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A Review of the Development History of Photodetectors

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Abstract. As a core component for the conversion of photoelectric information, the development of photodetectors plays a significant supporting role in modern science and technology and engineering applications. From early simple photosensitive components to today's high-performance integrated systems, photoelectric detection technology has continuously driven innovations in fields such as communication, sensing, and imaging. With the introduction of new materials, new structures and new mechanisms, the performance of detectors, such as sensitivity, response speed and spectral range, has been significantly improved. This article mainly summarizes the development process of photodetectors and the progress of some key technologies, and introduces the applications of photodetectors. In fields such as optical communication, biomedicine, and environmental monitoring, by comparing traditional silicon-based photodetectors and avalanche photodetectors, as well as new two-dimensional material-based, perovskite-based, and quantum dot-based photodetectors, the design methods of new photodetector materials and the methods for optimizing and improving their performance are introduced. Through the exploration of new materials and the design of heterojunction/composite structures, significant improvements have been achieved in the performance of detectors in terms of responsivity, detection rate and stability. However, this technology still faces practical application bottlenecks such as high cost, insufficient environmental compatibility, difficulty in large-scale production and poor long-term stability. Future research should focus on developing superior new materials and technologies and be committed to achieving higher performance, lower costs and wider application and promotion in various fields.

Keywords: Photodetector, development history, key technologies, application fields, future challenges

1. Introduction

As an important device in modern information technology, the development and application of photodetectors have directly promoted the progress of fields such as communication, biomedicine, and environmental monitoring. With the continuous improvement of scientific and technological levels, people's requirements for photodetectors are getting higher and higher. The development from the original single-function photosensitive elements to various high-performance photodetectors today not only reflects people's continuous exploration of new materials, new

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technologies and other fields, but also demonstrates the deepening of people's research on optoelectronic technology. In recent years, many new types of photodetectors have emerged, such as two-dimensional material-based, perovskite-based and quantum dot-based photodetectors, which have brought more new development space to photodetection technology. However, when it comes to these new devices, the selection of materials, design optimization and performance are still worthy of further exploration.

As an important device in modern technology, photodetectors play a crucial role in fields such as optical communication, biomedical imaging, and environmental monitoring. With the advancement of technology and the diversification of social demands, the research and development of photodetector technology have received increasing attention. This article focuses on the development history of photodetectors, discussing their development paths, which include the progress in photodetector materials, design, and performance improvement. It mainly explores the new opportunities and challenges faced by photodetectors in light of current scientific issues and technological advancements. The article presents its own perspectives on three major aspects: new materials, miniaturization, and multi-functional integration.

2. The development history of photodetectors

2.1. Traditional photodetector

The research on photodetectors can be traced back to the mid-20th century. Among them, silicon-based photodetectors achieved commercial application first due to their compatibility with CMOS technology. Early research focused on expanding the spectral response range of silicon-based avalanche photodetectors (Si-APD): by optimizing the structural parameters of the surface-to-non-depleted layer, multiplier layer and absorption layer, high light response rates were achieved for silicon-based avalanche photodetectors in the 300-400 nm wavelength range. Based on the principle of converting light to photoelectric detection layers using CdSe quantum dots, a CdSe quantum dot color conversion layer was designed and fabricated on the surface of SiAPD, which improved the light response rate of SiAPD and realized light detection in the ultraviolet-near-infrared wide spectral range. Finally, a visible-near-infrared Si/Ge—APD structure with surface front surface light capture nanochannels and silica back reflection gates was proposed. Through the optical absorption characteristics of different wavelengths of the extended structure, the front surface light capture nanochannels and SiO_2 back reflection gate structure were designed to improve the light response rate of the device in the visible-near-infrared wavelength range. This shows that silicon-based photodetectors have achieved some results in wide spectral response, which can provide certain reference significance for further related research.

