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Two-Dimensional Semiconductor Materials

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Abstract. Compared to traditional three-dimensional semiconductors, two-dimensional semiconductors exhibit a multitude of distinctive electronic transport and optical properties at the nanoscale. These exceptional properties, such as enhanced electron mobility, direct bandgap, and quantum confinement effects, offer groundbreaking possibilities for the development of novel nanoelectronics and optoelectronics devices. The unique characteristics of 2D materials enable the creation of ultra-thin, flexible, and highly efficient devices that can perform tasks previously unattainable with conventional materials. This opens up new avenues in various fields, including high-speed transistors, advanced photodetectors, and next-generation light-emitting diodes (LEDs), thereby revolutionizing the landscape of modern technology. Through the design of layered structures, two-dimensional semiconductors can achieve controlled quantum confinement effects in the vertical direction, demonstrating excellent charge carrier transport properties and optical characteristics. For instance, graphene is one of the most well-known two-dimensional semiconductors. It possesses high electron mobility and exceptional mechanical strength, making it suitable for flexible electronics and sensor technologies. In addition to graphene, materials such as molybdenum disulfide and tungsten disulfide also exhibit unique optoelectronic properties that can be utilized in photodetectors and photovoltaic devices. Research on these materials not only contributes to a deeper understanding of electronic behavior at the nanoscale but also has the potential to drive further miniaturization and performance enhancement of semiconductor devices. Overall, two-dimensional semiconductors represent a frontier research direction in the field of semiconductor materials, offering promising opportunities and challenges for the future development of nanoelectronics and optoelectronics.

Keywords: Electronic Materials; Thin Films and Semiconductors; MOS structure.

1. Introduction

With the continuous shrinking of process dimensions and the increasing scale of circuits, the impact of Electrostatic Discharge (ESD) on Integrated Circuits (ICs) is becoming increasingly significant. Static electricity generated by people walking on the ground can be extremely dangerous to electronic products. In addition to discharge shock, static electricity can also adsorb impurities in a clean environment or bond impurities and products together. Since the 1970s, the damage of ESD to electronic products has been, especially the discharge of human body static electricity has caused a large number of product failures and reduced yields.. Since then, the industry has conducted extensive research on device structure, circuit design, and process control. These efforts aim to reduce the damage of electrostatic discharge (ESD) to electronic devices. By focusing on these areas, researchers and engineers strive to develop more robust and resilient components that can withstand ESD events. This includes the implementation of protective measures and materials that can dissipate static charges effectively. Consequently, these advancements not only improve the reliability and longevity of electronic devices but also enhance their overall performance in various applications. Electrostatic Discharge (ESD) protection technology has emerged as a critical area of research within the integrated circuit (IC) industry. This paper delves into multiple dimensions of ESD protection technologies for integrated circuits, including the optimized design of ESD protection devices, comprehensive whole-chip ESD protection strategies, and the co-design of system-level packaging (System in Package, SiP) for enhanced ESD protection.It discusses the ESD protection design technology of integrated circuits at the different levels of device-circuit-system-level packaging. The main contents of this paper are summarized [1].

Combined with the existing research foundation, the ESD protection device silicon controlled rectifier (SCR) is optimized to improve the holding voltage and enhance the anti-latch-up effect. A layout optimization method of completely dividing the cathode and anode is proposed to reduce the emitter injection efficiency, improve the holding voltage, and maintain sufficient failure current capability. It has been experimentally verified and analyzed in bidirectional ESD protection; at the same time, two different completely divided SCRs (SeSCR and Anti-SeSCR) are verified, and the current distribution of the intrinsic SCR and the intrinsic diode in the overall device is changed by changing the current flow path, and the completely divided ratio, The factors such as the dividing width and layout form can be adjusted to obtain ESD protection characteristics that meet different application requirements.

Increasing the bypass current path and reducing the proportion of emitter current in the intrinsic SCR can also increase the holding voltage of the SCR. A method of emitter parallel resistance is studied. By adjusting the external parallel resistance, the holding voltage increases with the decrease of the parallel resistance, showing strong flexibility; for the emitter current in the SCR current path, an additional transistor is added to shunt the current, thereby affecting the holding voltage. This paper adds a compensation layer in the bidirectional SCR to achieve an increase in the holding voltage. The simulation analysis and test results are compared to illustrate the effectiveness of this method.

