lahore, Pakistan

Syed Muhammad Arqum Ejaz Shah

Dated:

DEDICATION

To ALLAH the Almighty

&

To My Parents Teachers & Family

RESEARCH COMPLETION CERTIFICATE

It is certified that the research work contained in this dissertation titled "**Reliability Assessment of UWBG Materials Based Optoelectronic devices**" has been investigated and carried out by **Mr. Syed Muhammad Arqum Ejaz Shah** Roll No. **MSEE-F21-008** under my supervision. Therefore, the undersigned hereby certify that they have read and recommended the dissertation entitled for the degree of Master of Science in Electrical Engineering.

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Dr. Saif Ur Rehman ______________________________

Assistant Professor

(Supervisor)

Department of Electrical Engineering

Superior University, Lahore

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Syed Muhammad Arqum Ejaz Shah

LIST OF ABBREVIATION

UWBG	Ultra Wide Band Gap
FPA	Focal Plane Array
APD	Avalanche Photo detectors
MSM	Metal Semiconductor Metal
CMOS	Complementary Metal Oxide Semiconductor
CCD	Charge Coupled Device
CFOM	Comprehensive Figure of Merit
UV	Ultraviolet
PMT	Photomultiplier Tube
NEP	Noise Equivalent Power
MSG	Maximum Stable Gain
MAG	Maximum Available Gain
TRL	Technology Readiness Level
WBG	Wide Band Gap
DUV	Deep Ultraviolet
UVC	Ultraviolet-C
UPG	Unilateral Power Gain
H21	Current Gain
R	Responsivity

Abstract

Here we provide a detailed analysis of the reliability analysis of the solar blind detector using AlGaN as the main material. AlGaN material with high WBG is suitable for UV optoelectronic devices due to its high sensitivity. The investigation entails conducting a literature study on the AlGaN properties, device manufacturing, and the reliability issues within structured solar-blind detection. Outline the experimental methods providing overviews of accelerated life testing and applying environmental factors for analyzing the stability of AlGaN-based detectors. The comparative analysis is also made for the other material used in solar-blind detectors and helps in understanding the prospect and problem of using AlGaN. Noticeably, several questions regarding AlGaN are considered throughout the study, these include, AlGaN's photosensitivity to UV radiation, degradation mechanisms, and influence of the environment. FMEA approaches are used to identify the possible sources of reliability problems, while preventive measures are recommended with a view of improving the stability of AlGaN-based solar-blind detectors. It also generalizes the study on the aging effect of AlGaN and takes into account the effect of years of UV exposure while dealing with design issues of calibration and stability. Thus, it is believed that the findings of this research will extend the current knowledge of the reliability of AlGaN for solar-blind detection and create a foundation for further research in material science and device technology fields. It not only brings new insights into such a structure of AlGaN, but also presents direction for improvement, which enriches the optoelectronic field and expands the occasions of solar-blind detectors' application. Thus, a forward looking dimension is introduced into the analysis, including the investigation of the aging effects related to AlGaN. This includes a thorough analysis of the material's response to constant exposure to UV radiation and a detailed analysis of calibration and stability issues that may arise during the long periods of usage of the object.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the continuum of the area of electronic and optoelectronic devices, UWBG materials with energy band gap more than 3. 0 eV possess enormous transformative opportunity in the arena of high power, high frequency, and efficient devices, the discovery and enhancement of which is the context of this research paper. UWBG stands for ultra-wide band gap and these are semiconductors that have a very high energy band gap. Band gap is the energy that lies in between Valence Band and Conduction Band of the material through which the material can pass current. There are many WBGs which have band gap greater than that of silicon (Si) and gallium arsenide (GaAs) etc. The materials usually have band gaps greater than 3 ev and the definitions of UWBG materials may differ depending on the context. The native semiconductors such as Si and GaAs have band gap of about 1. 0 – 1. 5 eV. UWBG materials have wide band gaps and this makes them possess special characteristics and benefits in many uses. Another is the fact that, UWBG materials can work at higher temperatures as well as higher working voltages without much degrading. They demonstrate a very good heat resistant capability and show a resistance to high temperatures. This property ensures that they can be used in the high power and temperature devices including power electronic circuits, high frequency devices, and power amplifiers. [1]

UWBG materials also feature high electron mobility, which determines the ability of electrons to move from one place to the other within the substance; this makes switching speeds to be higher. This characteristic makes them fit in applications with high frequency and also high power such as; wireless communication, radar technology and sophisticated sensors. UWBG materials are gallium nitride (GaN) and Diamond. The material has a band gap of approximately 3. 4 eV and is widely used in power electronics, light-emitting diodes, and radio-frequency power amplifiers because of its high-frequency/temperature behavior. Diamond with an electrical band gap of about 5. 5 eV exhibit good thermal conductivity and is being considered for use in high power electronics, radiation detectors and in quantum engineering. There is an ever-growing list of fields that are benefiting from the advent and improvement of the UWBG materials as they result to better and more efficient compact and robust electronics. Si based standard semiconductors have band gap of about 1. 1 eV while the UWBG have band gap more than 3 eV. Some of the UWBG materials include; ga2o3, algan, diamond, and BN. [2]

1.2 Ultra Wide Band Gap Materials

Some of the UWBG materials are stated below which are even more effective in optoelectronic devices and have a commendable influence on our work.

1.2.1 Diamond

UWB otherwise known as wide bandgap materials are the semiconductor materials with bandgaps wider than the traditional semiconductors like the GaN and Si. Most of these materials have a band gap greater than 4 electron volts (ie, eV) which makes them to have extraordinary electronic and optoelectronic characteristics to be used in high degree of frequency, high degree of power, and high temperature operations. Materials such as Diamond are some examples that have an ultra-wide band gap. It has a band gap of about 5. 5 eV which closes more than four times the efficiency band than a silicon (1. 1 eV) or a GaN (3. 4 eV). The highest band gap of diamond distances this material from the other semiconductors for various uses in more sophisticated applications that include high power electronic devices, transistors of high frequency, detectors of UV and X-ray and even quantum uses. The unusual characteristics present in Diamond include high carrier mobility, high thermal conductivity, good electrical insulation, and high mechanical strength. These characteristics make it extremely appropriate for use in tough environments, which may cause the failure of other semiconductors.

Yet, there are several experiments connected with the practical application of diamond as the electronic material. Special attention should be paid to the practically insolvable problem of large area, high quality film synthesis with acceptable cost. Moreover, the use of diamond in combination with other materials and the creation of new diamonds based devices is another problem of technological type that require solution to be solved in order to spread this material more actively. However, the constant search for new applications of diamond and other UWB materials continues because of their capability to be utilized in some specific functions and noteworthy progress has been made in the last few years. [1]

a) Optoelectronic properties of Diamond:

Diamond as an ultra-wide band gap (UWB) material indeed possesses exceptional optoelectronic properties that distinguish it from other semiconductor materials. Here's a closer look at these:

b) Ultra-Wide Band gap:

Diamond's band gap is approximately 5.5 eV, much larger than typical semiconductors like silicon. This wide band gap allows diamond to work at advanced voltages and temperatures without encountering breakdown, making it ideal for high-power and high-temperature electronics.

c) High Thermal Conductivity:

Diamond has highest thermal conductivity of any material (~22 W/cmK). This attribute allows it to competently disintegrate the heat produced in high-power electronic devices, reducing risk of thermal damage.

d) Transparency across a Wide Spectrum:

Diamond is translucent from the deep UV to the far IR wavelengths, making it a useful material for various optoelectronic devices. The ultra-wide band gap also makes diamond resistive to photon-induced damage, especially under UV radiation.

e) High-Electron & Hole Mobility:

Diamond exhibits high carrier mobility, which results in high-speed electronic devices. The electron mobility is about 4500 cm^2/Vs and the whole mobility is around 3800 cm^2/Vs.

f) Radiation Hardness:

Diamond is extremely resistant to radiation damage, which makes it suitable for optoelectronic devices in harsh environments such as space applications and radiation detectors.

g) Electron Saturation Velocity:

Diamond's high electron saturation velocity allows for faster-switching speeds and less time-delayed signal distortion, which is ideal for high-frequency and power devices.

These remarkable properties make diamond a promising UWB material for high power, high-temperature and high-frequency optoelectronics (Shown in Fig 1.1). However, challenges in fabricating and doping high-quality diamond still limit its wide-scale industrial application. Nevertheless, with the advances in synthetic diamond growth techniques, we might see more prevalent usage of diamond in future optoelectronic devices. [3]

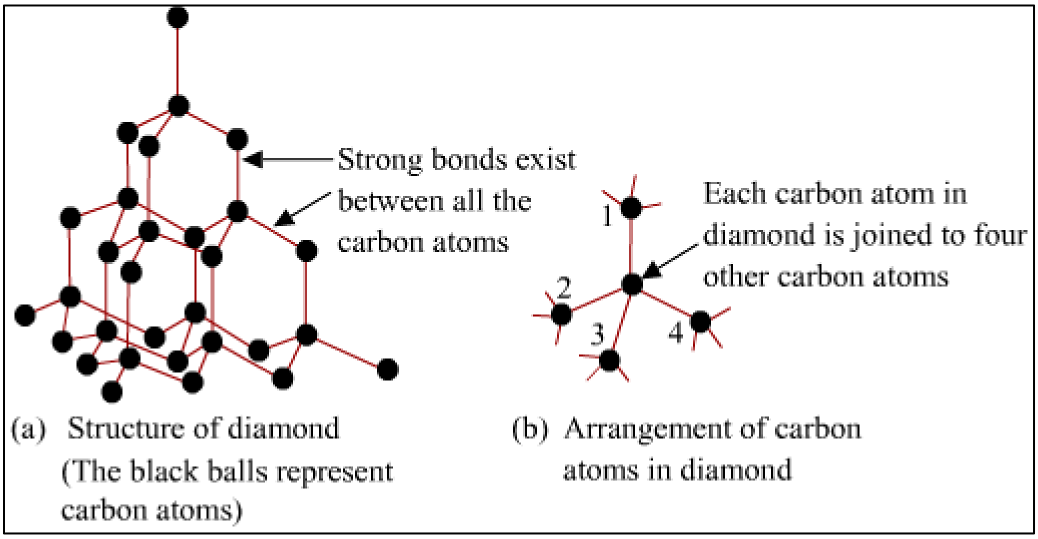

Figure 1.1: Crystalline Structure of Diamond [4]

1.2.2 β-Gallium oxide (β-Ga2O3)

β-Gallium oxide (β-Ga2O3) is an ultra wide bandgap material with a large band gap of approximately 4.5-4.9 eV. This surpasses other well-known wide band gap semiconductors such as gallium nitride (GaN, band gap 3.4 eV) and silicon carbide (SiC, band gap 3.3 eV), making it very promising for next-generation power electronic devices. The word "band gap" refers to the energy gap between the valence band (where electrons are in their lower energy, or ground, states) and the conduction band (where electrons can travel freely, contributing to electrical conductivity). Larger the band gap, the higher the voltage that the material can withstand before breaking down, and the better the material can function in high-power, high-temperature applications. [48]

Some potential benefits and applications of β-Ga_2O_3 include:

a) High-voltage electronics:

Thus, because of its large band gap, β-Ga_2O_3 is suitable for applications in high power and high voltage electronics devices. For instance, in power conversion systems such as power inverters for electric vehicles or power systems for renewable energy systems the proposed approach would improve efficiency and reduce the losses of power.

b) High-temperature electronics:

Another factor that comes with largish band gap, β-Ga_2O_3 also experiences high temperature tolerance in contrast to many semiconductors. This could make it advantageous especially in condition that are rough such as in automotive or aerospace industries.

c) UV detection:

The β-Ga_2O_3 has a large band gap, this makes ultraviolet devices such as photodetectors fabricated from β-Ga_2O_3. It may be applicable in several fields such as, tracking the sun's UV emission for climatic research and development or development of UV sensors for scientific or defense purpose.

d) Transparent electronics:

β-Ga_2O_3 is a transparent material, thus, it can be incorporated into the fabrication of transparent electronic devices including the mentioned transistors. This could be used in future display technologies among the other uses.

Nevertheless, also β-Ga_2O_3 has its drawbacks as it is any newly developed material. Its crystal growth process is however not simple, and establishing dependable fabrication techniques of devices from the material may prove to be time-consuming. Also, its electrical characteristics such as charge carrier mobility are still inferior to the characteristics of the commonly used semiconductors like silicon, silicon carbide, or gallium nitride. However, with advanced research and development, β-Ga_2O_3 will be an essential material component to the third generation electronic devices. [49]

1.2.2.1 Optoelectronic properties of β-Gallium oxide (β-Ga_2O_3)

Beta-gallium oxide (β-Ga_2O_3) is promising ultra wide band gap (UWBG) semiconductor that has gained substantial attention due to its unique properties. Here's an overview of some of its key optoelectronic properties.

a) Ultra Wide Band Gap:

The material has very large bandgap of approximately 4.6-4.9 eV, making it appropriate for high power and high frequency applications.

b) Breakdown Electric Field:

β-Ga_2O_3 has a high critical electric field, reaching up to 8 MV/cm, much higher than most other semiconductor materials. This high breakdown field allows for devices that can withstand high voltages, making it ideal for power electronics.

c) Thermal Stability:

Also being an UWBG material, the compound has good thermal stability, a desirable feature when the device produces a lot of heat or is to work in a high-temperature environment.

Optical Transparency:

For the similar reason of large bandgap, β-Ga_2O_3 is optically transparent in the visible range. This makes it a potentially useful material in optoelectronic devices especially those that operates in the Ultraviolet region such as the UV photo detectors and the light-emitting diodes (LEDs).

d) Carrier Mobility:

The electron agility of β-Ga_2O_3 is relatively high compared to additional wide band gap materials, with values typically in the range of 100-150 cm^2/Vs. This results in efficient charge transport which is useful in electronic devices.

e) Radiation Hardness:

β-Ga_2O_3 has shown a good tolerance to radiation, making it suitable for applications in harsh environments or for devices that require radiation hardness.

Despite its promising properties, one of the key challenges in working with β-Ga2O3 is controlling its defects. These defects can influence properties like carrier concentration and mobility, and can lead to instability in device performance. Nonetheless, β-Ga2O3 due to its crystalline structure (as shown in fig 1.2) is still an exciting material with great potential for a variety of power and optoelectronic applications. [5]

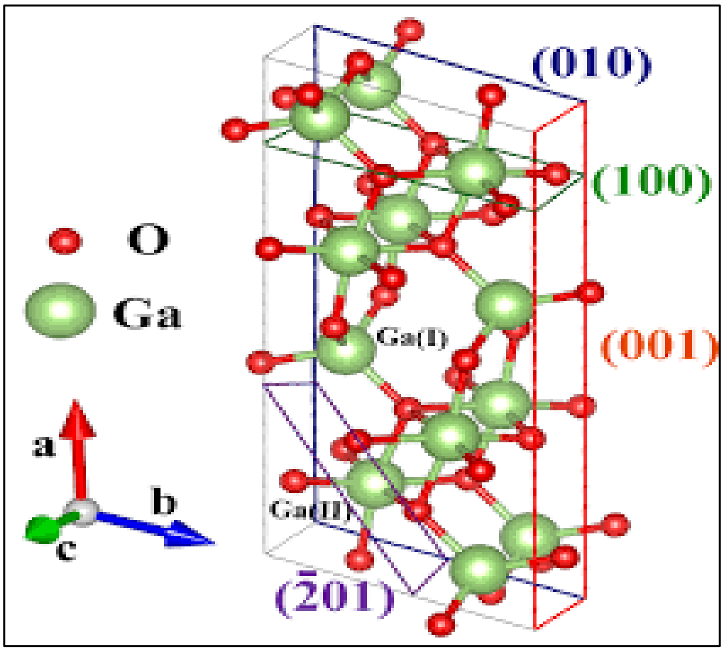

Figure 1.2: Crystalline Structure of β-Ga2O3 [6]

1.2.3 Hexagonal Boron Nitride (h-BN)

Hexagonal Boron Nitride is a variety of ultra-wide bandgap material that can reveal high positive aspects in electronics and optoelectronics. It is also called ‘‘white graphene’’ since it has similar hexagonal layers below the base plane as the graphene but it has a different electronic structure given by the interconversion of boron and nitrogen atoms. Semiconductor physics is a field of material science which deals with the band gap which is the specific measurement that defines the optical and electrical characteristics of a material. This is the energy gap between the valance band, the energy level at which the electrons in the atom reside and the conduction band, the energy level which renders the electron free to move within the material. The band gap indicates the energy needed to exhite an electron from the valence band to the conduction band; thus, the greater the band gap the higher the energy needed to stimulate the electron. Coming to the electronic band structure of h-BN, the band gap is approximately ~ 6 eV which is usually referred to as ultra-wide. To illustrate this, the most frequently used semiconductor material is silicon, with a bandgap of 11000 cm^(-1) or 1. 1 eV.

Hence, powders such as h-BN with ultra wide band gaps can operate at high power, high frequencies, and high temperature making them appropriate for application in extreme conditions and high-performance electronics devices. In addition, h-BN is chemically inert, possesses high thermal conductivity, and is highly resistant to oxidation/corrosion which enhances its candidacy in several applications. However, it should also be noted that the integration of h-BN into presently used electronic technologies also has some drawbacks. These challenges comprise problems in synthesis and processing and incorporating h-BN with other materials. In my available knowledge ending in September, 2021, further investigation is being done to remove these challenges and maximize application of h-BN and other UWBG materials. [14]

1.2.3.1 Optoelectronic properties of Hexagonal boron nitride (h-BN)

Hexagonal boron nitride (h-BN), sometimes referred to as "white graphene," is an UWBG material that is garnering consideration due to its unique optoelectronic properties. Let's look at some of these characteristics:

a) Ultra-Wide Band gap:

h-BN possesses a wide band gap of approximately 6 eV. This is one of the largest among known insulators, providing high breakdown voltage and making h-BN suitable for high-power, high-temperature electronic applications.

b) Optical Transparency:

Due to its wide band gap the h-BN appears transparent to visible and ultraviolet light almost to visible. This makes it appropriate for use in optical parts and protective coatings in optoelectronics.

c) High Thermal Conductivity:

Thermal conductance of the h-BN is of the order of isotopically pure diamond which is very desirable for heat dissipation in electronic componencts. This makes it a possibly suitable substrate or layer in high power electronic application or devices.

High Chemical and Thermal Stability:High Chemical and Thermal Stability:

h-BN is chemically inert and thermally stable, hence thereby making it suitable for use in high stress environments.

d) Dielectric Properties:

Solving this problem, h-BN is an excellent insulator with the high breakdown field and good dielectric properties that can be used for the gate dielectric layers in electronics.

e) Deep Ultraviolet Light Emission:

h-BN can alsogive deep ultraviolet light when it is electrically or optically stimulated, which situates it as a deep-UV lasing material.

However, it should be mentioned that the usage of h-BN is mostly as the part of structure with the other TMDCs and graphene. For example, h-BN is commonly used as an insulating layer in graphene-based devices because of its ability to eliminate the contact between charge traps and the corresponding devices as well as to decrease scattering based on substrate phonons. Despite its advantages, the effective application of h-BN in devices is still an issue; for example, growing high quality, large size h-BN film, and the controlled doping of h-BN layers. The studies in this field still go on, and new advances are likely to be made in the future. (Refer Fig 1.3) [15]

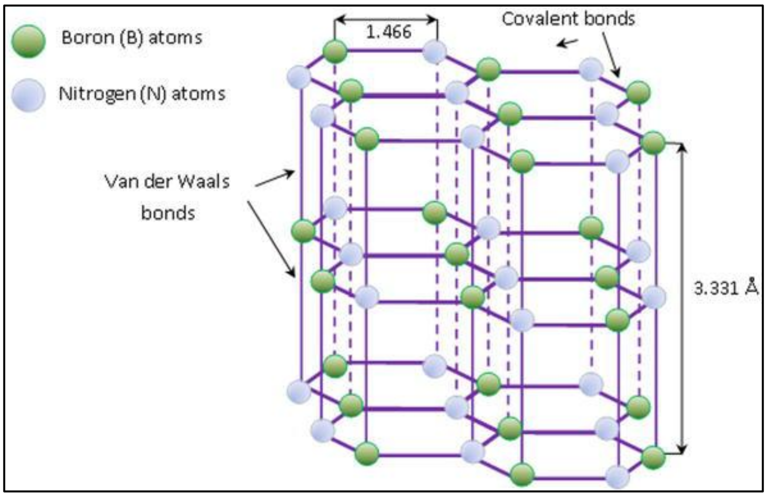

Figure 1.3: Crystalline Structure of h-BN [7]

1.2.4 Aluminum Nitride (AlN)

Aluminum Nitride (AlN) is another important ultra-wide bandgap material, with a bandgap around 6.2 electron volt, even wider than h-BN. This makes it an exceptional candidate for use in high power, high temperature, and high frequency electronic devices. Like other wide band gap materials, AlN exhibits remarkable thermal stability and thermal conductivity, making it particularly advantageous for uses that require efficient heat dissipation. These properties, combined with its high electrical resistivity, make AlN an attractive material for electronic and optoelectronic devices. One of the potential uses for AlN is in the development of deep UV light emitting diodes (LEDs) and the laser diodes. The wide band gap of AlN corresponds to photon energies in the deep UV range, allowing the fabrication of devices that can emit at these wavelengths. This has a extensive variety of applications, as well as water and air sterilization, medical treatments, and non-line-of-sight communications.

However, as with other wide band gap materials, there are challenges associated with the synthesis and processing of AlN. High-quality, large-diameter AlN crystals are difficult to grow, which can limit the feasibility of manufacturing large-area AlN devices. Moreover, doping AlN to modulate its electronic properties is also challenging. The optimization of AlN growth techniques and doping strategies is an active area of research as of my knowledge cutoff in September 2021. [8]

1.2.4.1 Optoelectronic properties of Aluminum Nitride (AlN)

Aluminum Nitride (AlN) is ultra wide bandgap material. It has attracted a lot of attention because of its unique physical & optoelectronic properties, that make it suitable for a wide range of applications including high-power electronics, high-temperature electronics, and deep-ultraviolet (DUV) optoelectronic devices.

Here are some of the key properties related to its use in optoelectronics:

a) Wide Band gap:

AlN has a direct bandgap of about of 6. 2 eV at room temperature very appropriate for optoelectronic devices especially for UVD LEDs and detectors.

b) High Thermal Conductivity:

AlN has very good TCR and Thermal conductivity and hence is very beneficial in case of heat dissipation in high power or high frequency devices. This property also make AlN substrates very suitable for high power LED applications where thermal dissipation is a major problem.

c) High Breakdown Field:

AlN also has a high electric field breakdown strength due to its wide ban dp. It therefore finds use in high power and temperature application like electronics and optoelectronics.

d) Radiation Resistance:

The wide band gap also plays a part in high radiation resistance thus, AlN is used in space areas and other areas where radiation is a problem.

e) Deep Ultraviolet (DUV) Optoelectronics:

Many papers on DUV LEDs and the laser diodes employ AlN as the substrate material for these devices. This is due to its large band gap which enables the ermission and detection of photon in the deep ultraviolet region.

Nonetheless, which these advantages, there are some issues that would govern the use of AlN in optoelectronic devices. For instance, the epitaxial growth of good quality AlN is a challenge, and doping of AlN to obtain p-type material is still a problem. Current researches are still being carried out in an effort to fully harness all the capabilities of AlN in optoelectronics as well as other sectors. Some of these areas are as follows, Increasing the quality of AlN crystals, Doping: methods to make AlN efficient, Fabrication of the AlN based DUV due to its structure as depicted in figure 1. 4.

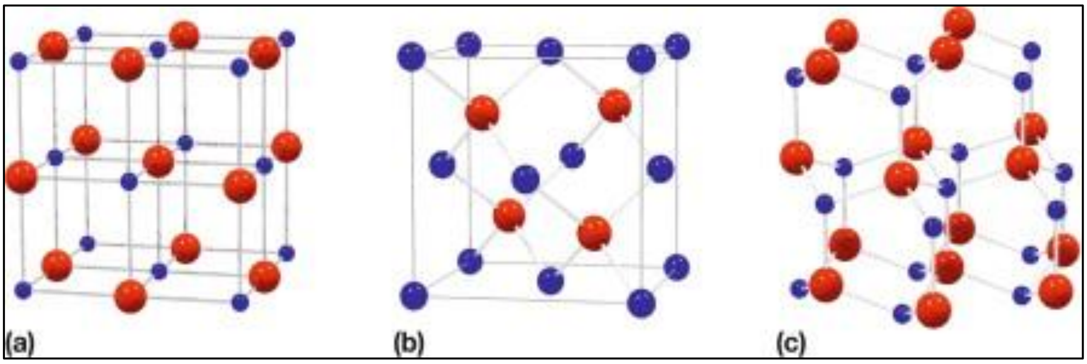

Figure 1.4: Crystalline Structure of AlN [9]

1.3 History of Ultra Wide Band Gap Materials

The history of ultra-wide band gap (UWBG) materials has evolved alongside the broader development of semiconductor materials and technology, particularly within the last few decades. Semiconductors were first discovered in the early 20th century. The first practical applications of semiconductors in electronics began in the mid-20th century, with materials like germanium and silicon. Silicon, with bandgap of 1.1 eV, became the most widely used semiconductor due to its abundance and stable properties [25]. The concept of band gap engineering, or manipulating a material's band gap to optimize its properties, emerged in the mid-20th century. The desire to extend the functionality of semiconductors, particularly in high- power, high-temperature, and high-frequency applications, motivated the research and development of wide band gap (WBG) materials, well-defined as materials with the band gap greater than that of silicon but less than 3 eV. [10]

The two new generation materials; Gallium nitride (GaN) & Silicon carbide (SiC) both are Wide bandgap material began in the last two decades of the 20th century. Possessing some superior features, the two materials show higher electron mobility and breakdown field, and better thermal conductivity than silicon. These were useful in LED’s, power electronics, and radio frequency devices. However, ultra-wide bandgap materials, those that have been recorded to be greater than 3 eV became a matter of concern later. Among the UWBG materials, diamond, boron nitride (BN) and aluminum nitride (AlN) have been researched since the late 20th century. The Gallium oxide (Ga2O3) also emerged as a capable UWBG material because of its better properties like high breakdown field; the fabrication cost is also reasonable [24]. The creation of new and high quality UWBG materials is considered to be a problem in the sphere of material science. It calls for the synthesis of large and perfect crystals with very few defects and the fabrication of good processes. However, progress has been made in the development of UWBG materials; and as pointed above, they are beginning to feature in a number of uses [22]. It is expected that they will perform a crucial part in the advancement of electronics in power systems as well as in communication technologies because of their better properties and performance. All the contributions are summarized in table 1.1 below. UWBG materials have a revolutionary impact on today's world especially in Electronic and optoelectronics devices. These materials, with a big band gap energy, show outstanding electrical and optical characteristic. The materials that falls under the category of UWBG includes Silicon carbide (SiC) and gallium nitride (GaN). In power electronics, UWBG materials help to design thermal stable devices with low loss at high operation temperatures and volumes to miniaturize and increase the efficiency of electronic systems. In the area of UV sensing, UWBG materials are central in solar-blind detectors applications in military and space age for chemical and biological sensing. Due to their robust tolerance to adverse environmental effects and use in solar-blind application domains, UWBG materials will remain critical to transforming various industries in terms of performance, robustness, and reliability in electronics and photonics.

