

Application of Ultra-Wide Bandgap Semiconductor Ga_2O_3 Material in Photodetectors

Zixue Huang

*Institute of Electronic Engineering, XiDian University, Xi'an, China
22022100021@stu.xidian.edu.cn*

Abstract. The rapid development of optoelectronic technology, the demand for high-performance photodetectors in various fields has been continuously increasing. Ultra-wide bandgap materials have attracted significant attention due to their potential to meet the requirements for high-temperature, high-power, and high-speed optoelectronic devices. Among them, Ga_2O_3 , as an emerging ultra-wide bandgap semiconductor material, has shown unique properties and great application prospects. This paper systematically reviews all the unique properties of Ga_2O_3 ultra-wide bandgap materials and also describes its advantages in photodetection applications. It examines the latest progress of Ga_2O_3 photodetectors in many application fields, including military early warning, industrial monitoring, biomedicine, etc. Moreover, this paper conducts a detailed analysis of some breakthroughs in key technologies, such as material epitaxial growth, device architecture design, and performance optimization strategies. This study further presents a prospective analysis of potential future research directions, specifically focusing on enhancing material growth techniques to achieve larger-sized, high-quality Ga_2O_3 single crystals, refining device architectures for improved power handling and faster response times, and exploring novel performance optimization strategies to further reduce dark current and enhance detection sensitivity. Additionally, a systematic review of the main research methods employed in related literature, including experimental characterization, theoretical modeling, and simulation approaches, is provided to offer a comprehensive understanding of the current state and future trends in Ga_2O_3 -based photodetector research.

Keywords: ultra-wide band gap, Ga_2O_3 material, photodetector

1. Introduction

At the market demand level of photoelectric detection technology, the demand for high-performance ultraviolet detectors in various fields is becoming increasingly urgent. In the field of military reconnaissance, the detection of ultraviolet signals in missile tail flares is a key link for the early warning system to function [1]. In industrial safety applications, flame monitoring requires ultraviolet detectors that can operate in harsh environments, but traditional sensors often struggle to meet the requirements in such conditions [2]. In environmental remediation work, the precise quantification of trace pollutants is achieved by analyzing their ultraviolet absorption spectra, which requires detectors to have high sensitivity and excellent selectivity [3]. However, traditional

detectors have many limitations and are difficult to be widely applied in these high-demand scenarios. For instance, the response band of silicon-based detectors is relatively wide, which can introduce visible light interference and thereby affect the detection accuracy [4]. Although GaAs/InGaAs detectors have superior performance, their high cost is not conducive to large-scale deployment [5]. The reliability of INP-based devices declines under high-temperature conditions, which limits their application in extreme environments [6].

In contrast, Ga_2O_3 , with its unique material properties, has become a highly promising candidate material in the field of ultraviolet detection applications. It features an ultra-wide bandgap of 4.8 eV, demonstrating excellent response characteristics to ultraviolet radiation even under direct sunlight [7]. Its breakdown field strength can reach up to 8 MV/cm, enabling it to operate stably in high-voltage scenarios. Meanwhile, its inherent heat resistance enables it to continuously perform at temperatures above 200°C [8]; In addition, Ga_2O_3 also has excellent radiation resistance and is suitable for both spaceborne and nuclear application scenarios [9]. In terms of material growth, advanced technologies such as edge-confined film feed growth (EFG) and hydride vapor phase epitaxy (HVPE) have made significant progress. Among them, EFG technology offers an economical and efficient solution for the production of high-quality Ga_2O_3 single crystals. It is estimated that the cost of 6-inch wafers produced by this technology is approximately 320 US dollars, which is nearly 50% lower than that of the Chaikorski (CZ) method [10]. The HVPE technology can achieve a relatively high growth rate, reaching several micrometers per hour, while maintaining good crystal quality [11]. However, the production of large-sized, high-quality single crystals with a diameter of over 40 inches is still highly dependent on imports, indicating that continuous research is still needed in this field [12]. In terms of device performance, Ga_2O_3 photodetectors based on Schottky junctions have demonstrated outstanding performance, including fast switching speed and high breakdown voltage. Researchers significantly increased the breakdown voltage from approximately 580 V to 2200 V by introducing a magnesium-based current barrier layer (Mg-CBL), while maintaining a low specific on-resistance of $4.8 \text{ m}\Omega \cdot \text{cm}^2$ [13]. These improvements have highlighted the potential of Ga_2O_3 in high-power device applications, further fueling research enthusiasm in this field.