It has been increased from 600V to 3.5kV to meet the needs of engineering applications. The above analysis uses Transmission Line Pulse (TLP) test, characterizes the port characteristics, analyzes the failure weakness, and optimizes the ESD performance of the circuit. (4) Based on the optimization design of device and whole-chip protection, this paper studies the co-design method of on-chip and board-level ESD protection in system-level packaging. Combined with the example of ESD protection scheme optimization of system-level packaging products, the characteristics of on-chip ESD protection structure are analyzed, and the scheme of board-level protection optimization design is proposed, which improves the ESD protection performance of thin film resistors and RS422 of mixed-signal SiP ports/485 chip differential signal ports, and achieves a balance among various factors such as reliability, cost, and time-to-market, thereby guiding the reliability design of multi-chip integrated products [2].

2. Research Background

With the continuous shrinking of process dimensions and the increasing scale of circuits, the impact of Electrostatic Discharge (ESD) on Integrated Circuits (ICs) is becoming increasingly significant. Static electricity generated by people walking on the ground can be extremely dangerous to electronic products. In addition to discharge shock, static electricity can also adsorb impurities in a clean environment or bond impurities and products together. Since the 1970s, the damage of ESD to electronic products has been especially the discharge of human body static electricity has caused a large number of product failures and reduced yields.. Since then, the industry has conducted extensive research on device structure, circuit design, and process control. These efforts aim to reduce the damage of electrostatic discharge (ESD) to electronic devices. By focusing on these areas, researchers and engineers strive to develop more robust and resilient components that can withstand ESD events. This includes the implementation of protective measures and materials that can dissipate static charges effectively. Consequently, these advancements not only improve the reliability and longevity of electronic devices but also enhance their overall performance in various applications. Electrostatic Discharge (ESD) protection technology has emerged as a critical area of research within the integrated circuit (IC) industry. This paper delves into multiple dimensions of ESD protection technologies for integrated circuits, including the optimized design of ESD protection devices, comprehensive whole-chip ESD protection strategies, and the co-design of system-level packaging (System in Package, SiP) for enhanced ESD protection.It discusses the ESD protection design technology of integrated circuits at the different levels of device-circuit-system-level packaging. The main contents of this paper are summarized [3].

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Table 1. The difference and comparison of various Moore's laws

Law name	Target characteristics	Main focus	Technical challenge
Deep Moore Law	Featured size slightly shrinks	Channel materials, device structure, manufacturing process	Meet the characteristics of the characteristic size under the physical limit
Beyond Moore's Law	Integrated diverse function	System -level packaging technology, non -traditional device integration	Integrate different functions and cannot be slightly shrinking elements to meet specific application needs
Beyond CMOS technology	Find the alternative of silicon -based CMOS	Use new materials and explore new device physical principles	Beyond the physical restrictions of silicon -based materials, and develop semiconductor devices with new functions

In order to continue Moore's law, academic and industrial circles are exploring a variety of new materials and technologies to replace silicon. Here are some materials and techniques that have been studied to replace silicon to continue Moore's law (Table 2) [6].

Table 2. The contrast between various materials

Materials/Technology	Description	Advantage	Challenge
Carbon nanotube	A nanoscale tubular structure composed of carbon atoms arranged in a specific way	High electronic migration rate, high thermal guidance	The manufacturing process is complicated, the consistency and purity control are difficult to be difficult
Graphene	The two -dimensional material composed of single -layer carbon atoms has a honeycomb structure	The high electronic migration rate, high strength and lightness	Lack of gap, it is difficult to directly apply to digital logic circuits
III-V semiconductor	It mainly refers to a compound semiconductor composed of III and V elements in the element cycle table	The migration rate of electronics and holes is higher than silicon, suitable for high - speed circuits	The cost of material is high, compatible with the existing silicon - based process
Germanium material	Similar to silicon elements, with a lattice structure similar to silicon	Electronic migration rate is high, compatible with silicon technology	In unstable performance at high temperature
Molybdenum disulfide	Molybdenum disulfide belongs to the transition metal sulfide, which is a two -dimensional semiconductor material	There is a large gap, which can be used to manufacture semiconductor components	Compared with grapne electronic migration rates lower
Black phosphorus	It is a kind of homogenous alien body for phosphorus, with a layered structure	There is a high electronic migration rate in the layer, and there is a certain gap	High production cost, stability problem
Silicon carbide	Silicon and carbon compounds are a semiconductor material	Can withstand high - power, high temperature environments	It has not been applied to integrated circuits on a large scale

The above materials and technologies are expected to become the key to continuing Moore's law in the future, but they still face their own technology and application challenges. Researchers are trying to overcome these challenges in order to bring next -generation high -performance electronic devices.

