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REVIEW ARTICLE

The Use of Wide Band Gap Semiconductors in the Production of Electronic Devices and its Feasibility Study in Nigeria – Review

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ABSTRACT: This study extensively analyzes the incorporation of third-generation semiconductors, examples of which are silicon carbide and gallium nitride, into electronic device fabrication. It evaluates their technical advantages, including enhanced performance and higher electron mobility, as well as economic benefits like lowered energy consumption and extended device lifespan. The investigation considers infrastructure readiness through collaborative efforts between academia and industry. Additionally, it identifies promising applications in power electronics, renewable energy, and high-frequency communication. Regular alignment is stressed for a conducive environment. Global case studies further validate successful wide-band gap semiconductor integrators. Moreover, this research provides a comprehensive appraisal of the feasibility and potential benefits of leveraging wide-band gap materials for improved electronic device manufacturing, fostering technological advancement and efficiency.

KEYWORDS: Electronic devices, semi-conductors, band-gap, Electron Mobility, Break down Voltage

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1. INTRODUCTION

The evolution of semiconductor materials has witnessed three distinct generations, each playing a crucial role in advancing electronic technology. The initial epoch, defined by the presence of silicon (Si) and germanium (Ge), started in the 1950s with germanium initially holding sway in the market, but it eventually yielded to silicon due to its superior stability and dependability. Silicon's remarkable attributes, such as high temperature and radiation resistance, established it as the predominant material, forming the backbone of over 95% of semiconductor devices and 99% of integrated circuits [1].

In the 21st century, silicon's dominance persists, yet its limitations in optoelectronics and high-frequency applications become evident. This sets the stage for the arrival of the second wave of semiconductor materials, which includes substances like (GaAs) and (InSb), as well as mixtures, solid combinations, and even organic and non-crystalline semiconductors. These materials excel in uses that demand swift, frequent operations and devices that emit light, contributing to advancements in fields such as telecommunications and GPS navigation. Nonetheless, their extensive use is hindered by issues like scarcity, toxicity, and environmental concerns [2].

The third wave of semiconductor materials arises, showcasing wide bandgap substances like silicon carbide, zinc oxide (ZnO), and aluminum nitride (AlN)[3,4]. These materials are known for their broad bandgap, high resistance to electrical breakdown, efficient heat conductivity, electron saturation capacity, and resistance to radiation. They excel in applications demanding high-temperature operation, high-frequency capabilities, and high-power performance. They find applications in semiconductor lighting, power electronics, lasers, detectors, and more, with varying levels of industrial maturity across different sectors. This progression highlights the continuous drive to push the boundaries of semiconductor technology, addressing evolving demands and expanding possibilities [5].

The problem is that silicon (Si) and germanium, the first-generation semiconductor

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materials, have restrictions that make it difficult to use them in optoelectronic, high-frequency, and high-power devices. Although appropriate, the second-generation substitutes, gallium arsenide (GaAs) and indium phosphate (InP) confront challenges because of their scarcity, high cost, and toxicity, which limits their use.

A survey conducted using Google Forms provided insights into the types of phones Nigerians use and prefer. Additionally, a small-scale phone design was carried out to assess technical feasibility. Overall, the paper concludes that embarking on domestic production seems feasible and promising for economic growth, meaning the semi-conductors need to be sourced locally or imported [6].

Electronic gadgets are versatile tools capable of multitasking at high speeds, enhancing efficiency and reducing laborious tasks. They serve various purposes, offering time and cost savings, information access, and simplified machine operations. Essential roles in entertainment, information, and communication technology (ICT) are played by these devices, covering sectors like healthcare, governance, commerce, banking, agriculture, and education [6]. Examples encompass phones, computers, TVs, radios, refrigerators, GPRS navigation systems, cameras, and medical equipment such as ECG machines, visual field analyzers, glucometers, and automated blood pressure devices. Advancements, like the shift from analog landlines to smart phones and from massive ENIAC computers to laptops, have brought health benefits and risks [7]. Positive impacts include improved healthcare via tele-consultation and disaster management. Negative effects encompass disruption of natural electromagnetic waves vital for health, environmental pollution, brain damage, psychological issues, visual impairment, cancer, cardiovascular diseases, uneven healthcare distribution, cognitive impairment, infertility, accidents, birth defects, and muscle pains. To reduce potential hazards, electronic devices can be equipped with anti-radiation chips and electromagnetic wave neutralizers. Reusing, reducing waste, and recycling electronic devices before landfill disposal is also crucial [8].

