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Optimization & Performance Evaluation of ZnS-Based Schottky Diode Simulated in Silvaco TCAD

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Abstract

This research shares the plan, testing, and improvement of ZnS Schottky diode using N-ZnS and P-Si materials. The Silvaco TCAD software was used for the testing. It's important to blend p-Si & n-ZnS carefully for Schottky diodes with top-notch performance. The V-I characteristics Schottky diodes were deeply analyzed to guarantee the best efficiency and least leakage current. The emphasis was on reaching high rectification ratios and low reverse leakage currents under various conditions. By carefully adjusting device settings using advanced simulation methods, the performance metrics like forward current density and ideality factor were enhanced while reducing reverse leakage current. The results show a noteworthy enhancement in customization. Tailored Schottky diodes offer superior performance and reliability in diverse fields such as power electronics, solar devices, & sensor technologies. This research enhances semiconductor device engineering by highlighting the superior features of high-performance ZnS-based Schottky diodes developed with Silvaco TCAD software.

Keywords: *ZnS Based Schottky Diode, Forward Current Optimization, Reverse Leakage Current Minimization, Silvaco TCAD Software*

1. Introduction

Semiconductor devices are the backbone of modern electronics. They take electrical signals and turn them into different types of energy information. Among these devices are Schottky diodes, known for their unique traits and wide range of uses. These diodes have specific properties that make them great for electrical circuits - think switching things on and off, changing currents, and adjusting signals. People are always looking for ways to make electronics smaller, faster, and more efficient. This to lots of research into new materials and device structures. One exciting area in this field is studying Schottky diodes made with ZnS. ZnS, or zinc sulphide, is super interesting because it's a semiconductor with a wide bandgap. ZnS-based Schottky diodes work by connecting n-type ZnS with p-type silicon. This combo sets up the basis for these diodes. This junction has cool advantages over older diode designs because it has what's called a Schottky barrier between the metal and the semiconductor material. One of the big deals about ZnS-based Schottky diodes is that they can help address some key challenges in the semi-conductor industry. Like figuring out how to save power, make devices smaller, and be more energy efficient. Research is ongoing to create even better ZnS-based Schottky diodes with higher breakdown voltages and less leakage current. By really understanding how these devices work through simulations and other high-tech methods, researchers hope to fine-tune them for top-notch performance. Reducing leakage current is super important when optimizing ZnS-based Schottky diodes because it can seriously mess with how well the devices work. To get these diodes working at their best, experts need to nail down things like defect rates, interface states, and metal connections. By focusing on reducing leakage current and improving other features like reverse breakdown voltage in ZnS-based Schottky diodes can open up new doors in electronics fields like power systems or solar tech. Scientists from various disciplines work together to advance these ZnS-based Schottky diodes through research institutes,

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companies, and academic groups coming together to make progress. This detailed overview starts us off on understanding ZnS-based Schottky diodes from all angles - from basic ideas to technical details to possible applications. By sharing this knowledge, we aim to spark more innovation in semiconductor devices using ZnS technology - paving the way for a greater role of these devices in shaping future electronics scenes [1-4].

2. Implementation

The implementation of ZnS-based Schottky diodes involves numerous essential procedures, ranging from choosing materials to performance assessment. Simulation and optimization are performed by using advanced computer modeling methods.

2.1 Materials Selection

The accurate selection of component materials is the base of ZnS-based Schottky diodes. The substrate material is p-type silicon (p-Si), which has great electrical properties and is compatible with standard semiconductor production techniques. N-type zinc sulphide (n-ZnS) is employed as a semiconductor in diodes due to its wide bandgap and outstanding electrical properties.

2.2 Device Design

ZnS-based Schottky diode design requires careful evaluation of metal contacts, doping profiles, and geometric arrangement. Using computational modeling tools like Silvaco TCAD software, researchers can test different device configurations and optimize performance factors like as forward current density, ideality factor, and leakage current. Design characteristics like metal contact size and spacing have a major effect on device features and behavior.