The technological breakthrough of avalanche photodetectors (APDs) lies in their high-speed and low-noise design. Based on this, the paper introduces the epitaxial layer optimization design of high-speed avalanche photodetectors based on semiconductor device simulation, the new high-performance SACMCT structure APD, and the design of the dual charge layer and transit layer introduced thereby, as well as the results of achieving high response speed and low dark current; at the same time, the improvement of the preparation process flow for ultra-high-speed APD devices has been completed, namely, the improvement of the BCB flattening process and composite passivation layer process has been accomplished, which has achieved the effect of further reducing parasitic capacitance and surface leakage. The research work obtained on this basis not only helps to enhance the research and development level of high-speed avalanche photodetectors with

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independent intellectual property rights, but also serves the research and development work of China's high-speed optical communication systems.

2.2. New type of photoelectric detector

2.2.1. Two-dimensional material-based photodetectors

Although traditional silicon-based and avalanche photodetectors can work well within certain wavelength bands, they are limited by the properties of the materials themselves and the spectral response range of the materials, and thus cannot meet the requirements of ultra-high frequency wideband photodetection. However, due to the thickness of the new two-dimensional materials ReS_2 and black phosphorus being only at the atomic level and having high carrier mobility, they are very suitable as new materials for the preparation of new photodetectors, such as the 300-1,075 nm wide-spectrum self-driven photodetection based on the bulk heterojunction of PM6:Y6 organic semiconductor materials, and the larger area ReS_2 films grown by atmospheric pressure chemical vapor deposition (APCVD) have both photodetection and electrochemical hydrogen evolution functions (responsivity 0.11 A/W, EQE 30.95%). Krishan Kumar et al. [1] reviewed the latest progress of MoS_2-based flexible photodetectors, highlighting their potential for widespread application in wearable devices and flexible electronics. Kunjie Wang et al. [2] developed a transparent flexible ultraviolet photodetector based on two-dimensional $H_4Nb_6O_{17}$, which exhibits high responsivity and good mechanical stability in the UV band.

2.2.2. Perovskite-based photodetectors

Beyond two-dimensional materials, perovskite materials have brought new breakthroughs to photodetectors due to their high absorption coefficient and tunable bandgap. Sun Tangyou et al. [3] proposed the use of Au nanorods to fabricate Cs2AgBiBr6 photodetectors, and used self-assembled PS nanospheres to prepare a periodic nanocolumn structure, which significantly improved the carrier separation rate and photoelectric output efficiency; Di Jiayu et al. [4] used the MACl post-treatment method to improve the quality of $MA_3Sb_2I_9$ perovskite films, and in the presence of Cl-Sb bonds, passivated the surface defects of the films, significantly improving the sensitivity and response rate of self-powered photodetectors. Jing Zhang et al. [5] used manganese dioxide oxidation of Spiro-OMeTAD as a hole transport layer to prepare efficient perovskite photodetectors, significantly improving the stability and photoelectric conversion efficiency of the devices. Thus, by optimizing the design of perovskite-based photodetector materials and adopting appropriate surface modification methods, the photoelectric performance of perovskite-based photodetectors can be greatly enhanced, which is conducive to the progress of future research on higher-performance photodetectors.

2.2.3. Quantum dot-based photodetector

Apart from perovskite materials, quantum dot-based photodetectors achieve efficient control over light absorption and carrier transport through the quantum size effect. Li Jing [6] prepared ZnSe quantum dots using the thermal injection method and transferred the ZnSe quantum dot film onto an ITO substrate using spin coating. The results showed that it had good photoelectric conversion ability in the visible light band, and the response current at 500 nm wavelength reached the maximum value of 5.8μA. Guo Guangtong et al. [7] proposed to position the multiplier layer close to the photosensitive surface, and designed and fabricated a near-ultraviolet high-response Si-APD

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structure that integrates a CdSe quantum dot color conversion layer on the surface of Si-APD. Experimental results showed that the Si-APD with the integrated quantum dot color conversion layer had significantly improved light response in the 320-450 nm band compared to the Si-APD without the quantum dot color conversion layer. Specifically, the average light response in the 320-360 nm near-ultraviolet range increased by 189%. In summary, quantum dot-based photodetectors have great potential to further enhance the spectral response range and photoelectric conversion efficiency of photodetectors. Future work requires more new quantum dot materials and research in the field of photodetectors.