Silicon carbide (SiC) and gallium nitride (GaN) represent significant instances of wide band-gap semiconductor materials, which are classified as third-generation semiconductors. The wide band-gap semiconductors, exemplified by SiC and GaN, exhibit a wider band gap, elevated saturated drift velocity, and a substantial critical breakdown threshold, setting them apart from traditional semiconductors like silicon (Si) or gallium arsenide (GaAs) [9]. These inherent advantages render wide band-gap materials highly desirable for applications characterized by significant power levels, elevated temperatures, increased frequencies, and radiation resistance. The outstanding characteristics of wide band-gap devices have drawn substantial global research attention, spurring intensive exploration in semiconductor technology. This article delineates the research endeavors undertaken by both the United States and Europe in this particular area of study, spotlighting recent progress in technology related to wide band-gap materials while addressing the challenges that lie ahead, as described by Jin et al. [9,10].

Semiconductor fabrication technology has become highly globalized, enabling companies to specialize in designing chips for specific applications like AI in self-driving cars, IoT, robotics, and more [11]. The industry has shifted from being dominated by large players to focusing on creating the best chips for particular purposes. Small semiconductor firms can compete effectively by making specialized chips for specific markets or developing new applications. Nigeria has an advantage due to lower entry barriers and the ability to focus on niche markets. Challenges, such as the lack of advanced research equipment, need to be addressed. Nigerian scientists are excelling in related research, and semiconductor fabrication could drive economic growth and long-term benefits for the country [12].

In this paper the use of wide band gap semiconductors in the production of electronic devices was discussed. To complete this work successfully, wide band gap semiconductors, and its effects on electronic products was analyzed and compared with the 1st & 2nd generation semiconductors showing results & improvements using graphical data. Then, the localized limitations and challenges associated with wide band gap semiconductor materials were examined.

Comprehensive Analysis of the First Semiconductors

The initial era of semiconductor materials primarily encompassed germanium (Ge) and Silicon (Si). During the twentieth century, germanium held sway in the semiconductor market, finding utility in transistors with low voltage, low frequency, and moderate power capabilities, along with light detectors [13]. Nevertheless, germanium-based semiconductor devices exhibited shortcomings in terms of resilience to elevated temperatures and exposure to radiation, leading to their gradual replacement by silicon devices by the late 1960s. Silicon-based semiconductor devices demonstrated notable high-temperature and radiation resistance. Deposition of Silica films via sputtering yielded highly pure and well-insulating layers, substantially enhancing device stability and reliability [14]. Consequently, silicon has evolved into the most extensively employed semiconductor material, because of its widespread use, silicon dioxide is found in approximately 95% of semiconductor devices and in over 99% of integrated circuits.

During the current century, Silicon's firm and crucial role in the semiconductor industry will continue unchanged.. Nonetheless, the inherent physical characteristics of silicon place limitations on its use in optoelectronic and high-frequency, high-power devices.

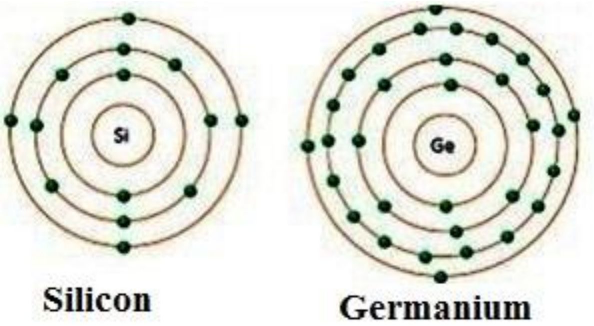

Figure 1: Atomic Structure of Silicon and germanium [15]

Effects of First-Generation Semiconductors

The effects of first-generation semiconductors, such as silicon and germanium, were profound. They ushered in the semiconductor industry, enabling the invention of transistors, integrated circuits, and the digital revolution. These semiconductors facilitated electronics miniaturization, telecommunications advancements, and scientific progress in materials science. They also contributed to energy-efficient technologies, laying the foundation for modern electronics, communication, and computing.