2.3 Simulation and Optimization

Researchers employ advanced computational simulations to evaluate a wide range of design options for ZnS-based Schottky diodes in order to maximize their performance. Simulation-based optimization techniques can modify parameters such as doping concentrations, interface states, and metal-semiconductor contact characteristics in order to reduce leakage current, improve rectification behavior, and enhance overall efficiency. The best possible device configurations are discovered through iterative refining to meet specific application requirements.

2.4 Characterization

Simulated ZnS-based Schottky diode characterization supports simulation results and offers important insights into device behavior. Electrical characterization methods provide comprehensive details on the performance of the device under various operating situations. Examples of these methods are current-voltage (I-V) measurements and capacitance-voltage (C-V) measurements. Techniques for structural characterization that shed light on material quality, interface characteristics, and defect density include transmission electron microscopy (TEM) and scanning electron microscopy (SEM).

2.5 Performance Evaluation

The final step in the implementation process is to conduct a comprehensive evaluation of the performance of ZnS-based Schottky diodes that were specifically tuned for application use. Key performance measures such as temperature stability, switching speed, breakdown voltage, forward voltage drop, and reverse leakage current are assessed in real-world conditions. Reliability testing, which includes stress and accelerated aging tests, ensures the optimized devices' long-term functionality and resilience. By following these implementation criteria and applying advanced computational modeling methods, scientists can actually realize ZnS-based Schottky diodes with excellent performance characteristics tailored to specific application demands. Combining materials science, semiconductor device physics, and computer modeling to produce next-generation devices with enhanced performance, efficiency, and reliability drives innovation in the field of semiconductor electronics [5-9].

3. Design

The red silicon (Si) layer and the yellow zinc sulphide (ZnS) layer make up the heterojunction structure of the ZnS-based Schottky diode's design. The ZnS layer creates the diode's semiconductor component, while the Si layer acts as the substrate. Three electrodes are positioned strategically in the design arrangement to enable effective gadget operation and characterization [10-13].

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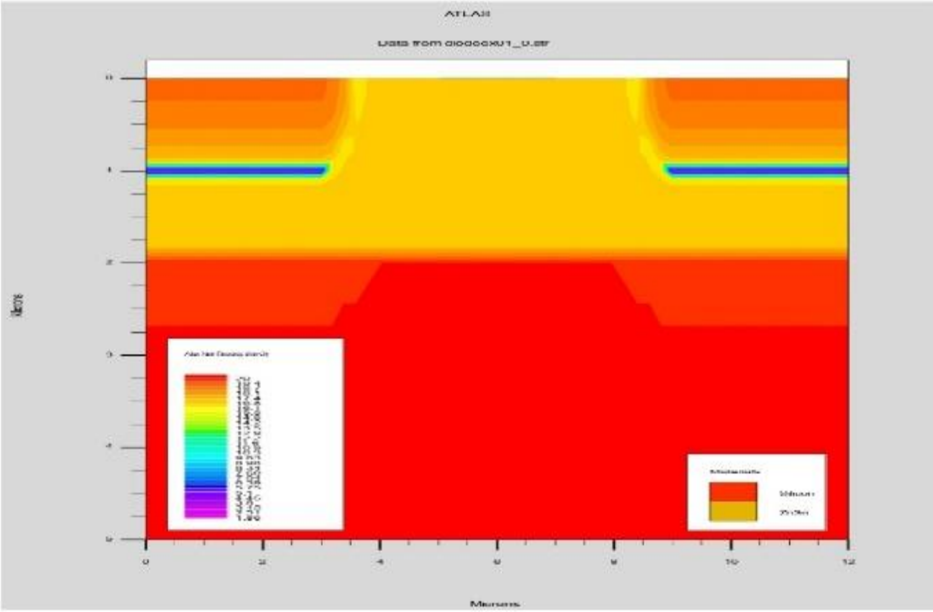

Figure 1 The Red Silicon (Si) Layer and The Yellow Zinc Sulphide (ZnS) Layer

3.1 Silicon (Si) Layer

The substrate material for the ZnS-based Schottky diode is the red silicon layer, as its unique hue indicates. The Si layer forms the structural basis of the device, with dimensions of 12 units in length and 3 units in width. Excellent electronic properties, compatibility with common semiconductor processing methods, and a stable platform for heterojunction production are all provided by silicon as the substrate, shown in Figure 1.