The main obstacles faced by Moore's law covered physical restrictions, economic costs, power consumption problems, and technical challenges. Specifically, the following are several key obstacles (Table 3 and Table 4) [7].

Table 3. The main restrictions of Moore's Law

Advanced material	**Peculiarity**	**Potential contribution**
Graphene	Excellent electron mobility, high thermal conductivity	It could be used to make faster transistors and increase the speed of integrated circuits
Carbon nanotube	Semiconductor behavior, high conductivity, high strength	Used to make smaller, better performing transistors
Two-dimensional atomic crystal materials	Such as the transition metal disulfide (TMDs), with a thin layer of atomic size, good mechanical elasticity	Make flexible electronic devices to provide better energy efficiency
12/5000 Superconducting materials by spintronics	The information is processed using the spin of the electron rather than the charge	Super chip for low power consumption

Table 4. The main limiting factor of Moore's Law

Hindrance	**Description**
Physical limit	As the characteristic size of transistors shrinks, transistors may be spaced only a few atoms wide, triggering effects such as quantum tunneling, in which a few atoms are theoretically separated without producing electronic effects
Economic barrier	Chip factories are extremely expensive to build, and investment in line sizes as small as 0.1 microns can be as high as $10 billion, which limits the continuation of Moore's Law
Power consumption problem	The rapid growth of dynamic and static power consumption limits the development of integrated circuits according to Moore's law
Production technology limitation	With the reduction of device size, more advanced production techniques are required, and the cost of non-linearity increases dramatically

In summary, the continuation of Moore's law has been hindered in many ways. These challenges need to be overcome through new materials, new technologies, and innovation of design and technology [8].

3. Main Way to Overcome Moore's Law

3.1. Use Materials to Overcome

In terms of overcoming the physical limit of Moore's Law Firm, a series of remarkable new materials have already been studied and explored. The following table highlights various new materials and their potential contributions to advancing integrated circuit technology. These materials promise significant enhancements in performance, reliability, and functionality for next-generation ICs.

3.2. More Promising Two-Dimensional Semiconductor Materials

Graphene: This is a two-dimensional material composed of a single layer of carbon atoms, known for its high electron mobility and high thermal conductivity, which is suitable for a number of fields, including electronic devices and energy applications1.

Transition metal disulfide compounds (TMDs), such as MoS_2 and WS_2, possess semiconductor properties and exhibit unique photoelectric characteristics. These materials hold significant potential for applications in nanoelectronics and optoelectronic devices due to their exceptional electrical and optical properties. Their ability to function at the nanoscale makes them highly suitable for next-generation electronic and photonic technologies [9].

Silicene: a two-dimensional atomic crystal material composed of silicon atoms, similar in structure to graphene, is an adjustable band gap semiconductor material, which is important for the development of new semiconductor devices3.

Black Phosphorus (Phosphorene): A two-dimensional material of phosphorus with a layered structure that exhibits direction-dependent conductivity and bandgap, suitable for use in field-effect transistors and optoelectronic devices-4. Boronene: A binary atomic crystal material composed of boron atoms, which has a unique porous structure and electronic properties and makes an important contribution to the study of novel catalytic reactions and battery materials. Because of their unique physical and chemical properties, these two-dimensional atomic crystal materials have broad application prospects in the next generation of electronic, optoelectronic and energy storage equipment.

3.3. Relatively Unpopular Two-Dimensional Semiconductor Materials

Among the two-dimensional semiconductor electronic materials that are relatively unpopular in current scientific research, this paper can mention tin disulfide (SnS2). SnS2 is an environmentally friendly electronic material composed of sulfur and tin, which are abundant in nature. Although it may not be as widely explored in theoretical and experimental research as Graphene or molybdenum disulfide (MoS2), it is still attracting the attention of researchers because of the great application potential it shows in microelectronics, solar cells, photocatalysis, etc. Furthermore, SnS_2's unique properties, such as its limited band gap, enhance its potential in nanoelectronic materials. These characteristics make SnS_2 particularly suitable for applications in electronic devices, where efficient charge transport and tunable electronic properties are crucial for performance and miniaturization.