Limitations of the First-Generation Semiconductors

The initial semiconductor materials, silicon (Si) and germanium, exhibited limitations that constrained their application in specific domains:

1. Optoelectronic Constraints: Silicon and germanium faced challenges in emitting and detecting light efficiently, restricting their effectiveness in optoelectronic devices such as LEDs and photodetectors.
2. High-Frequency Limitations: These materials struggled to operate effectively at high frequencies, hindering their use in high-frequency applications like radio frequency communication and radar systems.
3. High-Power Drawbacks: First-generation semiconductors were not well-suited for high-power applications due to their limited ability to handle substantial power levels without performance degradation or failure.
4. Temperature Sensitivity: Silicon and germanium devices were sensitive to temperature fluctuations, affecting their performance and reliability in environments with elevated temperatures.
5. Radiation Vulnerability: These materials were susceptible to radiation-induced effects, making them unsuitable for applications where exposure to radiation was prevalent, such as space exploration or certain industrial settings.
6. Limited Band Gap: Their narrow band gap hindered their application in devices that required wider band gaps for specific electronic behavior, such as high-power or high-temperature devices [16].

Comprehensive Analysis of the Second-Generation Semiconductors

The second wave of semiconductor materials includes compound semiconductors like gallium arsenide (GaAs) and indium antimonide (InSb), GaAsAl and GaAsP. Furthermore, it encompasses solid solution semiconductors like Ge-Si and GaAs-GaP, as well as glass semiconductors such as amorphous silicon and glass-state oxide semiconductor. Additionally, organic semiconductors are part of this category, including phthalocyanine, copper phthalocyanine, and polyacrylonitrile [16]

These materials are instrumental in the production of electronic devices characterized by Swift operation, elevated frequencies, robust power capabilities, and the emission of light. They exhibit exceptional performance in the creation of sophisticated devices for microwave and millimeter-wave applications, as well as devices capable of emitting light . Due to the rapid growth of information technology and the Internet, their usage has expanded significantly into areas like communication via satellites, mobiles, optics, and Global Positioning System (GPS) navigation.

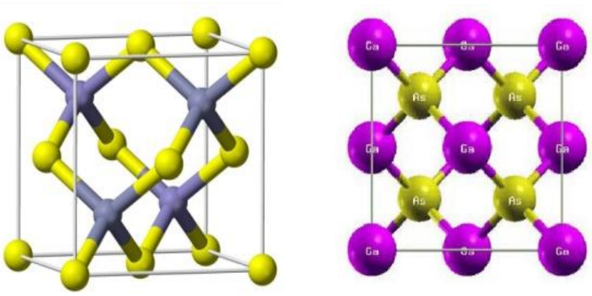

Figure 2: Structural characteristics of InSb and GaAs

Effects of Second-Generation Semiconductors

The utilization of semiconductor materials of the second generation, like Gallium Arsenide (GaAs) and Indium Phosphide (InP) had significant impacts on electronics and technology. These materials enabled the creation of high-performance devices for specialized applications, particularly in high-speed, high-frequency, and high-power contexts. They played a pivotal role in advancing communication technologies, including satellite, mobile, and optical communications. Optoelectronic devices based on GaAs and InP drove progress in optical communication systems, while also inspiring research into alternative semiconductor materials.

Limitations of the Second-Generation Semiconductors

The semiconductor materials of the second generation, exemplified by Gallium Arsenide (GaAs) and Indium Phosphide (InP), presented several limitations that impacted their widespread application:

1. Scarcity and High Cost: These materials are relatively in limited supply and, as a result, expensive to produce. This scarcity contributes to higher manufacturing costs, limiting their affordability for mass production.
2. Toxicity: Both GaAs and InP are toxic materials, posing environmental and health risks during production, usage, and disposal. This toxicity raises concerns about their safe handling and potential pollution.
3. Environmental Impact: The production and disposal of GaAs and InP materials can have adverse effects on the environment due to the release of harmful substances. This makes them less desirable in the context of sustainable and environmentally friendly technologies.
4. Limited Material Availability: The scarcity of GaAs and InP can lead to supply chain constraints, affecting the availability of components made from these materials, which may hinder large-scale adoption.
5. Specialized Applications: While GaAs and InP excel in specific high-performance applications, their limitations make them less suitable for general-purpose devices and consumer electronics, which require cost-effectiveness and widespread availability [17].