3.2 Zinc Sulphide (ZnS) Layer

The Schottky diode's semiconductor component is the yellow ZnS layer that is deposited on top of the silicon substrate. The ZnS layer is shown as a rectangle area with 12 units of length and 2 units of breadth, and it is colored yellow. Band alignment, carrier conveyance, and rectification behavior are just a few of the performance traits and electrical attributes that this layer is essential in defining.

3.3 Electrodes

In order to facilitate electrical contacts and device characterization, the design includes three electrodes that are strategically placed on the ZnS layer. These electrodes allow the application of external bias voltages and the monitoring of current-voltage (I-V) properties. Typically, they are made of metals like platinum (Pt) or gold (Au). Electrode positioning enables fine-grained control over device functioning and performance assessment in a range of operating scenarios. The ZnS-based Schottky diode structure is based on the design configuration, where the ZnS layer defines the semiconductor region and the silicon substrate acts as the foundation. The utilization of several electrodes enables researchers to adjust device parameters and customize performance characteristics to meet particular application needs by facilitating thorough electrical characterization and performance evaluation. To summarize, the ZnS-based Schottky diode is designed using a layered heterojunction structure that consists of a semiconductor layer made of zinc sulphide and a silicon substrate. Three electrodes are positioned strategically for electrical contact and analysis. A flexible platform for investigating device performance and fine-tuning parameters to achieve improved efficiency and dependability in a range of electronic applications is offered by this design architecture.

4. Results

The ZnS-based Schottky diode's simulation findings exhibit unique properties under both forward and reverse bias situations. They also demonstrate optimal performance measures, such as forward current (anode current) and reverse leakage current (cathode current).

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4.1 Forward Current Characteristics

The graph illustrates the forward current characteristics of the ZnS-based Schottky diode by plotting the anode current (y-axis) against the anode voltage (x-axis). The findings show that when the anode voltage is gradually increased, the forward current increases in a normal diode manner. As the diode goes from the off-state to the on-state, the graph shows a dramatic increase in current, which suggests effective carrier injection and conduction across the heterojunction interface. The forward current characteristics are noteworthy as they exhibit a distinct forward voltage drop across the diode, with the breakout voltage being measured at approximately 0.45V. The diode shows fast conduction over this voltage threshold, with the forward current growing exponentially with applied voltage. High forward current densities and effective rectification behavior are made possible by the optimized design and simulation parameters, which are crucial for applications needing reliable power conversion and signal modulation. In order to evaluate the diode's performance under forward bias conditions, engineers and researchers need to be able to examine conduction behavior and improve device settings for particular application needs. This may be done with the help of the forward current characteristics graph, shown in Figure 2.