Table 1.1: History of Development in UWBG Materials [23] [26]

Time Period	**Discoverers**	**Contributions in UWBG Materials**
Mid-20th Century	German physicist Arnold Sommerfeld	The concept of band gap engineering emerges
Late 20th Century	Dr. Sriram Krishnamoorthy	Initial research into ultra-wide band gap (UWBG) materials begins. Diamond, Boron Nitride (BN), Aluminum Nitride (AlN) are some of the early materials studied.
Early 21st Century	Siddharth Rajan	Gallium Oxide (Ga2O3) emerges as a promising UWBG material due to its superior properties and potential uses.
2014	Isamu Akasaki,	Development of the blue and white LEDs

	Hiroshi Amano, and Shuji Nakamura	based on Gallium Nitride (GaN) materials.
21st Century(2000s-2020s)	Umesh K. Mishra:	Active research and development into UWBG materials continues, focusing on improving crystal quality, reducing defect densities, and developing reliable fabrication processes.
Present Day	Joshua Caldwell	UWBG materials begin finding their way into various uses, such as UV LEDs, high voltage electronics, and high-temperature electronics. Further research and development is ongoing.

1.4 Statement of the Problem

Several problems are faced by DUV optoelectronics such as expensive and complicated fabrication, low crystal quality and growth process. Therefore, noteworthy research exertions are still compulsory to understand basic properties and to grow acquaintance processing techniques for utilizing new semiconductors material in efficient way to enhance DUV by using p type material with β-Ga2O3. There is dire need to introduce novel Ultra Wide Band Semiconductors Materials (UWBG) based devices with improved qualities and functionalities.

Effective doping strategies are lacking for UWBG materials, which greatly hinders the performance of UWBG devices. Although it is very challenging to achieve p-type doping in Ga2O3 we are trying to use fabrication techniques of the UWBG hetero structures for the development of high-performance electronic devices. In WBG semiconductors silicon based power transistors have reached limits of operation frequency, power density & breakdown voltage so main purpose of the research is to use UWBG semiconductor materials like β-Ga2O3, AlN, h-BN to resolve these issues.

1.5 Research Objectives

Proposed research contributions will be:

- To develop DUV photodetector in direction to attain high photoresponsivity using β-Ga_2O_3
- Enhance the performance of DUV by using p-type materials as hetero-junction with β-Ga_2O_3.
- Using different graphical software.
- Simulation results of UV will be observed to check the efficiency of the system after all calculations.

1.6 Difference between WBG and UWBG

Bandgap is the fundamental property of a material, which defines the energy essential for electron to jump from valence band (where the electrons are not allowed to move) to the conduction band (where the electrons are permitted to conduct electric current). This is essential for a material's electrical and optical properties. [50]

1.6.1 Wide band gap semiconductors

These have bandgap energy extending from ~1.5 eV to ~3.4 eV. Examples include Gallium Nitride (GaN, ~3.4 eV), Silicon Carbide (SiC, ~3.0 eV), and Gallium Arsenide (GaAs, ~1.4 eV). These constituents are appropriate for optoelectronic applications, high-temperature and high-frequency devices.

1.6.2 Ultra-wide band gap semiconductors

These materials have a bandgap energy greater than ~3.4 eV. Examples include Aluminum Nitride (AlN, ~6.2 eV), Diamond (~5.5 eV), and Gallium Oxide (Ga_2O_3, ~4.8 eV). These materials have features such as extremely high-breakdown electric field, high-thermal conductivity, and deep ultraviolet (UV) light emission and absorption. Therefore, they are considered apposite for high power electronics, high temperature electronics, and deep-UV optoelectronics.

The use of ultra-wide band gap materials is a relatively new field, and ongoing research is exploring their full potential and challenges in fabricating high-quality, ultra-wide band gap semiconductor devices [52]. Detailed analysis is given in Table 1.2

Table 1.2: Difference between WBG and UWBG

Feature	**Wide Band Gap (WBG) Materials**	**Ultra Wide Band Gap (UWBG) Materials**
Band gap Energy	Typically >1.1eV and <3eV	Typically >3eV
Example Materials	Silicon Carbide (SiC), Gallium Nitride (GaN)	Gallium Oxide (Ga2O3), Diamond, Aluminum Nitride (AlN), Boron Nitride (BN)
Breakdown Voltage	High, typically greater than silicon	Very High, typically greater then WBG materials
Operating Temperature	High, Greater than silicon, typically up to 600 °C	Very High, Can Operate at temperatures exceeding those tolerable by wide band gap materials
Thermal Conductivity	Typically greater than Silicon, allowing better heat dissipation	Can be very high, depending on the specific materials, allowing excellent heat dissipation
Operational Frequency	High , Allowing for faster switching and operation in RF devices	Very High, Allowing for operation at extremely high frequencies.
Applications	Power Electronics, LEDs, RF devices, Motor devices, electric vehicle component	High-power and High-voltage electronics, UV LEDs, UV photo detectors, High-temperature electronics, Space applications
Energy Efficiency	Better than silicon due to ability to operate at higher voltages with less energy source	Even better than Wide Band Gap Materials because of ability to operate at extremely high voltages with

		less energy source
Radiation Hardness	Better than silicon, but varies based on materials	Typically very good, making them suitable for space and nuclear applications
Research and Development stage	More mature, with commercial products widely available	Still under active research and development: some commercial products available, but not as wide spread

The above table shows the general trends, but it's important to note that the specific properties can vary greatly between different materials within the WBG and UWBG categories. Some WBG materials might perform better in certain aspects than some UWBG materials, and vice versa [54].

1.7 Properties of UWBG Materials

a) High Breakdown Voltage:

The critical electric field for UWBG materials is high giving the ability for the material to hold high voltage before it fails. This makes them suitable for high power and high voltage uses.

b) High Thermal Conductivity:

Owing to the extensive research and the examination of the use of UWBG materials, it has been found that such materials can work at a high temperature when compared to the regular semiconductors. This is even quite useful in power electronics where the devices produced a lot of heat most of the times.

c) High Electron Mobility:

Some of the UWBG materials possess high electron mobility that helps to increase the switching velocity and hence cutting down on the energy demands in certain uses such as power electronics and RF applications.

d) Resistance to Radiation:

As observed earlier, most UWBG materials are relatively immune to radiation degradation, hence they are well suited for space applications or environments where radiation is a major factor. [51]

The possibilities of using UWBG materials are manifest and cover many niches. A few include:

e) Power Electronics:

Due to high breakdown voltage and thermal dissipation UWBG materials can effectively be used in power electronic application devices of the next-generation. Some of the most common uses are in electric cars, renewable energy sources and storage as well as electric power distribution networks.

f) Radio Frequency Electronics:

Thanks to such features as a high electron mobility and a large band gap, UWBG materials are capable of operating at higher frequencies than traditional semiconductors, and this disadvantage turns them into useful components for radio frequency electronics, and telecommunication, specifically for the fifth generation, and the following ones.

g) LEDs and Lasers:

Certain materials of UWBG such as compounded of gallium nitride are used in production of light-emitting diodes (LEDs) and lasers particularly those that operate in the blue to UV region.

h) Photonics and Optoelectronics:

Due to their interaction with light and radiation, materials of UWBG are used in a range of photonic and optoelectronic appliances.

i) High-Temperature Electronics:

Because of this characteristic, UWBG materials finds applications in high temperature electronic devices including the aerial or auto industries.

j) Photonics and Optoelectronic Devices:

UWBG materials have a band gap energy exceeding 3 electron volts (eV). This large band gap energy brings out certain characteristics in these materials that make them ideal for use in phonic and optoelectronic applications. [53]

1.8 Electrical Properties of some UWBG Materials

Some Electrical Properties of UWBG materials such as AlN, β-Ga2O3, h-BN & Diamond are described in Table 1. 3.

Table 1.3: Electrical Properties of some UWBG Materials [2]

Parameter	AlN	β-Ga2O3	h-BN (2D)	Diamond
Band gap *(eV)*	6	4.9	6.1	5.6
Breakdown field E_C MV/cm	15.4	10.3	7	13
Electron Mobility(cm^2/Vs)	426	180	48±24(Si Doping)	7300
Hole Mobility (cm^2/Vs)	14	8.8	/	2000
Sat.Electron Velocity $(10^7 cm/s)$	1.3	1.1	/	2.7
Relative Permittivity	9.76	10	4.97	5.7
Thermal Conductivity(W/mK)	253-319	11-27	550±75	2290-3450

The specific on-resistance versus breakdown voltage plot, depicted on a log-log scale, illustrates the characteristics of and Ultra Wide Band Gap (UWBG) & Wide Band Gap (WBG) semiconductors. In this plot, the lower right region signifies higher Breakdown Field of Merit (BFOM), which directly corresponds to enhanced performance. This particular figure-of-merit is of significant interest in the context of low-frequency unipolar vertical power switches. All this details is shown in Figure 1.5 [2]

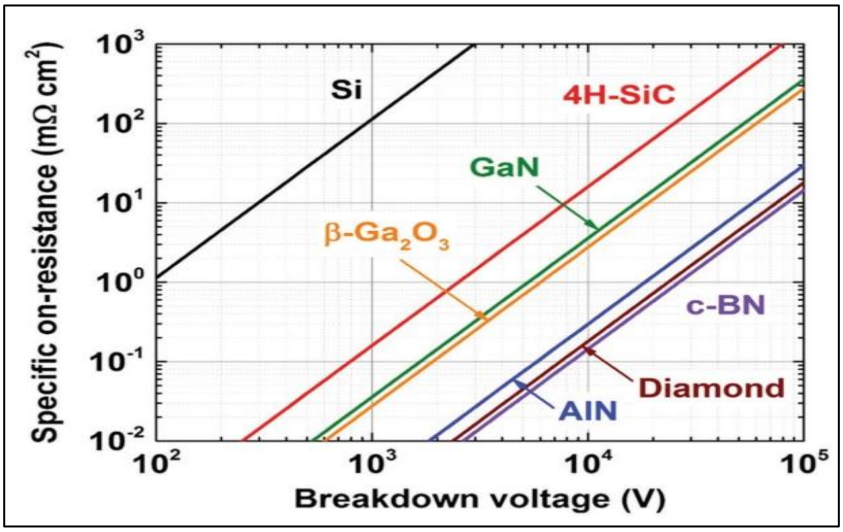

Figure 1.5: Baliga figure-of-merit (BFOM) [2]

This figure 1.6 is showing calculation of drift mobility's in Ga2O3 is reliant on temperature. The terms IO and NI are representative of ionized & neutral impurity scattering, respectively, while DP, NOP, and PO denote non-polar acoustic, non-polar optical, and polar optical phonon scattering, correspondingly. The dotted line, marked as NOP, signifies the isolated NOP mobility. The thick, unbroken line illustrates the cumulative drift mobility accounting for all types of scattering mechanisms.

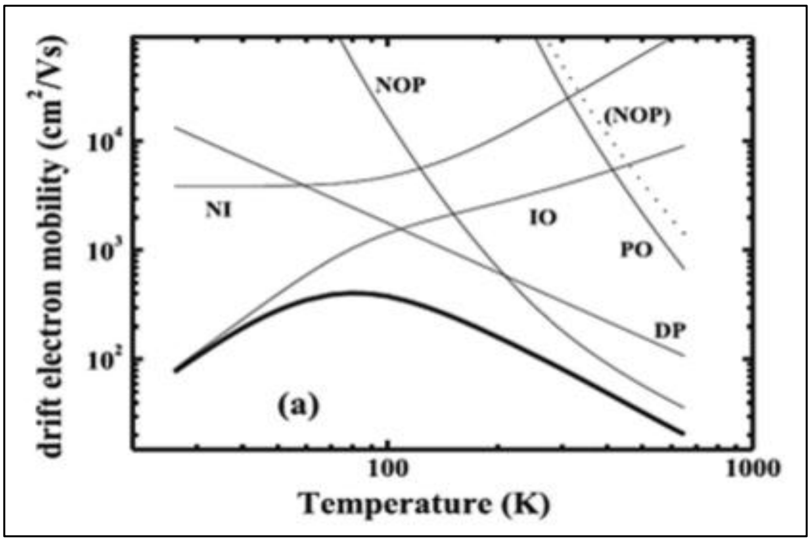

Figure 1.6: Electrical Properties of UWBG Materials (Gallium Oxide) [55]

1.9 Applications of UWBG Material in Photonics and Optoelectronics

a) Ultraviolet (UV) Devices:

Due to the fact that the band gaps of UWBG materials are relatively wide; the corresponding materials can emit and absorb light in the ultraviolet region. This makes them ideal for devising UV light-emitting diodes (LEDs) and UV photo detectors, SiC and sapphire are ideal materials for fabricating UV LEDs and photo. The uses of these devices include water and air purification, biomedical lab, flame sensing, and even in space exploration.

b) High-Power Devices:

There are no problems with dielectric breakdown in the case of materials used in UWBG. This makes them suitable for high power optoelectronic devices such as high power light source or laser diodes.

c) High-Frequency Devices:

Due to the high value of band gap of UWBG materials, they can operate at very high frequencies but with limited heat or noise. This makes them ideal for high speed optical communication system in which data is transmitted through light waves.

d) High-Temperature Devices:

The factor of UWBG materials to maintain high performance in working temperatures without degrading makes it ideal in optoelectronic devices in conditions such as automotive and aerospace.

e) Energy Efficient Devices:

Composing UWBG materials, devices can work at higher voltage which in turn reduces the amount of energy losses and increases energy density. This is particularly worhty in such presentations as the solid state lighting and the high power electronics.

Altogether, the UWBG materials, and particularly, the electrical and optical characteristics represented in fig 1.7 play a strategic role in the creation of new generation photonic and optoelectronic technology. High power, high temperature, and high frequency functions that the devices can handle unveil numerous enhanced applications. [1]

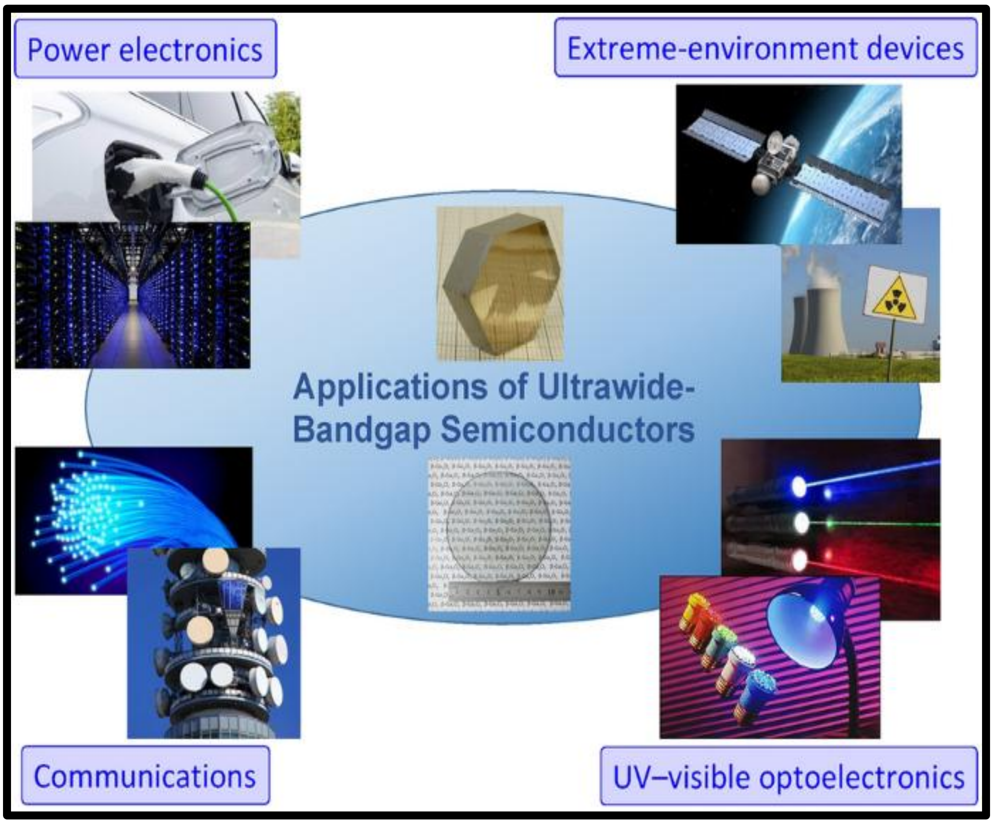

Figure 1.7: Applications of UWBG Materials [5]

1.10 Trends of UWBG Materials

UWBG materials are rapidly growing trend in materials science, semiconductors plus multiple domains of engineering. According to my knowledge cutoff in September 2021, this area was actively developing due to the possible applications of UWBG materials with band gaps greater than 3. 0 eV. Some of these include, Gallium oxide (Ga2O3), diamond, aluminum nitride (AlN), and many others. [27]

CHAPTER 2

LITERATURE REVIEW

2.1 Highlights and Introduction

The literature of the works that are having relation with the work done in this dissertation is described in this chapter. The experimental research complies with the UWBG Materials.

2.2 Survey of Related Work

The field of semiconductors has been given a tremendous boost with the beginning of the UWBG technology or Ultra Wide Band Gap technology. This section introduce the significance and prospect of the UWBG materials in various applications such as electronics, optoelectemics, power devices and so on. In this section, it will be investigates the fundamental characteristics of UWBG materials that set them apart from the rest of the family of semiconductors. The research concerning the characteristics such as large electric field strength, high heat transfer coefficient and their effects on the performance of the device can be described. This part will discuss on the methods used in synthesizing UWBG materials like physical vapor transport, molecular beam epitaxy (MBE), among other techniques. An overview of the techniques in relation to the benefits and drawbacks indicated in different research works will also be provided as to how changes in the methods have led to enhancements of the final product. About half of the review will be devoted to the devices that incorporate UWBG materials such as Schottky diodes and FETs, and others. This section should explain how the properties of UWBG materials are used in such devices and enhance their performance based on the literature.

This section consists of analysis of the work that has already been carried out in the area of research. It should indicate the major milestones, goals, current issues and any disparities of the various researchers' findings. In the end, the respective conclusions are made and the summary of the identified main issues in the existing literature and their conclusions with reference to the analyzed sources are presented. In some regards, it talks about the possibility of using UWBG materials and how the further study will go on embracing the advancement in the synthesis process, the design of the device and the coping of various barriers. This optional section might explain the possible directions of further investigation, whether in generation of new synthesis methods, new UWBG materials, or in engineering and applications of devices. [32]

UWB semiconductors are still emerging as absorbing branches of innovations in material science and electronics. The defining properties of UWB semiconductors are the fact that they have band gap energy higher than 4 eV and this particular property of the band gap has a direct relation to the semiconductors electronics characteristics. It can be pointed out that the UWB semiconductors can claim the future of power-electronics, solar-blind UV photo detectors, quantum information systems, and high-temperature electronics. The present literature review also reveals that extensive research has been done earlier in studying wide band gap semiconductors.

Specifically, works have been done on the material GaN and SiC as these two materials displayed outstanding physical and electronic characteristics. There are some sectors such as the power electronics as well as the optoelectronics sector where they have used these semiconductors and each of these semiconductors outperforms and silicon-based semiconductor. The current literature on semiconductors under discussion presupposes that UWB semiconductors could exceed the efficiency of the widely used today semiconductors such as GaN and SiC. Some of the characteristics of UWB semiconductors are beneficial for applications that would involve higher electric fields, high temperature and powerful densities. Also, some of them are UV sensitive and solar-blind UV detectors, and some of them are applied to quantum information systems. The researches in UWB semiconductors, however, are not without difficulty. It is noteworthy to note that material quality, doping efficiency, contact resistance and the reliability of the device have been all cited in literature as the main challenges. In more detail, the issues are in creating high-quality UWB materials and structures, and controlling of defects is one of the major problem. These new directions have appeared within the literature in the last dozen years in relation to the general study of UWB semiconductors and can include the use of novel material types such as Aluminum Nitride (AlN), Boron Nitride (BN), and Diamond. Sustainable fabrication processes, new materials and devices geometries, and the computational modeling for performance projections are also pointed out as the current trends. Therefore, the research in the context of UWB semiconductors can be considered as the rapidly growing and highly promising branch. Thus, one can conclude that the opportunities for research are immense and, despite the existing difficulties, the utilization of UWB semiconductors in different fields is immensely beneficial [34].

The Tauc plot method is one of the common techniques of estimating the energy bandgap of semiconductors based on their absorption coefficients, preferred in the optoelectronics field. This method was described first by J. Tauc in 1966 and it has been used in many experimental investigations since then. The Tauc plot method is based on the Tauc equation, which relates the absorption coefficient (α) of a material to the photon energy (hν) and the energy gap (Eg):The Tauc plot method is based on the Tauc equation, which relates the absorption coefficient (α) of a material to the photon energy (hν) and the energy gap (Eg):

$$\alpha(h\nu) = B(h\nu - Eg)^n \qquad (1)$$

In this equation, B is a constant that is equal to the transition probability and depends on the type of transition whether it is the direct or indirect band gap and n is proponent that rest on on the nature of the transition [43]. When the graph is plotted then it is possible to find the energy gap Eg. In order to use the Tauc plot method, one collects the UV-Vis abosrption spectrum of the material experimentally, mainly using spectrophotometer. It gives data concerning the dependence of the absorption-coefficient on the energy of the visible photons. It should be mentioned that the absorption coefficient can be calculated with the help of the Beer-Lambert law starting from the values of absorbance. On the basis of the above calculated value, the Tauc plot can be made by plotting the graph of (αhν)^2 against hν. The linear region of the plot that is named as the Tauc region relates to the direct or indirect allowed transitions in the material. To obtain this, the linear portion of the curve extrapolated toward the x-axis can be used to estimate of the energy-gap [44].

It is worth noting that the method of analysis from Tauc plot implies a direct or at least an indirect allowed band gap and exclude other types of transitions and excitonic ones. Hence, it is appropriate to use it when analyzing semiconductor materials that have a clear band structure. Specific software packages and programming languages are available in performing the Tauc plot analysis as well as in determining the energy gap. An example include tools such as MATLAB or Python with tools like SciPy or using software specifically designed for this use. In other words, Tauc plot method can be considered as a helpful technique in evaluating the energy gap of semiconductor materials by using the UV-Vis absorption spectra data. This format offers a simple and relatively universal method for describing the optical behavior of materials – especially in the framework of optoelectronics [45]. Origin Pro is a software application that acts as Graphing & Data Analysis Workspace which is useful for Scientists and Engineers.

It features are aimed at simplifying graphical analysis and interpretation of scientific data and information. Kindly note that I was only able to search up to September 2021, thus, it is possible that the features and specifications have changed since then.

2.3 Interpretation and Limitations

The Tauc plot is another way in which the energy band gap of a material can be deduced from the absorption spectrum.

It is also especially appropriate for the analysis of semiconductors and insulators but it is not limited to these types of material.

In cases of an indirect or direct band gap of the material, the Tauc plot invokes a variable represented with the symbol n in the Tauc equation.

However, the absorption edge of a material, especially for a semiconductor, might be affected by effects such as exciting effects, impurities and defects; hence it is only an approximate value of the band gap derived from Tauc plot.

Other methods, for instance, photoluminescence or other kinds of spectroscopic measurements might then be employed to confirm the accurate value of the band gap that has been calculated in the paper [44].

The Tauc plot is one of the most common methods used for determination of the energy band gap of the semiconductor materials with respects to their absorption spectra as illustrated in the fig below 3.1. It offers an unpretentious and graphical method of obtaining significant information about the electronic properties of materials and is a mandatory instrument involved in the description of numerous optoelectronic devices and material systems.

Below is a general outlook at what has been covered in Origin Pro 8. 5 based on the knowledge cut-off.

a) User Interface:

The layout of Origin Pro's user interface is straightforward and quite easy to understand on the overall. Toolbars and menus are frequent; the feature that can be seen is that the placed ones are conveniently united in groups that would make it easier for users to find the needed ones. It has options for working with multiple sheets within a workbook and tools for handling numerous calculations frequently required for analyzing big data.

b) Data Analysis:

In this context we can say that Origin Pro provides an ample coverage of data analysis methodologies. This appertain to signal processing, peak analysis, statistics and coming up with the best curves and the likes. It also entails a robust batch processing mechanism, which enables the user to conduct multiple operations sequentially.

c) Graphing:

As a summary of the capabilities of this particular application, it is critical to recognize that Origin Pro stands out when it comes to graphing. It offers many kinds of 2D and 3D graphs that can be altered and reloaded from the related data set. Publication quality is so high that figures produced by Origin Pro are ready to be used in articles.

d) Data Import and Export:

Import and export features of Origin Pro can accept varied formats of files that an analyst may need. This kind of files is text files, Excel files, and files from other scientific software.

e) Programming and Automation:

Regarding programming and automation, Origin Pro has the Origin C that is embedded, together with the Lab Talk as a scripting language. This feature may well be a major help to the user for example, if you have specific and numerous operations that need to be carried out.

f) Customer Support:

In origin pro, customers said that the company, ‘’Origin Lab’’, is very prompt to respond to customers’ complaints [47].

Perhaps, the high cost of Origin Pro may be the main drawback if the price is considered as a drawback – that’s because it is a product of the highest class, and small organizations, or independent researchers, may consider it too costly. It is also rather easy to confuse when used by freshmen or individuals who only recently transitioned to using data analysis software; however, the company offers an extensive amount of online support. Origin Pro 8. 5 is a very stable, universal, and all-encompassing software that serves scientists, engineers, and all professionals who work with valuable data and who need first-rate graphs. It may not be appropriate for everyone thanks to its pricing and the possible complexity it carries but it is a great application if one needs/has to use its competitive functions [46].

Another curious and rather interesting field in the applications of the semiconductor resources is ultra wide band gap (UWBG) semiconductors. Unlike the conventional semiconductors such as the Gallium Nitride which has a bandgap of 3. 4 eV, UWBG semiconductors possess wider bandgaps. This distinctive feature holds uncountable possibilities in different spheres of human life. One issue to take into consideration is the fact that quite a number of performance characteristics of semiconductor devices are related to the band gap in a way that is proportional to a power of the actual value. Therefore, UWBG semiconductors have been acclaimed for storied benefits over NBG semiconductors since a long time. Nevertheless, only in the past few years first Mature UWBG semiconductors, such as high Al-content AlGaN, diamond or gallium oxide Ga2O3 have become available, therefore, the possibility to harness the advantageous properties in the near future is realistic [2].

In this article, we introduce the current state of the art of UWBG semiconductors as materials, physics involved, and future possibilities and issues in extending device and application developments of these materials. Through the analysis of these aspects, we hope to reveal the possibility of the motor development in UWBG semiconductors and inspire people to consider the opportunities of its application in different technological fields.