Analysis of the Third Wave of Semiconductors (WBG Semiconductors)

Third generation semiconductors, which include silicon carbide (SiC), gallium nitride (GaN), zinc oxide (ZnO), diamond, and aluminum nitride (AlN), are characterized by their large band gaps ($E_g \geq 2.3eV$). These materials are used in a variety of industries, such as semiconductor-based lighting technology, electronics for power conversion and control, devices that produce coherent, highly focused light beams, and sensors and detectors for different signals, including electrical, light, and radiation [18].

The most recent advancements involve the use of Gallium Nitride (GaN) and Silicon Carbide (SiC) for crafting high-temperature, high-frequency, radiation-resistant, and high-power devices. SiC is particularly well-suited for storing energy, powering solar and wind systems, electric vehicles inclusive of the new energy vehicles which are reliant on demanding battery systems.

Conversely, GaN is optimal for applications that operate at elevated frequencies like information exchange devices and rapid charging solutions for mobile devices, tablets, and laptops. GaN is rapid charging stands out due to its higher power density, delivering faster charging within a compact package that's convenient for portability.

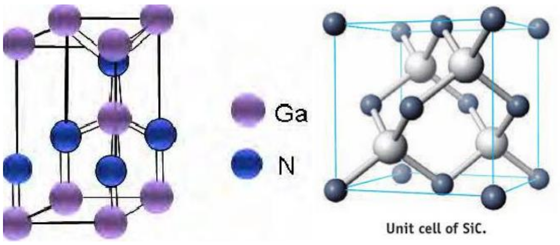

Figure 3: Structures of GaN and SiC

2. Effects of Wide Bandgap Semiconductors on Electronic Products

The emergence of semiconductor materials of the third era has brought about significant changes in electronic products [19]. These materials, characterized by wider bandgaps, have led to improved device performance, energy efficiency, and smaller designs. GaN-based fast charging has revolutionized device power delivery, while SiC's durability finds applications in renewable energy systems and challenging environments. These materials have also driven advancements in optoelectronics, high-frequency communication, and transportation technology. Overall, third-generation semiconductors have not only enhanced existing devices but also stimulated innovation across various scientific and technological fields [20]

3. High Relative Permittivity of Wideband Gap Semiconductors

Wide band gap semiconductors like Silicon Carbide (SiC) and Gallium Nitride (GaN) are known for their high relative permittivity, which is a key property in high-power applications.

• Silicon Carbide (SiC)

SiC exhibits a high relative permittivity (also known as dielectric constant), typically ranging from 9 to 15 [21]. This property is crucial in high-power applications such as power electronics and radio frequency (RF) devices [22]. The high permittivity allows for the efficient storage of electric charge, which is vital for capacitive devices used in high-power circuits.

• Gallium Nitride (GaN)

GaN, similarly, possesses a high relative permittivity, typically around 10 [23]. This characteristic contributes to its effectiveness in high-power applications like power amplifiers and high-frequency circuits [24]. The high permittivity of GaN aids in optimizing the performance of capacitors and other passive components in these applications.

Both SiC and GaN, with their high relative permittivity values, play a crucial role in enabling efficient energy storage and management in high-power electronic devices, making them valuable materials in this domain.

4. Manufacturing Process of Wide Bandgap Semiconductors (SiC and GaN)

Wide bandgap semiconductors, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), have garnered significant attention for their exceptional electrical properties, making them pivotal materials in modern electronics. The manufacturing processes of these semiconductors involve specialized techniques to produce high-quality wafers for electronic device fabrication. These processes play a crucial role in harnessing the full potential of wide bandgap materials for applications in power electronics, high-frequency devices, and optoelectronics [25].

a. Silicon Carbide (SiC)

- Crystal Growth: SiC wafers are typically grown using methods like physical vapor transport (PVT), chemical vapor deposition (CVD), or sublimation. These techniques involve heating silicon and carbon sources in a controlled environment to form single crystal SiC ingots.