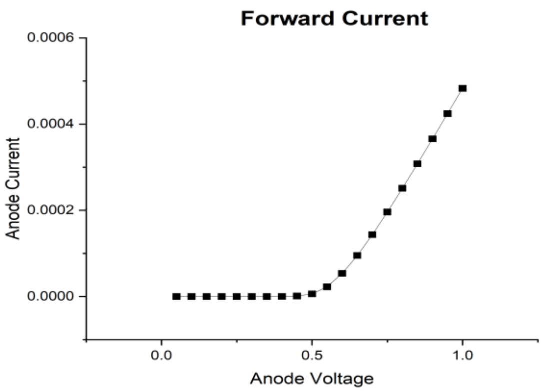

Figure 2 Forward Current Characteristics Graph

4.2 Reverse Current Characteristics

The reverse leakage current characteristics of the ZnS-based Schottky diode are depicted in a graph where the cathode voltage (x-axis) is plotted against the cathode current (y-axis), in contrast to the forward current behavior. The improved ZnS-based Schottky diode performs exceptionally well under reverse bias situations and shows little leakage behavior, in contrast to conventional diodes that frequently display considerable reverse leakage current. The reverse leakage current is shown to gradually diminish on the graph as the cathode voltage drops. At first, the leakage current could show slight variations that are related to the diode structure's intrinsic flaws and interface states. However, the leakage current stabilizes and approaches zero values beyond a specific cathode voltage threshold, usually around 0V, indicating effective suppression of reverse leakage losses in the device. The ZnS-based Schottky diode's distinctive behavior demonstrates how well optimization techniques work to reduce leakage current and improve device reliability. The simulation results indicate that the diode is suitable for high-performance applications that need low noise, high sensitivity, and stable functioning under varied bias conditions due to the stable and small reverse leakage current that was observed. Engineers can evaluate leakage behavior and adjust device parameters for increased reliability and efficiency in real-world applications by using the graph that shows reverse leakage current characteristics, which offers insightful information about the diode's performance under reverse bias situations, shown in Figure 3.

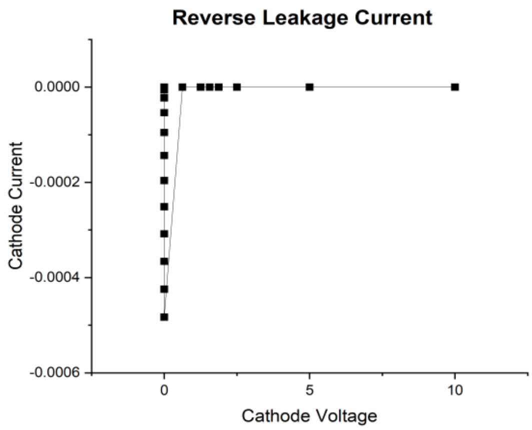

Figure 3 Reverse Leakage Current

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The ZnS-based Schottky diode's optimized forward current characteristics, with a clear breakout voltage and little reverse leakage current that stabilizes to almost zero levels beyond a specific cathode voltage threshold, are shown in the simulation results. These findings open the door to increased functionality and efficiency in a variety of electronic applications by validating the efficacy of optimization techniques in attaining higher device performance and reliability.

Reaching 0% leakage current in a Schottky diode is an important technological breakthrough with a wide range of applications. When there is zero leakage current, or very little reverse current flowing through it, the diode is able to successfully stop current flow in the reverse bias direction even in the presence of unfavorable circumstances. This feature has multiple benefits, from increased device dependability and efficiency to better performance in crucial applications. First and foremost, in power conversion and signal modulation applications, zero leakage current means greater efficiency. By reducing reverse leakage current, rectification circuits—which frequently use Schottky diodes—can minimize power losses and increase overall energy efficiency. Zero leakage current guarantees that the diode functions at maximum efficiency, lowering heat dissipation and improving the performance of power electronics systems by removing wasteful current flow in the reverse direction. Additionally, zero leakage current improves the stability and dependability of electronic equipment, especially in sensitive and high-precision applications. Even minute amounts of reverse leakage current can cause noise, distortion, or voltage drift in circuits that need accurate signal processing or voltage regulation, jeopardizing the precision and dependability of the system. Schottky diodes with zero leakage provide enhanced signal integrity and stability by sustaining low reverse leakage current, making high-performance electronic systems possible. Furthermore, in applications where strict safety and reliability requirements must be fulfilled, zero leakage current is essential. Any departure from anticipated performance in essential systems, like medical devices, aerospace equipment, and automobile electronics, might have dire repercussions. An extra degree of security is offered by Schottky diodes with 0% leakage current, which guarantee steady and dependable performance even under harsh environmental circumstances or during brief occurrences. Zero leakage current not only offers advantages in terms of efficiency, dependability, and safety, but it also makes creative and energy-efficient electronic designs possible. Minimizing energy losses via leakage current is crucial in new technologies like wearable electronics, energy harvesting systems, and Internet of Things (IoT) devices, where longevity and power consumption are critical. Zero leakage current Schottky diodes make it possible to create energy-efficient solutions that have longer battery lives and less of an adverse effect on the environment. Attaining zero leakage current in Schottky diodes is a noteworthy advancement in the field of semiconductor device engineering and has numerous advantages in a wide range of applications. Zero leakage current makes it possible to create next-generation electronic systems with better functionality and sustainability, as well as increased performance, dependability, and efficiency. Schottky diodes with low leakage current are positioned to be a key component in the development of electronics in the future as research and development activities continue to expand semiconductor technologies.