3. Key technological advancements in photodetectors

3.1. Materials and design

3.1.1. The development of new materials

In addition to the above, the exploration of new materials focuses on expanding the spectral response and improving the conversion efficiency, thereby developing new materials to enhance the performance of photodetectors. One of them is Wang Haoran et al. [8], who used PM6:Y6 as the material for the preparation of a near-infrared organic self-driven photodetector, achieving self-driven kinetic energy through a bulk heterojunction and Schottky contact structure, which expanded the spectral response range of the photodetector from 300 to 1075 nm; another is Sun Tangyou et al. [3], who prepared a periodic nanocolumn structure by assembling PS nanospheres and deposited a layer of Au nanocolumns on the surface, which enhanced the carrier separation efficiency of the $Cs_2AgBiBr_6$ film and improved the photoelectric output efficiency. The response times were 87ms/88ms and 85ms/85ms; another one is Li Jing [6], who obtained ZnSe quantum dots by the thermal injection method, prepared ZnSe quantum dot films using spin coating, and fabricated them on an ITO substrate. After high-temperature annealing, the obtained ZnSe photodetector exhibited good photoelectric conversion ability in the visible light band, and the maximum response current at the wavelength of 500 nm reached 5.8 μA. Using the atmospheric pressure chemical vapor deposition (APCVD) technology to grow large-sized two-dimensional ReS_2 films, it was found that they have the potential to become a powerful candidate in the field of electrochemical hydrogen evolution and photoelectric detection. The results show that the two-dimensional ReS_2 films grown by the APCVD technology can be used for hydrogen production by electrolysis, with a photoelectric detection response rate reaching 0.11 A/W, an external quantum efficiency (EQE) of 30.95%, and a detection rate of 2.91×10^{-6} Jones. The development of new materials has greatly improved the performance of photodetectors, providing a new idea for the subsequent development of high-performance photodetectors.

3.1.2. Heterojunction and composite structure

The new materials provide conditions for designing heterojunctions and composite structures, and improve the carrier transport path by engineering the interface. Wu Xiuwen and Liao Wenhu [9] studied the α-Se photodetector using the non-equilibrium Green function—first-principles calculation method, and investigated the effects of vacancies and doping on the photocurrent generation. The results showed that a single atomic vacancy could better disrupt the spatial symmetry of the device and generate a larger photocurrent. For the atom-doped device, the maximum photocurrent could reach 32.61 a/photon. Sun Tangyou et al. [1] used self-assembled PS

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nanoball arrays to prepare periodic nanocolumn structures, and grew a layer of Au nanocolumns on the surface to regulate the local electric field distribution under illumination and increase the carrier separation efficiency of the $Cs_2AgBiBr_6$ film. From this, it can be seen that the Au nanocolumn structure $Cs_2AgBiBr_6$ photodetector has good response performance under 365nm and 532nm incident light, with response times of 87ms/88ms and 85ms/85ms, respectively, under 365nm and 532nm incident light. In conclusion, heterojunctions and composite structures used in photodetectors can greatly improve the working performance of photodetectors, and after optimizing their structures, the sensitivity of photodetectors can be improved.

3.2. Performance optimization and improvement

3.2.1. Response rate and detection rate

This section mainly introduces the methods for enhancing the responsivity and detection rate of photodetectors, as well as the corresponding conclusions: Wu Xiuwen and Liao Wenzhao [6] used non-equilibrium Green's function and density functional theory first-principles calculation methods to study the effect of vacancy and doping regulation on the photogenerated current of α-Se photodetectors. They found that single-atom vacancies caused a greater disruption to the spatial symmetry of the device and produced a stronger photocurrent. When As atoms were doped, the maximum photocurrent of the device reached 32.61 a/photon. Later, Qiu Xianchun et al. [10] for the thermal-electric photodetector under polarization field regulation, introduced a gradient polarization field and obtained a PN junction-type thermal-electric photodetector with good response performance over a wide spectral range. At the same time, it has a high responsivity (up to 7.22 AW−1) and a high detection rate (about 1.17×1013 Jones). From the above analysis, it can be concluded that the responsivity and detection rate of photodetectors can be enhanced through various methods, such as material doping, vacancy regulation, and polarization field regulation, and these methods can enable photodetectors to be used in different fields.