- Wafer Processing: The SiC ingots are then sliced into wafers using diamond saws. These wafers undergo processes like lapping, polishing, and epitaxial growth to achieve the desired material properties for semiconductor devices.

- Device Fabrication: Standard semiconductor processing techniques like photolithography, etching, ion implantation, and metallization are employed to create electronic devices on the SiC substrate.

b. Gallium Nitride (GaN)

- Epitaxial Growth: GaN is typically grown using techniques like metalorganic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE). Epitaxial layers of GaN are deposited on suitable substrates like silicon, silicon carbide, or sapphire.

- Device Fabrication: Similar to SiC, GaN devices are created through standard semiconductor fabrication processes. This includes photolithography, etching, and metallization steps.

5. Process Difficulties of Wide Bandgap Semiconductors (SiC and GaN)

Wide Bandgap Semiconductors (WBGS) like Silicon Carbide (SiC) and Gallium Nitride (GaN) have garnered significant attention for their potential to revolutionize various electronic applications. However, their manufacturing presents distinct challenges. These difficulties arise from the unique material properties and specialized fabrication processes required. Understanding these hurdles is crucial for advancing the production of WBGS and realizing their full potential in high-performance electronic devices.

a. Silicon Carbide (SiC)

- Material Purity: Achieving high-purity SiC material can be challenging, as impurities can negatively impact device performance. The production of high-quality SiC substrates remains a significant focus of research and development [26].

- Wafer Quality and Defects: Fabricating defect-free SiC wafers is crucial for device performance. Dislocations, stacking faults, and other crystal defects can affect device yield and reliability [27].

b. Gallium Nitride (GaN)

- ***Substrate Mismatch:*** GaN is typically grown on non-native substrates, which can lead to lattice and thermal expansion coefficient mismatches. This can result in defects and strain in the epitaxial layers [28].

- ***Process Compatibility:*** Integrating GaN technology with existing silicon-based processes can be challenging due to differences in material properties and processing requirements [29].

6. Localized Limitations and Challenges Associated with Wide Bandgap Semiconductor Material

Localized limitations and challenges associated with wide bandgap semiconductor materials in Nigeria include:

a. Cost and Accessibility: Wide bandgap materials like (gallium nitride and silicon carbide) can be more expensive to produce compared to traditional semiconductors. Limited local manufacturing capabilities and dependence on imports can hinder their widespread adoption due to cost constraints.

b. Infrastructure and Expertise: Developing the infrastructure for producing and working with wide bandgap materials requires specialized equipment and technical expertise. The lack of such infrastructure and trained professionals can slow down research and development efforts.

c. Research and Development: Investing in research and development to understand the unique properties and applications of wide bandgap materials is essential. However, funding and support for advanced materials research may be limited in Nigeria, impacting the pace of technological advancements.

d. Education and Training: To fully leverage the potential of wide bandgap materials, skilled engineers and scientists are needed who understand their properties and applications. A lack of educational programs and training opportunities focused on these materials can be a challenge.

e. Energy Infrastructure: Wide bandgap materials have potential applications in power electronics and renewable energy systems. However, integrating these materials into existing energy infrastructure requires careful planning and investment, which might face regulatory hurdles and technical challenges.

f. Scale and Production: Scaling up the production of wide bandgap semiconductor devices requires investments in manufacturing facilities. Limited manufacturing capabilities in

Nigeria can hinder the local production of these materials and devices.

a. Awareness and Adoption: Creating awareness among industries, researchers, and policymakers about the benefits and potential applications of wide bandgap materials is crucial for their adoption. Without proper information dissemination, the adoption rate might be slow [30]

7. Deductions

The investigation into the feasibility of utilizing wide bandgap semiconductors for electronic device production in Nigeria revealed a series of critical insights. Wide bandgap materials, exemplified by gallium nitride (GaN) and silicon carbide (SiC), demonstrated the potential to revolutionize the electronics industry in the country. The benefits of these materials, including higher breakdown voltages, faster switching speeds, and improved thermal properties, hold the promise of enhanced device performance and energy efficiency [31].

Table 3.1 is presenting the electron mobility, band gap, breakdown voltage, and thermal conductivity parameters for various semiconductor materials such as GaN, GaAs, and Silicon [32]. Table 3.2 summarizes the three generations of semiconductor materials based on the materials used, their characteristics, applications, advantages, disadvantages, and improvements in various aspects.