This social history of semiconductors traces the roots of semiconductors beginning from the discovery of the first recorded instance of semiconductor effect by Faraday. The tribunal noted in this regard is a turning point not only in the observation but the discovery of Semiconductors as well. Concerning the division into technologies, it possible to note the first devices such as point contact rectifiers and transistors. These early devices were very instrumental in the development of today's electronics and represented key milestones in the development of semiconductor devices. Other important news in the history of semiconductor as field-effect transistors. FETs proved to be a significant improvement of previous devices because they provided better precision of electric current. It should be noted that theoretical concepts have been used to support the improvement of the construction and the functioning of the semiconductor devices. Present day devices like Silicon on Insulator (SOI), and multigate structures. SOI technology entails the development of transistors upon a thin silicon film and provides better performance than conventional technologies as well as less power usage. More complex structures of gates are called Multigate devices like FinFETs or nanowire transistors that offer even better control over the current characteristic and used in modern integrated circuits [16].

Indeed the field of Ultrawide-band gap (UWBG) semiconductor technology is experiencing a big boost in the present situation with higher material research, high-risk consideration on new ideas founded on preceding theories, huge change in new device designs, and recognition of new areas of utilization. This set of papers compiled in this focus issue provides timely and well-rounded submissions of research papers that demonstrate the existing status of development and use of UWBG materials. The papers include features of experimental results and theoretical works, as well as the general areas associated with UWBG technology. Some of these are the growth of UWBG bulk crystals and substrates, research on the UWBG defect and doping, innovations in the epitaxy of UWBG materials, work done in the electronic and optical electrical properties of UWBG materials, research in UWBG power devices and emitters. This preliminary presentation of the present special issue is aimed at summarizing the state of the art regarding basic scientific concepts and background information on selected UWBG semiconductors, namely, AlxGa1–xN alloys, BN, diamond, β-phase Ga2O3, and several other UWBG binary and ternary oxides. This focus area opens an opportunity for the readers to get a feel of the recent developments in the field of UWBG materials, the physics of UWBG materials and corresponding technologies. Even within this formative scientific field, quite a lot of progress has been made in research based upon the peculiarities of UWBG semiconductors. The UWBG research has been carried out at the materials level where AlxGa1–xN, diamond, β-Ga2O3, and other UWBG materials stand as promising materials. Such endeavours have started producing device outcomes that are in line with the innate benefit that these materials possess. Despite many issues pertaining to the semiconductors of the UWBG being raised, more questions still arise. To overcome these challenges, it has been deemed necessary to incorporate first-principles computational methods with experiments. As result of these syndicated strategies, significant improvements have been reported on the device performance, discovery new materials with required functionalities and opening of new research directions [17].

Development of Graphene has encouraged a lot of studies on other types of stable, ultra-thin layers of van der Waals material having potentially useful attractive properties in technology. Layered materials have been effectively prepared from many different complicated structures such as boron nitride, MXenes and transition metal chalcogenides with advanced performances. Thus, they start with an introduction of recently discovered two-dimensional (2D) materials, before focusing on 2D AlN (Aluminum Nitride), offering a detailed background, which includes theoretical analysis of the stability of infinite hexagonal AlN sheet, referred to as h-AlN. Here we analyze the differences in the electronic structure found in bulk and monolayer AlN and look at ways of changing the electronic and magnetic characteristics of the material with computational data from DFT [18]. In addition, we talk about the uses of the material and focus on its performance as a gas sensor for CO2, CO, H2, O2, NO, and NO2 with the interfering gas NH3. Furthermore, we investigate the factors affecting the growth processes for obtaining single-layer and few-layer AlN on substrate materials. At last, we pointed out that nano structure 2D AlN layers and nanotubes are with the ultra-wide band gap from 9. 20 ~ 9. 60 eV, which has significant application prospects to support the next generation and state of the art deep-ultraviolet optoelectronics devices.

Thus, the present review brings technical awareness of current developments and future directions in the area understanding properties, synthesis strategies, and probable utilization of 2D AlN Nano sheets or layers. Due to the lack of knowledge and revealed experience about the synthesis, stability of the structure, and physical properties of 2D AlN, this review mainly focuses on the most important theoretical prognosis and the latest experimental data on the synthesis of 2D AlN. For example, based on the DFT calculations, it can be shown that, while a sheet of h-AlN is slightly less stable than the wz-AlN (by about 6%), the former has an Indirect energy gap of 2. 81 eV. Through DFT analysis, info suggest that AlN Nano sheets' optical conductivity shows a band gap under both parallel electric field and perpendicular electric field, thus making it a semiconductor material. In this research, the authors have demonstrated a method for the control of strain in such AlN Nano sheets with high efficiency. The DFT findings indicate that the amount of strain can affect the band gap both quantitatively and qualitatively by implementing both the indirect and the direct transitions inside the band gap. In addition, more research on extended line defects, ELDs, in the honeycomb monolayer of AlN by first-principle density functional theory proposes that the honeycomb monolayer of AlN can be used in UV photonic waveguides. Chemical functionalization appears as an active strategy to modulate the electronic and magnetic characteristics of AlN sheets and the hydrogen–AIN connection is of utmost importance from the technological point of view. The electronic property of fully hydrogenated AlN Nano sheet with single bilayer is that it is an indirect band gap semiconductor but the fully hydrogenated AlN with greater than four bilayers demonstrates characteristics of ferromagnetic (FM) metal. It also outlines a strategy that can be used as a route of fine-tuning of the electronic as well as magnetic parameters to offer the wanted application in electronics as well as spintronics [19].

Notably, the structure of the researched material, aluminum nitride (AlN) nanosheets, is unadorned and the system is two dimensional isotropic. On the other hand, the AlN nanosheet when exposed to H and F on both the sides of the nanosheet exhibits the anisotropic semiconductor character. This directional variation is advantage for the use of non-uniform charge distribution for self-assembly by an applied electric field. Also, the occurrence of charge transfer between gas molecules and an AlN sheet allows the AlN sheet to act as CO2, CO, H2, O2, and NO gas sensor. Also, it shows promising signs in being utilized as a sorbent material in the separation and adsorption of CO2 from gaseous streams.

FT results suggest that electrical conductivity of AlN nanosheets might be enhances after adsorption of NO2 and, at the same time, AlN nanosheets might be electrically inactive after interaction with NH3 molecules. Therefore, the AlN sheet can individually differentiate NO2 molecules from NH3 molecules and generate a related electrical signal. Physics-chemistry molecular simulations also suggest that hexagonal AlN nanosheets doped with carbon or with nitrogen vacancies possibly make feasible adsorbing or detecting toxic CO gas. Hard experimental data available in the literature favour the development of thin hexagonal AlN nanosheets on substrates. These nanosheets possess a hexagonal lattice of graphite type with a larger a-parameter as compared to the bulk wurtzite AlN.

This assertion is further supported by ultraviolet photoelectron spectroscopy that indicated a low band gap, which is in agreement with expectations of hexagonal Aluminum Nitride, graphite like. However, AlN layers similar to graphene with a lateral lattice constant of 3. 08 Å has been deposited on a well prepared (8×8) Si3N4 template. This surface was prepared to be a (111) atomically flat silicon substrate and was prepared using ammonia MBE. In addition, a new significant accomplishment has been made by growing single crystal 2D AlN layers by epitaxial growth through utilizing the lower silicon and upper graphene substrates. This achievement was made for the initial time utilizing metal organic vapor deposition. The theoretically calculated direct band gap of as-grown 2D AlN layer is found to be ~9. 63 eV, while the experimental values are found to vary from 9. 20-9. 60 eV and hence there is a great potential for deep-ultraviolet opto-electronics devices. Also, 2D AlN can be synthesized chemically using chemical vapor deposition; however, it is only possible if Si substrates are coated with gold. Analyzing at the atomic level the processes taking place during MOCVD deposition of AlN on graphene, density-functional AIMD simulations have been used.

In conclusion, the information that metal substrates make the previously known only in theory tetragonal 2D-AlN more stable is a breakthrough. In conclusion, based on the discussed theoretical and experimental results, it is possible to note that the integration of the analyzed Schlafli diagrams demonstrates a high potential for 2D

AlN nanosheets as multifunctional nano materials with a wide range of perspectives for use. In addition, based upon the crystal structure, the nano-scale AlN can present itself with multiple number of band gap values along with other distinct features. These characteristics are of significant relevance in a nexus of electronic as well as optoelectronic gadgets. [20].

Wide and direct band gap semiconductors, abbreviated as WBSs, are very promising for numerous DUV applications. But there are some of the existing issues that hamper the development of DUV optoelectronics in the following ways. Such factors include problems related to the crystal quality and expensive and complex fabrication and growth course of distinct multidimensional device structures that hamper the creation of devices with superior performance suitable for large-scale utilization. During the course of this research for this dissertation, I have also proposed various new devices based on the WBS that operate with enhanced or brand-new features, which categorizes this as a breakthrough. The first part of this dissertation concentrates on the synthesis of highly ordered, well-defined hexagonal ZnO NT arrays without the assistance of a catalyst. These arrays were grown employing the method of pulsed laser deposition (PLD) with the base of p-GaN template and created very efficient and cheap UV light-emitting diodes (LEDs). In the next section, I report Gd-doped ZnO NRs deposited through PLD on relatively cheap metal substrates. For the first time, it is shown that these NRs can be functionalized with the CH3NH3PbI3 perovskite and ZnO photodetectors can sense in the infrared region beyond 1000 nm ($\lambda > 1000$ nm). The third part of this research demonstrates the generalization of the PLD method used, here together with other high-quality metal oxide nanostructures. Namely, well-faceted p-type CuO pyramid structures have been synthesized on Si substrates without using any metallic catalyst. Furthermore, the technique of laser ablation was improved from the vacuum method (PLD) to the liquid technique namely femtosecond laser ablation in liquid (FLAL). This advancement enabled preparing high quality ZnO quantum dots (QDs). This innovative concept was used to fabricate new high-quality self-powered DUV photo detectors using a p-CuO pyramids/n-ZnO QDs heterojunction device. In the last component of this study, the investigation was taken one step further by examining other metal oxides prepared with FLAL. Here, we have developed an excellent self-powered DUV photo detector by using p-MnO QDs grown via FLAL and high-quality n-β-Ga2O3 Nano flakes exfoliated from mechanical exfoliation method on SiO2 as the active hetero junction layer. Thus, using different fabrication techniques, and mainly the usage of hetero junction structures, predominantly p-n junctions, we have been able to overcome the issues related to the current WBS devices as discussed earlier in this paper [21]. The research works associated with the UWBG materials are mentioned in the following table: Table 2. 1

Table 2.1: Related Works on UWBG Materials

AUTHOR	**YEAR**	**TITLE**	**CONTRIBUTION**	**Ref,**
Mingfei Xu ,Dawei Wang, Kai Fu1, Dinusha Herath Mudiyanselage,Houqiang Fu2 and Yuji	2022	A review of ultrawide band gap materials: properties, synthesis and devices	Understand the basic properties and to develop associate processing techniques for the UWBG materials.	[1]
Chowdhury S, Hollis MA et al**.**	2018	Tsao JY, Ultrawide-band gap semiconductors: research opportunities and challenges. AdvElectronMater	It elaborates their optoelectronic properties, physics, applications, research opportunities and the challenges they are facing in implementation in present world.	[2]
Albert Zicko Johannes, Redi Kristian Pingak and Minsyahril Bukit	2020	Tauc Plot Software: Calculating energy gap values of organic materials	The results obtained here are also more accurate because of the use of the modified Tauc plot method	[12]
Mikrajuddin Abdullah, Khairurrijal Khairurrijal	2016	A Simple Method for Determining Surface Porosity Based on SEM	The proposed method was successful to predict the surface porosity of materials based on their	[56]

		Images	SEM images using instructions provided by OriginPro.	
Norah Mohammed Alwadai	2019	Emerging Materials for Optoelectronic Devices	The functionality of WBS-based devices that leads to many high performance DUV applications in the future.	[3]
Lidia Łukasiak and Andrzej Jakubowski	-	History of Semiconductors	The beginning of semiconductor electronics the number of transistors in an integrated circuit has been increasing exponentially with time.	[10]
Man Hoi Wong1, a) , Oliver Bierwagen 2 , Robert J. Kaplar3 , Hitoshi Umezawa 4	2021	Ultrawide‑bandgap semiconductors: An overview	Fundamental materials-level work in AlxGa1–xN, diamond, β-Ga2O3, and other emerging UWBG materials has begun to produce device results commensurate with the fundamental advantages that these materials promise.	[13]
Masataka Higashiwaki, Robert Kaplar, Julien Pernot, et a	2021	Ultrawide bandgap semiconductors	This particular subject matter offers readers a chance to gain insight into the latest developments in UWBG materials, physics, and devices.	[11]

2.4 Solar Blind Detectors

Significant research activities have been devoted for solar-blind photo detectors (refer to fig 2.1) because of its wide applicability as flame detection, air purification, space communication, and ozone layer monitoring and so on. Such applications require solar-blind photo detectors with high performance while having cut-off wavelengths that need to be shorter than 280 nm. So far, photodetectors of this type have been fabricated from , for instance, In2Ge2O7, InAlN, AlGaN, GaN, MgZnO and diamond. These materials have been used in various orientations like MSM structures, photoc Conductive ones and the PN photodiode. However, by such techniques, these materials still continue to pose several issues that need to be addressed to make them practically useful on large scale.

This compromises the device dimensions because adding features such as, a cooling system or extra layers of passivation will be required for the materials like Silicon (Si) and Zinc Oxide (ZnO) to work in extreme conditions. For the scenarios with ZnO and Si, the cut-off filters are essentials to prevent the wavelengths beyond 400 nm penetrating through them because their band gaps are relatively small. Consequently, the creation of innovative, wide-band gap materials is imperative for the development of solar-blind photo detectors that fulfill the demanding criteria of "5S": Stability; this is to do with the degree of fluctuation that is inherent in a given analytical technique or instrument. Speed; this is to do with the time that it takes to collect data using a particular technique or instrument. Signal-to-noise ratio ; this is to do with the proportion of the signal to the amount of noise that is present when data is collected using a particular technique or instrument. Sensitivity; this is to do with the

Figure 2.1: Solar Blind Detector View

On the basis of such beneficial characteristics, β-$Ga2O3$ elevates itself to the rank of a worthy contender in the sphere of Solar Blind Detectors. Some of these are a direct band gap of about 4. 9 eV and excellent chemical/mechanical/thermal stability. This extended the detector’s intoinic solar blindness, which entirely blocks wavelengths beyond 280 nm without the need for add-on optical filters.

Studied publications have focused on the fabrication and characterization of solar-blind photo detectors based on β-$Ga2O3$ films, wires, and flakes. In this regard, photo detectors based on lowdimensional semiconductor nanostructures outperform thin – film and bulk – material photo detectors. This boosts from their large surface-to-volume ratios and quantum confinement effects these nanostructures exhibit.

The present investigation however, pursues a different approach, using quasi-two-dimensional micro flakes of β-$Ga2O3$ which are obtained from bulk materials by applying mechanical exfoliation methods. These micro-flakes are used to fashion solar-blind photo detectors with an emphasis to their photo responsive qualities being subjected to methodical evaluation. Notably, these devices can be ranked among the most responsive thin-film wide band-gap materials in today’s body of knowledge.

Solar-blind detectors are those detectors which are very sensitive to ultra-violet (UV) radiation and are unaffected by visible light which is emitted by solar means. UV radiation is typically divided into three categories based on wavelength: There are three forms of UV radiation namely; UVA (320-400 nm), UVB (280-320 nm) and UVC (100-280) shown in Figure 2.2 below. More specifically, solar-blind detectors are drawn towards the UVC region because most of the UVA and UVB light reaching the earth are not fully attenuated by the atmospheric layer while on the other hand UVC radiation is heavily dampened by the atmosphere particularly the ozone layer. [58]

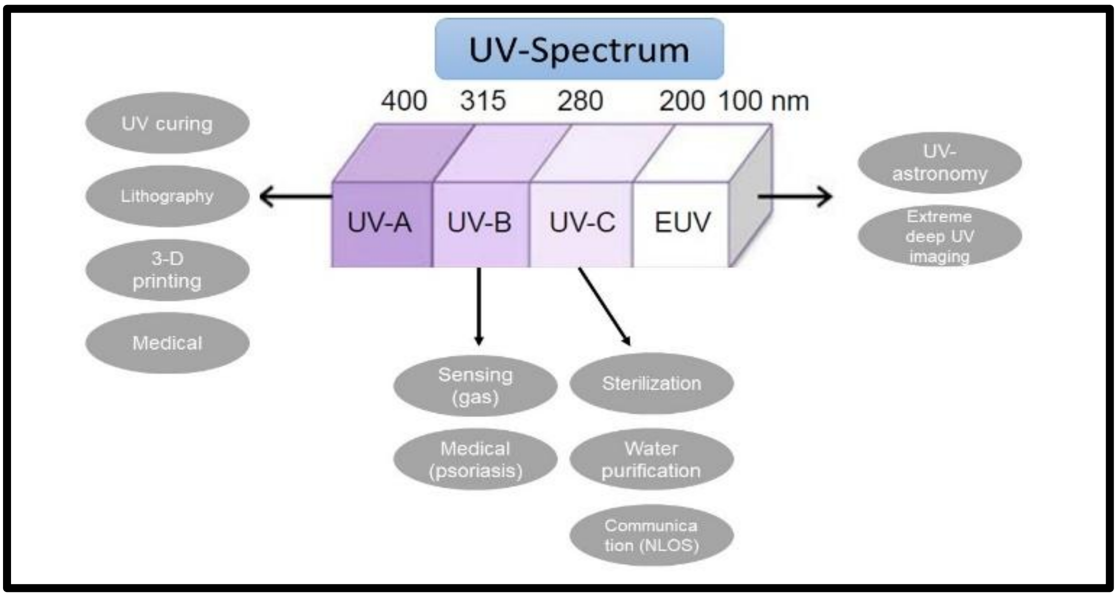

Figure 2.2: Applications of UV Spectrum

2.4.1 Figures of Merits for Solar Blind Detectors

Figure of merit (FOM) is the quantitative measure of the performance built up by incorporating many of the significant parameters in order to design as well as to compare the different devices or system (as demonstrated in the fig 2.3). In the case of SB detectors, there exists numerous indicators that may be employed to measure the efficiency of the given detectors in particular usages. Here are some common figures of merit for solar-blind detectors:Here are some common figures of merit for solar-blind detectors:

2.4.1.1 Responsivity (FOM-R)

One of the parameters that represent the ability of a solar-blind detector is its responsivity, which then indicates the detector's sensitivity to UVC radiation. For any given channel, it is important that the responsivity be high. The FOM for responsivity may choose the maximum of the responsivity in the solar-blind range depending on the wavelength necessary for the particular application.

2.4.1.2 Noise Equivalent Power (NEP) (FOM-NEP)

NEP is defined as the minimum detectable optical power or signal. Higher NEP values represent lower sensitivity while the lower NEP values represent the higher sensitivity. Depending on the approach of the FOM for NEP, the capability of the NEP in the solar-blind range and how it stands in regards to other detectors could be assessed. [59]

2.4.1.3 Specific Detectivity (D) (FOM-D)

Specific detectivity is a figure of merit that incorporates the detector responsivity, NEP and area of the detector and its bandwidth. Quantitative analysis measures the proficiency of the detector to identified low power signals. More specifically, the results pertaining to the variable Dx show that a higher score of this variable is preferential.

2.4.1.4 Dark Current (FOM-Dark Current)

Dark current is the current resulting from the activity of the photo detector with no light being incident on it. The dark current of the detector is declared in Amps and it is better when lower because lower dark current increases the signal-to noise ration.

2.4.1.5 Response Time (FOM-Response Time):

In relation to the Starlight Factor, gamma is the response time of a detector, the amount of time that it takes for a change in incident light to be acknowledged by the detector. In some cases, it is rather important to have a short response time.

2.4.1.6 Wavelength Selectivity (FOM-Wavelength Selectivity)

Since solar-blind detectors should be sensitive only to UVC wavelengths they must be very selective for these wavelengths. Interestingly, this figure of merit quantifies the extent up to which other wavelengths inclusive of visible or UV light, are rejected by the detector to minimize false alarms.

2.4.1.7 Operating Temperature Range (FOM-Temperature)

In certain uses of solar-blind detectors it will be necessary to work at these temperatures. The FOM for temperature could regard the possible range of temperature for the detector and its stability in such a range.

2.4.1.8 Linearity (FOM-Linearity)

Linearity refers to the determination of the extent to which the detector's response is proportional with the incident optical power. A linear detector is helpful in giving more accurate results about the heart than the nonlinear detector. [62]

2.4.1.9 Radiation Hardness (FOM-Radiation Hardness)

In some instances like space borne systems, the detectors need to be able to oppose the effects of radiation. Such factors relevant to the need for radiation hardness are addressed by the FOM for radiation hardness with regard to the detector.

2.4.1.10 Durability and Environmental Resistance (FOM-Durability)

The figure of merit for durability compares the detector's resilience to moisture, temperature fluctuations, and mechanical loads, which influence long-term performance.

2.4.1.11 Cost (FOM-Cost)

Though the material used for making the detector can be relatively cheap the fabrication cost is still important for most uses. Hence, the low-cost detectors are more preferred if they can meet the required performance specifications [60].

2.4.1.12 Competitive Landscape

Conduct the competitor analysis based on their rank on the market, company's position and their advantages and disadvantages. There are certain matters that may concern the market, which are: partnerships and collaborations or mergers and acquisitions that the market may have or experience.

2.4.1.13 Customer Needs and Preferences

Be able to identify the requirements of clients as well as their choices in different markets. This aims at performance demands, costs and any other requirements that may be in regard to special characteristics or functionality.

2.4.1.14 Market Trends

Examine and evaluate current trends in the UV sensing industry, more to do with technological improvements, market amalgamation, and new opportunities.

2.4.1.15 Barriers to Entry

Assess whether there are any major threats for new entrants in the market, including the question of IT rights, required financial investments, and UWBG materials knowledge.

2.4.1.16 Risk Analysis

Identify the possible risks and issues that might arise in the market that relate to technological inactivity, regulatory changes, or interruptions of the sources of UWBG materials.

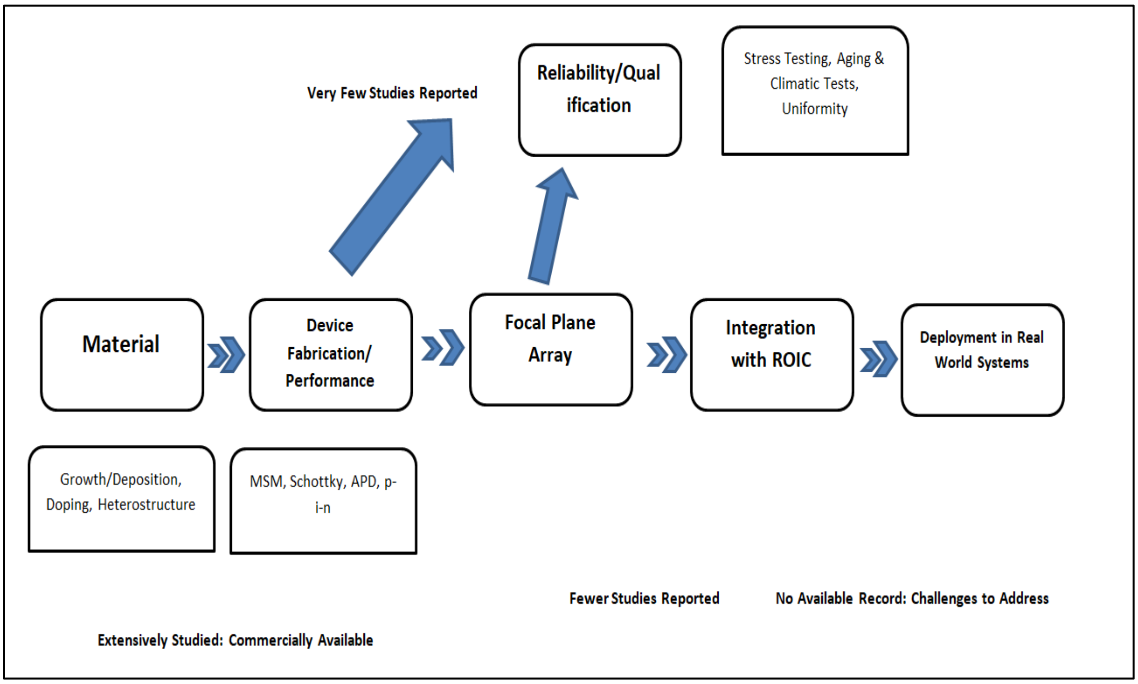

Figure 2.3: Complete Summary of Fabrication of Solar Blind Detectors

2.5 Factors Impinging Solar Blind Detector

2.5.1 Wavelength

Here, the wavelength of light connected with the UWBG materials is defined by the energy bandgap and appears to be very influential when considering the optical characteristics of the material. From figure 2.4, it is evident that an increase in wavelength is towards the UV Spectrum. Regarding the concept of wavelength, to illustrate it in the context of UWBG materials, one has to pay attention to the energy of the photons corresponding to a given light and the bandgap energy. [61]

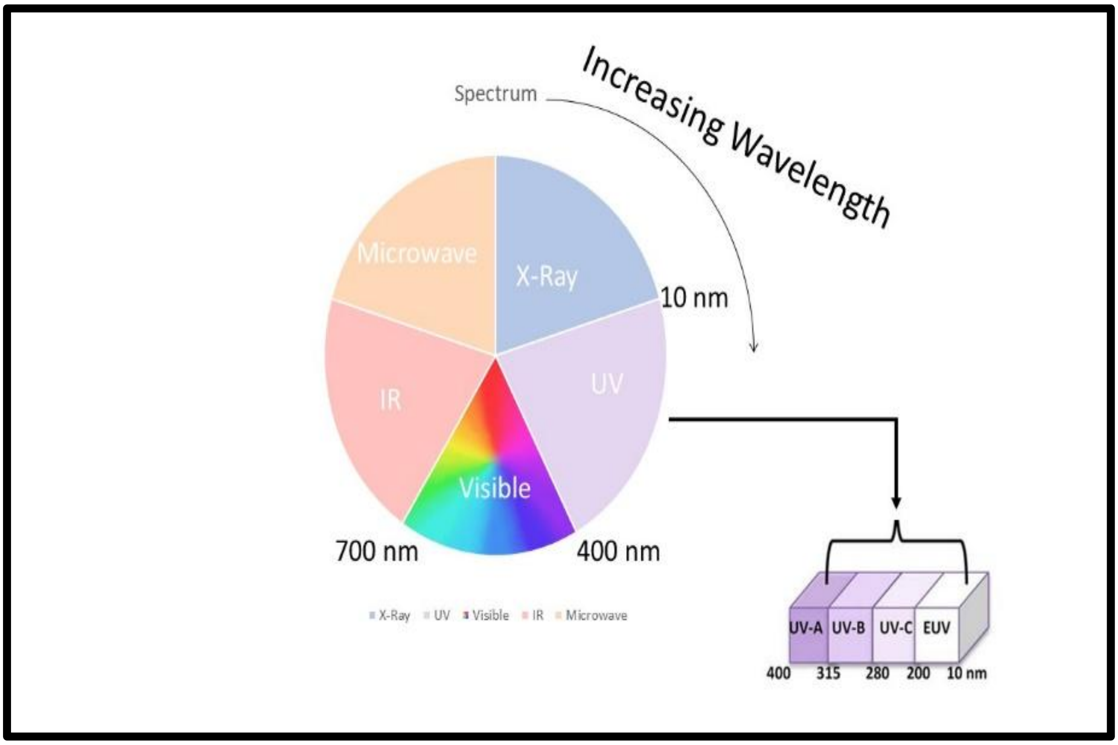

Figure 2.4: EM Spectrum Showing Wavelength Range for Various Solar Radiations

2.5.1.1 Energy of Photons (Light)

- Photons are quanta of electromagnetic radiation, this includes vision light, ultra-violet light and many other products of electromagnetism.
- The energy (E) of a photon is inversely proportional to its wavelength (λ) and is given by the equation: [63 As for videos, users shared 63% of videos in their posts.

$$E = h \times c / \lambda$$

Where:

- E is the energy of the photon.
- h is Planck's constant (a fundamental physical constant).
- c is the speed of light in a vacuum.
- λ is the wavelength of the light.