This article will systematically analyze the fundamental principles of Ga_2O_3 , including its unique electronic structure that gives it an ultra-wide bandgap, the physical mechanism behind its high breakdown field strength, and the factors that contribute to its excellent heat resistance and radiation resistance. These properties collectively make Ga_2O_3 a highly promising material for ultraviolet detection applications. On this basis, the application of Ga_2O_3 in photoelectric detection is explored. In terms of material growth, breakthroughs have been made in technologies such as EFG and HVPE, but large-sized (such as 40-inch) high-quality single crystals still rely on imports at present [3]. In terms of device performance, the research focus is concentrated on Schottky junctions.

2. Ga_2O_3 photoelectric detector method, principle, and technical characteristics

2.1. Material preparation method

The EFG approach is employed to control crystallization of high-quality Ga_2O_3 single crystals. This approach allows for continuous crystal pulling via capillary-driven replenishment of molten feedstock to the meniscus region atop a precision-shaped die, resulting in stable growth kinetics and consistent diameter control. Compared to conventional pulling methods, such as the Czochralski (CZ) process, EFG offers faster growth and simpler equipment. It supports the simultaneous growth

of multiple crystals. In a cost analysis, Heinselman et al. estimated that 6-inch Ga_2O_3 wafers produced by EFG cost about USD 320 per wafer, nearly 50% less than CZ-grown wafers [6].

Pre-melting of raw materials in a CO_2 atmosphere facilitates the reduction of impurities such as silicon and iron, thereby enhancing the structural integrity and electrical performance of the resulting crystals. Stabilization of the growth interface and precise control of the pulling rate further contribute to the suppression of crystallographic defects, including twin boundaries. Employing this methodology, $\beta\text{-Ga}_2\text{O}_3$ Crystals grown via the EFG technique have exhibited favorable surface morphology and high thermal and structural stability.

HVPE is a crystal growth method. The method is used to grow Ga_2O_3 materials. It can produce thin films and thick Ga_2O_3 layers. The process allows for a fast growth rate. The rate is higher than that of Metal-Organic Chemical Vapor Deposition (MOCVD) and Molecular Beam Epitaxy (MBE). The growth rate can reach several micrometers per hour. Some studies report even higher rates. The growth remains fast while maintaining good crystal quality. HVPE is suitable for crystal growth. The grown crystal showed (100) orientation. A suitable substrate was used. A single crystal was obtained. The surface was flat. The roughness was about 5 nanometers. The film showed high transparency. Light transmission exceeded 80 percent after the deposition of the $\beta\text{-Ga}_2\text{O}_3$ film, followed by the deposition of a GaP layer. This step formed a heterostructure with GaP on $\beta\text{-Ga}_2\text{O}_3$. The structure was examined by X-ray diffraction and Raman spectroscopy. The results confirmed the structure and its stability [13].

2.2. Device structure design principle

A structure of $\beta\text{-Ga}_2\text{O}_3$ Schottky barrier diode (SBD) with a magnesium-based current blocking layer (Mg-CBL) was proposed to achieve high breakdown voltage and strong power performance [3]. The device is a metal–semiconductor structure, where a rectifying junction is formed by placing a metal contact on n-type $\beta\text{-Ga}_2\text{O}_3$. Fast switching and high breakdown capability are enabled by this configuration. A spin-on-glass process was used to fabricate the Mg-CBL without causing surface damage. With the Mg-CBL, the breakdown voltage increased from approximately 580 V to 2200 V. The specific on-resistance slightly increased from $4.0 \text{ m}\Omega\cdot\text{cm}^2$ to $4.8 \text{ m}\Omega\cdot\text{cm}^2$. The power figure of merit exceeded $1 \text{ GW}\cdot\text{cm}^{-2}$, which can be expressed as [1]:

$$PFOM = \frac{V_{br}^2}{R_{on,sp}} \quad (1)$$

where V_{br} is the breakdown voltage and $R_{on,sp}$ is the specific on-resistance. The high PFOM indicates strong potential for high-power device applications.