Table 3.1: Parameters of Three Generation of Semiconductor Materials

Parameters of Different Semiconductor Material	**GaN**	**GaAs**	**Si**
Electron Mobility (cm2/Vs)	2000	6000	600
Band Gap (eV)	3.42	1.42	1.12
Breakdown Voltage (MV per /cm)	3.30	0.50	0.40
Thermal Conductivity (W/cm per K)	1.30	0.50	1.50

Table 3.2: Comparison of Three Generations of Semiconductor Materials

Generation	**First Generation**	**Second Generation**	**Third Generation**
Materials	Silicon, Germanium	GaAs, InP	GaN, SiC, ZnO, Diamond, AlN
Characteristics	Narrow bandgap, basic logic circuits	Wider bandgap, optoelectronic capabilities	Wide bandgap, high thermal conductivity
Applications	Early transistors, diodes	High-speed devices, optoelectronics	Semiconductor lighting, power electronics, high-frequency communication
Advantages	High temperature resistance, high purity, good insulation performance	high electron mobility, higher efficiency, better heat and moisture resistance	Superior thermal properties, radiation resistance, wide Bandgap

Disadvantages	Limited high-temperature uses	Scarcity, high cost, toxicity	They did not replace the two generations
Improvements	Transistor innovation, miniaturization	High-frequency performance, optoelectronic advancements	Enhanced high-temperature operation, rapid charging

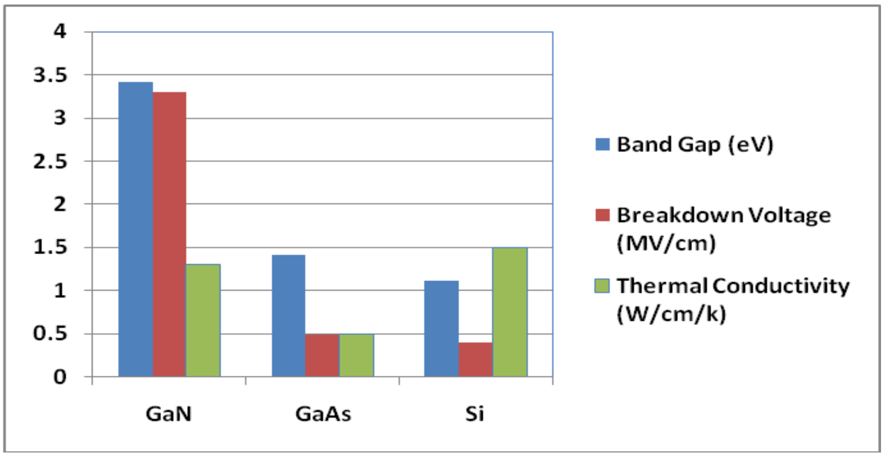

Figure 4 A Graph comparing the Three Generations of Semiconductors Considering Bandgap, Breakdown Voltage, and Thermal Conductivity

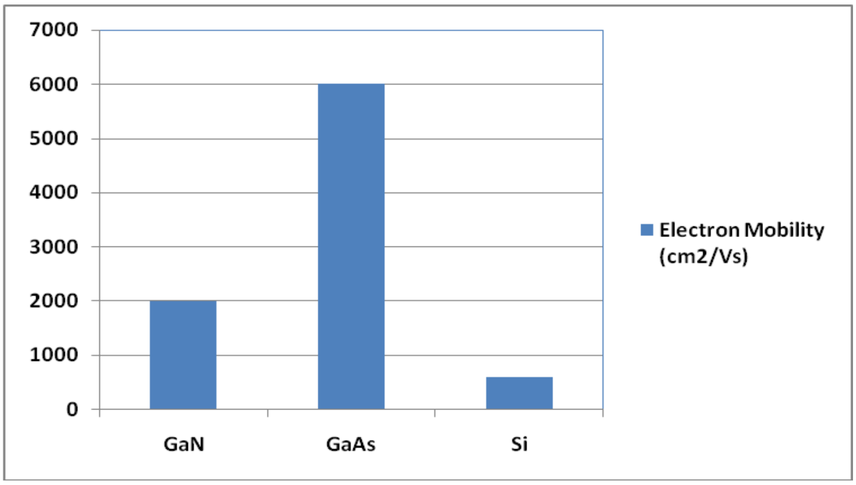

Figure 5 A Graph comparing the Three Generations of Semiconductors Considering Electron Mobility

8. Exploration of the Diverse Semiconductor Material Parameters in Three Generations

Despite the diversity of semiconductor materials, they possess inherent properties known as characteristic parameters. These parameters not only underscore disparities between semiconductors and non-semiconductors but also quantify distinctions in traits among various semiconductor materials and even within the same material under different circumstances.