3.2.2. Response speed and stability

This part mainly focuses on the progress in the response speed and stability of photodetectors. Wu Xiowen and Liao Wenhu [9] used non-equilibrium Green's function and density functional theory first-principles calculation methods to study the variation of photogenerated current in α-Se photodetectors under the vacancy doping effect. When considering single atomic vacancies in α-Se, the effect is more significantly influential on the spatial symmetry of the device, resulting in a stronger photocurrent. The visible light absorption in the y direction is more sensitive, demonstrating a better anisotropic light response. At the same time, Liu Tianhong [11] based on semiconductor device simulation tools, carried out the design optimization of the epitaxial layer of high-speed APD, and verified the proposed epitaxial design scheme through experiments. It was concluded that currently, photodetectors have significantly improved in response speed and stability. Through the optimization of materials and structures, the performance of photodetectors can be improved.

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4. The application fields of photodetectors

4.1. Photo-communication

Based on the above materials, innovations and performance breakthroughs have enabled photodetectors to demonstrate potential applications in multiple fields. In response to this issue, Liu Tianhong [11] used semiconductor device simulation software to improve and optimize the epitaxial layer of the high-speed APD, and innovatively designed a high-response SACMCT structure APD, which can operate well in a 40 Gbps high-speed optical communication system and significantly reduce dark current while improving signal-to-noise ratio. Guo Guangtong [7] studied the enhancement of Si-APD's response in the ultraviolet-near-infrared wide spectral range, proposing a design method that incorporates dopant element point color conversion layers and utilizes nano-pore arrays to increase the light response sensitivity of SiAPD within the wide spectral range, thereby improving the performance of SiAPD in the visible light short wavelength band and the optical fiber communication band, meeting the requirements of high-sensitivity optical communication systems. As mentioned above, in the field of optical communication, the development of photodetectors has undergone continuous research and technological innovation based on new materials and new processes, leading to the continuous upgrading of photodetectors and effective improvement of their performance, thereby further laying the foundation for the construction of high-speed optical communication systems in the future.

4.2. Biomedicine

This section mainly discusses the applications and development process of photodetectors in biomedicine. In 2025, Wang Haoran [8] reported a near-infrared organic self-driven photodetector based on PM6:Y6. It has extremely great application prospects in laser radar and biological imaging. By achieving self-driven energy levels based on the fabrication of heterojunction active layers, it has realized a significant enhancement in the spectral response range and stability of the device. Sun Tangyou et al. [3] replaced TiO_2 nanotubes with Au nanotubes, which increased the carrier separation efficiency and improved the response performance of the photodetector, and provided a new idea for the preparation of efficient perovskite photodetectors. These indicate that the application of photodetectors in the field of biomedicine is increasing. After modifying and optimizing the materials or structures, photodetectors can be improved to a certain extent, providing a new detection method for biomedicine. The application of photodetectors in biomedicine is quite extensive. However, to obtain high-performance photodetectors, it is necessary to improve and optimize the related materials and structures of photodetectors, because photodetectors can use some new materials to improve their performance. After multiple improvements, applying photodetectors to biomedicine can better exert their excellent effects.

4.3. Environmental monitoring

This section explains the application of photodetectors in environmental monitoring and mentions the related developments. Guo Guangtong [7] discovered that silicon-based avalanche photodetectors (SiAPD) have a very good response enhancement effect on the light in the ultraviolet-near-infrared wide spectral range. By optimizing the device structure, a high light response rate can be achieved in the 300-400 nm wavelength range, providing technical support for the detection of light in a certain wavelength band required in environmental monitoring. Qiu

Xianchun et al. [10] addressed the situation where there is a high polarization field in the modulated environment, using P-type GaN substrate ZnO, P-type Nb_2O_5 as the absorption layer, and indium tin oxide (ITO) and chemical deposition nickel (PdFeNi)/graphene double-layer electrodes and a gradient polarization field to achieve a PN junction type pyroelectric photodetector with excellent performance. It can not only achieve a better working efficiency under a higher intensity polarization field, but also respond quickly and have high sensitivity to the light signals in the environment. From the above work, it can be seen that the application of photodetectors will become increasingly widespread. After optimizing the device structure and introducing new physical mechanisms, the environmental monitoring performance of photodetectors will be greatly improved.