The Mg-CBL captures electrons and reduces the peak electric field near the anode. The electric field reduction near the junction can be estimated using the one-dimensional depletion approximation [8]:

$$E_{peak} = \frac{2V_{BR}}{W} \quad (2)$$

where W is the depletion width. Reduction in peak electric field leads to suppressed reverse leakage current.

I–V measurements at various temperatures showed a clear decrease in reverse saturation current. The reverse saturation current I_s follows the thermionic emission model [7]:

$$I_s = AA^* T^2 \exp\left(-\frac{q\Phi_B}{kT}\right) \quad (3)$$

Where A is the contact area, A^* is the Richardson constant, Φ_B is the Schottky barrier height, T is the absolute temperature, q is the elementary charge, and k is the Boltzmann constant.

Furthermore, the Schottky barrier height can be extracted from [7]:

$$\Phi_B = \frac{kT}{q} \ln\left(\frac{A^* T^2}{I_s}\right) \quad (4)$$

A Gaussian model was introduced to describe the barrier inhomogeneity at the metal–semiconductor interface. The model matched well with the measured data and described the changes in diode performance [3].

2.3. Performance optimization strategy

The performance optimization of β -Ga₂O₃ metal–semiconductor–metal (MSM) photodetectors mainly depends on two aspects: device structure and material control. In terms of structure, one study reported that using Ga₂O₃ films with micrometer-scale thickness improves device performance. Such films can form a low-field region, commonly referred to as a “dark zone.” The presence of this region guides carrier movement and enhances the transport efficiency of photo-generated electrons. As a result, the photoresponse becomes stronger and the response time becomes shorter. According to experimental data, a photodetector with this configuration achieved a photo-to-dark current ratio of approximately 10^8 , a responsivity exceeding 1300 A/W, and a detectivity up to 10^{18} Jones [4]. In terms of material control, researchers often introduce electron-trapping layers or modify the interface structure. Modifications include applying thin titanium layers as electrodes or inserting insulating layers between the metal and the semiconductor. In some cases, doping concentrations are adjusted. In other cases, an alternative substrate is selected to improve interface compatibility. These methods contribute to the reduction of dark current and improve carrier separation efficiency. The signal-to-noise ratio also increases under these conditions [4].

2.4. Key performance parameters

The β -Ga₂O₃ metal-semiconductor-metal photodetectors have key performance parameters. These parameters are responsivity, dark current, response time, light-dark current ratio, and detection rate.

Responsivity is one of the performance parameters. It refers to the photocurrent generated per unit of incident light power. A higher responsivity means better detector performance under weak ultraviolet irradiation. It also means a stronger electrical signal. Previous studies show that under specific bias conditions, the responsivity can exceed 1000 A/W [10].

Dark current is another parameter. It refers to the current in a device when there is no lighting. The dark current magnitude directly affects the detector's noise level and sensitivity. Experimental

results show that by optimizing the electrode spacing and treating the surface, dark current can be kept within picoamps to nanoamps.

Response time is also a parameter. It refers to the time a device takes to reach a stable output after lighting starts. It also refers to the time for the current to decrease after lightning ends. Response time includes rise time and falling time. A shorter response time means a faster reaction to light changes. In most reported experiments, the response time is at the microsecond level.

The light-dark current ratio is a parameter, too. It measures the current difference between the illuminated and non-illuminated states. A higher ratio means stronger switching characteristics. Many studies show that this ratio can reach or exceed 10^{26} [13].

Detection rate is a comprehensive indicator. It combines response rate and noise current. Detection rate is generally expressed in Jones, with the unit of $\text{cm} \cdot \text{Hz}^{1/2} / \text{W}$. A higher detection value means better detector performance under weak light conditions. The experimentally measured detection value is greater than 10^{15} Jones [8].