3.4. Unique Properties of Selenium Disulfide

Selenium disulfide (SeS2) as an electronic material has the following unique properties:

Potential as a lithium storage anode material: Selenium disulfide can be used as a cathode material for lithium-ion batteries. In some studies, the cathode material is prepared by loading SeS2 on sulfur-doped mesoporous carbon (SMC) and coating it with three-dimensional graphene (3DG). The electrochemical properties of this structure are improved 1.

Biomedical applications: Selenium disulfide has antifungal and antibacterial effects, and has significant efficacy in external use, especially for the treatment of scalp seborrheic dermatitis and sweat spots.

Application in the cosmetics industry: Selenium disulfide is widely used in the production of dandruff shampoos due to its anti-fungal and anti-sebum properties. However, it is important to note that there are specific restrictions on the use of selenium disulfide according to cosmetic safety technical specifications. The maximum allowable concentration of selenium disulfide in these products is limited to 1%.

Application of battery technology: In terms of battery technology, selenium disulfide is coated in polythiophene and graphene oxide composites, and the SeS2@PEDOT/GO double-coated composite electrode material formed has significantly improved the electrochemical performance5.

Existing problems: Selenium disulfide as a battery cathode material has poor conductivity, and there may be a "shuttle effect" during the charge and discharge process, which needs to be combined with other materials such as nanoscale hollow carbon balls to improve the performance 6.

These properties indicate that selenium disulfide is a multifunctional material with many potential applications. However, its application in different areas needs to comply with the corresponding safety standards and technical specifications [10].

3.5. Selenium Disulfide (Ses2) is A Promising Semiconductor Material for Energy

Storage systems, but it faces problems such as insufficient conductivity and shuttle effect. To address these challenges, researchers have investigated several doping techniques to enhance the performance of selenium disulfide. These methods aim to modify the material's properties, resulting in improved efficacy and stability. Below are some of the most effective doping techniques that have been developed for selenium disulfide:

Elemental Doping: Introducing foreign elements into the selenium disulfide matrix to alter its electronic and structural properties, thereby enhancing its overall performance.

Chemical Vapor Deposition (CVD): Utilizing chemical reactions in vapor form to deposit doped selenium disulfide onto substrates, allowing for precise control over the doping process.

Ion Implantation: Injecting ions directly into the selenium disulfide to create desired changes in its properties, improving its functionality for specific applications.

Hydrothermal Synthesis: Using high-temperature and high-pressure water-based reactions to incorporate dopants into selenium disulfide, resulting in improved material characteristics.

Sol-Gel Method: Employing a solution-based process to mix dopants with selenium disulfide, which is then transitioned into a solid gel form, enhancing its performance attributes.

Phosphate-doped porous carbon materials: The introduction of phosphate-doped porous carbon materials can improve electrochemical performance, because phosphorus atomic energy strengthens the adsorption of selenium and its reduction products, thereby improving the utilization of selenium and the stability of the electrode 1.

Polythiophene (PEDOT) coating: the surface of selenium disulfide (SeS2) is coated with a layer of polythiophene (PEDOT), which can significantly improve the conductivity, while inhibiting the diffusion and dissolution of polysulfides and selenides, preventing the shuttle effect 23.

Ultrasonic dispersion in the presence of graphene oxide (GO) : By ultrasonic dispersion of SeS2@PEDOT material into graphene oxide, the graphene can be tightly packed with selenium disulfide, which helps to mitigate structural instability caused by volume change.

Construction of selenium disulfide and graphene oxide composites: SeS2@PEDOT/RGO composites obtained after calcination at high temperature in an inert atmosphere can more effectively inhibit the structural collapse caused by volume change during charge and discharge, and improve the stability of selenium disulfide.

3.6. Doping Method of Selenium Disulfide

Doping of porous carbon materials: It is proposed to use porous carbon materials doped with high nitrogen elements to cover selenium disulfide, and strengthen the adsorption effect of the reaction intermediate products through the doping of nitrogen in the carbon matrix (especially pyridine nitrogen and pyrrole nitrogen), which can improve the stability of the electrode structure and improve the utilization rate of active materials 1.

Composite doping of PEDOT and GO: The composite material composed of SeS2 with polythiophene (PEDOT) and graphene oxide (GO) can effectively improve the conductivity and stability of SeS2 and inhibit the shuttle effect of polysulfide and polyselenide.