2.5.1.2 Relationship to Band Gap Energy

- In the context of UWBG materials, the band gap energy (Egap) is the minimum energy required for an electron to move from the valence band to the conduction band.
- When photons with sufficient energy (E_{photon}) strike a UWBG material, they can be absorbed, promoting electrons from the valence band to the conduction band if their energy exceeds the band gap energy. [64]

2.5.1.3 Wavelength and Band Gap Energy

- The wavelength (λ) of light that can be absorbed by a material is related to the band gap energy by the equation:

$$\lambda = c \times h / Egap$$

- In UWBG materials, the band gap energy is relatively large compared to conventional semiconductors. As a result, the corresponding wavelengths of light that can be absorbed or emitted by these materials are in the ultraviolet (UV) or even shorter wavelength ranges.
- For example, materials like aluminum nitride (AlN) and diamond, which are considered UWBG materials, have band gaps in the range of 5-6 eV. Using the above equation, you can calculate that the corresponding wavelengths of light they interact with are in the UV region (below 250 nanometers) [65]. Range of different WBG & UWBG materials wavelength is shown in table 2.2.

Table 2.2: Parallel Study of Wavelength of WBG & UWBG Materials

WBG Materials	**Wavelength Range**	**UWBG Materials**	**Wavelength Range**
ZnO	370nm-380nm	Beta Gallium Oxide	253nm-263nm
Gallium Oxide	254nm-263nm	Aluminum Nitride	213nm-220nm
Silicon Carbide	375nm-540nm	Hexagonal Boron Nitride	210nm-220nm

2.6 Absorbance

In other words, in the context of UWBG materials, absorbance speaks to the capability of the material to take up light or electromagne'tic radiation. Thus, the absorbance of a material depends on the bandgap energy as well as the energy of the incident photons.

In returning to discuss about absorbance pertained to UWBG materials, the following concept of absorbance (A), bandgap energy (Egap), and energy of the incident photon (Ephoton) can be used [66].

2.6.1 Absorbance and Wavelength

- The absorbance (A) can be related to the wavelength of the semiconductor material through the following general equation:

$$A = 2(n)/ \lambda$$

Where:

- A is the absorbance.
- n is refractive index of a material.
- λ is wavelength of Material Used.

Specifically, absorbance can be estimated from the formula $A = 2(n)/\lambda$, which is relevant to the UWBG materials found in today's technologies. The equation assists in illustrating how UWBG materials could impact the absorption or reflection of light at specific wavelengths[67].

a) Absorbance (A): Transmittance is the amount to which light transmitted through a material upon interaction with it is reduced. According to the theories dealing with the properties of materials, the absorbance of the material can be affected by the refractive index (n) and the wavelength (λ) of the exposed light in the case of UWBG materials.

2. Refractive Index (n): The refractive index is a parameter of the material that defines how the light is bent at the interface of the material. UWBG materials may have different properties due to their large band gaps and normally gives different optical properties such as high refractive indices than the normal materials. This

implies that, the higher refractive index can result into different nature of the incident light.

3. Wavelength (λ): Wavelength is the time period or the color of the light which it undergoes. There is also observed that the UWBG materials have much higher values of band gaps than other BGC materials; therefore, they correspond to the shorter wavelength of light or even ultraviolet (UV) region of the electromagnetic spectrum. [69]

2.6.2 Explanation of Absorbance Equation in context of UWBG materials

Of the variables in the equation, for UWBG materials, which are usually transparent to visible and Infrared light due to large band gap energies the interesting optical effects in the UV regions and shorter wavelengths are revealed.

UWBG materials' refractive index (n) may be higher than other materials unlike the other spectral regions, which cause strong references and interferences due to the interaction of UV light with these materials.

The civil equation indicates that as the wavelength (λ) of UV light becomes shorter which means that it is further into the UV spectrum, then the absorbance (A) is higher because of the interaction between the refractive index and the wavelength.

This relationship of absorbance, refractive index, and wavelength is quite useful when designing the optical components or thin films using UWBG materials for UV optoelectronic devices, UV sensors, or UV spectroscopy.

In conclusion, the given equation of $A = 2(n)/\lambda$ when relates to UWBG materials, we can illustrate how its differentiation in the interaction of various photonic modes and other related dielectric materials' properties make the UWBG materials unveil different features under the irradiation of UV and other even shorter wavelengths of light. Thus, comprehension of this relation is crucial for enhancing characteristics of UWBG-based optical devices including solid blind detectors [72].

2.6.3 Band Gap Energy

Band gap energy or simply the band gap is one of the most essential topics within solid-state physics and material science. It is especially significant when describing UWBG materials in which the bandgap width is significantly larger than in typical semiconductors. When explaining the response of the semiconductor material to the different wavelengths of light especially in the case of solar-blind detectors where the detector is sensitive to ultraviolet (UV) radiation but blind to the visible light, one is able to do so by using the band gap energy diagram (Fig. 2.5)

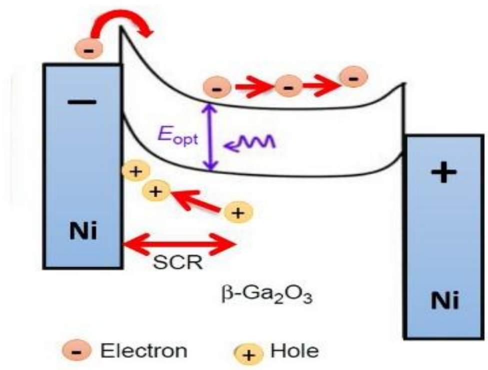

Figure 2.5: Representation of Band Gap Energy Diagram for Solar Blind Detector

2.7 Impact of Band Gap Energy on UWBG Materials

- UWBG semiconductors are a special group of materials that are distinguished by the fact that they have band gaps that start from not less than 4, 5 eV. These materials, therefore, exhibit band gaps which are much larger than the typical semiconductor materials such as Si and GaAs.

- It will be seen that the band gap in UWBG materials is rather large, and hence these materials can sustain higher electric fields and temperatures than conventional semiconductors. This renders them very appropriate for use in applications such as extreme climate conditions, high powered electronics, and high radiation products.

- Among the UWBG materials, there are AlN, diamond, BN, and GaN [75].

2.7.1 Band Gap Energy Calculation

The equation of band gap energy is given by:

(eV) = 1240/wavelength (nm)

(1)

2.7.2 Derivation of Above Equation

The formula relates the energy of the photon to its wavelength using the fundamental constants of the speed of light and Planck's constant.

The formula itself, "1240/wavelength," is a simplification of the equation:

Energy (eV) = (Planck's constant × Speed of Light) / Wavelength (nm) (2)

The Planck's constant is represented as “h”

$$h \simeq 4.135667696 \times 10^{-15} \text{ eV·s}$$

The speed of light is denoted as “c”

$$c \simeq 299{,}792{,}458 \text{ m/s (or about } 3 \times 10^{8} \text{ m/s).}$$

When you substitute these values into the equation, you get:

Energy (eV) = (4.135667696 x 10^-15 eV·s × 3 x 10^8 m/s) / Wavelength (nm) (3)

Simplifying further:

Energy (eV) = (1.240 x 10^{-6} eV·m) / Wavelength (nm)

(4)

This is where the "1240" in the formula comes from (1.240 x 10^{-6} rounded to 1240)

Table 2.3: Comparison of Band Gap Energy between WBG & UWBG Materials

WBG Materials	**Band Gap Energy**	**UWBG Materials**	**Band Gap Energy**
ZnO	3.32	Beta Gallium Oxide	4.9
Gallium Oxide	4.80	Aluminum Nitride	5.82
Silicon Carbide	3.3	Hexagonal Boron Nitride	5.83

In summary, band gap energy is a fundamental property of materials that determines their electrical and optical behavior. Ultra-wide band gap materials have exceptionally large band gaps, making them valuable for applications requiring high-temperature operation, radiation resistance, and high-power electronic devices. Their unique properties open up new possibilities in various technological fields [76].

2.8 Variation of Dark current and Responsivity

Two special characteristics which can be used to explain the performance of photo detector especially when it comes to optoelectronic devices, such as the solar-blind detectors are the dark current and Responsivity.

a) Dark Current:

Definition: Dark current is also commonly referred to as the leakage current which refers to the current that is measured when there is no light falls on the photodetector. It implements the internal noise of the detector.

b) Variation:

Dark current is a property of the particular detector, which depends on factors such as temperature, detector bias voltage and the detector's age etc.

c) Temperature Dependence:

In most cases, the generated dark current rises with the level of temperature. When temperatures are high, there will be increased generation of thermal carriers that in turn give high dark current.

d) Ageing Effects:

Periodically, the dark current of a detector may alter because of the factors like degradation of the material of the detector or the structure of the device.

e) Responsivity:

Definition: Responsivity is given by the ability of a photodetector to respond to light and is expressed as the ratio of the photocurrent generated to the optical power that has fallen on the detector.

f) Variation:

Responsivity can also prove to be different with some factors like wavelength, temperature and even the characteristics of the detector material.

g) Wavelength Dependence:

Responsivity is always found to be wavelength dependent that is different wavelengths of light can generate different photocurrents.

h) Temperature Effects:

Environmental changes, for instance, in temperature, can affect the characteristics of detector material and thus responsivity.

i) Material Properties:

The type of materials used in the construction of the detector plays a big role in the detector's responsivity.

2.8.1 Relationship between Dark Current and Responsivity

Inverse Relationship: It is made once again to note that in many cases, dark current and responsivity are inversely proportional. Dark current can also influence noise; the general tendency toward increased noise can affect the signal noise ratio and the detector's responsivity.

Optimization: Responsivity is one of the important parameters of a photodetector, yet another important parameter is dark current; therefore, the two must be balanced to obtain an optimal result. There are usually applications where responsivity is aimed to be maximized while at the same time the dark current in the detector needs to be at a minimum.

a) Monitoring and Control:

Regular Monitoring: Usually the dark current and the responsivity of the detector are measured periodically, if a high sensitivity to the optical signals is required.

b) Control Strategies:

Here are methods like temperature control, setting the right bias voltage, among others, which are used to regulate and reduce instability in dark current and the responsivity.

Dark current as well as responsivity are two areas of concern in solar-blind detectors and every other photodetectors. Therefore, their fluctuation may affect the efficiency of the detector, or, in other words, the chosen parameters should be controlled for the successful and accurate detection in optoelectronic systems. Figure 2.6 also shows variation.

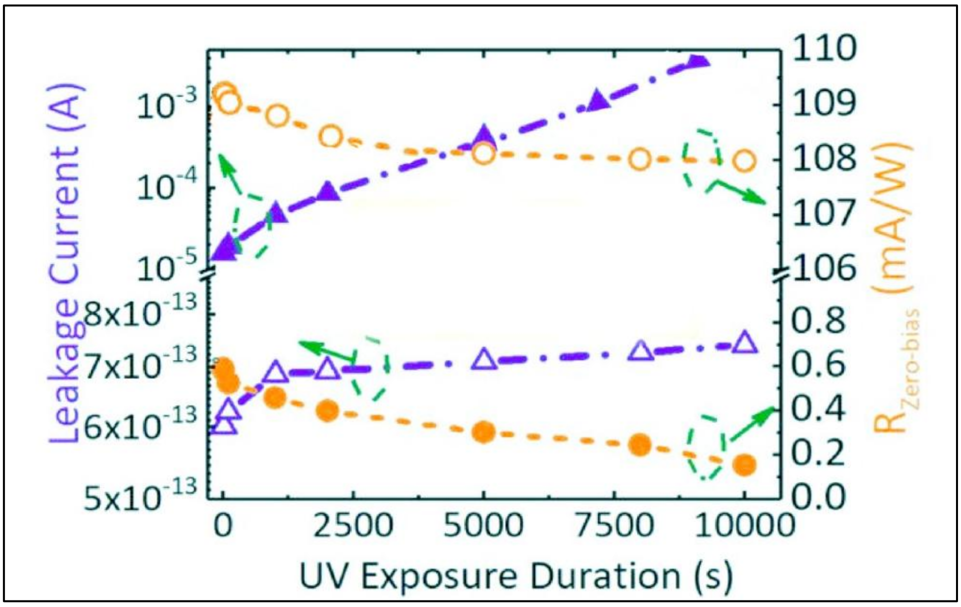

Figure 2.6: Variation of Current and Responsivity

2.8.2 Aluminum Gallium Nitride (AlGaN)

Aluminum Gallium Nitride (AlGaN) is a string semiconductor material that is expected to act as a promising material in the global market especially in the production of solar ultraviolet (UV) photodetectors and photovoltaic devices. Due to the advantages related to the high value of the bandgap and peculiarities of the material, this type of photodetector is effective in the UV range and in the solar-blind one (wavelength smaller than 280 nm). Here are some key points regarding the use of AlGaN as a material for solar UV photodetectors:Here are some key points regarding the use of AlGaN as a material for solar UV photodetectors:

a) Wide Bandgap:

AlGaN has a wide bandgap ranging from 3. 4 to 6. 2 eV up to the percentage of Al in the ternary alloy. This large corridor bandgap lets AlGaN befittingly the UV light and therefore, it is appropriate for use in the UV zone of the solar field.

b) Solar-Blind Detection:

The solar-blind region of interest covers approximately 200-280 nm which is used in applications such as solar observing and military perception. Contrary to this region, AlGaN-based detectors are quite famous for offering solar-blind performances.

c) High Responsivity:

Photodetectors made of AlGaN have high responsivity to UV light with a special reference to the solar-blind spectral range. This high responsivity is necessary since weak signals which are typical of solar UV radiation have to be detected.

d) Low Dark Current:

Dark current is essential in photodetectors for it affects the noise in the photodetector. Low dark current performances have been reported in the AlGaN based detectors, which upon improving the signal to noise ratio further improves the sensitivity.

e) Temperature Stability:

Multi-quantum-well AlGaN materials has high temperature stability and performance hence making it suitable for use in areas where the temperatures conditions may fluctuate.

f) Material Engineering:

Thus, in AlGaN, the aluminum content can be adjusted to achieve the desired characteristics to suit the intended application. The flexibility in engineering the material properties to the specifications of solar UV detectors are encountered in this structure.

g) Photovoltaic Applications:

However, in additional to photodetectors, AlGaN is also used for the application of the solar cell for converting the solar UV radiation energy into the electrical energy. The broad range in the energy band allows the light of high energy in the ultraviolet range to be absorbed which helps to increase the efficiency of the solar cells.

2.9 Challenges and Research Areas

Thus, the proposed system shall also face attacks such as material quality, defect density, and fabrication techniques. As for the future work, it is aiming at solving the above challenges to enhance the performance and stability of AlGaN-based solar UV photodetectors.

Specifically, AlGaN is recognized to be a promising material for solar UV photodetectors due to the special features such as solar-blind characteristic, high responsivity, low dark current, etc. Future innovation on material science and the fabrication method of the device may possibly improve the high efficiency and high reliability of AlGaN based devices for the solar UV application. In in Fig 2.7 we can see how we elaborate the schematic process of UV imaging.

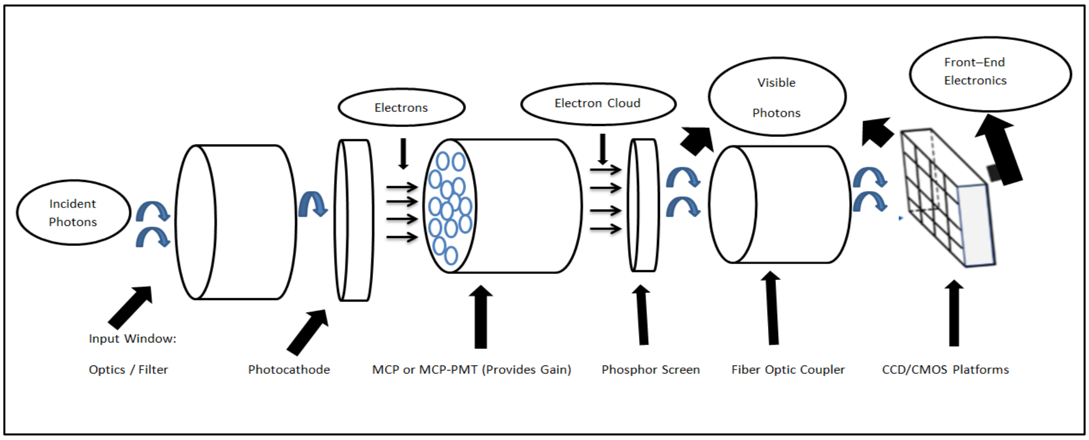

Figure 2.7: Schematic Assembly of Deep UV Imaging

2.10 Responsivity

2.10.1 Relation with UWBG Materials

1. Responsivity and UWBG materials are familiar when it comes to solar-blind detectors and they can go hand by hand. Responsivity defines the efficiency of the photo detector in terms of the incident optical power to the produced electrical signal and UWBG materials are selected based on their wide bandgap nature that effectively operates in solar-blind region. The following explains how responsivity and UWBG materials are related in solar-blind detector (Refer Table 2.4).

2. Ultra Wide Bandgap Materials for Solar Blind Detection: Substrate materials of UWBG include AlN, BN and diamond with wider bandgaps than silicon, or GaN substrates. These materials are relatively transparent to the visible and near UV light but they are highly photosensitive to the shorter-wavelength UVC light in the solar-blind region.

3. Responsivity in Solar Blind Detectors: Specifically, responsivity in solar-blind detectors is defined their individually sensitivity to UVC range of wavelength between 200 and 280nm. As a result, the introduced UWBG materials can potentially selectively and effectively easily adsorb the incident UVC photons resulting to the generation of electron hole pairs and thus a photocurrent. The energy associated with UVC photons is close to the energy level of clearing the wide bandgap, and therefore there will be a high responsivity in the detectors that utilize UWBG materials.

4. Quantum Efficiency: Responsivity has a synchronous connection with the quantum efficiency of the solar-blind detectors. Quantum efficiency is associated with the ability of the detector to create electron-hole pairs from the incident number of photons or photons absorbed. Due to their high quantum efficiency in UVC range, UWBG materials are to be used in the responsivity of the solar-blind detectors.

5. Selective UVC Detection: UWBG based solar-blind detectors are able to detect UVC radiation but block or remain insensitive to UV, visible, and near UV radiations. This selectivity along with the high responsivity for the UVC region is a basic advantage for uses where solar-blind performance is suitable for example in flame detection or in biological agent detection.

6. Optical Properties: This application also dwells on the wide bandgap of UWBG materials, which determine their optical characteristics. They let the detector collect UVC photons while blocking a large part of other unwanted wavelengths that are instrumental in generating noise and false alarms [77].

2.10.2 Formula for Calculating Responsivity

The formula of responsivity (R) of a photo detector depends on the change of electrical current (ΔI) caused by the photo detector to the incident optical power (P). Responsivity is usually expressed in amperes per watt (A/W) or volts per watt (V/W), depending on the given type of photo detector and measurements system.

The formula for responsivity is as follows:

$$R = \Delta I / P \qquad (1)$$

Where:

- **R** corresponds to the responsivity in A/W or V/W depending on the used units.
- ΔI is the change in electrical current (in amperes, A) or voltage (in volts, V) produced in the photo detector by the predicative optical power.
- P is the incident optical power in watts (W).
- The responsivity of a photo detector can be calculated with the help of photoelectric effect and energy of the sorted photons which was described above. The following derivation outlines the process for obtaining the responsivity formula:The following derivation outlines the process for obtaining the responsivity formula:
- **Step 1: Photoelectric Effect**
- The photo electric effect explains the process whereby photons of incident light falling on the surface of a material can knock off an electron from the material. The energy of each photon (Ephoton) is related to its frequency (ν) or wavelength (λ) by the equation:

$$E_{photon} = h\nu = hc/\lambda \qquad (2)$$

Where:

- Ephoton is the energy of a photon.
- h is Planck's constant (approximately 6.626×10^{-34} J·s).
- c is the speed of light (approximately 3×10^{8} m/s).
- ν is the frequency of the photon.
- λ is the wavelength of the photon

Step 2: Electron-Hole Pair Generation

After discussing the fundamental concepts of photo detectors, it is important to establish that when a photon is trapped by the photo detector then it transfers its energy to the electrons within the material leading to the formation of electron-hole pairs. Every emitted electron-hole pair taken into the conduction band comes out to be equal to the photon energy. This is true provided that the photon energy is greater than the material's band gap energy that is Egap so that electron hole pairs can be created.

Step 3: Responsivity Derivation

The responsivity (R) of a photo detector can be described as the change in electrical current (ΔI) generated at the detector given by the incident optical power (P) [78]. To derive the formula for responsivity, we consider that the generated current (I) is directly proportional to the number of absorbed photons (N_photons) and their energy:

$$I = q \times N_{photons} \times E_{photon}$$

Where:

- I is the current generated.
- q is the charge of an electron (approximately 1.6×10^{-19} C).
- $N_{photons}$ is the number of absorbed photons.

Now, let's express N_photons in terms of incident optical power (P) and the energy of individual photons (E_{photon}):

$$N\_photons = P / E_{photon}$$

Substituting this into the equation for current:

$$I = q \times (P / E_{photon}) \times E_{photon}$$

The photon energy (Ephoton) cancels out, resulting in the equation for current:

$$I = q \times P$$

Now, we can express responsivity (R) as the ratio of the change in current (ΔI) to the incident optical power (P):

$$R = \Delta I / P$$

Table 2.4: Showing Values of Responsivity for WBG & UWBG

Wide Band Gap Material	**Responsivity**
Zinc Oxide	1125A/W
Gallium Oxide	70.26A/W
Ultra Wide Band Gap Material	**Responsivity**
Beta Gallium Oxide	149A/W
Hexagonal Boron Nitride	5.022A/W
Aluminum Nitride	20.81 mA/W

2.11 Analysis

In terms of responsivity for the solar-blind detectors possible advantage over WBG materials is that: UWBG materials, with even larger band gap, are theoretically capable of providing much higher solar-blind sensitivity. It can entail very short wavelength ultraviolet (UV) radiation with greater efficiency, thus better fitted for applications where the differentiation between UV and the other incidental light wavelengths is very important. As a result, the responsivity of the UWBG materials should be higher in the UV compared to the broader BG materials due to the higher band gap. This means that they can create a better charge for incident UV radiation, probably making them more effective in converting UV photons to electrical signals. Higher solar-blind sensitivity as well as responsivity of UWBG material can lead to a high signal to noise ratio of solar-blind detectors. This means that, UWBG detectors are able to provide better signal to noise ratios in real application scenarios, and hence improve on the measurement accuracy. It remains uncertain whether UWBG materials will increase the detectable range of solar-blind detectors and include the radiation that WBG materials exclude. This is particularly beneficial in environments where the identification of even the ultra-violet light that is in the extreme end of the UV spectrum is required. The specified characteristics of UWBG materials may create new application areas to what fields that necessitate high solar-blind sensitivity, such as advanced UV spectrometry, UV communication, and UV physical study with high energy radiation.

2.12 Summary of Related Work

The literature review provides a comprehensive overview of the properties, synthesis methods, applications, challenges, and future prospects of ultra-wide band gap materials. It highlights the potential of these materials to revolutionize various fields by enabling high-performance devices with improved efficiency, power handling, and temperature resilience.

This work on evaluating the reliability of ALGaN materials in optoelectronic devices is novel since it advances our knowledge of long-term stability and performance in practical settings. This study fills in the knowledge gaps about the behavior of these materials under varied stress conditions and over extended periods of time by concentrating on ALGaN, which is recognized for its broad bandgap and excellent efficiency. In order to improve the accuracy of device lifespan and reliability forecasts, this work presents new testing protocols and methodologies that are especially designed to take use of the special qualities of ALGaN. It is anticipated that these developments will raise the bar for engineering and design, which will increase the robustness and efficiency of optoelectronic devices that use these materials. Additionally, this work opens the path for the future by identifying and describing the degradation mechanisms specific to ALGaN.

2.13 Conclusion

This will help us to overview the previous work and give us the path for new advancements in UWBG materials field. A literature review helps us to build a comprehensive understanding of the theoretical, experimental, and practical aspects of assessing optoelectronic properties in UWBG materials. Begin by reviewing literature that explains the fundamental concepts of optoelectronic properties. This includes the behavior of materials in response to light, such as absorption, emission, and photoconductivity.

CHAPTER 3

METHODOLOGY

Chapter outlines the research procedure, encompassing the materials utilized in the study, the experimental process, the development of research tools, and the procedures for data analysis.

3.1 Research Design:

It is experimental research. The main purpose of this experimental study is to analyze which Ultra-Wide Band Gap (UWBG) material is most appropriate to be used in photonics. Experiments are performed to compare wide band and UWBG materials band gap energies. These energies defines and show through experiments which material is best to be used in future studies.

3.2 Sample of Research:

Different Wide Band Gap & UWBG Materials are used as sample of the research study. These are Beta Gallium Oxide, AlN, h-BN. [13]

3.3 Instrument of Study:

Tauc Plot and Origin Pro Software is used as the instrument of study to evaluate our research. [12]

3.4 Data Collection Procedures:

3.4.1 Tauc Plot

This article shows the definition and application of Tauc Plot, also known as Tauc plot analysis or Tauc's method, describes a graphical technique widely utilized in material science and solid-state physics for the purpose of controlling the optical bandgap energy of semiconductors. It allows exploring electronic properties, for instance, of the absorption or optical spectra, in different materials. Tauc Plot software is one of the important software that is used in the process of analyzing the optical absorption spectra in order to determine the band gap energy of the interested material. It is used significantly in the research of the inherent characteristics of semiconductors and other material, important to science and technology. As a result of this the software comes equipped with features and functions that are uniquely designed to assist the researchers in analyzing and visualizing absorption spectra therefore disentangling the energy level and optical behavior of examined materials. As a result of the easy-to-use graphical interface supported by powerful analytical functions, Tauc Plot is now a critical reference in materials science and associated fields [43].