2.5. Device classification and characteristic comparison

Table 1 summarizes the key performance parameters of $\beta\text{-Ga}_2\text{O}_3$ -based photodetectors fabricated using different device structures. The different device structures mentioned here include metal-semiconductor-metal, Schottky barrier diodes, and p-n or p-i-n structures. This article compares parameters such as response rate, dark current, response time, ratio of light to dark current, and detection rate. MSM photodetectors generally have A relatively high responsiveness, reaching (up to 1300 A/W [6]. Their dark current is relatively low, ranging from 10^{-12} to 10^{-9} A [11]. Their response time is very fast, reaching the microsecond level. The SBD structure shows a relatively lower dark current and relatively high detectivity, with a detectivity of up to 10^{18} Jones. Pin-type devices exhibit an excellent light-to-dark current ratio, and their detection capability exceeds 10^{15} [9]. However, their response times vary, ranging from microseconds to milliseconds. These comparisons clearly show that there are trade-offs among various device architectures and can also provide some guidance for choosing the appropriate structure based on specific application requirements.

Table 1. Key performance parameters of $\beta\text{-Ga}_2\text{O}_3$ -based photodetectors with different device structures

Device Type	Responsivity (A/W)	Dark Current (A)	Response Time	Photo-to-Dark Ratio	Detectivity (Jones)
MSM [4]	100-1300	$10^{-12} - 10^{-19}$	$\sim \mu\text{s}$	$10^4 - 10^6$	$10^{13} - 10^{15}$
SDB [5]	100-800	10^{-12}	$\sim \mu\text{s}$	$>10^5$	$10^{14} - 10^{18}$
P-N / PIN [6]	10-500	$10^{-15} - 10^{-12}$	$\mu\text{s} - \text{ms}$	$>10^6$	$>10^{15}$

3. The relationship and optimization between material characteristics and photodetector performance

3.1. The correlation between material properties and device performance

The photoelectric performance of $\beta\text{-Ga}_2\text{O}_3$ -based photodetectors is primarily determined by the band structure and carrier transport properties of $\beta\text{-Ga}_2\text{O}_3$. A wide bandgap of around 4.8 eV enables strong absorption in the deep ultraviolet region and suppresses visible-light sensitivity [7]. Different crystal orientations introduce anisotropic band dispersion, which affects carrier excitation rates.

As shown in Figure 1, which displays the electronic band structure of $\beta\text{-Ga}_2\text{O}_3$ aligned at the Fermi level zero, we can observe the detailed energy levels and band dispersion. The conduction band minimum and valence band maximum exhibit variation under an external field, reflecting internal band bending and anisotropy. This internal band bending and anisotropy play a crucial role in enhancing UV absorption and charge separation. The specific arrangement of energy bands, as depicted in Figure 1, provides a clear visualization of how the electronic structure of $\beta\text{-Ga}_2\text{O}_3$ supports its excellent photoelectric characteristics, which are essential for high-performance photodetectors [7].

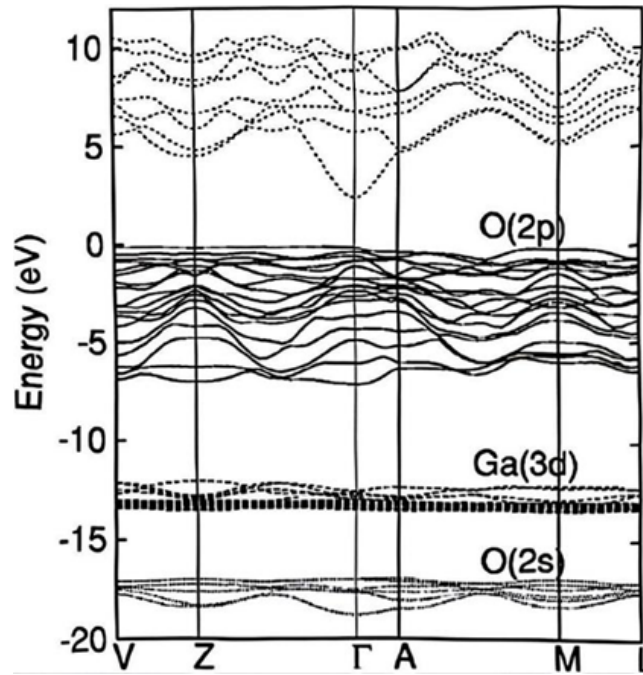


Figure 1. Electronic band structure of $\beta\text{-Ga}_2\text{O}_3$ with Fermi level at zero [7]

Carrier dynamics in heterojunctions are critically affected by band alignment, interface states, and optical excitation conditions. Optimized $\text{Ga}_2\text{O}_3\text{-GaN}$ interfaces with minimal defect density facilitate efficient carrier transport and suppress recombination losses. Figure 1 presents the energy band diagrams of a $\text{Ni/Au-Ga}_2\text{O}_3\text{-GaN}$ heterojunction under dark conditions and 262 nm and 365 nm illumination [7]. Ultraviolet excitation induces photo-generated carriers and modifies the band bending, promoting carrier separation and enhancing photocurrent response. The distinct response to different wavelengths highlights the wavelength-selective detection capability of the device [8].