Metal doping: Although there is a lack of research on direct metal doping of selenium disulfide, reference can be made to the research on cerium doping in tin disulfide, which can improve the photocatalytic performance of the material, 3 and may also be applicable to the research on the performance improvement of selenium disulfide materials.

3.7. A Better Doping Method

Among the various doping methods to enhance the performance of selenium disulfide, the combination of polythiophene (PEDOT) and graphene oxide (GO) stands out as particularly effective. This combination has shown significant improvements in the material's overall efficiency and stability.

This method can enhance the electrical conductivity of the material, and inhibit the shuttle effect by constructing the core-shell structure, which improves the stability and utilization rate of the active material. The following is a detailed description of the doping method of selenium disulfide:

Doping materials: polythiophene (PEDOT) and graphene oxide (GO)12.

Improve the effect: improve the conductivity of selenium disulfide, ease the shuttle effect, and increase the electrochemical stability of the battery 3.

Core mechanism: the polythiophene layer enhances electrical conductivity, while the graphene oxide layer acts as an external protection, inhibiting volume expansion and preventing loss of active material 2.

Electrochemical performance improvement.

After the PEDOT/RGO composite coating layer is applied to the prepared selenium disulfide cathode material, the battery's performance sees significant enhancements. The initial discharge specific capacity shows a noticeable improvement, providing a higher initial energy output. This enhancement is crucial for applications requiring high energy density. Additionally, the cycle stability is enhanced, resulting in a longer lifespan for the battery. These improvements make the coated selenium disulfide cathode material highly suitable for advanced energy storage systems, meeting the demands of modern electronic devices and electric vehicles. These advancements highlight the potential of composite coatings in battery technology, ensuring that the battery maintains its performance over a longer period of usage.

To sum up the above information, the most important way of doping selenium disulfide is through the introduction of PEDOT/RGO to improve its electrochemical performance in the battery. The design of this composite material not only improves the electrical conductivity, but also effectively prevents the material structure damage and active material loss caused by volume expansion during the battery charging and discharging process, which is an important method to achieve the performance improvement of selenium disulfide materials.

3.8. Main Characteristics of Various Doping

Doping methods provide several benefits for improving the performance of selenium disulfide ($SeS2$). These benefits include enhanced conductivity, increased structural stability, and improved battery performance. Below is a summary of key doping techniques and their associated advantages."

The benefits of doping methods are explained:

Polythiophene (PEDOT) and graphene oxide (GO) composite doping improves electrical conductivity and stability by building SeS2@PEDOT/RGO composite material, the electrical conductivity is significantly improved, the shuttle effect is alleviated, and the structural collapse caused by volume change is prevented 1.

Controlling the reaction conditions of sodium selenite and sodium sulfide to produce nano-sized selenium disulfide can reduce the particle size of SeS2, which is conducive to improving its reactivity and electrochemical performance.

Coating the electrode material to prevent the loss of active substances Coating PEDOT and RGO on the surface of the electrode material to effectively inhibit the diffusion and loss of active substances during the battery charge-discharge process21.

Porous carbon material with high nitrogen doping improves the utilization rate of active material and electrode stability. The fused SeS2 is packed into porous carbon material with high nitrogen doping. The stability and energy density of the electrode are improved by the adsorption of the intermediate product by the doped nitrogen.

4. Outlook for the Future

Applications of electronic devices: As a two-dimensional material with excellent electronic properties, selenium disulfide may be further developed for high-performance field-effect transistors (FETs), sensors and optoelectronic devices12.

Photodetector: Because of its good photoelectric response characteristics, selenium disulfide can be developed for a wide spectral range of photodetectors, to achieve visible light to near infrared band detection 3.

Composite application with other two-dimensional materials: by forming van der Waals heterojunction with other two-dimensional materials such as MoS2, SnSe, etc., it is possible to design composite structures with novel electronic and photoelectric properties, and then find applications in new optoelectronic devices4.

Exploration of nanoscale properties: Selenium disulfide may exhibit different properties from bulk materials at the nanoscale, and its electronic properties can be regulated through size and surface engineering5.

Highly integrated electronic devices: As integrated circuits continue to shrink in size, the layered structure and excellent performance of selenium disulfide make it a strong candidate for future developments. Its properties position it as an ideal material for the next generation of compact, high-performance, and low-power electronic devices and integrated circuits.