Here is a detailed explanation of the Tauc plot:

3.4.1.1 Background

Energy band gap is another critical property of a semiconductor material referring to the amount of energy that is needed to promote an electron from the valance band to the conduction band.

Tauc plot is derived from the Tauc equation which express the absorption coefficient of a material α as a function of the incident photon energy hν and the energy band gap Eg the power law relationship. [12]

3.4.1.2 Tauc Equation

According to Tauc, the energy gap values can be obtained from the following equation:

$$(\alpha hv)\ 1/m = B\ (hv - E\text{g}) \qquad (1)$$

Where,

α = Absorption Constant

h = Planck's constant (4.135 × 10-15 eV),

v = frequency (s-1),

B = a comparative constant

Eg = energy gap (eV).

m = indicates the type of electronic transition, with values for different transitions being ½ = Direct 3/2 = Direct forbidden 2 = Indirect 3 = Indirect forbidden

The value of m hinge on on the nature of absorption process and is typically assumed to be 1/2 or 2 for direct or indirect band gap materials, respectively.

a) Derivation of Equation:

The Tauc plot, also known as the Tauc equation or the Tauc plot equation, is a commonly used empirical relation in semiconductor physics to describe the absorption coefficient (α) as a function of photon energy (hν) in a material. The equation is derived based on the assumption of direct allowed transitions in the material.

The Tauc plot equation is given by:

$$\alpha(h\nu) = A(h\nu - E\_g)^n \qquad (2)$$

Where:

α (hν) is the absorption coefficient as a function of photon energy.

A is a constant related to the transition probability.

Eg is the optical band gap energy of the material.

n is the exponent that depends on the nature of the transition.

Now, let's go through the derivation of the Tauc plot equation:

The absorption coefficient is related to the absorption cross-section (σ) by the equation:

$$\alpha = (1/d)\times\sigma \qquad (3)$$

Where d is the thickness of the material.

The absorption cross-section (σ) is related to the absorption probability (P) by the equation:

$$\sigma = \lambda \times P \qquad (4)$$

Where λ is the wavelength of the incident light.

According to Tauc's assumption, the absorption probability (P) is proportional to the density of states (DOS) and the incident photon energy (hν) raised to the power of n:

$$P \propto DOS \times (h\nu)^n \qquad (5)$$

The density of states (DOS) is assumed to be constant in the vicinity of the band gap.

The photon energy ($h\nu$) is related to the wavelength (λ) by the equation:

$$h\nu = hc/\lambda \quad (6)$$

Where h is Planck's constant and c is the speed of light.

Combining equations 3, 4, and 5, we have:

$$P \propto (h\nu)^n \quad (7)$$

$$P \propto (hc/\lambda)^n \quad (8)$$

Substituting equation 6 into equation 2, we have

$$\sigma = \lambda \times (hc/\lambda)^n \quad (9)$$

$$\sigma = (hc)^n \times \lambda^{(1-n)} \quad (10)$$

Substituting equation 8 into equation 1, we have:

$$\alpha = (1/d) \times \sigma \quad (11)$$

$$\alpha = (1/d) \times (hc)^n \times \lambda^{(1-n)} \quad (12)$$

We can rewrite λ as $\lambda = (hc)/(h\nu)$, substituting this into equation 8:

$$\alpha = (1/d) \times (hc)^n \times [(hc)/(h\nu)]^{(1-n)} \quad (13)$$

$$\alpha = (1/d) \times (hc)^n \times (hc)^{(1-n)} \times (h\nu)^{(-1+n)} \quad (14)$$

Rearranging the terms, we get:

$$\alpha = A \times (h\nu)^{(-1+n)} \quad (15)$$

Where A = [(hc)^n × (hc)^(1-n)]/(d)

To simplify the equation, we can set the exponent (-1+n) as n. This assumes that n is a positive value, which is typically the case for direct allowed transitions.

$$\alpha = A \times (h\nu - E\_g)^n \quad (16)$$

where $E\_g = (1/n) \times (hc)^n \times (hc)^{(1-n)}$ is the optical band gap energy of the material.

Thus, we have derived the Tauc plot equation, where the absorption coefficient (α) is expressed as a function of photon energy ($h\nu$), with the exponent n and the band gap energy (E_g) as fitting parameters. [12]

b) Tauc Plot Construction:

In order to obtain the Tauc plot, the absorption coefficient (α) is normally found through the experiment whereby the absorption of a material at different values of photon energy is ascertained.

The Tauc plot is then derived by plotting the square of absorbance, αhν]^2 against the photon energy, hν, where h is the Plank's constant on both the Y and X axes respectively.

The square of (αhν) is multiplied so as to bring into consideration the power-law relationship in the Tauc equation.

Analysis and Band gap Determination:Analysis and Band gap Determination:

The Tauc plot of the material is obtained by extrapolating the linear region of the graph up to the point where the linear behavior is disrupted, which represents the absorption edge of the material.

The linear part of the plot shifts to low photon energies and is extrapolated until it reaches the value hν = 0.

On the x-axis intercept, it can be obtained that the energy band gap (Eg) of the material.

The value of Eg can be obtained either by extrapolation of the linear region or by regression of linear part of the plot [44].

3.4.1.3 Implementation of Tauc Plot

c) Data Preparation:

The absorption spectra data concerning the material under investigation was obtained using UV Spectrum on the substance. The information was gathered in compatible format, in the form of CSV file which can be uploaded into the system of Tauc Plot.

Import Data:

Tauc Plot was initiated and the absorption spectra data was configured to be inputted into the software program. The data file was initialized in the program with the help of built-in data import feature as depicted in fig 3.1

Data Visualization:

Tauc Plot presents different techniques for the visualization of the absorption spectra to identify and study. Thus applying the approaching method provided by the Tauc Plot in plotting for the absorption spectra gave a better visualization of the distribution of data and the trends of the band gap energies of different materials.

Band gap Calculation:

Tauc plot's band gap calculation feature was used in order to determined the energy band gap of the materials. This was often achieved by carrying a straight line or curve through the absorption edge of the spectrum and then projecting it on to the energy axis. The energy of the interacting vehicles on the roads can be determined by locate the intersection point of the extrapolated line with the x-axis.

Analysis and Interpretation:

After attaining the band gap energy, the data was analyzed and the results in the light of the objectives of the research work was interpreted. Different aspects which were discussed based on the value of band gap energy for the optical and electronic behavior of the material were listed against fig. 3.2.

Export and Reporting:

Further analysis or incorporation involves the exporting of analyzed data, graphical representations, and related results through Tauc Plot (Refer: Fig. 3.3) to the subsequent software namely Origin PRO [47].

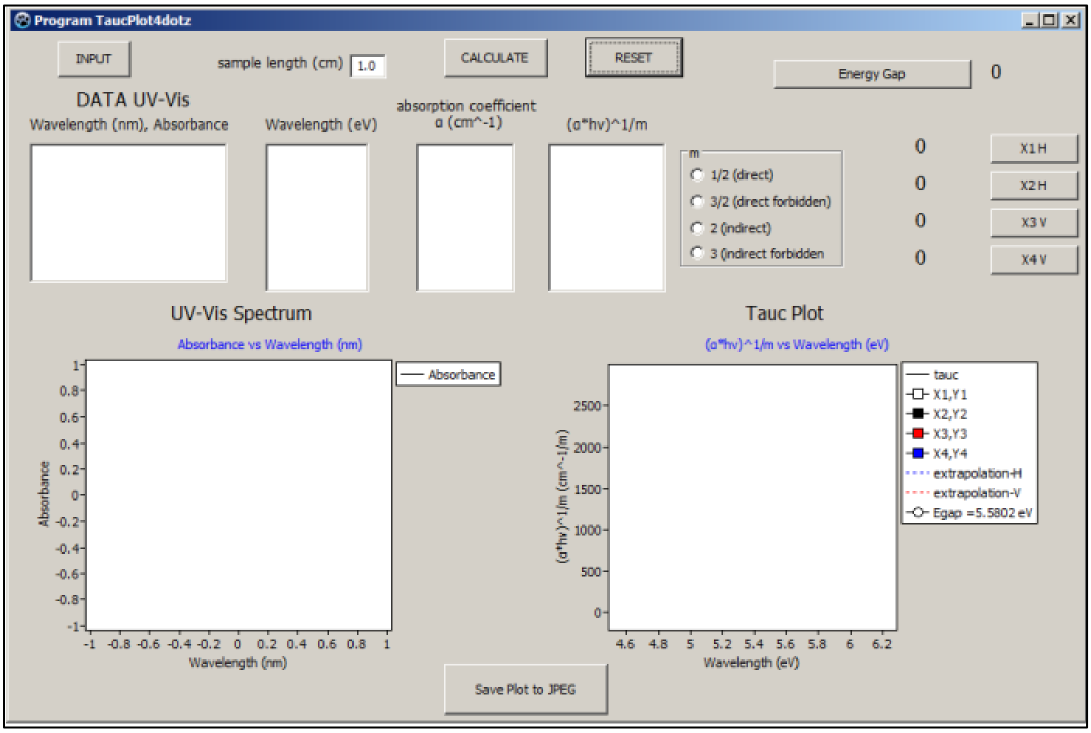

Figure 3.1: Graphical User Interface of Tauc Plot

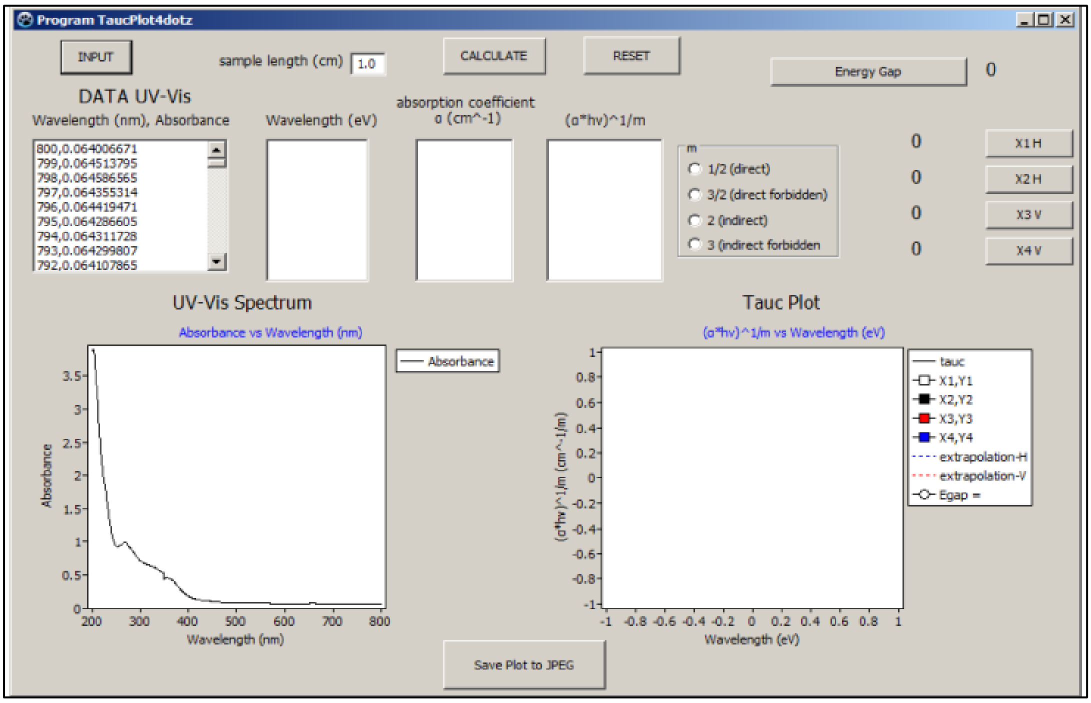

Figure 3.2: Data Input Sample

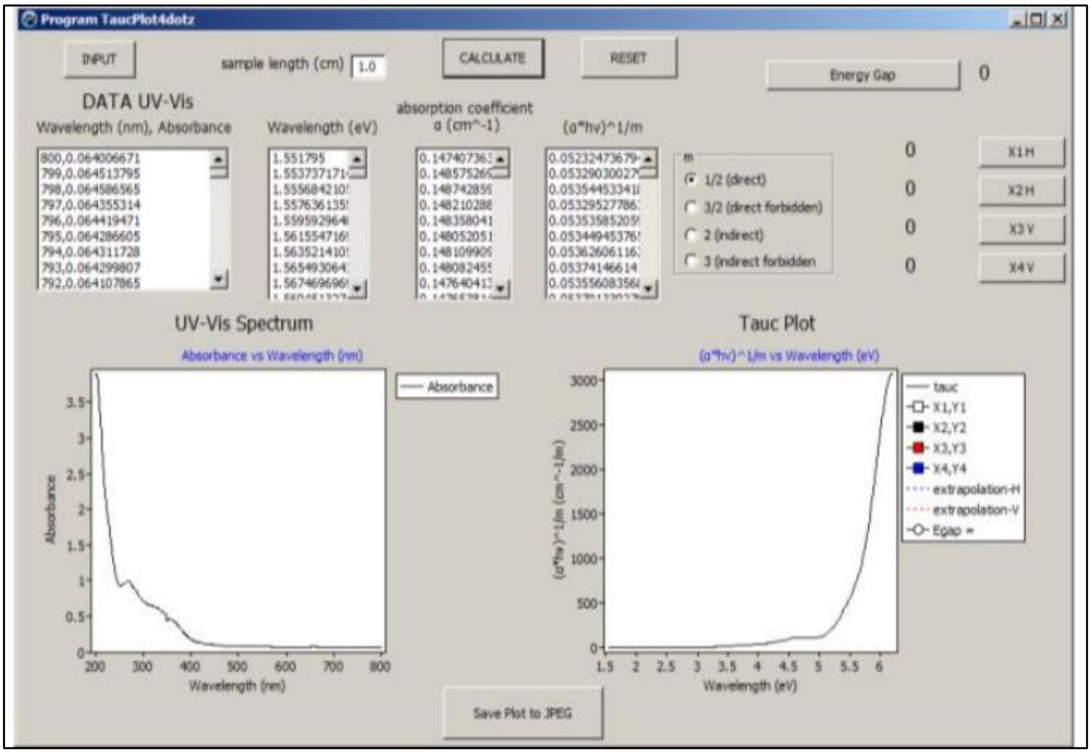

Figure 3.3: Result Calculations of Wavelength, Absorption Coefficient and (ahv) 1 / m.

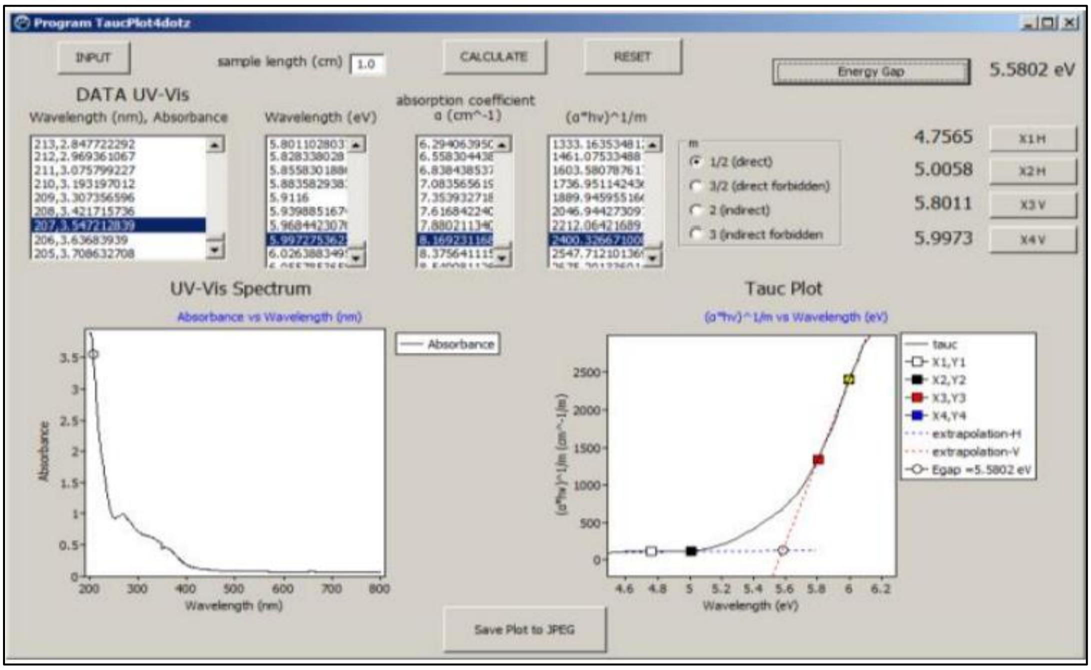

Figure 3.4: Result Obtained of Energy Gap

During this phase, software testing is conducted using sample data: ZnO, which is data that has been adjusted and extracted from previous studies on leaf extracts the testing process involves the following steps:

a) Data entry:

The user inputs the data by pressing the INPUT button and selecting the data format as × .csv. This action generates the initial plot.

b) Calculation of absorption coefficients:

The software allows the user to select a value for "m" and determine the sample length. By pressing the CALCULATE button, the software computes the absorption coefficients and converts the wavelength to (ahv) 1 / m. The results are presented in figure 3.4 along with the calculated values and a second plot.

c) Linear area determination and extrapolation lines

Once the results are obtained, the next step is to identify the linear area of the curve in the second plot. Four points need to be specified for the extrapolation lines. The user selects these points from the "linear area" of the curve, with X1H and X2H chosen from the horizontal part, and X1V and X2V chosen from the vertical part.

d) Energy gap calculation

After selecting the four points, the user presses the Energy Gap button to obtain the energy gap values. These values represent the energy gap information derived from the selected points.

This process yields various results, demonstrating the software's ability to analyze the data and provide energy gap calculations. This is also shown in he given flow chart. While it provides a wide range of tools and features for analyzing different types of data, including ultra-wide band gap (UWBG) materials, the software itself does not specifically focus on UWBG materials.

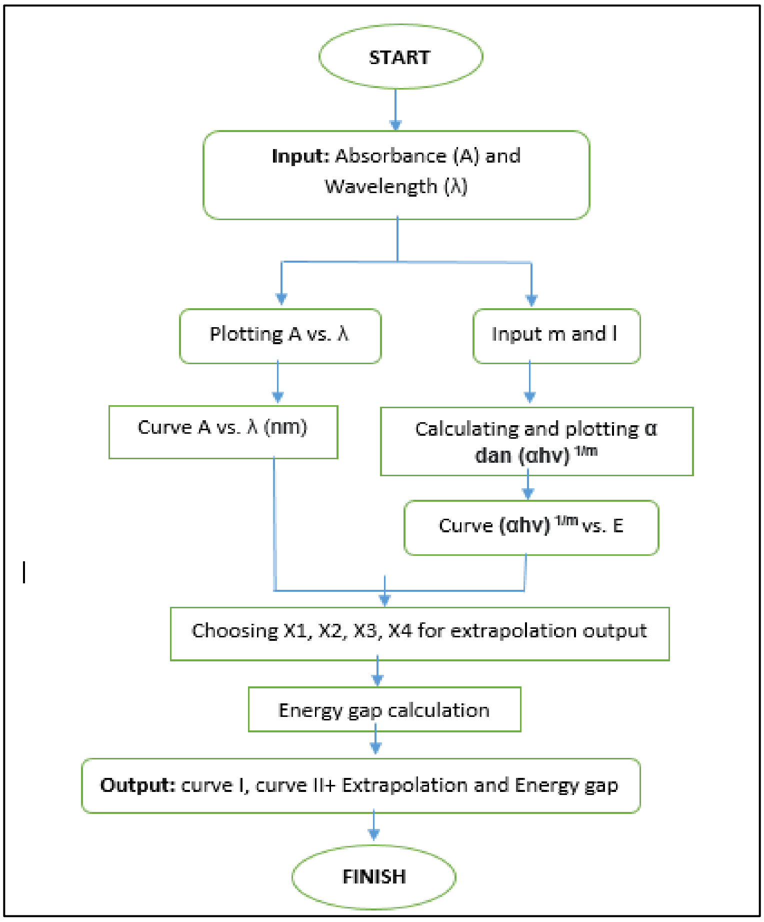

Figure 3.5: Flowchart Showing the Steps of Tauc Plot Designing

3.4.2 Origin Pro

Origin Pro is an analytical charting and statistical computation application from the house of Origin Lab Corporation. Origin Pro is quite popular CE software that is often used for data analysis and visualization in numerous scientific disciplines as well as in engineering. Thus, although it does not ease the process of determining automatic parameters, Origin Pro can be used effectively for the analysis of experimental data obtained from UWBG materials research. Origin Pro offers data import from the text file, Excel, databases, and other specific file formats. Imported data can be cleaned, filtered, and transformed as well preprocessed by using powerful data manipulation tools of this software. Thus, one can join the information, divide the columns, use some operations on the numbers, etc. OriginPro creates great opportunities that enable a user to represent data in the required way because of presented tools. The types of plot are line plots, scatter plots, bar/column charts, pie charts, histograms, contour plots and 3D plots. Extra options include error bars, symbols, and dramatic colors of the plot, and density of the plot with the shadows and gradients, and smooth curve fitting. Origin Pro has the feature of the graph customization, which enables One to change axes, labels, titles, legends, annotations, and many other characteristics of the plot. The same multiple plots can be arranged within one graph page, and this will help to compare and analyze the data obtained in the course of the investigations. Origin Pro has several tools for statistical and mathematical analysis of data within a project to make interpretations easier. Some of the analyses one can do are descriptive statistics, hypothesis, correlation and difference testing, analysis of variance, and regression analysis. The program provides linear or nonlinear curve fitting with the choice of supplied functions and the option of stating equations.

The packages include principal component analysis (PCA), cluster analysis, and multivariate analysis though these are in an advanced level. It also has some options linked to signal processing, image processing, peak analysis, fourier transforms, and smoothing methods. Users can programme using Origin C, the software's own scripting language, and also using other languages like Python and R. Possible to write user scripts or automation routines for performing any number of advanced analyses and operations on the data and for augmenting the capability of the software. Origin Pro also has a built-in feature to create Code Builder for scripting as well as testing and debugging original scripts and linking to other libraries and tools. It has the feature to produce publication standard graphs, reports and even presentations. The layout of graphs can be changed, text and images can be included, usage of templates, multilayered graphs are also possible.

This one feature has individual and batch plotting and exporting options for creating more than one graph or report at a time. With Origin Pro there are options of exporting the graphs and the reports in PDF, EPS, TIFF, PNG, and even PowerPoint. Origin Pro contains additional tools for particular use, these tools include chromatography tools, surface tools, and particle size tools. It has tools for image processing where the user can modify, filter, threshold and even draw and measure on the image.

The external software, database, and programming languages interfaces and APIs can also be easily connected with Origin Pro. These ones include Excel CSV

HDF5 SQL and MATLAB and others and for exporting the data it supports different formats of data. Considering more integrated applications, Origin Pro is capable of compatibility with another well-known packages and data formats used in the scientific research.

In conclusion, it could be stated that the functions, the variety of options, and the intuitive approach of this tool called Origin Pro grant it a potential usage in numerous disciplines of science and engineering for data analysis and presentation. It makes the capabilities of researchers and analysts to search, analyze, or represent big data or large datasets in multiple ways, tendencies, or formats for facile understanding.

In Study Tauc Plot is implemented in the following manner:In Study Tauc Plot is implemented in the following manner:

Data Import

Input was done by transferring data into the software. It was ensure that the data is formatted correctly to fit the required fields in the database and other organized systems.

Data Manipulation

The next step was to format the data for use during the analysis or for visualization. Original Pro encompass a broad assortment of capabilities for data management, including, filtering, sorting, merging, and transforming of data. These tools were used as and when necessary to bring the data into a suitable form for analysis.

a) Graph Creation:

Appropriate graphs or visualizations to represent data were drawn. Origin Pro provides a variety of graph types, including line plots, scatter plots, bar charts, histograms, and more. Line Plot graphs were used as per research objectives. The graph appearance was customized by modifying axis scales, labels, colors, and other visual properties.

b) Data Analysis:

Statistical and analytical procedures were applied on data using the built-in analysis tools in Origin Pro.

c) Customization and Annotation:

Graphs were enhanced and analysis of outputs was done by customizing them further. Labels, legends, titles, and annotations to provide clear explanations and context were added.

d) Output and Reporting:

Graphs, statistical outputs, and analysis results from Origin Pro were exported for use in research report (Refer Fig. 3.6) for understanding.

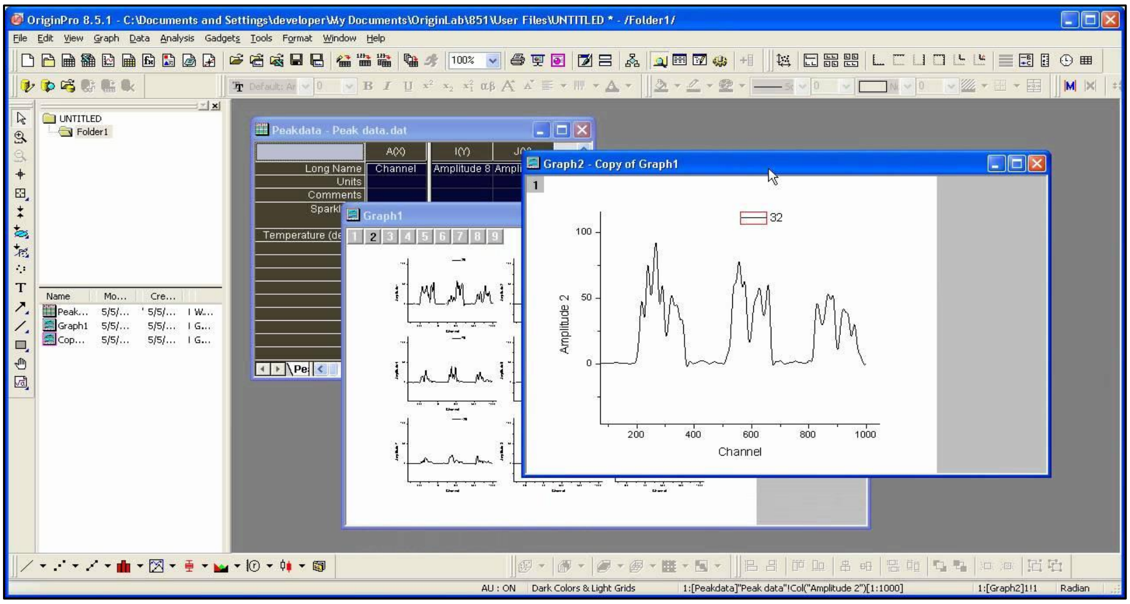

Figure 3.6: Graphical Analysis and Overview of Origin Software [14]

CHAPTER 4

SIMULATION AND RESULTS

4.1 Simulation of Different WBG & UWBG Materials

4.1.1 Zinc Oxide

Zinc Oxide is a WBG material having wavelength range between 370nm-380nm with the band gap energy to be 3.3eVas shown in table 4.1 below. It is being used in different optoelectronic devices due to these qualities but there are some shortcomings i.e. it exhibits intrinsic defects and non-stoichiometry, leading to variations in its properties. These defects, such as oxygen vacancies and zinc interstitials, can influence the electronic and optical characteristics of the material. Which results in moving us towards UWBG materials Secondly Zinc oxide tends to undergo thermal decomposition at elevated temperatures, limiting its use in certain high-temperature applications. This can affect the stability and reliability of devices operating under such conditions. Thirdly zinc oxide has a relatively wide band gap, its tunability is somewhat limited compared to other semiconductors. This restricts its application in certain electronic devices where a specific band gap is required for optimal performance [77].