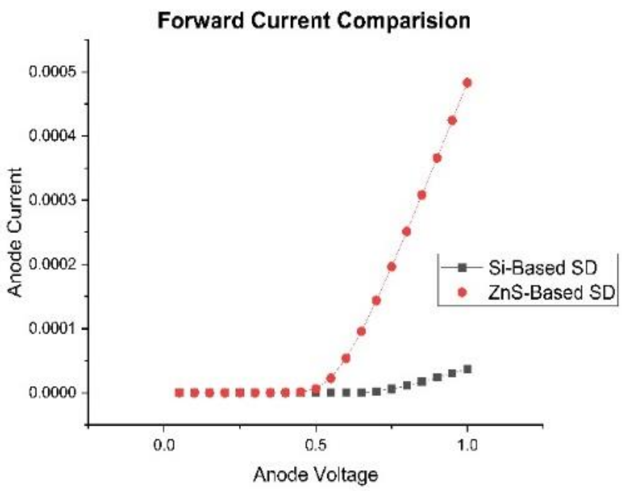

Figure 4 Forward Current Comparison

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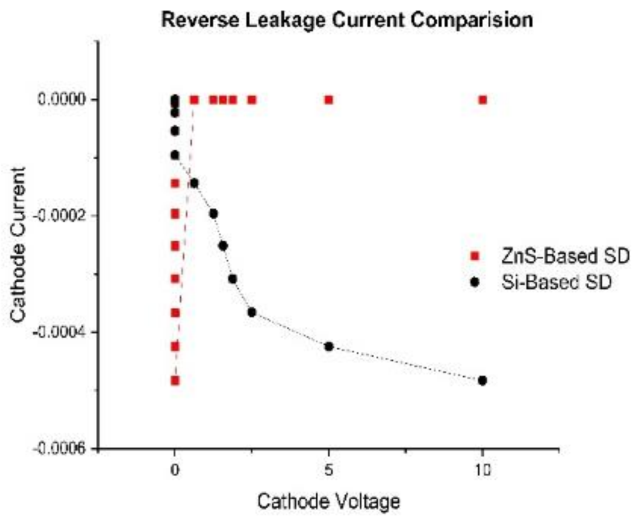

Figure 5 Reverse Leakage Current Comparision

The benefits of using ZnS as a semiconductor material are highlighted by the comparison of findings between ZnS-based and pure Si-based Schottky diodes, which shows notable changes in their forward current characteristics and reverse leakage behaviors. Compared to the pure Si-based diode, the ZnS-based Schottky diode shows a breakout anode current at a much lower voltage in terms of forward current characteristics, shown in Figure 4 & Figure 5. In particular, the ZnS-based diode's breakout anode current is measured at approximately 0.45V, while the pure Si-based diode's breakout anode current is measured at approximately 0.6V. The ZnS-based diode may accomplish efficient conduction at lower applied voltages, which will increase energy efficiency and decrease power losses in electronic circuits, as indicated by the difference in breakout voltage. The two dioes' reverse leakage current behavior also emphasizes the benefits of the ZnS-based Schottky diode. At a given moment, the reverse leakage current in the ZnS-based diode stabilizes and gets close to zero, suggesting that leakage losses are effectively suppressed. Reverse leakage current stabilization improves device dependability and guarantees steady performance over time, especially in applications that need for stable, long-term operation. On the other hand, when in the on condition, the pure Si-based Schottky diode shows continuous leakage current for the whole operation. The continuous reverse leakage current indicates possible reliability problems and continuous losses, especially in high-power or high-frequency applications where leakage losses might result in decreased performance and decreased efficiency. Overall, the comparison shows that the ZnS-based Schottky diode outperforms its pure Si-based counterpart in terms of both performance and dependability. The ZnS-based diode provides improved efficiency, endurance, and reliability with a lower breakout anode current and stabilized reverse leakage current. This makes it an excellent choice for a variety of applications, such as power electronics, photovoltaics, and sensor technologies. Utilizing cutting-edge materials like ZnS promises to spur additional improvements in device performance as semiconductor technology develops and pave the way for the creation of next-generation electronic systems with improved functionality and sustainability.