Application of photovoltaic devices: Photovoltaic devices based on selenium disulfide can be used to improve the performance and energy conversion efficiency of solar cells because of their suitable band gap width and high photosensitivity.

5. Conclusion

Two-dimensional semiconductor materials (2D semiconductor materials) are semiconductors with a two-dimensional structure, usually only a few atomic layers thick, where electron movement is primarily confined to the two-dimensional plane. These materials have garnered significant attention and research interest in the scientific and engineering communities due to their unique physical and chemical properties and wide range of potential applications.

Here are some key conclusions from research on 2D semiconductor materials: Due to quantum confinement effects, 2D semiconductor materials often exhibit superior electronic and optical properties compared to their three-dimensional counterparts. For example, graphene, a single layer of carbon atoms arranged in a hexagonal lattice, possesses extremely high electron mobility, which makes it an excellent conductor. This unique characteristic is primarily due to the reduced scattering of electrons, which can move through graphene's lattice with minimal resistance.

Similarly, molybdenum disulfide (MoS_2) in its monolayer form exhibits direct bandgap properties, which is a significant deviation from its indirect bandgap nature in bulk form. This direct bandgap enables efficient electron-hole pair generation and recombination, making MoS_2 highly suitable for optoelectronic applications such as photodetectors, light-emitting diodes (LEDs), and solar cells. The combination of these unique properties in 2D materials opens up new possibilities for advanced electronic and photonic devices, driving innovation in various technological fields.

For instance, monolayer graphene is one of the strongest known materials, capable of withstanding extremely high tensile strength [11].

The thickness of 2D semiconductor materials greatly affects their electronic structure and bandgap properties. For example, monolayer MoS_2 has a direct bandgap, while multilayer MoS_2 exhibits an indirect bandgap. Tunable Electronic Properties:The electronic properties of 2D semiconductor materials can be precisely tuned using external methods such as electric fields, strain, and chemical doping. Therefore, they are highly promising for applications in electronic devices, sensors, and energy conversion equipment."

Different 2D materials can be stacked to form heterojunctions and superlattice structures, enabling new functionalities and properties. Heterojunctions, for instance, can be used to design efficient electronic and optoelectronic devices. Due to the high surface-to-volume ratio of 2D materials, surface defects and impurities play a significant role in their properties. Researching and controlling these defects and impurities is crucial for achieving high-performance 2D semiconductor devices.

2D semiconductor materials show potential applications in various fields, including field-effect transistors (FETs), photodetectors, solar cells, flexible electronics, biosensors, and photocatalysts. In summary, 2D semiconductor materials are a field filled with both potential and challenges. Their unique physical and chemical properties make them crucial in the development of modern technology, and they are expected to lead a new wave of technological revolution in electronics, optoelectronics, energy, and biotechnology.

References

[1] Huang Yiqing. The purpose of some inorganic selenium [J]. Color smelting, 1986: 67.

[2] Xia Jing, Wang Lei, Zhu Dandan, Li Xuanze, Meng Xiangmin .sns_2-nanometer's preparation and its device application progress [J]. "Image Science and Optics", 2016: 219-232, a total of 14 pages.

[3] Research on the UV-NIR wavelength detector of a parallel parallel PTSE2/thin Si Schottky [D]. Hefei University of Technology, 2021.

[4] MOS2/SNSE vertical heterogeneous node control synthesis and optoelectronic device application research [D]. Hunan University, 2021.

[5] Research on the preparation and photoelectricity of selection of selenium BI2SE3 [D]. Xihua Normal University, 2020.

[6] Study on the performance of two -dimensional tungsten electrical electrical performance [D]. Beijing Jiaotong University, 2018.

[7] Optoelectronics detectors and applications based on γ-in2se3 thin film [D]. Hefei University of Technology, 2021.

[8] The design and performance optimization of Yuyan. Alkaline metal-sulfur (selenium) battery material [C] .2020.

[9] Hu Jinlong, Ren Yilun, Zhang Lingzhi. Three-dimensional graphene covered with sulfur doped carbon load load disinity composite materials and its lithium storage performance research [J]. New energy progress: 20-26.

[10] Study of phosphorus doped carbon in sulfur and selenium -based batteries [D]. Jiangsu Institute of Technology, 2020.

[11] Study of phosphorus doped carbon in sulfur and selenium -based batteries [D]. Jiangsu Institute of Technology, 2020.