Table 4.1: Showing the values of wavelength, absorbance and band gap energy

	A(X1)	B(Y1)	C(X2)	D(Y2)
Long Name	Wavelength	Absorbance	Energy	ahv
Units	nm			
Comments				Direct
F(x)=			1240/col(A)	(2.303*col(B)*col(C))^2
1	370	0.0113	3.35135	0.00761
2	371	0.0113	3.34232	0.00757
3	372	0.0112	3.33333	0.00739
4	373	0.0117	3.3244	0.00802
5	374	0.0117	3.31551	0.00798
6	375	0.0112	3.30667	0.00727
7	376	0.0111	3.29787	0.00711
8	377	0.0106	3.28912	0.00645
9	378	0.0105	3.28042	0.00629
10	379	0.011	3.27177	0.00687
11	380	0.011	3.26316	0.00683

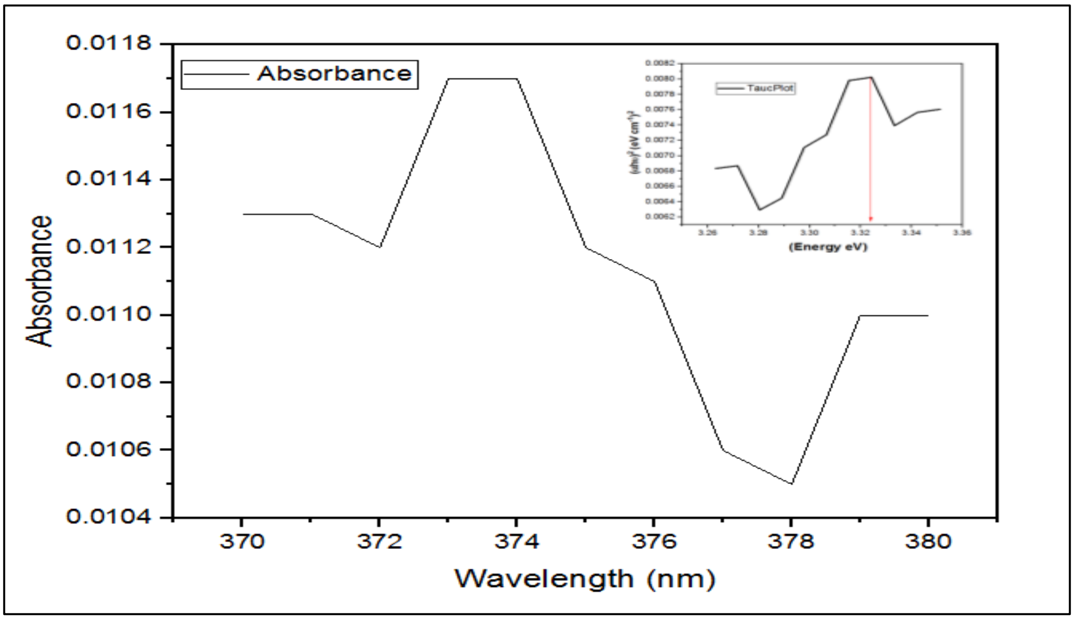

Figure 4.1: Relation Between Absorbance and Wavelength of Zinc Oxide

The figure above shows the graph drawn between absorbance and wavelength at different ranges. We can analyze from these values that at which wavelength we have to design our devices to get better results.

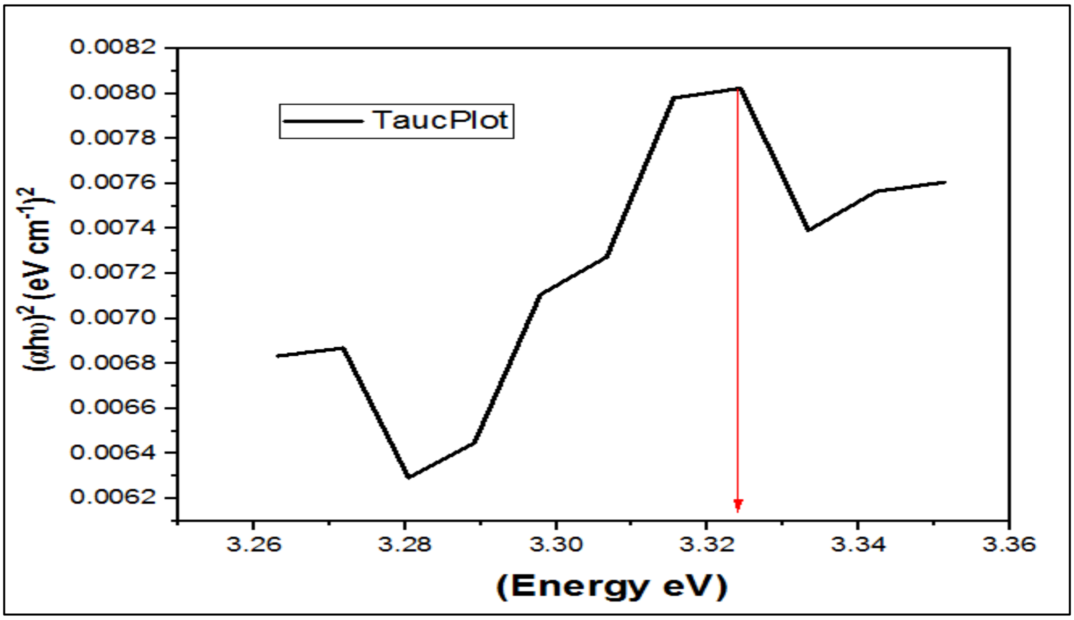

Figure 4.2: Band gap energy value of Zinc Oxide

The figure 4.2 shows the band gap energy of Zinc Oxide which is to be around 3.3eV. this value allows us to use it in different devices but as this value is less as compared to other materials now its use is becoming limited.

4.1.2 Gallium Oxide

Gallium oxide emerges as a promising material for optoelectronic devices, boasting a wide band gap energy typically exceeding 4.5 eV as shown in table 4.2. This characteristic renders Gallium oxide suitable for applications demanding sensitivity to ultraviolet (UV) light. However, challenges accompany its utilization. The relatively complex fabrication processes and the need for high-quality crystalline structures pose hurdles to scalability. Moreover, issues related to defects, impurities, and the control of doping levels can impact the material's performance.

Table 4.2: Showing the values of wavelength, absorbance and band gap energy

	A(X1)	B(Y1)	C(X2)	D(Y2)
Long Name	Wavelength	Absorbance	Energy	ahv
Units	nm		eV	
Comments				Direct
F(x)=			1240/col(A)	(2.303*col(B)*col(C))^2
1	254	0.015	4.88189	0.02844
2	255	0.016	4.86275	0.03211
3	256	0.01593	4.84375	0.03158
4	257	0.0158	4.8249	0.03082
5	258	0.0157	4.8062	0.0302
6	259	0.0157	4.78764	0.02997
7	260	0.0156	4.76923	0.02936
8	261	0.0155	4.75096	0.02876
9	262	0.0154	4.73282	0.02818
10	263	0.0154	4.71483	0.02796

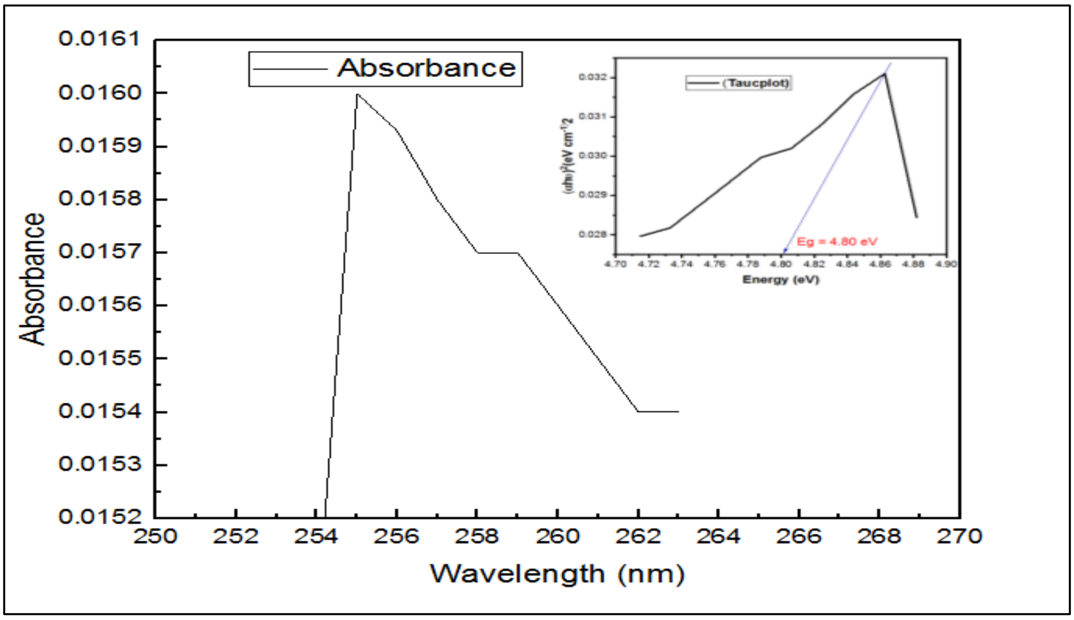

Figure 4.3: Graph Between Absorbance and Wavelength of Gallium Oxide

The above figure shows the graph plotted between absorbance and different wavelength ranges. From this graph we can conclude that gallium oxide is the good material to be used in different devices due to its absorption value.

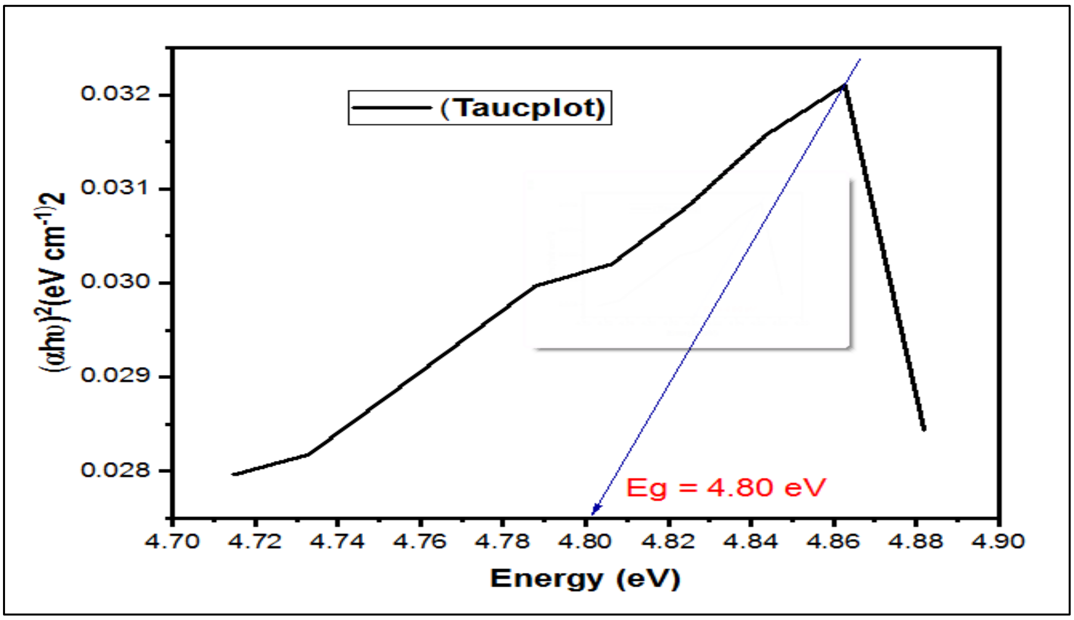

Figure 4.4: Band gap energy value of Gallium Oxide

Figure 4.4 demonstrates that gallium oxide (Ga_2O_3) has a higher bandgap energy compared to other wide-bandgap (WBG) materials, which contributes to its superior reliability and performance. With a bandgap energy exceeding 4.8 eV, Ga_2O_3 is particularly effective at absorbing ultraviolet (UV) light while remaining transparent to visible and infrared wavelengths. This high bandgap energy enhances Ga_2O_3's resistance to high voltages and high-energy radiation, making it more reliable for high-power and high-frequency applications.

The elevated bandgap of Ga_2O_3 also confers better thermal and chemical stability, allowing it to perform reliably in extreme conditions. This property is crucial for solar-blind detectors, where Ga_2O_3's ability to efficiently absorb UV light while ignoring longer wavelengths makes it ideal for precise UV detection. Overall, Ga_2O_3's high bandgap energy provides a distinct advantage over other WBG materials, reinforcing its suitability for advanced optoelectronic devices and high-power electronics.

4.1.3 Beta Gallium Oxide

In conclusion, the beta Gallium oxide (β-Ga2O3) is among the promising materials for optoelectronic devices, the wide band gap energy is typically greater than 4. 8 eV as depicted in the table 4.3. The table analyses the absorbance of Beta Gallium Oxide at a number of wavelengths including the band gap energies at the specified wavelength. This characteristic makes it appropriate where there is a need to consider the ultraviolet (UV) light applications with high short wavelengths and efficient absorption. Other qualities of morphology of β-Ga2O3 such as thermal stability and good mechanical properties will also add the support for high power and high frequency of optoelectronic devices. The systematic study of this compound thus is promising for the creation of new technologies ranging from power electronic devices to high end sensing applications. The prospects of big size production together with the material's integration with existing semiconductor technologies make it promising for further application [78].

Table 4.3: Showing the values of wavelength, absorbance and band gap energy

	A(X1)	B(Y1)	C(X2)	D(Y2)
Long Name	Wavelength	Absorbance	Energy	(ahv)
Units	nm		eV	
Comments				Direct
F(x)=			1240/col(A)	(2.303*col(B)*col(C))^2
1	253	0.0157	4.90119	0.0314
2	254	0.0156	4.88189	0.03076
3	255	0.0156	4.86275	0.03052
4	256	0.0153	4.84375	0.02913
5	257	0.0152	4.8249	0.02853
6	258	0.0151	4.8062	0.02793
7	259	0.0149	4.78764	0.02699
8	260	0.0148	4.76923	0.02642
9	261	0.0147	4.75096	0.02587
10	262	0.0147	4.73282	0.02567
11	263	0.0146	4.71483	0.02513

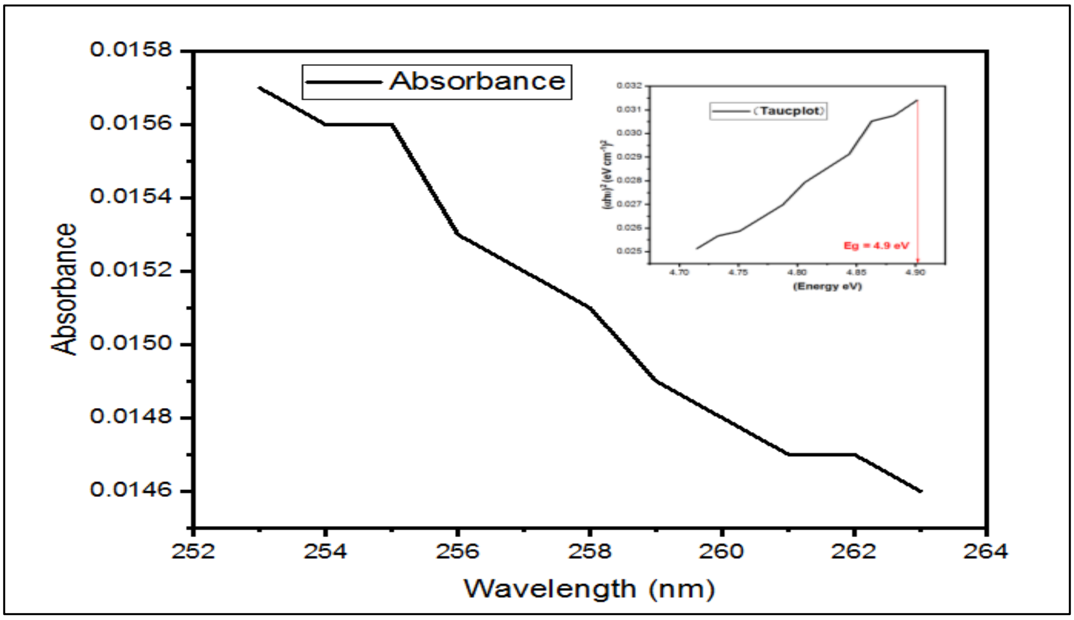

Figure 4.5: Relation Between Absorbance and Wavelength of Beta Gallium Oxide

The graph illustrates how the absorbance of an aqueous solution of copper sulfate changes with varying wavelengths, and this can provide insights into the optical properties of materials like β-Ga2O3 (beta gallium oxide) when compared to other UWBG materials.

Absorbance refers to the extent to which a material can absorb light at specific wavelengths. This property is crucial for understanding how different materials interact with light, particularly in optoelectronic applications. The graph shows that as the wavelength increases, the absorbance of the material changes, which is directly related to the material's bandgap energy.

In the case of β-Ga2O3, the graph indicates that this material exhibits higher absorbance at shorter wavelengths. This behavior is characteristic of materials with a large bandgap energy. β-Ga2O3 has a wide bandgap, typically greater than 4.8 eV, which means it is more effective at absorbing higher-energy (shorter wavelength) photons. Materials with larger bandgaps generally have their absorption edge in the ultraviolet (UV) region of the spectrum. Therefore, β-Ga2O3's increased absorbance at shorter wavelengths suggests that it is well-suited for applications that require UV detection or solar-blind detection. The observed higher absorbance of β-Ga2O3 at shorter wavelengths implies that it is particularly sensitive to UV light, which aligns with its properties as a UWBG material. This characteristic is beneficial in applications where detecting UV radiation accurately and effectively is essential. The graph underscores β-Ga2O3's potential in optoelectronic devices that operate in the UV range, highlighting its suitability for advanced technologies requiring high precision and sensitivity. Lastly, the research outcomes could influence policies related to the adoption of advanced optoelectronic technologies across various sectors. Demonstrated improvements in device performance and longevity due to ALGaN materials might encourage policy adjustments to promote their integration into critical applications such as telecommunications, defense, and medical devices.

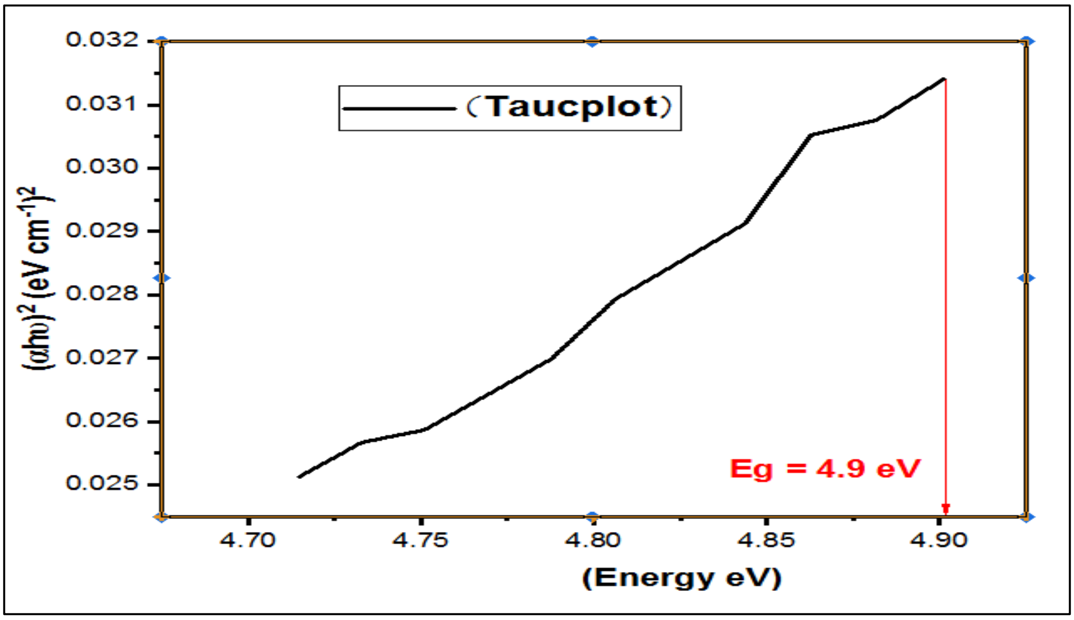

Figure 4.6: Band gap energy of Beta Gallium Oxide

As evident from the figure 4.6 above the band gap energy for the beta gallium oxide is 4. 9eV. Thus, indicating that high band gap energy is preferred in the materials that are used in applications such as, sensitivity to ultraviolet (UV) light. High band gap energy materials respond quickly to shorter wavelengths of light; thus, are ideal in applications such as UV detector and sensor.

4.1.4 Aluminum Nitride

Aluminium Nitride (AlN) is looked into as one of the most promising candidates for optoelectronic devices with the following attributes such as, Band gap energy are typically in a range of Ultra wide, especially around the range of 5. 8eV, as can be seen from table 4.4. This big band gap puts this material, AlN, among the most sought materials where big sensitiveness to Ultraviolet (UV) light with short wavelength as well as high absorption ability is needed. Future growth in the deposition of complementary metal-oxide-semiconductor (CMOS) technology and superior thermal conductivity reinforces this material's suitability for powerful optoelectronics. Although, AlN has shown huge prospect in uses such as deep UV light emitting diodes and photo detectors. Furhter works will be dedicated to enhance the characteristics of AlN and due to its applicability to a wide range of state-of-art devices and systems, it will continue to remain as an essential material to optoelectronics in the foreseeable future.

Table 4.4: Showing the values of wavelength, absorbance and band gap energy

	A(X1)	B(Y1)	C(X2)	D(Y2)
Long Name	Wavelength	Absorabance	Energy	(ahv)
Units	nm		eV	
Comments				Direct
F(x)=			1240/col(A)	(2.303*col(B)*col(C))^2
4	213	0.0206	5.8216	0.07628
5	214	0.0205	5.79439	0.07484
6	215	0.0195	5.76744	0.06708
7	216	0.0203	5.74074	0.07203
8	217	0.0202	5.71429	0.07067
9	218	0.0192	5.68807	0.06326
10	219	0.0191	5.6621	0.06203
11	220	0.019	5.63636	0.06083

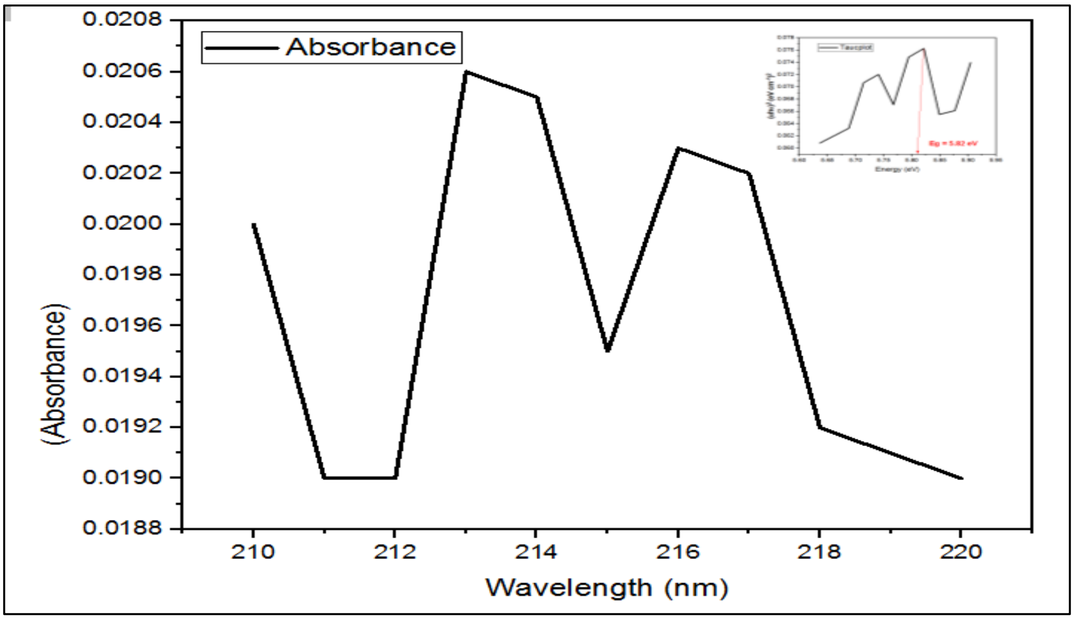

Figure 4.7: Graph showing relation between Absorbance and Wavelength of AlN

The graph illustrates a clear trend where absorbance increases at shorter wavelengths, indicating that materials like Aluminum Nitride (AlN) exhibit higher absorption values in the UV region. This high absorbance at shorter wavelengths is characteristic of materials with a wide bandgap, such as AlN, which is known for its bandgap energy of approximately 6.2 eV. This property enables AlN to effectively absorb high-energy UV photons.

Due to its significant absorbance in the UV spectrum, AlN proves to be highly efficient for use in optoelectronic devices. This efficiency is crucial for applications such as UV detectors and UV light-emitting diodes (LEDs), where the ability to detect or emit UV light is essential. The graph's results highlight AlN's suitability for these applications, ensuring enhanced performance and sensitivity in devices that operate in the UV range.