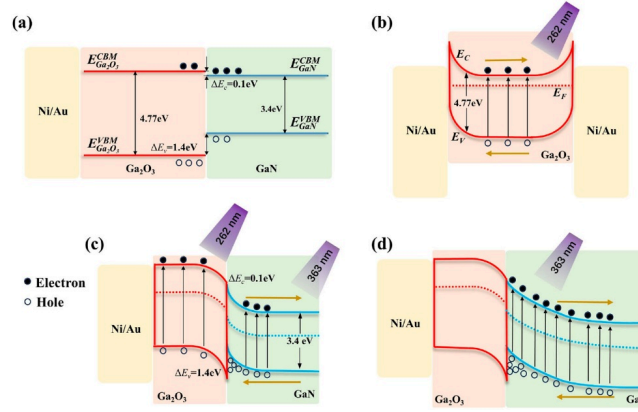


Figure 2. Band diagrams of Ni/Au-Ga₂O₃-GaN heterojunction under illumination [8]

Interface and contact engineering play a pivotal role in optimizing carrier collection under optical excitation. As shown in the PtO_x/β-Ga₂O₃ Schottky structure (refer to Figure 2(b)-(d)), the formation of an interfacial dipole significantly increases the barrier height at the metal–semiconductor junction. The specific sub-figure can be adjusted according to the actual context. Here, we assume a general reference to Figure 2.

Taking a closer look at Figure 2, for instance, in the relevant energy-band-related sub-figures (such as those showing energy band alignments at different interfaces), we can see the detailed energy band configurations. The enhanced barrier effectively promotes unidirectional carrier transport and substantially suppresses leakage current under ultraviolet illumination.

The corresponding energy band diagram (presented in Figure 2) reveals how the combined effects of elevated Schottky barrier height and band bending enable selective carrier flow and improve photoresponse stability. For example, in the energy band diagrams of Figure 2, we can observe how the energy levels at the interface change, which directly affects the movement of electrons and holes.

The specific energy differences (such as ΔEc and ΔEv shown in Figure 2(a) and (c)) and the overall band-bending profiles are crucial for understanding the carrier transport mechanisms. These visual representations in Figure 2 help us to better comprehend how the interface and contact engineering contribute to the improved performance of β-Ga₂O₃-based photodetectors [10].

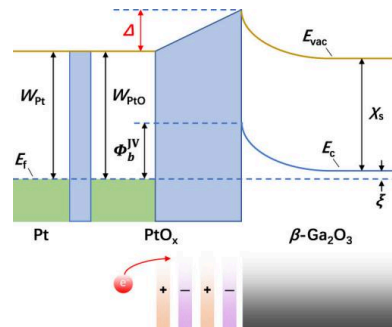


Figure 3. Energy band alignment at PtO_x/β-Ga₂O₃ interface [9]

In the research of photodetectors based on β-Ga₂O₃, the interface characteristics between metals and semiconductors play a decisive role in the performance of the devices. As shown in Figure 3, it presents in detail the schematic diagram of the Pt/PtO_x/β-Ga₂O₃ interface.

From this figure, the band arrangement at the interface can be observed, where the work function of Pt (W_{Pt}), the work function of PtO youdaoplaceholder6 (W_{PtO}), and the built-in potential at the interface are clearly marked. The band diagram on the right side of Figure 3 shows the positions of the vacuum energy level (E_{vac}), conduction band edge (E_c), and Fermi energy level (E_f) in β -Ga₂O₃, and also marks the electron affinity potential (χ_s) of β -Ga₂O₃.