Mobility of Electrons

It quantifies how rapidly and effectively electrons can traverse a substance in response to an applied electric field. It can be influenced by various factors such as the material's crystal structure, impurities, and temperature.

- ***GaN and GaAs with respect to Electron mobility:***
  When you compare the electron mobility values of GaN (2000) and GaAs (6000), it means that in GaAs, electrons are able to move about three times faster than in GaN when subjected to the same electric field. This higher mobility in GaAs suggests that electrons experience fewer obstacles or scattering events that slow them down compared to GaN.
  In practical terms, higher electron mobility is beneficial for electronic devices because it allows for faster electron movement and thus faster electronic performance. This is particularly important in high-frequency applications like radiofrequency devices and high-speed transistors. GaAs, with its higher electron mobility, might be preferred in such applications where rapid electron movement is crucial.

- ***Si and GaN with respect to Electron mobility:*** In this case, GaN (gallium nitride) has an electron mobility of 2000, while Si (silicon) has a mobility of 600. A higher mobility value indicates that electrons can move more easily through the material. So, when comparing GaN and Si, the electron mobility of GaN being 2000 means that electrons can move more efficiently through GaN compared to Si, where electrons face greater resistance to movement due to the lower mobility value of 600.

- ***Si and GaAs with respect to Electron mobility:*** When you mention that the electron mobility of GaAs is 6000 and Si is 600, it means that electrons can move more efficiently through GaAs compared to Si when an electric field is applied. Higher electron mobility indicates that electrons can drift faster in response to an electric field, resulting in better conductivity.

Bandgap

The energy difference between a material's valence band, which is normally where electrons reside, and its conduction band, where electrons can move around, is known as the band gap. A wider energy gap between these bands is indicated by a larger band gap.

- ***GaN and Si with respect to Bandgap:*** In the context of GaN (gallium nitride) and Si (silicon), GaN with a band gap of 3.42 (electronvolts), meanwhile Si with a band gap of 1.12 electron Volt. This means that it takes more energy for electrons in GaN to transition from the valence band to the conduction band compared to Si electrons. GaN as a semiconductor with wider bandgap, while Si is a more typical example of a semiconductor. The wider band gap of GaN implies that it can withstand elevated voltages and increased temperatures making it suitable for electronic devices characterized by substantial power and elevated frequency. Conversely ,Si's narrower band gap makes it more suitable for applications like microelectronics.

- ***Si and GaAs with respect to Bandgap:*** In the case of GaAs (gallium arsenide) with a energy gap of 1.42 (electronvolts) and Si (silicon) with a energy gap of 1.12 electron volt, the energy required to move an electron from the valence band to the conduction band of GaAs is more in comparison to silicon (Si).This means that GaAs is a wider band gap semiconductor than Si. Wider band gap materials like GaAs are generally better suited for electronic devices characterized by substantial power and elevated frequency due to their ability to withstand higher voltages and temperatures. They also exhibit better performance in optoelectronic applications like lasers and LEDs. On the other hand, narrower band gap materials like Si are commonly used in most electronic devices, as they can efficiently conduct electricity at room temperature and are widely available and cost-effective.

- ***GaAs and GaN with respect to Bandgap:*** In the context of GaAs (gallium arsenide) and GaN (gallium nitride), the band gap values of 1.42 eV and 3.42 eV, respectively, indicate that GaN requires more energy than GaAs to transition an electron from the valence band to the conduction band. This higher energy gap in GaN makes it a wide-bandgap semiconductor compared to GaAs, which is a narrow-bandgap semiconductor.