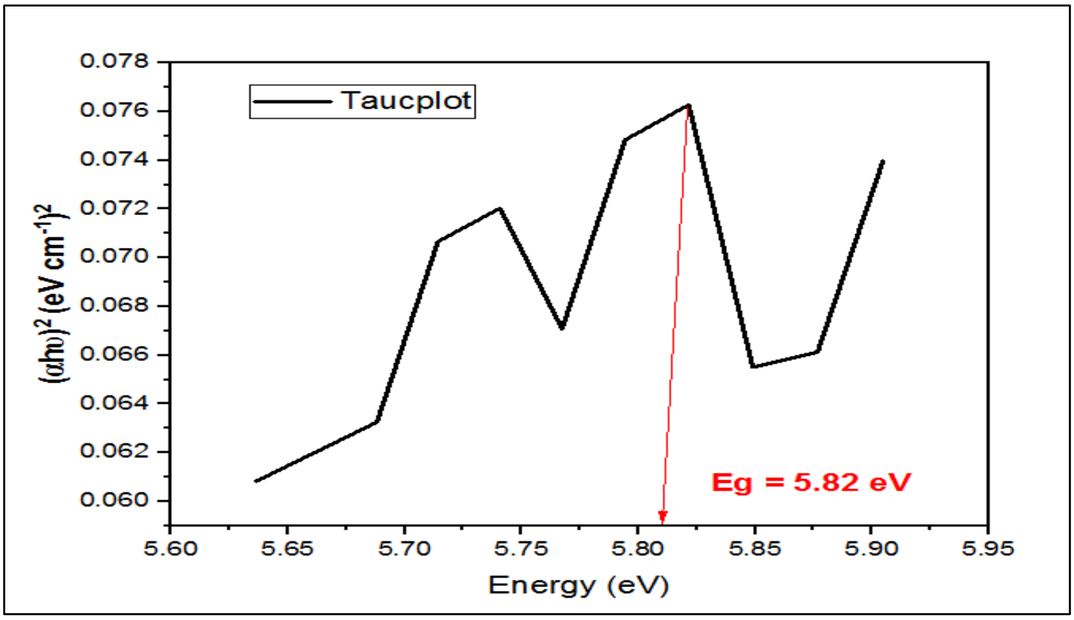

Figure 4.8: Band gap energy of AlN

This figure above shows the high band gap energy of AlN due to which it is one of the promising material to be used in future for different electronic and optoelectronic devices [79].

4.1.5 Hexagonal Boron Nitride

Hexagonal Boron Nitride (h-BN) stands as a captivating candidate for optoelectronic devices, marked by its unique band gap energy, typically exceeding 5.9 eV. as shown in table 4.5 below. This substantial band gap positions h-BN at the forefront of applications demanding sensitivity to ultraviolet (UV) light, characterized by short wavelengths and efficient absorption properties. The exceptional thermal and chemical stability of h-BN further extends its appeal for optoelectronic applications, ensuring robust performance in diverse environmental conditions. While h-BN has showcased promise in areas such as deep UV photonics and quantum optics, challenges persist, including the need for scalable production methods and improved integration techniques.

Table 4.5: Showing the values of wavelength, absorbance and band gap energy

	A(X1)	B(Y1)	C(X2)	D(Y2)
Long Name	Wavelength	Absorbance	Energy	ahv
Units	nm		eV	
Comments				Direct
F(x)=			1240/col(A)	(2.303*col(B)*col(C))^2
1	210	0.019	5.90476	0.06676
2	211	0.0189	5.87678	0.06543
3	212	0.0188	5.84906	0.06413
4	213	0.0197	5.8216	0.06976
5	214	0.0196	5.79439	0.06841
6	215	0.0186	5.76744	0.06104
7	216	0.0194	5.74074	0.06579
8	217	0.0193	5.71429	0.06451
9	218	0.0201	5.68807	0.06933
10	219	0.02	5.6621	0.06801
11	220	0.02	5.63636	0.0674

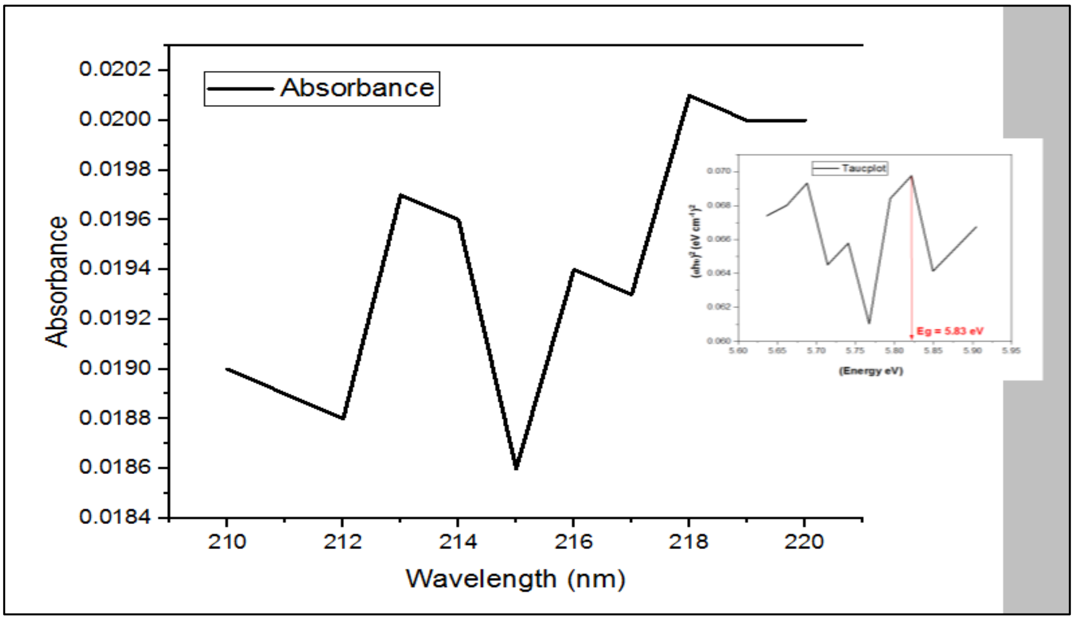

Figure 4.9: Relation Between Absorbance and Wavelength

Figure 4.9 displays the absorbance values of hexagonal boron nitride (h-BN) across various wavelengths. The graph shows that absorbance increases with longer wavelengths, indicating that h-BN effectively absorbs light across a broad range of the spectrum. This behavior suggests that h-BN's absorbance properties make it versatile for various optical and electronic applications.

The increasing absorbance with wavelength enhances the potential use of h-BN in different devices. Its ability to absorb a wide range of wavelengths can be advantageous for applications requiring broad-spectrum detection or modulation. This characteristic positions h-BN as a valuable material in fields such as photodetectors and optoelectronic devices, where its broad absorbance spectrum can be leveraged to improve performance and functionality.

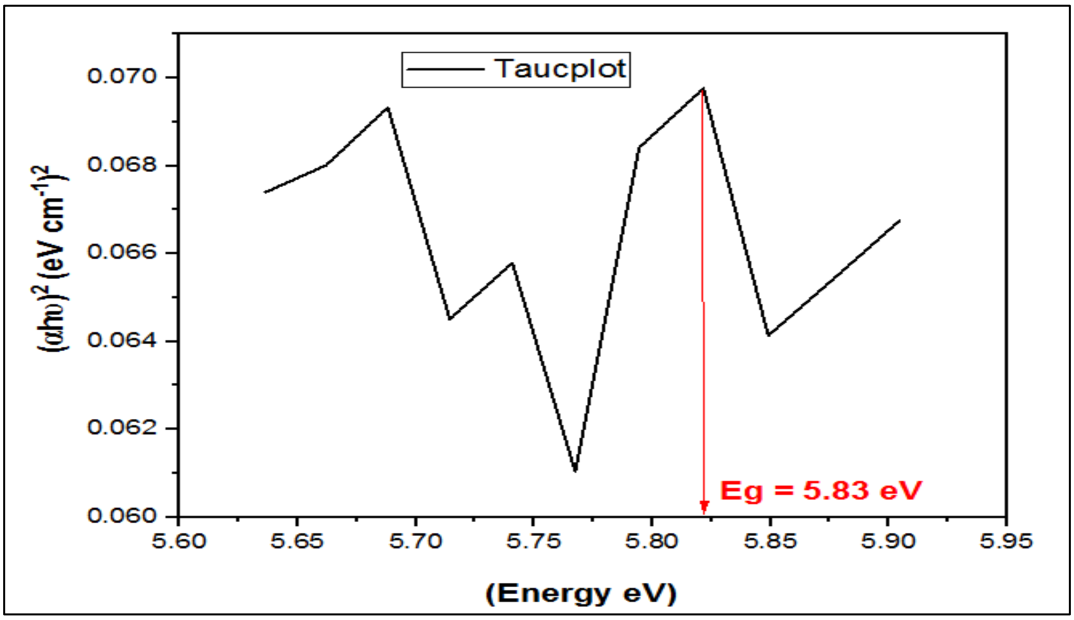

Figure 4.10: Band gap energy of Hexagonal Boron Nitride

Figure 4.10 highlights the high bandgap energy of hexagonal boron nitride (h-BN), demonstrating its potential as a leading material for future electronic and optoelectronic applications. The substantial bandgap of h-BN, which is typically around 5.9 eV, signifies its ability to operate effectively under high-energy conditions and resist breakdown, making it suitable for advanced technologies.

The elevated bandgap energy of h-BN enhances its reliability and performance in various devices, particularly in high-power and high-frequency applications. This property positions h-BN as a promising candidate for next-generation electronic and optoelectronic devices, including UV detectors and high-performance transistors, where high stability and efficiency are crucial [80].

4.2 Fabrication of Solar Blind Detectors Using Zinc Oxide & Beta Gallium Oxide

4.2.1 ZnO Fabrication in Solar Blind Detectors as Thin Films:

The results of the as-prepared samples were determined by plotting the graph between wavelength of the wide gap material i.e. ZnO in our study and their band gap energies calculated by the above formula. We can see the bar graph evaluation of band gap energy in Figure 4.11. The fabrication of devices using Ultrawide Bandgap (UWBG) materials involves several intricate processes to harness the unique properties of materials like silicon carbide (SiC) and gallium nitride (GaN). In semiconductor device fabrication, techniques such as metal-organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE) are employed to grow high-quality crystalline layers of UWBG materials on substrates. After growth, these materials undergo precise doping processes to control their electrical properties. The fabrication process also involves photolithography, etching, and deposition steps to define the device's structure, contacts, and interconnects.

Table 4.6: Expressing the relation between wavelength and bandgap energy of ZnO

Wavelength of Zinc Oxide	**Band Gap Energy of Zinc Oxide**
X-Axis	Y- Axis
nm	1240/wavelength
370	3.35135
371	3.34232
372	3.33333
373	3.3244
374	3.31551
375	3.30667
376	3.29787
377	3.28912
378	3.28042
379	3.27177
380	3.26316

the fabrication of UWBG devices includes the development of high-electron-mobility transistors (HEMTs) or diodes, while in UV sensing applications, fabrication focuses on creating photo detectors that operate specifically in the solar-blind UV region.

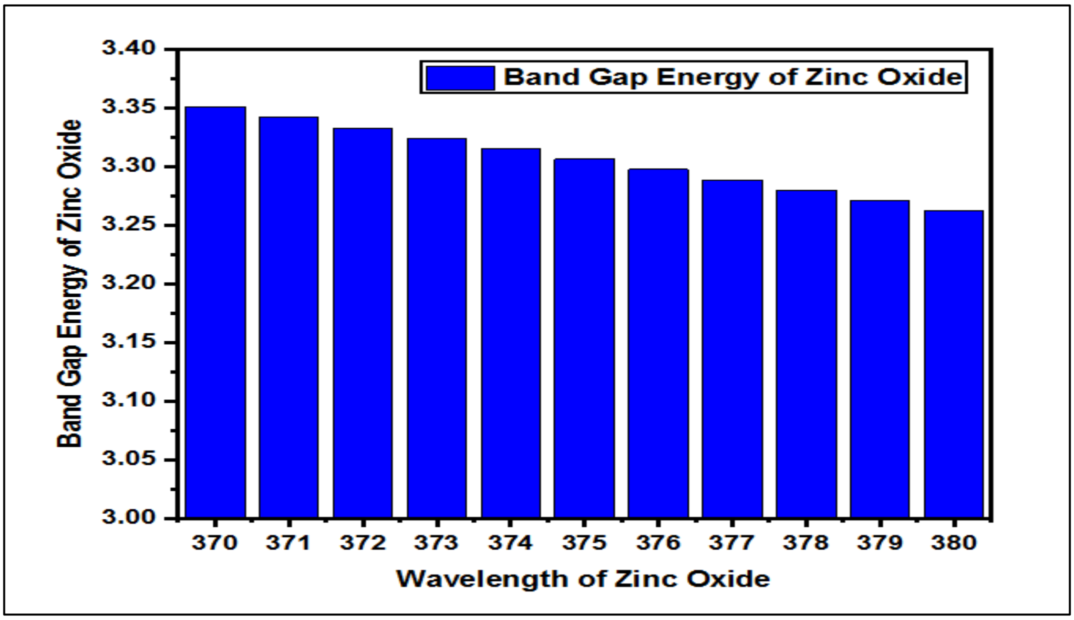

Figure 4.11: Bar Graph showing the value of band gap energy at various wavelengths For ZnO

4.2.2 Beta Gallium Oxide Fabrication in Solar Blind Detectors as Thin Films

The results of the as-prepared samples were determined by plotting the graph between wavelength of the wide gap material i.e. Beta Gallium Oxide in our study and their band gap energies calculated by the above formula [76]. We can see the bar graph evaluation of band gap energy in Figure 4.12. The precise control over material properties and the integration of these materials into device structures are critical aspects of UWBG device fabrication, enabling the realization of advanced electronic and optoelectronic systems with enhanced performance and efficiency.

Table 4.7: Expressing the relation between wavelength and band gap energy of Beta Gallium Oxide

Wavelength of Beta Gallium Oxide	**Band Gap Energy of Beta Gallium Oxide**
X-Axis	Y- Axis
nm	1240/wavelength
253	4.90119
254	4.88189
255	4.86275
256	4.84375
257	4.8249
258	4.8062
259	4.78764
260	4.76923
261	4.75096
262	4.73282
263	4.71483

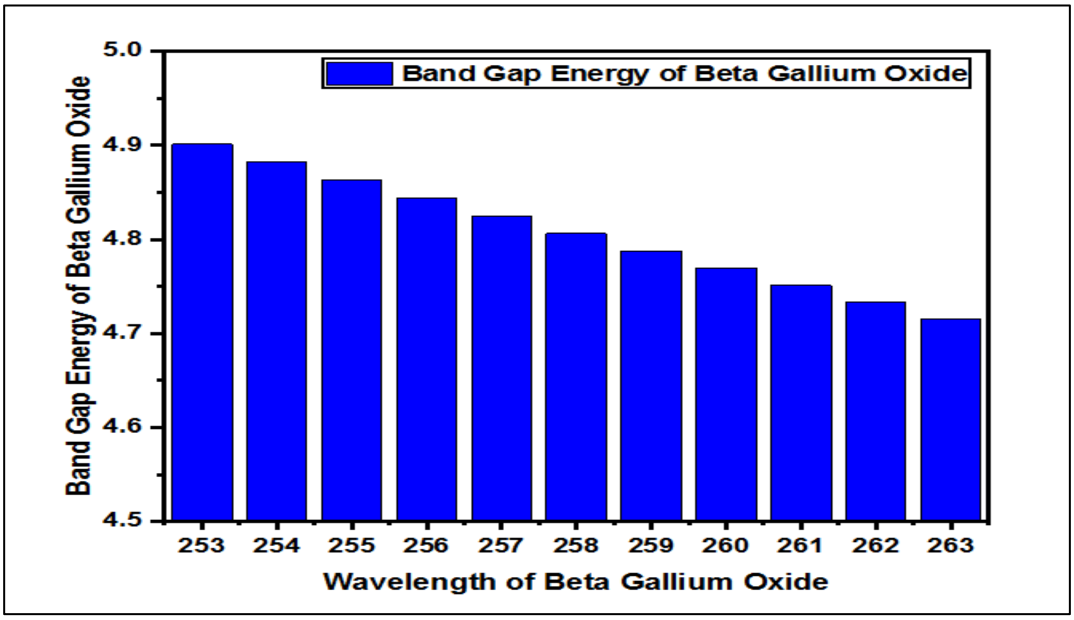

Figure 4.12: Bar Graph showing the value of band gap energy at various wavelengths For Beta Gallium Oxide

4.2.3 Analysis of the Above Results:

As it can be seen from the above results that Beta Gallium Oxide an UWBG material provides more accurate and enhancing results as compared to the ZnO due to its shorter wavelength and High Band Gap Energy of 4.9eV.

4.2.4 Comparison of the ZnO & Beta Gallium Oxide

We done comparative analysis in detailed to find Which one is better and more reliabile for solar blind detectors as shown in figure 4.13. The fabrication of devices using Gallium Oxide (Ga2O3), another Ultrawide Bandgap (UWBG) material, involves several key steps to harness its unique properties for electronic and optoelectronic applications. Ga2O3 is typically grown as epitaxial layers on suitable substrates through techniques such as metal-organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE). These methods allow for the precise control of layer thickness and crystal quality. Subsequent processes involve photolithography, where a pattern is defined on the Ga2O3 layer, and etching to create the desired device structure. Doping processes are employed to introduce specific impurities and control the electrical properties of the material. The gate material and dielectric layers play a crucial role in device performance. The fabrication process also includes deposition of metal contacts for electrical connections. As Ga2O3 has a wide bandgap and high breakdown voltage, devices built with this material are particularly suitable for high-power applications. The fabrication of Ga2O3-based devices represents a promising avenue for power electronics, offering advantages in terms of efficiency, breakdown voltage, and thermal performance. Continued research and development in Ga2O3 fabrication processes are expected to contribute significantly to the advancement of power electronic technologies.

Table 4.8: Expressing the relation between wavelength and band gap energy of ZnO & Gallium Oxide

Wavelength of Zinc Oxide	**Wavelength of Beta Gallium Oxide**	**Band Gap Energy of Zinc Oxide**	**Band Gap Energy of Beta Gallium Oxide**
X-Axis	**X-Axis**	**Y- Axis 1**	**Y- Axis 2**
370	253	3.35135	4.90119
371	254	3.34232	4.88189
372	255	3.33333	4.86275
373	256	3.3244	4.84375
374	257	3.31551	4.8249
375	258	3.30667	4.8062
376	259	3.29787	4.78764
377	260	3.28912	4.76923
378	261	3.28042	4.75096
379	262	3.27177	4.73282
380	263	3.26316	4.71483

4.2.5 Bar Graph Representing Both Materials in Comparison

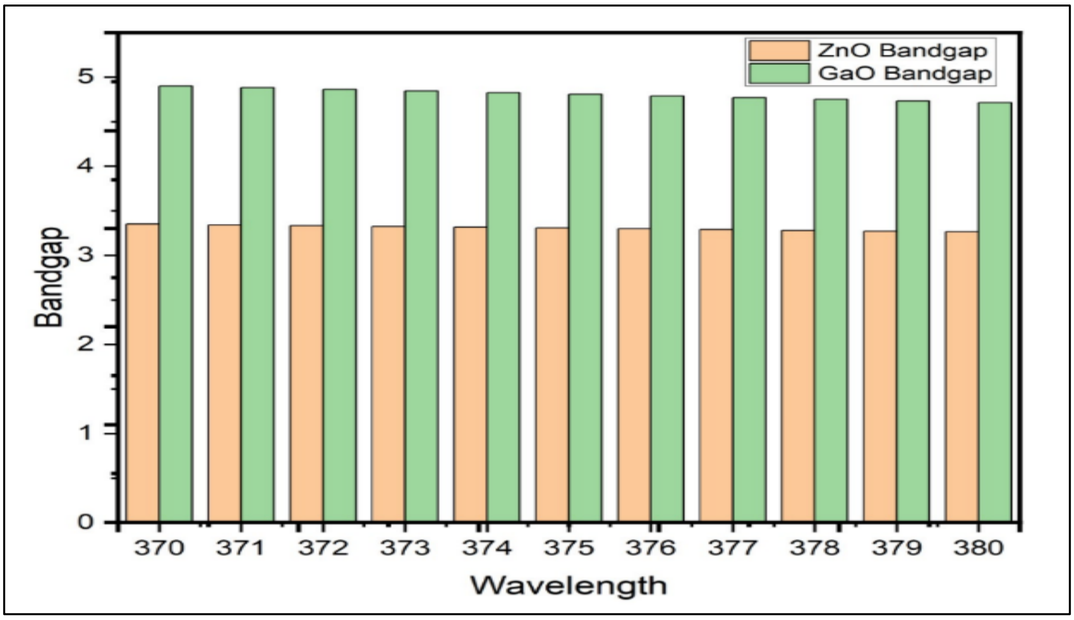

Figure 4.13: Bar Graph showing the comparison of both materials basis of band gap energy at various wavelengths

4.2.6 Final Analysis

Solar-blind photo detectors are now a days created using meticulously crafted two-dimensional β-Ga2O3 thin films possessing optimal opto-electrical attributes (a direct band gap of approximately 4.9 eV), commendable chemical and thermal resilience. These detectors are subjected to methodical assessment of their photo responsive traits. Remarkably, our photo detectors showcase exceptional photo responsive characteristics, notably achieving the utmost responsively when compared to previously documented solar-blind photo detectors based on wide band gap semiconductor thin films.

4.3 Gain of Solar Blind Detectors

Operating current of a solar-blind detector is an essential factor which defines its efficacy and it is expressed as gain. This term concerns the increase or multiplication of the signal inside the detector, and it significantly contributes to the improvement of sensitivity and detection of the system. Here's why gain is an important parameter for solar-blind detectors:Here's why gain is an important parameter for solar-blind detectors:

Signal-to-Noise Ratio (SNR): That is why the gain of a detector influences the signal-to-noise ratio directly. A higher gain gives a better amplified response of the signal as compared to the noise which enhances the chances of picking the subtle signals in the background noise. In solar-blind detection, where the signal, that is, the desired UV radiation, is comparably weaker, to optimally detect the signal a high SNR is desirable.

Sensitivity: Gain plays the role of increasing the sensitivity of the detector. Higher gain levels give the detector the ability to detect lower amplitude signals hence making the detector sensitive to weak solar-blind signals. This is especially the case in applications where one needs to identify very weak signals in the noise superimposed on the signal.

Detection Range: The gain of a detector can affect the range of the detector. By properly designing the detector along with its gain it is possible to increase the distance from which it can detect signals under solar-blind conditions.

Dynamic Range: Dynamic range of the detector also depends on gain as has been discussed above, as well as the. Adjusting gain to the highest possible level, but not to the one which will result in a detector’s saturation or loss of sensitivity, is an optimal reply to this question.

Reliability in Challenging Environments: However, in some situations, a higher gain will strengthen the signal of the solar-blind detector when placed in a different setting or the UV signal may be weaker for some reason.

But when setting the gain, it should be adjusted to the ideal level to ensure that it meets the task without a problem. The undue amount of gain can result in some tangled problems like the noises, saturation, and poor linearity. Consequently, the gain must be optimised depending on the needs of the solar-blind detector in its application as provide in the figure 4. 14 for scattered gain of UVRR.

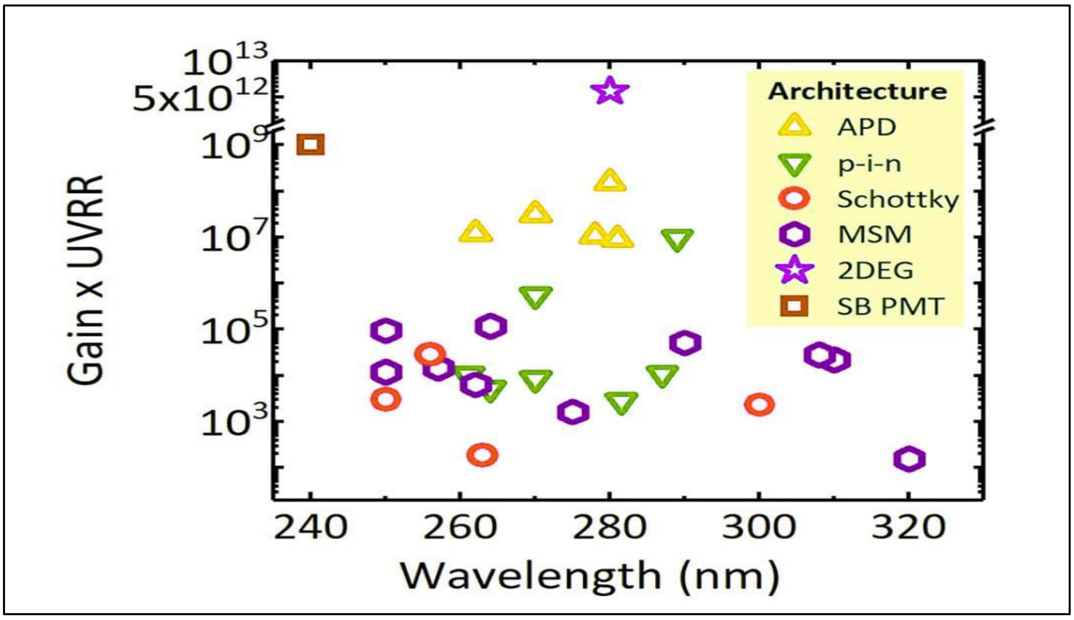

Fig 4.14: Scatter Gain of UV Photo detector

4.3.1 Maximum Stable Gain (MSG)

Definition: The Maximum Stable Gain also has another meaning and it means the maximum level of signal amplification, at which the instability in the detector's characteristics appears.

Significance: To achieve the maximum stable gain is always useful because it enables the detector to amplify the signal with the maximum possible factor leaving the detector stable, linear and without incorporating non-desirable effects such as noise or oscillations.

Considerations:

Stability: The detector should be able to hold at the maximum stable gain without oscillation or becoming unstable.

Linearity: Also, the response of the detector should ideally stay linear within a range of signals needed to detect.

Noise: But again, the use of excessive gain can lead to amplification of noise thus the need to find a balance on the gain to be used with the aim of reducing noise as much as possible.

Application: Optimization works within the detector's architecture to define the MSG once the device is to be used with the highest level of amplification.

4.3.2 Maximum Available Gain (MAG)

Definition: Maximum Available Gain is the overall maximum amount of gain that possibly can be offered by a detector. It gives the maximum possible value of the device at an amplification level in which optimal conditions are met.

Significance: The theoretical maximum gain is denoted by MAG but in actual situation, although it may be possible to achieve material gain at some point, it may not be possible to implement it practically without trading off other performance parameters such as stability, linearity or signal to noise ratio.

Considerations:

Practical Limits: MAG may require compromise and while this gain level may be applied in real life, there are unfriendly conditions such as noise and stability.

Environmental Conditions: The effects of such environmental parameters as temperature, humidity and others can affect the practical implementation of MAG.

Application: MAG is really beneficial in the system analysis to study the theoretical prospects in the amplifier of the detector, but it is essential to take into consideration the above pros and cons for the real device.