The PtO <s:1> layer formed at the Pt/ β -Ga₂O₃ interface will cause changes in the band structure. The built-in electric potential Φ_b^{IV} generates an electric field at the interface, which will affect the transport of carriers. As indicated by the red arrow at the bottom of Figure 3, the movement of electrons is affected by this electric field. This electric field induced by the interface can effectively separate photogenerated electron-hole pairs, thereby improving the photoresponse performance of the detector.

In addition, as shown in Figure 3, the band bending near the interface plays a significant role in regulating the flow of carriers. It can prevent the recombination of electrons and holes, thereby enhancing the quantum efficiency of the photodetector. The detailed band information provided in Figure 3 helps us better understand the intrinsic working mechanism of the photodetector based on Pt/PtO youdaoplaceholder0 / β -Ga₂O₃ and provides guidance for further optimizing the device structure.

3.2. Device design and performance optimization strategy

The selection of junction type has a very fundamental and crucial impact on the electrical and photoelectric properties of photodetectors based on β -Ga₂O₃. Schottky junctions are generally formed by depositing metal contacts on N-type β -Ga₂O₃. Due to the presence of an inbuilt field at the metal-semiconductor interface, they are relatively easy to manufacture. The response speed is also relatively fast. However, Schottky junctions have the problem of limited uniformity of barrier height and relatively high dark current. These conditions can reduce the sensitivity of the device. Unlike Schottky junctions, heterojunctions formed by the combination of β -Ga₂O₃ and wide bandgap P-type materials, such as those formed by the combination with GaN or NiO, this heterojunction will introduce a stronger built-in electric field and better band alignment, which helps improve the separation of carriers and reduce leakage current. Compared with Schottky paired devices, β -Ga₂O₃/NiO heterojunction photodetectors exhibit lower dark currents and higher responsiveness to ultraviolet light. This is because they have a stronger interfacial electric field and can also suppress surface states [10].

In addition to junction engineering, surface passivation is an effective strategy that can reduce the density of surface states and enhance the stability of devices. There are high-density trap states near the β -Ga₂O₃ surface, which mostly act as recombination centers and can lead to a decline in device performance over long-term operation. There are various dielectric materials, such as Al₂O₃ and SiO₂, which have been used as passivation layers to mitigate these adverse effects. After the application of atomic layer deposition of Al₂O₃ coatings on β -Ga₂O₃ MSM photodetectors, the dark current has been significantly reduced. It also improved the time response. The passivation layer can act as a physical barrier and chemical stabilizer on the surface, which helps to enhance the reliability of the device under repeated ultraviolet radiation [11].

4. Conclusion

This article comprehensively reviews the application of ultra-wide bandgap semiconductor Ga₂O₃ materials in photodetectors. Ga₂O₃ has a wide bandgap of 4.8 eV, a high breakdown field strength,

and good thermal stability. These properties make it an ideal material for preparing high-performance photodetectors. This paper discusses the material preparation methods, such as EFG and HVPE, emphasizing their capabilities in producing high-quality crystals and films. The device structures, such as β -Ga₂O₃ Schottky barrier diodes with magnesium-based current barrier layers and MSM photodetectors, have demonstrated significant performance improvements in terms of responsivities, dark currents, and response times. In addition, the paper also studies performance optimization strategies, including interface engineering and surface passivation to improve the efficiency and stability of the device.

Although certain progress has been made in the research, there are still many fields that need to be further optimized. It is crucial to enhance the quality of materials by reducing impurities and defects. Improving epitaxial growth technology and developing larger-sized high-quality single crystals can help enhance the scalability and cost-effectiveness of devices. Exploring new heterojunction structures and optimizing the interface characteristics between Ga₂O₃ and other materials can further enhance device performance. In addition, integrating Ga₂O₃ photodetectors into complex systems and exploring their new applications in fields such as quantum sensing and high-speed communication is expected to create new development opportunities. Overall, the continuous research and development in the field of Ga₂O₃ photodetectors is expected to drive the progress of ultraviolet detection technology.