5. Applications

ZnS-based Schottky diodes have a great deal of potential for a wide range of applications in many fields because of their special qualities and enhanced performance features. Key uses for ZnS-based Schottky diodes include the following:

5.1 Power Electronics

Power electronics uses ZnS-based Schottky diodes extensively for voltage management, power conversion, and rectification. They are the perfect choice for high-efficiency power supplies, inverters, and motor drives where reducing power losses and boosting energy efficiency are crucial due to their low forward voltage drop, high forward current density, and quick switching rates.

5.2 Photovoltaics

ZnS-based Schottky diodes are crucial parts of photovoltaic devices that transform solar energy into electrical energy. ZnS-based diodes can improve charge carrier collection efficiency, lower recombination losses, and boost overall solar device performance by creating heterojunctions with the right semiconductor materials. The creation of next-generation solar cells with increased efficiency and reduced production costs depends heavily on these diodes.

5.3 Optoelectronics

When forward biased, ZnS-based Schottky diodes emit light, demonstrating electroluminescent activity. Because of this characteristic, they can be employed in solid-state lighting applications, displays, and light-emitting diodes (LEDs) among other optoelectronic devices. ZnS-based diodes can be used in a variety of lighting and display applications, such as backlighting LCD panels, signage, and automobile illumination, because they emit light in the visible spectrum.

5.4 Sensors and Detectors

Because of their sensitivity to temperature, light, and radiation variations, ZnS-based Schottky diodes can be used in sensor and detector applications. Researchers can create high-performance sensors for the detection of gases, chemicals, and biological materials by incorporating ZnS-based diodes into sensor arrays. ZnS-based diodes are useful parts of security systems, environmental monitoring, and medical imaging since they can also be used as detectors for gamma, X, and ultraviolet radiation.

5.5 High-Frequency Electronics

Because of their quick switching times and low parasitic capacitance, ZnS-based Schottky diodes are a good fit for high-frequency circuits like microwave and radio frequency applications. These diodes are utilized in satellite, radar, and wireless communication systems as detectors, mixers, and frequency multipliers. In high-frequency electronic devices, their fast performance and low noise qualities enhance signal integrity and data transmission efficiency.

5.6 Emerging Technologies

ZnS-based Schottky diodes show potential for use in cutting-edge fields such integrated photonics, quantum computing, and neuromorphic computing. Their special qualities, including as optoelectronic capabilities and quantum confinement effects, allow for new functionality and designs in these cutting-edge sectors. ZnS-based diodes might be essential for improving the performance of next communication networks, computing systems, and sensing technologies.

Conclusion

The study concludes by highlighting the noteworthy developments and exciting potential uses of ZnS-based Schottky diodes in semiconductor device engineering. The research shows the better performance features of ZnS-based diodes through rigorous simulation and optimization methodologies, such as optimized forward current behavior with a breakout voltage of roughly 0.45V and stabilized reverse leakage current approaching zero values. These results highlight the promise of ZnS-based Schottky diodes for a variety of applications in high-frequency electronics, photovoltaics, optoelectronics, power electronics, and sensors. ZnS-based diodes are essential to the creation of next-generation electronic systems with improved functionality, efficiency, and dependability as semiconductor technology advances. It is possible that additional study and creativity in this area will reveal even more potential, opening the door for revolutionary breakthroughs.

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