Voltage at which Breakdown occurs

The voltage at which the breakdown occurs refers to the voltage at which a semiconductor material transitions from being an insulator to becoming conductive due to the breakdown of its insulating properties. A higher breakdown voltage indicates that the material can withstand higher electric fields before this breakdown occurs.

- ***GaAs and GaN with respect to Breakdown Voltage:*** In the case of GaAs (gallium arsenide) and GaN (gallium nitride), the breakdown voltage values of 0.50 volts and 3.30 volts, respectively, mean that GaN can handle higher electric fields before undergoing breakdown compared to GaAs. This property makes GaN more suitable for high-power and high-voltage applications where the material needs to tolerate significant electrical stress without losing its insulating properties. GaN's higher breakdown voltage contributes to its use in various applications such as power amplifiers, radio-frequency (RF) devices, and high-efficiency LEDs.

- ***Si and GaAs with respect to Breakdown Voltage:*** In the context of GaAs (gallium arsenide) and Si (silicon), the breakdown voltage values of 0.50 volts and 0.40 volts respectively, mean that GaAs can withstand slightly higher electric fields before breakdown compared to silicon. This suggests that GaAs have a slightly better ability to function as an insulator in the presence of higher electrical stress. In typical applications, both GaAs and silicon are used for their electronic properties, with silicon being one of the most widely used semiconductor materials due to its abundance and established manufacturing processes.

- ***Si and GaN with respect to Breakdown Voltage:*** Comparing the breakdown voltage values of GaN (gallium nitride) and Si (silicon), where GaN has a breakdown voltage of 3.3 V and Si has a breakdown voltage of 0.4 V, it means that GaN can endure higher electric fields before breaking down compared to silicon.

Heat Conductivity

It quantifies a material's ability to transmit heat. A greater thermal conductivity value signifies that the material can efficiently transfer heat.

- ***GaN and GaAs:*** In the context of GaN (gallium nitride) and GaAs (gallium arsenide), where GaN having heat conductivity of 1.3 W/m per K and GaAs having heat conductivity of 0.5 W/m per K, it means that GaN is more effective at conducting heat compared to GaAs.

  Higher thermal conductivity in GaN makes it better suited for applications where efficient heat dissipation is crucial, such as high-power electronics, high-performance LEDs, and high-frequency devices. GaAs, with its lower thermal conductivity, might not be as efficient in dissipating heat and could be better suited for applications where heat transfer is not a major concern.

- ***GaN and Si:*** Comparing heat conductivity values of GaN (gallium nitride) and Si (silicon), with GaN having a thermal conductivity of 1.3 W/m per Kalso Si having heat conductivity of 1.5 W/m per K, this means that silicon is slightly better at conducting heat compared to GaN.

- ***GaAs and Si with Respect to Thermal Conductivity:*** Comparing the thermal conductivity values of GaAs (gallium arsenide) and Si (silicon), where GaAs has a thermal conductivity of 0.5 W/(m·K) and Si has a thermal conductivity of 1.5 W/(m·K), it means that silicon is better at conducting heat compared to GaAs.

9. CONCLUSION

In conclusion, the analysis of utilizing wide bandgap semiconductors in electronic device production underscores a promising avenue for advancing technology and addressing the evolving needs of various industries. The distinctive properties of wide bandgap materials, offer enhanced performance, increased efficiency, and improved thermal management in electronic devices.

The investigation reveals that while challenges such as initial costs, infrastructure requirements, and regulatory considerations exist, the long-term benefits of adopting wide bandgap materials are substantial. Reduced energy consumption, extended device lifetimes, and the potential to drive innovation in diverse sectors position these materials as catalysts for positive change.

As industries continue to seek more efficient and reliable solutions, the integration of wide bandgap semiconductors emerges as a compelling strategy. The success stories and advancements witnessed across various applications globally further underscore the feasibility and potential of harnessing wide bandgap materials.

In navigating the path forward, collaboration among academia, industries, and policymakers becomes pivotal. Investments in research, development, and education are essential to unlock the full potential of wide bandgap semiconductors and ensure a skilled workforce capable of harnessing their benefits.

In summary, the analysis resoundingly suggests that the incorporation of wide bandgap semiconductors in electronic device production holds significant promise. Embracing these materials not only paves the way for more energy-efficient and high-performance devices but also propels technological innovation toward a brighter and more sustainable future.

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