References

- [1] Liu, W., Feng, Q.J., Yi, Z.Q., Yu, C., Wang, S., Wang, Y.M., Sui, X. and Liang, H.W. (2023) Preparation and Ultraviolet Detection Performance of Cu Doped β -Ga₂O₃ Thin Films. *Chinese Physics Letters*, 40, 218101.
- [2] Gao, Y., Li, S., Li, Y. and Zhang, M. (2022) Research Progress of Preparation and UV Photoelectric Detection Performance of Ga₂O₃ Thin Films. *Applied Physics*, 12, 621-634.
- [3] Kurowski, M. J., Teixeira, J., Ao, C., Brown, S., Davis, A. B., Forster, L., Wang, K.-N., Lebsock, M., Morris, M., Payne, V., Richardson, M. T., Thompson, D. R., and Wilson, R. C. (2023) Synthetic observations of the planetary boundary layer from space: A retrieval observing system simulation experiment framework. *Bulletin of the American Meteorological Society*. 104(11), E1999-E2022.
- [4] Aruev, P. N., Belik, V. P., Zabrodskii, V. V., Kruglov, E. M., Nikolaev, A. V., Sakharov, V. I., Serebryakov, I. T., Filimonov, V. V., and Sherstnev, E. V. (2020) Quantum yield of a silicon avalanche photodiode in the wavelength range of 120–170 nm. *Technical Physics*. 60, 1333-1339.
- [5] Zhang, Z., Yan, P., Song, Q. W., Chen, H., Zhang, W., Du, F., Liu, D., Chen, D., and Zhang, Y. (2023) Recent progress of Ga₂O₃ materials and devices based on the low-cost, vacuum-free Mist-CVD epitaxial growth method. *Fundamental Research*. 4(5), 1292-1305.
- [6] Heinselman, K. N., Haven, D., Zakutayev, A., and Reese, S. B. (2022) Projected cost of gallium oxide wafers from edge-defined film-fed crystal growth. *Crystal Growth and Design*, 22(8), 4854–4863.
- [7] Wang, C., Zhang, J., Xu, S., Zhang, C., Feng, Q., Zhang, Y., Ning, J., Zhao, S., Zhou, H., & Hao, Y. (2021) Progress in state-of-the-art technologies of Ga₂O₃ devices. *Journal of Physics D: Applied Physics*, 54(24), 243001.
- [8] Tang, R., Zhang, J., Wei, Y., Qian, K., Tang, Z., Chen, X., Liu, S., and Li, C. (2025) Wide bandgap tunable deep ultraviolet Ga₂O₃/GaN heterojunction photodetector. *AIP Advances*, 15(7), 075306.
- [9] Jian, G., Hao, W., Shi, Z., Han, Z., Zhou, K., Liu, Q., He, Q., Zhou, X., Chen, C., Zhou, Y., Zhao, X., Xu, G., and Long, S. (2022) Elevated barrier height originated from electric dipole effect and improved breakdown characteristics in PtOx/ β -Ga₂O₃ Schottky barrier diodes. *Journal of Physics D: Applied Physics*, 55(2022), 304003.
- [10] Jia, M., Wang, F., Tang, L., Xiang, J., Teng, K. S., and Lau, S. P. (2020) High-performance deep ultraviolet photodetector based on NiO/ β -Ga₂O₃ heterojunction. *Nanoscale Research Letters*, 15(1), 47.
- [11] Roy, S., Chmielewski, A. E., Bhattacharyya, A., Ranga, P., Sun, R., Scarpulla, M. A., Alem, N., and Krishnamoorthy, S. (2021) In-situ dielectric Al₂O₃/ β -Ga₂O₃ interfaces grown using metal-organic chemical vapor deposition. *arXiv*: 2103.15280.
- [12] Zhang, Q., Gao, H.L., Denh, J.X., Meng, X., Tian, K., Xu, J.W., Yang, X.L., Kong, L., Meng, L.J., Du, J., Yang Q.Q., Wang, G.S. Meng, J.H. and Wang, X.L. (2024) The performance of ultraviolet solar-blind detection of p-Si/n-Ga₂O₃ heterojunctions with/without hole-blocking layer. *J Mater Sci: Mater Electron* 35, 1125.

- [13] Dhanabalan, D., Sakthivel, R., Moorthy Babu, S., et al. (2025) Single-crystal growth and characterization of β -Ga₂O₃ (100) for GaP/ β -Ga₂O₃ heterostructures by hydride vapor phase epitaxy. *Physica Status Solidi A: Applications and Materials Science*. Advance online publication.