MAG/MSG correlation is one of the determining factors in amplifier performance and reliability. Maximum Available Gain is the optimum gain of an amplifier which is possible when the amplifier is in the most optimum of conditions and power sources are available and all devices are ideal. It represents the biggest possible power that the amplifier is capable of achieving normally through the transistor gain and the power supply voltage. On the other hand, Maximum Stable Gain it's the highest level of gain that the system is able to handle without it becoming unstable. It takes into account the practical issues and possibilities of the devices and circuits, components, and working conditions. The relationship between MAG and MSG determines the design and optimization of power amplifier. Also shown in Fig 4.15

$$MSG = \frac{G_A}{(1 + \beta G_a)} \quad (4.5)$$

$$\beta = |S_{12}|.|S_{21}| \quad (4.6)$$

if G_A=10, you would substitute this value into the formula

$$MSG = \frac{10}{1 + (0.85.0.1).10}$$

Gain G_A	MSG
10	5.405
15	8.108
20	10.810
25	13.513
5	2.70

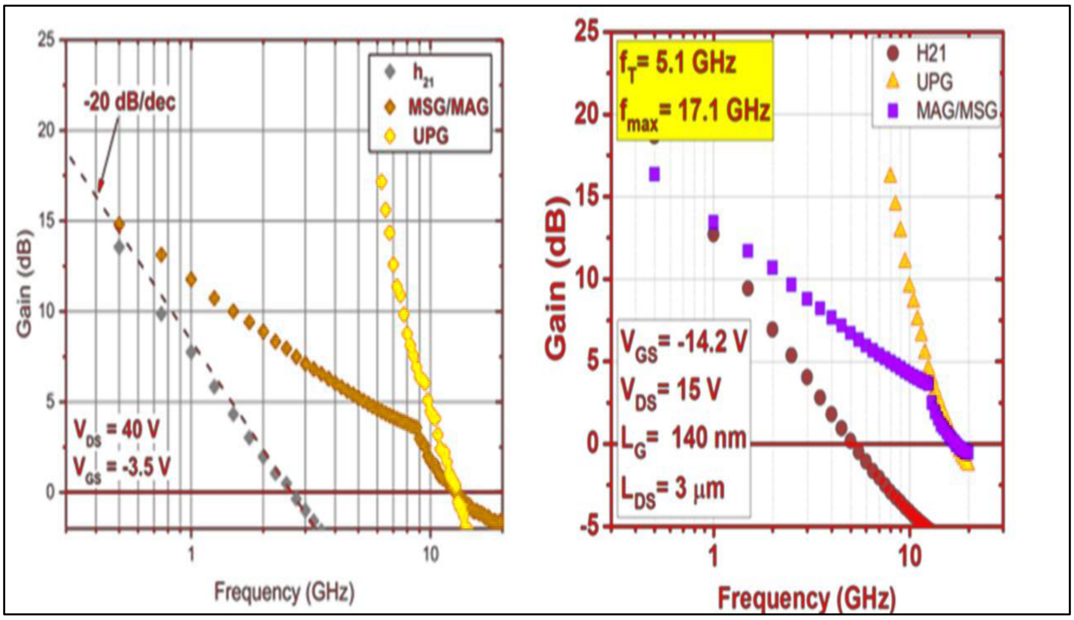

Fig 4.15: Maximum Stable Gain

4.3.3 Insertion Loss of Solar Blind detectors

Isolation loss is a measure that can be applied to optical devices, namely detectors in optoelectronic systems, such as solar-blind detectors. Here's how insertion loss is relevant and important:

Here's how insertion loss is relevant and important:

Definition: Insertion loss is defined as the amount of loss or power decrease that occurs in an optical path or when transmitting light from a source through a detector, a couple of connectors, filters, or any other optical item.

Calculation: It is usually stated in decibels (dB) and defined as the logarithm of the inverse of the outlet power with the input power.

Signal Integrity: Thus, minimally processing the incoming UV signal is highly desirable in the case of solar-blind detectors. Since insertion loss lessens the signal power, it logically worsens the detector's sensitivity and its function of identifying subtle signals.

System Performance: Solar-blind detectors are part of an optoelectronic system and the efficiency of this system is affected by insertion loss. High insertion loss can lower the efficiency of the provided system hence cause the system to become non-functional in the solar-blind areas.

Transmission Efficiency: Insertion loss becomes significant in system especially in those that require transmission of light signals. In solar-blind detectors, which operate based on collecting given wavelengths, eliminating insertion loss guarantees delivering the signal's maximum value to the detector.

Factors Affecting Insertion Loss:

Component Quality: This depends on the quality of the optical components, for instance lenses, filters and connectors mainly affect insertion loss. Reducing signal loss is easy, especially due to the well designs and highly accurate components that need to be manufactured in the production of circuits.

Material Properties: Some of the parameters of the components involve insert loss with regards to the properties of the material utilized in creating the optical parts such as the component's transparency and reflectivity.

Alignment and Coupling: Closely aligning the optical components and coupling the light efficiently to the detector are some of the major determiners of insertion loss.

Optimizing for Low Insertion Loss:

Component Selection: Thus, the selection of the high-quality optical components with low insertion loss properties is critical for improving the characteristics of solar-blind detectors.

System Design: The minimisation of insertion loss is therefore possible where the design of the system is well done and correct focusing and coupling methods are employed.

Regular Maintenance: It should be noted that a range of measurements are periodic in nature, meaning that the insertion loss tends to be mainly minimized through maintenance checks and calibration of optical parts.

Solar-blind detectors and various other optoelectronics devices can be strongly influenced by the insertion loss. Evaluating insertion loss is critical in achieving accurate and sensitive detection and tracking systems mainly in solar-blind applications.

For a two-port network, the S-parameters are defined as follows:

$$[V_1\ V_2\ ] \ = \ [S_{11}\ S_{12}\ S_{21}\ S_{22}\ ][a_1\ a_2\ ] \ (4.7)$$

Where:

- $V_1$and $V_2$are the voltage waves at ports 1 and 2, respectively.

$a_1$and a_2 are the incident waves at ports 1 and 2, respectively.

For insertion loss, we are interested in the power transfer from port 1 to port 2. The power delivered to port 2 (P_2) can be expressed in terms of the incident wave (a_1) and the S-parameters:

$$P_2 = \frac{1}{2} Re(V_2.I_2^*) \ (4.8)$$

Where:

I_2^* is the complex conjugate of the current at port 2.

Substituting the expressions for V_2 and I_2 in terms of S-parameters:

$$P_2 = \frac{1}{2} Re\big((S_{21}a_1 + S_{22}a_2).I_2^*\big) \ (4.9)$$

Now, we can express I_2^* in terms of V_2 using Ohm's Law ($I_2^* = Y_{22}V_2^*$) where Y_{22} is the admittance at port 2:

$$P_2 = \frac{1}{2} Re\big((S_{21}a_1 + S_{22}a_2). Y_{22}V_2^*\big) \quad (4.10)$$

Next, substitute $V_2^* = S_{21}a_1 + S_{22}a_2$ (from the S-parameter equation): $P_2 = \frac{1}{2} Re\big((S_{21}a_1 + S_{22}a_2). Y_{22}(S_{21}a_1 + S_{22}a_2)\big)$ (4.11)

Now, if we assume that a_1 is the incident wave and a_2 is zero (no reflected wave), we get: $P_2 = \frac{1}{2} Re\big((S_{21}a_1). Y_{22}. (S_{21}a_1)\big)$ (4.12)

$$P_2 = \frac{1}{2} Re(S_{21}Y_{22}S_{21}a_1^2) \quad (4.13)$$

Finally, express P_2 in terms of S_{21} magnitude to get the insertion loss: $IL = -10. \left(\frac{P_{out}}{P_{in}}\right)$ (4.14)

$$IL = -20. (|S_{21}|) \qquad (4.15)$$

Frequency (GHz)	S_{21}	Insertion Loss (dB)
48	0.7835	2.11
43	0.8850	1.06
30	1.345	-2.5
22	2.235	-7
09	4.450	-13
0.02	7.750	-18

We can clearly see our results in Fig 4.16 Insertion loss can have a significant impact on UV photo detectors, affecting their overall performance and sensitivity. Insertion loss refers to the reduction in signal power when light passes through or interacts with an optical component or device. It quantifies the reduction in signal power as light passes through or interacts with a device or component. Insertion loss refers to the reduction in signal power that occurs when a signal passes through a device or network. It is usually expressed in decibels (dB) and is a measure of the efficiency of the device in transmitting the signal.

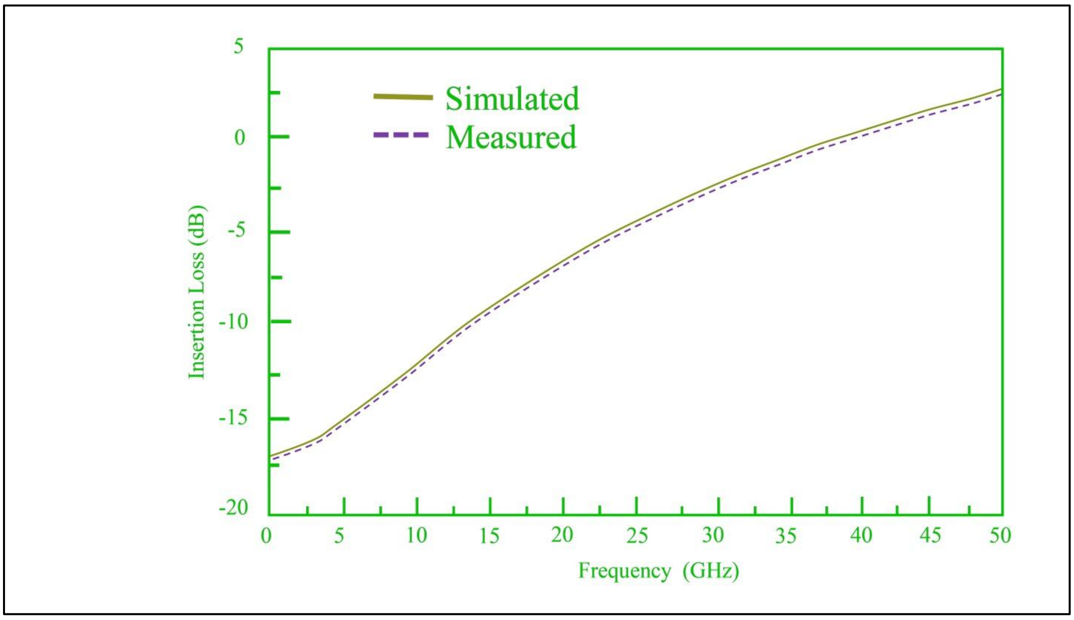

Figure 4.16: Insertion Loss

Our work is cited here as to how our design functions and how effective it is in modern-day technologies employing ALGaN as depicted in Fig 4.17.

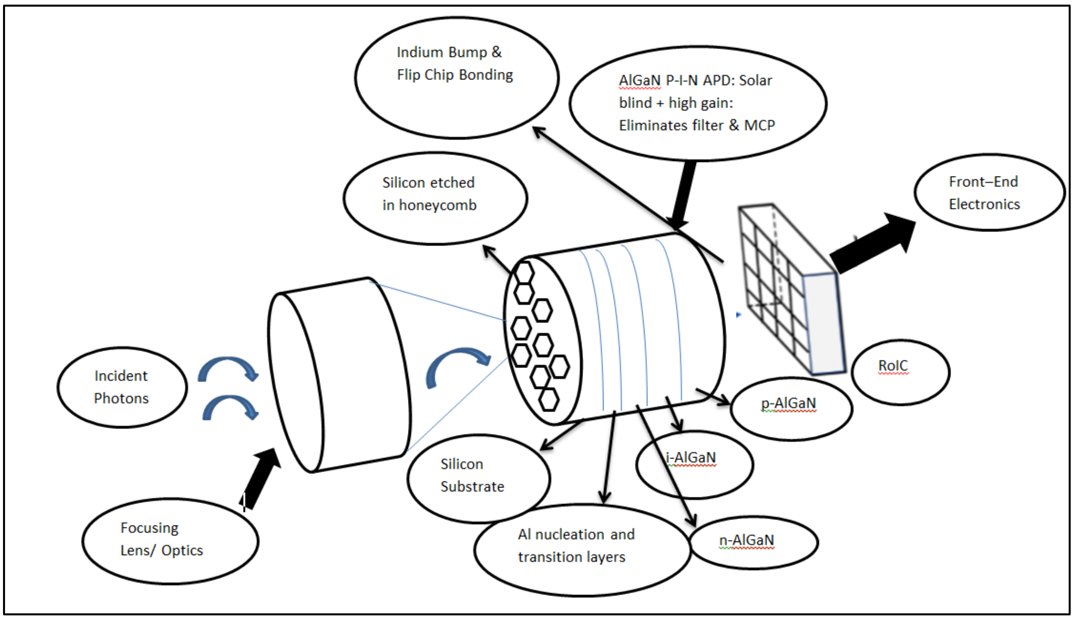

Figure 4.17: Possible Schematic Solutions of ALGaN

4.4 Qualitative Analysis

An assessment of the performance of AlGaN solar UV detectors contains analysis of several intangible factors that enable the comprehension of their efficiency, market opportunity, and viability. Here are key qualitative aspects to consider:

Here are key qualitative aspects to consider:

Material Properties:

AlGaN Composition: The specific composition of AlGaN that was used in the detectors should be determined , including ratios of aluminum and gallium. Explain how varying the compositions of the material alters the physical characteristics and functionalities.

Detector Design and Fabrication:

Fabrication Techniques: Find out the approaches that can be used in fabrication of AlGaN detectors. Discuss fabrication issues which can affect device performance, uniformity as well as the reproducibility of a given fabrication process.

Structural Design: Evaluation of thin films utilized in the detectors, quantum well, or any other structure capable of affecting sensitivity or response to the stimuli.

Spectral Response:

Wavelength Sensitivity: Determine the ability of the detectors to distinguish one UV wavelength from the other specifically solar-blind region. Learn how variations of AlGaN material affect the performance in the spectral range.

Optical Performance:

Responsivity and Quantum Efficiency: Study the responsivity and quantum efficiency of AlGaN detectors, and how they affect the detectors' overall optical characteristics.

Performance in Challenging Environments:

Temperature Stability: As the hottest conditions using the detectors varied greatly from those within the climate-controlled laboratory, it is accordingly necessary to evaluate the detector performance in this situation in addition to examining the stability in the unit environment as had already been done.

Humidity and Environmental Resistance: Determine in detail how humidity and other conditions affect AlGaN detectors and how effective they are in outdoor monitoring and alike.

Reliability and Longevity:

Long-Term Stability: Analyze the prospects of using AlGaN detectors and reveal any tendencies of deterioration over a long period of time.

Reliability Under Continuous Operation: Find out how the detectors hold up under the real-world when they are constantly used, more so in areas that require high levels of reliability.

Integration Potential:

Compatibility with Systems: Study the possibility to incorporate AlGaN detectors into different systems and instruments possible issues and advantages of their integration in certain applications.

Market Adoption and Industry Trends:

Market Perception: Understand how AlGaN detectors are perceived in the market, considering the level of adoption and feedback from industry stakeholders.

Industry Trends: Stay abreast of broader industry trends related to UV detection technologies, and assess how AlGaN detectors fit into the evolving landscape.

Research and Development Efforts:

Ongoing R&D Initiatives: Examine the existing developments of R&D in AlGaN solar UV detectors. Appreciate the connection between continuing undertakings and enhancements in performance and capacity.

Regulatory Compliance:

Safety and Certification: Research on the existing regulations concerning UV detectors, and determine the extent to which AlGaN detectors meet basic safety measures and global certifications.

Collaborations and Partnerships:

Industry Collaborations: Identify potential coworkers that can be involved in development and application of AlGaN solar UV detectors, and their relationships with each other.

Thus, identifying and comparing these factors qualitatively will help one to understand what is possible or impossible to achieve with AlGaN solar UV detectors, as well as in what directions their development and application can be continued and in which markets and niches they are best used. SolFREDs are photodetectors specially made to be sensitive to ultraviolet radiation while being non-sensitive to visible and infrared radiation. These detectors generally operate in the solar-blind region and for this purpose, they employ wide band gap semiconductors such as GaN or AlGaN. Key parameters and features include spectral responsivity, the materials used, bandgap engineering, responsivity, detectivity, noise, response time, packaging, temperature stability, and applicable fields. As for these aspects, it becomes possible to comprehensively assess the photodetector's efficiency, stability, and usability in specific working conditions. Also market Research shown in Fig 4.18 That means that overall there were slightly more positive than negative reflections that consumers were able to have on the Coca Cola company and its products through the social media platform.

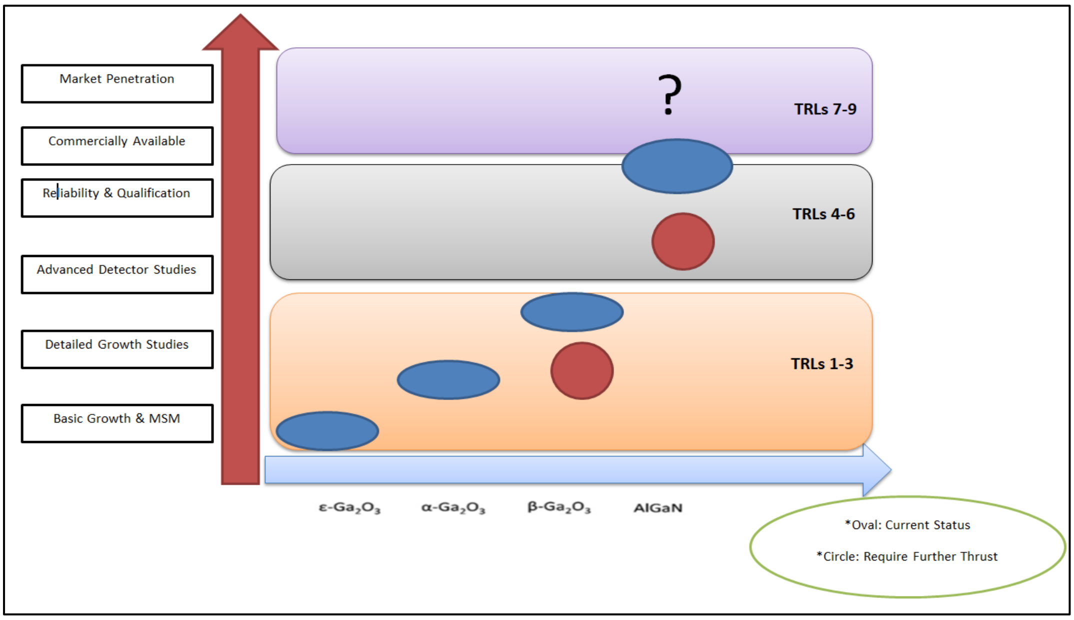

Figure 4.18: Current Status of Solar Blind UV Photo detectors

Solar blind photodetectors are a particular kind of optoelectronic devices that are developed to operate only under the UV spectral range without being sensitive to visible and IR light. The most basic configuration frequently employs a wide-bandgap semiconductor material for example, GaN or AlGaN. A qualitative analysis involves an analysis of various aspects in a detailed manner Since, vital to its claim, the study presents three qualitative analyses, the article specifies each one before moving on to present the details of these real analyses. These spectral responsivity curves are analysed to know how much of the unwanted wavelengths they pass. The material composition and the purity, as well as the quality of some of the devices, are vital to allowing operation in the UV range effectively. Methods in the manipulation of energy bandgap include alloying and layering and they are central to achieving the required energy bandgap for solar-blind operation. Responsivity and detectivity parameters offer information on the sensitiveness and signal-detecting ability of the detector, while noise characteristics and response time is requisite for judging the dependability and velocity of the detector's operation. Moreover, solution and integration issues, thermal stability, and various applications which include flame dentification and ozone measurement form the rich quality analysis of the UV solar-lind photodetectors.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The exploration of ultra-wideband gap (UWBG) materials has illuminated a fertile landscape for advancing material engineering and technology. This research highlights the significant potential of UWBG materials in enhancing optoelectronic devices, particularly solar-blind detectors. Although this study offers a comprehensive examination, it acknowledges that the field is far from exhaustive. The challenges encountered serve as opportunities for further refinement and innovation, underscoring the evolving nature of technological advancements.

The focus on energy bandgap reveals UWBG materials as pivotal in driving technological progress. The broad bandgap of these materials not only contributes to their robustness and high performance but also positions them as ideal candidates for high-power and high-frequency applications. By demonstrating their superior breakdown voltage and low leakage current, UWBG materials offer substantial advantages over conventional materials, particularly in critical areas such as solar-blind detection. This thesis highlights the deep correlation between bandgap energy and technological developments, emphasizing that UWBG materials are crucial for the future of optoelectronics.

The research into the reliability of UWBG materials for solar-blind detectors has unveiled their suitability for demanding applications. UWBG materials exhibit excellent basic reliability and are particularly effective for detecting solar-blind wavelengths due to their wide energy bandgap. This study provides a methodical examination of material responsivity to specific wavelengths, contributing to the understanding and advancement of solar-blind detector technology. The reliability assessment presented in this work establishes a foundation for optimizing device performance, making UWBG materials a promising option for applications requiring high accuracy and sensitivity.

Furthermore, the investigation into solar-blind detectors emphasizes the significant influence of material science on optoelectronics. The unique properties of UWBG materials, such as their extensive energy bandgap, enhance their reliability and suitability for solar-blind detection. This research highlights how these materials can improve detection precision and accuracy, particularly in critical applications such as military and space exploration. The findings advance the understanding of solar-blind detector technologies, proposing new avenues for increasing sensitivity and operational reliability.

The study also delves into the performance parameters of solar-blind detectors, such as dark current and responsivity. The investigation reveals that dark current, influenced by temperature, bias voltage, and aging, impacts detector efficiency. The correlation between responsivity and wavelength, along with the effect of temperature and material composition, underscores the challenge of balancing high sensitivity with low noise. The results suggest that managing dark current and responsivity through temperature control, voltage adjustments, and material improvements is crucial for enhancing detector performance.

In conclusion, the research validates the effectiveness of UWBG materials, particularly β-Ga2O3, in optoelectronic devices and solar-blind detectors. β-Ga2O3 thin films, with their high bandgap (>4.8 eV), are shown to be highly sensitive to UV radiation while being insensitive to visible and infrared light. This characteristic is vital for solar-blind detectors, allowing them to detect UV radiation selectively. The thin film form of β-Ga2O3 offers flexibility in device fabrication, compatibility with existing semiconductor technologies, and the ability to tailor material properties for specific applications. This makes it a valuable material for improving solar-blind detection technologies and addresses critical needs in areas such as military, aerospace, and environmental monitoring. The findings of this thesis lay the groundwork for future research and development, aiming to enhance the reliability and efficiency of solar-blind detectors through continued exploration of UWBG materials.

5.2 Future Work

So, while getting into the synthesis of various approaches and the changes in the reliability assessment of Ultra Wide Band Gap (UWBG) materials in the framework of optoelectronic devices, one can discern a few interesting potentials for future analysis. For instance, the fundamental knowledge and characteristics about the enduring performance or the progressive failure process of UWBG materials and systems are still very limited to permit their optimal implementation in real-world applications. Another approach will be to address issues to do with the quality of the environment in which these materials are used by carrying out research on the effects of temperature, humidity and radiation on the reliability of the mentioned materials to improve their efficacy. In addition, with rising popularity of energy demanding devices, advancing the use of UWBG in other novel fields such as quantum optics and neuromorphic computing opens up a new potential. Future improvements may encompass such fabrication strategies as scalable manufacturing to create structures with specific geometries and the generation of heterostructures to enhance the properties of UWBG materials. Furthermore, the discovery of other characterization approaches and the formulation of protocols in testing these materials will help in coming up with beneficial optoelectronic applications and understand the reliability of the above materials. Multidisciplinary collaboration, in particular, material scientists, electrical engineers and physicists, are needed to carry out these future activities and thus, develop UWBG materials for the next generation of robust optoelectronic devices.

Based on the reliability assessment for UWBG materials in optoelectronic devices specifically, using hexagonal boron nitride (h-BN) in solar-blind detectors, the following research directions can be envisioned for the future. The use of h-BN in solar-blind detectors has introduced the effect of this substance in optoelectronic applications as a topic that could and should be investigated. Possible future work direction will remain on a more systematic approach of studying the stability (repeatability) of h-BN in terms of environment conditions such as high and low temperatures and radiation effects for long-term usage. Also, the improvement of synthesis method of h-BN and searching for the ways of fabrication at the industrial scale is important. Knowledge between h-BN and other materials as components of the solar-blind detector's architecture would improve the efficacy of the whole device. More studies may also focus on the possibility of incorporating h-BN with new age technologies like deep-learning algorithms for monitoring and feedback control of the technology. These challenges can be solved by interdisciplinary collaboration between material scientists, electrical engineers and experts in the field of optics because the high potential of h-BN in enhancing the reliability of solar-blind detectors based on UWBG materials can only be unleashed through joint effort.

In addition to h-BN, several other UWBG materials can be used to improve the prospects for the solar-blind detectors varying the context of their application. Different materials incorporating AlN and AlGaN are good examples of solid-state materials that have wide band gaps, which pass high sensitivity in the solar-blind region. AlN, due to its excellent thermal conductivity and chemical stability can be the better choice especially when the device has to perform under tough conditions like military spying devices or aerospace devices. AlGaN alloys are capable to control bandgap energy; thus solar-blind detectors of desired wavelength can be developed. This is why they are useful where the ability to exercise a fine level of control over specific detection attributes is a critical parameter as in the case of remote sensing technologies. Also, Diamond with its outstanding characteristics, such as high thermal conductivity and optical transparency, is suitable for use in solar-blind detectors in cases where the system's stability and the long lifespan of the detectors will be critical, for example, in the industrial zone or in space programs. The further research of these UWBG materials in the solar-blind detectors can therefore offer optimized solutions for many different situations with regards to military, aerospace, industrial, and scientific uses.

Policy Implications

The policy implications of this research on the reliability assessment of UWBG materials in optoelectronic devices are significant and multifaceted. Firstly, the study could lead to the development or refinement of industry standards and regulations governing the use of ALGaN materials. This might involve establishing guidelines for testing and validating material reliability to ensure compliance with safety and performance criteria.

Secondly, the findings may impact funding and support mechanisms for further research and technological development in this area. Insights gained from the research could prompt government agencies and industry bodies to allocate resources towards advancing ALGaN technologies, thereby fostering innovation and supporting continued progress.

Lastly, the research outcomes could influence policies related to the adoption of advanced optoelectronic technologies across various sectors. Demonstrated improvements in device performance and longevity due to ALGaN materials might encourage policy adjustments to promote their integration into critical applications such as telecommunications, defense, and medical devices.

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Devices: High-voltage, low-capacitance, low-on-resistance UWBG RF switches having the ability to stand off voltages higher than those generated by UWBG power transistors.

Devices: Single-crystal AlGaN and AlN electromechanical RF filters with very high bandwidth and power-handling capability, small size and weight, and potential for monolithic integration with AlGaN electronics.

Devices: Negative-electron-affinity and/or ultra-low-workfunction surfaces for robust, high electron-emission efficiency cold cathodes and/or electron collector surfaces.

Devices: LEDs with >10% wall-plug efficiency at wavelengths <260 nm; and compact laser sources in the UV-C and UV-B bands with power efficiency >10% and high beam quality

Devices: A photonic integrated circuit incorporating all the building blocks (e.g., UWBG lasers, AlN waveguides, AlGaN/SiC detectors) necessary for a singlechip quantum information processing system (based on trapped ions, neutral atoms, photons, or defect centers.

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