5. Conclusion

The entire text traces the development route of photodetectors from the earliest traditional silicon-based photodetectors to the current large number of new two-dimensional material-based photodetectors, perovskite-type photodetectors, and point-based photodetectors. Moreover, by continuously exploring new materials and introducing new heterojunctions or composite structures on the materials, the performance of photodetectors can be greatly improved (such as increasing the response rate, detection rate, response speed, and stability, etc.). However, today's photodetector technology remains immature: high costs, limited scalability, and poor long-term stability still hinder real-world deployment. Future efforts must therefore target these bottlenecks—through novel materials and breakthrough processes—to deliver higher-performance, broadly applicable devices.

This article reviews the current status of photodetectors from traditional silicon-based photodetectors and avalanche photodetectors to new types of photodetectors based on two-dimensional materials, perovskite, and quantum dots; summarizes and concludes them; and explains the important progress made in their material design and performance optimization, as well as their application situations in optical communication, biomedicine, and environmental monitoring. Based on the current research situation, it can be seen that in the field of photodetectors, emphasis is placed on the exploration and utilization of new materials, and the exploration of heterojunctions and composite structures on different types of photodetectors to improve the response rate, detection rate, and stability of photodetectors; in addition, there are still problems in the practical application of photodetectors, such as cost issues, whether they meet environmental requirements, and whether they can achieve large-scale production.

References

[1] Krishan Kumar, Davinder Kaur. (2024) A review on recent advancements in the growth of MoS_2-based flexible photodetectors [J]. Solar Energy Materials and Solar Cells.
[2] Kunjie Wang, Zhiping Mao, et al. (2024) Two-dimensional H4Nb6O17 for transparent and flexible UV photodetectors [J]. Journal of Alloys and Compounds.
[3] Tangyou Sun, Junli Chen, Haiou Li, et al. (2025) Research on Au Nanolum-based Cs2AgBiBr6 photodetector [J]. Journal of Guilin University of Electronic Technology, (02): 166-174.
[4] Jiayu Di, Yan Cui, Ruixiang Wu, Bin Lu. (2025) High-performance zero-dimensional lead-free perovskite thin-film photodetectors [J]. Chinese Optics (in Chinese and English), (04): 748-755.
[5] Jing Zhang, Yukun Wang, Haoran Zhaojia, Xujianeng Du, Wenhong Sun. (2024) High-efficiency perovskite photodetectors using manganese dioxide oxidation Spiro-OMeTAD as hole transport layer [J]. Ceramics International, (6).
[6] Jing Li. (2025) Preparation and Performance Study of ZnSe Quantum Dot Photodetectors [J]. Shihezi Science and Technology, (03): 16-18.
[7] Guangtong Guo. (2025) Research on Response Enhancement of Silicon-Based Photodetectors in the Ultraviolet-Near Infrared Broadband Spectrum [D]. University of Chinese Academy of Sciences (Changchun Institute of

DOI: 10.54254/2753-8818/2026.CH30391

Optics, Fine Mechanics and Physics, Chinese Academy of Sciences). DOI: CNKI: CDMD: 1.1025.377333.
[8] Haoran Wang. (2025) Research on Near-Infrared Organic Self-Driving Photodetector Based on PM6: Y6 [D]. University of Chinese Academy of Sciences (Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences). DOI: CNKI: CDMD: 2.1025.377518.
[9] Xiuwen Wu, Wenhu Liao. (2025) Photoelectric Current Effects of α-Se Photodetectors under Vacancy/Doping Regulation [J]. Journal of Jishou University (Natural Science Edition), (04): 73-80.
[10] Xianchun Qiu, Meng Zhu, He Huang, Zimumeng Zeng, Zhaona Wang. (2025) Polarization Field-Controlled Pyroelectric Photodetectors: From Uniform Polarization to Gradient Polarization [J]. Optics Communications, (07): 1160-1181.
[11] Tianhong Liu. (2025) Design and Performance Study of High-Bandwidth InGaAs/InAlAs Avalanche Photodetectors [D]. University of Chinese Academy of Sciences (Chinese Academy of Sciences, Changchun Institute of Optics, Fine Mechanics and Physics). DOI: CNKI: CDMD: 2.1025.377411.